UNDERGROUND TRANSMISSION

AND

DISTRIBUTION

UNDERGROUND TRANSMISSION AND DISTRIBUTION

FOR

ELECTRIC LIGHT AND POWER

BY

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PREFACE

The rapid growth of the electric light and power industry with the resultant increase in the number of overhead wires, has brought about the policy on the part of municipal authorities of compelling utility companies to operate their systems underground. This has led to the development of a more or less specialized branch of electrical engineering; it involves large expenditures annually and gives rise to operating difficulties in many cases not clearly understood by the central station engineer.

While there are various treatises which deal with special branches quite fully, there appears to be no work which covers the general field of underground construction, transmission and distribution. The writing of this book was undertaken by the author because of repeated requests from engineers engaged in the construction and operation of underground systems, for information bearing on many of the details of this branch of central station work.

In the preparation of this volume, the author has not included such data as can readily be obtained from handbooks. The treatment of the subject assumes on the part of the reader a general knowledge of the fundamentals of electrical theory. The subject matter has been treated from the American point of view, since European practice differs considerably from that followed in America, due to the difference in conditions under which electric lighting properties are operated.

A part of the material contained in this volume originally appeared in the various reports of the National Electric Light Association Committee on Underground Construction, on which committee the author has served for the past five years, and acknowledgment is hereby made to the Association for permission to use data from these reports.

The author wishes to acknowledge the assistance and ready coöperation of the various cable manufacturers and others who have contributed for publication much valuable information and many photographs and cuts, and is indebted to Messrs. J. T. Foster, H. S. Vassar and Paul Lüpke for valuable suggestions received during the preparation of the manuscript.

E. B. MEYER.

NEWARK, N. J.,
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CHAPTER I

HISTORICAL

Periods of Development.—For a number of years after electric lighting was first introduced, the distribution of current was effected almost entirely by means of overhead wires carried on poles. The development in many of the large cities where the early market for electricity was found, proceeded at such a rapid rate that it soon became practically impossible to take care of the number and size of feeders required for distribution by means of overhead construction.

Large amounts of money had been expended in attempting to beautify various cities, but these improvements were offset to a great extent by the erection of unsightly overhead lines. To remedy this condition and eliminate the fire hazard, it was realized by engineers that some other form of construction would be necessary.

When the idea was first conceived of relieving the streets and boulevards of the presence of electric wires, by placing them underground, there were few engineers who believed the innovation practicable, either from the viewpoint of service or economy. The cry immediately arose that the first cost of an underground installation would be prohibitive and it was firmly believed that the efficiency and capacity of the wires would be greatly lessened. This view was supported by the failures which attended the early attempts to bury electric wires.

The earliest recorded attempt to lay a cable in the United States for the purpose of transmitting an electric current appears to be that made by Samuel F. B. Morse on Oct. 18, 1842. That evening he hired a boat at the Battery water front, in New York, and paid out a reel of copper wire laboriously insulated with pitch, tar and rubber, as he was being rowed to Governor's Island. He set up and prepared to demonstrate his electromagnetic telegraph instruments at Castle Garden and the Island on the following day. Only a few signals had been exchanged, however, when an anchor fouled the cable, and it was cut by ignorant sailors who dragged it up. Thus this first effort ended in failure.

After strenuous exertion Morse secured from Congress, on the last day of the session, March 3, 1843, an appropriation of $30,000 "to test the practicability and efficacy" of his telegraph system. He decided on a line from Washington to Baltimore and planned to use underground construction, supposing that

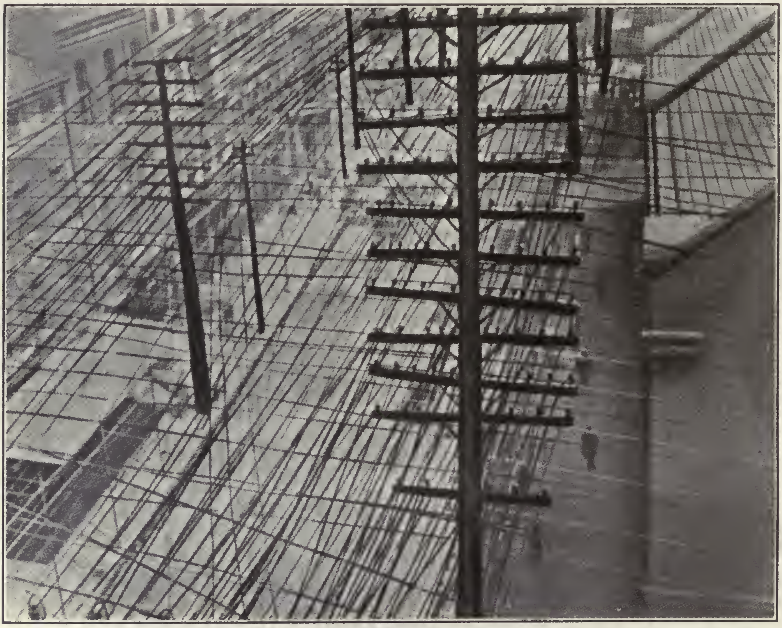


Fig. 1.—Calvert and German Streets, Baltimore, Md. Before removal of poles and overhead wires. (By courtesy of Mr. Chas. E. Phelps, Chief Engineer, Baltimore Electrical Commission.)

this method had already been successfully used in England by Professor Wheatstone for his indicating needle telegraph. Morse figured on four No. 16 copper wires covered with cotton and insulating varnish and drawn into a lead pipe. The estimated cost was about $600 per mile. The cable was constructed under the supervision of an assistant who was supposed to carefully test it. However, when part of the cable had been put down, it was found to be faulty due to charring of tbe insulation in the "hot process" employed in applying the lead. The assistant was reluctantly dismissed and the faithful Ezra Cornell, who took his place, dexterously managed to smash the cable-laying outfit by skillfully guiding the trenching plow against a rock, thereby furnishing a convenient excuse for the change to overhead construction which brought about the success of the enterprise. The precedent thus established dominated future developments for a considerable period. Lack of care caused failure of underground construction in this case, and the same cause can probably be held responsible for more subsequent failures than any other.

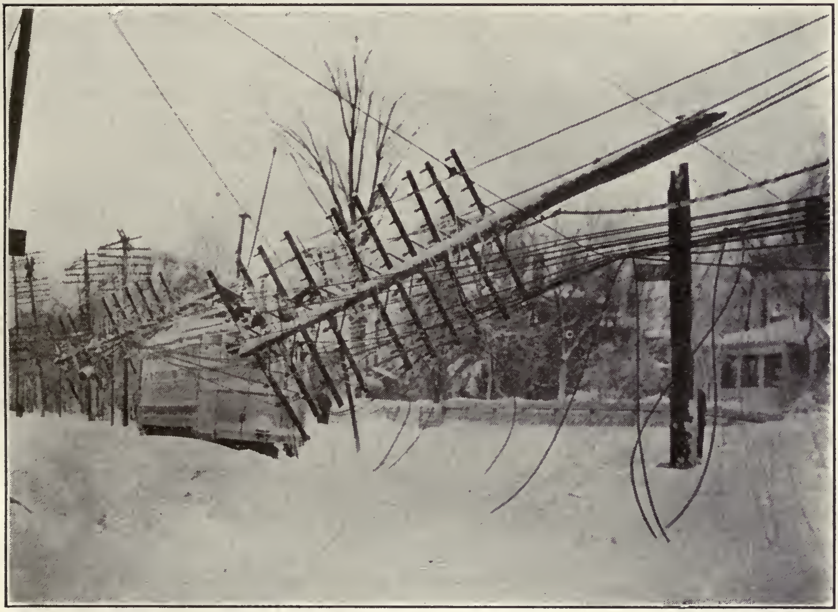


FIG. 2.—Damage to overhead wires resulting from snow and sleet storm.

In the years following, the use of overhead wires for transmission of electric currents multiplied. Besides telegraphic communication, various signal systems, such as fire alarms and police telegraphs, district-messenger-call systems and stock-ticker circuits, were established. Beginning in about 1876, commercial application of the telephone entered the field, increasing the number of overhead wires at a rapid rate, so that when in 1878 the first series-arc circuits made their appearance there was already a conspicuous tangle of wires strung indiscriminately above the public highways. The situation was aggravated by the neglect of defunct enterprises to remove the "dead wires."

This abandoned and ownerless equipment in combination with poorly insulated electric light wires constituted a real menace, that soon led to a public outcry against further increase of overhead wires and the immediate undergrounding of those already in use.

Ill-considered and impracticable legislation was the natural consequence of this situation.

A remarkable exception to the general practice was the radical departure from accepted methods made by Mr. Edison in the introduction of his low-tension multiple system.

As one of the items in Mr. Edison's programme for the development of his "system," we find in Dyer and Martin's book, "Edison, His Life and Inventions," the following:

> "To elaborate a system or network of conductors *capable of being placed underground* or overhead, which would allow of being tapped at any intervals, so that service wires could be run from the main conductors in the street into each building. Where these mains went below the surface, as in large cities, there must be protective conduit or pipe for the copper conductors, and these pipes must allow of being tapped wherever necessary. With these conductors and pipes must also be furnished manholes, junction boxes, connections and a host of varied paraphernalia insuring perfect general distribution."

The development of such a "system or network" with all the necessary accessories was accomplished, and on Sept. 4, 1882, current from the Pearl Street Station was turned into underground wires laid under the streets of a downtown section of New York City, supplying 225 houses wired for about 5,000 lamps.

However, this system was not applicable to the high-tension series currents used for arc lighting and the number of overhead wires for this purpose continued to increase until in the congested sections of the larger cities the situation became unbearable.

The general unsightliness, the menace to firemen, the dangers to the employees of the companies and to the public at large were too apparent to be further ignored. In 1884 the New York Legislature passed a law requiring the removal of wires from the streets before the first day of November, 1885. The physical impossibility of compliance with this law and the concrete fact that at the date set for their disappearance the overhead wires were still very much in evidence led to the passage of another act in 1885 which provided "that, if no suitable place should be proposed for placing the said wires underground it should be the duty of the said Board of Commissioners (created by this act) to cause to be devised, and made ready for use, such a general place as would meet the requirements of the said Acts of 1884–5 and the said Board should have full authority to compel all companies to use such subways so prepared."

A great variety of schemes was submitted to this Board, by outside parties, about 450 in all, but the electric light companies generally opposed the placing of electrical conduits underground, claiming that it was a physical impossibility to accomplish the feat successfully, and that in any event the cost would be prohibitive.

Finally the Board entered into a contract with a conduit company and a system of iron pipe conduit was put down in certain streets of the city. On these streets the authorities proceeded, in 1889, to cut down the poles and to remove the overhead wires and thus ruthlessly compelled progress in underground construction.

In Europe the situation had become acute before it was felt in this country, and various methods were tried with but little success, including the plan of running the wires on supports located on the roofs of the buildings.

In France there was developed the Berthoud-Borel System employing copper wires wrapped with cotton saturated with linseed oil, which had been previously treated by heating. The heat treatment appears to have made the oil more stable in character and to have increased its insulating properties.

One of the earliest forms of underground construction was the trench system, in which an attempt was made to use the same general methods as were used in overhead lines. The system consisted of a closed trench in which were placed conductors, either bare or insulated, fastened to insulating supports.

Professor Jacoby, of St. Petersburg, laid a form of armored cable consisting of cotton-covered cord, laid in lead pipe with the intervening spaces filled in with resin. There were many attempts along similar lines, none of which were successful until, with the discovery of petroleum in 1856, paraffine came into the market as a cheap and satisfactory insulating material.

The principal difficulty seemed to be in finding an insulation which could be made to adhere to the conductor. Many substances were found which were good insulators in dry places, but there were few which would stand the acid and alkali fumes and the ravages of sewer and illuminating gas to which the conductors were exposed when buried under the streets of our large cities.

Attempt was made to use oil as an insulation for cables and what was known as the Brook's System, Fig. 3, was employed for a time to some extent. It was found that wires insulated with resin and oil were difficult to short-circuit, even under a high potential difference. Of course, no pure oil could be used in

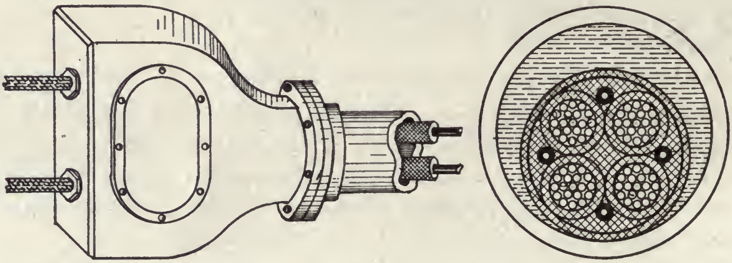


Fig. 3.—Brooks system of service-box cable and oil pipe.

the construction of cable, even when encased in lead, as in the jointing process the oil leaked out before the joint was sealed. It was proposed to lay iron pipe for the distance to be traversed, the pipes to terminate in hermetically sealed boxes. Cables which were carefully dried out to get rid of the moisture and then covered with jute and boiled in oil were drawn into these pipes, after which the pipes were filled with oil so that no moisture could enter. The oil was kept under pressure by means of a standpipe or pump, the theory being that if small leaks developed and allowed the oil to escape, the pressure on the oil would prevent the entry of either air or moisture. In addition, insulation break-downs would be self-healing.

However, it was found exceedingly difficult to obtain oil sufficiently heavy for good insulation, and that the pressure from the standpipe or pump could not be transmitted for any great distance.

Experiments with this type of construction were made by the Pennsylvania Railroad Co. and the Western Union Telegraph Co., between Newark and Jersey City, across the salt marshes.

In England, a system was developed by Johnson and Phillips, which gave satisfactory service. In their system the idea of using oil under pressure was abandoned and more attention was paid to the laying of pipes without leaks, taking especial precautions to seal the junction boxes and the pipe ends.

This system was particularly adapted for electrical lines crossing private grounds and for long trunk lines in which there was little probability of their being disturbed after laying. It was very difficult, however, to keep this system in proper repair, as leaks in the pipe line necessitated the placing of additional junction boxes which were difficult to install without removing the cable and refilling the entire length of the pipe. Other disadvantages lay in the objection of workmen to handling cables saturated with heavy oils and in difficulty in making extensions or branch connections to the system.

The failure to obtain an insulation which would stand up under moisture and other deteriorating influences brought about the development of the solid or built-in system.

Built-in Systems.—Numerous solid or built-in underground systems using both insulated and bare conductors were tried as a substitute for overhead electrical wires. The enormous expense of making the change, as well as the utter lack of experience with buried circuits, made this a very difficult problem from the start, and as is usual in such cases, extraordinary methods were devised for overcoming the difficulties.

In England, the Crompton System, Fig. 4, of bare copper strips was used quite extensively. This system used bare conductors supported at intervals on insulators and laid in a specially prepared trench. The system was tried in two forms: In the first, sag or strain bars were placed at a suitable distance apart. These took up most of the strain and very little came upon the insulating supports which were located about 50 ft. apart and carried on cast-iron cross-bars. In the other form of this system, no strain bars were used, but the number of supporting insulators was increased. In both forms, but particularly in the latter, trouble was experienced due to leakage of current to earth at the insulator supports, probably caused by water leaking along the support and reaching the conductor.

The system, in both its forms, was abandoned because of the high cost of construction and maintenance and because of inherent defects, due principally to the following:

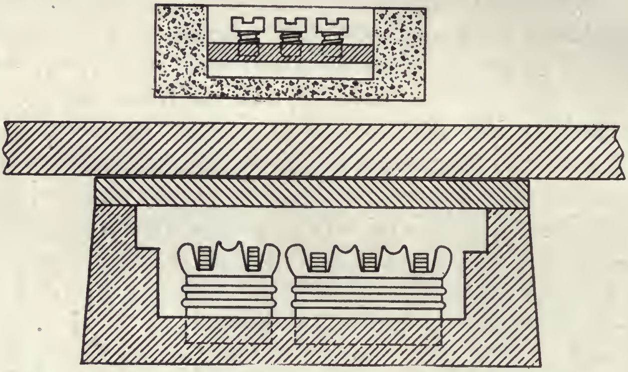


Fig. 4.—Section of Crompton and Kennedy conduit.

1. Temperature changes caused buckling of the strips, resulting in heavy short-circuits and interruptions to service.

2. Lack of efficient drainage and ventilation which caused leakage of current due to moisture and the collection of gases in the trench. Arcing at a poor connection ignited these gases, causing disastrous explosions.

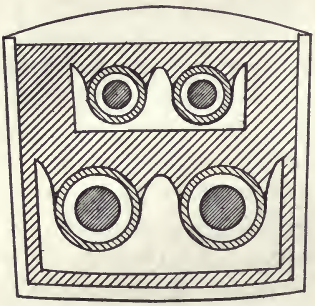


Fig. 5.—Section of Callender system.

3. Heavy short-circuits set up electromagnetic forces between conductors, causing them to buckle and communicate the trouble by coming into contact with other circuits.

What is known as the Callender Solid System, Fig. 5, consisting of a series of cast-iron troughs laid along the bottom of a trench, was also used to some extent. The required number of insulated conductors were strung in a cast-iron trough. After stringing the conductors, the trough was filled with an asphalt compound and closed with cast-iron covers. Experiments were carried on with other forms of cast-iron troughs, some of which were made in short sections and bolted together, the cable being placed in the troughs as laid. The troughs were usually filled with some kind of compound to exclude moisture. These methods of providing underground distribution, however, were so expensive as to be almost prohibitive. Moreover, all systems which employed tarry or bituminous filling had two serious disadvantages. It was difficult to keep them rigid under all conditions of temperature, as at high temperatures the softening of the material caused sagging of the system under the weight of the earth above, resulting in damage to both the ducts and the wires which they carried. At the low winter temperatures the conduit was likely to crack and admit moisture. The second disadvantage lay in the fact that in making extensions to the system it was necessary to tear up the street to get at the cable on which work was to be done.

The first objection was finally overcome by the use of iron pipe filled with compound to give the necessary rigidity, but the second was an inherent defect and was to a large extent responsible for the final abandonment of the built-in system.

In the early eighties, the Edison Tube System of underground construction was devised and later commercially adopted by a number of the larger cities in the United States and Europe.

This system consists of 20-ft. lengths of iron pipe inside which the conductors are embedded in a bituminous compound. The conductors, which are not removable, are usually in the shape of round copper rod, the main tubes being designed for use on the three-wire system. Each rod is wound with a layer of rope which serves to keep the rods separated in case a softening of the insulating material in the tubes should occur. After the rods have been provided with the layer of rope, they are bound together by means of a wrapping of rope and inserted in the iron pipe, the rods projecting for a short distance at each end. The whole tube is then filled with an insulating compound which becomes hard when cold. The 20-ft. lengths are made in various sizes of conductors from No. 1 gage up to 500,000 cm. for mains, and 1,000,000 cm. for feeders. Sections of the tube are designed for use as distributing mains, and are made with three conductors of the same size, while those designed for feeders are often made with one conductor about half the area of the others. This small conductor is used as the neutral for which, in a balanced system, little capacity is required. Tubes are also provided with potential leads to indicate at stations or substations the voltage at the outer end of the feeder. The tubes are laid in the ground about 30 in. below the surface of the pavement and are joined together by means of coupling boxes. The conductors are connected together by means of short flexible copper cables provided with lugs to fit over the rods and soldered in place. The coupling boxes are made in two similar halves. After being placed in position the two sections are securely bolted together by means of flanged bolts. After this is done, melted compound is poured through an opening in the upper casting and the joint completed. Branch connections are made with T coupling boxes

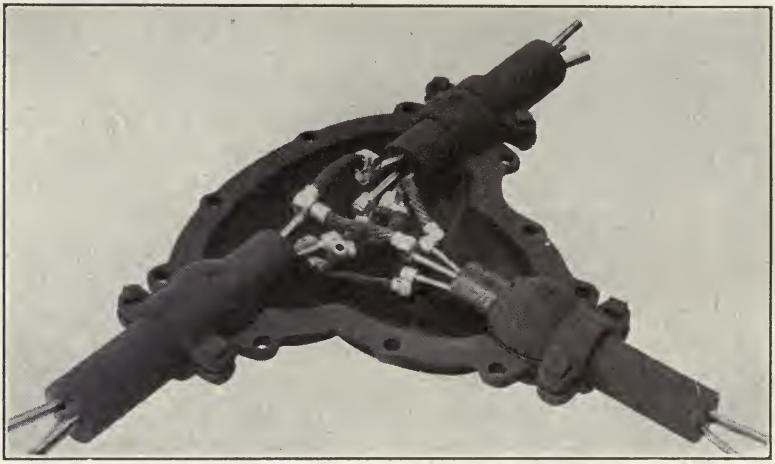


Fig. 6.—Edison tube coupling joint.

which are filled with compound in a similar manner. At centers of distribution junction boxes are provided at which the main feeders and the supply wires from the station join. The junction boxes are provided with fuses and water-tight covers to allow inspection and testing. When trouble occurs, the usual method of procedure is to dig a hole at one of the couplings and separate the ends. By making a number of breaks in this way at different locations, the section in which the ground or short-circuit occurs is located and the defective length of tube replaced. The Edison System remained standard for low-tension distribution for about 15 years, when cables drawn into ducts began to be employed for the heavy feeders. It is still used to some extent in cities where a large investment had been made for such work before the development of the drawing-in system.

In some instances, especially in European countries, armored cables laid directly in the earth have been employed for underground distribution. The armor, which is in the form of a steel wire or tape, is relied upon for mechanical protection. This form of installation which is used quite extensively at the present time has advantages for certain purposes, as described elsewhere in this volume. However, the ease with which repairs may be made in the drawing-in systems has caused these systems to become standard throughout the United States.

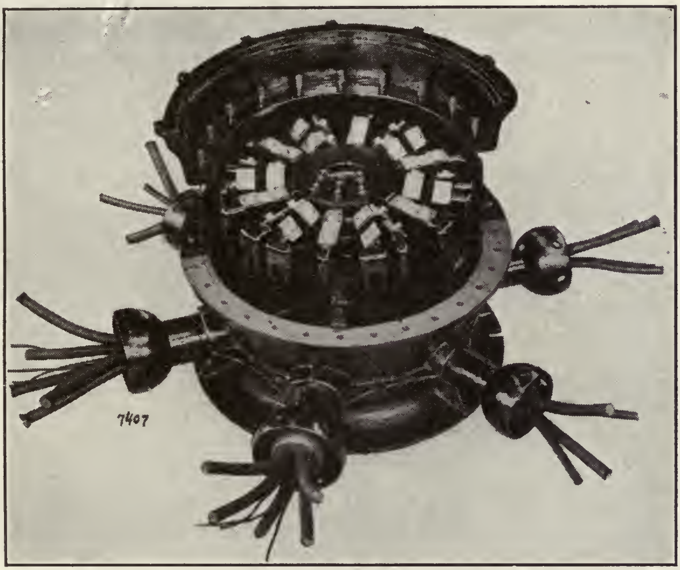


FIG. 7.—Edison tube junction box.

Drawing-in Systems.—With the development of the alternating-current system of distribution and the use of high-potential circuits of from 1,000 to 7,000 volts for street-lighting circuits, the need was felt for some form of insulation sufficiently flexible to permit of drawing cables into the ducts. The built-in system had been abandoned to a large extent because of its failure to stand high potential and because it was found necessary to dig up the streets when increased load demanded reinforcements or additions. The constant tearing up of the pavement for these purposes created an antagonistic feeling on the part of the municipal authorities and in many cases they were reluctant to grant permits for the laying of additional conductors in the streets.

In the early forms of drawing-in systems the chief difficulty appears to have been the lack of an insulating material capable of withstanding the high potential of arc circuits. Some trouble was also experienced on account of disintegration of the lead sheath itself.

Lead-covered cables were being operated successfully at low voltages, but with the undergrounding of arc-light wires failures of the insulation soon resulted.

The difficulties which were experienced in the early days of the drawing-in system were due not to the fact that the underground system was fundamentally wrong, but rather to the fact that in cable manufacture lack of experience prevented the intel-

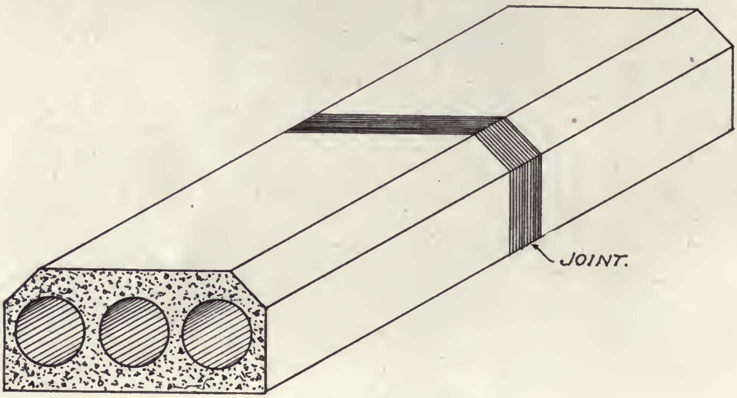


FIG. 8.—Dorset conduit.

ligent design of the subsurface structure which was to carry the conductors.

The problem resolved itself into three parts:

1. The insulation of the conductors.

2. The protection of the insulation from the effects of moisture and corrosion.

3. The protection of both conductors and insulation from mechanical injury.

Elaborate experiments were conducted with all kinds of cable and with a variety of conduits, but it was found that copper conductors insulated with any of the compounds which had thus far been tried failed under high potential within a short time. Where lead was used to protect the insulation the life of the cable was materially increased.

The Dorsett Conduit System which consisted of sections of duct made with bituminous concrete was at one time largely used in New York and Minneapolis and proved a complete failure on account of the fact that it was impossible to make sure that the compound between the ducts effected a thorough cementing and in consequence after construction the blocks were frequently found to have cracked apart and fallen out of alignment, thus sacrificing all the insulating properties and reducing the cross-section of the duct.

This type of construction was somewhat modified by General Webber, of the British Postal Telegraph Co., and he was able to construct a satisfactory cable-carrying conduit, but could not make the system entirely waterproof.

In Webber's System, the 4-in. or 5-in. space between ducts was filled with the same material of which the ducts were formed in a molten state. This molten material melted enough of the conduit surface to form the whole into a solid mass. The system, however, did not permit of the use of uninsulated wires.

The system used in Minneapolis by the Interior Conduit Co. consisted of impregnated paper tubes with paper ferrules at the joint laid in a trench. The trench was filled with a compound composed of asphaltum and coal tar, poured while hot, entirely covering the paper tubes. Bare copper wires were drawn into the ducts and manholes were provided. These consisted of double wooden boxes sealed with compound and covered with water-tight covers. The system worked well for several years, but was finally abandoned because of the original use of unsatisfactory material. The paper ducts were found to be not absolutely impervious to moisture and as the supporting wooden blocks in time became saturated with moisture which seeped through the paper conduits, short-circuits were frequent. The installation was not water-tight and in many instances the whole duct structure was filled with water after heavy rains.

The Interior Conduit Co. later used a system of paper tubes one within the other, designed to be laid with broken joints. The tubes were protected externally by an iron pipe or laid in asphaltic concrete supported on blocks of earthenware. Iron manholes were substituted for the double wooden boxes used in the earlier systems.

Another system, known as the Cumming Duct, was used to some extent. Four wooden ducts were enclosed in an iron pipe, the intervening space being filled with an asphaltic compound. This system was limited to the use of low-potential conductors where a small number of cables were installed.

In Milwaukee, three systems were tried and abandoned: namely, a wooden-trench plan, tarred iron pipe, and grooved wood. In Detroit, the Thomson-Houston Co. employed a cable of the most expensive and approved character in the Dorsett

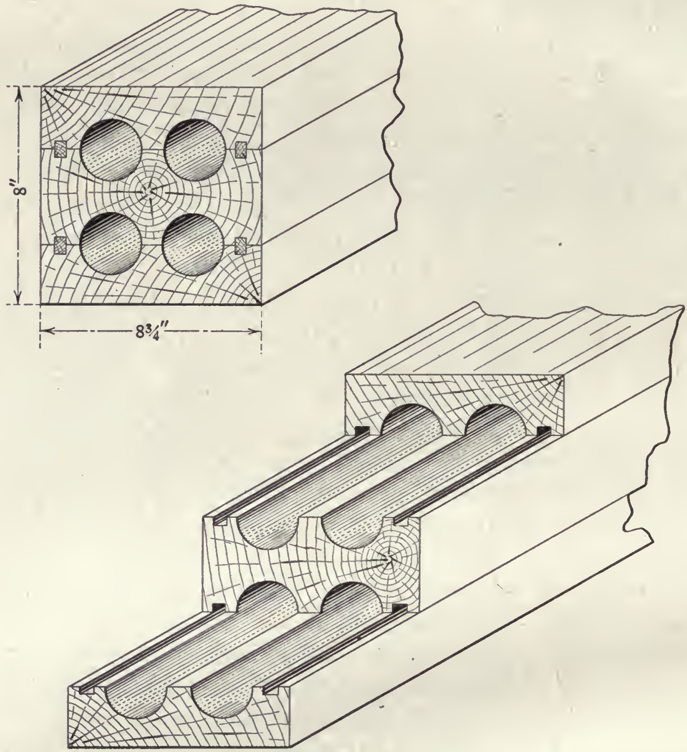


Fig. 9.—Types of wooden duct.

conduit, and the mechanical work was of the best quality. The conduit was made of a so-called concrete consisting of asphaltum and sand moulded into 3½-ft. lengths, with the desired number of ducts. One end of each section was flanged and two sections were jointed and fitted together by means of hot concrete, the manholes being made of the same material. In this installation it was found that while the cables were new the results were fair, but the loss by leakage rendered it impossible to provide proper voltage regulation at the lamps.

Creosoted wood, or what is commonly known as pump-log conduit, was used in a number of installations. This conduit though cheap was found to deteriorate very rapidly and to cause much trouble by catching fire when a cable burnout occurred. In many installations the decay of the wood formed acetic acid which attacked the lead sheathing of the cable. As the result of these difficulties the use of wood as a conduit was soon abandoned.

Cement-lined pipe was largely used about 15 years ago. This consisted of sections of thin wrought-iron pipe, No. 26, B.W.G., 0.018 in. thick, securely held by rivets 2 in. apart. The tube was

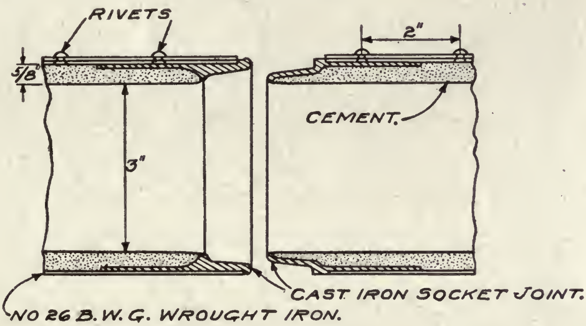


Fig. 10.—Details of cement-lined pipe.

lined with a wall of Rosendale cement ⅝ in. thick, the inner surface of which was polished while drying, so as to form a perfectly smooth tube. The ends of the tubes were provided with a cast-iron beveled socket joint to obtain perfect alignment. The cement lining in this form of conduit, after several years service, separated from the outer iron form, causing considerable trouble in the installation and withdrawal of cables. In some cases the cement lining was porous and with the absorption of moisture the conduit soon disintegrated so that this form of construction had a very short life.

Wrought-iron or steel pipes screwed together by means of couplings were used for a number of years, particularly where the high cost was not a serious objection. Wrought-iron pipe laid up in cement and additionally protected with 2-in. plank was for a long time considered standard construction in New York

City. Its special advantages are: great strength to resist the severe strains caused by the pressure of the earth, and that it is well adapted to withstand blows from workmen's shovels and tools, to which conduits in large cities are subjected because of the frequency of street excavation work. The pipes are standard 3-in. and 4-in. diameter and are made gas- and water-tight by means of a tapering screw-thread coupling. The pipes are laid about an inch apart and the spaces around them filled with concrete. It is evident that this form of construction is extremely

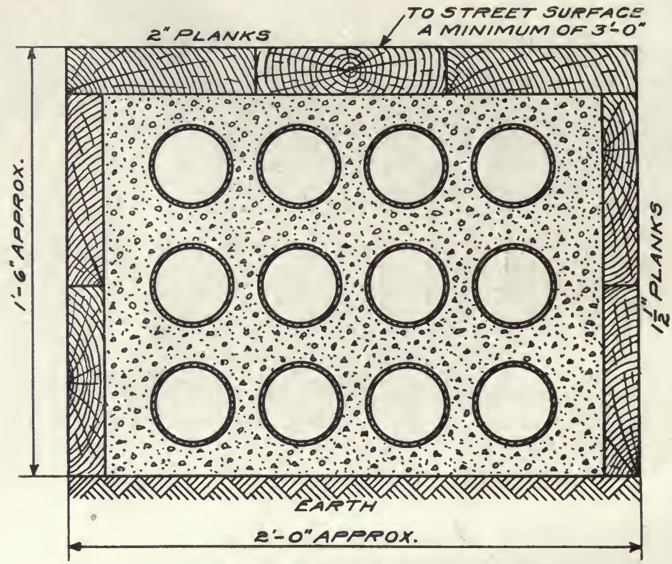


FIG. 11.—Cross-section of iron-pipe conduit.

substantial and will withstand the most severe mechanical stresses, but because of its high first cost it has been superseded by cheaper systems.

In the city of Paris, the sewers, which are egg-shaped in form, are purposely constructed much larger than necessary for carrying sewage, so that the upper portion may be rented for pipe and conduit lines. Service connections are made through the sewer pipes connected to each house, thus avoiding the use of manholes. The sewers are large enough to allow a man to stand upright, while the main sewers are often 27 ft. in diameter. Perforated manhole covers are provided at intervals to allow for ventilation and give access for cleaning. The air in the sewers is fresh, although a slight musty odor associated with sewage is noticeable. Gas mains are not carried in the sewers as they are considered a danger on account of the possibility of an explosion. Electric service connections are carried through the individual service connections to the buildings.

Present Forms of Construction.—Tile and fiber conduits are now used almost exclusively. The first is manufactured from vitrified clay in single duct and multiples of two, three, four and six ducts, in either round or square bore. The ducts are laid end to end and usually surrounded with an envelope of concrete which reinforces the structure. The joints are staggered and wrapped with either burlap or iron and covered with cement.

While there is some difference of opinion among engineers as to which type of conduit is the better, the clay-duct system is more generally used in distribution work. The newer material, known as fiber conduit, is rapidly coming into general favor, and at present is considered standard construction and used successfully by a number of the larger companies.

In some locations stone pipe is being used to advantage and its cost compares favorably with that of tile and fiber conduit. An ideal conduit would provide absolute protection for the cables from every destroying influence. It should be proof against acids, alkalies, gases and all other chemical elements; it is likewise essential that it be non-corrosive and absolutely permanent in character and composition; it should also have high insulating qualities to protect the cables from outside circuits and avoid electrolysis. The joints should be self-aligning and insure permanently fixed alignment, and the duct should have a hole with a smooth and strictly non-abrasive inner surface, to entirely prevent injuries to the covering of cables while drawing them in and out of the ducts. The ducts should be light in weight to save expense in freighting, handling, and laying, and should be strong and tough for proper protection of cables and to avoid loss from breakage, in shipping and handling, and lastly the first cost should not be excessive.

It is a well-established fact that when a system is properly designed, the saving in the cost of maintenance, the increase in efficiency, the superior service and absolute insulation, in a very short time unquestionably repay for the increased first cost. The cost of the subsurface structures among the larger central-station companies may be said to amount to one-fourth of the entire investment, and for the reason that these structures are themselves as important as any link in the chain of central-station equipment, and because of the relatively large investment involved, great care should be exercised in determining the kind and type of underground construction to be used. In the succeeding chapters the types of construction which are in use to-day are described in detail, together with specifications, costs, and other data to be used as a guide for the central-station engineer in the design and operation of underground systems of transmission and distribution.

CHAPTER II

PRELIMINARY SURVEY

Planning the System.—In planning a conduit system for general use in housing both transmission and distribution feeders, as well as mains and service cable, the first thing to be decided upon is the method of distribution. The system of distribution depends to a large extent upon local conditions and in many cases will follow the general plan of the existing overhead system, except in large cities where obstructions in the streets and the expense of approved paving methods will frequently determine to a great extent the route to be followed.

In some cities, local ordinances prescribe the use of poles in alleys for block distribution, and in such cases the conduits are usually laid on the main streets or thoroughfares. Where the use of overhead alley distribution is permissible, the problem of eliminating pole lines from the streets is relatively easy and the cost of underground construction is materially reduced.

Maps.—When the method of distribution has been decided upon and the streets on which the ducts are to be laid have been determined, a map should be prepared showing the location and size of the proposed duct line.

The problems presented to the engineer who is responsible for the installation of an underground system are many, but he has a comparatively large field from which to choose methods and materials. Local conditions will determine to a large extent the character of the construction to be employed. Conduit systems are usually laid subsequent to other subsurface structures such as water and sewer pipes and gas mains, and it is therefore necessary in preparing specifications and estimates that locations of existing subsurface structures be known in advance as definitely as possible. The engineer should, therefore, provide himself with a map of the district to be covered in order that he may determine what streets can best be used after considering the load on the system and determining the method of distribution. Maps or surveys should be drawn to scale in order that the locations of foreign structures may be plotted thereon.

A record of the subsurface structures can generally be obtained by applying to the municipal authorities. While this information will frequently be found of great value in making a preliminary layout, too much dependence should not be placed thereon, as such records are not always accurate and are quite often incomplete.

It is, therefore, necessary to check up these records in the streets where underground structures are numerous, particularly in cases where the space available for a conduit installation is limited by such structures.

Test Holes.—Obstructions are most likely to be encountered at street intersections, and these obstructions should be located as accurately as possible before beginning the trench excavation.

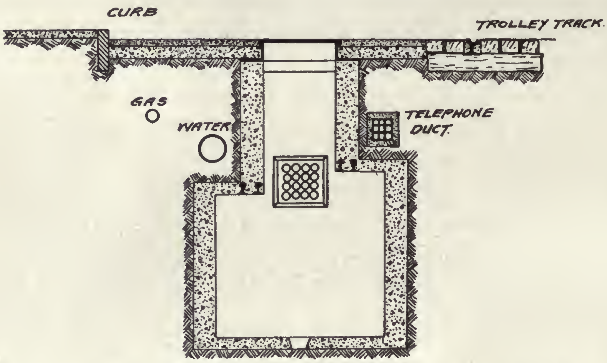


Fig. 12.—Method of building manhole around obstructions.

It is best to find obstructions, such as water and gas mains and the service connections of other utilities by digging test holes along the line of work, and so laying out the work as to avoid them when possible.

These test holes are usually about 2 ft. in width, extend from curb to curb and are of sufficient depth to show the locations of the lowest structures. Only one-half of the street is opened at one time in order not to interfere with traffic. To determine definitely that the proposed location of the conduit line is clear of other underground structures and obstructions, these test holes should be dug at intervals along the line far enough in advance of the trench so that any errors in records of previous work in the streets or in the location of the conduit line will be disclosed before incurring the expense of digging the trench.

Where possible, test holes should be dug at the proposed manhole sites with the double purpose of utilizing the extra excavation and of obtaining definite information as to the availability of the proposed manhole location.

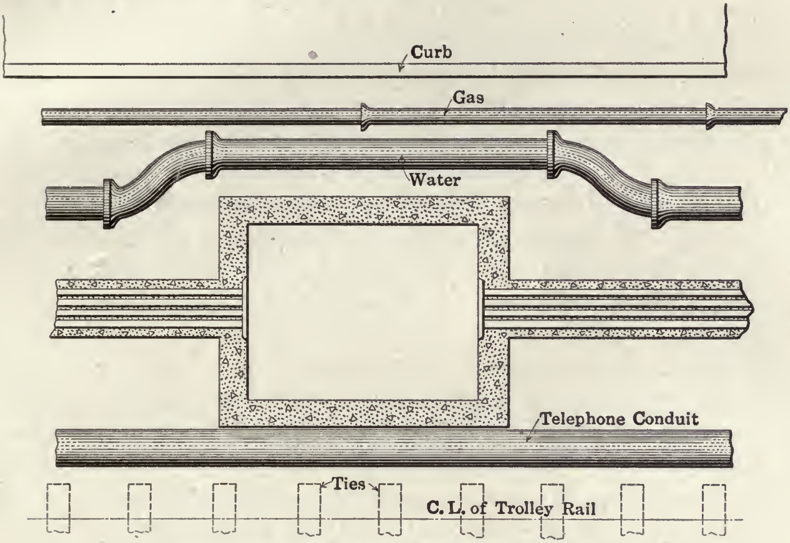


Fig. 13.—Street main cut around manhole.

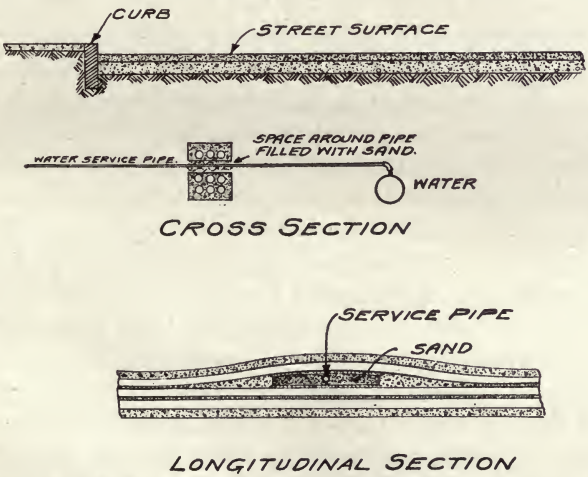


Fig. 14.—Method of building conduit around service pipes.

It is frequently found after measurements are taken in the test holes, that while there is sufficient space for the conduit, the space for manhole construction is so limited as to make it necessary to provide a special form of construction. In Fig. 12 is illustrated a method of installing a manhole in a congested street where foreign obstructions make it necessary to resort to an unusual design. In some cases it may be cheaper to have the water or gas pipes cut around the manhole as shown in Fig. 13. The conduit, when installed parallel to water or gas mains, should be placed at a grade which will not interfere with the water- or gas-service connections. But where this is impossible, the service pipe is usually run through the conduit, the ducts being divided and the space around the service pipe, where it passes through the conduit, filled with sand, as shown in Fig. 14. Gas mains should not be run through manholes except only in very special cases. Where it is necessary to take a gas main into a manhole, it should be encased in concrete.

Permits and Right-of-way.—Before proceeding with any actual construction work in the streets, the engineer should acquaint himself with the local municipal laws, ordinances and regulations or other requirements relating to the excavation or the occupancy of space in the public streets. Notes as to obstructions or any other points relating to the work should be made and arranged in a form convenient for reference.

In some cities pavements are laid by contractors under bond with the municipal authorities to keep such pavements in good repair for a period of years. In such cases it is usually necessary to restore the pavement after street excavations have been made. In many instances it is impossible to obtain permits for street opening after a new pavement has been installed, and this should be given consideration in laying out a route for the conduit system, as it has often been found advisable to install a conduit system in advance of the laying of a permanent pavement in order to keep the cost within reasonable limits.

The engineer should confer with the local authorities in the matter of obtaining permits for the opening of streets, the use of fire hydrants and the methods of obtaining permits and the rates of payment for water used for construction purposes.

In many European cities it is the practice to install the subsurface structures of the utilities beneath the sidewalk. Regulations are in force prescribing the exact location beneath the sidewalk within which each utility must be placed. In some places a movable pavement is provided which may be removed and replaced without great expense, allowing repairs to be made to the subsurface structures. The advantages of locating utilities beneath the sidewalks as compared with their placement beneath the street pavement are that it is less expensive to remove a cheap sidewalk than a costly pavement, and the maintenance cost is lowered. Structures placed under the sidewalk are not subjected to the shock and vibration from heavy overhead traffic, and the installation of transportation subways is made considerably less expensive where no underground utilities have to be maintained in service during construction.

In some of the larger cities in the United States, the streets have become so congested with both surface and subsurface structures that the matter of subsurface construction has been placed under the control of a Municipal Board consisting of the Chiefs of Bureaus of Highways, Surveys, City Property, Electrical Bureaus, etc., the idea being to have all departments concerned with surface or subsurface construction of streets represented on the Board. One of the most important duties of this Board is the obtaining, compiling and mapping of all possible information concerning existing or projected structures under streets. For carrying out the work, a corps of field inspectors and draftsmen is maintained, and necessary authority and power given the Board to enable it to obtain the required information and to control the action of both corporations and individuals in their use of the streets.

In some cities it is required that plans showing all existing underground structures be filed in duplicate together with complete details of proposed construction. All work and material used must be satisfactory to the Chief of the Electrical Bureau and any work and material condemned must be at once replaced in acceptable form. After work is completed, the party to whom the permit is issued is required to file complete plans in detail showing the work as constructed, with all previously existing structures encountered during the construction work.

The foregoing applies to only a few cases where subsurface structures and transportation subways occupy practically all of the available space under the street surface.

When electrical companies are required to remove overhead wires and poles from streets or public highways, it is the usual practice to confer with the authorities and arrange for some satisfactory manner of procedure. While franchise requirements will govern the form of the agreement in any particular case, the following is submitted as a specimen:

FORM OF AGREEMENT

AN ORDINANCE granting permission to (name of company), its successors and assigns, to lay and maintain underground conduits, cables, wires and manholes for electrical conductors in the streets, avenues and public places of the city (or town) of ..... for the use and purposes of its business, and providing for the removal of certain overhead wires and pole lines.

BE IT ORDAINED by the Common Council of the city (or town) of .... as follows:

Section I.—That (name of company), its successors and assigns, be and it is hereby authorized and empowered to construct and maintain for the use and purposes of its business, a system of subways and underground conduits, laterals, service conduits, service boxes and manholes beneath the surface of the streets, avenues, and other public places of the city (or town) of ..... as the boundaries thereof are now or may hereafter be, and to place, maintain and operate therein wires, cables and other electrical conductors necessary for such purposes; provided that said subway shall be confined within a space of four (4) feet in width, except the manholes, which may be constructed of the usual size and shape necessary or advantageous for the conduct of the business of said company.

Section II.—That (name of company) shall, within six (6) months after the passage and acceptance of this ordinance, proceed to construct its subways or underground conduits with the necessary laterals, service conduits, service boxes, manholes and street openings in (state requirements of first year's work, giving names of streets and avenues in which conduits are to be installed). After the completion of the subways or underground conduits in the above-mentioned streets, said (name of company) may extend its conduits and subways through the other streets, avenues, and public places of the city (or town) of ..... from time to time, as the requirements of its business shall demand.

Section III.—That within one year from the laying of subways or conduits in any street, avenue or public place in the city (or town) of ..... or any section thereof, said company shall remove its electrical conductors, poles and fixtures from above the surface of those sections of said streets, avenues or public places beneath which said subways or conduits shall be constructed, except where said poles and fixtures are used for supporting public lights, or for the purpose of supporting or connecting with wires in intersecting streets, and thereupon the right of said company to maintain the poles so required to be removed shall cease and become void; and the said company shall repair the sidewalks from which said poles shall have been removed.

Section IV.—That the said (name of company) before opening any street for the doing of any part of the work hereby authorized, shall from time to time file in the office of the city (or town) of ..... a map or plan showing the proposed location and dimensions of the subways, underground conduits and manholes, or any portion thereof, proposed to be constructed in any such street, avenue or highway, which location or locations shall become operative from the time of such filing. The said subway or underground conduits shall be made of (specify the kind and types of construction), and shall be laid not less than two (2) feet beneath the surface of the streets, and not less than one (1) foot outside of the curb lines, except where necessary to avoid obstructions; and shall conform to the laws of the State governing the laying of subways for the transmission of electricity for light, heat or power.

The manholes shall be located beneath the surface of said streets at such points along the line of the subways or underground conduits as may be necessary or convenient for placing, reaching and operating the electrical conductors which the said company may from time to time place in subways or underground conduits, and shall be so constructed as not to interfere with the passage of the public over and along the said streets; and the said company shall restore such street or avenue which may be disturbed in the construction and maintenance of the subways, conduits, laterals, or manholes to the condition in which it was at the commencement of the work thereon, and free from any cost or expense whatever to the city (or town) of ...... In backfilling of the trenches, the earth shall be put in layers of not more than six (6) inches at a time; it shall be thoroughly rammed and compacted before another layer of dirt is placed thereon, and where necessary it shall be carefully and thoroughly puddled. The electrical conductors and conduits therefor shall be so placed as to do no injury to any shade tree or to the property of any person or persons, or to any public or private sewer, or to any water or gas pipe, or to the wires or conduits of any other company. At least forty-eight (48) hours before the opening of any street or avenue, the said company shall notify, in writing, the city (or town) engineer of the desire of the said company so to do, stating the place and purpose of such proposed opening, and the said company and its servants and employees, in the laying of any wires or conduits, in excavating and replacing the earth in any street or avenue, and in replacing the pavement thereon, shall be under the supervision of the city (or town) engineer, or the proper officer appointed by him having supervision of streets and highways. The earth removed in making any excavation shall be restored, and the pavement taken up and relaid by the said company in a thorough and workmanlike manner, and in such manner as to prevent any future sinking of the pavement. The pavement so disturbed or taken up, either in the original construction of said work or in any subsequent repairs to the work, shall thereafter be maintained by the said company for a period of one (1) year, unless said street is repaved within such time, in as good condition as the surrounding pavement. No street, avenue or public place shall be encumbered for a longer period than shall be necessary. In prosecuting said work not more than one thousand (1,000) feet of any street, avenue or highway shall be opened at one time, and in all cases and at all times during the prosecution of such work in any street, avenue or highway, a proper passageway for vehicles shall be kept open and free at the intersection of streets.

The cost of restoring the earth or otherwise and the cost of replacing the pavement and repairs thereto, caused by the opening of any such street or avenue, shall be paid for by said company, and the said company shall likewise pay the cost of an inspector appointed by the city (or town) of ..... to supervise the work. The expense of such supervision and the cost of such inspector shall be paid by said company upon the presentation of bills therefor, certified by the proper officer of the city (or town) and the expense to which the city (or town) of ..... shall be put from the neglect of said company, or its employees or the doing of any work in an unworkmanlike manner in the digging of trenches or holes, or in the restoring of the earth, or of the relaying or replacing of any pavement, shall in like manner be paid by said company. In case the work or any part thereof shall not be done to the satisfaction of the city (or town) engineer, or the person appointed by him having the supervision of streets and highways, the said city (or town) engineer may, without waiving any of its rights hereunder, cause the said work to be performed or material to be supplied to its satisfaction; and the company agrees upon the presentation of bills therefor, certified by the proper officer in the city (or town) to pay at once the same, including the cost of both inspection and of labor and material; provided, however, that before any work shall be done or material supplied by the city (or town) of ..... for the cost of which (name of company) under this section shall be liable, the city (or town) engineer shall give notice in writing to (name of company) of the work required to be done and the material required to be supplied, and the company shall have ten (10) days within which to begin the work and supply material by such notice required to be done or provided, and shall have a reasonable time thereafter within which to complete the said work.

Section V.—The said company shall indemnify and save harmless the city (or town) of ....., its officers, servants and agents, against all loss, and shall assume all liability and pay all damages which may at any time arise, come or occur to the city (or town) of .....,its officers or agents, from any injury to person or property, from the doing of any work hereinbefore mentioned, or from the doing of said work negligently or unskillfully, or from the neglect of said company or its employees to comply with the provisions of any ordinance of the city (or town) of ..... relative to the use of the streets, or from the failure to put up proper lights and barriers at or around excavations, or from the failure to support properly the tracks of steam railroads or street railways during the prosecution of the work and thereafter, and the acceptance by the company of this ordinance shall be an agreement by said company to pay the city (or town) of ..... on any sum of money for which the city (or town) of ..... may become liable from or by reason of any injury or damage.

Section VI.—The said company shall file with the city (or town) of ..... its acceptance of this ordinance within thirty (30) days from the date on which it shall take effect.

Section VII.—That the company shall repay the city (or town) of ..... the amount of the cost and expense to the city (or town) of ..... of all official publication of this ordinance.

Section VIII.—That this ordinance shall take effect immediately.

Other forms of agreement provide for the removal of overhead wires and poles in certain definitely prescribed sections of the city or town, covering a period of from 5 to 20 years. In such cases the operating company has the advantages of being in a position to lay out definitely its work from year to year, and to make plans for the entire system, thus providing at the very start for the ultimate number and size of conduit and manholes.

Still other forms of agreement provide for the expenditure of a certain sum ranging from $5,000 to $50,000, depending on the size of the city and the financial condition of the operating company.

Some companies have agreed to construct each year a certain number of lineal feet of underground conduit, the municipality exercising the right to designate the streets in which it desires to have conduit installed, covering not more than one-half of the total amount, the remainder being left to the judgment of the company. The streets designated by the city (or town) must be contiguous to the present subway system. The forms of agreement regarding the amount of work to be done are dependent entirely on local conditions, and the foregoing outline is given merely to aid the engineer in determining a proper method of procedure.

Regulations.—Many states have enacted laws to regulate the construction and maintenance of subway systems, with a view to safeguarding workmen.

In some cases these laws fix the size of manholes so as to provide sufficient working space for the necessary jointing and repairs, and the size and location of manhole covers. The proposed National Electrical Safety Code, in the preliminary edition issued by the Bureau of Standards, April 29, 1915, contains the following recommendations covering manholes, handholes and ducts:

Location

Underground systems of electrical conductors should be so located as to be subject to the least practicable amount of disturbance. When being designed and installed, care should be exercised to avoid catchment basins, street railway tracks, gas pipes, or other underground structures which have been installed or are planned for the future.

To facilitate installing and withdrawing cables and conductors, the ducts between adjacent manholes or other outlets should be installed in straight lines, except when it is necessary to install curves, in which case they should be of not less than 25 ft. radius, and manholes or other outlets spaced closer together than on straight runs.

Grading

Manholes should be so located and ducts so graded that drainage of ducts will always be toward manholes or handholes. To insure satisfactory drainage, the ducts should be so installed as to provide a grade of not less than 3 in. in 100 ft. of length.

Accessibility

Manholes should be so located as to provide safe and ready access, and, if possible, so that the least horizontal distance from any rail of a railroad track to the nearest edge of a manhole opening is not less than 3 ft.

Mechanical Details

The mechanical design and construction of manholes and handholes shall be such as to provide sufficient strength to safely sustain the mechanical loads which will be imposed upon them.

The entrance to all manholes shall be not less than 24 in. minimum diameter. Round openings are recommended.

Manholes should be so constructed when practicable that the least inside dimension will be not less than 3 ft. 6 in., and should be so arranged as to maintain a clear working space whose least dimensions are not less than 3 ft. horizontally and 6 ft. vertically, except that where the opening is within 1 ft. on each side of the full size of the manhole the depth may be less. Where conditions will permit, a larger working space than the above should be provided.

Manholes and handholes shall be so arranged, if practicable, as to provide permanent drainage through trapped sewer connections or otherwise for such surface or drainage water as may flow into them.

Manhole Covers

Manholes and handholes while not being worked in shall be securely closed by covers of sufficient strength to sustain such mechanical loads as will be imposed upon them, and so secured in place that a tool or appliance is required for their opening or removal.

Mechanical Barriers and Guards

Manhole openings shall be so arranged that they may, when uncovered, be surrounded by substantial metal barrier guards.

Material, Size, and Finish of Ducts

Ducts used in underground systems of distribution for electrical supply and signal conductors shall be of such material, size, mechanical strength, and finish as to permit the safe installation and maintenance of all conductors or cables to be maintained in them.

Installation of Ducts

Conduits should, where necessary, be laid on suitable foundations of sufficient mechanical strength to protect them from settling and be protected by covers where necessary to prevent their disturbance by workmen when digging, or by other causes. A sufficient depth shall be provided between the top of the duct covering and pavement surface or other surfaces under which the duct run is constructed.

Ducts shall have clear bores and be freed from burrs before laying. They shall be laid in line in such manner as to prevent shoulders at joints.

Duct openings into manholes, handholes, or other permanent openings of underground systems shall be provided with an effective bushing.

Duct runs should provide as great a clearance from other underground structures as practicable. Conduits for underground conduit systems to be occupied by signal conductors for public use should, where practicable, be separated from underground conduit systems for supply conductors by not less than 3 in. of concrete or its equivalent.

Joints in duct runs shall be made reasonably water-tight and mechanically secure to maintain individual ducts in alignment.

No duct should enter any manhole, handhole, or other permanent opening of underground systems of distribution at a distance of less than 6 in. above the floor line or below the roof line.

Ducts of laterals supplying service to buildings should be effectively plugged or cemented by the use of asphaltum, pitch, or other suitable means to prevent gas entering the consumers' premises through the ducts.

The foregoing notes are included with the idea that they may be useful to companies in their dealings with commissions and municipal bodies.

CHAPTER III

CONDUIT AND MANHOLE CONSTRUCTION

Selection of Materials.—"Whether it is the intention of the central-station engineer to build the conduit line himself, or to have it built by contract, there will be certain material and labor used, and these should be the best of their kind in either case."[1] Having decided on the routes of the conduit, the type of conduit line to be constructed should be determined.

A few years ago a 3-in. diameter duct was considered sufficiently large, but for feeder cables called for today, which are often over 3 in. in diameter, nothing less than a 3½-in. bore conduit should be used.

If the material selected is of the best, and the workmanship all that it should be, there is no reason why a first-class conduit should not last indefinitely and the repair and maintenance charges be low.

Installation of Conduit.—In the laying of conduit, trenches should be dug to a line stretched along the street to keep the ditch straight, and the width should be kept constant by means of a stick cut to the required length and used as a gage. The ditch should be dug in the rough, somewhat narrower than the finished width, the exact width being obtained by trimming. This method produces a straight smooth finish on the sides of the trench and will aid materially in keeping the ducts straight and also in reducing the quantity of concrete required for any given duct section.

The bottom of the trench should be carefully leveled and graded to the required depth and grade stakes should be driven at intervals throughout the length of the ditch for the purpose of limiting the thickness of the concrete base and of fixing the exact grade of the finished conduit.

Ducts should be so laid as to drain toward manholes, for if pockets are formed and the duct line is submerged it is likely to freeze in winter weather and injure the insulation of the cable, and possibly, damage the conduit.

[1] Hancock, N. E. L. A., 1904.

In the laying of conduit great care should be taken to insure that the alignment of the ducts is not disturbed previous to or during the process of filling in the space between the ducts and sides of the trench, or in placing the top cover on the concrete.

In digging the trench, paving materials or old concrete should be carefully separated from the earth and all excavated material should be thrown well back from the brows of the ditch to provide wheeling space for concrete and other materials, in order to prevent them from being brushed into the ditch by workmen. Where deep ditches are required, and the soil is of an unstable character, shoring or bracing will be necessary. This is especially necessary in case of severe rains during the progress of the work, and the force engaged in the work should always be so arranged that the smallest possible amount of trench consistent with economical working, will be opened at one time.

In many cities there is a limit set on the amount of street which may be opened at one time.

Where it is the intention of the engineer to furnish his own labor and material in the construction of the conduit line, it is essential that he provide himself with a general foreman, or general superintendent, who is thoroughly familiar with the laying out of the work, handling the men and attending to the details of city-street construction. It will be necessary to place considerable confidence in this man and his ability should be such that the payroll will be reduced to a minimum and the amount of work completed each day be consistent with the number of men employed.

The superintendent of construction should be familiar with all of the details of the work, and see that his assistant properly protects the life and property of others observing the city regulations and providing bridges over openings at intersecting streets. Proper barriers should be placed where required, and excavations should be flagged at all times, to avoid accidents to pedestrians, or interference with traffic. The trench should be properly patroled at night by a watchman, whose duty it should be to see that the lanterns are kept lighted throughout the night.

It is important that records be made of the progress of each day's work and that measurements be taken showing the actual location of the work, foreign conduits, pipes, and any other obstructions encountered in the installation, as well as any troubles experienced during the construction period.

The principal object in keeping itemized records is to enable the engineer to determine the unit cost for similar work, and to analyze expenditures with a view to improving the method of working, as well as the class of labor to be employed. The records should show the amount of each class of work completed daily so that the many kinds of work may be divided into units and the unit cost obtained.

In all forms of conduit construction which require the formation of ducts, the base or foundation section of concrete should be not less than 3 in. in thickness. The laying of the conduit should be immediately followed by the concrete required to fill in between the sides of the trench and the conduit line, in order to give support to the sides of the trench and to insure a proper joining of the concrete in the base and side sections.

Concrete.—The concrete required for conduit work should be mixed in a thorough and careful manner. Where the streets are surfaced with a smooth, clean pavement, and the municipal authorities will permit the use of the pavements, no mixing board will be required. Where the work is being done on unimproved streets or rough pavements, mixing boards should be provided if the concrete is to be mixed by hand. Mixing boards made of a sheet of boiler iron will be found convenient. These should be about 8 ft. square and 1/4 in. thick, and provided with holes and rings at the corners to which a length of chain can be fastened to facilitate moving from place to place.

TABLE I.—MATERIALS REQUIRED FOR A CUBIC YARD OF RAMMED CONCRETE

Mixtures			Stone 1 in. and under, dust screened out			Stone 2½ in. and under, dust screened out			Stone 2½ in. with most small stone screened out			Gravel ¾ in. and under		
Cement	Sand	Stone	Cement, bbl.	Sand, cu. yd.	Stone, cu. yd.	Cement, bbl.	Sand, cu. yd.	Stone, cu. yd.	Cement, bbl.	Sand, cu. yd.	Stone, cu. yd.	Cement, bbl.	Sand, cu. yd.	Stone, cu. yd.
1	2.0	4.0	1.46	0.44	0.89	1.48	0.45	0.90	1.53	0.47	0.93	1.34	0.41	0.81
1	2.5	5.0	1.19	0.46	0.91	1.21	0.46	0.92	1.26	0.48	0.96	1.10	0.42	0.83
1	3.0	5.0	1.11	0.51	0.85	1.14	0.52	0.87	1.17	0.54	0.89	1.03	0.47	0.78
1	3.0	6.0	1.01	0.46	0.92	1.02	0.47	0.93	1.06	0.48	0.97	0.92	0.42	0.84
1	3.0	7.0	0.91	0.42	0.97	0.92	0.42	0.98	0.94	0.42	1.05	0.84	0.38	0.89
1	4.0	7.0	0.83	0.51	0.89	0.84	0.51	0.90	0.87	0.53	0.93	0.77	0.47	0.81
1	4.0	8.0	0.77	0.47	0.93	0.78	0.48	0.95	0.81	0.49	0.98	0.71	0.43	0.86

Concrete for conduit work should be mixed from good Portland cement and clean sand and gravel, or broken stone, in the proportions of 1 part cement to 3 parts of sand and 5 parts of gravel or broken stone, with sufficient water to thoroughly wet the mix, and allow a small amount of water to come to the surface when the concrete is ready for pouring.

Most brands of Portland cement manufactured at the present time appear to be satisfactory and will pass the strength tests if the cement is a representative sample of the manufacturer's output.

It is customary to test cement for tensile strength, the reason being that concrete is weaker in tension than compression.

Specifications for cement may be obtained from any of the members of the Association of Portland Cement Manufacturers, and they will, therefore, not be printed here. It is customary to test samples of cement from each shipment received, some engineers testing one sample from each 8 or 10 bbl. received, others testing only one sample from each carload. The number of samples to be tested depends on the importance of the work, but in ordinary conduit work and manhole construction one test from each carload should be sufficient.

There are several important considerations to be observed in the selection of aggregates for concrete. The material entering into the concrete must be of such structure and quality as to suit the use to which the concrete is to be put. Aggregates should remain in an unaltered physical state as long as the concrete lasts and should be so graded as to give a maximum density, strength and impermeability. The material selected should show a definite strength in combination with the cement.

The matter of using a good quality of sand is very important. All sands are derived from the decomposition of natural rock of various kinds. It is frequently stated in specifications that clean sharp sand must be used, and while this is important, it is more important that sand be properly graded so as to secure a dense mass. Sand containing loam or clay should not be used, for if it has been properly washed all such foreign materials will have been removed.

When mixed by hand, the cement, sand and stone should be turned at least three times dry and twice wet, and the concrete should be placed immediately after mixing. When all the concrete has been placed in the trench, it should be allowed to take its initial set before the trench is filled in and tamped, and the pavement replaced in order to avoid throwing the conduit out of line or fracturing the concrete while it is still weak.

Tile Duct.—Tile duct is made of clay which has been worked up in a pug mill to the proper consistency, passed through a press from which it emerges in the desired shape, carefully dried, and burned until it is thoroughly vitrified. It is then given a salt glaze and allowed to cool slowly.

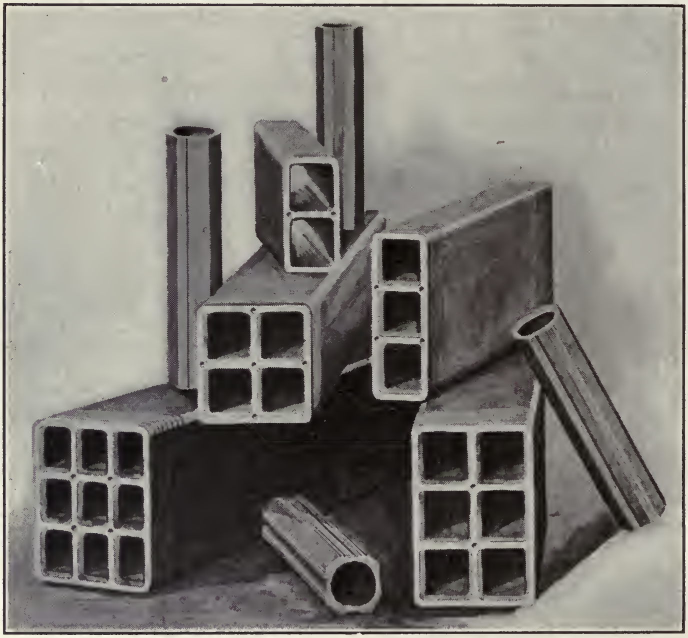


FIG. 15.—Single- and multiple-tile duct.

The quality of the duct is very materially affected by many of the processes, and it is, therefore, important that it be purchased on carefully drawn specifications.

The clay should be free from gravel and of such composition that it will work up into a solid homogeneous mass, 60 per cent. fire clay and 34 per cent. shale making a very desirable combination.

The duct, when moulded and dried, should be burned thoroughly, but not scorched or fused. The glaze should thoroughly cover the inside of the ducts so that they will present a smooth surface to the cable. Single duct should not have a bend of over $\frac{1}{8}$ in. from a straight line, and multiple duct should not have more than $\frac{3}{16}$ in. bend. Twisted or distorted pieces should be rejected as these cannot be lined up and may interfere with the installation of the cable. No duct having salt blisters or drips which project more than $\frac{1}{8}$ in. inside, or $\frac{1}{4}$ in. outside should be used. Air- and fire-checked pieces should also be rejected. The test for straightness should be made by passing through the duct a mandril of the length of the piece and $\frac{1}{8}$ in. smaller than the inside diameter of the duct. If the mandril will not pass, the duct is too crooked to be installed.

If the tile is properly vitrified, it will give a clear ringing sound when struck by a piece of tool steel. If it gives a dead sound, it indicates softness and porosity, which will result in a high breakage in handling.

Tile conduit will last indefinitely, and when free from iron it possesses high insulating properties. It also has great mechanical strength, and shows an average puncture test of 25,000 volts dry, and 21,000 volts after immersion in water for several days. While the dielectric strength of the tile is very high, the insulation resistance of the system is greatly lowered in consequence of the number of joints which are made with cement or other moisture-absorbing material. Instead of the entire system withstanding 20,000 volts, it will be found that, due to the presence of joints, the installation will not be able to stand more than 5,000 volts, depending, however, on the general characteristics of the soil surrounding the ducts.

Multiple-tile conduit is usually made in lengths of 3 ft., the number of ducts varying from two to nine, and in some special installations even more.

The pieces are laid end to end and are usually held in alignment during the construction period by iron dowel pins which fit into the holes formed in the ends of each section.

In making joints in multiple-duct tile, it is impossible to prevent communication between the ducts, and, owing to this condition, multiple-duct affords the least protection to the cables. If the streets in which the conduit is to be installed are congested under the surface, the use of single-tile duct permits of a more flexible installation, whereas, the multiple-tile duct is used to good advantage in suburban districts where there are few obstructions to interfere with the course of the line.

Multiple-tile duct is better adapted for telephone, telegraph and other similar wires than for use in connection with power cables, since, as explained, the ducts communicate at each joint between the sections of tile, and in case of trouble on a cable, in addition to the communication at each joint, the thin tile is apt to be melted and evaporated, permitting the burning cable to damage other cables in the same conduit line.

In the laying of single-duct tile, the ordinary methods of brick laying are used and the joints are made by simply putting the

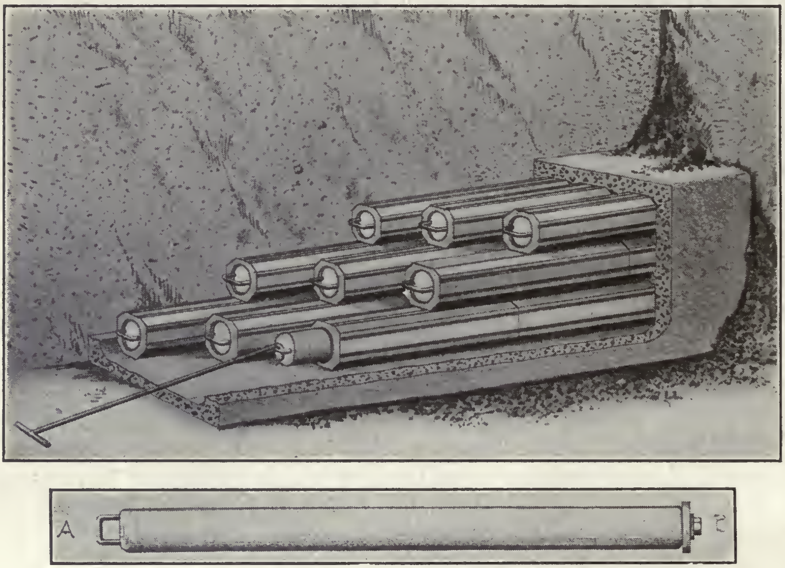


FIG. 16.—Section of tile conduit illustrating use of mandril.

two pieces of tile together. Alignment is secured by the aid of a mandril. Since the length of the sections is shorter and the area much less than in the case of multiple-tile, a more perfect butt joint can be obtained in a single-duct installation.

It is not customary in laying single-duct tile to wrap the joint with any form of protection to prevent the mortar or concrete running through the joint. It is almost certain, however, that some mortar will work its way through the joint and in order that this may be removed before it hardens, a wooden mandril, such as is shown in Fig. 16, 3 in. in diameter and about 30 in. in length, is used. At one end is provided an eye (*a*), which may be engaged by a hook, in order to draw it through the conduit, while at the other end is secured a rubber gasket (*b*) having a diameter slightly larger than that of the interior of the duct. One of these mandrils is placed in each duct when the work of laying is begun. As the work progresses, the mandril is drawn along through the duct by the workmen by means of an iron hook at the end of a

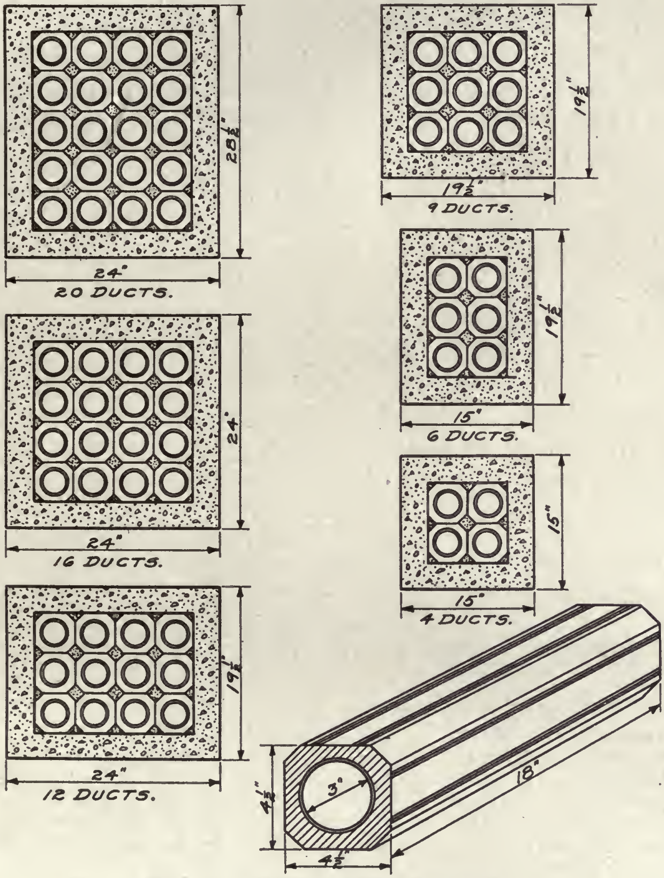


Fig. 17.—Single-tile duct sections.

rod about 3 ft. long. By this means the formation of shoulders on the inner walls of the ducts at the joints is prevented, and any dirt that may have dropped into the duct is also removed. The cylindrical part of the mandril insures good alignment of the ducts, thus securing a perfect tube from manhole to manhole. The use of such a device will leave a smooth inner surface, free from projections and burrs, which if left would be likely to damage the sheaths of the cables during the drawing-in process.

The principal advantage to be gained from the use of single-duct lies in the ability to break joints in all ducts. Provided a jacket of concrete or mortar surrounds each individual longitudinal row of tiles, perfectly solid ducts may be produced. If the tiles are not completely surrounded by such a jacket, a burning cable is very likely to discharge the gases produced by the arc through the butt joints with such force that the hot gases and the flame which results from their combustion will cause damage to the cables in adjacent ducts.

Single-duct tile, being vitrified, requires the same general provisions for inspection as multiple-duct and all duct purchased should be rigidly inspected at the factory before shipment is made.

The weight of 3½-in. tile is approximately 8 lb. per duct ft. and this heavy weight increases the freight cost and the labor cost of laying.

The question of breakage is an item which must be taken into consideration. This will vary from 5 to 10 per cent. of the total shipment, depending upon the composition, quality and firing of the clay of which the duct is made.

Table II.—Table of Information on Standard Vitrified Conduit

Style of conduit	Dimension of square duct, in.	Dimension of round duct, in.	Outside dimensions of end section, in.	Reg. stock lengths, in.	Short lengths, in.	Approx. weight per duct ft., lb.
2-duct multiple.....	3⅜ sq.	3¼	5 by 9	24	6, 9 and 12	8
3-duct multiple.....	3⅜ sq.	3¼	5 by 13	24	6, 9 and 12	8
4-duct multiple.....	3⅜ sq.	3¼	9 by 9	36	6, 9 and 12	8
6-duct multiple.....	3⅜ sq.	3¼	9 by 13	36	6, 9 and 12	8
9-duct multiple.....	3⅜ sq.	3¼	13 by 13	36	6, 9 and 12	8
Common single duct.	....	3⅜	5 by 5	18	6, 9 and 12	8
Single duct, self-centering............	......	3⅜	5 by 5	18	6, 9 and 12	10
Round single duct, self-centering......	......	3¼	5 in. round	18	6, 9 and 12	10

Minimum car lot, 5,000 duct ft. or 40,000 lb.
Maximum car lot, 7,500 duct ft. or 60,000 lb.

Where very cheap work is desired, multiple-duct tile is sometimes laid either without concrete or with a single bottom layer for a foundation and with perhaps a top layer for protection against future excavations. The concrete in such cases gives little or no support to the tile and should the earth shift or settle, the tile is apt to give way under the strain, resulting in damage to the cables. Such construction is not recommended and in no case should it be used where permanency is desired.

In the laying of tile duct both of the single and multiple type the ducts should all be thoroughly cleaned out by drawing through

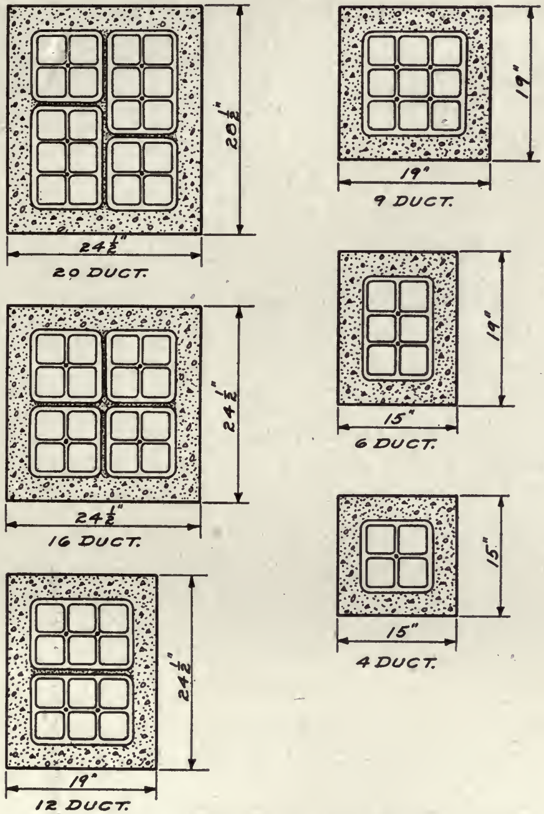


FIG. 18.—Multiple-tile duct sections.

them a wire brush or flue cleaner slightly larger than the duct. Any particles of sand or loose bits of mortar left in the duct may be removed by following up the brush or cleaner with a cotton-rope mop. It is essential that the cleaning be done as soon as possible after the placing of the concrete in order that concrete or mortar which may have been introduced into the ducts through the joints may be removed before it has a chance to harden. Where it is necessary to cut pieces of the tile for fitting lengths together, the tile is notched all around at the desired point by means of a hammer and cold chisel. It should break off at the mark after continued chipping, though it frequently happens that the cracks run off in some other direction. It is, preferable, therefore, to have fitter lengths, furnished by the manufacturer.

Stone Duct.—Stone duct has been used quite extensively in the City of Chicago. It is made of a high grade of limestone and Portland cement, in the proportions of 4.75 to 1.00, the materials being thoroughly blended together with water.

Moulded-stone duct is manufactured under the Graham process and is moulded in two half moulds or sections in especially designed machines. This mould contains a mandrel form that is displaced by a larger mandrel having a tapered steel point. Both mandrels are revolved by means of individual motors and the tables holding the moulds are moved parallel with the mandrels. As the form is displaced by the tapered steel points, all inequalities in filling are eliminated.

This method insures a perfectly smooth inner and outer surface of the pipes. After being removed from the conduit machines, the ducts are allowed to stay in the lower half of the mould for 48 hr. to take their initial set. They are then placed in racks and sprinkled continuously for about 6 weeks to insure their perfect curing, after which they are allowed to dry for 2 weeks. They are then ready for use. The ducts are made in 5-ft. lengths and the units are provided with metal rings. These rings, which are used for connecting two sections together afford a tight joint, making it impossible for any foreign material to get into the duct. It is claimed that this type of conduit is not injured even by the short-circuiting of heavy power cables. In this way communication of trouble from one duct to another is avoided.

This conduit is laid with an envelope of concrete. It forms a monolithic mass as the envelope makes an excellent bond with the duct. The ducts can be readily cut with an ordinary cross-cut saw, and the weight of the duct is approximately the same as that of tile duct. With the use of metal sleeves, unskilled labor may be employed in its installation. Its length permits of the same staggering as is obtained with the use of fiber conduit. The conduit is made up in various forms and in split sections, thus allowing repairs to be made in ducts carrying cables. It weighs approximately 7½ lb. per ft., has a bore of 3½ in., with a wall ⅝ in. thick and approximately 4,000 ft. can be loaded for shipment on a standard car.

Fiber Duct.—Fiber conduit is the most recent addition to the materials used for subway construction, and has come into very general use for all classes of underground electrical work. This type of conduit has been in use approximately 15 years, and the writer has had occasion to examine fiber duct which has been

Fig. 19.—Stone conduit.

installed in moist soil for about 10 years. The inspection failed to show the slightest signs of deterioration. Fiber pipe was originally used for irrigation purposes and was installed under the most unfavorable conditions in all kinds of soil, both wet and dry, and in a number of cases without any concrete or cement protection. It is made of wood pulp which has been thoroughly saturated with a bituminous compound containing about 6 per cent. of creosote in solution. The creosote prevents rotting by killing the organisms which might act on the vegetable matter in the pulp. The conduit is made in various styles of joint to suit the particular service conditions; sleeve, drive or screw joints may be obtained as required. The joints, which are turned up true in a lathe during the process of manufacture, are self-aligning.

TABLE III.—DATA ON FIBER CONDUIT

Inside diameter, in.	Type of conduit	Approximate average weight per ft.-lb.	Feet in minimum car shipped in bulk	Average load one-team truck, ft.
1	Socket joint	0.38	80,000	10,500
1½	Socket joint	0.70	42,000	5,700
2	Socket joint	0.85	35,000	4,700
2½	Socket joint	1.02	30,000	4,000
3	Socket joint	1.20	25,000	3,300
3½	Socket joint	1.45	21,000	2,750
4	Socket joint	1.62	18,000	2,450
1½	Sleeve joint	0.74	40,000	5,400
2	Sleeve joint	0.90	33,000	4,400
2½	Sleeve joint	1.10	27,000	3,600
3	Sleeve joint	1.30	23,000	3,000
3½	Sleeve joint	2.50	12,000	1,600
4	Sleeve joint	3.20	9,400	1,250
2	Harrington joint	0.90	33,000	4,400
2½	Harrington joint	1.10	27,000	3,600
3	Harrington joint	1.30	23,000	3,000
3½	Harrington joint	1.55	19,300	2,550
4	Harrington joint	1.90	15,500	2,100
3	Screw joint	2.20	13,600	1,800
3½	Screw joint	2.50	12,000	1,600
4	Screw joint	3.20	9,400	1,250
2	"Linaduct"	0.55	54,000	7,300
2½	"Linaduct"	0.65	42,000	6,100
3	"Linaduct"	0.75	24,000	5,300
3½	"Linaduct"	0.85	21,500	4,700

These joints make it possible to lay the sections in the trench unit by unit with great rapidity. No wrapping with burlap or other material is required and no trowel work is necessary, thus permitting employment of unskilled labor in laying the duct.

Where it is desirable to make a perfectly water-tight joint, liquid compound is usually applied to the male end of each section as it is placed in position. The simplicity of this form of duct and the ease of handling give it an important advantage over other classes of duct. When the ends are properly fitted together, they remain in perfect alignment.

Tests which have been conducted on fiber, show that it will withstand a puncture test of 32,000 volts when dry and 24,000 volts after immersion in water for about 200 hr. It is impervious to moisture, gases, acids and other corrosive elements and as it is a non-conductor, troubles from stray currents are negligible.

The non-abrasive feature of the conduit is very important, as it permits of drawing cables into the ducts without injury to the sheaths by such grinding or cutting action as often results

Fig. 20.—Installation of fiber and multiple duct.

when the ducts are composed of a hard material and the inner wall is not perfectly smooth.

Absence of abrasive or gritty surfaces adds to the ease and rapidity with which the cable may be installed. The lightness of the conduit gives it a decided advantage not only as regards handling and laying, but also as regards shipping, since about 20,000 ft. can be loaded in a standard box-car, owing to the lightness of the conduit. It is made in 5-ft. lengths, which is a convenient length for shipping and handling in the trenches; this also results in fewer joints, thereby effecting a considerable saving in labor.

Bearing in mind its light weight, the lengths of the sections in which it is manufactured, and the simplicity in the method of jointing, it is readily seen that a greater amount can be laid in less time by a less number of men than is the case with other forms of duct. Unskilled labor can be used in its installation and the

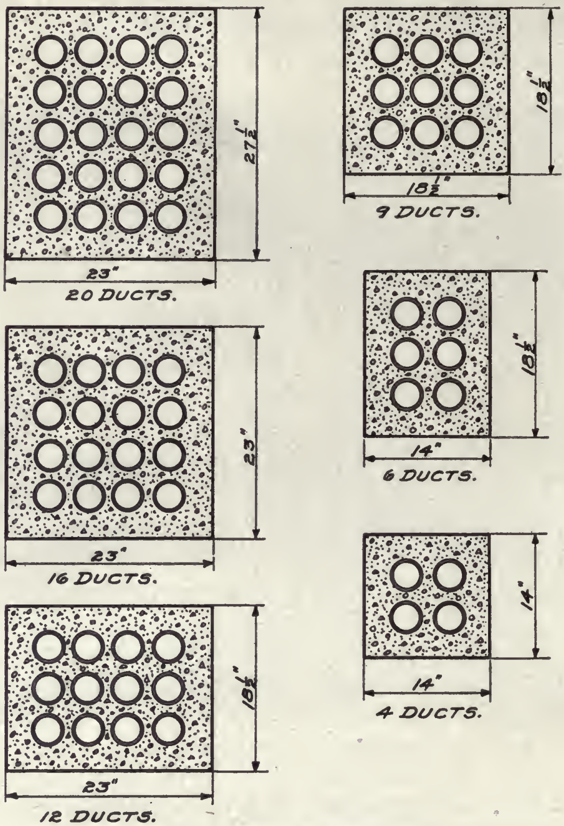


Fig. 21.—Fiber-duct sections.

cost of laying is thereby considerably reduced. Breakage amounts to practically nothing owing to the great tensile strength and the shock-resisting properties of the material.

In the laying of fiber conduit a concrete base 3 in. thick is provided similar to that used in other forms of construction. There is also provided a side and top cover with 1 in. of concrete separating the adjacent duct, and with fiber conduit, as well as with other forms, it is well to avoid water pockets in the ducts.

After the foundation of concrete has been placed, the first or bottom row of pipes is laid directly on its surface and these are spaced by means of a wooden spacing block or comb, illustrated in Fig. 22. The desired duct section is then built up in successive tiers and a 1-in. spacing is maintained throughout the line of conduit by means of the spacing block just mentioned. In laying the duct care should be taken to stagger the joints in the adjacent pipes in the conduit, and it is important that all joints be perfectly tight, otherwise the concrete is apt to work into the duct and cause obstructions.

The concrete should be worked thoroughly around each pipe to prevent voids in the structure, and for this kind of work the concrete should be mixed with gravel or broken stone, which will

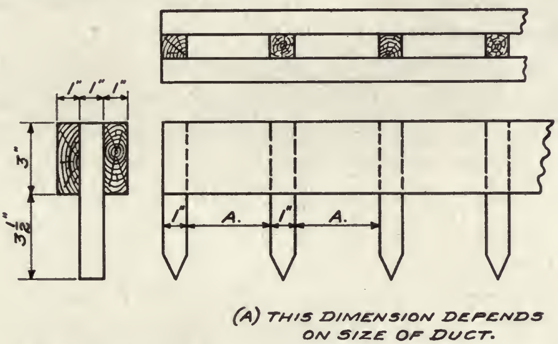


FIG. 22.—Detail of comb for spacing fiber ducts.

pass through a sieve of ¾-in. mesh. In laying the fiber duct, each piece should be inspected to see that it is perfect and that no foreign material has lodged inside the tube.

In considering the merits of the numerous kinds of conduit material, which are used in underground systems, it must be understood that each has its particular field and the conditions which will govern the type of installations are to be carefully considered, not only from the standpoint of interest and depreciation on the investment, but also with a view to securing freedom from interruptions to service.

The question of the relative mechanical strength of fiber, tile and stone conduit is of minor importance, because the strength of the surrounding concrete will determine the strength of the structure as a whole. Since the best grade of concrete will stand a compression test of about 3,000 lb. per sq. in., it will be seen that, regardless of the duct material, the structure will have sufficient strength to meet the most exacting demands of service conditions.

Manhole Construction.—Manholes are usually built at street intersections or turns in the conduit line, to afford a place for jointing the cables. The distance between these manholes depends on local conditions. It is safe to say that this limiting distance, where large cables are to be employed, should be 500 ft.

In pulling in long runs of cable, the sheath is subjected to severe strains which are to be limited as much as possible.

Manholes designed for high-tension cables should be spacious and should have good drainage facilities. Their design should be such as to avoid sharp bends between the point where the cables enter and the position on the manhole wall where they are to be jointed and racked.

Ample facilities should be provided in each manhole for the shelves or racks on which the cables are to be supported. Many cables have had to be renewed on account of insufficient manhole room and careless racking.

It is also wise to give some attention to the location of the lower and top ducts in the manholes to permit drawing in cables without damaging them.

Manhole covers are preferably located at the center of the manhole making it easy to set and rack cables and rendering it impossible for careless workmen to ruin the cables by using them as steps in entering and leaving manholes.

In transmission systems it is very desirable, as previously stated, to limit the distance between manholes to less than 500 ft., as this permits of carrying in stock standard lengths of cable which can be used in any part of the transmission line. Wherever practicable manholes should be connected to sewers so that the water will run off. A suitable trap should be employed to prevent the sewer water from backing up and filling the manhole or conduit line. Where it is impossible to make the necessary connection to the sewer, the following method may be used to advantage:

When excavating for manhole work, a hole a trifle deeper and larger than an ordinary barrel is dug and a barrel without top or bottom placed in it; the outside of the barrel is surrounded with a concrete covering about 3 in. thick and the barrel filled with gravel or small stones. The concrete foundation of the manhole should then be laid and the top of the barrel set flush with the floor.

The tendency in the past has been to give too little attention to the matter of future requirements and this has resulted in the very congested condition of cables and equipment now found in the manholes of many of our large cities. The importance of providing adequate facilities will be appreciated when it is considered that the efficiency of men, when working under cramped conditions, is seriously impaired.

Sewer and Illuminating Gas.—In the construction of manholes, provisions should be made for sufficient ventilation to carry off any gases which may accumulate.

The gases most commonly found in manholes are sewer gas and illuminating gas, and now, with the extensive use of automobiles, we may find gasolene vapors mixed with the sewer gas.

Sewer gas consists of approximately 90 parts of nitrogen, 2 to 4 parts of oxygen, 1 to 3 parts of carbon dioxide, 3 to 5 parts of carbon monoxide, methane and other gases. It has an odor due to the organic decomposition constantly going on in the sewers. It is not poisonous in the true sense of the word, but, due to its high percentage of nitrogen and its low percentage of oxygen, there is not a sufficient amount of oxygen to support respiration, and hence a person is slowly smothered in an atmosphere of this gas. It is non-explosive in itself, and, due to its high nitrogen and low oxygen content, would, undoubtedly, prevent the explosion of otherwise explosive gas when mixed with it. This gas easily finds its way into the conduit lines through the entrapped connections which the manholes have with the sewers.

Illuminating gas, or city gas, as generally distributed, may be coal gas, water gas, Solvay gas, or a mixture of any two or all of these gases. It is colorless, but usually has a strong penetrating odor, so that a small percentage may readily be detected by the sense of smell. It is very poisonous in itself and with air forms a highly explosive mixture. Gas mains and distribution lines are closely interwoven with the conduit lines and breaks or leaks in the gas system lead to the escape of the gas into the conduits and manholes.

Sealing of Ducts in Manholes.—When troubles occur in which there is an arc in series with considerable resistance, the lack of sufficient oxygen for the combustion of the gases, which are generated, will cause these gases to flow through the conduits and burn in adjacent manholes, unless there is some positive barrier to prevent the gas flowing between manholes. It is, therefore, considered advisable to cement the ducts in each manhole along the heavier runs of cable where the spreading gas could cause the greatest damage. Some companies using concentric cables, subject to creeping on account of expansion and contraction at periods of heavy and light loads, do not consider it advisable to cement the ducts. They also consider the omission of the sealing of the ducts an advantage from the standpoint of providing more ventilation to the manholes and, therefore, less chance of accumulation of gases, and perhaps increased heat radiation in the ducts. All ducts or pipes leading from manholes to the premises of customers should be cemented in the subway and at the entrance into the customer's buildings to prevent obnoxious gases entering the premises. Several devices are on the market which have been designed to be placed in the duct before applying a mortar to aid in removing the latter. A weak cement mortar is sufficient for this purpose.

Types of Manhole Construction.—Manhole construction may be classified under three headings:

(*a*) Brick construction.

(*b*) Monolithic concrete construction.

(*c*) Concrete block construction.

The design of each of these three types of construction may be divided into two classes: namely, design to properly facilitate the training of cables for transmission purposes; and design to provide for the training of cables for distribution purposes, including the installation of transformers, boxes, and other subsurface equipment.

Monolithic concrete seems to be advocated for manhole construction, particularly where a number of manholes of the same size are to be built, and where local conditions and the space available in the street will permit the use of a standard form. One of the advantages of the use of monolithic concrete for manhole construction is the fact that common labor may be employed for mixing and placing the concrete, whereas, with brick construction, the service of experienced masons is necessary. Brick construction seems to be very desirable in congested sections where the use of either a wooden or metal form for concrete work would be almost prohibitive on account of the high cost of special forms to meet the local conditions.

One of the disadvantages in the use of concrete manholes lies in the fact that the soil in many locations is sandy clay, which will not stand unless properly supported by bracing. The result of this soil condition is that in the locations where the absence of other constructions permits the use of concrete manholes, the soil requires an outer as well as an inner form. In such cases the resulting cost is higher than for brick manholes. The presence of water in some localities at a depth of 3 or 4 ft. makes it necessary to build brick manholes. In such locations, a manhole of brick can be built by driving sheet piling and using a sufficient number of pumps to remove the water from the hole. The brickwork is started directly upon the sand and the manhole is filled up with sand as the work progresses. This prevents the water which seeps into the hole washing out the mortar of the brickwork.

Building Manholes in Quicksand.—It is frequently necessary to build manholes in a sandy soil when the permanent water level is only 2 or 3 ft. below the surface, and in such cases manholes have been successfully built by using a modified form of open-caisson construction. The excavation to the quicksand is made in the ordinary manner. Then a wooden framework is built, having the same horizontal section as the manhole wall. This framework is built up of 2-in. planks to a total thickness of 6 in., the corners being well fastened to eliminate diagonal bracing and leave the center of the framework free for the excavation. The framework is then placed in a level position on the quicksand and the manhole is built of brick to the required height, the walls being well plastered on the outside.

After setting for 3 or 4 days, the excavation of the manhole proceeds. By digging along the walls inside of the manhole and under the wooden framework, the manhole will usually settle to the required depth. During the excavation only sufficient water should be removed to allow the men to work to advantage, as otherwise the sand becomes quite hard. The settlement, if slow, can be accelerated by placing bags of sand or other weights on top of the manhole walls. Ordinarily the excavation and settlement of the manholes to the required depth will not require more than 8 or 10 hr. unless obstructions are encountered. After the manhole has reached the proper depth, the settlement is stopped by backfilling the excavation and tamping around the outside of the manhole wall.

Upon completion of the settlement, the water is removed from the manhole, the sand excavated to the level of the bottom of the wooden framework and a heavy concrete bottom is placed in the manhole. The openings for the conduit are cut in the manhole walls after it is entirely completed and has settled to the proper depth.

In building such manholes, the labor cost is about double that of the ordinary manholes. The wooden framework is the only other additional item of expense.

Concrete blocks have not been used to any considerable extent for building manholes, although this form of construction would, undoubtedly, be the cheapest if a considerable number of manholes of a standard size were to be built. One reason why this type of construction is not more common is the difficulty of making connections between the manhole and the conduit lines. Concrete manholes are limited to localities in which the underground conditions permit the use of standard sizes and shapes, and where the ground is of sufficiently firm composition as to require no outer form for the concrete. Moreover, concrete manholes should be allowed at least 48 hr. for setting, which practically prevents their use in streets with dense traffic. The brick manhole is preferable where irregular shapes only can be used and where a large number of future connections are to be made, it being much less liable to damage by these connections than the concrete manholes.

Roof Construction.—Manhole roofs are sometimes built of second-hand T-rails laid in two layers crosswise and filled in with concrete. I-beams and other standard shapes are also used, and sometimes, on moderate spans, concrete reinforced with expanded metal. The iron roof framing should be thoroughly embedded in the concrete for protection and to avoid corrosion.

While cables and other manhole equipment are usually so constructed as to operate successfully when submerged in water, it is desirable to have manholes free of water. It is the general practice to install sewer connections, which are usually provided with a back-trap valve. Drains are particularly necessary for those manholes which contain transformers and other equipment that should not be flooded.

Type of Cover.—There are several types of manhole heads in use, both round and rectangular, the round type being more

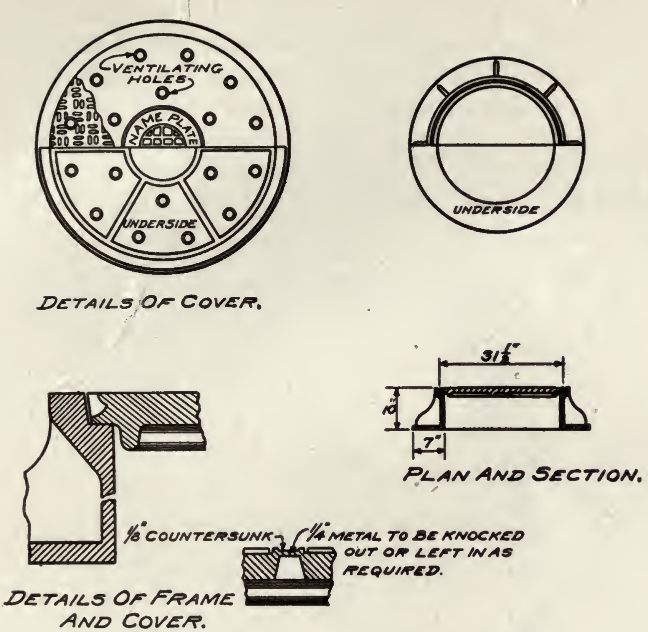


Fig. 23.—Small round manhole head and cover.

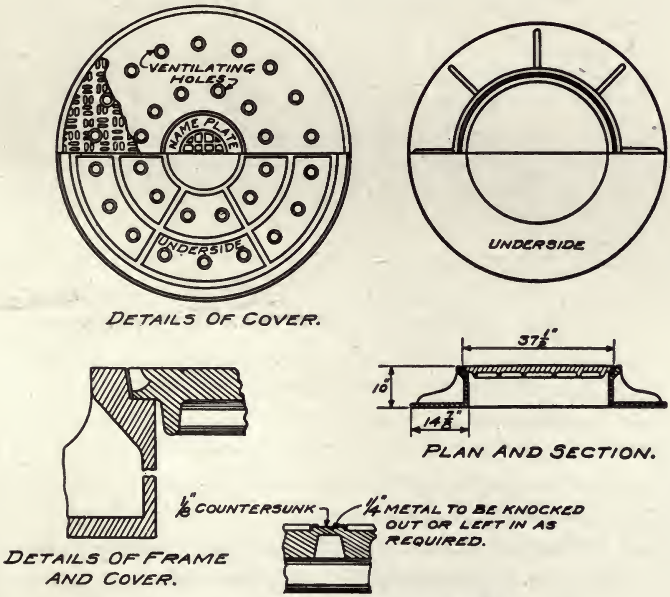
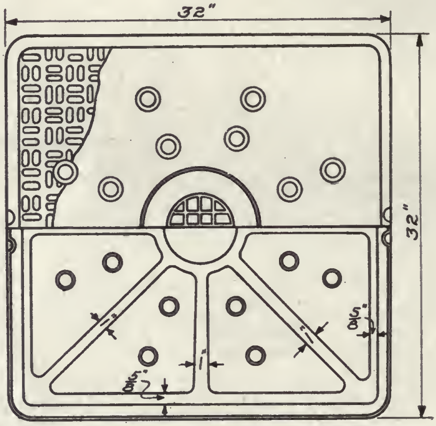
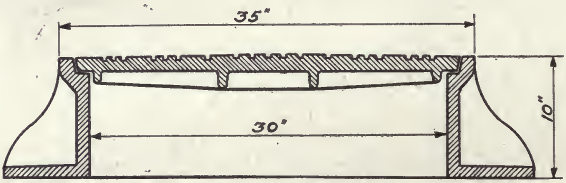


Fig. 24.—Large round manhole head and cover.

generally used. The use of rectangular covers should be avoided as far as possible, as in the hands of careless workmen the cover may be dropped into the manhole causing damage to cables and equipment. Some companies use an inner cover, which is fastened tightly to the outer frame by means of a lock bar and nut and made waterproof by a rubber gasket. In some installations this inner cover is intended only for a pan to catch the dirt which



TOP AND UNDERSIDE OF COVER.



SECTION OF FRAME AND COVER.

Fig. 25.—Square manhole frame and cover.

falls through the ventilated outer cover. Such pans, however, are not in general use. Ventilated covers are quite necessary in streets where conduits and gas mains parallel each other in close proximity, as without ventilation there is always danger of gas explosions and fires in the manholes.

When manholes are constructed in unimproved streets, it is well to allow for any uncertainty regarding the exact grade of the finished paving. If, therefore, the roof is built about 4 in. low and the head casting is brought to the surface by being set on bricks instead of directly on the iron frame, it will allow a space of 4 in. for lowering the head without disturbing the roof frame in

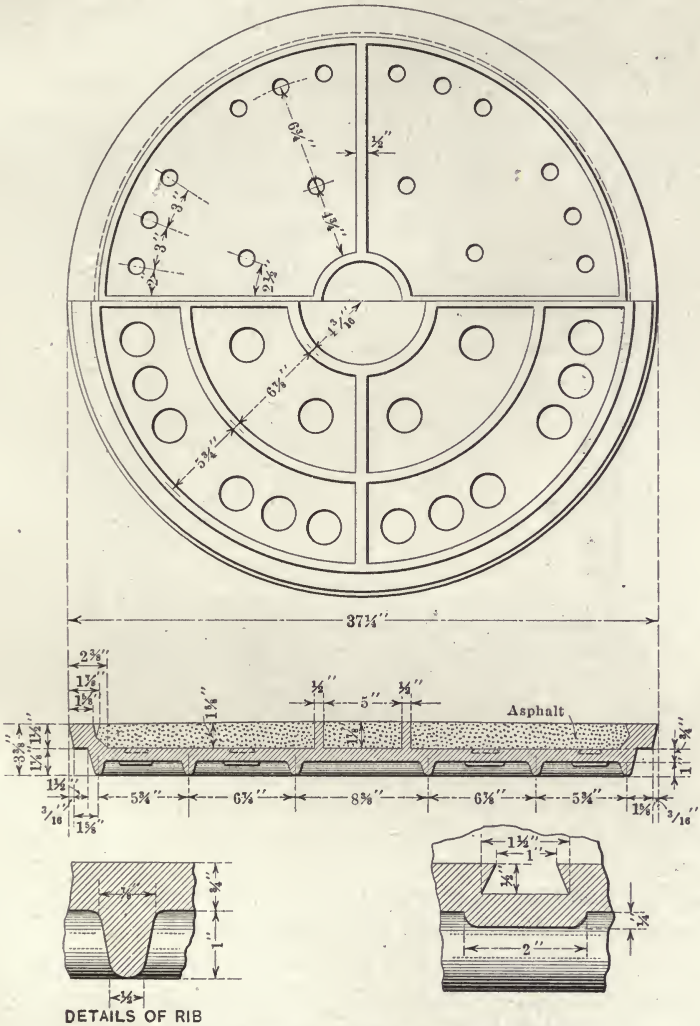


Fig. 26.—Manhole cover for asphalt filling.

case the grade of the street is changed when permanent pavement is laid. Manhole heads should be set ½ in. above street grade to prevent surface water draining into the hole.

Fig. 26 shows details of a manhole cover with space at the top which can be filled with asphalt. This cover is for use in locations where the noise made by wagons running over an iron cover is objectionable, or where the authorities object to the appearance of the standard type of cover. Covers of this type can be developed to match any kind of street pavement.

Waterproofing Manholes.—Few attempts seem to have been made to waterproof manholes. In a few special cases tarred paper painted over in the usual manner with waterproofing compounds has been employed to coat the exterior surface of the manholes to prevent seeping of water. This method of waterproofing has not been entirely satisfactory owing to the number of corners and outlets, such as duct lines and service connections, around which it is very difficult to make a water-tight joint. Concrete manholes, in which the concrete is mixed with some form of waterproofing compound, have been built below tide water and made quite waterproof. Probably the most satisfactory method of securing this result is to keep the manhole as dry as possible when pouring the concrete, and to use a rich cement mortar, tamping it carefully. A cement waterproof coating applied on the inside of a concrete manhole has given very good results.

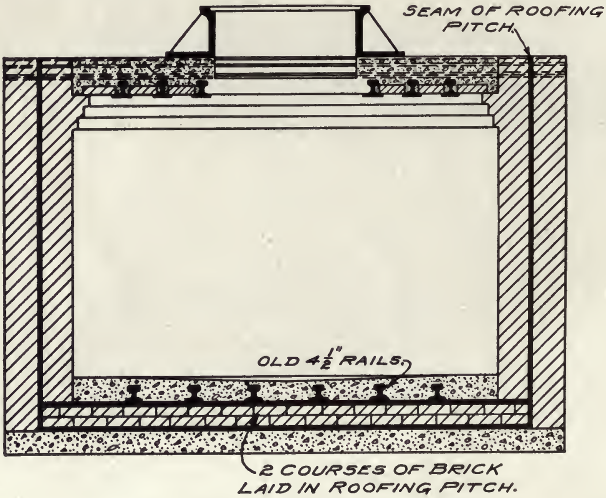


FIG. 27.—Waterproof manhole.

Design of Manholes for Transmission and Distribution Work.—Manholes are either two-way, three-way or four-way, Fig. 28, according to the number of conduit outlets, which is determined largely by service requirements. For transmission purposes the two-way manhole of elliptical or oblong octagonal shape is well-suited, because it provides sufficient wall space for the making of cable joints and at the same time eliminates the necessity for sharp bends in the cable. The three-way manhole practically follows the lines of the two-way manhole on the outlet sides excepting that the side free from ducts is built straight. The

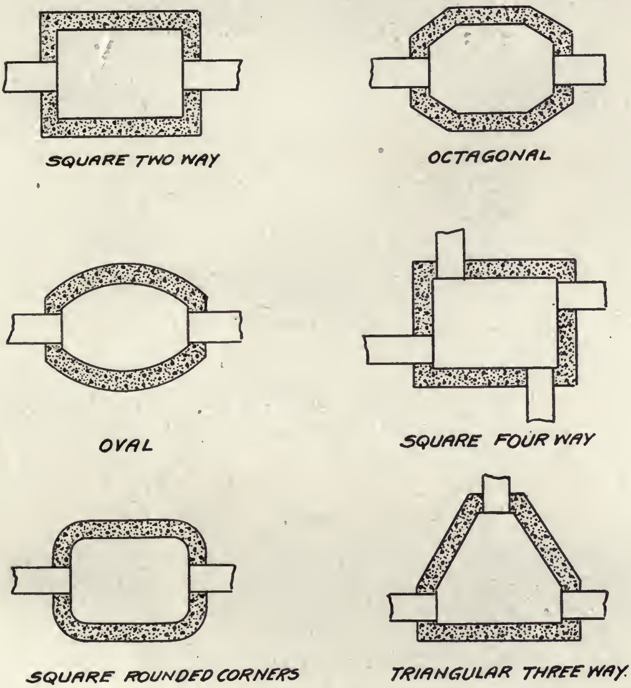


FIG. 28.—Types of manholes.

ideal shape of a four-way manhole is rectangular, but with the opposite duct entrances centrally displaced. This provides sufficient spacing for the training of cables in all cases.

Transformer Manholes.—Frequently separate manholes or vaults are provided for transformers. These manholes are installed, usually, immediately adjacent to one of the main-line manholes, and are very desirable when the space in the street will allow construction of this type to be followed. Manholes in which there is likely to be any considerable amount of work should have a clear head room of at least 6 ft., to provide working space for cable splicers.

In the design of manholes for the installation of underground transformers consideration should be given to the fact that manholes must be well-ventilated and so constructed that they can be kept reasonably free from water during rain storms. Where sewer connections are not possible, a dry well for drain-

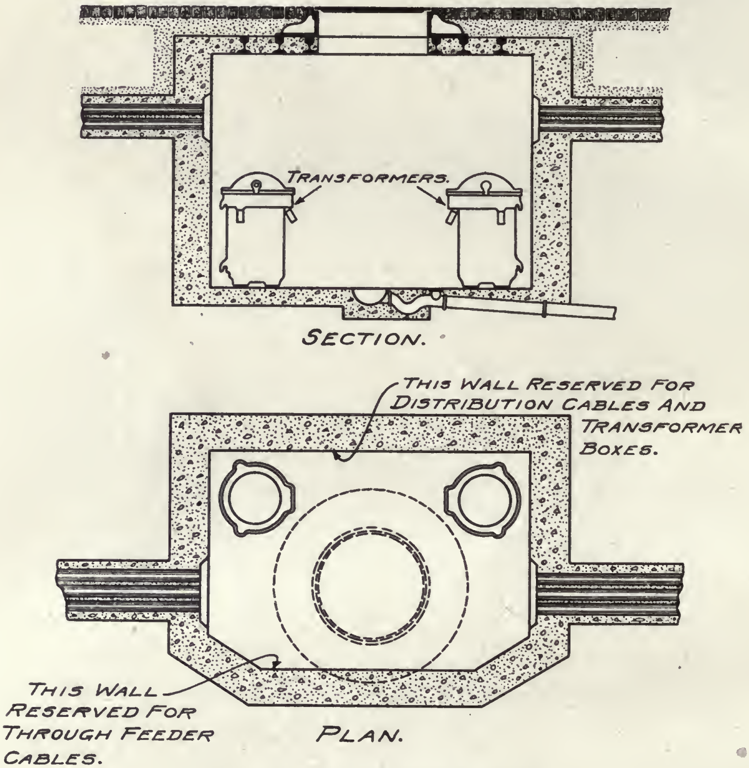


FIG. 29.—Transformer manhole.

ing moisture from the bottom of the manholes is advocated as an efficient means of disposing of surface drainage which may enter the manholes. Natural ventilation is preferred in all cases where the conditions are favorable, and sufficient space should be allowed so that at least 3 cu. ft. per kva. of transformer capacity is provided.

In general, where the total capacity of the transformers installed in a manhole does not exceed 100 kw., the natural heat

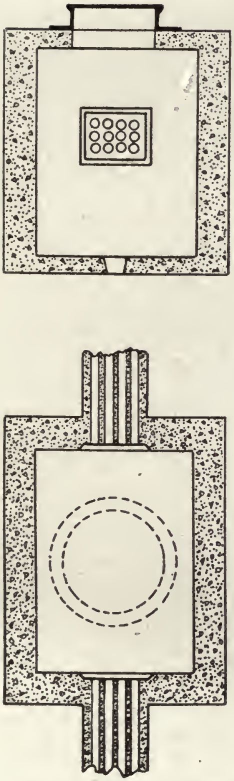


Fig. 30.—Ducts grouped in center of manhole.

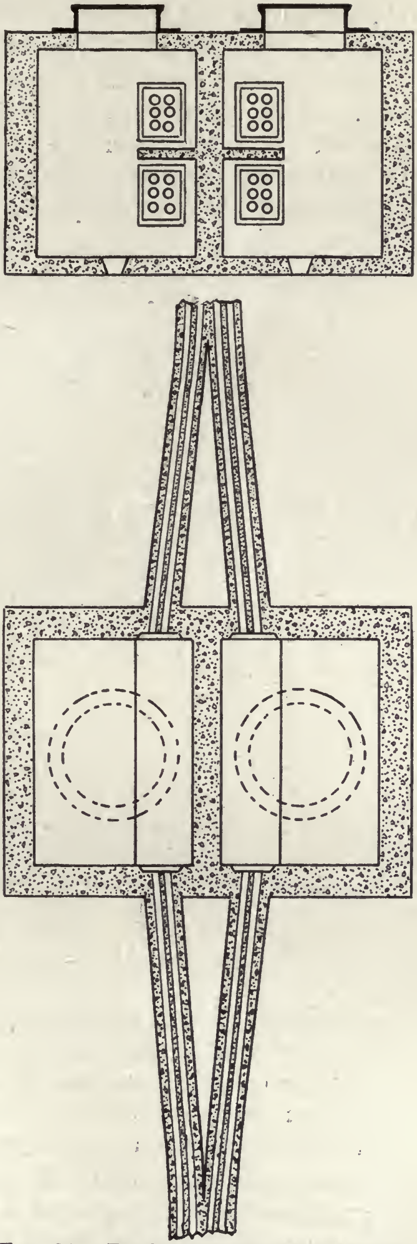


Fig. 31.—Double manhole with divided duct lines.

radiation from the manhole through the ground is sufficient to keep the transformer within safe temperature limits. In extreme cases it is advisable to provide artificial means of ventilation. Many advantages are derived from the use of separate manholes for transformers, and in cases where it is necessary to install transformers of large capacity in underground systems it is frequently found advisable to arrange with large consumers

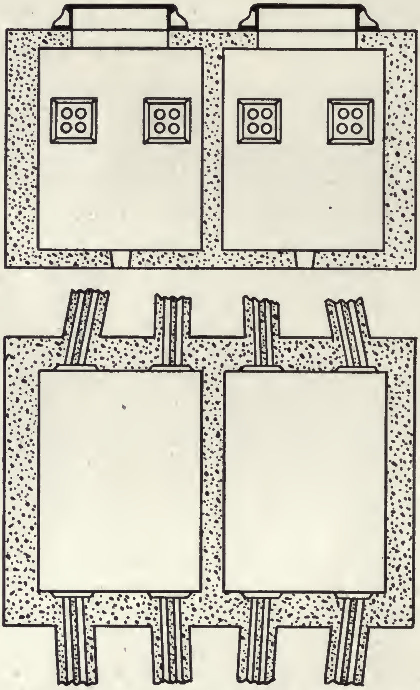


Fig. 32.—Double manhole with ducts separated.

for the installation of transformers in the basement of buildings where they are accessible for inspection and repairs.

In some cases it is necessary to provide separate manholes, sometimes called subsidiary manholes, which are installed some distance from the main conduit line, either in intersecting streets or underneath a sidewalk. No cables pass through these holes other than the cables feeding the transformers installed therein, with the result that the heating effect is reduced to a minimum.

Double manhole construction is very desirable where it is necessary to install transmission and low-tension power feeders in the same conduit line. In such installations a dividing wall in the manhole permits the complete separation of high-tension and low-tension cables.

The ducts in some cases run straight through the manhole wall, Fig. 30, to the center of the manhole, where the cables divide, half going to one side and half to the other, the cables being racked on the manhole wall. Grouping of ducts in this manner is very objectionable on account of the sharp bends in the cable, which may crack the insulation and cause breakdowns. Rise in temperature in one cable is readily communicated to another when the ducts are grouped in this manner.

The form of construction adopted by the Niagara Falls Power Co. for one of their recent installations is shown in Fig. 31. Where the space in the street will permit of this design, very satisfactory results may be obtained.

In places where rock is near the surface necessitating shallow excavation and affording excellent conditions for the radiation of heat, the type of construction illustrated in Fig. 32 will give good service.

All of these special methods depend upon local conditions in the streets and can be used only where foreign structures do not interfere.

In Fig. 33 is illustrated a typical design of a two-way manhole, as recommended by the Committee on Power Distribution of the Railway Engineering Association. This type of hole is well-adapted to railway service, as it permits the installation of heavy power cables in almost a straight line, very little bending of the cable being required, and the slack in the manhole being reduced to a minimum. It will be noted that every third layer of bricks is projected to act as a shelf for the cables, and while this may be good construction for railway feeders which as a rule run straight through the manhole, for electric light and power cables, the installation of shelves of this type is not so desirable. Manholes for electric light and power cables frequently contain junction boxes and other equipment, and to facilitate their installation, smooth walls are desirable, the cables being racked on the wall by means of portable hangers conveniently arranged. The installation of eye-bolts, as shown in the sketch, is a very good feature, as by their use the drawing in of cables is much simplified. Bolts of this type should be installed in all manholes, as it

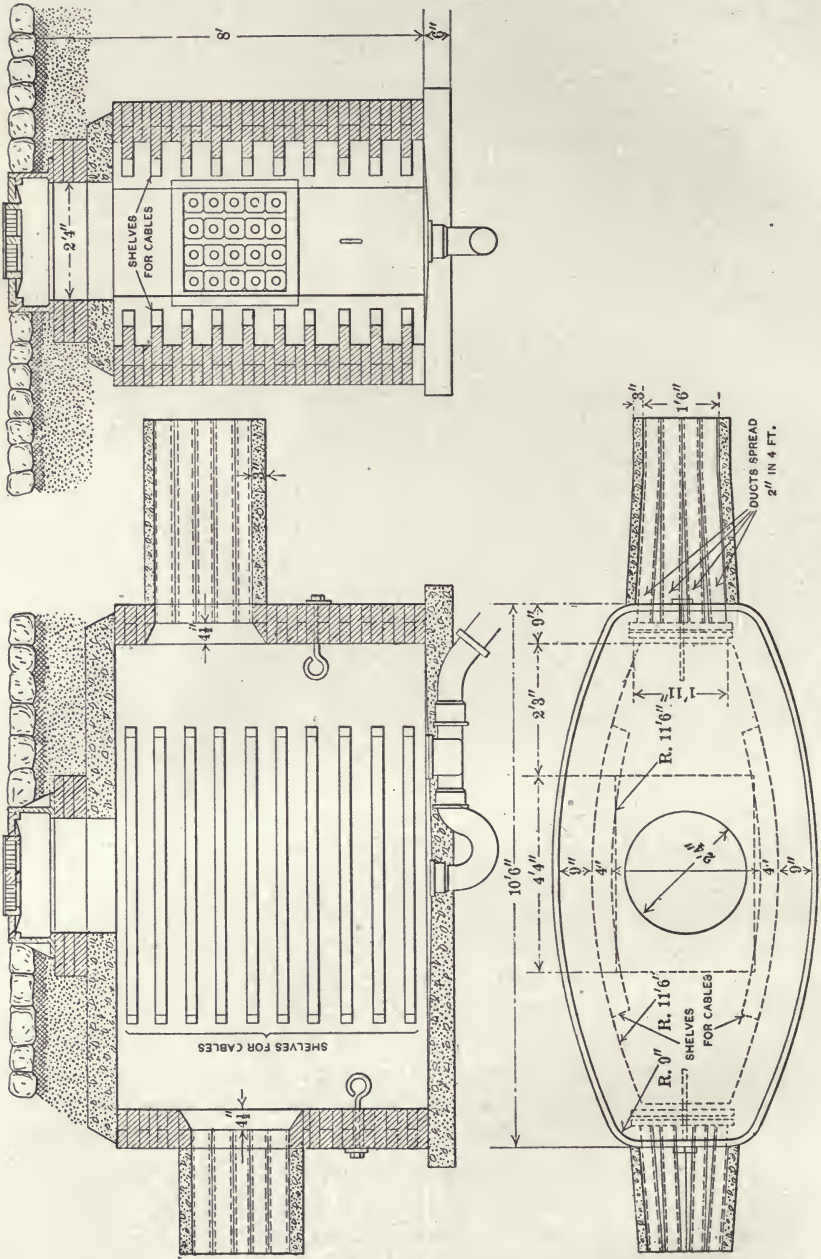


Fig 33.—Two-way manhole.

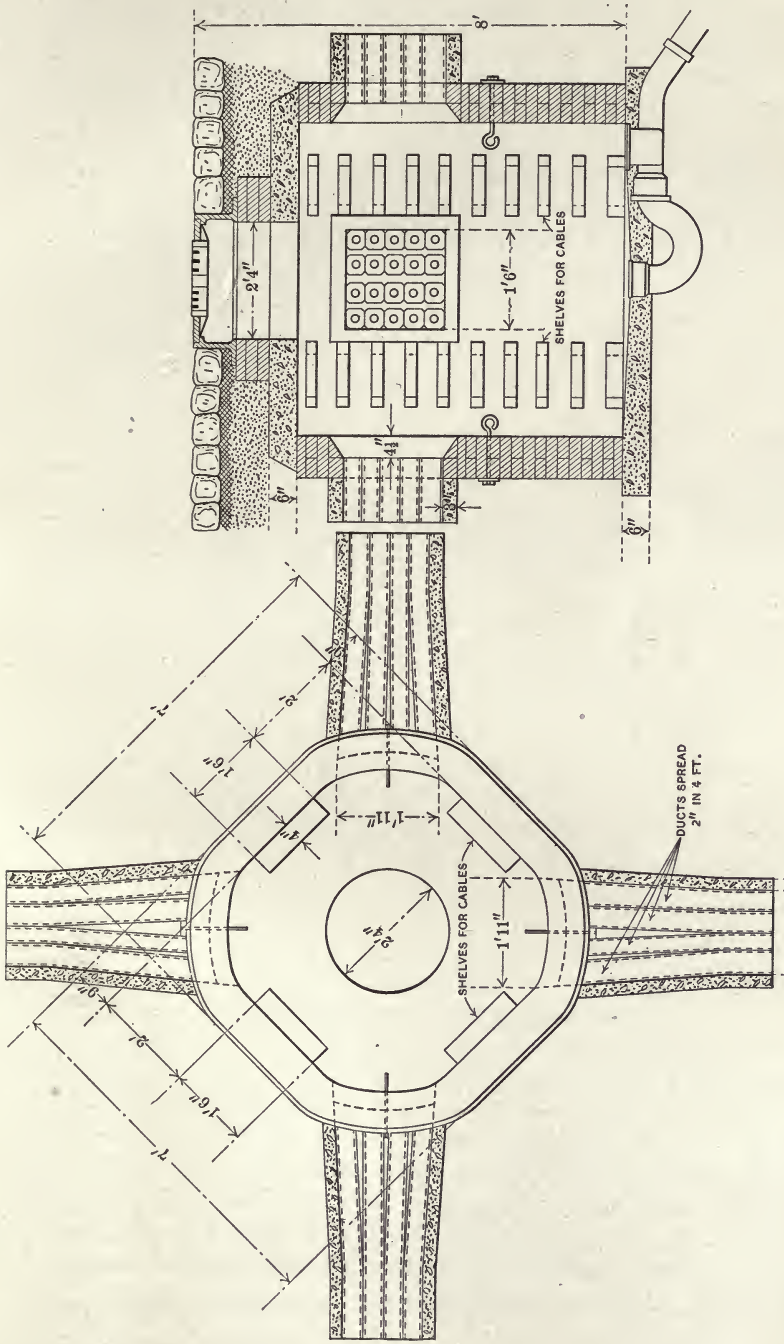


Fig. 34.—Four-way manhole.

greatly facilitates the rigging of cable tackle as described elsewhere, under the heading of "Cable Installation."

Manholes of the four-way type, as illustrated in Fig. 34 are usually placed at intersecting streets where two main conduit lines cross.

Concrete Manhole Forms.—The choice of forms will be governed by the character of the work to be done. Usually forms are made of wood but where there is considerable repetition and

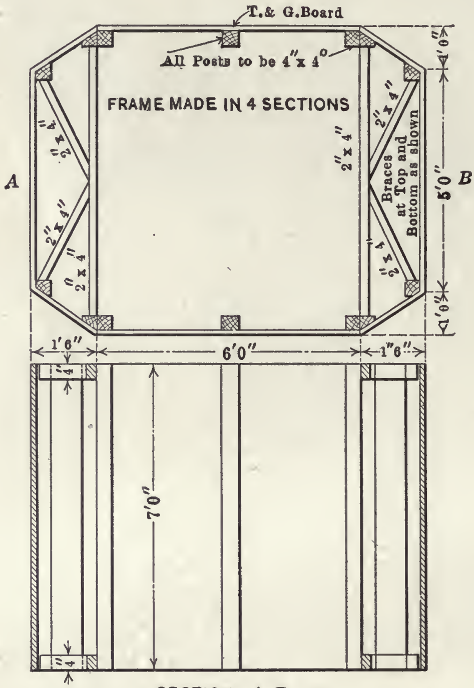


Fig. 35.—Wood form for concrete manholes.

no obstacles are encountered steel forms have been used to advantage. They may be used a number of times because they retain their shape. They, moreover, produce a very smooth finish on the interior of the manhole wall.

In Fig. 35 is shown a manhole form constructed of wood so designed as to permit of the building of manholes of various sizes by simply changing the spacing between the end sections. The outer surface of the form should be of dressed lumber in order to insure a smooth surface on the inside wall of the manhole. Usually forms are removed the second day following the placing of the concrete, but some consideration should be given to temperature conditions and the kind of cement used. It will take concrete considerably longer to set in winter weather and under unfavorable atmospheric conditions, than during the summer months.

In order that the forms may not adhere to the concrete after it has set, it is customary to oil them before the concrete is placed.

The concrete should be of a consistency known as "wet mixture," and should be thoroughly paddled and worked in around the form so as to avoid a porous or honeycombed structure.

The mixture most commonly used is 1 part cement, 3 parts sand and 5 parts stone. The proper portions in any particular case must be determined by a knowledge of the conditions under which the structure is to be installed and operated and of the quality of materials making up the aggregate.

After the removal of the forms any rough surfaces should be smoothed off and the voids filled with cement mortar. However, if care is taken in the paddling of the concrete, by spading it well around the forms, there should be no need of smoothing over rough surfaces after the forms have been removed.

Distribution Holes.—Service or distribution holes should be located at intervals of 100 to 150 ft. between manholes in order to reduce the length of service runs. These service holes should be of ample size to allow room for the proper racking of cable and placing of subway boxes. They should be not less than 3 ft. square and of sufficient depth to allow a man to work in them. In Fig. 36 two methods of installing distribution holes are shown. Where the space in the street will allow, the holes should be built on the side of the main conduit, as shown in the illustration. In congested streets, however, this plan is not always feasible and under such conditions the hole may be placed on top of the main conduit and sufficient ducts run therein for distribution cable.

A suitable concrete foundation should be laid not less than 3 in. in thickness. The walls should be built of brick or concrete, depending on the type of construction to be used.

Reinforcing I-beams or old scrap rail are used in the roof of the hole for supporting the iron frame or cover, which is of the same design as those used on manholes, except that it may be of smaller diameter to conform to the size of the hole. The type and size of the hole depends entirely upon the service requirements, loads and other local conditions.

Cable Tunnels.—In some cities which are divided into two or more parts by a river, it has been found expedient to build tunnels for carrying cables across the river. The tunnels are built in the shape of an inverted U, with a vertical height 6 ft. 6 in. in the clear, and the width 6 ft. with 9-in. concrete wall. The

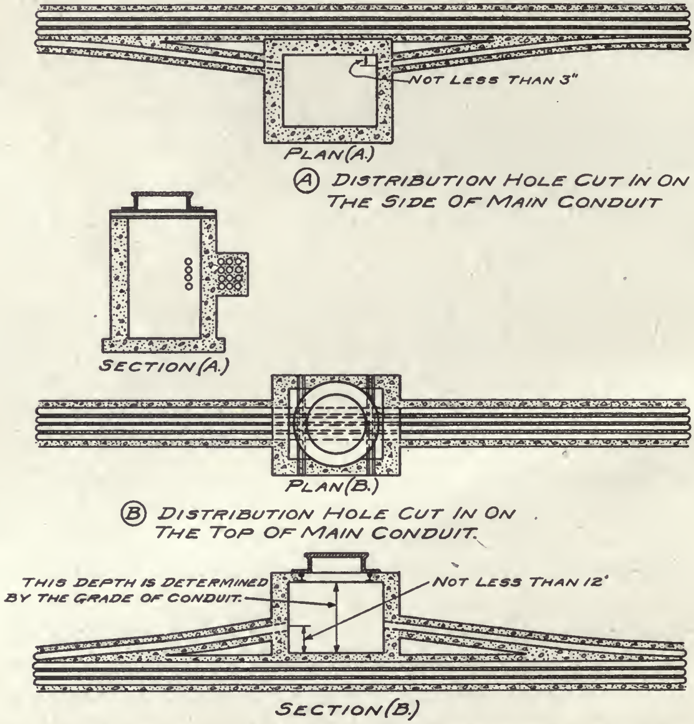


Fig. 36.—Methods of building distribution hole in main conduit line.

tunnel has a slope of 1 or 2 per cent. toward a sump at the foot of one of the shafts so that the tunnel can be pumped out preliminary to cable pulling. At each end of the tunnel is a shaft 6 ft. 6 in. internal diameter, with 15-in. walls built of concrete. At the upper end of each shaft is a manhole which forms the terminus of the conduits leading to and from the tunnel. It is advisable to have the tunnel shaft extend 2 ft. above the bottom of the manhole for convenience in working and as a protection to the workmen. A permanent galvanized-iron grating is placed over the unoccupied portion of the upper end of the shaft so as to prevent accidents.

On completion of the tunnel a standard conduit is installed in a horizontal position, and in each of the shafts, leaving a gap at the junction of the tunnel with the shafts to allow for proper training of the cables. This junction should be built with a curve having a radius of about 6 or 8 ft., to give proper working space and permit the cable to be installed with easy curves. The vertical conduit in the shafts can be built with single-duct, vitrified tile, fiber pipe or stone conduit. Tee irons are fitted into the shafts at intervals of about 2 ft., so as to leave a clear

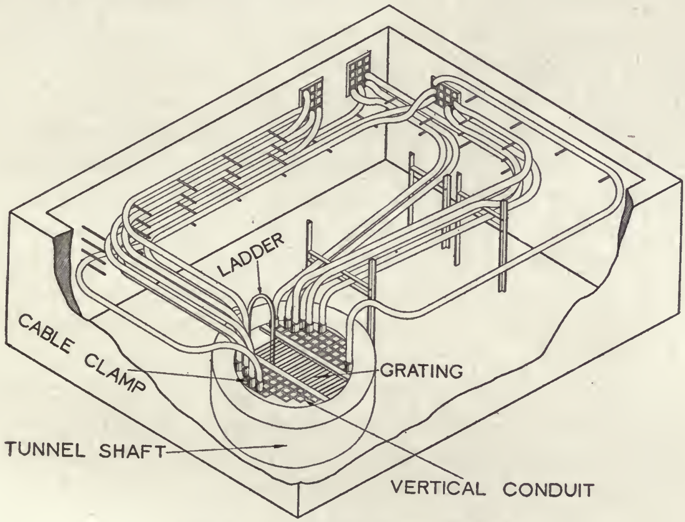


Fig. 37.—Cable tunnel shaft.

space in the center of the shaft about 2 ft. wide. With the dimensions given for the shaft about 35 or 40 ducts can be installed between the tee irons and the shafts on each side.

A brick or concrete pier under the curve in the cables at the lower end of the shaft will support a considerable portion of the weight of the vertical cable. Some additional means of support for each cable should be installed at the top of the shaft. Care should be exercised to avoid clamping the cable too tightly or placing too great a strain on the lead sheath.

Fig. 37 illustrates the method of training cable in the manhole over a tunnel shaft.

The telephone company in Chicago has used iron pipes exclusively for the vertical conduits in shafts and has made the connections between these vertical pipes and the conduits in the tunnel with bends of 6 or 8 ft. radius in such a manner that the duct is continuous from the top of one shaft to the top of the other. Copper lead-wires are installed at the time that the conduit is built, so as to avoid difficulty, which might be experienced with iron wires. This provision allows the pulling in of cables at any future time without pumping out the tunnel, and at the same time eliminates all joints from the bottom of the shafts. It is probable that the same scheme could be used with smaller cables for electric light and power purposes, but this is not the usual practice.

A useful auxiliary in connection with such tunnels is a motor-driven pump of about 15 hp. capacity for removing the water from the tunnel. Such pumps can be obtained with either a direct-current or alternating-current motor, and can be readily lowered in the clear space in the tunnel. These outfits are preferably built with a vertical shaft, and for convenience in assembling, are made in two parts.

The tunnel shaft should be erected from 25 to 50 ft. away from the river edge, depending on local conditions. Where the river bank consists of filled ground, it may be necessary to use a steel shield, extending into the impervious clay below the river. With a stiff clay the depths of the tunnel below the lowest portion of the river should be about 15 or 20 ft. If there is not sufficient depth of clay above the rock to give this amount of clearance to the river, the tunnel should be built in the rock. In Chicago these tunnels are located at least 15 ft. below the surface of the rock, so as to avoid the danger of letting in any water while blasting.

The cost of such a tunnel, if in clay, will be about $25 to $35 per lin. ft., plus $50 to $60 per ft. for the shaft. If built in rock the expense will be increased about 50 per cent.

These prices do not include manholes at the top of the shafts, or the conduits in the tunnel and shaft.

Very little water has been encountered in building tunnels in hard blue clay. Considerable water is usually present in building tunnels through rock, as the surrounding rock is somewhat shattered by the blasting, opening up water seams, which adds considerable difficulty to the construction of the tunnel. When completed, the tunnels through clay are generally dry, while those through rock are somewhat leaky.

Slight leaks that do not interfere with the construction work or prevent pumping the tunnel out for cable installations are not objectionable as it is the practice to allow the tunnel to fill up with water after the cables are installed. Tunnels built in the manner just described have been in service for as much as 12 years and no serious operating difficulties have been experienced.

Specification and Contract.—It is very often desirable to have subway construction work done by an outside contractor, and while contracts are frequently drawn by engineers, it is necessary that the subject matter be in legal form. Specifications should be clear and so written that the precise meaning of each sentence is understood and that no doubt exists in the mind of the contractor as to their intent. It is not necessary in preparing a specification to model the language after that used in many legal documents, but the specifications should be complete in every detail and, as far as possible, the use of long or involved sentences should be avoided. This is particularly desirable in view of the fact that such specifications are often placed in the hands of construction foremen whose knowledge of legal phraseology is limited. Short and simple wording is preferable and it should be the aim of the engineer to make the language crisp and concise, rather than to produce a literary masterpiece.

The specifications should describe in detail the work to be covered and should give directions as to how it is to be done. Specifications are usually accompanied by plans of the work and the drawings should be mentioned in the specification giving the number, date and title of the drawing. Contractors are usually required to give a bond which provides for the payment to the owner of an indemnity in case the contractor fails to live up to a part or all of his agreement. While there are many forms of specifications in use, the following specimens cover most classes of conduit and manhole construction.

SPECIFICATION AND CONTRACT

THIS AGREEMENT, made and concluded this .... day of .... in the year ...... between .... a Corporation of the State of .... of the first part, and .... of the State of ...., of the second part:

WITNESSETH: That the said party of the second part (hereinafter designated Contractor) has agreed and by these presents does agree with the said party of the first part (hereinafter designated Company) for the consideration hereinafter mentioned and under the penalty expressed on a bond bearing even date with these presents, and hereunto annexed, at his own proper cost and expense, to do all the work and furnish all the material called for, in the manner and under the conditions set forth in the following specifications, and the attached plans, which constitute a part of this contract. It is understood that the work covered by this contract is intended for ....

1. Wherever the term "Engineer" appears it shall mean the engineer employed by the company and in charge of the work and construction to be done hereunder.

2. The subways for electrical wires and cables covered by this contract, and these specifications and plans herewith attached, are to be built in the following streets, alleys, lanes and public places of the city of........... in the State of .... viz: .... and in such other streets, alleys, lanes and public places in said city of .... as may hereafter be designated by the company.

The foregoing schedules of streets and alleys contain those upon which are to be located the conduits, manholes and service boxes that it is now intended to be built, but it is agreed that, during the progress of the work, any additional extensions or subtractions to the conduits, manholes, service boxes or laterals shall be constructed by the contractor as required by .... The terms and conditions of this agreement shall apply to and cover all such conditions, provided that such work is reasonably similar to that which is now specified. It is also agreed that .... may decrease the amount of work in any way it shall deem advisable without becoming liable to the contractor for any compensation or damage for such change, provided .... shall notify the contractor in writing before instructions are given to commence the portion of the work. If said change in combination of ducts and trench feet now shown on plans herewith attached, should be altered so as not to be substantially similar to the schedule figured on, then a revised figure is to be agreed upon and made the basis upon which payment is to be made.

3. Due notice will be given by the company as to the location of certain divisions of the work and when same shall be commenced, in order to insure perfect coöperation between the company and the contractor in prosecuting the work without delay.

4. The company will obtain the rights-of-way and street permits needed for the prosecution of the work contemplated under this agreement.

5. The work to be done by the contractor is to include the furnishing of all materials (except the conduit, service-box castings, manhole castings, eye beams, expanded metal for manhole roofs, and form for drain opening in floor of manhole), all labor, tools, night lights, bridging, guard rails, shoring, and so forth. The contractor is also to remove the pavements along the route of the work to excavate for trenches and manholes, and to refill the same, and to repave the streets in a complete and workmanlike manner in accordance with the original specifications under which the street pavement is laid. For refilling the trenches the best and most substantial part of the

materials excavated shall be used, it shall be thoroughly tamped, rammed, rolled or flushed, as may be deemed necessary to the engineer or required by the city authorities, and shall be done with the proper tools and in a manner to prevent, as far as possible, a settlement of the earth after completion.

6. The backfilling of the trenches shall be done according to the regulations of the city of .... and the requirements of the city civil engineer and all new or other material required for this purpose and the hauling thereof shall be furnished and done by the contractor at his expense. The contractor shall furnish all materials and labor required for installing walls and floors of manholes and labor for setting forms for the drain opening in floor of the manholes and shall set manhole and service-box covers.

7. The work is to be done under the line of streets, alleys, lanes and public places as designated by the engineer.

8. The trenches, manholes, and service boxes are to be located according to the position assigned by the engineer in charge of work under approval of the city authorities.

9. The work performed and material supplied under this specification shall be subject to inspection of the engineer of the company, and the contractor must remove and make good, at his own cost, all material that does not fully comply with the specification. The decision of the engineer shall be final on all matters under this contract.

10. The company shall maintain engineering inspection of the work during its progress, and should the contractor fail to fulfill the specifications or any portion of the contract, or in any particular fail to perform the work herein specified, he shall be given a written notification of such failure, and must correct the same and proceed with the work within twenty-four (24) hours of such notice, and his failure to correct the faults or to so proceed with the work shall be deemed sufficient cause for voiding of the contract which the company may at its option do.

11. Should the contractor cease work hereunder for ten (10) consecutive days unless prevented from proceeding therewith from stress of weather or unavoidable casualty or accidents, or by act or default of the company, the company may, at its option, treat the work and contract as abandoned and proceed as is herein provided to be done in case of such abandonment.

12. Should the contractor abandon said work, or if this contract should be terminated by the company as above provided, all material delivered and on the line of the work shall become the property of the company, and such material and all tools, implements, vehicles and machinery along the line of the work may be used by the company or its agents or employees to complete the construction provided for by its contract.

13. If the contractor shall refuse or neglect to proceed immediately with the correction of any default, or to proceed with the work as required by the engineer, said company may employ men and teams and purchase material to effect the requisite corrections or to complete the work at the expense of the contractor, the cost thereof to be deducted from any moneys due to the contractor or to be recovered from him and the sureties on his bond.

14. In case the contractor shall not be present upon the work at any time when it may be necessary to give instructions, the foreman in charge for the time being shall receive and obey any orders that the engineer may give.

15. The engineer may require the discharge from the work of any incompetent or unfaithful employees who may neglect to execute the work in accordance with the specifications and the direction of the engineer, and the contractor shall not again employ such person on any part of the work without the consent of the engineer.

16. The handling of materials and all work relating thereto must be done in compliance with the regulation established by the city authorities of the city of .... The contractor shall immediately remove all surplus material as fast as the work is finished and dispose of same at his own cost.

17. The contractor shall furnish all necessary watchmen, place sufficient and proper guards for the prevention of accident, and shall put up and keep at night suitable and sufficient danger lights and barricades as required by the ordinance of said city, and shall indemnify and save harmless the company, its officers, agents and servants against and from all damages, cost and expense, which they may suffer, or to which they may be put by reason of injuries to person or property of another, resulting from negligence or carelessness or accident on the part of said contractor.

18. The contractor must furnish all necessary guard rails, staging or bridging that may be necessary to cover over the trenches so as to not obstruct public travel at crossings.

19. If, in the excavation of trenches a water main or pipe service, a line of gas pipe, or any private or public underground service of any character is encountered, all necessary protection from injury thereof must be provided by the contractor, and if necessary to make any changes thereto same must be done entirely by the contractor and to the approval of the owners; payment for same should be agreed upon in writing.

20. The contractor must assume all responsibility for damage of any kind caused by his employees to any sewer, gas pipe, conduit or other underground system and must make such damage good at his own cost and expense. The repairs must be satisfactory to the owners.

21. The contractor will assume, and shall be held liable for, any damage to property, or any accident to men or material, connected with the work described in these specifications which may occur prior to the final completion of the work and its acceptance.

22. The contractor shall pay, discharge and satisfy all claims for material furnished and labor done in carrying out this contract and shall fully protect the company and .... from all such claims or liens on account thereof and the bond to be given by the contractor shall comply with this clause.

23. The contractor is to furnish such a force of men and teams, and such labor-saving devices, such as concrete mixers, rock drills, tools, machinery, and so forth, as in the judgment of the engineer is necessary to prosecute the work with satisfactory speed.

24. If the contractor does not prosecute said work as rapidly as in the opinion of the engineer he should, the contractor shall employ and put to work so many additional men, teams and labor-saving devices as the engineer may require, and if the contractor fails to do so, the company may

employ and put to work such additional men, teams and labor-saving devices, and shall charge the contractor with the cost thereof.

25. The work shall be prosecuted in such a manner as to cause as little inconvenience as possible to public travel and to property owners on the streets, alleys, lanes and public places where the conduit is laid. The order in which the work shall be prosecuted and the sections which shall be first laid will be indicated by the engineer. The work shall be commenced within .... days of the execution of the contract and completed on or before ....

26. The paving, if any, removed from the trench, shall be neatly and compactly piled along the trench on the curb line, except in cases of cross streets, when a modified disposition may be advisable, but the flow of water in gutters or drains shall not be obstructed.

27. All pavements disturbed by the contractor must be replaced by him with a paving of the same character and equal quality and he must give bond guaranteeing the maintenance of the pavement during the term of one year from the completion and acceptance of the work to be done under this contract, all new material required to replace pavement as aforesaid shall be furnished by the contractor. Where it is necessary to disturb pavements which have been laid under a guaranty the contractor is to arrange with the municipal authorities to have this pavement replaced under the original guaranty. In such case the contractor is to make temporary repairs to the pavement, which he shall maintain for a period of at least sixty (60) days or until such time that the pavement is permanently restored to its original condition.

28. All excavations and openings of streets must be done in compliance with the regulations established by the city authorities of the city of......

29. The engineer will give any explanations or directions required to complete or give proper and due effect to the provisions of the specifications, and will appoint such assistants and inspectors as he may deem necessary to secure compliance with the same.

30. The engineer shall determine all questions that may arise in regard to lines, levels, locations, dimensions, materials and workmanship.

31. If, in the opinion of the engineer, it is necessary to make changes in said plans, the same may be made by him and the work shall be done in accordance with the plans as changed, and the contractor shall not be entitled to extra pay therefor, unless the engineer shall certify that work required by the changes is in addition to, or of a different and more costly character than, that embraced in the original plans, and such extra pay shall be agreed upon before the extra work is done.

32. The trench shall be excavated by the contractor to such width and depth as may be required to receive the number of ducts required by the company, as designated by the engineer. There shall be an allowance of three (3) inches for work space on each side of the completed duct. The grade of the trench shall be such as will conform to the requirements of the street route for making a continuous line of conduit from manhole to manhole, and where the obstructions or other underground service are met with, the excavation shall be done as far as may be required to afford facilities for laying of conduits around, under or over such obstructions. Should it

be found necessary for the conduit to straddle gas or water pipes or any other obstructions, either vertically or horizontally, the excavation must be made accordingly, and in these details, as the inspecting engineer on the work may direct.

Loose Dirt

33. Loose dirt on bottom of trenches is to be tamped solid previous to laying conduits, and any sharp stones or rocks which are encountered in bottom of trench, or in filling dirt, must be removed to prevent injuring conduits.

34. The sides of the trenches will be vertical, and wherever required the contractor must shore the trenches to prevent caving. The contractor must assume all responsibility for the safety of the work and no extra charge will be recognized for the shoring and other protection of the work. During the progress of the work the trenches must be kept absolutely free from water. All pumping that may be necessary must be done by the contractor without extra cost.

Laying

35. Conduits to be laid so as to break joints and true to line, so that no shoulders or offsets shall be formed in the bores, to be built up in tiers to the required arrangement and bedded in cement mortar. Conduits must be laid to drain to the manholes. Conduits may be laid to vary slightly from a straight line, providing there are no "sags" or "pockets" which will not drain themselves. Where multiple-duct is used the joints are to be thoroughly protected by a strip of tarred burlap not less than six (6) inches wide and long enough to go around the conduit in a continuous piece and overlapping on the top by not less than four (4) inches. This burlap must be applied before applying the cement mortar. A mandrel shall be drawn through each duct as work progresses. Conduits must be laid with at least thirty (30) inches between the top layer of ducts and the finished street surface. This distance may be modified by the engineer of the company, if the exigencies of the work demand it and the engineer thinks it advisable. Wherever it may be deemed expedient or necessary by the company's engineer, ducts shall be reamed by the contractor in a manner approved by the company's engineer and at the sole expense of the contractor.

Mortar

36. Mortar for laying conduit to be mixed of one (1) part of .... cement, to two (2) parts clean sharp sand, and must be used within .... after being mixed.

Concrete

37. A concrete bed three (3) inches in depth and of width sufficient to extend three (3) inches beyond the sides of the conduits must be placed on the bottom of the trenches and brought to smooth even surface of uniform grade. After the conduits are in place, three (3) inches of concrete must be

placed on the sides and top. If the space between sides of conduits and sides of trench is too great to be entirely filled with concrete, and boards are used, these must be left in place or else withdrawn so as not to disturb concrete or earth filling and in a manner acceptable to the engineer. All concrete to be made of one (1) part .... cement, two (2) parts clean sharp sand, and five (5) parts of screened gravel. Cement and sand to be first thoroughly mixed dry, then a sufficient quantity of water added to form a soft mortar; the gravel to be afterward added and thoroughly mixed. The concrete when placed in trench to be tamped till water flushes to the surface. The placement of concrete to be so conducted as not to disturb the conduits while mortar is setting.

38. Service laterals shall be installed by the contractor at the places designated by the engineer and run into the basement or cellar. These laterals will be run with single conduit and under same specifications as the other conduit work.

Plugs

39. Wherever and whenever work is suspended, the open end of all ducts must be plugged with hard-wood plugs conforming accurately to the shape of the duct, and at the larger end at least one-quarter (¼) of an inch greater in dimension than the duct.

Blasting

40. Where blasting is required, moderate charges of explosive must be used, and the blast covered with heavy logs and chains, or other measures taken to protect life and property. Excavation of ledge, rock or such boulders as may contain ten (10) cubic feet or more will be subject to extra payments at rates hereinafter named.

Rodding

41. Upon completion of the entire work and before acceptance by the company, the contractor will be required to pass through each duct, from manhole to manhole, an iron or iron-shod mandrel conforming in shape to that of the duct, and of not more than one-quarter (¼) inch smaller dimension. Any obstruction to the free passage of the mandrel through the ducts must be removed by the contractor at his own expense.

Extras

42. No claim for extra payment is to be made except for extra work done in obedience to written orders from the engineer approved by the company.

Manholes

43. Manholes and service boxes will be as shown on accompanying plans, unless otherwise directed by the inspecting engineer. They are to be constructed of the best .... cement. Concrete mixed over one (1) hour, or that has commenced to set, shall not be retempered or used. All

manholes shall be drained by means of a round opening located in the floor of the manholes at such points as shall be designated by the engineer, and the form for this opening will be furnished by the company. All service holes must have drain tubes, supplied by the company, installed in the walls of same, at points designated by the engineer of the company.

Manhole Frames

44. Manhole and service-hole frames and covers to be as per plans. Each manhole and service-hole frame when set shall be bedded in cement mortar and must be set to a line not exceeding one-half (½) inch above grade of finished pavement, and shall not in any event be below said grade after settlement.

Measurement

45. The number of duct feet to be paid for under these specifications shall be according to the actual measurements of the finished work from face to face of manhole walls. The manhole and service manholes will be paid for at so much per manhole complete. Service laterals will be paid for according to the actual measurements of the finished work from face of service box or manhole to face of basement or cellar wall or floor line where there is no basement or cellar. Where, owing to obstructions, manholes cannot be built to a specified dimension, and in order to get the desired working space, it is necessary that the manhole be constructed of a shape and size not shown on the plans; the contractor is to be paid at a unit price per cubic yard of brick work or concrete, in the sides, top and bottom of the hole.

46. Contractor shall use every care in handling conduit, and any damage through carelessness on his part to be replaced at his expense.

47. Any work proving defective within one (1) year after completion of the work, if due to the use of poor material or faulty construction, or both, shall be replaced free of charge by the contractor.

48. All walls when broken through in installing laterals as provided for in Paragraph 38, shall be, by the contractor at his own expense, left in as good condition as they were before such laterals were installed.

49. Test pits shall be put down at the contractor's expense wherever thought desirable and of such size as is necessary to determine the feasible location for the trench, manholes and service holes.

50. Particular care shall be taken not to obstruct access to fire hydrants, manholes, catch basins and grates belonging to the city or any other corporation or individual in the vicinity of the work and to arrange free passage ways for the fire department.

51. Such ducts as may be deemed necessary for the installation of the said conduit system across any canal or river shall be installed in proximity to the various bridges crossing the canal or river at such points as may be designated and approved by the company's engineer.

Bond

52. The contractor will be required to execute a bond in the sum of .... with such sureties as shall be approved by the company.

53. The undersigned contractor hereby proposes to build subway for the undersigned as itemized in, and shall do so all in accordance with the foregoing specifications and the attached plans, and agrees to receive the following prices in full compensation for furnishing all materials (including or excepting manhole castings) and all labor necessary for the complete installation:

For 4-duct subway under (?) pavement, per duct foot...............

For 6-duct subway under (?) pavement, per duct foot...............

For 12-duct subway under (?) pavement, per duct foot...............

For 24-duct subway under (?) pavement, per duct foot................

For manholes under (?) pavement, each.............................

Note.—Above may be specified the various sizes of conduits and manholes, as well as kinds of pavement under which they are constructed.

For service laterals under (?) pavement, per foot.....................

The price for extra work is as follows:

Per cubic yard for dirt excavation and removal.........................

Per cubic yard for dirt excavation and refilling..........................

Per square yard for repaving...

(Here mention various kinds of paving work to be done.)

Per cubic yard of concrete in place....................................

Per cubic yard for rock excavation and removal........................

Per cubic yard for clean, sharp building sand, delivered on the work.....
....

Per barrel of cement, delivered on the work............................

Per cubic yard for clean, freshly crushed stone, delivered on the work.....
....

Per thousand brick, delivered on the work............................

Per thousand brick, laid in place......................................

Per day of ten (10) hours for double team, truck and driver.............

Per day of ten (10) hours for common labor..........................

The undersigned company, by its duly authorized officer or representative, hereby accepts the proposal of the undersigned contractor, and agrees that it will cause to be made each month, approximate monthly statements of the work done and material delivered, and it will pay to the contractor on or before the .... day of each month .... per cent. (%) of the value of the estimated work done and materials delivered during the next previous month. The company further agrees to pay to the contractor at or before the expiration of .... ( ) days after the work has been completed in accordance with the agreement and formally accepted by the company, the whole amount of money then remaining due.

IN WITNESS WHEREOF, the undersigned have hereunto set their hands and seals the year and day first above mentioned.

FORM OF BOND

KNOW ALL MEN BY THESE PRESENTS: That we .... a corporation of the State of .... as principal, and .... as sureties, are hereby held and firmly bound unto .... a corporation of the State of

.... in the sum of .... Dollars ($) lawful money of the United States of America, to be paid to the said .... or its certain attorney, its successors and assigns for which payment, well and truly made, we bind ourselves, our heirs, executors and administrators, jointly and severally, firmly by these presents:

Sealed with our seals, dated the .... day of .... in the year one thousand, nine hundred and ....

WHEREAS, the said .... has entered into a contract with the said .... for the building of conduits for electrical wires in the City of .... in the State of .... bearing date the .... day of .... one thousand, nine hundred and ....

NOW, THE CONDITION OF THIS OBLIGATION IS SUCH, that if the said .... shall well and truly keep and perform all the terms and conditions of the said contract on its part to be kept and performed, and shall indemnify and save harmless the said .... as herein stipulated, then this obligation shall be of no effect; otherwise it shall remain in full force and virtue.

(Witnesses) .... (Signed) ....

....

Construction Costs.—The cost of construction and of materials varies so much with different localities that it is impossible to give data which could be considered standard for all classes of work; and the following schedule, which is compiled to serve as a guide in making up estimates, is such as to cover average conditions. The figures include the cost of all materials, excavation, removing dirt, mixing and placing concrete, hauling and laying duct, replacing pavement and the expense of city inspection. In the conduit cost, the figures provide for the duct line to be surrounded on all sides by a 3-in. envelope of concrete, the top row of ducts being 30 in. beneath the surface.

The cost of removal of obstructions is an item which cannot be estimated with any degree of certainty. The expense of this work will vary from 5 to 50 cts. per ft., depending on the size of conduit and the number of obstructions.

Since it is difficult for workmen to carry on the work in a trench less that 18 in. wide, it is necessary to remove a strip of pavement of at least this width. Engineering expense will also vary considerably, depending on whether the work involves any special features.

Table IV gives the estimated cost of single-tile duct under various kinds of pavement, and a similar cost for fiber conduit is given in Table V.

TABLE IV.—SINGLE TILE DUCT COSTS. ESTIMATED COST PER 100 FT. OF CONDUIT

Based on 3-in. tile duct, 3 in. of concrete on all sides and top of conduit 30 in. below the grade of the street

Amounts

Items	Number of duct						
	2	4	6	9	12	16	20
Excavation and removal, cu. yd.	4.12	5.98	7.85	10.29	12.73	15.76	18.78
Excavation and refilling, cu. yd.	11.77	11.77	15.43	15.43	15.43	19.10	19.10
Duct, ft.	200	400	600	900	1,200	1,600	2,000
Concrete, cu. yd.	3.05	3.78	4.51	5.25	5.98	6.92	7.45
Paving, sq. ft.	184	184	217	217	217	260	260
Cost of conduits							
Excavation and removal, $1.00 per cu. yd.	$4.12	$5.98	$7.85	$10.29	$12.73	$15.76	$18.78
Excavation and refilling, 60 cts. per cu. yd.	7.06	7.06	9.26	9.26	9.26	11.46	11.46
Duct, 6 cts. per ft. laid	12.00	24.00	36.00	54.00	72.00	96.00	120.00
Concrete, $7.00 per cu. yd.	21.35	26.46	31.57	36.75	41.86	48.44	52.15
Plus 20 per cent.[1]	8.91	12.70	16.94	22.06	27.17	34.33	40.48
Total cost	53.44	76.20	101.62	132.36	163.02	205.99	242.87
Cost of paving							
Macadam, 10 cts. per sq. ft.	$18.40	$18.40	$21.70	$21.70	$21.70	$26.00	$26.00
Belgian block on sand, 15 cts. per sq. ft.	27.60	27.60	32.55	32.55	32.55	39.00	39.00
Asphalt, 25 cts. per sq. ft.	46.00	46.00	54.25	54.25	54.25	65.00	65.00
Granite block and brick, 35 cts. per sq. ft.	64.40	64.40	75.95	75.95	75.95	91.00	91.00
Wood block, 37 cts. per sq. ft.	68.08	68.08	80.29	80.29	80.29	96.20	96.20
Total cost of conduits							
Macadam	$71.84	$94.60	$123.32	$154.06	$184.72	$231.99	$268.87
Belgian block on sand	81.04	103.80	134.17	164.91	195.57	244.99	281.87
Asphalt	99.44	122.20	155.87	186.61	217.27	270.99	302.87
Granite block and brick	117.84	140.60	177.57	208.31	238.97	296.99	333.87
Wood block	121.52	144.28	181.91	212.65	243.31	302.19	339.07

[1] Covers Engineering, Inspection, Sheathing, Obstructions, Insurance, etc.

Table V.—Fiber Duct Costs. Estimated Cost per 100 Ft. of Conduit Based on 3-in. Fiber Duct, 3 in. of Concrete on all Sides and Top of Conduit 30-in. Below the Grade of the Street

Items	Number of duct						
	2	4	6	9	12	16	20
Amounts							
Excavation and removal, cu. yd......	3.42	5.04	6.66	8.80	10.95	13.61	16.27
Excavation and refilling, cu. yd.......	10.80	10.80	14.27	14.27	14.27	17.75	17.75
Duct, ft............	200	400	600	900	1,200	1,600	2,000
Concrete, cu. yd....	2.93	4.05	5.19	6.58	7.99	9.65	11.33
Paving, sq. ft.......	166	166	200	200	200	250	250
Cost of conduits							
Excavation and removal $1.00 per cu. yd................	$ 3.42	$ 5.04	$ 6.66	$ 8.80	$ 10.95	$ 13.61	$ 16.27
Excavation and refilling, 60 cts. per cu. yd............	6.48	6.48	8.56	8.56	8.56	10.65	10.65
Duct, 5 cts. per ft. laid.............	10.00	20.00	30.00	45.00	60.00	80.00	100.00
Concrete, $7.00 per cu. yd............	20.51	28.35	36.33	46.06	55.93	67.55	79.31
Plus 20 per cent.[1]...	8.08	11.97	16.31	21.68	27.09	34.36	41.25
Total cost..........	48.49	71.84	97.86	130.10	162.53	206.17	247.48
Cost of paving							
Macadam, 10 cts. per sq. ft	$ 16.60	$ 16.60	$ 20.00	$ 20.00	$ 20.00	$ 25.00	$ 25.00
Belgian block on sand. 15 cts. per sq. ft..	24.99	24.99	30.00	30.00	30.00	37.50	37.50
Asphalt, 25 cts. per sq. ft.............	41.59	41.59	50.00	50.00	50.00	62.50	62.50
Granite block and brick 35 cts. per sq. ft.............	58.19	58.19	70.00	70.00	70.00	87.50	87.50
Wood block 37 cts. per sq. ft..........	61.42	61.42	74.00	74.00	74.00	92.50	92.50
Total cost of conduit							
Macadam..........	$ 64.09	$ 88.44	$117.86	$150.10	$182.53	$231.17	$272.48
Belgian block on sand.............	73.44	96.83	127.86	160.10	192.53	243.67	284.98
Asphalt............	90.08	113.43	147.86	180.10	212.53	268.67	309.98
Granite block and brick.............	106.68	130.03	167.86	200.10	232.53	293.67	334.98
Wood block........	109.91	133.26	171.86	204.10	236.53	298.67	339.98

[1] Covers engineering, inspection, sheathing, obstructions, insurance, etc.

As these tables include unit quantities, the costs may be revised to suit local conditions where actual unit costs are known.

As in the case of conduit construction, the cost of manholes also varies with different localities. For city work, and especially in congested districts, brick is sometimes more suitable than other forms. Where numerous obstructions are met with, a manhole made of brick can readily be made of such shape as to avoid other structures. In cross-country work the concrete manhole is cheaper, since the iron or wooden forms can be used a number of times. The figures given in Table VI and Table VII may safely be used for estimating. These include all material and labor (exclusive of paving) and the cost of the cast-iron frame and cover.

Table VI.—Brick Construction

Estimated Costs of Manholes

	8 by 10 ft. by 6 ft. 6 in.	7 by 9 ft. by 6 ft. 6 in.	6 by 8 ft. by 6 ft. 6 in.	6 by 6 ft. by 6 ft. 6 in.	5 by 7 ft. by 6 ft. 6 in.	4 by 7 ft. by 6 ft. 6 in.
Excavation and removal	$ 37.00	$ 34.00	$ 30.00	$ 23.00	$ 21.00	$ 18.00
Brick in place	120.00	110.00	96.00	86.00	86.00	60.00
Rail	22.00	18.00	15.00	14.00	9.00	9.00
Head and cover	26.00	26.00	26.00	26.00	26.00	26.00
Concrete	13.00	12.00	9.00	7.00	7.00	7.00
Incidentals	20.00	20.00	18.00	15.00	15.00	12.00
Supervision	5.00	5.00	5.00	4.00	4.00	3.00
	$243.00	$225.00	$199.00	$175.00	$168.00	$135.00

Table VII.—Monolithic Concrete Construction

	8 by 10 ft. by 6 ft. 6 in.	7 by 9 ft. by 6 ft. 6 in.	6 by 8 ft. by 6 ft. 6 in.	6 by 6 ft. by 6 ft. 6 in.	5 by 7 ft. by 6 ft. 6 in.	4 by 7 ft. by 6 ft. 6 in.
Excavation and removal	$37.00	$ 34.00	$ 30.00	$ 23.00	$ 21.00	$ 18.00
Concrete	84.00	78.00	63.00	54.00	52.00	48.00
Rail	22.00	18.00	15.00	14.00	9.00	8.00
Head and cover	26.00	26.00	26.00	26.00	26.00	26.00
Frames for concrete	10.00	10.00	10.00	8.00	8.00	7.00
Incidentals	18.00	17.00	14.00	12.00	12.00	10.00
Supervision	5.00	5.00	5.00	4.00	4.00	3.00
	$202.00	$188.00	$163.00	$141.00	$132.00	$120.00

The above estimated costs are exclusive of paving.

When the area and type of the pavement is known, the cost can be estimated and added to the figures given in the table to obtain a total cost.

As previously stated, under certain conditions concrete manholes may be constructed at a cost somewhat less than that of brick construction, and the relation between the cost of the two forms of construction is shown in Fig. 37*a*. This curve is computed on the basis of the cost per cubic foot of manholes of various sizes.

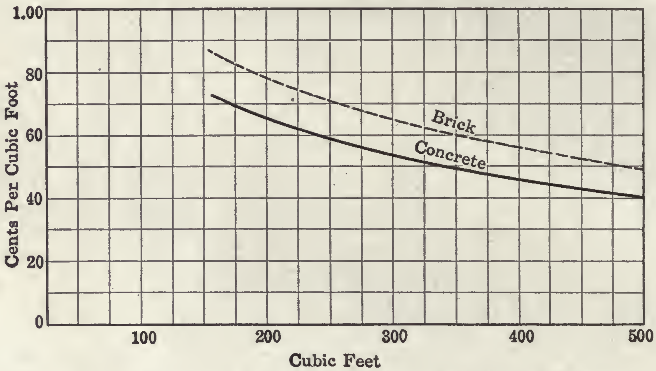


FIG. 37*a*.—Approximate cost of manholes exclusive of paving.

For further details the reader is referred to the various electrical handbooks which include underground construction costs.

CHAPTER IV

METHODS OF DISTRIBUTION

Street Distribution.—In large cities the arrangement of service laterals and subsidiary connections from the main duct line to the consumer's premises is a matter of importance because it forms a large part of the underground investment. A single-conduit system with service connections is shown in Fig. 38. In some cases it is advisable to install duplicate conduit lines in the same street; one conduit consisting of a sufficient number of ducts to carry all the main cables, and the other usually consisting of about four ducts on the opposite side of the street for distribution cables, Fig. 39. The main conduit also carries about

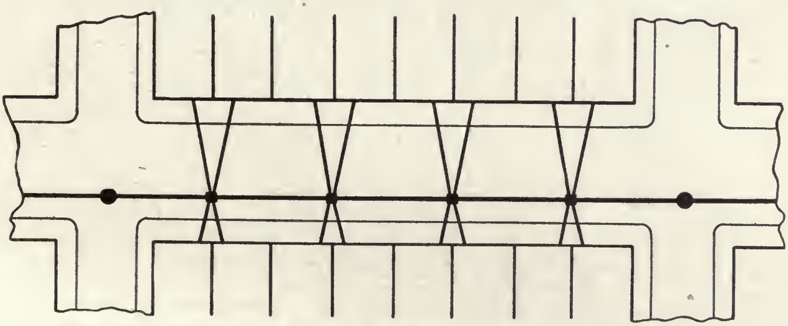


FIG. 38.—Service handholes and laterals, single-conduit system.

four ducts reserved for these purposes. In Fig. 40 is shown a single-conduit system with crossings.

The desirability of installing duplicate conduit depends entirely upon local conditions and the width of the street. With duplicate-conduit systems the service or lateral connections are usually of a shorter length than in the single-conduit system and the service holes are placed about 100 ft. apart. Where the streets are more than 100 ft. wide a double-conduit line installation is convenient as it saves long lateral connections. In some localities a single service connection serves several buildings, the intermediate buildings being connected by means of interior wiring through the side wall or basement. While this method is considerably cheaper than supplying individual service to each building, and requires fewer distribution holes, it has the disadvantage that a fault in the main wiring will interrupt service in all the buildings connected thereto. If such a fault develops in the service connection supplying a building which is closed

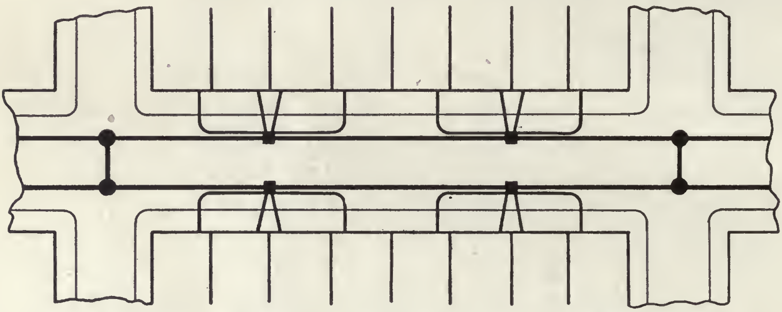


FIG. 39.—Service handholes and laterals, double-conduit system.

during certain hours of the day while the other buildings are still open, it is sometimes difficult to gain entrance in order to make necessary repairs and to restore service to other buildings tied in on the same service. Still another system which is similar to the duplicate conduit is to provide crossings at each dis-

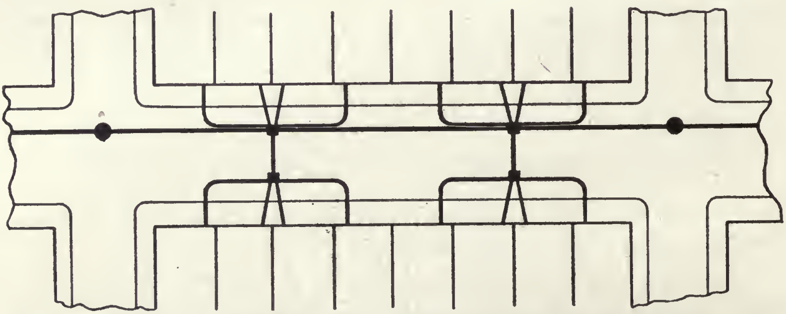


FIG. 40.—Service handholes and laterals, single-conduit system with crossings.

tribution hole from which the service connections are run on each side of the street.

Interior Block Distribution.—What is commonly known as back-yard or block system of distribution, Fig. 41, has been used quite extensively in the suburban sections of a number of large cities. From the results obtained through its introduction there seems to be good reason for the enthusiastic way in which it has been taken up. So far as appearances go this plan possesses nearly all the advantages of the complete duct system and the cost of reaching suburban houses with electrical service in sections where the underground connections in streets would be necessitated, is not much greater than would be entailed by the straight overhead system. In the larger cities arrangements have been made whereby the lighting companies have deeded to them by the owner of the property the ground on which poles may be erected in the rear of houses, together with the right of

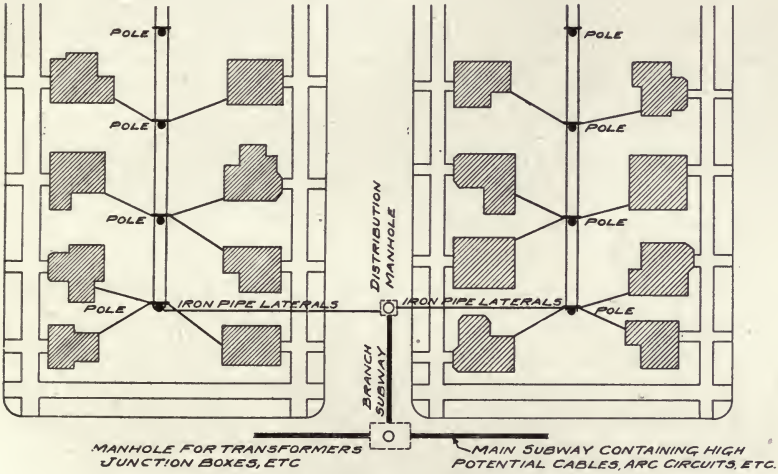


FIG. 41.—Plan of back-yard pole lines, with overhead-service connection fed from main subway.

free access at all times, the company in return for this privilege placing on the street an improved type of lamp post. In this method of distribution the mains are run to the back-yard lines and the high-potential circuits are run underground to the transformer manhole nearest the desired streets. From this point low-potential circuits run to the street opposite the pole line whence they branch and run underground to the end pole on the other side. The mains are then brought up through conduits to the crossarm. Service connections are made to the main and brought in to the rear of the house, thus relieving the front of the property from overhead wires and service connections. The pole line extends from block to block, depending on the number of houses to be connected. The property owner usually appreciates the effort to keep the streets free from poles and the shade trees from being killed or marred owing to the presence of overhead wires in the street. Few difficulties, therefore, are encountered in securing free grant of the ground and the right of access.

The scheme has met with public approval in many cities where detached houses abound. With this system of distribution the problem of street lighting becomes more difficult as it involves the use of long overhead branches to each lamp, or underground laterals of the same length at a considerably greater cost.

The need of a cheap, yet good system, of subway distribution in suburban districts is being felt at this time when there is so much agitation about the injurious effects of wires in trees. The springing up of shade tree commissions in the larger cities has particularly aggravated the situation. It is believed that in sections where the business would not warrant a complete installation of an underground system the combination of an underground system with the overhead system just described will be most satisfactory and economical.

Sidewalk Distribution.—In the sidewalk system of distribution the conduit is usually laid under the grass plot between the curb and the sidewalk with handholes located at every second property line from which the service pipes lead in to the meter board on the consumer's premises. Sometimes the ducts are sunk below the sidewalk level, the record of their exact location being kept so that they may be quickly located in case of trouble. The box as shown in Fig. 42 is well adapted to this type of construction. It is constructed of cast iron with a removable cover and is cast with holes of a convenient size to receive the duct and the service pipe.

Handholes may also be installed with a cast-iron cover which is set flush with the sidewalk. Fig. 42 illustrates an installation of this type.

The duct may be either fiber or iron pipe, the fiber duct, however, being considerably cheaper than the iron pipe. It is not necessary to lay the duct in concrete, as a special sleeve may be employed, which has sufficient strength to insure proper alignment of the duct during the refilling of the earth. The ends of the duct should fit tightly in the sleeve, which is about 5 in. long. Cement covered joints are also used to good advantage when the conduit is not entirely laid in concrete. In this case slip joints are wrapped with muslin tape before the protective covering of cement is applied, thus preventing any water from entering the conduit. This system, however, has its limitations and is practicable only in suburban sections where the houses set well back from the property line and have no vaults extending to the curb.

In the larger cities where real estate promoters have built blocks of houses, and desire to keep all overhead wires off the property, it is customary for them to install subway services to the sidewalk distribution system, since the revenue from the

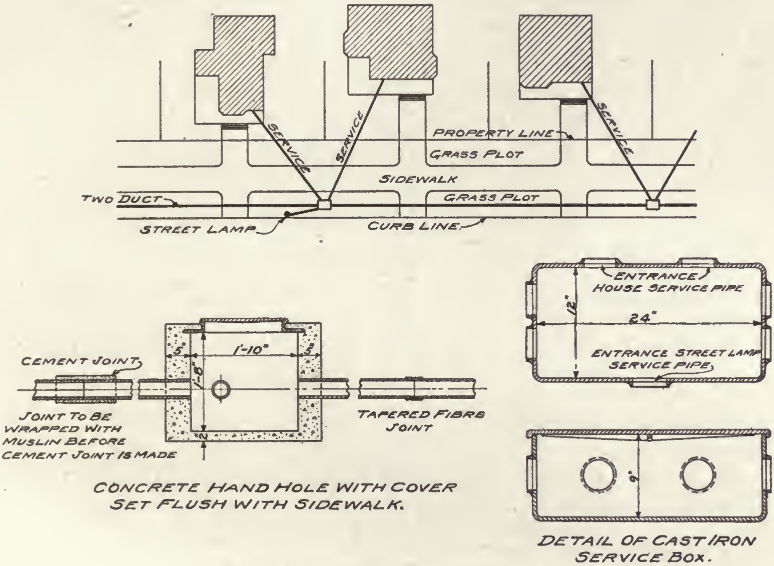


Fig. 42.—Sidewalk distribution.

customers is very often not sufficiently large to justify the expenditure on the part of the lighting company of the amount necessary to install underground connections. An agreement with the owner is made whereby the latter will install the conduit at his own expense under the supervision of the company, the company agreeing to install the necessary wiring without any future expense to the owner.

Duct Arrangement.—Conduit lines of a large number of ducts are undesirable and should be avoided wherever possible. More than 20 or 24 cables entering a manhole by one conduit line are difficult to properly train around the manhole walls and a manhole fire with so many exposed cables may cause great trouble and damage.

Unless conditions are such as to make it absolutely necessary, it is not good practice to use more than 20 ducts, partly because of the limiting of the current-carrying capacity, due to the difficulty in dissipating the heat from the line and partly because of the danger of shutting down the whole duct line due to communication of trouble from one cable to another.

The layout of the conduit system should be one which will give the shortest cable lengths and at the same time avoid the bunching of cables in any one manhole or conduit run. It is advisable to divide into two or more runs at the supply point or center of distribution, such as the generating station or substation. When the number of cables for present and future use has been ascertained, the various duct sections to be laid should be determined by increasing the number of ducts required by 25 or 30 per cent.

This increase is advisable on account of the relative cheapness of the ducts so installed as compared with the high cost of installing needed ducts at some future time when unforeseen contingencies require their use.

While the number of ducts will be fixed by requirements, there must be sufficient to care for local distribution and distribution feeders and transmission lines, as well as to care for future requirements.

It is not advisable to lay less than four ducts in a line except in side streets or for lateral connections and where there is no probability of the line becoming part of a through line.

In selecting a route for conduits, due consideration should be given to the character of the streets or alleys in which the work is to be done. It often develops that it is cheaper to lengthen the conduit and cables to some extent than to install them in streets where very expensive pavement is laid or where rock excavation or difficult obstructions will be encountered.

Parallel Routing.—Because of the likelihood of large cables in one conduit or in one street to be interrupted by accidents, the attempt is usually made, in case of important lines running from a power house for some distance, to route them in separate conduit lines or even in separate streets, and it is, therefore, advisable, instead of using a large number of ducts, to provide parallel conduit lines with fewer ducts. Among some of the causes which might interrupt such lines are burning of cables by severe short-circuits, by caving in of streets due to excavation for building foundations, sewers or subway construction, explosions due to illuminating gases, blasting, malicious mischief, washing out of pavement and conduit due to bursting of water mains, collapse of large buildings in case of fires, earthquakes or faulty construction.

In Fig. 43 is shown a system with all main cables installed in a single-conduit system.

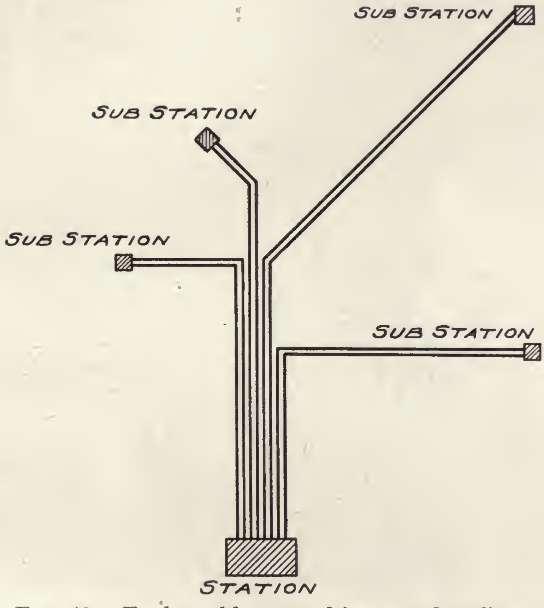


FIG. 43.—Feeder cables routed in same duct lines.

While much of this constitutes an ever-present menace, any real danger of interruption of service on any line from these causes is quite remote and the justification of any increased investment to provide a duplicate route should be gaged accordingly. Some engineers are of the opinion that the greatest protection warrantable would be to provide duplicate routes for conduit lines in the same streets. Others go to the extreme of providing a duplicate route for a single line, which necessitates a much longer run than the original route.

Inquiries among a number of the leading companies show that some would not provide a duplicate if it required any material increase in the length of the second line, while others in some special cases would favor the use of a duplicate route, as shown in Fig. 44.

In order to avoid more than two cables paralleling along the wall of the manhole at the same elevation, the conduit should be so arranged that not more than four ducts in width enter a manhole. Where the conduit is several ducts wide, it is frequently found advantageous to separate the ducts where they enter the manhole. The arrangement of the ducts, however, is usually determined by the space available in the street.

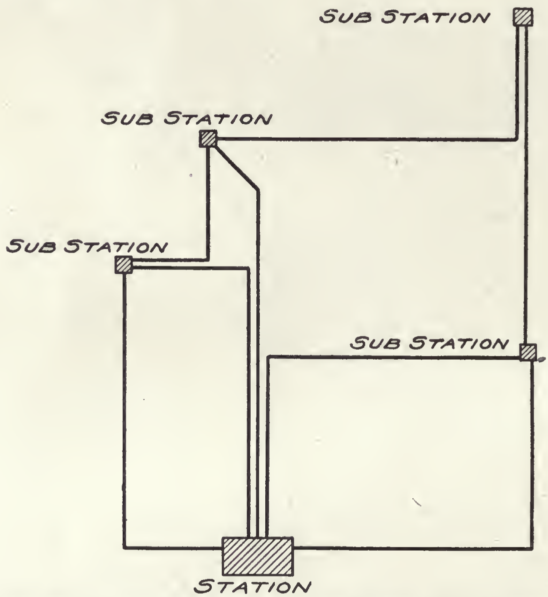


FIG. 44.—Feeder cables routed in different duct lines.

Where conditions will allow, a good form of duct arrangement is as follows:

Two-, four- and six-duct conduit.......	Two ducts wide.
Nine- and twelve-duct conduit...........	Three ducts wide.
Sixteen-, twenty- and twenty-four-duct conduit..............................	Four ducts wide.

Solid System.—The need for an inexpensive system of underground distribution in suburban sections where the complete installation of a drawing-in system would be prohibitive on account of the cost, has led some companies to experiment with a so-called "solid" system. One of the large illuminating companies several years ago constructed a system which consisted of fiber conduit laid directly in the ground without concrete, but with a protective covering of "kyanized" planking resting directly on the fiber tube.

The conductors consisted of ordinary line wire and were arranged for three-wire distribution with the center or neutral

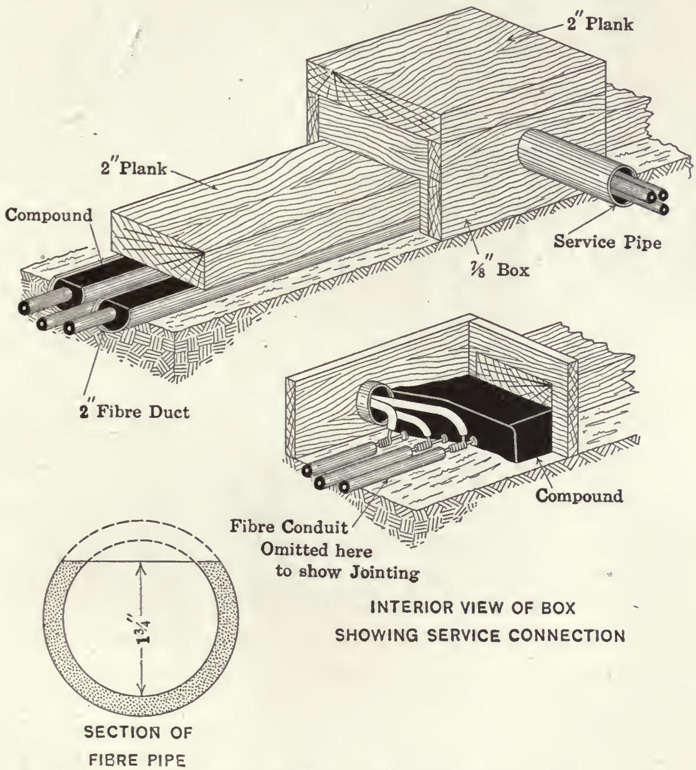


Fig. 45.—Experimental solid system.

wire lying directly in the earth between the two outside conductors.

After laying the wire the fiber tubes were filled with an insulating compound. A complete installation of this type is shown in Fig. 45. Service connections for customers were made by removing a short section of the covering and connecting service wires to the mains, after which the joint was filled with compound and the covering restored. The writer has been advised that this system has been in service for about 8 years in suburban sections, without showing any indication of deterioration, and with no displacement of the compound during the summer months even when laid on 5 per cent. grades.

The compound used in the installation shows a dielectric strength of about 2,300 volts per in. and an expansion from solid to liquid from 5 to 10 per cent. It is not affected by moisture and has a flash test of about 700°F.

Service Connections.—Service or lateral connections from manholes to the consumers' premises are usually installed in wrought-iron or steel pipe. The pipe should be thoroughly coated with an asphaltic compound or other suitable protection to prevent corrosion. Galvanized or sherardized pipe is sometimes used in order to prolong the life of the service. In a number of installations the iron pipe is used only in the street between the manhole and the curb line where the traffic is heavy, and under the sidewalk or on private property fiber pipe or some other form of conduit may be used. It is customary in installing service connections in a street which is about to be improved with a permanent pavement, to install the laterals not only to present consumers, but also to prospective customers, terminating the pipe at the curb, a record being taken of the exact location in order that the service may be continued to the consumers, premises as the occasion requires.

For convenience in locating the pipe services, markers are frequently placed in the sidewalk to fix the location.

These service markers consist of an iron rod which is driven into the ground to the end of the pipe. The rod is capped with a cast-iron plate which indicates the class of service.

Wooden plugs or metal caps are placed at the end of the pipe in order to prevent earth or other material entering the pipe when the excavation is being refilled.

It is frequently found necessary to install service pipes under cement sidewalks or under highways, and since such installations require a permit and the expenditure of considerable money for restoration of the pavement, the use of a pipe-forcing jack will be found economical. This jack is specially designed for forcing pipe horizontally through the ground and may be used advantageously where it is desired to install pipe under the conditions mentioned above, or under railroad tracks or other crossings. The device effects a considerable saving in both time and money. This jack, which is illustrated in Fig. 46 consists of a carriage which travels on a track so designed that when the carriage reaches the limit of its travel it can be drawn back to the starting point to permit of a new section of pipe being inserted. The operation of this apparatus is thus carried on until the desired distance to which the pipe is to be forced has been reached. It has been found advisable to provide for the driving in of a section of pipe 1 or 2 ft. long and of a size larger than the pipe to be laid. This short length of pipe is equipped

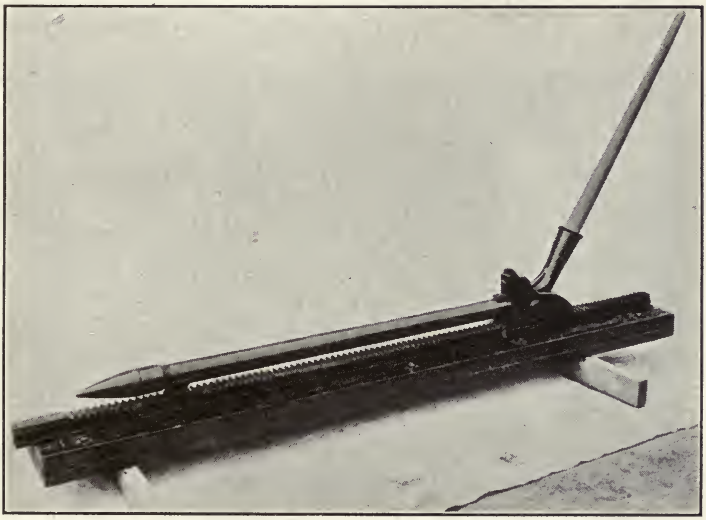


Fig. 46.—Pipe forcing jack showing pipe and steel nose mounted in position.

with a steel nose so that it can readily cut its way through a reasonable amount of earth, rock and stones or roots in its path. Under favorable soil conditions this jack will force pipe up to 4 in. in diameter for a reasonable distance. In using the jack in public highways, however, care should be taken to avoid coming into contact with any foreign structures, as the writer has known of several cases where lack of care has caused damage to underground pipes or other conduits. The jack should, therefore, be used only where the operator is certain that no obstructions of this nature will be encountered in the path of the pipe being forced.

Underground construction, when employed for service connections of small capacity, usually requires an abnormal investment in comparison with the business to be served. Where a number of customers in a single building are to be served by a single service, local municipal regulations usually require that the main service switch be placed in a location accessible at all times for the replacement of fuses, etc.

This is usually easily accomplished in a building one or more stories in height, where there are no partitions or dividing walls cutting the building vertically into several parts by locating the service in the main entrance or in some position in the basement which is used in common by all tenants.

In the case of a block of one-story buildings, as shown in Fig. 47 constructed with or without basements, each having

FIG. 47.—Method of installing service box in buildings.

its own entrance, recourse must be had to installing a separate service connection to each subdivision of the block, as shown in Fig. 48.

In many cases such services may serve a load of only ½ kw. or even less, thus involving a heavy and unwarranted expenditure for the business served.

In efforts to reduce the cost of this form of construction, a material saving has been effected by the introduction of a service box adapted for the supply of an entire block or group of customers of the character last described.

The service box comprises a suitable weatherproof iron box built into the wall of the building at the street level in a manner to conform to the general architecture of the building and in no way to detract from its appearance. The company terminates its service in this box, installing a main switch properly fused for the supply of the entire premises to be served. The owner of the building installs a common main from the service box, running the same horizontally to connect with all the separate premises to be served.

This main, when installed in conduit, in strict accordance with the rules of the National Board of Fire Underwriters, intro-

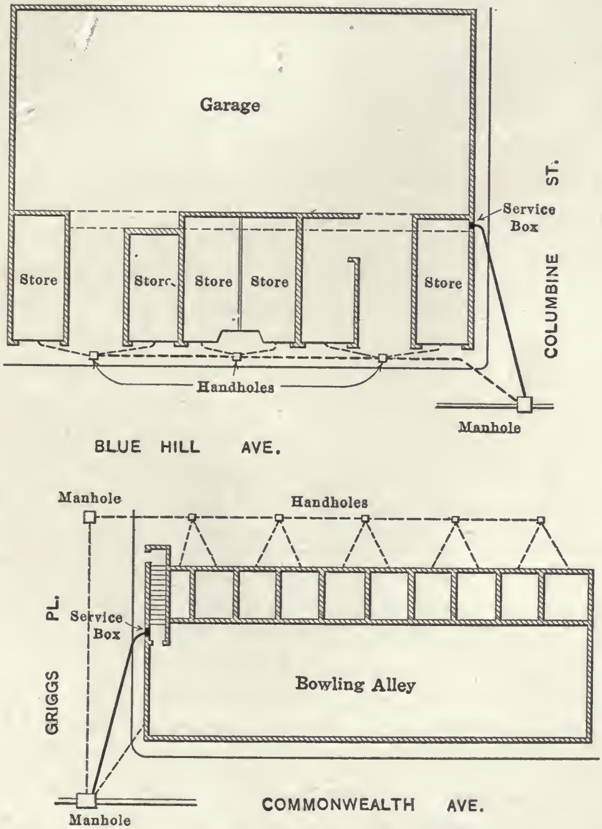


FIG. 48.—Method of installing separate underground services.

duces no hazard of any character, and simply duplicates the conditions under which vertical mains or risers are installed to serve tenants in buildings of one or more stories in height. In both cases branch connections are taken from the main on each tenant's premises, thus giving the tenant access at all times to the devices controlling his service.

The main service box, located in the outside wall of the building, is always accessible to the company's employees for re-fusing, inspection, etc., and also to firemen or other municipal agents who might desire to discontinue the service in the building in emergencies. While the box is ordinarily locked, provision is made for forcing the door without damage to the box itself.

Armored-cable System.—In Europe the installation of armored cable is practically standard for all underground systems supplying large, as well as small, service requirements.

These systems employ armored cables with or without lead sheaths, laid directly in the ground or in insulated troughs which are sometimes filled with compound as may best suit the local conditions governing the installation.

Junction or distribution boxes are employed at the center of distribution and service connections for customers are made by means of wiped joints where lead-sheath cables are employed and by connection boxes where non-leaded cables are used.

In the latter case these connection points are filled with compound after the connection is completed. In this country the armored-cable system has demonstrated its advantages for use in cities where service requirements are of a difficult nature and are subject to radical changes, and for residence streets where there is a strip of land between the curb and the sidewalk line.

It can readily be installed in places where the drawing-in system would be impossible owing to the necessity of passing around large obstacles such as rocks, trees, etc.

The necessity for a safe and inexpensive conduit system in many of the smaller cities or towns, and in the parks, playgrounds and boulevards of larger cities, has brought about a great demand for steel-tape cable. This cable is made in various sizes and is adapted for any voltage. The conductors are insulated with a rubber compound and taped. After the required number of conductors has been laid and covered with jute and tape, a lead sheath is applied and the whole served with jute. The armor is then applied. This usually consists of two layers of steel tape over which is applied the asphalt and jute which serves for the outside or final layer, as illustrated in Fig. 49.

Such construction is closely analogous to that of the standard submarine cable and each layer or cover has its special function. The outer jute covering protects the steel armor against the action of water and chemicals and the steel tape affords mechanical strength and protection to the conductors. The layer of jute under the armor acts as a cushion between the armor and the lead sheath. The lead sheath absolutely excludes moisture. The economies effected by this type of installation have allowed a number of municipalities to install street-lighting systems at a minimum cost. The growing demand for improved methods in the installation of ornamental street-lighting systems using underground conductors seems to have been met by the use of steel-armored cable, as it permits the installation of a complete system

Fig. 49.—Forms of steel taped cable.

in the minimum time and at the least cost, in any kind of weather and with practically no interruptions to traffic.

One of the largest installations of this type is in Central Park, New York City, where over 500,000 ft. of steel-tape street-lighting cable is in use.

Installations of steel-armored cables have been in service in this country for a number of years and have operated very satisfactorily. The cable is usually laid about 1 ft. deep in a trench of spade width, as illustrated in Fig. 50. No reinforcement or protection is provided except at street crossings and roadways where there is apt to be heavy traffic. At such places it is customary to run the cable through an iron pipe.

Where the ground is sufficiently level the cable may be laid directly from the reel mounted on a pair of wheels. Where necessary the same cables may be used as submarine cable for crossing lakes or streams. No joints are made in the cable as it is usually looped in through the lamp post. Terminal blocks are located in the bases of the posts as shown in Fig. 51.

Steel-tape cable, being frostproof and waterproof, may be laid just deep enough to prevent accidental damage or injury.

FIG. 50.—Installation of armored cable.

Cable has been used to good advantage where it has been found necessary to cross railroad tracks, in which case the above type of installation furnishes an ideal solution of the problem. When crossing under tracks, excavation is sometimes avoided entirely by boring through the ground with an auger and slipping the cable through the hole thus made.

The writer's investigation regarding the experience of a number of companies using this type of cable indicates that troubles which have developed have been due chiefly to mechanical injury to the system caused by carelessness or accidents.

If, therefore, the cable is carefully manufactured and properly installed, it is rarely necessary to take it up again to locate and repair faults.

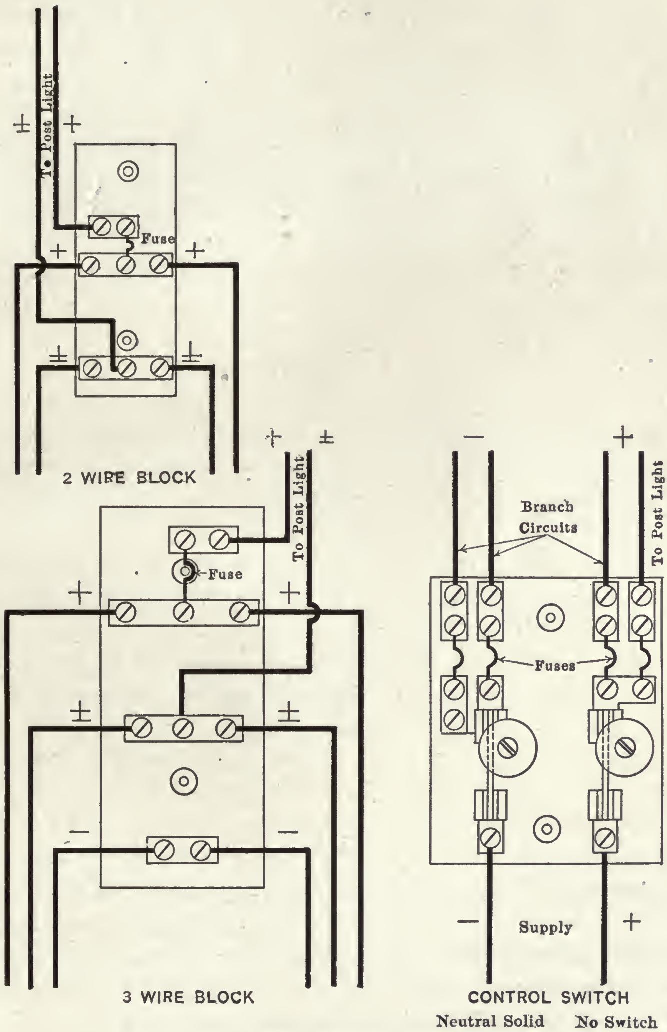


FIG. 51.—Terminal blocks.

Installing Steel-taped Street-lighting Cable.—When used for ornamental street lighting, the usual practice is to bury the cable in the street close to the curb and just beneath the paving. Where the street is paved with brick, cobbles, granite or wood blocks, the installation simply requires the removal of one or two rows of the paving material and the cable is laid 3 in. below the pavement, filled over with sand and the paving replaced.

Another method largely used is to remove one course of brick or block next to the curb, lay the cable in and cover with concrete to the pavement level. This method may also be used with asphalt or macadam pavements, a shallow groove being chopped or chiseled away, the cable laid in, and the groove filled flush with concrete. In either of these cases, the cable is brought up to the lighting post either under the curbing or through it, and up through a hole in the sidewalk.

Another style of construction sometimes used in business districts where the sidewalks run out to the curb, is to cut a channel in the walk just inside the curb (about 2 in. by 2 in. in section) in which the cable is buried in concrete.

Where there is a parkway between the sidewalk and curb, the cable can be laid in a narrow, shallow trench, dug in the sod inside the curb. Where an intersecting walk is encountered, it can be crossed in a narrow channel chiseled out and filled with concrete.

When crossing intersecting streets, a row of brick or block is removed and the cable laid beneath; or the asphalt or macadam is channeled, the cable laid in, and the surface restored. If car tracks must be crossed, a hole is bored beneath the track and the cable pulled through. The right-of-way is not disturbed and the car service need not be interrupted.

Where obstructions of any kind are encountered in the trench, the cable is simply pulled under, or laid around the obstacle.

Where the standards can be set upon concrete walks of sufficient thickness and sound quality, no other footing is necessary. The base can be set on the walk, holes marked and drilled, and the foundation bolts set in head down, bedded in lead, sulphur or grout. A hole for the cable is drilled through the walk, and another through or under the curb. The cable is brought up through, the standard set over it and bolted in place.

When there is no cement walk, or where the concrete is not strong enough, it will be necessary to build a concrete base or put in a cast-iron sub-base for the lamp standard. Fig. 52 shows a simple form of concrete base made in a plain square wood form.

Instead of the curved tile shown, a wood box may be used, or a piece of steel conduit or iron pipe. In some cases the cable has been bedded directly in the green concrete base.

It is advisable to connect the conductors of the cable to a cut-out in the base of the lamp standard, at least a foot above ground. The jute is cut away, the steel tape rolled back the right distance and cut off, and the lead casing removed to within about 1 in. of the end of the steel tape. The copper conductors are then separated, bared, and fitted or bent into loops at the end, for connection to the cutout. The end of the lead sheath should be carefully taped and painted with waterproof compound, to seal it against moisture. The steel tape should be bound with wire

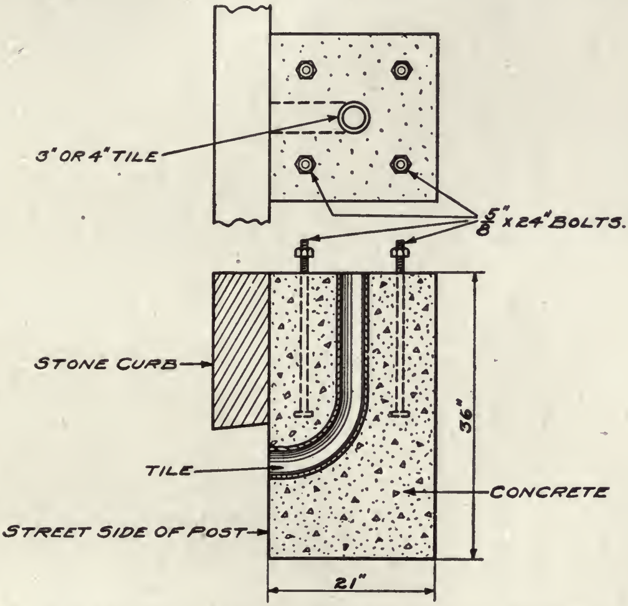


FIG. 52.—Design for concrete base for lamp standard.

at the end and the outside woven covering taped or wrapped with twine to prevent fraying.

At the point where the cable connects with overhead lines, the best practice is to carry the cable to the top of the pole and make connection in a suitable pothead for protection against weather.

In an installation of steel-taped cable for ornamental street lighting at Maryville, Mo., 74 five-light standards are used, the top light being a 100-watt Mazda and the four lower lights being 40-watt Mazdas. The top light burns all night, and the others up to 11:00 p. m. Three-wire cable is used, being placed under the brick pavement at the curb.

TABLE VIII.—STEEL TAPED CABLE

Dimensions and Weights

600 Volts

Size of conductors	Thickness of rubber, in.	Single conductor		Two-conductor flat		Three-conductor	
		Outside diameter, in.	Approx. shipping weight per M ft., lb.	Outside diameter, in.	Approx. shipping weight per M ft., lb.	Outside diameter, in.	Approx. shipping weight per M ft., lb.
Solid							
12 B. & S.	1/16	0.687	850	0.970	1,375	1.030	1,750
10 B. & S.	1/16	0.720	1,200	1.000	1,545	1.062	1,900
8 B. & S.	1/16	0.750	1,300	1.062	1,700	1.125	2,100
6 B. & S.	1/16	0.782	1,365	1.125	2,045	1.187	2,500
Stranded							
4 B. & S.	1/16	0.875	1,700	1.312	2,185	1.375	3,430
2 B. & S.	1/16	0.906	1,875	1.437	2,810	1.500	4,010
1 B. & S.	5/64	1.000	2,065	1.625	3,320	1.687	5,120
0 B. & S.	5/64	1.030	2,200	1.687	3,650	1.812	5,650
00 B. & S.	5/64	1.062	2,400	1.750	3,900	1.906	6,250
000 B. & S.	5/64	1.125	2,600	1.875	4,620	2.030	7,125
0000 B. & S.	5/64	1.187	2,850	2.000	5,145	2.156	8,950
2,400 Volts							
Solid							
12 B. & S.	4/32	0.781	1,415	1.188	2,100	1.281	2,790
10 B. & S.	4/32	0.813	1,500	1.218	2,265	1.328	3,070
8 B. & S.	4/32	0.828	1,550	1.250	2,365	1.375	3,165
6 B. & S.	4/32	0.859	1,640	1.313	2,535	1.453	3,415
Stranded							
4 B. & S.	4/32	0.938	1,865	1.469	2,970	1.609	4,075
2 B. & S.	4/32	1.015	2,085	1.625	3,700	1.734	5,250
1 B. & S.	4/32	1.047	2,200	1.688	3,840	1.828	5,600
0 B. & S.	4/32	1.034	2,360	1.781	4,120	1.921	6,110
00 B. & S.	4/32	1.140	2,550	1.875	4,575	2.046	6,825
000 B. & S.	4/32	1.218	2,765	1.969	4,950	2.156	7,950
0000 B. & S.	4/32	1.281	3,500	2.094	6,140	2.281	8,800
5,000 Volts							
8 B. & S. solid	5/32	1.062	1,680	1.375	2,680	1.656	3,920
6 B. & S. solid	5/32	1.094	1,800	1.500	2,900	1.719	4,220
4 B. & S. stranded	5/32	1.156	2,075	1.719	3,685	1.906	5,430

The diagram (Fig. 53) shows the wiring scheme. Two transformers and two primary circuits are required. Switches at the station control each primary circuit and by this means constant load is carried on each transformer. The usual practice in a system of this kind is to control the lights by means of switches placed at some convenient point on the secondary lines.

Table VIII lists the standard specifications for steel-taped cable in the voltages for which it is regularly manufactured. Special sizes and voltages not listed may be obtained when required.

Comparative Costs of Installation.—It is impossible to state just what the saving realized by a system of steel-taped cable will be over a conduit system, without a careful analysis of the conditions. In general it may be said that the saving will rarely be less than 30 per cent., and may run higher, under conditions

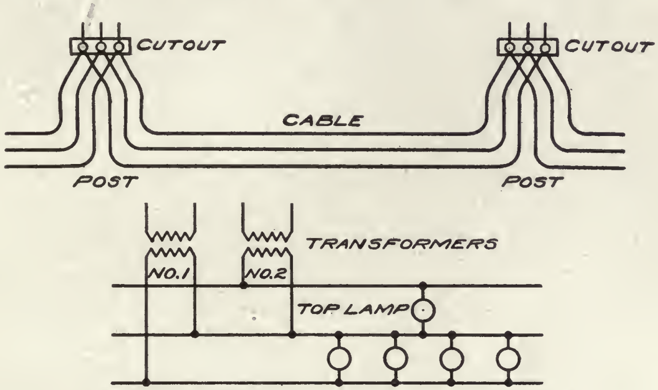


FIG. 53.—Wiring diagram for street lamps.

peculiarly adverse to the conduit. In fact, the cable has been successfully and cheaply installed under conditions which absolutely prohibited the use of conduit.

The following comparison has been worked out on some arbitrary assumptions, with a special effort to make the figures just in each case. A length of 1,000 ft. is taken as a basis of comparison, laid in brick-paved streets:

Cost of lead-encased, 600-V.R.C. cable in fiber duct:	
1,000 ft. No. 6 three-conductor cable	$200
1,000 ft. 2-in. fiber conduit	50
Cost of installing in loop system	420
	$670
Cost of steel-taped, 600-V.R.C. cable:	
1,000 ft. No. 6 three-conductor, 600-volt steel-taped cable	$260
Cost of installing in loop system	165
	$425

Saving by the use of steel-tape cable, $245, or 36 per cent.

CHAPTER V

CABLES

General.—In present-day practice of underground construction lead-covered insulated cables are used almost exclusively. The three essential members of such a cable are: The conductor itself, the wall of insulating material and the outer protective covering, and they will be considered in the order named.

Terminology.—The following definitions relating to wire and cables are based on *Bulletin* No. 37, issued by the Bureau of Standards, January, 1915.

Wires and Cables

Wire.—A slender rod or filament of drawn metal.

Conductor.—A wire, a combination of wires not insulated from one another, suitable for carrying a single electric current.

Stranded Conductor.—A conductor composed of a group of wires, or of any combination of groups of wires.

Cable.—(1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

Strand.—One of the wires or groups of wires of any stranded conductor.

Stranded Wire.—A group of small wires used as a single wire.

Cord.—A small and very flexible cable, substantially insulated to withstand wear.

Concentric Strand.—A strand composed of a central cord surrounded by one or more layers of helically laid wires or groups of wires.

Duplex Cable.—Two insulated conductor cables, twisted together.

Twin Cable.—Two insulated single-conductor cables, laid parallel, having a common covering.

Triplex Cable.—Three insulated, single-conductor cables twisted together.

Twisted Pair.—Two small insulated conductors twisted together without a common covering.

Twin Wire.—Two small insulated conductors laid parallel, having a common covering.

Conductor.—Theoretically the transmission of electricity through any substance is a matter of degree; practically we may make a distinction between conducting and insulating materials.

The following table gives a list of materials approximately arranged in order of their conducting powers.

Conductors	Non-conductors or insulators	
All metals	Dry air	Ebonite
Well-burned charcoal	Shellac	Gutta percha
Plumbago	Paraffine	India rubber
Acid solutions	Rosins	Silk
Metallic ores	Sulphur	Dry paper
Living vegetable substances	Wax	Dry leather
Moist earth	Glass	Porcelain
Water	Mica	Oils

The conducting power of any substance depends largely upon its physical state, and the conductivity of all substances materially alters with a change of temperature.

The general trend of this change in conductivity with rising temperature is toward a decrease with metals and toward an increase with other substances.

In commercial transmission of electricity we are limited to the use of three metals: copper, iron and aluminum, although abnormal conditions of late have added zinc in certain countries. Copper ranks first in importance, with aluminum next, and iron last, and whether or not the use of zinc will survive after normal conditions are restored appears uncertain. Pure copper, in addition to its high conductivity, possesses many other physical properties of special value in cable work.

Its strength, malleability and cost in comparison with that of other metals makes it an ideal material for cable work. The malleability, ductility, tensile strength and electrical conductivity of copper are somewhat modified by impurities. These, when present, usually are of one or more elements such as bismuth, arsenic, antimony, sulphur, etc.; however, the electrolytic wire bars so largely used in the manufacture of wires and cables for electrical purposes are almost pure.

Refining of copper and its separation from the multitude of alloying metals is a complex metallurgical process, but a very necessary one. Even traces of other metals affect the conductivity to a remarkable degree, as the following table will show:

Element	Per cent. present in copper	Per cent. conductivity
Carbon	0.05	77.87
Sulphur	0.18	92.08
Arsenic	0.10	73.89
Silver	1.22	90.34
Tin	1.33	50.44
Aluminum	0.10	86.49

Copper enters readily into combination with the constituents of rubber insulation and must be coated with a protective such as tin, which is not easily attacked.

Copper is easily soluble in nitric acid, aqua regia and strong boiling sulphuric acid; and in diluted sulphuric acid, when exposed to the air, it dissolves slowly.

The tensile strength of annealed copper is usually about 30,000 lb. per sq. in., but when it is hard-drawn or medium hard-drawn, its strength is increased to 50,000 and 65,000 lb., depending upon the size of the wire.

Table IX gives the average values of breaking weight for various sizes.

TABLE IX.—TENSILE STRENGTH OF PURE COPPER WIRE IN POUNDS

Size B. & S.	Hard-drawn		Annealed		Size B. & S.	Hard-drawn		Annealed	
	Actual	Average per sq. in.	Actual	Average per sq. in.		Actual	Average per sq. in.	Actual	Average per sq. in.
0000	8,260	49,700	5,320	32,000	7	1,050.0	64,200	556.0	34,000
000	6,550	49,700	4,220	32,000	8	843.0	65,000	441.0	34,000
00	5,440	52,000	3,340	32,000	9	678.0	66,000	350.0	34,000
0	4,530	54,600	2,650	32,000	10	546.0	67,000	277.0	34,000
1	3,680	56,000	2,100	32,000	12	343.0	67,000	174.0	34,000
2	2,970	57,000	1,670	32,000	14	219.0	68,000	110.0	34,000
3	2,380	57,600	1,323	32,000	16	138.0	68,000	68.9	34,000
4	1,900	58,000	1,050	32,000	18	86.7	68,000	43.4	34,000
5	1,580	60,800	884	34,000	19	68.8	68,000	34.4	34,000
6	1,300	63,000	700	34,000	20	54.7	68,000	27.3	34,000

Many experiments have been made determining the effect of temperature on the tensile strength of copper, and a summary of the results may be stated as follows:

Up to about 400°F. the loss in strength is about 10 per cent.;

at 500°F. it is about 16 per cent. and above 500°F. it is so great as to make the metal almost useless.

As the conductivity of any one wire will, in general, differ from that of any other, it is necessary in comparing or specifying wires to refer to some standard.

The present practice in copper specifications for cable work, is to refer to the standardization rules of A.I.E.E. of which the following shall be taken as normal values of standard annealed copper.

1. At a temperature of 20°C., the resistance of a wire of standard annealed copper, 1 meter in length, and of a uniform section of 1 sq. mm. is $\frac{1}{58}$ ohm = 0.017241 .... ohm.

2. At a temperature of 20°C., the density of standard annealed copper is 8.89 grams per c.c.

3. At a temperature of 20°C., the "constant mass" temperature coefficient of resistance of standard annealed copper measured between two potential points rigidly fixed to the wire is 0.00393 = $\frac{1}{254.45}$ .... per degree Centigrade.

4. As a consequence, it follows from (1) and (2) that, at a temperature of 20°C., the resistance of a wire of standard annealed copper of uniform section, 1 meter in length, and weighing 1 gram, is $(\frac{1}{58}) \times 8.89 = 0.15328$ ... ohm.

Table X gives a comparison of wire gages of the Brown & Sharpe, or American ("B. & S."), the Birmingham (B.W.G.) and the British Standard (S.W.G.) wire gages.

In Table XI is given the diameter, weight and resistance of copper wires.

The following Table XII gives data regarding standard concentric strands of different sizes of cable, as recommended by the General Electric Co.

The area of the finished cable is that of the individual wires cut at right angles to their axes, when laid straight, multiplied by the number of wires in the cables. Special attention is called to this point, since in some cases the area of the individual wires is figured as if cut after twisting, *i.e.*, on the "bias," thus using a figure larger than the actual area of the finished conductor, and results in a cable having less copper than if the area was correctly figured.

Insulating Wall.—The principal materials used for insulating power cables are rubber, saturated-paper tapes, varnished cambric or cloth and graded insulation usually consisting of a combination of the foregoing.

TABLE X.—COMPARATIVE SIZES WIRE GAGES IN DECIMALS OF AN INCH

No. of wire gage	American Steel & Wire Gage	Brown & Sharpe Gage	Birmingham, or Stubs'	British Imperial Standard[1]	Old English or London	French	No. of wire gage	American Steel & Wire Gage	Brown & Sharpe Gage	Birmingham, or Stubs'	British[1] Imperial Standard	Old English or London	French
0000000	0.4900	....	.....	0.500	......	.....	18	0.0475	0.04030	0.049	0.0480	0.04900	0.238
000000	0.4615	0.58000	.....	0.464	......	.....	19	0.0410	0.03589	0.042	0.0400	0.04000	0.250
00000	0.4305	0.51650	0.500	0.432	......	.....	20	0.0348	0.03196	0.035	0.0360	0.03500	0.263
0000	0.3938	0.46000	0.454	0.400	0.4540	.....	21	0.0317	0.02846	0.032	0.0320	0.03150	0.279
000	0.3625	0.40964	0.425	0.372	0.4250	.....	22	0.0286	0.02535	0.028	0.0280	0.02950	0.290
00	0.3310	0.36480	0.380	0.348	0.3800	.....	23	0.0258	0.02257	0.025	0.0240	0.02700	0.303
0	0.3065	0.32486	0.340	0.324	0.3400	.....	24	0.0230	0.02010	0.022	0.0220	0.02500	0.316
1	0.2830	0.28930	0.300	0.300	0.3000	0.033	25	0.0204	0.01790	0.020	0.0200	0.02300	0.331
2	0.2625	0.25763	0.284	0.276	0.2840	0.400	26	0.0181	0.01594	0.018	0.0180	0.02050	0.342
3	0.2437	0.22942	0.259	0.252	0.2590	0.050	27	0.0173	0.01420	0.016	0.0164	0.01875	0.356
4	0.2253	0.20431	0.238	0.232	0.2380	0.063	28	0.0162	0.01264	0.014	0.0148	0.01650	0.371
5	0.2070	0.18194	0.220	0.212	0.2200	0.068	29	0.0150	0.01126	0.013	0.0136	0.01550	0.383
6	0.1920	0.16202	0.203	0.192	0.2030	0.083	30	0.0140	0.01003	0.012	0.0124	0.01375	0.394
7	0.1770	0.14428	0.180	0.176	0.1800	0.097	31	0.0132	0.00893	0.010	0.0116	0.01225	0.408
8	0.1620	0.12849	0.165	0.160	0.1650	0.110	32	0.0128	0.00795	0.009	0.0108	0.01125	0.419
9	0.1483	0.11443	0.148	0.144	0.1480	0.120	33	0.0118	0.00708	0.008	0.0100	0.01025	0.431
10	0.1350	0.10189	0.134	0.128	0.1340	0.135	34	0.0104	0.00630	0.007	0.0092	0.00950	0.448
11	0.1205	0.09074	0.120	0.116	0.1200	0.149	35	0.0095	0.00561	0.005	0.0084	0.00900	0.458
12	0.1055	0.08081	0.109	0.104	0.1090	0.162	36	0.0090	0.00500	0.004	0.0076	0.00750	0.472
13	0.0915	0.07196	0.095	0.092	0.0950	0.172	37	0.0085	0.00445	.....	0.0068	0.00650	0.485
14	0.0800	0.06408	0.083	0.080	0.0830	0.185	38	0.0080	0.00396	.....	0.0060	0.00575	0.499
15	0.0720	0.05706	0.072	0.072	0.0720	0.197	39	0.0075	0.00353	.....	0.0052	0.00500	0.509
16	0.0625	0.05082	0.065	0.064	0.0650	0.212	40	0.0070	0.00314	.....	0.0048	0.00450	0.524
17	0.0540	0.04525	0.058	0.056	0.0580	0.225							

[1] Also called New British or English Legal Standard.

TABLE XI.—DIAMETER, WEIGHT AND RESISTANCE OF COPPER WIRE

			Weight, bare wire		Resistance at 75°F.		
No. B. & S.	Diameter, mils	Area, circular mils	Pounds per 1,000 ft.	Pounds per mile	Ohms per 1,000 ft.	Ohms per mile	Feet per ohm
0000	460.000	211,600.00	640.73	3,383.0400	0.04904	0.25891	20939.2000
000	409.640	167,805.00	508.12	2,682.8500	0.06184	0.32649	16172.1000
00	364.800	133,079.00	402.97	2,127.6600	0.07797	0.41168	12825.4000
0	324.950	105,592.50	319.74	1,688.2000	0.09827	0.51885	10176.4000
1	289.300	83,694.50	253.43	1,338.1000	0.12398	0.65460	8066.0000
2	257.630	66,373.20	200.98	1,061.1700	0.15633	0.82543	6396.7000
3	229.420	52,633.50	159.38	841.5000	0.19714	1.04090	5072.5000
4	204.310	41,742.60	126.40	667.3800	0.24858	1.31248	4022.9000
5	181.940	33,102.20	100.23	529.2300	0.31346	1.65507	3190.2000
6	162.020	26,250.50	79.49	419.6900	0.39528	2.08706	2529.9000
7	144.280	20,816.70	63.03	332.8200	0.49845	2.63184	2006.2000
8	128.490	16,509.70	49.99	263.9600	0.62849	3.31843	1591.1000
9	114.430	13,094.20	39.65	209.3500	0.79242	4.18400	1262.0000
10	101.890	10,381.60	31.44	165.9800	0.99948	5.27726	1000.5000
11	90.742	8,234.11	24.93	131.6500	1.26020	6.65357	793.5600
12	80.808	6,529.94	19.77	104.4000	1.58900	8.39001	629.3200
13	71.961	5,178.39	15.68	82.7920	2.00370	10.57980	499.0600
14	64.084	4,106.76	12.44	65.6580	2.52660	13.34050	395.7900
15	57.068	3,256.76	9.86	52.0690	3.18600	16.82230	313.8700
16	50.820	2,582.67	7.82	41.2920	4.01760	21.21300	248.9000
17	45.257	2,048.20	6.20	32.7460	5.06600	26.74850	197.3900
18	40.303	1,624.33	4.92	25.9700	6.38800	33.72850	156.5400
19	35.890	1,288.09	3.90	20.5940	8.05550	42.53290	124.1400
20	31.961	1,021.44	3.09	16.3310	10.15840	53.63620	98.4400
21	28.462	810.09	2.45	12.9520	12.80880	67.63020	78.0700
22	25.347	642.47	1.95	10.2720	16.15040	85.27430	61.9200
23	22.571	509.45	1.54	8.1450	20.36740	107.54000	49.1000
24	20.100	404.01	1.22	6.4593	25.68300	135.60600	38.9400
25	17.900	320.41	0.97	5.1227	32.38330	170.98400	30.8800
26	15.940	254.08	0.77	4.0623	40.83770	215.62300	24.4900
27	14.195	201.50	0.61	3.2215	51.49520	271.89500	19.4200
28	12.641	159.80	0.48	2.5548	64.93440	342.85400	15.4000
29	11.257	126.72	0.38	2.0260	81.88270	432.34100	12.2100
30	10.025	100.50	0.30	1.6068	103.24500	545.13300	9.6860
31	8.928	79.71	0.24	1.2744	130.17600	687.32700	7.6820
32	7.950	63.20	0.19	1.0105	164.17400	866.83700	6.0910
33	7.080	50.13	0.15	0.8014	207.00000	1092.96000	4.8310
34	6.304	39.74	0.12	0.6354	261.09900	1378.60000	3.8300
35	5.614	31.52	0.10	0.5039	329.22500	1738.31000	3.0370
36	5.000	25.00	0.08	0.3997	415.04700	2191.45000	2.4090
37	4.453	19.83	0.06	0.3170	523.27800	2762.91000	1.9110
38	3.965	15.72	0.05	0.2513	660.01100	3484.86000	1.5150
39	3.531	12.47	0.04	0.1993	832.22800	4394.16000	1.2020
40	3.144	9.88	0.03	0.1580	1049.71800	5542.51000	0.9526

If the insulating body is of paper, it is necessary to saturate it with an insulating compound and the character of the compound is of utmost importance in determining the quality and permanence of the cable. In varnished-cloth insulation, specially prepared cotton fabric, coated on both sides with multiple films of insulating varnish is used.

Paper and varnished-cloth insulation, being composed of staple commercial fabrics, impregnated with compound of well-

TABLE XII.—STANDARD STRAND[1]

Size B. & S.	No. wires in strand	Dia. of individual wires, in.	Actual circular mils	Dia. of bare cable, in.	Approx. weight of copper per M ft., lb.	Size B. & S.	No. wires in strand	Dia. of individual wires, in.	Actual circular mils	Dia. of bare cable, in.	Approx. weight of copper per M ft., lb.
14	7	0.0243	4,133	0.0729	13	350,000	37	0.0974	351,010	0.6818	1,087
12	7	0.0306	6,555	0.0918	20	400,000	37	0.1040	400,198	0.7280	1,242
10	7	0.0386	10,430	0.1158	32	450,000	37	0.1110	455,877	0.7770	1,415
8	7	0.0485	16,466	0.1455	51	500,000	61	0.0906	500,710	0.8154	1,554
6	7	0.0613	26,304	0.1839	81	550,000	61	0.0950	550,525	0.8550	1,709
5	7	0.0688	33,134	0.2064	103	660,000	61	0.0992	600,279	0.8928	1,864
4	7	0.0773	41,827	0.2319	129	650,000	61	0.1033	650,924	0.9297	2,020
3	7	0.0868	52,740	0.2604	164	700,000	61	0.1072	701,002	0.9648	2,177
2	7	0.0974	66,407	0.2922	206	750,000	61	0.1110	751,581	0.9990	2,333
1	19	0.0664	83,770	0.3320	259	800,000	61	0.1146	801,123	1.0314	2,487
0	19	0.0746	105,738	0.3750	328	900,000	61	0.1216	901,980	1.0944	2,813
00	19	0.0838	133,426	0.4190	414	1,000,000	61	0.1281	1,000,986	1.1529	3,110
000	19	0.0940	167,884	0.4700	520	1,250,000	91	0.1173	1,252,095	1.2903	3,888
0000	19	0.1056	211,876	0.5280	658	1,500,000	91	0.1284	1,500,276	1.4124	4,660
250,000	37	0.0823	250,612	0.5754	775	1,750,000	127	0.1173	1,747,430	1.5262	5,435
300,000	37	0.0906	303,709	0.6342	943	2,000,000	127	0.1255	2,000,282	1.6315	6,212

[1] General Electric Co.

known oils, etc., are not readily susceptible to adulteration or imitation, and consequently do not suffer much in quality from attempts by the manufacturers to lessen the cost of production.

Rubber compounds, on the other hand, being made of any material mixed with any amount or grade of rubber, are easily adulterated and even imitated. The extent to which this is sometimes carried makes it necessary for engineers to insist on complete mechanical and electrical tests of the compound.

Rubber Insulation.—Rubber-producing trees and vines of one kind or another are found in all tropical countries. Various grades of crude rubber are known by the name of the country or seaport whence they come; hence the terms "Para," "Ceylon," etc., as names of the particular grades of rubber. In the preparation of rubber for insulating purposes, the first step is to free it from all impurities, which is done by passing it between corrugated steel rolls, revolving at different speeds and under a constant stream of water. In this manner the rubber is washed and prepared in sheets ready to be dried. As crude rubber is affected very much by the changes in temperature and readily oxidizes in the uncured state, the rubber must be compounded with other materials to obtain the properties needed in the insulation of a wire. Compounding consists chiefly of adding other substances, such as powdered minerals, including a small percentage of sulphur. After the crude rubber has been warmed to a plastic condition in heated mixing rolls, it is thoroughly kneaded until the resulting compound is homogeneous in nature and of suitable physical condition for the work that is expected of it. Another reason for compounding is that the cost of pure rubber for insulating purposes is excessive. The matter of compounding is of prime importance and requires exhaustive tests and experiments to develop a suitable insulating material for various conditions of service. Compounded rubber before vulcanizing is plastic and cohesive, and can be shaped into any form desired. In order to apply it to a wire, two different methods are commercially employed; in one a machine similar to a lead press is used and the rubber is forced by a revolving worm into a closed chamber at high pressure, the wire entering this chamber through a nozzle of its own diameter and leaving from a nozzle having the diameter of the intended insulation. The wire thus comes out with a seamless coat of rubber, forced on at high pressure.

In the other method of application, the rubber is sheeted on a calendar having heavy smooth rolls, and the sheets thus made are cut into narrow strips, the width and thickness of which depend on the wire to be insulated, and the number of covers to be used. By this method a wire is passed between two or more curved rolls, running in tangent to each other. As the wire enters each pair of rolls, strips of rubber enter at the same time and the grooves form a uniform thickness of rubber about the wires, the edges meeting in a continuous seam.

Surplus rubber is cut off the rolls and the seams, being made between two pieces of the same unvulcanized cohesive stock under pressure, become invisible in the wire, and can be determined only by a ridge along the insulation.

In the process of vulcanization, the rubber at the seams is kneaded together so that the rubber at this point is as dense and homogeneous as at any other part of the insulation.

FIG. 54.—Crude rubber.

Good rubber compound will last indefinitely in pure or salt water, but if the water contains sewage, acids, oils, or other destroying agents, it will have a short life unless protected with some outer covering, such as a lead sheath.

In order to vulcanize rubber compounds, they are subjected to temperatures somewhat above the melting point of sulphur, which temperatures are usually obtained by steam under pressure. This operation causes the sulphur in the compound to chemically unite with the rubber and other ingredients with the result that the rubber is no longer plastic; it becomes firm, strong, elastic, susceptible neither to heat nor cold, and not readily affected at ordinary temperatures by the usual solvents of unvulcanized rubber. Its mechanical properties depend considerably on the time and temperature of vulcanization, as well as the amount of sulphur used. In producing high-grade insulation, proper vulcanization is fully as important as the selection of the crude materials. Rubber insulation is usually protected by a winding of tape or braid, or a tape and one or more braids, depending upon the class of service for which it is to be used. When used for station work it is sometimes provided with an outer braid of asbestos or other form of flameproof covering, to serve as a fire protection. When installed in underground conduits where it is subjected to the severest conditions, it should be covered with a lead sheath.

Paper Insulation.—The use of paper-insulated cables for electric light and power work is rapidly increasing, and when properly constructed and installed such cables give excellent service.

Various kinds of paper have been used for cable insulation; the extremes of quality are represented by that made from wood pulp, which is the poorest, and that made from manila rope fiber, which is the best. Between these extremes there are combinations of wood pulp with jute, jute with manila fiber and wood pulp, jute and manila fiber. A paper containing any appreciable amount of pulp will "felt down" when saturated with insulating oils. In other words, the fibers of the paper stand up before saturation, giving a thickness of insulating wall, which is greatly diminished during impregnation; because of this "felting down" even the most tightly wound insulations composed of pulp paper, will be found quite loose after saturation. Wood fiber or pulp paper is apt to be injured during the drying process to which it is subjected before impregnation, and it has been known to rot badly under the influence of certain of the substances used in the impregnating solution. A paper containing any appreciable amount of jute, either alone or in combination with pulp and manila, will have practically all the disadvantages of pulp paper and in addition the jute will saturate very slowly, which sometimes may result in an unevenly saturated cable. Manila-rope paper is free from this objection and its structure is hard, close and even. It may be dried perfectly without loss of strength and will not rot under the action of properly prepared impregnating oils.

Manila-rope paper of the very highest grade should be used in all paper-insulated cable. The impregnating oils now used by the majority of cable manufacturers consist of solutions of rosin and rosin oil, and solutions of rosin and petroleum oil, or a mixture of these solutions. Commercial rosin, as ordinarily found on the market, is a mixture of what may be termed rosin, some undecomposed turpentine gum, some water, acetic acid and butyric acid, together with light turpentine naphthas and turpentine. These impurities are found to a much larger extent in second-run rosin oil. The method of preparing rosin oil for impregnation varies with different manufacturers in accordance with their particular formula, and the lack of uniformity in commercial rosin oil requires that great care be taken in the preparation of the oil for insulating purposes. The dielectric value of paper, depends not only on the quality of the paper and the manner of applying it to the conductor, but to a great extent upon the composition of the insulating compound. Increasing the fluidity of the compound within certain limits will improve the puncture test and will increase the flexibility of the cable, but will reduce the megohm tests and *vice versa.* A dense, thick compound will result in a very stiff cable, but one having a higher insulation resistance. The insulation of such a cable is apt to crack or break if bent at a low temperature. In the preparation of paper-insulated cables automatic machines are employed to wind narrow strips of paper spirally around the conductors until there are enough layers to secure the requisite dielectric strength. If the cable is to consist of two or more conductors, the necessary number of conductors, each encased in its wrapping of paper, are laid up together and the whole encased in an outer wrapping, or belt, composed of additional layers of paper.

Before the outer wrapping of paper is applied, the cable is filled with jute laterals to make the whole cylindrical. For high-tension cables some manufacturers use a fine grade of twisted tissue paper in place of the jute laterals. The cable, after being insulated, is placed in the vacuum drying and impregnating tanks. Here every particle of moisture and air should be removed even from its inner interstices, and the hot impregnating oil is forced under pressure into every crevice filling the pores of the paper and making it one homogenous structure. The cable is then put through a hydraulic press and covered with a closely fitting lead sheathing so as to exclude all air and moisture and to retain the insulating compound. Paper cables are generally cheaper and have a lower electrostatic capacity than rubber or varnished-cambric cables. The insulation is strong and uniform in quality and, except when frozen solid, is quite flexible. Paper cables can be worked safely at higher temperature than can other kinds, but experience has demonstrated that their usual life is determined by the integrity of the lead sheath.

Paper is less liable than rubber to deterioration from excessive electrostatic strains; in fact, paper-insulated cables, when properly constructed and sheathed, can be recommended as the best for most conditions.

Varnished-cambric Insulation.—Varnished-cambric cables are made by winding strips of even-varnished cotton or muslin served separately about the conductor in a sufficient number of smooth, tightly drawn layers to make the required thickness of dielectric. It is customary to place a separator of treated paper, cloth or rubber over the copper core to prevent any possible action of the varnished-cambric film on the copper, and over the separator a taped strip of fabric which has been coated with special insulating varnish. The dielectric strength of this material is very high, as single thicknesses of cotton well-treated with varnish will withstand potentials of approximately 10,000 volts for 5 sec., depending upon the number of coats of varnish with which the cloth has been treated.

The varnish prevents the tape from unwrapping when the cable is cut and permits the adjoining layers of varnished cambric to slide upon each other. It also prevents capillary absorption of moisture between the layers of tape, seals any possible skips in films and precludes air spaces.

In multiple-conductor cables it is usual to place a portion of the required thickness of insulation in the form of a belt about the core of conductors as is the case in paper cables. This class of cables is in general more flexible than paper cable, more impervious to moisture and lower in cost than rubber cables, and can be used for station work without lead sheathing. It is especially suitable for the insulation of wire and cables for generators, motors and transformer leads, for high- and low-tension switchboard connections and wherever the following conditions are to be met in service: namely, moisture, oil drippings, or spasmodic increases of voltage of considerable amount but of short duration.

Where this type of cable is to be used in locations where it is likely to be submerged in water, it should, of course, be used with a lead cover, since it has been found that no material suitable for wire or cable insulation is permanently lasting in non-leaded form when subjected to alternating periods of heat and cold, wetness and dryness. The jointing of varnished-cambric cables is simpler than that of paper-insulated cables as the insulation of the former does not absorb moisture and, not being attacked by mineral oil, is particularly adapted for use in connecting to apparatus submerged in oil, such as switches and transformers. It can be operated at a temperature higher than rubber insulation but not quite as high as impregnated paper insulation. When the cable is to be used on insulators or through insulating bushings, and exposed only to such moisture as is held in suspension in the surrounding air, the lead cover is usually replaced by one or more coverings of a weatherproof, flameproof or asbestos braid.

Graded Insulation.—For exceptionally high-voltage work graded insulation has been employed and insulating material having different capacities has been used.

It is a well-known fact that the potential gradient of insulated wire is much higher in that portion of the insulation near the conductor than in the outer layers; and the fall of potential across a series of insulators of varying specific inductive capacity is inversely proportional to those capacities. Cables insulated with two or more materials so proportioned as to their relative thickness and specific inductive capacities as to take advantage of this law, have been on the market for some time and the advantages to be secured are that a smaller diameter of cable may be used with the same factor of safety or a cable may be operated at a higher voltage, the outside diameter and factor of safety remaining the same. Cables have also been constructed with rubber and paper, or rubber and cambric insulation, not with the view of obtaining the results to be secured by grading, but primarily for the purpose of reducing the cost. In some cases multiple-conductor cables have been insulated with a covering of paper or varnished cloth on the individual conductor and a reinforced rubber jacket, the outer rubber jacket being made up of several layers of rubber and cloth as a protection against moisture.

In ordinary underground work the use of graded cables is unnecessary and the cost of such cable apparently is unwarranted except in special cases. For more detail information on the subject of the grading of cables, the reader is referred to the *Transactions* of the American Institute of Electrical Engineers, vol. 29, part 2, page 1553, "Potential Stresses in Dielectrics," by Harold S. Osborne.

Lead Covering.—In order to protect the insulation of cables from injurious effects common to most underground systems, and provide a protection of the insulation from mechanical injury, they should be covered with a lead sheath. While rubber-insulated cables have been used in a limited way without a metallic covering, it is not considered good engineering practice to use such cables in installations of a permanent character, as the dependable life of the insulation does not exceed 10 years; whereas the same insulation, if protected by a lead sheath, would last indefinitely.

Lead, or a composition of lead and tin, is the most usual material for sheathing in this country.

While lightning, electrolysis, heat, long-continued vibrations and mechanical injuries have been considered about the only cause for breakdown or disintegration of the lead sheaths, there are cases on record where the lead has been destroyed by a species of lead-eating insect. These insects have been found in Australia and in the southeastern portion of the United States. An interesting paper on this subject was read before the International Congress of Electrical Engineers, at the Convention in St. Louis, in 1904, by Mr. John Hesketh.

Lead is the heaviest metal used to any large extent for commercial purposes, and the only metal used for the protection of hygroscopic insulating media. It is not used in a chemically pure state for commercial purposes; and the slight traces of arsenic, antimony, copper, tin, etc., which are sometimes found in the extra high-grade lead used for pipe and cable sheaths are rather a benefit than an objection, as they tend to slightly harden the metal. Lead is also hardened by hammering, but easily regains its original softness on being annealed.

When lead is alloyed with small percentages of tin, its melting point is lowered and its hardness and tensile strength increased. The melting point continues to decrease with increasing amounts of tin up to a critical value of 63 per cent. when the alloy then becomes a definite chemical compound. Further addition of the tin results in an increased (instead of a decreased) melting point.

Lead, as is well known, is very malleable, but lacking in ductility.

No very reliable data are obtainable as to the tensile and compressive strength of lead, the discrepancy in results arrived at by different experimenters being due, doubtless, to the influence of impurities and temperature variations.

The purest commercial lead obtainable is generally used for a sheathing. It is sometimes necessary to harden and strengthen the lead sheath by the addition of 1, 2 or more per cent. of tin, but it is a question as to whether much is gained by this addition. The two metals do not alloy uniformly and in sheaths where much tin is used, hard or brittle sections may develop, due to the segregation of one of the metals. The purpose of tin in the lead sheath is, not to prevent chemical action, but to stiffen the sheath so that it may better retain its cylindrical form when the enclosed core is soft, as is the case in some of the dry-core telephone cables. It appears to be a waste of money to put tin in lead sheaths of cables used for electric light and power purposes, as the introduction of tin adds at least 10 per cent. to the cost of the cable and the slight advantages gained therefrom do not warrant the extra expense. If tin is desired as a protection against chemical action, or the lead cover, the proper place for it is on, not in, the latter, for that places it where it will do the most good.

As to the thickness of lead, especially in connection with paper-insulated cables, some manufacturers advocate a slightly heavier thickness than for rubber cables as the life of the cable is entirely dependent on the permanency of the lead sheath.

The following Table XIII shows the thickness of lead for various outside diameters of the cable core as determined by the best engineering practice.

Table XIII.—Thickness of Lead Sheath

Diameter of core, mils	Corresponding thickness of sheath, in.	Diameter of core, mils	Corresponding thickness of sheath, in.
0–299	5/64	1,250–1,999	1/8
300–699	3/32	2,000–2,699	9/64
700–1,249	7/64	2,700–over	5/32

The sheath should have an average thickness of approximately that indicated in the foregoing table, and the minimum thickness should in no place be less than 90 per cent. of the required thickness.

Types of Cables.—Electric light and power cables may be divided into the following classes: namely, single conductor, duplex, concentric and multiple-conductor cables consisting of three, four or more conductors under the one sheath as shown in Fig. 55.

Single-conductor cables are most commonly used for low-tension electric-lighting, power and arc-light service, but they are also used under special circumstances for high-tension transmission. For railway feeders and direct-current power mains, single-conductor cables are almost always used, as the size of conductor required for this class of service is usually too large to permit the installation of a multi-conductor cable of equal conductivity in a single duct. In general, single-conductor cable is most frequently employed for service mains where a number of taps are required. Duplex cables are employed for feeders

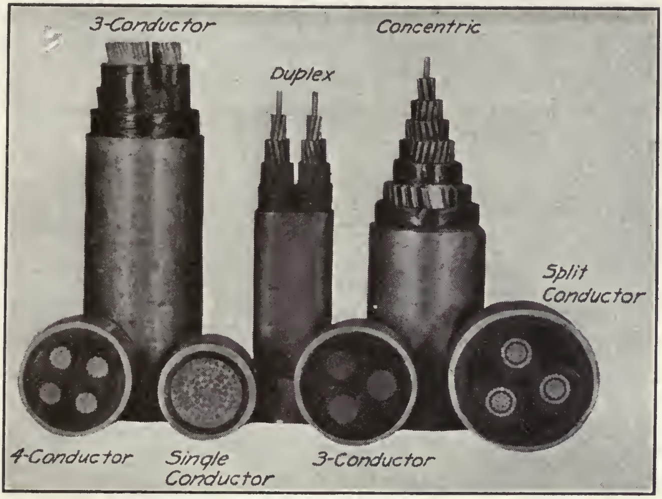


FIG. 55.—Types of underground cables.

which do not require frequent taps, such as alternating-current, single-phase circuits where both legs of the circuit cover the same routes. For arc-light circuits or portions thereof, or for low-pressure distribution mains, duplex cables are frequently used. Relatively less duct space is required and duplex cables are safer to handle than two single-wire cables and in addition are less expensive in first cost. Double- and triple-concentric cables have the same advantage as just stated for duplex cable, and they are preferable in large conductor sizes where the side-by-side arrangement of duplex cable would be difficult to bend. The concentric arrangement is frequently employed for large feeders and low-tension Edison direct-current service when a feeder of 750,000 cm. or larger would require two ducts, if single-conductor cable were used. Where numerous feeders are employed and the duct space is limited, this item is of much importance.

In some cases, particularly in the Edison direct-current feeder, pressure wires are used to indicate and regulate, at the station, the pressure or difference in potential existing at outlying points. A No. 14 or No. 16 insulated pressure wire can be incorporated at some suitable point in the cable, generally in the outer layer of the stranded conductor, or in the valleys or interstices of bunched cables as shown in Fig. 56.

In alternating-current two- and three-phase circuits, feeders of two, three and four conductors are preferable on account of their lower cost. For this class of service paper-insulated cables are employed as they are considerably cheaper than either varnished-cloth or rubber-insulated cables. In the case of multiple-conductor cables, the wires are twisted together with a suitable

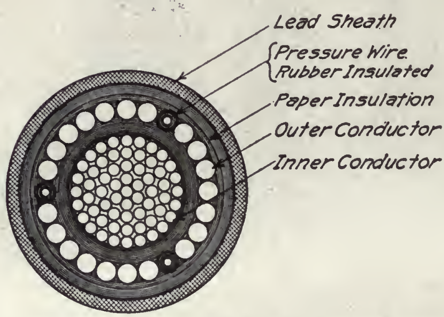


Fig. 56.—Concentric cable with pressure wires.

lay, the interstices are filled with jute or paper laterals to make the core substantially round, and a further covering (called "the belt") of the same insulating material is placed around the core, generally to the same thickness as the insulation around the individual wires. In the case of rubber cables the belt is sometimes made of paper instead of rubber, depending upon the pressure at which it is to be used, and especially if it is intended for comparatively low pressure. Even in paper cables for low-tension service, the belt is not always made of the same thickness as the insulation in the individual wires, but for high-tension service, the usual practice is to "split" the insulation (from which these cables are sometimes spoken of as cables with "split insulation") equally between the conductors and the belt.

When it is desired to connect multiple-conductor cables to overhead lines, single-conductor cables have been employed, but with multiple-conductor pole terminals, as described in another chapter, the use of multiple-conductor cables for the lateral pole connection is now rapidly becoming general practice.

In single-conductor cables, or an alternating-current system, carrying heavy loads, there is apt to be an inductive action and the magnetic field may become strong enough to induce an appreciable difference of potential between the lead sheaths of single-conductor cables of a circuit, resulting in the flow of sufficient current to cause damage to the sheaths where they come into contact with each other. For connections to subway transformers, junction boxes and manhole switches, single-conductor cables are used to tap on or connect to the multiple-conductor feeders, as they facilitate the making of such connections.

Diameter and Length of Cables.—As a rule cables having a diameter of over 3½ in. should not be specified on account of the difficulty of handling and drawing into the conduits. The greater the diameter, the greater the danger of the lead cover buckling or breaking when bent, and abrading in the operation of pulling in. For underground cables, the net diameter of the duct will control the maximum diameter of the cable, which latter should be approximately one-sixth less than the former, and in no case less than one-eighth smaller in diameter. A margin or difference of one-fourth the duct diameter represents the best condition for ease and safety of drawing in cables.

Cable may be made in almost any length, but it is desirable, on account of manufacturing operations, to confine the length to certain practical economic limits. Extraordinary lengths require the temporary adoption of extraordinary methods and devices in manufacture, shipment and installation, at an increased cost quite out of proportion to the safer and simpler expedient, practicable in most cases, of making a few more splices or building a few more manholes. Cables weighing 1 lb. or less per ft. can usually be supplied in lengths of 2,500 to 3,500 ft. on a single reel, and heavier cables in approximately inverse proportions; thus for cables weighing 6 lb. per ft., the reel should contain something under 600 ft. of cable.

Table XIV gives the maximum length in feet of cable that can be shipped on standard reels.

TABLE XIV.—CABLE REEL DATA[1]

Overall dia. of cable, in.	Reel No. 6, 24 by 12 in. max. length, ft.	Reel No. 5, 30 by 21 in. max. length, ft.	Reel No. 4, 48 by 24 in. max. length, ft.	Reel No. 3, 60 by 24 in. max. length, ft.	Reel No. 2, 60 by 41 in. max. length, ft.	Reel No. 1, 66 by 41 in. max. length, ft.
0.25	2,000	7,000				
0.30	1,500	4,800				
0.35	1,100	3,350				
0.40	900	2,500				
0.45	600	2,000				
0.50	500	1,750	5,000			
0.55	400	1,450	4,500			
0.60	300	1,200	4,200			
0.65	300	1,000	3,400	4,500		
0.70	225	850	2,900	4,000		
0.75	200	750	2,700	3,500		
0.80	.....	700	2,250	3,100		
0.90	.....	550	2,000	2,400		
1.00	.....	400	1,600	2,100	4,200	
1.10	.....	.....	1,200	1,750	3,500	3,900
1.20	.....	.....	950	1,400	2,800	3,300
1.30	.....	.....	750	1,200	2,400	2,800
1.40	.....	.....	700	975	1,950	2,300
1.50	.....	.....	650	800	1,600	2,100
1.60	.....	.....	.....	750	1,500	1,750
1.70	.....	.....	.....	700	1,400	1,650
1.80	.....	.....	.....	625	1,250	1,500
1.90	.....	.....	.....	550	1,100	1,225
2.00	.....	.....	.....	460	920	1,100
2.25	.....	.....	.....	325	650	850
2.50	.....	.....	.....	275	550	700
3.00	.....	.....	.....	210	420	525
	Approximate Maximum Weight of Cable per Reel, lb.					
	225	650	1,500	3,100	6,200	8,000
	Approximate Weight of Empty Reel, lb.					
	24	70	190	345	415	465
	Approximate Weight of Reel with Slats, lb.					
	36	100	240	495	650	760

[1] General Electric Co.

For example: 1,000 ft. of any cable ⅝ in. in diameter and weighing 650 lb. would require a No. 5 reel.

Fiber Core Cables.—Owing to the fact that alternating current flowing in large cables has greater density on the surface of the conductor than in the center (so-called skin effect), ordinary cable will not carry as much alternating current with the same temperature rise as direct current. In order to overcome this it is advisable on single-conductor cables, 700,000 cm. and larger for 60-cycle circuits and 1,250,000 cm. and larger for 25-cycle circuits, to make up the cable with a fiber core with the copper stranded around it. The weight of the copper in this type of cable is the same per foot as in an ordinary cable, but owing to its annular cross-section the cable is much more efficient in carrying alternating current and also has a somewhat greater current-carrying capacity due to the larger radiating surface. These copper strands can be insulated with any desired type of insulation.

Table XV gives the diameter of core recommended for various sizes, and the overall diameter as well as the ampere capacity at 30°C. and 60°C.

TABLE XV.—FIBER CORE CABLE DATA[1]

Size	Dia. fiber core, in.	No. of wires in strand	Size wire in strand, in.	Overall dia. copper core, in.	Ampere capacity	
					30°C.	60°C.
2,000,000	7/8	210	0.099	2.065	1,400	1,750
1,750,000	25/32	210	0.091	1.870	1,300	1,625
1,500,000	11/16	182	0.091	1.780	1,200	1,500
1,250,000	9/16	168	0.086	1.590	1,150	1,400
1,000,000	15/32	98	0.102	1.280	900	1,150
800,000	11/32	51	0.125	1.100	775	925
700,000	9/32	51	0.117	0.990	700	830

[1] General Electric Co.

Transmission Cables.—In no branch of the underground-cable problem have the conditions been more difficult than in that of transmission with high-tension current, for the reason that the far greater pressure considerably increases the tendency to disrupt the insulation, allowing the current to escape from its conductor. Great difficulties were encountered, and failures were experienced, principally due to inexperience or utter disregard of proper care on the part of those in charge of the laying, jointing, or operating of the cables, but each failure led to a better understanding of the conditions to be provided for and the invention and adoption of the means of overcoming them, so that now it is entirely practicable to manufacture and install cables for transmission to operate at 25,000 and 30,000 volts. Several hundred miles of such cables are now in successful daily operation.

Transmission lines, which are usually three-phase, are almost universally of three-conductor cable with a thickness of insulation on each conductor sufficient for voltages between phases. One of the first installations of three-phase, high-tension cables was made in St. Paul, Minn., in 1900. The highest potential used underground prior to that time was 11,000 volts. Since this time cables of 25,000 and 30,000 volts have been installed in a number of places. In certain sections of Europe extensive underground cable systems operating at 30,000 volts have been very successful and results obtained by certain cable manufacturers through the use of improved insulating material and processes of manufacture definitely indicate that satisfactory cable may now be obtained to operate at 30,000 volts. As it is both inconvenient and expensive to change the maximum voltage of a cable system once established, recognition of the present situation should be given and cables purchased for future extension which may be operated at the highest convenient voltage.

General Cable Data.—The following Table XVI gives the working and test voltages for any size cable with a given thickness of insulation, or the proper thickness of insulation may be determined for various voltages.

The working voltages in the foregoing tabulation are based on all conductors of the circuit being insulated. For three-phase "Y"-connected circuits with grounded neutral with three-conductor cables, thickness of insulation between conductors and ground need only be seven-tenths of that between conductors. The required thickness of insulation can be placed about each separate conductor before it is laid up into the core, or, as is more general, especially with paper and varnished cloth, a portion of the required amount of insulation can be placed in the form of a belt about the assembled conductors. This latter method makes a more even distribution of the insulating material and is the one most commonly used.

The approximate outside diameters of three-conductor cables with various thickness of insulation and with 1/8-in. lead sheath throughout is given in Table XVII.

The largest size outside-diameter cable which can safely and conveniently be installed in a standard 3-in. duct is approximately 2.7 in. It will, therefore, be noted from the foregoing

TABLE XVI.—WIRES AND CABLES

Working and Test Voltages[1]

Kilovolts, work. press.	Sizes	Thick., insulation	Test in kilovolts					
			At factory			After installation		
			5 min.	30 min.	60 min.	5 min.	30 min.	60 min.
0.6	14–2	1/16	2.0	1.6	1.3	1.6	1.3	1.0
0.6	1–4/0	5/64	2.0	1.6	1.3	1.6	1.3	1.0
0.6	225,000–500,000	3/32	2.0	1.6	1.3	1.6	1.3	1.0
0.6	550,000–1,000,000	7/64	2.0	1.6	1.3	1.6	1.3	1.0
1.0	12–2	5/64	2.5	2.0	1.6	2.0	1.6	1.3
1.0	1–4/0	3/32	2.5	2.0	1.6	2.0	1.6	1.3
1.0	225,000–500,000	7/64	2.5	2.0	1.6	2.0	1.6	1.3
1.0	550,000–2,000,000	1/8	2.5	2.0	1.6	2.0	1.6	1.3
2.0	10–4/0	7/64	5.0	4.0	3.2	4.0	3.2	2.5
2.0	225,000–500,000	1/8	5.0	4.0	3.2	4.0	3.2	2.5
2.0	550,000–2,000,000	9/64	5.0	4.0	3.2	4.0	3.2	2.5
3.0	8 and larger	5/32	7.5	6.0	4.8	6.0	4.8	3.8
4.0	8 and larger	3/16	10.0	8.0	6.4	8.0	6.4	5.1
5.0	6 and larger	7/32	12.5	10.0	8.0	10.0	8.0	6.4
6.0	6 and larger	1/4	15.0	12.0	9.6	12.0	9.6	7.7
7.0	5 and larger	9/32	17.5	14.0	11.2	14.0	11.2	9.0
9.0	5 and larger	5/16	22.5	18.0	14.4	18.0	14.4	11.5
11.0	4 and larger	11/32	27.5	22.0	17.6	22.0	17.6	14.1
13.0	4 and larger	3/8	32.5	26.0	20.8	26.0	20.8	16.6
15.0	3 and larger	13/32	37.5	30.0	24.0	30.0	24.0	19.2
17.0	3 and larger	7/16	42.5	34.0	27.2	34.0	27.2	21.7
19.0	2 and larger	15/32	47.5	38.0	30.4	38.0	30.4	24.3
21.0	2 and larger	1/2	52.5	42.0	33.6	42.0	33.6	26.8
23.0	1 and larger	17/32	57.0	46.0	36.8	46.0	36.8	29.4
25.0	1/0 and larger	9/16	62.5	50.0	40.0	50.0	40.0	31.9

Kilovolts = 1,000 volts.

Above working voltages are based on all conductors of the circuit being insulated. For d.c. 600-volt railway single conductor use, 2000-volt class. For three-phase "Y" connected circuits with grounded neutral with three-conductor cables, thickness of insulation between conductors and ground need only be seven-tenths of that between conductors. Tests on such cable in proportion to thickness of insulation: Example, three-phase 13,000-volt circuit "Y," neutral grounded, insulation on each conductor 3/16 in. (total between conductors 3/8 in.), outer belt 3/32 in. (total 9/32 in.); test pressure at factory for 5 min., between conductors 32,500 volts, each conductor to earth 17,500 volts.

[1] General Electric Co., *Bulletin* No. 4787.

table that the largest conductor size for 5/32 by 5/32 cable with 1/8-in. lead (7,000 volts working pressure) is 350,000 cm.; whereas, for 10/32 by 10/32 and 1/8-in. lead (25,000 volts working pressure) the largest conductor size to be installed in a 3-in. duct is No. 4 wire.

TABLE XVII.—APPROXIMATE OUTSIDE DIAMETERS OF THREE-CONDUCTOR COPPER CABLES

(1/8 Lead Throughout)

Insulation Thickness on Each Conductor, and Over Bunch Respectively Equal to

Size	5/32 + 5/32	6/32 + 6/32	7/32 + 7/32	8/32 + 8/32	10/32 + 10/32
	Diam.	Diam.	Diam.	Diam.	Diam.
4	1,735	1,930	2,129	2,324	2,717
3	1,795	1,990	2,189	2,384	2,777
2	1,864	2,059	2,258	2,453	2,845
1	1,950	2,145	2,344	2,539	2,933
0	2,038	2,233	2,432	2,627	3,020
00	2,137	2,332	2,531	2,726	
000	2,246	2,442	2,640	2,839	
0000	2,371	2,567	2,765	2,960	
Cm.					
250,000	2,472	2,668	2,866		
300,000	2,588	2,785	2,983		
350,000	2,700	2,895			
400,000	2,803	3,000			
450,000	2,898				
500,000	2,988				

Tables XVIII and XIX give the thickness of insulation as specified by the cable manufacturers for rubber, paper and varnished-cambric insulation.

TABLE XVIII.—THICKNESS OF CAMBRIC INSULATION[1]

Normal working voltage	Insulation about each conductor, in.	Insulation about three conductors, in.
7,000	4/32	4/32
10,000	5/32	5/32
13,000	6/32	6/32
17,000	7/32	7/32
20,000	8/32	8/32
23,000	17/64	17/64
25,000	19/64	19/64

[1] General Electric Co. *Bulletin* No. 4591.

In the table furnished by the Safety Insulated Wire & Cable Co. no jacket is provided with the rubber-insulated cables intended for use at the lower voltages. This is due to the fact that a thin rubber jacket will be reduced in thickness by the pressure from the insulated conductors, as it appears to be impossible to maintain a uniform pressure of the jute and the conductors against the jacket.

TABLE XIX.—THICKNESS OF RUBBER AND PAPER INSULATION.[1]

Normal working voltage	Rubber insulation		Paper insulation	
	About each conductor, in.	About three conductors, in.	About each conductor, in.	About three conductors, in.
5,000	5/32	None	4/32	4/32
7,000	7/32	None	5/32	5/32
10,000	5/32	5/32	6/32	5/32
13,000	7/32	5/32	7/32	6/32
17,000	8/32	5/32	7/32	7/32
20,000	9/32	6/32	8/32	8/32
25,000	10/32	7/32	10/32	10/32
30,000	12/32	10/32	12/32	12/32

[1] S. I. W. & C. Co.

TABLE XX.—DATA ON PAPER CABLE OPERATION

Company	Line voltage	Insulation	Thickness of insulation in thousandths of an inch				Neutral grounded
			Between conductors	Between conductors and ground	Per 1,000 volts		
					Between conductors	Between conductors and ground	
New York Edison	6,600	Paper	312	312	47	47	No
Brooklyn Edison	6,600	Paper	342	342	52	52	No
Phila. Elec. Co.	6,600	Paper	312	312	47	47	No
N. Y. Metropolitan	6,600	Paper	436	343	66	52	No
St. Louis	6,600	Paper	312	312	47	47	No
Boston	6,900	Paper	436	436	63	63	No
Chicago	9,000	Paper	375	312	42	60	Yes
Hartford	9,500	Paper	374	374	39	39	No
New York Subway	11,000	Paper	436	468	40	43	No
New York Manhattan	11,000	Paper	436	436	40	40	No
Long Is. R. R.	11,000	Paper	436	436	40	69	Yes
New York Central	11,000	Paper	436	375	40	59	Yes
Niagara	11,000	Paper	406	406	37	37	No
Buffalo	11,500	Paper	500	406	43	35	No
Minneapolis	13,000	Paper	375	375	29	50	Yes
Philadelphia	13,200	Paper	375	375	28	28	No
P. S.-N. J.	13,200	Paper	436	436	33	33	No
Milwaukee	15,000	Paper	500	437	33	29	No
Chicago	20,000	Paper	562	375	28	32	Yes
Detroit Edison	23,000	Paper	562	375	24	28	Yes
St. Paul	25,000	Paper	562	484	22	19	No
Montreal	25,000	Paper	562	406	22	16	No
P. S.-N. J.	26,400	Paper	562	531	21	20	No

It is rather difficult to determine mathematically the proper thickness of insulation to use for a given potential and it is, therefore, better to rely on tables furnished by cable manufacturers. Certain difficulties in the manufacture, such as unevenness of the application of insulation on the conductors, eccentric placing of the insulation and mechanical considerations of strength, make such tables of insulation required for different voltages and sizes of conductors more valuable and reliable than formulæ.

As illustrating the difference of opinion among engineers as to the proper factors of safety to use in the design of high-voltage cables, the following tabulation (Table XX) shows the

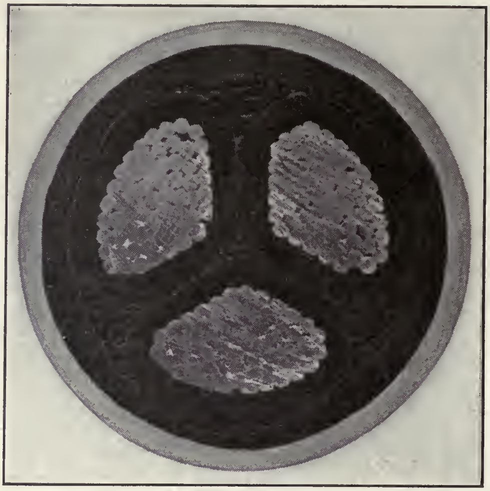


Fig. 57.—Sector-type three-conductor transmission cable.

practice of a number of important operating companies using three-conductor high-tension cables.

Sector Cables.—With the growth of electric service and the increase in size of conductors for transmission systems the maximum size of three-conductor cable which can be safely installed in a duct nominally 3 in. in diameter has been reached. To meet this condition and make it possible to install cables having larger conductors or thicker insulation, cables have recently been constructed in a clover leaf or sector form, as illustrated in Fig. 57.

Cables of this form of construction have been in use in Europe for a number of years, but American manufacturers have taken up the making of sector cables only within the last 5 years. This form of conductor permits of a more economical utilization of duct space and the cable is slightly less expensive than round-conductor in sizes of No. 000 B. & S. gage or greater. Several large central-station companies have adopted this form of cable for transmission purposes where it has been impossible to secure space for large-sized round-conductor cables.

Clover-leaf or sector cable in sizes under No. 00 B. & S. gage is not manufactured to any extent, due to the fact that difficulty is experienced in maintaining the shape of the conductor when forming the cable.

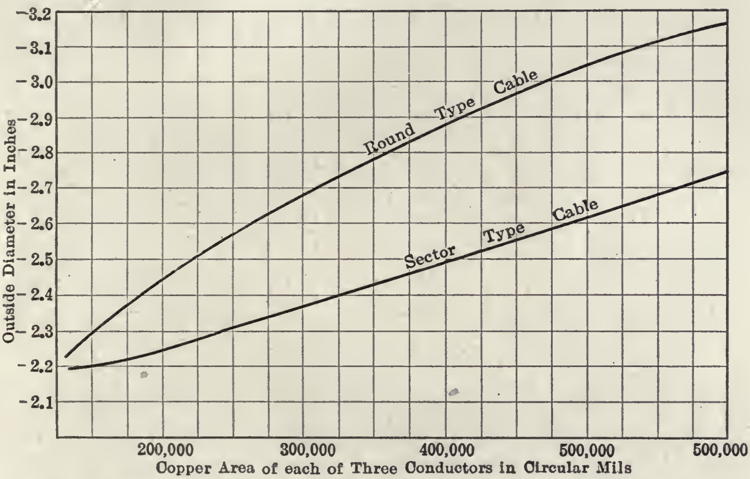


FIG. 58.—Relative outside dimensions of round and sector cable having 11/64-inch insulation on each conductor, 5/32-inch belt and-1/8 inch lead.

In determining the rating for the various sizes of sector cable, it should be noted that, due to its shape, a larger portion of the periphery of each conductor is nearer the lead sheath than in an equivalent round-conductor cable. This allows a greater radiation with a consequent higher current rating of the cable. No fixed standard governing the carrying capacity of cables can be given as this depends largely on the conditions governing heat radiation. The position of cables in duct lines, the nature of the soils through which the duct lines run, and their exposure to the elements, are all factors to be considered in determining the rating of a cable. Data obtained from operating companies on sector cable is given in Table XXI, the information being

TABLE XXI.—DATA ON SECTOR CABLE USED BY FIVE LARGE ELECTRIC-SERVICE COMPANIES*

Name of company	Amount, ft.	Service, voltage	Thickness in 1/32 in. of insulation around: Each conductor	Thickness in 1/32 in. of insulation around: Insulated Conductors	Conductor cross-section, circ. mils	Carrying capacity, permitted
New York Edison Co.[1]	459,360	8,000 Same to cable shell	5½	5	350,000	3,500 kva., with 50 per cent. overload for 1 hr. at 6,600 volts
	163,680	15,000 Same to cable shell	7	7	350,000	6,000 kva., with same per centage of overload rating
United Electric Light & Power Co.	19,324.50	7,500	5½[2]	5	350,000	
	14,127.10	7,500	6½[3]	5½	350,000	
	3,861.20	7,500	7[4]	7	350,000	
	141,472.51	15,000	7[5]	7	350,000	
	910.00	15,000	8[6]	8	350,000	
	72,284.10	23,000	8½[7]	4	350,000	
	2,730.00	23,000	8[8]	8	350,000	
	258,081.41[9]					
Public Service Electric Co. of New Jersey	200,000	13,500	6	6	350,000	7,500 kva.
Brooklyn Rapid Transit Co.[10]	209,668	6,600[11]	6	6	350,000 2.78 to 2.89 in. outside diameter	
Detroit Edison Co.	64,416	4,600-volt trunk line	5	5	450,000	3,000 kva.[12]
	11,616	4,800-volt distribution to overhead lines	5	5	450,000	3,000 kva.[12]

[1] Specifications call for 31 strands per conductor. Thickness of sheath is ⅛ in. Alternating-current test voltage for 5 min. between conductor and ground, 25,000 volts, and between conductors, 25,000 volts.

[2] 7,500 volts between conductors and sheath.

[3] In generating stations and substations to afford additional reliability.

[4] In generating stations to permit changing to 15,000-volt service.

[5] 15,000-volt service, same pressure to sheath.

[6] 15,000-volt submarine section to permit changing to 23,000 volts.

[7] 23,000-volts half voltage to sheath.

[8] 23,000-volt service, submarine section.

[9] Includes 3,372 ft. of odd sizes representing older practice.

[10] Specifications call for 49 strands per conductor, the diameters of the individual strands being largest at the cores of the conductors and graded off toward the outside to permit flexibility and maintenance of the sector shape. Tin is not specified in the lead sheath. Break-down test between each of two conductors and the other two connected to lead sheath of 30,000 volts for ½ hr. (at factory) and 23,000 volts for 10 min. (after installation). Limits of insulation resistance in megohm miles, 100–400 corrected to 15.5°C.

[11] Cables are designed for 11,500 volts to permit changing to that pressure in the future.

[12] This low rating has been given because the 450,000-circ. mil cables are mixed in with heavily loaded 200,000-circ. mil cables, so it is necessary to restrict the loading on the larger ones to about 350 amp. to prevent high temperatures in ducts.

* *Electrical World*, Feb. 19, 1916.

based on safe operating practice as predetermined for specific conditions.

It will be noted in the foregoing Table XXI that the maximum voltage under which sector cable has been operated is 23,000 volts and considerable discussion has arisen as to the advisability of operating this type of cable at high voltages, due to the excessive dielectric stresses produced at the corners of the individual conductors.

Fig. 58 shows the relative outside dimensions of cables of the round and sector types, the copper area and thickness of insulation being the same for each type.

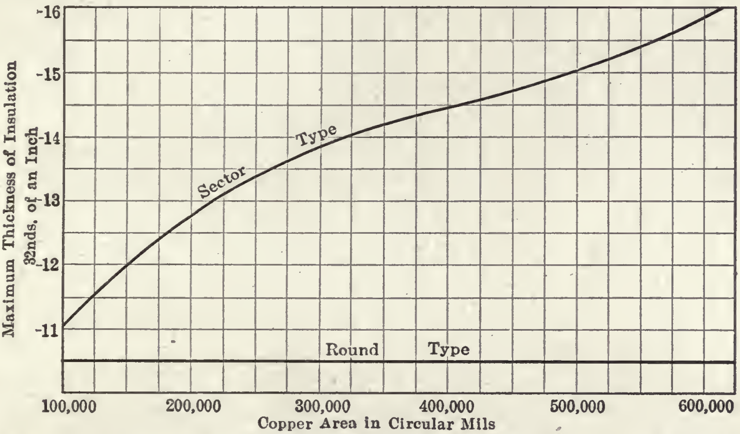


Fig. 59.—Increase in thickness of insulation possible by using sector instead of round conductors, the outside diameter and copper area being the same for each type. Insulation around conductors the same as outer belt.

Fig. 59 shows the increased wall of insulation which can be put on a cable of the sector type, the copper area and outside diameter being the same for each type.

Submarine Cables.—For crossing rivers, small lakes, bays or ponds, the beds of which are mud or sand and free from pebbles, stones or sharply defined channels, ordinary lead-covered cables have been used, but the addition of one or two well-saturated stout braids has been found advantageous. If fiber or paper insulation is used, it should be thoroughly saturated and filled so as to limit the damage in case of injury to the lead cover, even though the cables be also armored with steel tape or wires.

As a rule, however, and especially where long lines of cables are to be laid under water, it is best to use rubber-insulated conductors so that in case the protective covering should be broken or cut, the insulation will still exclude moisture for a considerable period of time, if not permanently.

Where the submarine cable is at all likely to be subjected to considerable tensile strains, the lead sheath should be protected with a heavy serving of tarred jute, and armored with galvanized-steel wires of a size varying with the size of the cable and the conditions under which the cable is to be laid and operated. Heavily galvanized and pliable medium-strength steel is used for armor wire and the size and thickness of armor for various diameters of cable is given in the Standard Armor Table XXII.

When the bottom on which the cables lie is soft and there is no danger from boats or dragging anchors, paper cables with extra heavy lead, with or without additional fibrous covering over the lead, have been used very successfully.

It is impossible to give instructions covering the installation of submarine cables under all conditions but in general the following method will be found practicable:

After procuring a tug or boat of suitable size to carry the cable reel and crew, the reel is mounted on heavy trusses at the bow of the boat, using a heavy shaft to support the weight and allow the reel to revolve readily.

The cable should pass from the bottom of the reel over rollers or pulleys back to the stern of the boat and should be securely fastened on the shore at its proper location.

The reel should be provided with a brake so that it will not overrun as the boat moves, and men should be stationed at the reel and cable roller to guard against any damage to the cable.

The boat should move slowly to the point where the cable is to land, and should anchor, or beach, bow on. The remainder of the cable is then unreeled and dropped alongside, and the shore end carried to the point at which it is to meet the underground or aerial line.

The shore end should be laid in a trench extending far enough into the water to protect the cable against ice and boats which may ground at such points. In navigable waters a sign, "Cable Crossing," should be prominently displayed at the cable landings to prevent damage from boats inadvertently anchoring along or near the line of the cable.

In the laying of a submarine cable the boat should not be

TABLE XXII.—STANDARD ARMOR TABLE*

O.D. cable, mils[1]	Band iron		Wire armor	
	Thickness	Weight, lb.	Sizes	Weight, lb.
300	....	....	0.095	655
400	....	....	0.095	783
500	0.030	748	0.134	171
600	0.030	843	0.134	1,298
700	0.030	927	0.134	1,426
800	0.030	1,020	0.148	1,741
900	0.030	1,107	0.148	1,891
1,000	0.030	1,198	0.148	2,045
1,200	0.030	1,374	0.148	2,348
1,400	0.030	1,555	0.180	3,202
1,600	0.050	2,454	0.180	3,562
1,800	0.050	2,703	0.180	3,913
2,000	0.050	2,953	0.180	4,265
2,200	0.050	3,202	0.203	5,107
2,400	0.050	3,450	0.203	5,600
2,600	0.050	3,700	0.203	6,100

* General Electric Co.
[1] Overall diameter of cable in mils before armor is applied.
NOTE: For jute and 0.030 band steel add 0.60 to diameter.
For jute and 0.050 band steel add 0.70 to diameter.
For jute and 0.095 wire armor add 0.60 to diameter.
For jute and 0.134 wire armor add 0.68 to diameter.
For jute and 0.148 wire armor add 0.70 to diameter.
For jute and 0.180 wire armor add 0.80 to diameter.
For jute and 0.203 wire armor add 0.85 to diameter.

ARMOR TABLE

O.D. cable, mils	10 B.W.G. weight	8 B.W.G. weight	6 B.W.G. weight	4 B.W.G. weight
300	915	1,200	....	....
400	1,050	1,390	....	....
500	1,185	1,590	2,100	....
600	1,290	1,790	2,400	2,880
700	1,430	1,980	2,600	3,250
800	1,550	2,180	2,800	3,500
900	1,690	2,380	3,000	3,750
1,000	1,940	2,580	3,300	4,000
1,200	2,200	2,780	3,620	4,500
1,400	2,450	3,180	4,120	5,000
1,600	2,710	3,570	4,500	5,500
1,800	3,040	3,970	5,000	6,000
2,000	3,300	....	5,500	6,550
2,200	3,550	....	5,880	7,060
2,400	3,880	....	6,370	7,560
2,600	4,200	....	6,750	8,060

allowed to drift with the stream current, as a loop is apt to be formed in the cable if a straight course is not maintained. If the cable is allowed to slack off the reel resulting in the forming of a loop, there is a possibility of creating a kink in the cable when the strain is again put upon it.

Fig. 60 illustrates the result of a condition such as just described. This piece of cable was cut from a length of three-conductor, 13,200-volt, No. 2/0, paper-insulated, lead-covered and armored cable, and in spite of this extraordinary physical abuse the cable continued to operate and was still in service when the kink was discovered.

In a recent installation of two submarine cables across the Golden Gate at San Francisco, a messenger wire was first laid from shore to shore and anchored securely at both ends. This cable is approximately 13,000 ft. long and as it could not

FIG. 60.—Twisted submarine cable.

be made in one continuous length it was necessary to make a number of splices. The messenger, which was a 37-wire galvanized-steel strand 1⅜ in. in diameter, was used to take the strain, thus relieving the cable and joints from all tension. In laying the cable a barge of 125 tons capacity was used, the cable reels being mounted with their axes parallel to the long axis of the barge; in this way the barge was least affected by the prevailing action of the tide and waves in the channel. The tow for the cable-laying equipment was a 50-hp. launch; during very heavy tide runs two launches were necessary for towing the equipment. When ready to lay the cable, the messenger was picked up at the shore and laid across the barge. Two No. 6 galvanized wires were wound around the messenger and cable. These wires were applied by a serving machine driven by a gasoline motor. Every 20 ft. the movement of the barge was stopped by means of a grip and a considerable number of turns wound around the cable and the messenger at one point. The speed, when laying the cable, was about 8 ft. per min. and when the cable laying was once started the barge remained attached to the messenger until the load had been paid out.

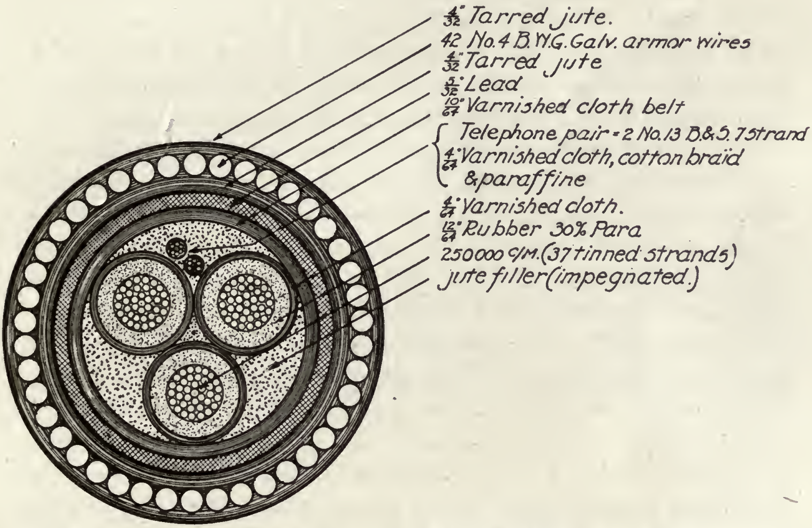


Fig. 61.—Section of submarine power cable, 11,000 volts working pressure.

The submarine cables (Fig. 61) are three-conductor, 250,000-cm. copper, each conductor having an insulation of $\frac{6}{32}$ in., 30 per cent. Para rubber over which was placed a $\frac{4}{64}$-in. layer of

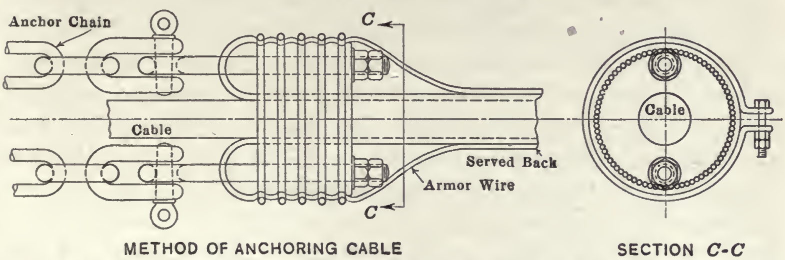


Fig. 61*a*.—Details of power cable-anchor, showing method of taking the strain on the armor wires.

varnished cambric. The three conductors are laid together in circular form (a jute-filler being used), a $\frac{10}{64}$-in. varnished cambric belt being applied over all. The enclosing sheath is $\frac{5}{32}$ in. pure lead. Over the lead two layers of jute are applied, to a total thickness of $\frac{4}{32}$ in. The jute forms a cushion for the steel-wire armor, consisting of 42 wires of No. 4 B.W.G. extra heavy galvanized iron and this armor is in turn covered with a layer of jute $\frac{4}{32}$ in. thick, to which was applied a sand and asphaltum finish for mechanical protection.

Each cable contains a twisted pair of telephone wires of No. 13 B. & S. copper. Fig. 61*a* shows the detail of the power-cable anchor and method of taking the strain on the armor wires.

Specifications.—In submitting specifications to cable manufacturers, it is well to state the conditions under which the cable will be used as this will assist the manufacturer in determining the particular cable which will best suit the operating conditions. When the specific requirements covering details of construction, tests and guarantees of cable are furnished, a more perfect understanding is established and the manufacturer can better serve the customer's needs. Specifications are of all classes, good, bad and indifferent, and taken collectively, indicate a wide difference in ideas. On the cable depends the success of the electrical system of transmission and distribution as a poorly constructed or improperly insulated wire or cable will surely imperil the service. The insulation should be of the proper kind and quality for the purpose intended. To insure the service the cable must be properly tested, properly installed and properly protected.

Cable should be tested at the manufacturer's plant before shipment, at a potential somewhat higher than the maximum working voltage and it is essential that a similar test be made after installation. There still seems to be a difference of opinion as to the proper pressure and duration of such tests and there is a great tendency on the part of engineers to make this test too severe. In general it may be said that tests of two and one-half times working pressure for 30 min. at the factory and twice the working pressure after installation for 15 min. are considered conservative. Cables tested under these conditions have given no indication in practice that the margin of safety was not ample. High-potential tests are not intended to show the ultimate strength of the cable, but to show that the cable is safe and satisfactory for the purpose for which it is intended.

In many cases engineers have specified high-puncture tests on cables and it was considered that if the insulation passed these exacting tests it was in first-class condition. High-potential tests frequently strain the insulation to such an extent that the cable fails after the first physical or potential strain is imposed upon it. A high-potential test is not always conclusive proof of insulating merit, but on the other hand it should not be assumed that puncture tests are of no value. The object of puncture tests is to disclose imperfections in the insulating wall of the cable and in this respect they are of great importance. A cable may be well made of poor material or it may be imperfectly made of the very best material. In the one case there is good workmanship with poor material, and in the other, bad workmanship with good material.

Cable specifications in general should provide for the fixing of the copper conditions, the insulating material, the sheath or braid and the mechanical, electrical and chemical tests. They should include clauses providing for the methods of tests and apparatus to be used and, finally, instructions as to the method of packing and shipping. It should not be the intent of the specification to tell the manufacturer how he shall make the cable. The main purpose should be to state the operating conditions which the cable must satisfy in order that the manufacturer may endeavor to meet these conditions.

Details of installation and service may radically affect the design of any cable and it is, therefore, necessary that full information be given the manufacturer in order to secure intelligent consideration and to insure correct design.

Rubber-insulated Cable Specifications.—The numerous specifications for 30 per cent. rubber compound do not materially differ as to chemical tests, nor in their requirements for mechanical properties as determined by stretch, return, and ultimate break. Many requirements for chemical and mechanical properties now found in specifications for 30 per cent. compounds appeared originally in specifications for wires and cables intended for low-tension service. The same requirements were later incorporated in specifications for high-tension service and accepted as satisfactory, but experience has developed the fact that a change should have been made to secure the best results for this work. The ingredients of a compound govern its characteristics, and a change in the proportion of a given ingredient may improve one characteristic to the detriment of another. Many engineers leave the thickness of the insulation to be determined by the manufacturer from specified tests. This practice has the disadvantage of permitting the various competing manufacturers to submit their bids based on different thicknesses of insulation and safety factors.

There are many different grades of rubber, all varying in price as in quality, and it is only by a knowledge and recognition of this wide diversity of character that an engineer can intelligently make up specifications and rigidly enforce them. The better grades of rubber insulation contain from 20 to 40 per cent. Para rubber.

The specific gravity of rubber compounds varies from 1.10 to 2.0 depending on the ingredients used. The higher the per cent. of rubber, the lower the specific gravity. The tensile strength of high-grade rubber compound is about 1,200 lb. per sq. in.

Rubber insulation, owing to its composition, attacks copper and it is, therefore, necessary that the conductor be properly tinned before the insulation is applied. In testing rubber-covered cables it is customary to apply the potential test at the factory while the cables are immersed in testing tanks in which the water is maintained at a constant temperature. These tests are made when the conductor is covered with the vulcanized compound and before the application of any covering other than a non-waterproof tape. The analysis of rubber compounds presents extraordinary difficulties and in the present state of the art no one procedure is applicable to all compounds. Serious difficulties have arisen in the past, due to the want of standard methods. For several years no attempt was made to standardize specifications, and much trouble was given the manufacturers by the diversity of requirements contained in the various specifications. In 1911, Mr. E. B. Katte, chief engineer of electric traction of the New York Central and Hudson River Railroad Co., invited a number of manufacturers and consumers to a conference in order to discuss the possibility of standardizing specifications and analytical methods for rubber insulation. As a result of this conference which was held in New York on Dec. 7, 1911, a committee was appointed to devise a specification and analytical procedure for rubber insulation. The committee, which has become known as the Joint Rubber Insulation Committee, was composed of men representing the various interests, and a report was submitted on the procedure for chemical analysis and the interpretation of the results obtained. A specification and chemical limits for a 30 per cent. compound was also included.

The procedure applies only to a limited class of compounds and is not ordinarily applicable to compounds containing less than 30 per cent. of rubber. The committee report is printed in full in the *Proceedings* of the American Institute of Electrical Engineers, vol. 33, 1914.

The following specification for 30 per cent. rubber insulating compound is submitted for lead-sheathed cables for operating at pressure in excess of 2,000 volts. The general clauses covering conductors, sheaths, patents, quantities, shipments, reels, terms of payment, permits, measurements, etc., as given under the heading of paper-insulated cable specification, will also apply for rubber cable specifications.

Specification for Rubber-insulated Cables

1. Conductors shall be properly tinned.

2. The insulating compound shall be made exclusively from pure, dry, raw, wild South American Para rubber, of best quality of the grade known as "fine," solid waxy hydrocarbons, suitable mineral matter and sulphur.

3. It shall be properly and thoroughly vulcanized.

4. The vulcanized compound shall show on analysis, freedom from all foreign organic or injurious mineral matter; not less than 30 nor more than 33 per cent. of above-specified rubber; not more than 4 per cent. of solid waxy hydrocarbons; not more than 1.5 per cent. of rubber resins; not more than 0.7 per cent. of free sulphur and not more than 2.65 per cent. of total sulphur in any form.

5. The manufacturer shall submit to the company a method of procedure for chemical analysis of his compound for the guidance of the company's chemist in order that intelligent comparisons may be made in the event of dispute between the manufacturer and company.

6. The compound must be homogeneous in character, tough, elastic, adhere strongly to, and be placed concentrically about the wire, and in section as stripped from the wire must have a specific gravity of not less than 1.75 as compared with distilled water at 60°F.

7. A sample of the vulcanized compound not less than 4 in. in length and of uniform cross-section shall be cut from the wire and marks placed on it 2 in. apart. The sample shall be stretched longitudinally at the rate of 12 in. per min. until the marks are 6 in. apart and then immediately released. One minute after such release the marks shall not be over 2½ in. apart. The sample shall then be stretched until the marks are 10 in. apart before breaking.

8. The compound shall have a tensile strength of not less than 1,000 lb. per sq. in., based on the original cross-section of the test piece before stretch.

9. The above mechanical tests shall be made at a temperature of not less than 50°F.

10. Each and every length of conductor shall comply with the mechanical

and electrical requirements indicated in the following tables "A" and "B." The tests at the works of the manufacturer shall be made when the conductor is covered with the vulcanized compound and before the application of any covering other than a non-waterproof tape.

11. Electrical tests at the factory on single-conductor cables shall be made after at least 12 hr. submersion in water and while still immersed. The insulation test shall follow the voltage test and shall be made with a battery of not less than 100 volts or more than 500 volts and the reading shall be taken after 1 min. electrification.

Table "A"

Voltage tests on single-conductor cables insulated with high-tension rubber compound. Duration of test at factory 5 *min.; after installation,* 30 *min. Tests at factory as per table; after installation at table values for* 5 *min., then at* 80 *per cent. for* 25 *min.*

Size conductor	Minimum thickness of insulation in inches							
	3/32	7/64	4/32	5/32	6/32	7/32	8/32	14/32
Stranded								
1,000 M.C.M.	....	6,000	8,000	12,000	16,000	19,000	22,000	30,000
750 M.C.M.	....	6,000	8,000	12,000	16,000	19,000	22,000	30,000
500 M.C.M.	5,000	7,000	9,000	13,000	16,000	19,000	22,000	30,000
350 M.C.M.	5,000	7,000	9,000	13,000	16,000	19,000	22,000	30,000
4/0 A.W.G.	6,000	8,000	10,000	13,000	16,000	19,000	22,000	30,000
2/0 A.W.G.	6,000	8,000	10,000	13,000	16,000	19,000	22,000	30,000
1/0 A.W.G.	6,000	8,000	10,000	13,000	16,000	19,000	22,000	30,000
2 A.W.G.	7,000	9,000	11,000	14,000	16,000	18,000	20,000	30,000
Solid								
4 A.W.G.	7,000	9,000	11,000	14,000	16,000	18,000	20,000	30,000
6 A.W.G.	7,000	9,000	11,000	14,000	16,000	18,000	20,000	30,000
8 A.W.G.	7,500	9,000	10,000	11,000	12,000	....	....	....
10 A.W.G.	7,500	9,000	10,000	11,000	12,000	....	....	....
12 A.W.G.	7,500	9,000	10,000	11,000	12,000	....	....	....
14 A.W.G.	7,500	9,000	10,000	11,000	12,000	....	....	....

13. Samples of the cables 6 ft. in length taken from any reel of cable must show an ultimate dielectric strength capable of resisting the application of twice the voltage specified above for a period of 5 min. without failure.

14. Insulation resistance and electrostatic capacity tests made (before and after voltage tests as per Table "A") and under equivalent temperature conditions must not indicate fatigue or overstrain of dielectric.

15.

TABLE "B"

Insulation tests on single-conductor cables insulated with high-tension rubber compound. Tests at factory as per table; after installation 80 *per cent. of table value.*

MINIMUM MEGOHMS PER MILE AT 60°F.

Size conductor	Minimum thickness of insulation in inches								
	5/64	3/32	7/64	4/32	5/32	6/32	7/32	8/32	14/32
Stranded									
1,000 M.C.M....	....	....	300	340	420	490	560	630	....
750 M.C.M....	....	....	350	400	490	570	650	730	....
500 M.C.M....	....	....	410	460	570	660	750	830	....
350 M.C.M....	....	....	520	580	700	810	910	1,010	....
4/0 A.W.G....	....	530	610	680	820	940	1,060	1,170	2,000
2/0 A.W.G....	....	650	740	820	980	1,130	1,260	1,380	2,240
1/0 A.W.G....	....	710	800	980	1,060	1,210	1,350	1,470	2,400
2 A.W.G....	....	950	1,070	1,170	1,380	1,560	1,720	1,870	2,750
Solid									
4 A.W.G....	....	1,130	1,260	1,380	1,610	1,800	1,980	2,140	3,200
6 A.W.G....	....	1,330	1,480	1,610	1,860	2,070	2,260	2,430	3,600
8 A.W.G....	....	1,560	1,720	1,870	2,140	2,360	2,570	2,750	....
10 A.W.G....	....	1,810	1,990	2,150	2,440	2,680	2,890	3,000	....
12 A.W.G....	1,860	2,080	2,270	2,440	2,750	3,000	3,220	3,420	....
14 A.W.G....	2,120	2,360	2,560	2,740	3,060	3,320	3,550	3,750	....

SPECIFICATIONS

FOR

PAPER-INSULATED, LEAD-ENCASED CABLES

FOR

ELECTRIC-LIGHTING, RAILWAY AND POWER SERVICE

1. GENERAL

(*a*) The word "Company" where occurring in these specifications shall mean the purchaser of the cable herein referred to, or its duly authorized representative.

(*b*) The word "Manufacturer" where occurring in these specifications shall mean the manufacturer of the cable herein referred to, or his duly authorized representative.

2. RATING OF CABLE

(*a*) The rating of a cable shall be understood to be the highest equivalent working pressure in volts corresponding to any of the specified conditions of service or test. Such rating shall be determined from the following

Rating Table XXIII, all unlisted intermediates taking the next higher listed figure.

TABLE XXIII.—VOLTAGE RATING OF CABLES

Working pressure volts	Test at factory, volts			Test after installation by manufacturer, volts		
	5 min.	30 min.	60 min.	5 min.	30 min.	60 min.
500	1,250	1,000	1,000	1,000	1,000	1,000
1,000	2,500	2,000	1,600	2,000	1,600	1,300
1,500	3,750	3,000	2,400	3,000	2,400	1,950
2,000	5,000	4,000	3,200	4,000	3,200	2,600
2,500	6,250	5,000	4,000	5,000	4,000	3,250
3,000	7,500	6,000	4,800	6,000	4,800	3,900
4,000	10,000	8,000	6,400	8,000	6,400	5,200
5,000	12,500	10,000	8,000	10,000	8,000	6,500
6,000	15,000	12,000	9,600	12,000	9,600	7,800
7,000	17,500	14,000	11,200	14,000	11,200	9,100
8,000	20,000	16,000	12,800	16,000	12,800	10,400
9,000	22,500	18,000	14,400	18,000	14,400	11,700
10,000	25,000	20,000	16,000	20,000	16,000	13,000
11,000	27,500	22,000	17,600	22,000	17,600	14,300
12,000	30,000	24,000	19,200	24,000	19,200	15,600
13,000	32,500	26,000	20,800	26,000	20,800	16,900
14,000	35,000	28,000	22,400	28,000	22,400	18,200
15,000	37,500	30,000	24,000	30,000	24,000	19,500
16,000	40,000	32,000	25,600	32,000	25,600	20,800
17,000	42,500	34,000	27,200	34,000	27,200	22,100
18,000	45,000	36,000	28,800	36,000	28,800	23,400
19,000	47,500	38,000	30,400	38,000	30,400	24,700
20,000	50,000	40,000	32,000	40,000	32,000	26,000
21,000	52,500	42,000	33,600	42,000	33,600	27,300
22,000	55,000	44,000	35,200	44,000	35,200	28,600
23,000	57,500	46,000	36,800	46,000	36,800	29,900
24,000	60,000	48,000	38,400	48,000	38,400	31,200
25,000	62,500	50,000	40,000	50,000	40,000	32,500
26,000	65,000	52,000	41,600	52,000	41,600	33,800
27,000	67,500	54,000	43,200	54,000	43,200	35,100
28,000	70,000	56,000	44,800	56,000	44,800	36,400
29,000	72,500	58,000	46,400	58,000	46,400	37,700
30,000	75,000	60,000	48,000	60,000	48,000	39,000
Factors....	2.5	2.0	1.6	2.0	1.6	1.3

For street railway service (nominal 500-volt d.c.), the e.w.p. shall be 2,500 volts for all cables to be operated with a maximum regular working voltage not exceeding 750 volts d.c. and a maximum momentary pressure (30 sec. or less) not exceeding 1,500 volts d.c.

(*b*) For street-railway service nominal 600 volts d.c., the equivalent working pressure shall be 2,500 volts for all cables to be operated with a maximum regular working voltage not exceeding 750 volts d.c., and a maximum momentary pressure (30 sec. or less) not exceeding 1,500 volts d.c.

(*c*) For three-conductor three-phase "Y"-connected circuits with grounded neutral, the thickness of insulation between any conductor and ground need be only seven-tenths of that between conductors, and the test voltage between any conductor and ground may be taken at seven-tenths of the above tabulated figures for the corresponding equivalent working pressure.

3. Conductors

(*a*) Each conductor shall consist of not less than the following number of soft-drawn copper wires free from splints, flaws, joints, or defects of any kind, and having at least 98 per cent. conductivity of that of pure annealed copper, as defined by the American Institute of Electrical Engineers Standardization Rules. The conductors shall be concentrically stranded together having an aggregate cross-sectional area when measured at right angles to the axes of the individual wires at least equal to that corresponding to the specified size, viz:

No. 4 B. & S. G.	and smaller	Solid
No. 3 B. & S. G.	to No. 2 B. & S. G.	7-wire strand
No. 1 B. & S. G.	to No. 4/0 B. & S. G.	19-wire strand
250,000 cm.	to 500,000 cm.	37-wire strand
600,000 cm.	to 1,000,000 cm.	61-wire strand
1,100,000 cm.	to 2,000,000 cm.	97-wire strand
2,100,000 cm.	and larger	127-wire strand

Intermediate sizes take the stranding of the next larger listed size.

4. Insulation

(*a*) The insulation shall consist of the best manila paper free from jute, wood fiber or other foreign material applied helically and evenly on the conductor, and shall be capable of withstanding the test and service conditions corresponding to the highest equivalent working pressure as determined from the rating table set forth in paragraph 2 hereof. In the case of the cables consisting of more than one conductor (except concentric cables) and Fig. 8 or flat form of duplex cables, the separately insulated conductors shall be twisted together with a suitable lay, and interstices rounded out with the jute before the belt insulation is applied. The minimum insulation thickness or thicknesses shall in no case be less than 90 per cent. of the agreed average thickness or thicknesses. The completed core shall be thoroughly insulated with an insulating compound.

5. Sheath

(*a*) The sheath shall have an average thickness of not less than that indicated in the tabulation next following and the minimum thickness shall in no case be less than 90 per cent. of the required average thickness.

Diameter of core in mils	Corresponding thickness of sheath in inches
0–299	5/64
300–699	3/32
700–1,249	7/64
1,250–1,999	1/8
2,000–2,699	9/64
2,700–over	5/32

(*b*) The sheath shall consist of commercially pure lead, freshly mined and shall contain no scrap, and shall be free from blow holes, cracks, scales or imperfections of any kind.

6. Factory Tests

(*a*) The manufacturer shall, when so stipulated in the order, notify the company in writing when the cables are ready for test, so that proper tests may be made at the works of the manufacturer by the duly accredited representative of the company. Free access to the testing department shall be given to said representative at all times while the cables are being tested hereunder, and the requisite facilities and apparatus for the tests described in these specifications shall be supplied by the manufacturer without extra charge. In case the representative appointed by the company to make factory tests is not wholly and permanently in the employ of the company, said appointment shall be subject to the approval of the manufacturer.

(*b*) *Conductivity.*—The conductivity of the copper shall be determined at least once for each day's output.

(*c*) *Dielectric Strength.*—Each length of cable shall withstand tests at factory of a voltage corresponding to the rating (highest equivalent working pressure) of the cable as determined from the rating table. The condition and conduct of test shall conform to the Standardization Rules of the American Institute of Electrical Engineers.

(*d*) *Insulation Resistance.*—The insulation resistance shall be determined on each length of cable and shall not be less than 50 megohms when measured at, or corrected to, 60°F. This test shall be made subsequent to the tests for dielectric strength. (Higher insulation resistance can be furnished, but necessitates the use of a harder insulating compound, which is more inclined to dry out and cannot safely be bent in cold weather.)

(*e*) *Testing Apparatus and Methods.*—Any disagreement as to the accuracy of testing apparatus or method not specifically covered by this specification shall be referred to the Bureau of Standards, Washington, D. C.

7. PATENTS

(*a*) The manufacturer, shall, at his own expense, defend any or all suits or proceedings that may be instituted against the company for the infringement or alleged infringement of any patent or patents, by the use of any cable or goods covered by this specification, and sold to the company by the manufacturer provided such infringement shall consist in the use by the company, in the regular course of its business, of any of said cable or goods or parts thereof, and provided the company gives to the manufacturer immediate notice in writing, of the institution of the suit, or proceedings, and permits the manufacturer through his counsel, to defend the same and gives all needed information, assistance, and authority to enable the manufacturer so to do, and thereupon, in case of an award of the damages, the manufacturer shall pay such award and in case of an injunction against the company, the manufacturer shall, upon return of the article, the use of which has been enjoined, repay to the company the amount paid by it for the same.

8. QUANTITIES

(*a*) The quantity of each cable specified in the order shall be subject to an increase or decrease of not exceeding 5 per cent., at the option of the company, provided that such option is exercised by the company in writing not less than 30 days before the date fixed for final shipment on account of said order.

9. SHIPMENTS

(*a*) Unless otherwise provided all deliveries shall be f.o.b. factory of the manufacturer. Any material not called for by the company in time to permit the manufacturer (at the agreed shipping rates) to make shipment within the agreed time, and for which final shipping instructions are not filed by the company with the manufacturer at least 1 month prior to the expiration of said agreed time, shall be paid for as if shipped at the expiration of said agreed time. Provided, however, that said agreed time shall not be more than 6 months after date of order. A receipt given by the company or its representatives for any material shipped by the manufacturer, and which fails to note any apparent injury to or bad condition of reels, cases or contents shall terminate the manufacturer's responsibility for the condition of said material.

10. REELS

(*a*) All reels and lagging shall not be included in the contract price, but shall be charged separately therefrom and shall be paid for in accordance with paragraph 11 thereof, "Terms of Payment," and when returned f.o.b shipping factory in good condition complete with all lagging (reasonable wear and tear excepted) within 6 months from date of shipment shall be credited at the price charged. Reels and lagging thus returned after 6 months from date of shipment shall be credited at one-half the price originally charged.

(*b*) Each reel shall be plainly marked, giving the length of cable, purchaser's order number, and date of manufacture. Each reel shall have a numbered metal tag, permanently attached.

11. TERMS OF PAYMENT

(*a*) Net cash within 30 days from date of payment by manufacturer; or ½ per cent. discount for cash within 10 days from said date of shipment.

12. INSTALLATION BY MANUFACTURER

(*a*) The following additional conditions contained in paragraphs 12 to 22, both inclusive, hereof shall apply when cable is installed in underground ducts and manholes by the manufacturer, and then only; in which case the conditions of paragraphs 10 and 11 hereof shall be cancelled.

13. PERMITS AND INFORMATION

(*a*) The company shall provide all necessary permits and information to enable the manufacturer to carry on the work uninterruptedly.

14. MEASUREMENTS

(*a*) The company shall furnish the manufacturer correct measurements for detail manufacturing lengths, but in case the company so elects at the time of placing the order, the manufacturer shall make said measurements, which shall be approved by the company before the manufacture of the cable is begun. In either case the lengths as thus determined shall be paid for under paragraph 21 hereof, relating to "payments," and the scrap or excess cable, if any, shall become the property of the company.

15. CONDUITS, MANHOLES, ETC.

(*a*) All conduits, manholes, or locations provided by the company for the reception of cable shall be clean and free from obstructions, safe and suitable for the purpose intended. The ducts shall be such as to permit the passing through them of a steel mandrel, 3 ft. in length and of a diameter at least 3/8 in. greater than that of the cable to be installed therein, but in no case of a smaller diameter than 1/4 in. less than that of the nominal diameter of the ducts; in case obstructions or defects in the ducts assigned by the company cause unavoidable delay to the manufacturer or damage to cable through attempts to install therein, the company shall pay to the manufacturer the actual loss resulting from said delay, and cost of repairing said damage.

16. JOINTING

(*a*) The manufacturer shall make all joints in a substantial and workmanlike manner, using proper connectors of the proper conductivity, which shall be sweated to the conductor so as to furnish perfect continuity at all points. Sufficient insulating material shall be supplied to insure insulation and dielectric strength equal to the average obtained to equal lengths of the cable as manufactured. The joints shall be provided with lead sleeves of thickness not less than that of the sheath of the cable; they shall be thoroughly made, wiped, and filled with compound to prevent the probability of moisture, reaching the insulation.

17. INSTALLED TEST

(*a*) After the cable is pulled in and jointed by the manufacturer, and before being put into service, it shall be subjected to an installed test at a voltage corresponding to the rating or highest equivalent working pressure of the cable as determined from the rating table set forth in paragraph 2 hereof. Unless otherwise specified by the company in writing at or prior to time of test, the latter shall be the listed test for 5 min. set forth in said rating table. The necessary current and apparatus for making the test shall be supplied by the company, the conditions and conduct of tests shall conform to the recommendation of the Standardization Rules of the American Institute of Electrical Engineers.

18. TERMINALS AND JUNCTION BOXES

(*a*) Terminals, junction boxes, manhole cable supports and in general all cable accessories or auxiliary apparatus not necessarily required to be used in connection with the pulling in and jointing of the cable, shall be provided by the company.

(*b*) If so instructed by the company, the manufacturer shall make connection between the cable and terminals, junction boxes, or equivalent, but shall not be required to guarantee the same hereunder unless said terminals and junction boxes or equivalent are approved by him.

(*c*) In any estimate or count of the number of joints the following understanding shall apply:

Each straight joint counts as one joint.

Each additional branch or tap cable from a straight joint counts as one joint.

Each cable entering or leaving a junction box, test box, terminal, pothead or equivalent, counts as one joint.

19. GUARANTEE

(*a*) In case any cable furnished hereunder fails within 1 year from date of shipment by the manufacturer, and said failure results from defects of material or workmanship for which the manufacturer is shown to be solely responsible, the manufacturer shall be immediately notified and shall (being given sufficient time to enable him to do so) at his own expense make all necessary repairs to make the cable affected, in every way equal to its condition previous to its failure.

(*b*) Should the manufacturer fail to attend to the repairs promptly, or should the exigencies of the company's business be such as to necessitate repairs before the manufacturer can be notified, the company shall have the right to make the necessary repairs at the manufacturer's expense, preserving the available evidence of the cause of the failure.

(*c*) Should the evidence fail to show the liability of the manufacturer under this specification, the company shall pay to the manufacturer the cost of repairs made by the latter.

20. ACCIDENT LIABILITY

(*a*) The manufacturer shall save the company free and harmless from any and all claims or demands of the manufacturer's employees or his legal representatives for injury which may be substained while employed in the construction of the work herein contemplated, or while going to or from the place where said work is to be performed, unless such injury is due to negligence on the part of the company or its employees; also from any and all claims or demands for damages, for injury to other parties, caused by the fault or neglect of the manufacturer, his agents, servants, or employees in the construction of said improvements.

(*b*) Provided that in the event of any action or actions which may be instituted either by the agent, servants, or employees of the manufacturer against the company, or by third persons who may claim injuries to have been sustained, within the meaning of the foregoing clause (which injuries are alleged to be the result of the fault or neglect of the agents, employees, or servants of the manufacturer), the company shall immediately notify the said manufacturer thereof, and shall permit him to institute suit or action and appear and participate in the trial by counsel of his own selection. Provided, further, however, that this proviso shall not in anywise prevent the said company from defending against suit or action with as full force and effect as though the preceding paragraph in the said contract, to which this is a proviso, had not been inserted in contract.

21. TERMS OF PAYMENT

(*a*) Net cash for 80 per cent. of the installed price shall be paid within 30 days from date of shipment. Ten per cent. of the installed price (one-half of the remaining 20 per cent.) shall be paid upon the tenth day of each calendar month for all cable pulled in and jointed during the preceding calendar month, and the remaining 10 per cent. due for each separate cable, shall be paid within 10 days from the date when each such cable shall have been tested and accepted such test and final acceptance or rejection of each separate cable to be made within 10 days from notice by the manufacturer to the company that such cable is ready for final test. If the installation of any cable or part thereof be delayed for more than 3 months by failure or inability of the company to provide the manufacturer with the necessary facilities for prosecuting the installation, or by other causes not attributable to the manufacturer, the full balance remaining unpaid for such cable (taking into consideration the due proportion of installation work done upon the cable, if any), also the unpaid balance for all cable accessories furnished in connection therewith and the manufacturer's customary charge for the reels thus retained by the company, shall be due and shall be paid forthwith.

High-tension Cable Specification.—The National Electric Light Association Committee on Underground Construction suggest the following specification for three-conductor paper-insulated cable. It will be noted that in this specification a bending test is included. In European cables the bending test is applied three times to a radius of six times the cable diameter. American manufacturers consider as too severe a bending test, first in one direction and then in the other, twice repeated, to a radius of six times the cable diameter. The specification herewith presented, therefore, increases the radius of bending to seven and one-half times the cable diameter.

Insulating Material

The insulating material shall be of the best manila paper, free from jute, wood fiber, or other foreign material. It shall be cut in strips and helically and evenly applied to the conductor to a uniform thickness of ...../32 in. After insulation the three conductors shall be laid together, with a uniform twist, having a pitch not exceeding 25 times the diameter of one conductor measured over the insulation. The interstices shall be filled with jute or paper so as to form a true firm cylinder without openings or air spaces, over which is to be applied a paper-insulating jacket in the same manner, and of the same quality as specified for each conductor.

During the process of applying the paper insulation and the jute or paper filler and immediately before the insulation is impregnated, the cable shall be subjected to such treatment as will insure the expulsion of all air and moisture, incident to which treatment the cable shall be impregnated with an insulating compound of low specific inductive capacity, guaranteed not to run appreciably and to retain its sticky adhesive qualities during the life of the cable, and also guaranteed not to develop any chemical action within itself or with any other component of the completed cable.

Tests

The following electrical tests shall be made by the manufacturer at his works and without expense to the purchaser, the manufacturer supplying all necessary apparatus and the purchaser to have the privilege of being represented when these tests are conducted. The manufacturer shall furnish the purchaser with copies of data sheets showing the behavior of the cable during these tests.

(*a*) *Voltage Test.*—Each length of cable is to be tested with alternating current, having a frequency preferably the same as that of the system of which the cable is to be a part. The test voltage is to be applied between all three conductors and between conductors and lead sheath at a temperature of 150°F. If the cable is to form part of a system having a permanently grounded neutral, the neutral point of the test generator shall be connected to the cable sheath during the test. If the cable is to form part of a system with an ungrounded neutral, two tests shall be made, the first with conductor *A*, the second with conductor *B*, grounded to the cable sheath. The apparatus supplying the energy for the voltage test must have a kilovolt-ampere capacity at least four times the kilovolt-ampere capacity absorbed by the length under test, and in any event must not be less than 25 kva. capacity. The time of application of the test and test pressure shall be: 5 min. at a voltage having a peak value two and one-half times the peak value of the normal working pressure as determined by spark-gap in accordance with the American Institute of Electrical Engineers Standardization Rules.

(*b*) *Insulation Resistance Test.*—(1) An insulation-resistance test shall be made immediately before and after the voltage test. (2) The measurement shall be made with a direct-current voltage of not less than 100 volts, the reading to be taken after 1 min. electrification, and shall show no appreciable decrease in the value of the insulation resistance between the two successive measurements. Measurements shall be made between each conductor and each of the other two and between each conductor and the lead sheath. Any section of cable which shows a marked variation from others of the same type manufactured at the same time shall be held for further examination and if such variations cannot be satisfactorily explained the section shall be rejected.

(*c*) *Breakdown Test.*—Samples from 10 to 25 ft. long and selected by the purchaser at random from any cable lengths shall not break down under five times the working pressure applied for 5 min. between all three conductors and between conductors and lead sheath, after samples with ends sealed have remained at a temperature of 150°F. for 100 hr. in straight single lengths with axes inclined 15° to the horizontal.

(*d*) *Bending Test.*—A sample from any length of cable shall be bent around a cylinder having a diameter equal to 15 times the outside diameter of the cable over lead sheath, and then be straightened out. It shall then be bent in the opposite direction around the cylinder and straightened out. This operation shall be performed twice in succession, after which the cable shall be capable of withstanding a voltage test two and a half times working pressure applied for a period of 5 min. between the conductors and between the conductors and the lead sheath, and shall show no signs of mechanical injury or electrical injury when dissected.

Test after Installation.—The cable shall be capable of withstanding twice normal working pressure applied between all three conductors and between conductors and lead sheath for a period of 10 min., after being drawn into the ducts and jointed. An insulation-resistance test shall be made immediately before and after the breakdown test, using the method specified under (*b*–2) above, and the insulation resistance shall not be materially reduced as a result of this test.

Moisture in Cable Insulation.—Some companies, in their high-tension paper-insulated cable specifications, include a clause to limit the percentage of moisture in the insulating compound. This appears to be a step in the right direction but such specifications should be accompanied by an exact description of the method to be employed in determining the percentage of water in the insulating compound.

Different methods of tests give different results, some of which are accurate only to within approximately 25 per cent. It is evident that in order to have accurate results the insulation must be removed from the lead and copper and the difficulty is to accomplish this without exposing the insulation to the air, thus allowing it to absorb moisture, so that tests made from the same cable show variations in accordance with the percentage of moisture in the atmosphere at the time the tests are made.

In the production of high-grade transformer oils, great care is used to eliminate even minute percentages of moisture. In ordinary cases $\frac{1}{10}$ per cent. is considered objectionable, and it is believed that where trouble is experienced with impregnated-paper cables it is due to the lack of this same attention to the question of moisture in the original compound or in the paper itself.

The rosin of commerce which is used for a base in most paper cables is the residue from a steam-distillation process for turpentine and contains from 8 to 10 per cent. of water. The rosins obtained from the so-called "dry process" contain less moisture than this, but are of an inferior grade.

In usual methods of making rosin-oil compound the mixture of rosin and oil is heated so that the water is boiled off. This method, if carried to an extreme, may result in the reduction of the water to as low as 1 per cent., but in common practice rarely reaches this minimum. There is also water present in unstable molecular combination with the rosin and when cable is operated above normal temperatures this molecular condition is destroyed, and actual water and a further liberation of volatile ingredients results. This fact apparently accounts for some cable troubles which are otherwise unexplainable.

However, the present-day methods of paper-cable manufacture have reached a degree of perfection where very little trouble need be feared from overheating due to the presence of residual moisture in the insulation, if the cable is operated within the limits of voltage for which it has been designed. Only in cases where the insulation has not been properly treated will excessive dielectric losses be noticed.

Numerous tests have been made to determine heating due to dielectric losses, but in no case have these losses been found to be abnormal provided the cable insulation has been properly treated and applied.

It would, therefore, seem that there is no good reason for believing that there is ever enough residual moisture in the cable insulation to cause any appreciable increase in normal dielectric hysteresis, and that where companies are experiencing trouble of this nature the cause is not due to residual moisture in the compound, but to moisture entering the cable after installation, either through small holes in the lead sheath, or when joints are made under unfavorable conditions in damp weather.

CHAPTER VI

INSTALLATION OF CABLES

Handling Lead Cables.—No attempt will be made to indicate all the details of cable installation; it is the intention rather to outline the general method of installing underground cables and to emphasize the importance of some parts of the work in connection therewith. Cables are shipped from the manufacturers on wooden reels of suitable size to accommodate one or more lengths of cable.

When coiling a cable on a reel, the first end, usually termed the test end, is put through a slanting smooth hole in the side of the reel so as to have both ends of the cable accessible for testing before shipment. After testing, both ends are capped or sealed, thus protecting the cable insulation from moisture. The test end of the cable is usually left protruding through the side of the reel from 12 to 18 in. and is boxed over. It is customary to lag the reel from flange to flange with heavy wooden slats nailed to the flanges and further secured by wires encircling the slats to protect the cable thoroughly from injury in transit or while standing on the street.

Transporting reels of cable from the railroad to the manhole should be entrusted only to experienced truckmen; and if a low wagon is not available, and a high wagon must be used, the reels of cable should be carefully lowered from the wagon by means of a windlass and skids and not allowed to drop to the ground. To avoid the loosening of the cable, the reels should be rolled in the direction of the point of the arrow painted on the side of the reel.

The reel of cable is then placed at the manhole, over the duct into which the cable is to be drawn, in such a way that the cable will unwind from the top of the reel. It should next be mounted on jacks and not until that is done should the slats be removed, care being taken that no nails come into contact with the cable or are left in the flanges to do damage.

An improved form of jack designed to handle cable reels of varying sizes is shown in Fig. 62. It is provided with three forged-steel hooks, as well as a swivel top, so that the reel can be picked up on the hook nearest its center and suspended with a very small amount of ratcheting, at the same time being just high enough to clear the ground.

A pair of these jacks will safely support cable reels of any ordinary size, the combined safe carrying capacity of a pair being

FIG. 62.—Reel jack.

over 6 tons on the top hook. Reels weighing from 6 to 10 tons may be raised on the swivel top or, if the diameter of the reel permits, on either of the two lower hooks.

The jack is superior to the screw type of cable-reel jack, as it raises or lowers the load faster and by the use of the hook arrangement, which is not applicable to an ordinary screw jack, one pair of jacks can handle almost any size reel.

The utmost care should be taken not to bend the cable sharply, nor to break through, cut, abrade, kink or dent the lead sheath; and, above all, not to allow the slightest trace of moisture to enter the ends of the cable after the seals have been broken. A failure to observe these points may result in the loss of the cable. The useful life of an underground cable is determined by that of the insulation, which in turn usually depends upon the integrity of the lead sheath.

Choice of Ducts.—Before drawing cables into a new conduit system, there is often a question as to which of the ducts shall be used first. Workmen, when about to install cables, may have been told to use any one of the ducts, and naturally they draw the cable into those which are most convenient, without any consideration for the cables which are to be installed later. There are cases where a manhole has been completely blocked by the first few cables installed. There is another important reason for using care in the selection of the ducts to be used for power cables, as will be seen from the following:

It is not possible to foretell the current-carrying capacity of a cable without previous knowledge of all the controlling factors which will influence temperature rise in such a cable. Some of the most important factors are: natural temperature of the ducts and manholes; amount of moisture present; condition and action of soil surrounding the conduit; and exact location of the cable in the conduit with respect to other cables which have previously been installed. All of these greatly influence both the radiation and dissipation of heat generated in each conductor or cable and consequently the current-carrying capacity of the conductor.

Usually the ducts which dissipate heat most rapidly, and therefore run coolest, are those located at the lower corners of the conduit. Those nearest to the outside of the system run fairly cool, but the middle and top ducts, which not only take up heat from the lower cables but must dissipate heat through adjoining ducts, operate at a fairly high temperature. Attention to these points, when planning a new system, may prove very profitable in the end.

Regarding the selection of cables, it should be borne in mind that other conditions being equal, those insulated with rubber compound dissipate heat more readily than those insulated with paper or other fibrous material. On the other hand, it has been found that a cable insulated with an oil-saturated paper will operate for a longer time at a high temperature without deterioration than when insulated with rubber compound. This, however, does not hold true if too much resinous material has been used in making up the paper insulation.

To economize in space, as many as six cables are, at times, drawn into one duct. While this may be an advantage, it is accompanied by the danger of losing all six cables through the failure of one.

A cable should never be drawn over one already in position, as the wear of the rubbing lead is excessive; and one cable,

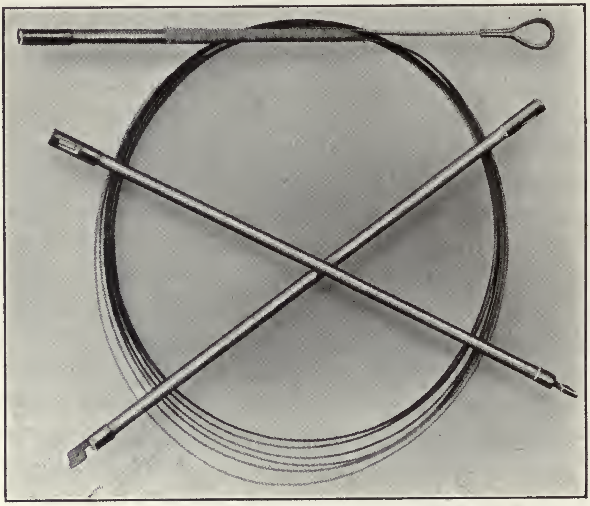


FIG. 63.—Rodding sticks and snake wire.

usually the one in place, is almost sure to be damaged by the lead being worn through.

Rodding Ducts.—After having decided upon the duct into which the cable is to be drawn, preparations are made to wire the duct and to clean it thoroughly, freeing it from any obstructions which might injure the cable when being drawn in. To accomplish this, a snake wire or rodding stick, of which there are several types, Fig. 63, is worked through the duct. If the sections between manholes are short, rods are not required, a snake wire alone being used. The latter is also better adapted to wiring ducts with curves, but cannot be used in very long lengths owing to the friction encountered. By means of a galvanized wire a suitable rod to which is attached a scraper, gage, brush, or swab is next drawn through the duct to insure a clear passage for the cable. Gages so used should be about 3/8 in. larger than the cable to be installed.

It is customary to rod long sections of conduit, using wooden rods about 1 in. in diameter and 3 or 4 ft. long, provided at each end with coupling devices by means of which the various sections may be jointed together. These coupling devices consist of either screw connections or a sliding coupling which may be more quickly joined.

The method of rodding is as follows:

A bundle of rods is placed in the manhole; a workman standing in the hole pushes one rod into the duct, attaches a second to the first and pushes it ahead, continuing this operation until the first rod appears at the next hole. A rope is then fastened to the rod at the distant manhole and the rods with the rope attached are drawn back into the first hole and disconnected as they are drawn from the duct until the rope appears. If a large quantity of duct is to be rodded, it is, of course, impracticable to draw a rope into each section, yet it is advisable to have the line rodded somewhat in advance of the cable gang. In this case a small piece of steel wire (No. 10 or No. 12 B.W.G.) is drawn into the duct by the rods and left in place to be later used to draw in the rope. This wire, if properly handled, and drawn out and reeled or coiled neatly, may be used several times. Obviously, rods may be drawn out at the distant manhole and there disconnected from the wire fed in at the first hole. This method is usually adopted when a long straight run of duct is to be wired, the rods being shoved into the next duct section as they are drawn out and disconnected from the first section. If the ducts are in a straight line across the manhole, the rods may often be passed into the next section without disconnecting.

Obstructions in Ducts.—A completed conduit system should always be tested for obstructions previous to its acceptance from the contractor by drawing through each duct a test mandrel about 24 in. in length and 1/4 in. less in diameter than the bore of the duct.

Ordinary obstructions, such as pieces of cement or dirt, may be removed by mounting a mandrel consisting of a piece of steel pipe on the end of the first rod and drilling away the projecting cement Sometimes obstructions are met which cannot be so removed. These must be located by a measurement of the rods pushed into the ducts until the trouble is reached, the street opened at that point and the ducts repaired or replaced by new sections.

Several forms of mandrels or duct cleaners have been used, but attention is called to Fig. 64 which shows a flexible cleaner so designed that, when drawn through the conduit, particles of cement are broken off and removed from the duct. It is usual, when cleaning ducts, to attach to the cleaner a swab or brush of some sort to remove properly the loose particles from the duct line.

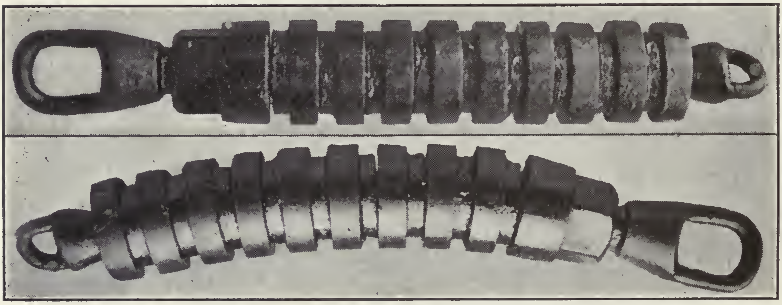


Fig. 64.—Flexible duct cleaner.

Drawing in Cables.—Before drawing the cable into the duct the ends should be examined to see that they are perfect. A wire-pulling grip of some form is then drawn through the cable end. To the end of this grip is next fastened a flexible steel or manila pulling-rope, which in the meantime has been drawn through the duct ready for pulling. Proper cable protectors are placed in the mouth of the duct. These protectors are usually made of leather and placed in the end of the duct to prevent damage to the sheath. The cable from the top of the reel should enter the mouth of the duct by a curve of large radius, Fig. 65, without touching at any intermediate point. The pulling can be done by capstan, winch, motor truck, horses, or, in the case of a small cable, by hand. When guiding the cable into the duct, a small amount of common grease should be spread on the cable so as to allow it to slide more easily and lessen the strain on the cable. Enough extra cable should be drawn into the manhole to provide for racking around the manhole and the making of joints. During the installation, no cable should be bent sharper than to a radius equal to ten diameters of the cable. If it is not intended to joint the cables as soon as they are drawn in, the caps or seals should be examined to see that they are safe before leaving the work. The cable should be protected at the edge of the duct, and should not be left hanging loosely or lying on the bottom of the manhole, but should be placed on the racks provided for it. Paper-insulated cables should not be installed at temperatures below 40°F. without first warming them up by charcoal fires, or other means, so as to make them more flexible and avoid any possibility of cracking the insulation. Also when cables are being racked around the manhole wall they should be thoroughly warmed if the temperature is low. Before jointing, the ends should be cut back far enough to positively insure against the presence of moisture. No matter how excellent a cable the

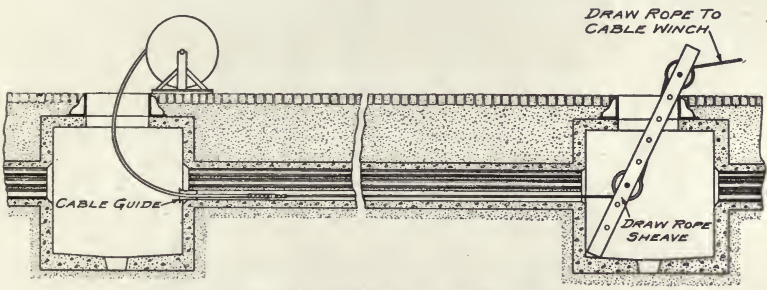


Fig. 65.—Setting up cable reel.

manufacturer may produce, if it is not carefully installed and properly cared for thereafter, it will inevitably fail, and it is, therefore, necessary that the work be done by experienced and reliable workmen. It will generally be found more satisfactory for a small company to have its cables installed by the manufacturer. A large company, however, frequently finds it cheaper to install its own cables. All large-sized cables should be ordered in exact lengths, making the proper allowance for training in manholes and necessary waste.

Cable-pulling Grips.—Many devices for fastening the cable and draw rope together have been used and abandoned as unreliable. Where the ducts are dry, a good serviceable grip is obtained by punching two holes through the center of the cable from side to side, the holes being spaced about 3 in. away from each side of the cable end. A No. 10 or No. 12 B.W.G. steel wire is then passed several times through the eye of the rope and the holes in the cable, and the ends of the wire are twisted firmly together. This method is not recommended where there is any danger of water in the ducts, as the water is certain to enter the cable through the holes; and in case of paper cable, to penetrate so far that the ends often cannot be cut back far enough to clear the trouble thus introduced. A better form of grip, and the one which is used almost universally to-day is shown in Fig. 66*A*.

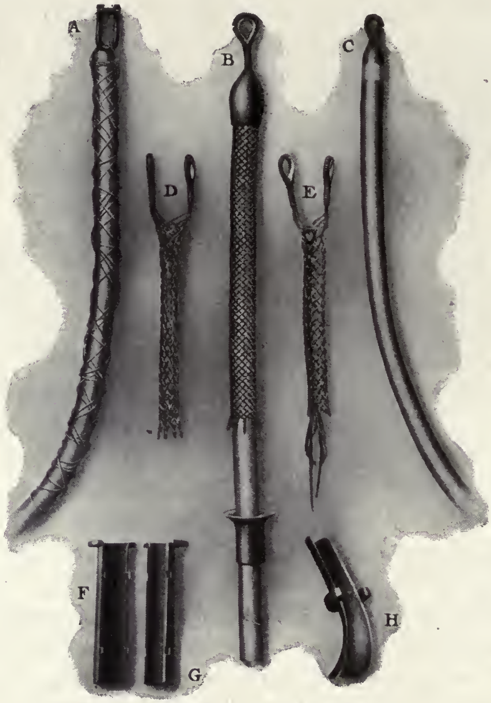


Fig. 66.—Wire-cable grips.

A block of wood about 3 in. wide is placed against the end of the cable, and steel wire of No. 10 or No. 12 B.W.G. cut in 6-ft. lengths is then bent in the middle of the wood block and wrapped around the cable sheath in opposite directions, the number of wires required depending on the severity of the pull. When the pull of the rope comes on these wires, they bind harder on each other, on the lead, the insulation, and the conductors, as the pull grows harder, and the strain is equally distributed.

With this type of grip, the seal on the lead of the cable is not broken and no water can, therefore, get into the insulation. A form of basket-wire grip which has been used to good advantage is illustrated in Fig. 66, *B*, *D*, *E*.

Where a section of cable is to be installed in a duct of a bore only slightly larger than the diameter of the cable, the ordinary woven-wire cable grip often fails, the reason for its failure being that the diameter of the cable is increased by the wire of the grip leaving insufficient clearance. The excessive strain, moreover, has a tendency to strip the lead sheath from the cable.

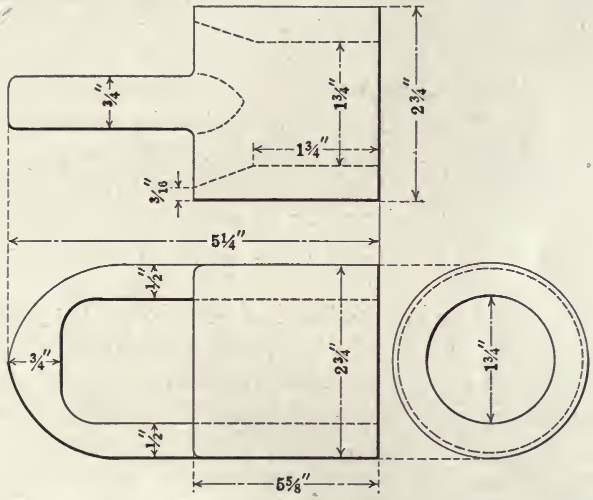


FIG. 67.—Construction of a cable grip suitable for pulling cables up to 2¾ inches outside diameter.

Considerable thought has been given to the various methods utilized in fastening the pulling-rope to the cable ends when large-sized cable is to be pulled into a duct line. A very satisfactory method is to use what is known as a cable eye. This cable eye is made of round steel about ⅝ in. in diameter, and an eyelet, approximately 1½ in. in size turned on one end. The proper procedure to be followed in fastening this eyelet to the cable is to strip back the lead sheath 6 or 8 in., remove the insulation from the conductors, then place the eyelet between the conductors and wind them securely around it and solder them fast. Next the portion of the lead sheath, which was stripped back, is moulded around the conductors and eyelet, the whole soldered and sealed so that it is waterproof. In using this eyelet all the strain is placed on the conductors and there is no danger of moisture entering the cable during the process of installation due to damaged ends or improper seals.

What may be termed a "basket grip" is described in the *Electrical World*, March 25, 1916. This grip may be cast of iron or phosphor bronze. The grip illustrated in Fig. 67 is suitable for pulling cables having an outside diameter up to 2¾ in. About 4 in. of the lead and insulation is cut away from the end of the cable and the bare conductors are tinned and pushed up through the basket. The conductors are then spread in the upper part of the basket, which is tapered to accommodate this process and molten solder is poured over the spread conductors. After the solder has cooled, the hooks attached to the pulling-rope are passed through the loop of the basket, and the cable can then be drawn through the ducts. However, if the duct is wet or muddy, it is best to prevent water getting into the cable end by winding a good quality of rubber-filled tape around the lower end of the basket and the adjacent lead sheath of the cable.

If the cable to be installed is single-conductor instead of multi-conductor, the basket grip is equally adaptable. The method of procedure is similar to the above, and the cable can be prevented from slipping out of the basket by spreading the individual strands of the conductor.

Draw Rope.—For general purposes a manila rope of best quality and from ¾ to 1½ in. in diameter will be found most satisfactory for pulling in cables. A steel hoisting rope is sometimes used, but it deteriorates rapidly from rust and hard usage on the street unless protected by some form of covering. Whatever style of rope is used, the ends should be provided with an "eye" around a steel thimble fastened to a short length of chain provided with a swivel at the end. In very hard pulls any rope tends to untwist, and unless a swivel is inserted between the rope and cable, this twist will be imparted to the cable itself and may injure the lead or the conductors. It is advisable to terminate the swivel with a pair of sister-hooks, Fig. 68. These are readily inserted in the loop of the wire grip on the cable and prevented from opening by several wraps of wire.

What is known as a "durable steel-stranded" rope is used by a number of companies for pulling in cable. The rope is made up with a flexible core and the strands are covered with specially prepared braided hemp, which binds the strands together forming a cushion between strands and protecting the rope from wear. The rope is rustproof and will outwear a number of coils of ordinary manila rope. The ¾-in. size replaces the ordinary 1¼-in. manila rope. It is especially desirable when power-driven winches are used.

Drawing Apparatus.—If the cable is light and short, it may be pulled in by hand, but usually some apparatus will be found necessary to secure sufficient power.

Fig. 68.—Sister hooks.

Horses are sometimes used to haul in the cable by hitching them directly to the cable rope which passes from the manhole over snatch blocks or sheaves. This method is undesirable as it is impossible to stop horses instantly in case of an accident to the reel or to the cable at the mouth of the duct, or in case of meeting other unforeseen obstructions; and serious damage to the cable is liable to ensue.

In some cities where great quantities of cable are installed yearly, winches as shown in Fig. 69 run by electricity or gasoline engines mounted on a wagon, are used for pulling in the cables, but this device is too expensive in the first cost and maintenance for profitable use unless large quantities of cable are handled regularly.

For drawing in underground cables, in many locations a small ship's capstan mounted on a stout framework fastened to the pavement has been used. The frame on which the capstan is fastened is provided with wheels easily removable to facilitate moving the apparatus from place to place. The draw rope is led over pulleys from the duct in the manhole to the capstan on the street and is wrapped several times around the drum to give the required purchase. The power is furnished by men in the regular way.

In some locations manholes are so near car tracks or other obstacles that there is not sufficient space for either form of capstan with the projecting handle bars. In such cases a winch,

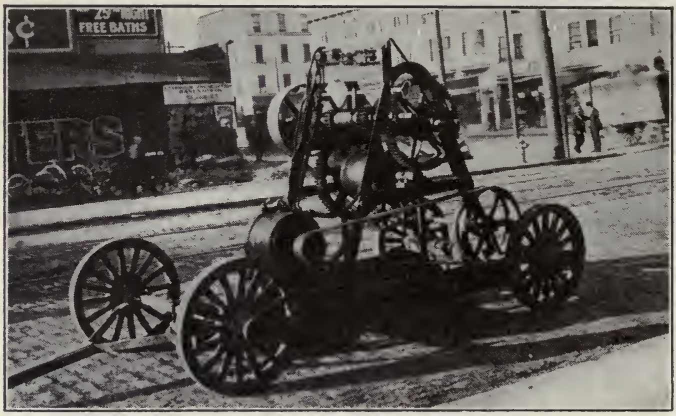


Fig. 69.—Electric motor-driven winch.

Fig. 70, mounted on a strong framework is most convenient. The framework is placed directly over the manhole opening and the rope is led from the duct through a snatch block directly to the drum of the winch, the power being applied by two cranks

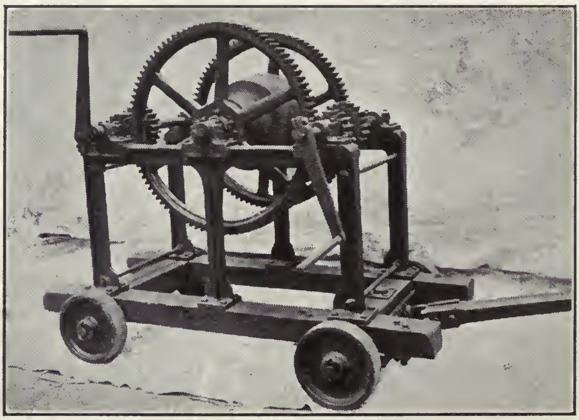


Fig. 70.—Hand winch.

(revolving handles) one on each side of the drum and directly opposite each other, so placed that when one crank is down the other is up. The snatch block in the manhole may be fastened in place by attaching it to eye-bolts built into the walls or by suitable blocking.

When constructing manholes, it is advisable to provide facilities for drawing cables through ducts so that special guide supports do not have to be used. The accompanying illustration, Fig. 71, shows how manholes may be equipped for this purpose. In the wall opposite and about 12 in. below each duct entrance is an eye-bolt which extends through the wall and is bent over on the end to bear on an iron plate which reduces the unit pressure

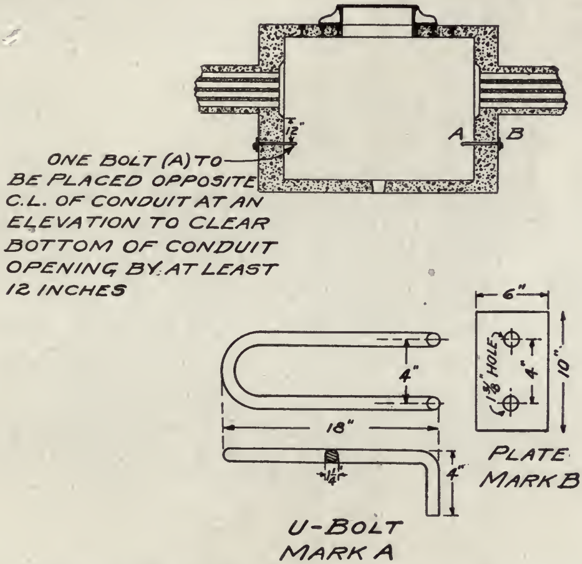


FIG. 71.—Diagram showing equipment of manhole to facilitate cable installation.

on the manhole wall. This eye-bolt may be employed to support a guide block during the usual installation of a cable, or it may be connected to a block and tackle when it is necessary to draw a cable into place for splicing in cases where sufficient length has not been left for this operation.

A flexible arrangement of the pulleys may be secured by means of two steel channels or guide sheaves of such length as to reach from the bottom of the manhole to a point about 3 ft. above the surface of the ground. The channels are provided with holes every few inches along the entire length, through which heavy steel pins secured by cotter pins may be placed, thus providing movable shafts for the pulleys, as shown in Fig. 72. The lower pulley is placed opposite the duct and the rope leaving the duct passes under this pulley up to and over the upper pulley just above the street surface. The bottoms of the chan-

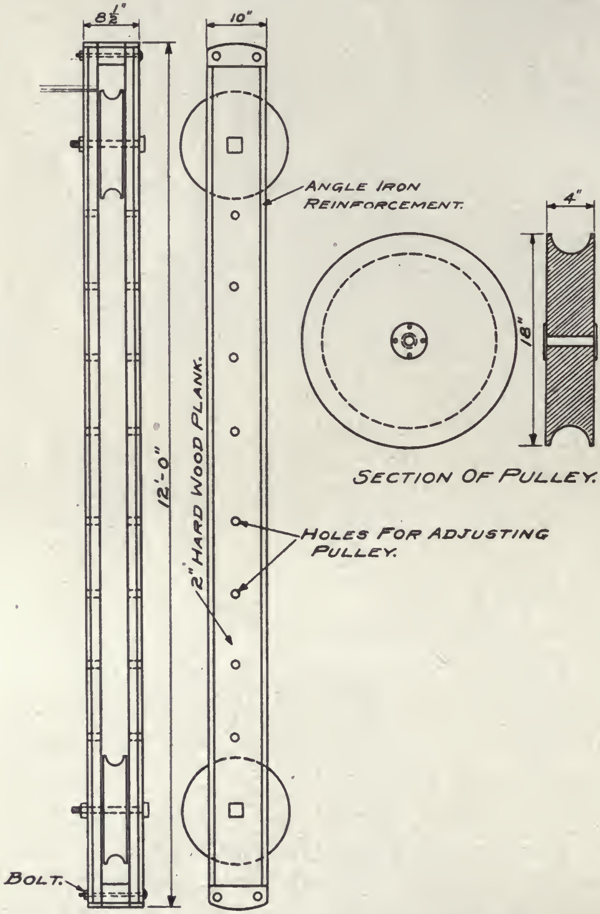


Fig. 72.—Guide sheave for cable pulling.

nels rest against the wall of the manhole and the tops against the manhole cover frame.

Power Trucks.—In the 1916 report of the National Electric Light Association Committee on Underground Construction, under the heading, "Use of Power Trucks for Underground Work" the following data is given. Of the 12 large operating companies reporting, all use power trucks for their cable work. Nearly all companies use electric trucks, but some use both electric and gasoline engine-driven trucks.

The electric truck most suitable for underground work should have a speed of 10 to 12 miles an hour, and designed to run at least 35 miles on one charge.

In addition to the use for pulling in cable, the trucks are used for hauling reels of cable to the jobs, delivering material, and for emergency work. Specially designed bodies with compartments for tools are very desirable, Fig. 73. Compartments may be built along both sides of the truck to hold tools, fire extinguishers, sand buckets, etc. A compartment for the records of the dis-

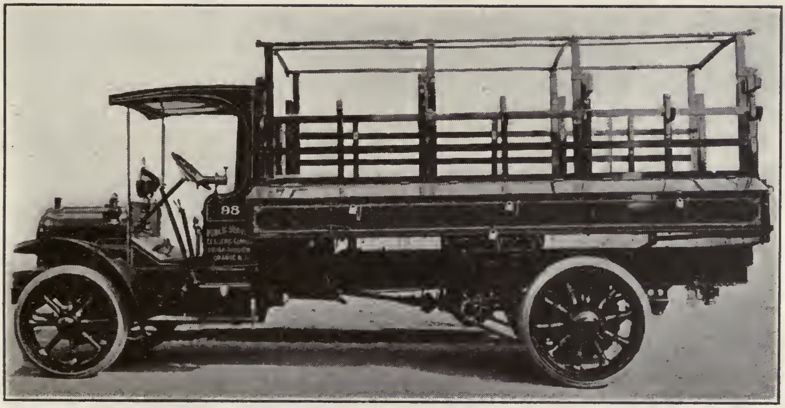


FIG. 73.—Cable truck.

tribution system may also be provided and so arranged that the cover of the pocket forms a desk on which the records rest while being used by the emergency man.

There are two methods of pulling in cable:

1. By means of pulleys set on I-beam uprights.

2. By means of a pulley or snatch block anchored in some manner in the manhole.

In Fig. 74 is illustrated various ways of arranging the trucks and cable-pulling apparatus which represents the practice of several of the large electric companies.

When manholes are near car tracks, it is sometimes impossible to use the I-beam upright method of pulling cable without interfering with street-car traffic. For this reason it is a good plan to have the truck equipped with facilities for pulling cable with a rope leading from the rear or from the front. A New York company has its trucks provided with facilities for pulling from either side as well.

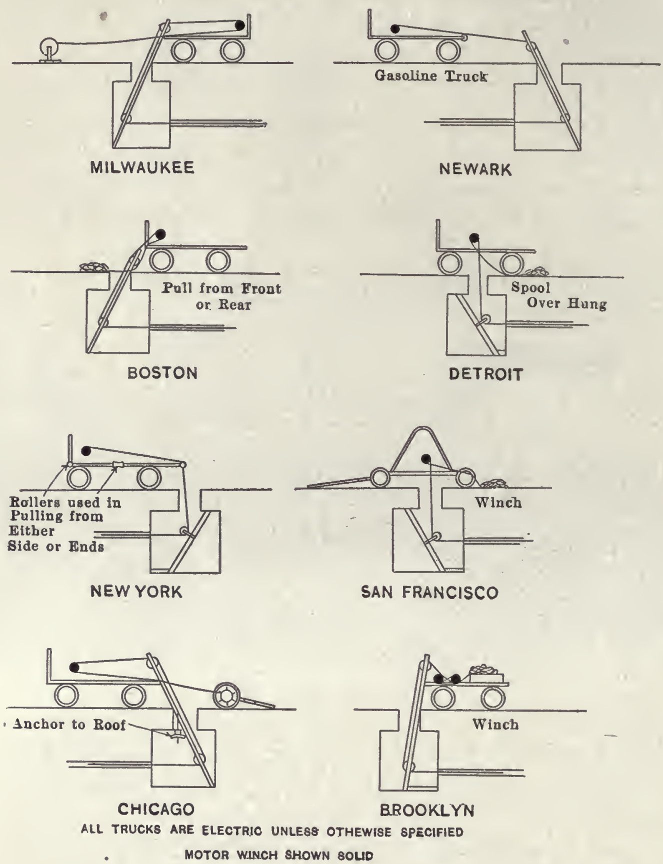


FIG. 74.—Methods of pulling cable.[1]

Some difficulty has been encountered in maintaining the I-beam uprights in position when pulling heavy cable on account of the enormous strain. In order to obviate this difficulty, a Chicago company has devised an anchor with wing bolts that may be adjusted to any manhole. This anchor holds the uprights in

[1] N. E. L. A. Report, 1916.

position by a strain on the roof of the hole, as illustrated in the figure.

When the rope is passed through the hole in the floor of the truck, the strain on the truck as well as on the winch is downward and very little difficulty is experienced in holding the winch to its fastenings. When this method is used, the truck is placed over the manhole, a position which takes up less working space in the streets and eliminates the hazard of injuries to pedestrians on account of an unprotected open manhole. It may be difficult to design the truck so that the rope leading directly downward through the trap door will not interfere with the battery or running gear. Having a rolling spool for the rope on the side of the truck and an eye-bolt for a snatch block in the center of the floor, a method which a New York company uses, accomplishes the same results as the trap-door method without introducing its objectionable features. To prevent accident, cable-pulling winches which are motor-driven should have all of the gears or movable parts covered with guards.

It is recommended that trucks for underground work be wired with socket for an extension cord to both the front and the rear of the truck. This will greatly facilitate locating trouble at night. For splicing cable at night, however, a portable storage battery outfit is more suitable and efficient. The use of an outfit of this kind eliminates the hazard encountered by the use of candles or lanterns in gassy manholes, besides providing the light necessary for good jointing work.

Most central stations have provided charging stations for electric vehicles throughout their territory. Where the territory is not too great, one central charging station is adequate for a truck that will make 35 miles on one charge. A boosting charge during the noon hour, however, is recommended where the facilities are at hand.

Slack.—Enough slack must be left in each manhole to enable the cables to pass around the sides, to make and place the joints on the wall supports and to keep the center of the hole free from cables. When extra slack is needed, employ a short rope with one end frayed for 5 or 6 ft. and wrap the soft end spirally around the cable near the duct so as to obtain a tight grip without denting or kinking the cable. Pass the rope around the capstan or winch and draw the cable out until the fastening reaches the drum or block, slip the hitch back to the duct and repeat the operation until sufficient cable has been secured. Always determine the location of the splice in the manhole and provide the foreman of the drawing-in gang with a diagram and list showing exactly how much cable should project from the duct into the manhole at each end of each section.

After a cable has been drawn in, an experienced workman should examine the ends to see if the solder seal is intact or, if broken, whether any moisture is present. If moisture is discernible, boil it out thoroughly or (if enough stock is available) cut back the cable until all dampness is removed; and in all cases leave the end carefully soldered up.

The cable should be protected at the edge of the duct, and it should not be left hanging loosely or lying on the bottom of the manhole, but should be placed on the racks provided for it. If the cables have paper insulation and the temperature is below 40°F., they should be warmed by torch or other means, so as to make them more flexible and avoid any possibility of cracking the insulation when the cables are being racked around the manhole walls.

Jointing of Cables.—It is generally admitted that the greater part of cable trouble is due to poorly made joints or to the presence of moisture or cracks in the insulation near the joints. With good material and careful and competent workmen, the insulation of the joint can be made as reliable and as durable as that of any part of the cable. The construction of a joint is, therefore, of prime importance, and unless the engineer has at his command experienced and thoroughly reliable cable workmen, he would do well to contract with the manufacturers, who have every facility for doing this class of work, for the complete installation of the cable.

In the making of a perfect joint, the following points are especially worthy of comment and caution:

(*a*) The work should be done by reliable and experienced cablemen.

(*b*) High-grade insulating materials should be carefully chosen to suit the special conditions.

(*c*) Every trace of moisture should be excluded from the joint and adjacent parts of the cable.

(*d*) The layers of insulating tape should be made to overlap each other and should be drawn tight to exclude air.

(*e*) The sleeve should be well-filled with suitable compound which should be sufficiently hot before pouring.

(*f*) The joint should be in proportion to the size of the conductor, and the insulation on the joint should be at least 20 per cent.

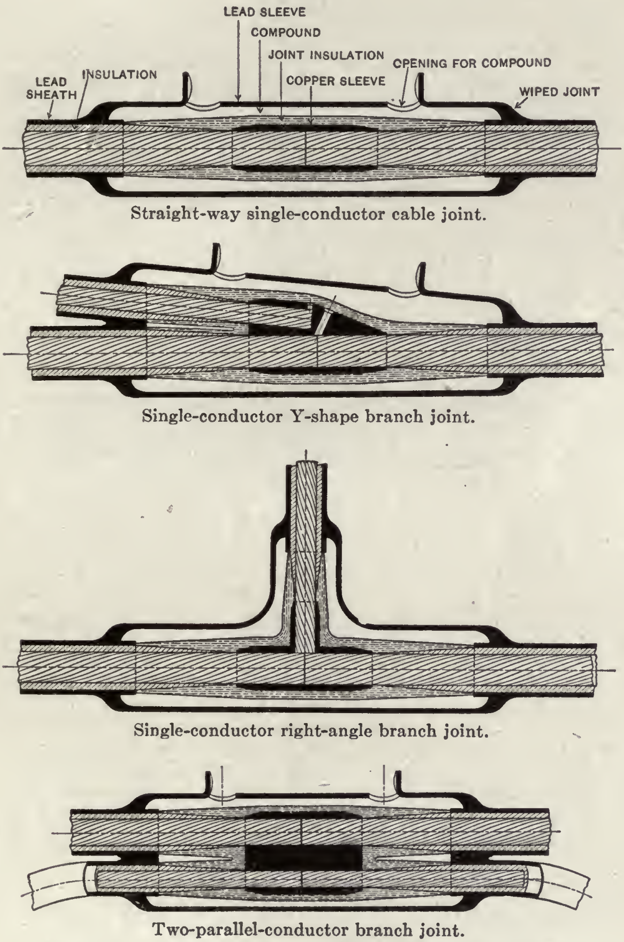
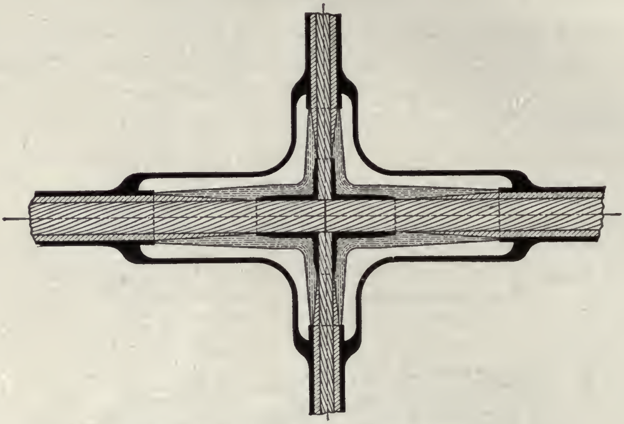


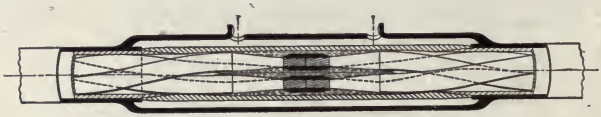
Fig. 75.—Various types of cable-joint construction.

thicker than on the cable itself. Fig. 75 illustrates various types of joint construction.

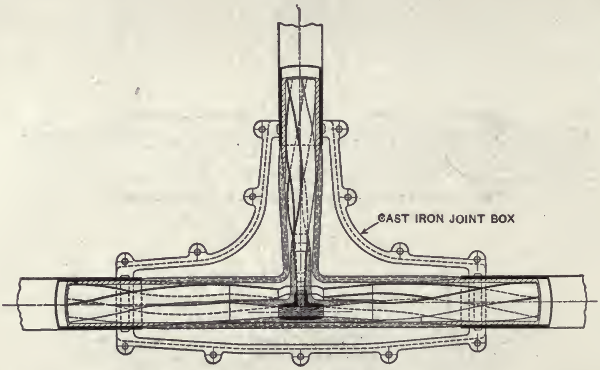
While not a part of joint making, it is perhaps well to say a few words regarding the training of cables in manholes. Great care should be exercised in bending cables into position. Sharp



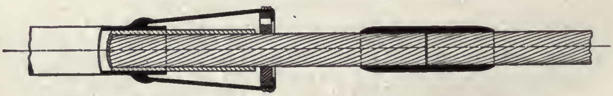
Two-right-angle conductor branch joint.



Straight-way three-conductor cable joint.



Three-conductor right-angle branch joint.



Insulated single-conductor cable connection to a bare cable.

FIG. 75.—(*Continued.*)

bends in high-voltage cables should be avoided, and the cable should never be bent against the edge of the duct but should be shaped around a form to avoid abrading the lead. It should be the duty of the jointer to see that protectors of some sort are left under the cable at the edge of the duct to act as a cushion. Carelessness in observing the above precautions is frequently the cause of considerable trouble.

GENERAL DIRECTIONS FOR MAKING JOINTS ON LEAD-COVERED CABLES

The cables are usually left by the pulling-in gang without very much reference to final arrangement, and it should be the jointer's first duty to inspect the cable thoroughly from the edge of the duct to the sealed end in order to discover any mechanical injury or intrusion of moisture. Where there are several cables to be jointed in one hole, care must be exercised that the corresponding incoming and outgoing sections are spliced together. Absurd as it may seem, such mistakes are sometimes made. After placing protectors in the mouth of the ducts, the cables should be neatly bent and stored around the sides of the manhole and the ends brought into position for jointing at the designated point which should always be such that the joint, when finished, will be between two supports or hangers so that there will be no strain on the joint itself when completed and stowed away.

When the ends of the cables have been allowed to lie for any length of time in manholes where there is water, a very slight imperfection in the soldered end will admit more or less moisture to the insulation. A careful examination should always be made, and if any moisture is evident, the cable should be cut back a little at a time until all evidence of moisture disappears, care being taken not to cut back so far as to render it too short to make the joint. When no more cable can be cut off and moisture is still present, as shown by bubbles when the cable is dipped into hot insulating compound, apply heat to the lead cover of the cable, beginning at the point nearest the duct and very slowly approaching the end of the cable, the object being to drive all moisture to the open end. Wherever it is allowable, a furnace or gasoline torch may be used for this purpose; and if the cable is covered with saturated fiber, a metal screen should be interposed between the flame and the cable to prevent ignition of the fiber. If the use of a furnace or torch is forbidden, or it is unsafe on account of the presence of gas, the heating should be effected by pouring very hot insulating compound over the cable, catching it in a vessel held underneath. Where there is still doubt as to freedom from moisture, it is best to make a careful insulation test before the joint is made. This test may indicate the necessity of replacing the cable section. Never cut off the second section until sure that there is no moisture in the first. There will thus be an opportunity to change the location of the splice in case the other end must be cut back for moisture.

SCORING THE LEAD

When the cables are placed in position and ready for joint, the ends should be marked at the point to which the lead is to be removed, and scored or cut entirely around. This cutting is easily and accurately accomplished by means of a tool which works on the principle of an ordinary pipe cutter.

REMOVING THE LEAD

The lead sheath is then cut lengthwise of the cable from the circular score to the end by the chipping knife, and the piece of lead is removed with a pair of pliers. In making the longitudinal cut which goes entirely through the lead, great care must be exercised not to injure the insulation. The knife should be held at such an angle that it will go through the lead tangent to the insulation (*i.e.*, so that the knife will pass between the insulation and the lead and not cut the insulation), or a special tool may be used.

After the lead has been removed, the parts where the lead was scored should be carefully examined and all sharp edges or projections, which might tend to penetrate the insulation of the cable, should be removed by a knife, or the lead should be slightly belled out by some blunt instrument such as the end of a pair of pliers.

LEAD SLEEVE

When the lead covers of the two cable sections have been thus treated, a lead sleeve, which will later be used in jointing, is slipped over the more convenient end and pushed back out of the way. The lead of this sleeve should be at least as thick as the lead of the cable itself, and in view of its exposed position, may (in the case of thin lead on the cable) be made somewhat heavier to give greater mechanical strength.

Before slipping it on the cable, each end of the sleeve is thoroughly scraped with a shave hook or knife for a length of about 2 in., and the cleaned portion thoroughly smeared with some suitable flux (usually a tallow candle), which, by preventing the formation of the usual film of lead salts, insures a close union of the lead and the wiping metal which is used to make the joint between sleeve and cable sheath. The internal diameter of the sleeve should exceed the diameter over the lead of the cable by ½ in. in the case of single-conductor cables, and by 1 to 1½ in. in the case of multi-conductor cables, or cables for high voltage where high insulation of the splice and maximum separation between the conductors and lead are necessary. The following Table XXIV is somewhat more liberal in allowances for clearance between inside of sleeve and outside of cable, but it is fairly representative of average practice in this respect, as well as in the sleeve lengths.

Table XXIV.—Approximate Data as to Lead Sleeves, Weights of Solder and Splicing Compound for Straight Joints (Two-way)[1]

	Outside diam. of cable, mils	Inside diam sleeve, in.	Length of sleeve, in.	Ozite per joint, gal.	Wiping solder per joint, lb.
Single conductor E. L. & P., up to 6,600 volts..	Up to 550	1	8	0.05	0.9
	551— 950	1½	10	0.10	1.7
	951—1,350	2	12	0.20	2.8
	1,351—1,750	2½	12	0.30	4.2
	1,751—2,150	3	14	0.50	5.5
	2,151—2,550	3½	14	0.60	6.8
Single conductor E. L. & P., above 6,600 volts..	Up to 550	1	10	0.05	0.9
	551— 950	1½	12	0.10	1.7
	951—1,350	2	14	0.20	2.8
	1,351—1,750	2½	16	0.40	4.2
	1,751—2,150	3	18	0.60	5.5
	2,151—2,550	3½	18	0.80	6.8
Multi-conductor E. L. & P., all voltages.......	Up to 800	1½	14	0.20	1.5
	801—1,200	2	16	0.25	2.5
	1,201—1,600	2½	16	0.35	3.7
	1,601—2,000	3	18	0.60	5.0
	2,001—2,400	3½	18	0.80	6.3
	2,401—2,800	4	18	1.00	7.6
	2,801—3,200	4½	20	1.40	8.3

[1] Standard Underground Cable Co.

COPPER CONNECTORS

One of the important features to be considered in the making of joints, as already mentioned, is in the choice of proper copper jointing sleeves. They should be made in suitable lengths for regular underground joints, tinned and well-finished. They are usually provided with an opening along the entire length so as to permit of the solder flowing freely throughout the joint when made, thus insuring a good soldered union. Both ends of the sleeve should be beveled off, to remove sharp edges which would have a tendency to cause a puncture through the insulation after the joint has been finished. Table XXV gives the A. S. & W. Co. standard dimensions of copper sleeves for jointing cables.

TABLE XXV.—STANDARD DIMENSIONS OF COPPER SLEEVES FOR JOINTING CABLES[1]

Size of conductor	Outside diameter of conductor, in.	Outside diameter of sleeve, in.	Thickness of copper, in.	Length of sleeve, in.	Weight per 100 sleeves, lb.
2,000,000	1.6302	2.168	0.268	6.00	280
1,750,000	1.5246	2.027	0.251	5.65	242
1,500,000	1.4124	1.879	0.233	5.30	200
1,250,000	1.2892	1.715	0.212	4.90	150
1,000,000	1.1520	1.532	0.190	4.45	110
900,000	1.0935	1.454	0.180	4.25	88
800,000	1.0305	1.360	0.170	4.05	76
750,000	0.9981	1.327	0.162	3.95	67
700,000	0.9639	1.282	0.159	3.80	62
600,000	0.8928	1.187	0.147	3.60	52
500,000	0.8134	1.082	0.134	3.35	45
400,000	0.7280	0.968	0.120	2.10	36
300,000	0.6321	0.841	0.104	2.75	23
250,000	0.5754	0.766	0.095	2.60	16
0000	0.5275	0.702	0.087	2.45	14
000	0.4700	0.625	0.078	2.25	10
00	0.4180	0.556	0.068	2.10	7
0	0.3730	0.496	0.062	1.95	4
1	0.3315	0.441	0.055	1.80	
2	0.2919	0.388	0.048	1.70	
3	0.2601	0.347	0.043	1.60	
4	0.2316	0.308	0.038	1.50	
5	0.2061	0.275	0.034	1.40	
6	0.1836	0.244	0.030	1.25	
7	0.1635	0.218	0.027	1.25	
8	0.1455	0.194	0.024	1.25	
9	0.1305	0.172	0.022	1.25	
10	0.1155	0.154	0.020	1.25	

[1] American Steel & Wire Co.

The removal of sharp projections of solder from the copper connectors is of utmost importance in the case of high-voltage cables where sharp points or edges act as discharge points to induce puncture of the insulation.

INSULATING THE CONDUCTOR

After the conductors have been connected and soldered together, they are thoroughly insulated with tape of the same material as is used on the cable itself, and to a thickness somewhat greater than that of the cable insulation, as tape applied by hand is never as compact and free from air spaces as when put on by machinery. Where the insulation is thicker than the copper connector, it should be tapered down with a sharp knife to the same thickness as the connector so as to leave no abrupt edges, and to allow the tapes, when applied, to run evenly from connectors to insulation without ridges.

The insulated splice should be thoroughly boiled out with hot insulating compound, which is usually heated in a large pot, the ordinary plumber's gasoline furnace being used. The compound should be of such a temperature as to throw off moisture readily, and yet not hot enough to ignite a piece of heavy paper dipped into it.

The determination of the proper temperature is a matter of practice and is one of the many points in which an expert's experience is of the utmost value.

A large pan held under the splice serves to catch the surplus compound, which can be returned to the pot, reheated and used again. A hot closed pot of compound should not be taken down into a manhole unless it has first been opened on the surface of the ground to ascertain that it is at the proper temperature. Paraffine especially and, in a lesser degree, all insulating compounds, when unduly heated, will ignite when poured on damp insulation, and the result may be to destroy the cable and severely burn the workman.

WIPED SOLDER JOINT

The lead sleeve previously slipped on the cable is now brought into position so as to extend equally over the lead on each cable end, and the ends of the sleeve are dressed down close to the lead of the cable, care being exercised to have the lead sleeve concentric with the cable. The sleeve and the cables are then joined by a wiped solder joint.

FILLING THE SLEEVE

The joint is next filled with hot compound, except in the case of rubber-insulated cables. Two holes are tapped in the sleeve, hot insulation is poured slowly in one hole until it appears at the other, and then in each hole alternately until the joint is completely filled.

If any moisture appears in the joint, as shown by frothing of the insulation, the compound should be allowed to flow freely out of one hole until all moisture is removed.

The joint should be allowed to cool for a suitable period before moving it, and any shrinkage or settling of the insulation should be compensated for by the addition of more compound. This is a particularly important point in the splicing of high-tension cables, and should be carefully watched.

Jointing Rubber-insulated Cables.—The splices on rubber-insulated cables differ from splices on other forms of cable only in the kind of tapes used.

The wire splice is made precisely as hereinbefore described. This splice is then covered by a layer or layers of pure rubber tape spirally applied to a thickness of $\frac{1}{64}$ to $\frac{1}{32}$ in. This is covered by rubber-compound tapes applied spirally until a total thickness slightly greater than the insulation of the cable is secured. Over all is placed a layer of linen tape thoroughly impregnated with rubber to render it adhesive. The lead joint is then made in the regular manner, but is not filled with hot compound. In some instances it is necessary to vulcanize thoroughly the rubber tapes so as to cure the rubber and render it homogeneous, elastic and water-tight. This process should be entrusted only to experts.

Jointing Armored Cables.—When lead-covered cables are provided with steel-wire armor, a joint in the armor wires is required in addition to the joint on the cable, the latter being made in the regular manner. While making the lead-covered joint, the armor wires should be bound by tie wire on either side, and bent back out of the way. When the cable is spliced and the lead joint completed, the cable should be protected with wrappings of jute over the lead sleeve and the armor wires, from one side, bent down and spaced uniformly over the sleeve. The sleeve being larger than the original cable, there will be space between the armor wires, and these are filled by the armor wires from the other side of the joint, the two sets of wires being thus interlaced. If there is not space enough between the wires from one side for all the wires from the other, the surplus wires are cut off short on one section and the corresponding wires on the other section left long enough to butt against the short wires, thus covering the joint completely and evenly with the armor wires. Where the armor wires are thus placed, they are firmly bound together by a tight serving of wires wound in a short spiral around the entire length of the splice and carefully soldered to the armor. A joint thus made will be mechanically as strong as any other part of the cable.

As the durability of a joint is dependent upon the proper execution of what might seem to be the most minute details, a description of some of the methods of making up joints on three-conductor paper cables is printed herewith.

Paper and Cambric Tape-insulated Joints.—The ends of the cable are prepared in the usual manner by stripping off the lead. The paper insulation is trimmed away to expose the conductors. Split copper sleeves are slipped over the conductors that are to be joined and the sleeve is then sweated on with solder. No acid should be used as a flux in soldering, as it is likely to injure the insulation.

The insulation on the conductors on each side of the sleeve should be cut down to a pencil point so as to allow the tape to be built up evenly without butt joints. The best work that can be done by hand will be considerably looser than the machine-wrapped insulation on the main cable, and for that reason the tape should be put on thicker than the original insulation. In applying tape on cables used for voltages over 10,000, a suitable compound should be applied with a brush to each layer of tape. This will tend to prevent the formation of air cells which invariably accompany the taping of a joint and which have been found to impair seriously the insulation of a high-voltage joint. During the progress of the wrapping, the insulation should be boiled out thoroughly by pouring hot compound over the layers of tape to exclude all moisture. Moisture from the hands of the splicer may be sufficient to destroy an otherwise perfect joint.

After all conductors are thoroughly taped and boiled out, a

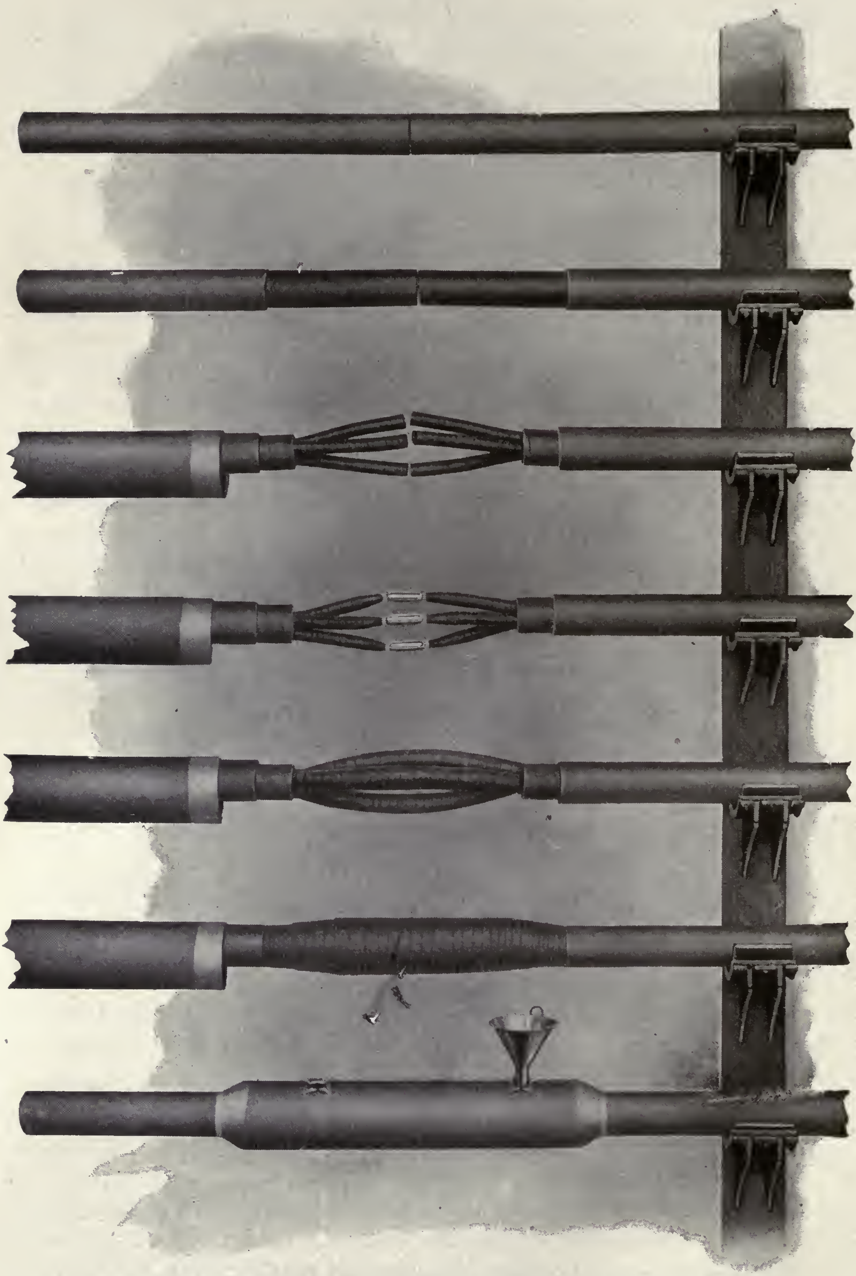


FIG. 76.—Steps in making three-conductor paper-insulated lead-covered cable joint.

small roll of tape should be placed between the conductors to separate them. An outer wrapping of tape should be applied, which is drawn tight and wrapped until it is considerably larger than the original insulation but not too large to permit the lead sleeve to be placed over it. Numerous incisions are then made in the outer wrapping in order to allow the compound to fill up all the voids on the inside. Great care must be taken in punching these holes not to injure the insulation on the individual conductors.

The lead sleeve which has previously been prepared and placed over one of the cable ends, is now beaten into proper form and placed evenly over the joint. The sleeve is then soldered to the cable sheath with a regular wiped joint. The wipes must be absolutely water-tight and should be carefully inspected, especially on the underside of the joint, by means of a small mirror to insure smoothness, solidity, and absence of air holes. This is most important as the presence of small blowholes is known to have caused perhaps more trouble than any other feature in joint making. The various steps in the making of a three-conductor high-tension cable joint are fully illustrated in Fig. 76.

For filling the joint, two holes are punched in the top of the lead sleeve about 3 in. from each end, one to pour compound through and the other to serve as an air vent. The compound should be poured very hot and the pouring continued until the compound overflows at the opposite end. After standing for half an hour or more, the sleeve is refilled, after which the openings in the sleeve are sealed by soldering a small lead patch over each.

Paper-tube Joints.—The Standard Underground Cable Co. recommend the following procedure for making high-voltage paper-tube joints:

Cut off ends of cable square. Cut off lead on one cable at a point approximately 6 in. back from end; and on the other cable approximately 9 in. back from end. (Caution.—The longitudinal cut in lead should be made by inserting cutting knife tangential with the inside curve of the lead sheathing. Circumferential cut should be made by nicking lead only part way through and then tearing by pulling it apart with pliers.) Remove belt insulation to a point about 1½ in. from edge of lead. (Caution.—Inner layers of paper of belt should be torn rather than cut, to prevent damaging insulation on individual conductors.) Pull jute filler back and cut off at point close to end of belt insulation. The individual conductors will now be found to be about 3 in. longer on one cable than the other.

Strip individual conductors of insulation for a distance ½ in. greater than one-half the length of the copper sleeve.

Thread lead sleeving over one of the abutting ends of cable and move back out of the way. Thread large enclosing joint tube, when used, back over cable end and back out of the way. Thread the small jointing tubes over the ends of the long-length individual conductors (*i.e.*, the conductors on the cable and whose lead sheathing was trimmed back 9 in.), and push back far enough to leave copper ends of conductors easily accessible.

Tin conductors thoroughly with hot solder applied by ladle. Insert ends of conductors intended to be connected together, into the split copper connectors, which should preferably be of such size that even when compressed upon the conductor, the longitudinal split will remain open 1⁄16 or 3⁄32 in. With split in copper sleeve uppermost, apply hot solder with a ladle, and when thoroughly heated, compress copper tube. Then sweat tube and connectors thoroughly together, keeping joint as full of solder as possible. Wipe off all fins or points before solder sets. (Caution.—Do not file off fins or sharp points unless the tubes and insulation of all the conductors are protected from falling particles of metal. Do not move the sleeve or joint, otherwise the solder, if it be at about the critical temperature when mealiness appears, may not unite the parts satisfactorily.)

Fill space between end of copper sleeves and insulation on each side with loosely woven and easily impregnated cotton tape. (For previous preparation of cotton tape see below.) Apply similar tape in layers over the copper connector to a diameter equal to the diameter of the insulated conductor. Boil out tape and adjacent cable ends carefully with insulating compound at a temperature of about 375°F. (Caution.—As the tape must have its moisture boiled out in case any is present, and be thoroughly impregnated besides, nothing but very hot compound will suffice.)

After all conductors have thus been connected, move each of the splicing tubes back to cover thoroughly the completed joint on the conductor. (Caution.—Proper position for splicing tube is such that the middle of the tube shall be over the middle of the copper sleeve, or so that the tube shall equally overlap the original conductor insulation at each end.) Fasten each end of a piece of dry cotton tape to the conductor at each side of and bridging the tube, thus holding it permanently in place. Move the enclosing or large splicing tube back over the smaller tubes so that it occupies a middle position. Bind in place with tape in a manner similar to that just described for individual conductors. (Caution.—Do not put wrappings of any sort—either paper, linen or rubber—over the tubes, as this prevents the proper ingress of filling compound into the interstices between tubes and conductors, and between inner and outer tubes, a condition absolutely essential to complete success in a joint of this type.)

Move lead sleeving back into proper position, *i.e.*, so that at each end it overlaps equally the lead sheathing of the abutting cables. Dress down ends of sleeves to fit neatly around cable sheathing. Wipe joint carefully with edges of the wipe at least ¾ in. back from the line at which the lead sheathing and the lead sleeving meet. Make two holes, one at each end and on top of the lead sleeving. One of these is for admission of the hot compound, the other for its overflow. These holes should be of V-shaped form, and the one selected for filling should be preferably on the end farthest away from the paper tubes, and so located that the stream of hot filling compound will strike the paper-belt insulation of the jointed cable. Tilt the joint slightly so that the filling hole will be slightly above the level of the other hole. Pour in filling compound heated to a temperature of from 325°. to 350°F. until it issues from the other hole; and if bubbles appear, indicating moisture in the joint, continue pouring at upper hole and emptying through lower hole until every evidence of moisture disappears. After allowing to settle for ½ or ¾ hr., pour in additional compound, after which seal both holes carefully with solder. (Caution.—A heavy soldering iron properly heated must be used to insure adhesion of plenty of solder around the opening.)

The illustration shown in Fig. 77 indicates the various steps in the making of a tube joint as just described.

Advantages of Paper-tube Joint.—The following points of superiority are claimed for the above type of joint:

(*a*) Absolute certainty of proper insulation and separation between conductors and between conductors and lead, the judgment of the workmen as to these points being entirely eliminated.

(*b*) Freedom from moisture, the tubes being thoroughly impregnated with insulation at the factory by immersion in hot compound.

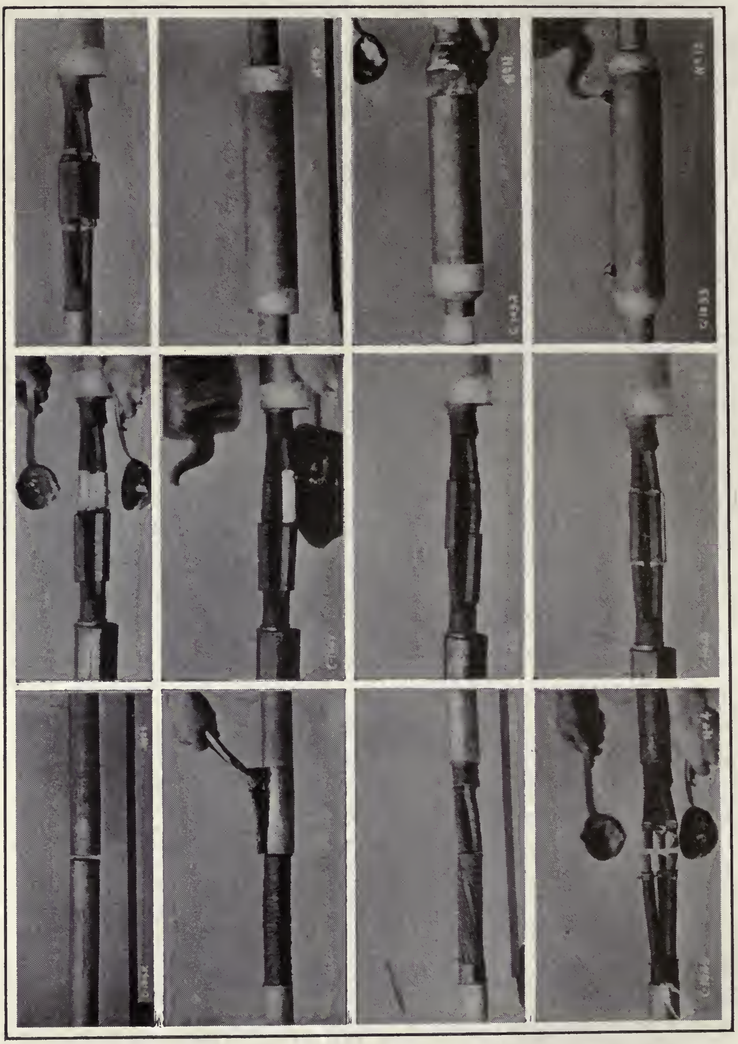


Fig. 77.—Various steps in the making of a three-conductor paper-tube joint.

(*c*) Freedom from air spaces. The fact that there are no convolutions of tape to be penetrated by the compound used in filling the sleeve, makes it certain that the entire joint will be thoroughly filled.

(*d*) Ease of application, with consequent saving in labor and expense.

Sleeve-filling Material.—There seems to be a general impression among cable users who have not carefully investigated the matter, that almost any compound is good enough for a cable joint. Paraffine has met with general favor in spite of its inherent disadvantages. Some of the properties which are considered desirable for a good jointing compound are:

1. High melting point.
2. Adhesiveness.
3. Not brittle at ordinary temperatures.
4. Resists high-puncture tests.
5. Low coefficient of contraction.

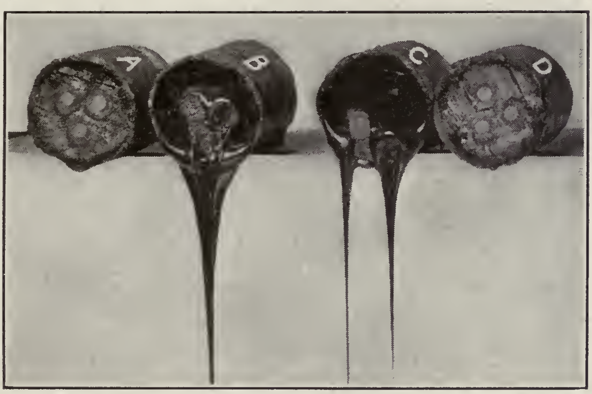


Fig. 78.—Sections of high-voltage cable joints filled with different compounds.

Some of the objections to the use of paraffine are: It does not have the property of sticking tightly to smooth surfaces. It becomes extremely fluid at about 125° or 130°F. At the time of cooling, paraffine has an excessive contraction coefficient which results frequently in voids which have a dielectric strength lower than ordinary atmospheric air.

There are cases where very good results have been secured with compounds of an inferior grade but this constitutes no argument in favor of the reduction of the factor of safety through the use of such inferior compounds since the unfavorable conditions for jointing and operating underground cables almost everywhere existent in cities imperatively demand the use of the best compound available.

In Fig. 78 are illustrated sections of actual test joints on high-voltage cables. *A* and *D* are joints filled with high-grade compound; *B* and *C* with inferior compound offered for similar use. *A* and *B* were exposed to a temperature of 110°F. for 2 hr.; *C* and *D* to a temperature of 80° to 85°F. for 6 weeks. Note the way the high-grade compound held its place in the sleeve, although it remained soft and rubbery to the touch and showed no signs of brittleness. The other compound, soft enough to almost empty the sleeve, was so brittle that at 85°F. a slight blow with a lead pencil broke the streamers into fragments.

Breakdowns solely attributable to the use of inferior insulating compounds or to good compounds which are ill adapted to

FIG. 79.—Viscosity test of cable-sleeve-filling compounds.

the conditions under which they are being used, are of frequent occurrence.

A high coefficient of expansion is indeed somewhat objectionable, but a moderate one must be accepted as unavoidable, if the other desirable characteristics of a good insulating compound are to be obtained in anything like a satisfactory degree.

The necessity for having compound which will keep its place in the joint cannot be overemphasized. In many manholes the joints are somewhat higher than the cables themselves, and where compounds with too light a base are used, there is almost always danger of the compound slowly moving away from the joint into the abutting cable end, it being a peculiar characteristic of some of these compounds that they flow no matter what the temperature is. In such joints, even when they appear very hard and brittle, the compound will be capable of flowing out of extremely small openings, the rate of flow being dependent upon the pressure and temperature. This is well illustrated in Fig. 79, which shows one compound flowing, even though it is hard and brittle, the other compound retaining its elasticity to a large degree and showing almost no sign of movement.

There is an additional reason, however, particularly in high-voltage cable, for keeping the joint full of compound. If any-one will take the trouble to experiment with a copper conductor surrounded with thin layers of insulating material and over which is a thin metallic sheath, he will discover that when various voltages are applied (starting with say 1,500 volts) between the con-

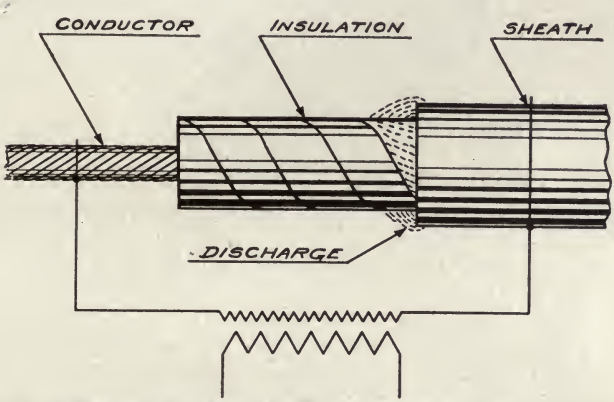


Fig. 80.—Electrical discharge between insulation and conductor of a cable.

ductor and sheath, there will appear, when the experiment is made in a sufficiently dark room, an electric discharge accompanied by a glow of light, where the metallic sheathing comes into contact with the cable insulation (see Fig. 80). This electrical discharge is of the corona or brush type, and with it there is given off a considerable quantity of ozone, dependent in amount, among other things, upon the thickness of insulation which separates the conductor and the sheath, and upon the voltage applied. Now this ozone is being produced in a manner very similar to that which has been adopted so extensively during the last few years for sterilizing water by oxidation of its vegetable and animal impurities. Its effect upon vegetable insulating material, such as paper, fiber, varnished cloth, rubber, etc., is very deleterious, and ultimate destruction of the insulation almost invariably ensues where it is exposed to the action of newly produced or nascent ozone for any considerable time. So long as the edge of the sheath and the neighboring wall of cable insulation are thoroughly covered by insulating compound, so that air is excluded, there will be little or no deterioration of the insulation at these points.

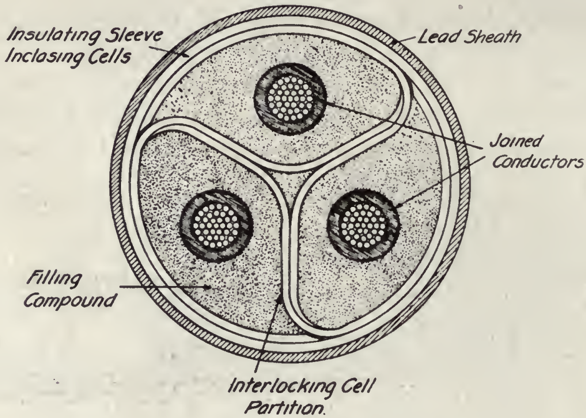


FIG. 81.—Conducell cable-joint insulators.

Conducell Cable-joint Insulators.—There has lately been placed on the market a new design of insulating form for use in making cable joints. These forms are made of thin sheets of mica, cemented together and made up over an iron form. The insulators for the individual conductors are so made as to fit

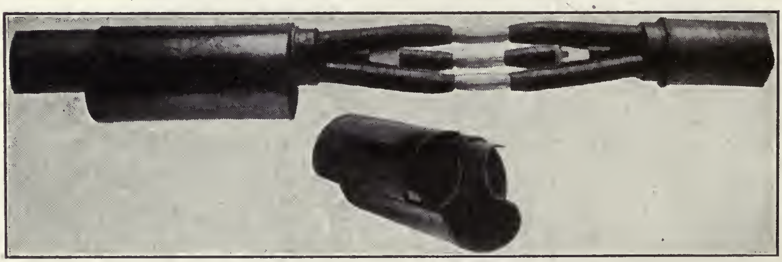


FIG. 82.—Cable joint made with Conducell insulators.

into one another, as illustrated in Fig. 81, giving a round outer surface, over which the outer cylindrical sleeve is slipped. A porcelain spacer at each end holds the separators symmetrically about the three conductors and centrally in the lead sleeve, Fig. 82.

The advantages claimed for this construction are:

1. It is not necessary to cut the insulation back so far as when tubes or hand wrapping are used, as the forms do not have to be slipped back on the conductors but can be put into position from the side after the conductors are jointed.

2. The conductors do not have to be bent as much as when hand-wrapped. This bending is apt to crack the paper near the edge of the belt.

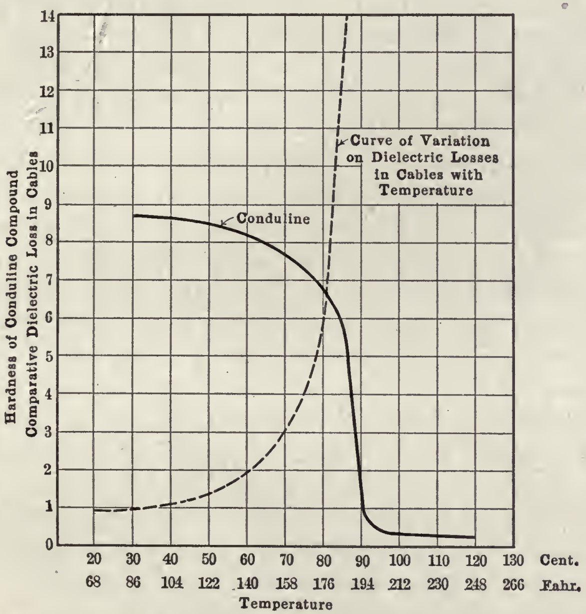


Fig. 83.—Hardness of Conduline compound and comparative dielectric losses in cables.

3. The joint can be made up in about one-half the time required to make a hand-wrapped joint.

4. The material used possesses very high dielectric properties and does not absorb atmospheric moisture to any appreciable extent.

Advantages 1 and 4 are peculiar to the joint material here mentioned, while 2 and 3 would apply to any type of tube joint.

For the filling of these joints, a compound has been developed which is especially suited to the purpose.

The curve, Fig. 83, illustrates the properties claimed for the filling compound mentioned.

The mica forms are supplied in three different grades:

4-in., No. 209 for use on from 2,000 to 9,000 volts.
4-in., No. 1,014 for use on from 10,000 to 14,000 volts.
5-in., No. 1,525 for use on from 15,000 to 25,000 volts.

Laboratory tests indicate that joints made up with the No. 1,014 material break down at from 90,000 to 100,000 volts between conductors. On other tests, joints heated to 70°C. stood 50,000 volts 2 hr. or more after a 14-hr. preliminary run at 50,000 volts at room temperature.

In none of these tests did the breakdown occur in the joint proper, but all were in the cable beyond the joint, usually under or beyond the wipe.

Several companies have these joints in service on 8,000- and 15,000-volt circuits without failure and have adopted the material as standard construction on emergency work because of the reduced time required to return feeders to service.

High-voltage Vacuum Joint.—The tendency toward centralization of power generation has recently necessitated the operation of underground cables at considerably increased transmission voltages.

While the cable itself is so designed as to operate satisfactorily at high voltages, a great deal of trouble has been experienced due to breakdowns in the cable joints. The joints employed when cables were first used to transmit at voltages higher than 13,000 to 15,000 were of essentially the same type of construction as the joints which had been in general use and which had given satisfactory service at the lower voltages.

Experience has shown, however, that joints as ordinarily constructed frequently fail at operating voltages in excess of 15,000.

A series of high-voltage tests made by a large operating company on joints using various types of compound failed to give uniform and satisfactory results. Paraffine compounds shrink during cooling and leave voids in the joint space. High-melting-point gum compounds, because of their viscosity, do not completely fill the crevices and have the additional disadvantage that short-circuit conditions develop cracks in the compound which are not self-healing.

These disadvantages are not serious enough to cause much trouble at lower voltages, but under high-voltage stresses the danger of joint breakdowns is greatly increased.

Experiments have been made on a joint insulated with liquid fillers, such as rosin or mineral oil, which are fluid at low temperatures. These joints gave uniformly good results, but some difficulty was experienced from the leaking of the oil from the joint space along the cables. This difficulty was overcome after considerable experimenting; and a very satisfactory high-voltage joint has been designed and patented by Mr. Philip Torchio, chief electrical engineer of the New York Edison Co.

In making this joint the cutting of the insulation and the application of new insulation conforms to a special gage which is part of the cable-splicers' equipment. The lead sheath is stripped off in the usual way preparatory to jointing. After the conductors are soldered, all metal points and burrs are removed by filing and with emery cloth, and the space between the conductors is thoroughly cleansed of all particles of emery and copper. A liberal application of compound is given to the conductor to be insulated, and impregnated-paper tape ⅞ in. wide and 3 mils thick is wrapped tightly around it. Each layer of tape receives an application of compound before the next is applied and each turn of the tape is drawn tight so as to squeeze out any air bubbles which might collect in the space between the layers. The hand-applied insulation at its thickest point is about one and one-quarter times that of the mill-applied insulation.

After each of the three conductors has received its applied insulation, the space between the conductors is filled with compound, and strips of jute, laid parallel to the conductors, are packed into the space so as to completely fill it; and the whole is then saturated with compound. The belt insulation of impregnated-paper tape, 1 in. wide and 6 mils thick, is next applied, and the same general method of application is adhered to as was used in insulating the individual conductors, so as to eliminate pockets and voids.

The finished belt is pierced in six places with the idea of facilitating the removal of air and complete impregnation with the compound, and is encased in a metal sleeve, made of 30-mesh No. 30 copper wire gauze, which covers the joint and extends about ½ in. under the belled ends of the lead sheath. The metal sleeve is drawn tight so as to bear evenly on all parts of the splice, and the belled ends of the sheath are beaten down and soldered to the gauze.

The use of this metal sleeve is important in that it establishes

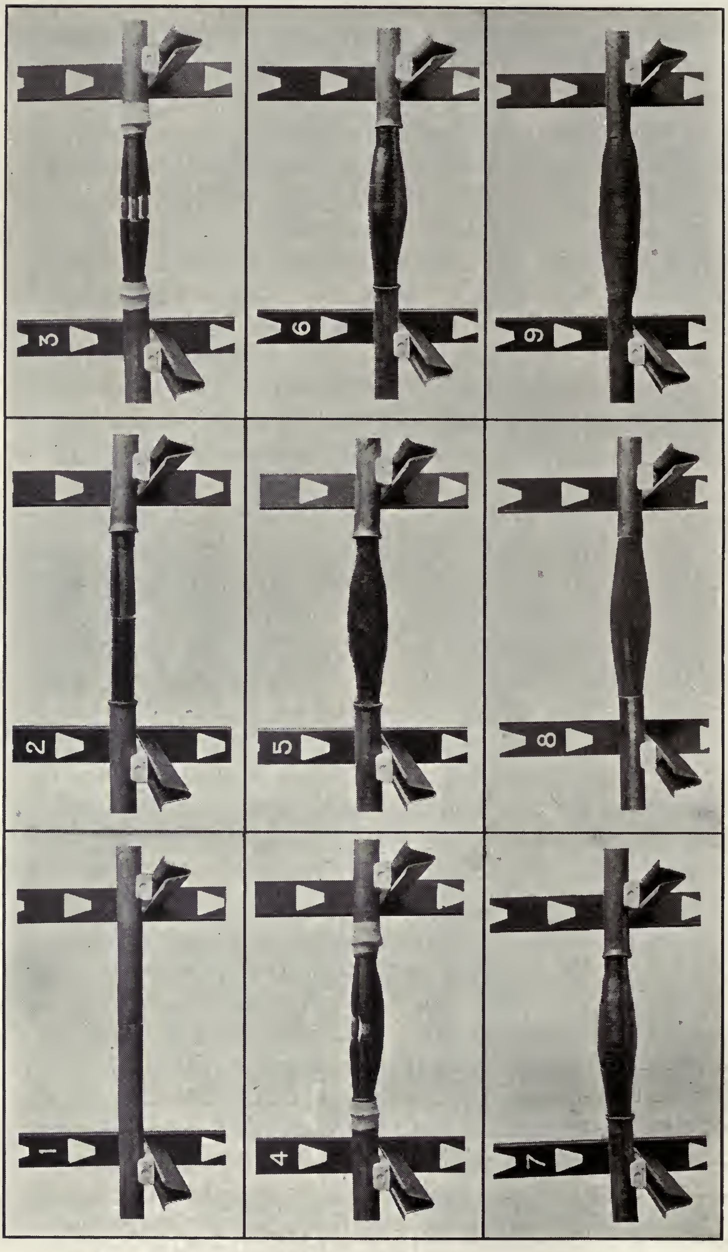


Fig. 84.—Steps in the process of splicing 25,000-volt joint.

1. Cut-ends of cables in position for joining. 2. Lead armor removed from cable ends and belled. 3. Paper belt stripped from insulated conductors, cheesecloth wrapped around belled armor, and connectors soldered to conductors. 4. Insulation on each side of connectors has been tapered and lower conductor wrapped with paper tape. 5. Spaces between conductors filled with compound and impregnated jute rope. 6. Paper-tape belt applied. 7. Holes pierced through compound and belt and passing between conductors. 8. Copper-gauze stocking applied around joint. 9. Gauze wrapped with cotton wick.

permanently the potential gradient between the inner conductors and ground regardless of the dielectric material in the annular space between the sleeve and the sheath.

Over the gauze sleeve is wound a cotton wick, 1½ in. wide and about 3/32 in. thick. The middle of the splice is covered by only

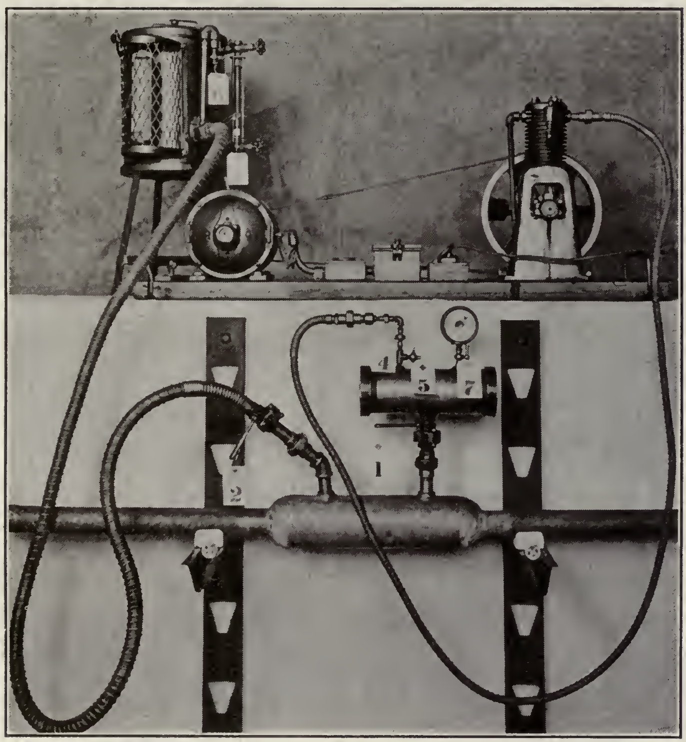


Fig. 85.—Connections of apparatus for creating vacuum in joint and filling with compound.

At the upper left-hand corner of the illustration is a reservoir and kerosene furnace for heating compound to 275°F. Attached to the reservoir is a thermometer with a range of 50 deg. to 450°F. and a gage glass for indicating the height of compound in the tank. At the right is a 3-in. by 3.5-in. vacuum pump which is belt-driven by a 90-volt 0.5 hp. motor. Attached to the right-hand end of the cable-joint sleeve is a suction chamber equipped with a vacuum gage. This chamber is connected with the pump by a 0.5-in. flexible spiral-metal hose capable of withstanding more than 29-in. vacuum. The hose between the compound reservoir and the left-hand end of the splice is 1 in. in diameter. Valves Nos. 1, 2 and 3 are Lunkenheimer quick-acting lever-type and valves Nos. 4, 5, 6 and 7 are two-way straight pet cocks.

one layer, but at the ends the covering is several layers thick, and when the wick is saturated with compound, these end layers act as a reservoir which supplies the center layer with compound by capillary attraction, thus keeping the splice saturated at all times. The joint is then filled with compound under high-vacuum conditions. The various steps in making this joint are shown in Fig. 84.

FIG. 86.—Joint-filling apparatus mounted on electric vehicle.

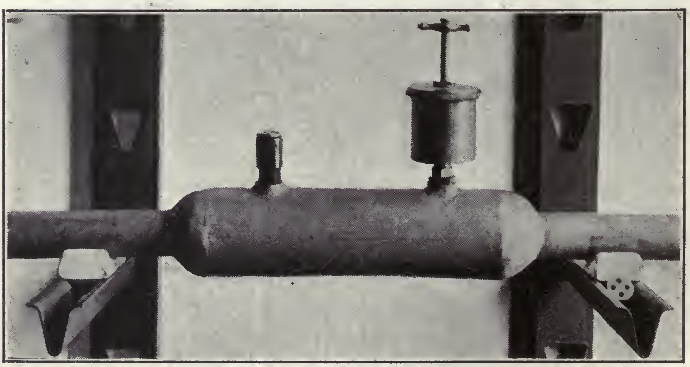


FIG. 87.—Apparatus supplying compound to compensate for absorption by cable.

Fig. 85 illustrates an assembly of the apparatus necessary for filling and sealing the joint; and the illustration in Fig. 86 shows the vacuum machine in use on an electric truck. When tests show that there are no leaks in the connections or joints and at least 27 in. of vacuum is obtained, the pumping is continued for about 15 min. to increase the vacuum to 28 in. or more. Then the compound is allowed to flow in, after which the apparatus is disconnected.

A pressure cup, Fig. 87, is connected to one of the splice plugs and the compound is forced through until it overflows at the other nipple, which is then capped. The cup is filled up with compound, the T-handle screwed out to its furthest position and the spring-actuated piston forces compound into the joint space to compensate for any contraction which may occur during cooling. The pressure cup is left in place until the joint space is completely

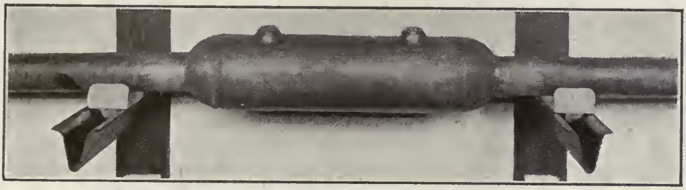


FIG. 88.—Completed cable joint with apertures closed by plugs.

filled; the cup is then disconnected, the nipple capped, Fig. 88, and the joint is ready for operation.

This method of joint construction has been used on three 25,000-volt feeders of the United Electric Light & Power Co. for supplying power to the New Haven Railroad at the West Farms Substation.

Unit Packages for Cable-Joint Material.[1]—Considerable advantage may be gained in putting the material for cable joints in unit packages. One company has used this method in the construction of joints for three-conductor, 350,000-cm., sector-type, 25,000-volt cable feeders. Reference to the special construction of this type of joint is made in another part of this chapter, but it may be stated here that each joint was made to a template and the necessary material was delivered on the job in cans or packages, Fig. 89, two cans being used, one for the filling compound and one for the paper tape and other miscellaneous insulating material.

All of this insulating material was prepared at the cable factory,

[1] N.E.L.A. Underground Committee report, 1916.

submitted to 29 in. vacuum and impregnated with the same compound which was used in filling the joint. The insulating material is placed in the can in layers in the order required to make up the joint, so that all of the material in each layer has to be used in its entirety in each successive operation. The illustration shows all the material used to make one complete joint of this type.

Another company reports the following practice:

When the lead sleeve is 3 in. or larger in diameter, this sleeving is cut to the exact length required for the joint, wooden end plugs and through bolts are used to seal the ends, and the tape, solder, copper sleeves and soldering paste are placed within the sleeve.

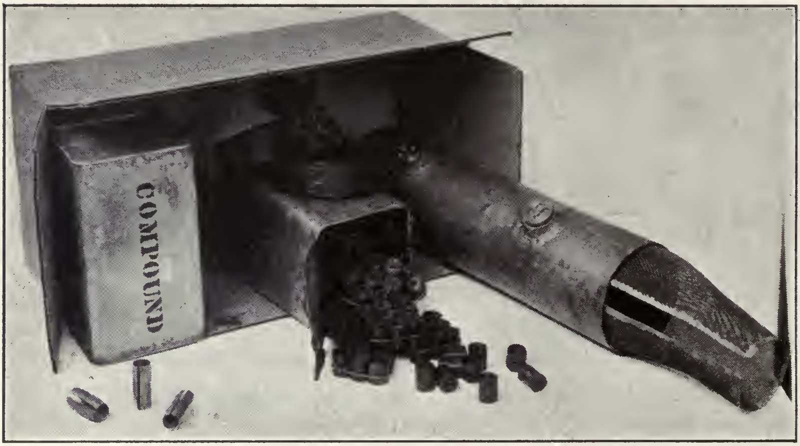


Fig. 89.—Contents of sealed-unit package.

If the package is sent out in advance of the work, the ends are sealed by dipping in melted paraffine.

When the sleeve is smaller than 3 in. in diameter, a pasteboard or sheet-metal container is used to hold the lead sleeve and other material. The material is placed in the pasteboard container if it is to be used immediately, and in the sheet-metal container if it is to remain on the job a day or two before being used. The latter is necessary in order to keep the tape dry. Each package made up for No. 6 and No. 0 single-conductor cable contains material for four joints.

As the exact quantity of material required is sent out in each package, uniform joints are secured. Less time is required on the job to get material ready for the joints because the lead sleeve is cut to the proper length and all material is in a form convenient to handle. There is also considerable saving in the storeroom, as these packages can be made up during slack time and are more quickly and easily handled when delivered.

Protection of Cables in Manholes.—In an underground system where cables are carrying from 2,000 to 5,000 kw., damage to such cables becomes a matter of serious consequence, and their protection from mechanical injury, especially in manholes, is very important.

In order to prevent trouble on one cable from communicating to the other cables in the same manhole, it is desirable to cover the cables in manholes with some type of fireproof covering. The principal types of protection used are as follows:

1. Concrete shelves.
2. Asbestos tape saturated with silicate of soda.
3. Asbestos tape covered with a soft-steel band armor.
4. Split-tile duct with cemented joints.
5. A cement-mortar coating with ¼ in. rope bond.

Concrete shelves make a good protection between cables on the several shelves but, without other protection, do not prevent trouble in one cable from extending to others on the same shelf. Nor is it feasible under ordinary conditions to extend the shelves right up to the conduit end, so that with this scheme of protection the cables are ordinarily exposed to damage when they enter and leave the manhole. These are the most vulnerable points in any scheme of protection, and are also the points at which repairs to cables are the most awkward and expensive.

In some cases specially designed octagonal-shaped manholes have been used, receiving but two cables on the same horizontal plane, one turning to the right and one to the left, giving very gradual bends and resting throughout their length on reinforced-cement shelves 1 in. thick. In the construction of these shelves expanded metal of 1 in. mesh is stretched in forms, into which the concrete is poured, a mixture of 1 part cement to 2 of sand being used. A plan and elevation of a cable manhole of this type is shown in Fig. 90.

The shelves are removable and are laid upon angle irons built into the manhole walls. These barriers protect the cables from being walked upon by careless workmen, or struck by ladders, falling tools, etc. They also are considered a protection above and below in case of severe short-circuit in adjacent conductors; moreover, the weight of the cables is quite uniformly distributed, which is a considerable advantage over the method of supporting them from manhole cable racks. These shelves cost about 12 to 15 cts. per sq. ft. They need be manufactured and added only as the multiplication of cables in the conduit line warrants.

The several forms of asbestos-tape protection that have been used for many years serve to protect cable from flame due to gas

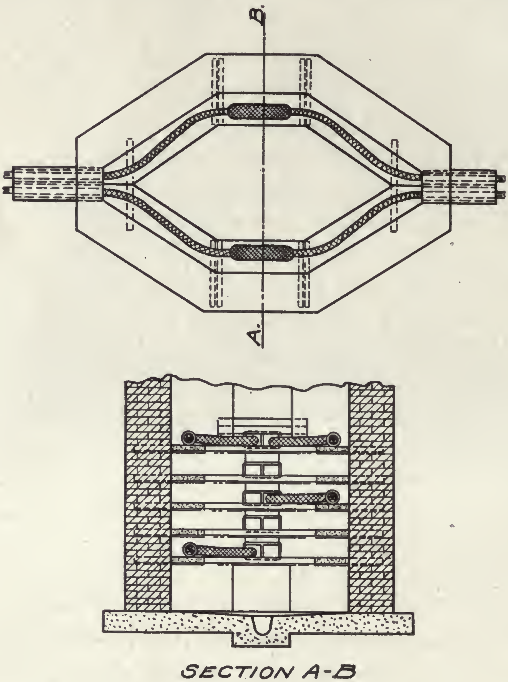


FIG. 90.—Concrete shelves in manhole.

burning in the manhole or from similar flames, but will not withstand the action of an arc at short range. Asbestos, therefore, cannot be considered a reliable form of protection where immunity from troubles of this kind is desired. The asbestos coverings, furthermore, are not suitable for the protection of cable sheaths in wet manholes where stray currents are in evidence. Electrolytic action appears to be accelerated by the presence of the asbestos wrapping, the cause apparently being due to chemical decomposition of the contents of the asbestos covering under conditions which promote rapid destruction of cable sheaths.

Split tile laid on concrete or other types of shelves has been used by a number of companies as a protective covering. Several manufacturers make split tile in straight sections of regular length as well as in short, straight lengths and with various degrees of curvature. There still exists with this type of protection the difficulty of applying the protection right up to the end of the conduit; and while it has been used in the past in large quantities, its use has been abandoned in favor of the cement-mortar covering. Although tile is fireproof in the ordinary sense, it will melt and flow in the case of a severe electric arc, and when this occurs, the cable is exposed to the arc which melted the tile. The tile is also injured by manhole explosions. It is difficult to cement the joints properly so that there are, in general, a number of weak points in the covering in each manhole. In addition, there is considerable difficulty in a crowded manhole in tracing individual cables after all have been covered with tile. The prices demanded by the tile manufacturers for the split-tile duct in straight pieces and in bends were of considerable influence in the decision to abandon this type of covering.

The cement-mortar coating is not affected by manhole explosions, and although the quality of the concrete and its strength may be seriously affected by the arc, it will in general remain in place and serve as a protection until it has been mechanically removed. The companies that have tried this type of protection are highly impressed with its value, and freely recommend its adoption.

In determining the type of protection to be used, the heat-resisting qualities of the covering are of more importance than the heat-conducting qualities. Even when covered with the best non-conductor, the cables in the manholes will probably be cooler than the cables in the conduit. The type of covering used, therefore, has little, if any, influence on the carrying capacity of the cables.

The cost of protecting cables by the several methods described will, under ordinary circumstances, range between 20 and 30 cts. per lin. ft. of cable.

Recent tests made to determine the relative value of two types of protective covering for cables show very clearly the marked superiority of cement mortar as compared with asbestos and steel-tape covering. Briefly, the tests showed that a cable protected with cement mortar was much less damaged by an arc of 425 amp. for 101 sec. than was a similar cable with asbestos and steel-tape covering by an arc of 450 amp. for 35 sec.

An objectionable feature connected with the asbestos covering is the presence of the iron banding tape which may become grounded and so actually involved in the arc circuit, which condition could not exist where the cement covering is used.

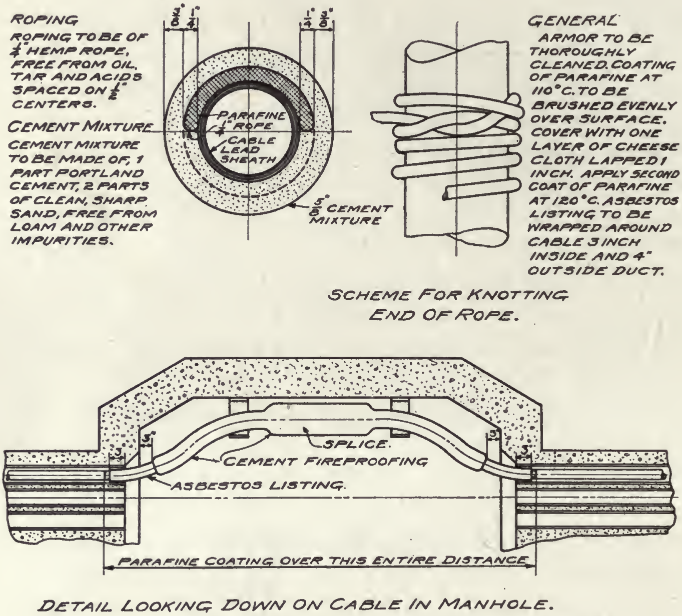


FIG. 91.—Method of fire proofing cables in manhole.

Fig. 91 shows the method of fireproofing cables with cement mortar. In applying the cement mortar, the lead sheath of the cable is first cleaned and then coated with paraffine brushed on evenly. A cover of cheese cloth is then applied, over which the rope is wound, spaced about ½-in. centers. The cement mortar of a mixture of 1 part Portland cement and 2 parts of clean sharp sand is then placed over the rope by hand with leather pad and smoothed down with a trowel to a thickness of ⅝-in. The method of protection illustrated in Fig. 91 provides for asbestos listing to be wrapped around the cable 3 in. inside and 4 in. outside the duct. This plan need not be followed when the space in the manhole will allow the cement covering to be carried right up to the duct and so make the protection practically continuous with the conduit.

Cement armor has been found to be of considerable protection to cables in cases where they might be accidentally struck by tools, etc., and serves also to prevent the cables from being bent and twisted by men not conversant with the proper handling of this material.

Current-carrying Capacity of Cables.—The current-carrying capacity of insulated copper cables sheathed with lead depends primarily upon:

(*a*) The size and number of conductors and their relative position.

(*b*) The ability of the insulating material to withstand high temperatures and to conduct heat away from the copper conductors; this latter being in turn dependent upon the kind of insulation and its thickness.

(*c*) The initial temperature of the medium surrounding the cable.

(*d*) The ability of the medium surrounding the cable to dissipate heat with small temperature rise.

(*e*) The number of operating cables in close proximity and their relative position.

Where a number of insulated conductors are under the same sheath, they are subject to an interchange of heat somewhat similar to that which takes place when a number of separate cables are laid closely together; and for that reason each conductor of a multi-conductor cable will have a smaller current-carrying capacity than a single-conductor cable. If the various conductors are separately insulated and laid together in the form of flat or round duplex or triplex cables, their carrying capacity will be greater than if they are laid up in the form of concentric cables. Assuming that unity represents the carrying capacity of single-conductor cables, the capacity of multi-conductor cables would be given by the following:

Two-conductor, flat or round form	0.87
Three-conductor, triplex form	0.75
Two-conductor, concentric form	0.79
Three-conductor, concentric form	0.60

In any cable the area from which heat is dissipated is proportional to the circumference of the conductor or (since the circumference varies as the diameter) upon the diameter of the conductor, while the cross-section of the conductor varies as the square of the diameter. Hence the size of conductor varies much more rapidly than its heat-radiating surface, and, in consequence, the amperage per square inch or circular mil of copper section must be less for large size conductors than for small in order to have the same rise of temperature under the same conditions. The usual formula for carrying capacity, $\text{Current} = \frac{(\text{Diam. of Cond.})^{3/2}}{\text{A constant}}$, takes account of this fact but not to a sufficient degree, and we find that for cables as ordinarily used in underground work, a more correct expression is $\text{Current} = \frac{(\text{Diam. of Cond.})^{5/4}}{\text{A constant}}$.

Rubber insulation is a somewhat better heat conductor than dry or saturated paper, and, therefore, when applied to the same size conductor in equal thickness will permit of a larger current flowing in the conductor for the same rise of temperature above the surrounding air. On the other hand, rubber deteriorates much more rapidly at high temperatures than does saturated paper, and while this disadvantage is apparently compensated for up to about 150°F. by its superior heat-dissipating qualities, at higher temperatures deterioration takes place, finally becoming so serious that the value of the material as an insulating medium disappears in a comparatively short time.

As the thickness of the insulation is increased, the temperature of the conductor, with any given current flowing, gradually increases and, therefore, the current-carrying capacity is reduced. This reduction in capacity, however, is not very great, being in the ratio of about 93 for $^{14}/_{32}$-in. insulation to 100 for $^{7}/_{32}$-in. insulation, so that the values in the table given below should be slightly decreased when greater thicknesses than $^{7}/_{32}$-in. are used.

As it is the final temperature reached which really affects the carrying capacity, the initial temperature of the surrounding medium must be taken into account. If, for instance, the conduit system parallels steam or hot water mains, the temperature of 150°F. (which has been assumed in Table XXVI to be a maximum for safe continuous work on cables) will be reached with lower values of current than would otherwise be the case; and as 70° is the actual temperature which has been assumed to exist in the surrounding medium prior to loading the cables, any increase over 70° must be compensated for by reducing the current carried.

Table XXVI.—Recommended Current Carrying Capacities for Cables and Watts Lost per Foot*

For each of four equally loaded paper-insulated lead-covered cables, installed in adjacent ducts in the usual type of conduit system where the initial temperature does not exceed 70°F., the maximum safe temperature for continuous operation being taken at 150°F.

(Copyright by Standard Underground Cable Co.)

Size B. & S. G.	Safe current, amp.	Watts[1] lost per ft. at 150°F.	Size, cm.	Safe current, amp.	Watts[1] lost per ft. at 150°F.
14	18	0.97	300,000	323	4.22
13	21	1.03	400,000	390	4.61
12	24	1.09	500,000	450	4.91
11	29	1.15	600,000	505	5.16
10	33	1.25	700,000	558	5.36
9	38	1.39	800,000	607	5.56
8	45	1.53	900,000	650	5.71
7	53	1.67	1,000,000	695	5.86
6	64	1.85	1,100,000	740	6.01
5	76	2.08	1,200,000	780	6.13
4	91	2.31	1,300,000	820	6.25
3	108	2.54	1,400,000	857	6.37
2	125	2.77	1,500,000	895	6.49
1	146	3.00	1,600,000	933	6.61
0	168	3.23	1,700,000	970	6.73
00	195	3.46	1,800,000	1,010	6.85
000	225	3.69	1,900,000	1,045	6.97
0000	260	3.92	2,000,000	1,085	7.09

* Standard Underground Cable Co.

[1] This column represents the amount of energy which is transformed into heat and which must be dissipated. It is what is usually called the I_2R loss and it is figured by using for I the current values given; and for R the resistance of the respective conductor at a temperature of 150°F.

Note: The table is compiled from a long series of tests made by the Standard Underground Cable Co., in conjunction with the Niagara Falls Power Co.

For rough calculations, it will be safe to use the following multipliers to reduce the current-carrying capacity given in Table XXVI to the proper value for the corresponding initial temperatures:

Initial temperature.....	70	80	90	100	110	120	130	140	150
Multipliers............	1.00	0.93	0.86	0.78	0.70	0.60	0.48	0.34	0.00

The formulæ and tables prepared by Mr. H. W. Fisher, and given in the handbook of the Standard Underground Cable Co., have been found to give excellent satisfaction in practice, and are here reproduced through the courtesy of that company.

Table XXVII.—Equivalent Conductor Areas

Of Single Conductor of Any Size, from 0000 to 15, in a Stated Number of Smaller Conductors[1]

B. & S. G. No.	In 2 conductors	In 4 conductors	In 8 conductors	In 16 conductors	In 32 conductors	In 64 conductors	In 2 conductors, one each of
0000	No. 0	No. 3	No. 6	No. 9	No. 12	No. 15	Nos. 00 and 1
000	1	4	7	10	13	16	0 and 2
00	2	5	8	11	14	17	1 and 3
0	3	6	9	12	15	18	2 and 4
1	4	7	10	13	16	.....	3 and 5
2	5	8	11	14	17	.....	4 and 6
3	6	9	12	15	18	.....	5 and 7
4	7	10	13	16	.....	.....	6 and 8
5	8	11	14	17	.....	.....	7 and 9
6	9	12	15	18	.....	.....	8 and 10
7	10	13	16	.....	.....	.....	9 and 11
8	11	14	17	.....	.....	.....	10 and 12
9	12	15	18	.....	.....	.....	11 and 13
10	13	16	.....	.....	.....	.....	12 and 14
11	14	17	.....	.....	.....	.....	13 and 15
12	15	18	.....	.....	.....	.....	14 and 16
13	16	.....	.....	.....	.....	.....	15 and 17
14	17	.....	.....	.....	.....	.....	16 and 18
15	18						

For the same temperature rise more current can be carried by using divided circuits and the greater the number of divided circuits for the same equivalent cross-section the greater the amount of current that can be carried. See Table XXVI, Carrying Capacities.

[1] Standard Underground Cable Co.

The temperature which the insulation of underground cables will withstand is the condition which limits the current which may be carried, and it is extremely important that this temperature shall not exceed its critical value. Within a limited range the temperature increments are directly proportional to the increments of I^2R, but a point will be reached where this proportionality no longer exists, and it will be found that the temperature increase per unit increase in I^2R continually becomes larger. In the case of cables used for direct current, the temperature rise of the cable (other conditions being equal) depends solely upon the I^2R loss; and for low-voltage alternating-current cables this is approximately true.

However, when a cable is used for carrying alternating current at a high voltage, the heat due to dielectric hysteresis is added to the heat produced by ohmic resistance, and the effect is a lowering of the temperature at which the insulation may be safely operated.

The operation of high-tension alternating-current cables of over 10,000 volts at too high a temperature is especially dangerous because the effect of dielectric losses on temperature rise is cumulative. It has been found that after the safe temperature has been passed, the leakage currents through the dielectric increase rapidly, causing increased heating and facilitating the passage of more and more leakage current. If this process continues unchecked, the failure of the insulation will quickly result.

Excessive operating temperature, if continued for a considerable length of time, has a deteriorating effect which is permanent and which reduces very materially the useful life of a cable.

There is a lack of accurate information such as would enable an operating company to know when the danger point in cable operation is reached. It is believed that, because of this lack of information, the tendency, in underground practice, is to underload rather than overload the cable system. When the magni-

TABLE XXVIII.—RECOMMENDED POWER-CARRYING CAPACITY IN KILOWATTS OF DELIVERED ENERGY[1]

Three-conductor, Three-phase Cables

Size in B. & S. G.	Volts							
	1,100	2,200	3,300	4,000	6,600	11,000	13,200	22,000
	Kilowatts							
6	92	183	275	333	549	915	1,098	1,831
5	109	217	326	395	652	1,087	1,304	2,174
4	130	260	390	473	781	1,301	1,562	2,603
3	154	309	463	562	927	1,544	1,854	3,089
2	179	358	536	650	1,073	1,788	2,145	3,575
1	209	418	626	759	1,253	2,088	2,506	4,176
0	240	481	721	874	1,442	2,402	2,884	4,805
00	279	558	836	1,014	1,674	2,788	3,347	5,577
000	322	644	965	1,172	1,931	3,217	3,862	6,435
0000	372	744	1,115	1,352	2,231	3,717	4,462	7,435
250,000	413	827	1,240	1,503	2,480	4,132	4,960	8,264

These tables are based on the recommended current-carrying capacity of cables given in Table XXVI. A power factor = 1, was used in the calculation and hence the values found in the last table are correct for direct currents. For alternating current the kilowatts given in both tables must be multiplied by the power factor of the delivered load.

[1] Standard Underground Cable Co.

TABLE XXVIII.—RECOMMENDED POWER-CARRYING CAPACITY IN KILOWATTS OF DELIVERED ENERGY.—*Continued.*

Single-conductor Cables, A.C. or D.C.

Size in B. & S. G.	Volts							
	125	250	500	1,100	2,200	3,300	6,600	11,000
	Kilowatts							
6	8.0	16.0	32	70	141	211	422	704
5	9.5	19.0	38	84	167	251	502	836
4	11.4	22.8	45	100	200	300	601	1,001
3	13.5	27.0	54	119	238	356	713	1,188
2	15.6	31.2	62	138	275	413	825	1,375
1	18.3	36.5	73	161	321	482	964	1,606
0	21.0	42.0	84	185	370	554	1,109	1,848
00	24.4	48.8	97	215	429	644	1,287	2,145
000	28.1	56.3	113	248	495	743	1,485	2,475
0000	32.5	65.0	130	286	572	858	1,716	2,860
300,000	40.4	80.8	162	355	711	1,066	2,132	3,553
400,000	48.8	97.5	195	429	858	1,287	2,574	4,290
500,000	56.3	112.5	225	495	990	1,485	2,970	4,950
600,000	63.1	126.3	253	556	1,111	1,667	3,333	5,555
700,000	69.8	139.5	279	614	1,228	1,841	3,683	6,138
800,000	75.9	151.8	304	668	1,335	2,003	4,006	6,677
900,000	81.3	162.5	325	715	1,430	2,145	4,290	7,150
1,000,000	86.9	173.8	348	764	1,529	2,294	4,587	7,645
1,100,000	92.5	185.0	370	814	1,628	2,442	4,884	8,140
1,200,000	97.5	195.0	390	858	1,716	2,574	5,148	8,580
1,400,000	107.1	214.3	429	943	1,885	2,828	5,656	9,427
1,500,000	111.9	223.8	448	985	1,969	2,954	5,907	9,845
1,600,000	116.6	233.3	467	1,026	2,053	3,079	6,158	10,263
1,700,000	121.3	242.5	485	1,067	2,134	3,201	6,402	10,670
1,800,000	126.3	252.5	505	1,111	2,222	3,333	6,666	11,110
2,000,000	135.6	271.3	543	1,194	2,387	3,581	7,161	11,935

tude of the investment called for in this branch of the industry is considered, the importance of increasing the carrying capacity of cables to the maximum possible value is realized.

The current-carrying capacity of rubber, cambric and paper insulated cables, as recommended by the General Electric Co., is given in Table XXIX.

The problem of determining the proper loading for underground cables remains to a large extent unsolved, but more and more attention is being given to this subject, and it is, therefore, very desirable that operating companies and cable manufacturers work in conjunction with the view to the formulation of a set of standard rules.

Table XXIX.—Current-carrying Capacity

Rubber, Cambric and Paper Cables[1]

Under ordinary conditions a cable will attain about 60 per cent. of its total rise in temperature during the first hour, 30 per cent. during the second hour, the final maximum being gradually reached during several following hours.

Concentric cables will safely carry about 20 per cent. less current on each conductor than the same size of single conductor cable. Four-conductor cables, 10 per cent. less than same size triple conductor. All temperatures refer to temperatures of copper core.

Initial Temperature, 20°C.

Size of cable, circ. mils	National electric code, rubber	Low tension cable single conductor		High tension cable three conductor
		Rubber, 30°C. rise	Var. cam. or paper, 60°C. rise	Rubber and var. cam., 30°C. rise; paper, 35°C. rise
		Amp.	Amp.	Amp. on each conductor
2,000,000	1,050	1,400	1,750	
1,500,000	850	1,200	1,500	
1,000,000	650	900	1,150	
750,000	525	750	900	
500,000	390	550	660	440
400,000	330	460	560	360
300,000	270	370	450	290
250,000	235	320	390	250
200,000	200	270	310	210
150.000	160	220	260	175
125,000	140	180	210	140
100,000	120	160	190	125
80,000	104	140	165	110
60,000	82	110	130	85
40,000	63	75	90	60
6 B. & S. solid	46	50	60	40
8 B. & S. solid	33	30	36	24
10 B. & S. solid	24	20	24	16

[1] General Electric Co.

Cooling Duct Lines.—The heating of a duct line depends upon the composition of the duct itself, the arrangement of the ducts relative to one another, and the nature of the surrounding medium. Where a duct line is of the multiple type, the ducts furthest away from the heat-dissipating surfaces will run hottest, and the top row of ducts will run at a higher temperature than the lower rows. Care should, therefore, be taken in assigning ducts to the various cables that those cables which are expected to carry the heaviest load be placed in the ducts which can best dispose of the heat generated.

The nature of the surrounding medium is of importance in determining the temperature of a duct line. It is a well-known fact that the temperature of a duct of any given construction will vary with changes in the character of the soil through which it runs. Thus a line may give no trouble from overheating where it runs through moist soil but is very likely to overheat in sections where the soil is dry or sandy. Attempts have been made to produce artificially the conditions favorable to rapid heat dissipation, and various methods of cooling overheated duct lines have been proposed, but as yet none has shown results which would justify general adoption. A method of cooling by the use of a porous-tile drain laid in a trench above the conduit line was described in detail by Mr. L. E. Imlay in a paper presented before the American Institute of Electrical Engineers in February, 1915. It was shown that the soil surrounding a buried conduit containing active electric cables may become hot, dry and powdery, a condition which would reduce its thermal conductivity to a minimum. The addition of moisture to the soil, either from above or from below through a vacant duct, brought about a very distinct reduction in the temperature of the cables as well as in the temperature of the surrounding soil. It seems readily possible that future installations of heavily loaded conducting cables, buried in conduits, will have special water-cooling ducts laid in their immediate vicinity for the purpose of keeping down the cable temperatures. A noteworthy point brought out by the observations of the author is the relatively great distances to which the heat liberated from active cables in the buried conduit can appreciably raise the temperature of the ground. It appears that the temperature of the soil 1 meter below the surface was raised by some 20°C. at a distance of half a dozen meters from the buried conduit.

The method employed by the Niagara Falls Power Co. for cooling its underground cables was to circulate water through one of the vacant ducts adjacent to the occupied ducts. Later porous drain tiles were installed parallel to and above the cable ducts so that water flowing through the tile could percolate through the ground surrounding the cable and finally be carried away through agricultural tile drains installed below the ducts.

The approximate temperatures of the cables were ascertained by inserting resistance thermometers in ducts adjacent to the cables which were supposed to be the source of heat.

Tests were made by the Consolidated Gas, Electric Light & Power Co. of Baltimore in sections of their conduit system where cable burnouts were frequent. Most of the troubles in this part of the insulation were due to the high temperature of the duct line during the summer months. The soil around the ducts

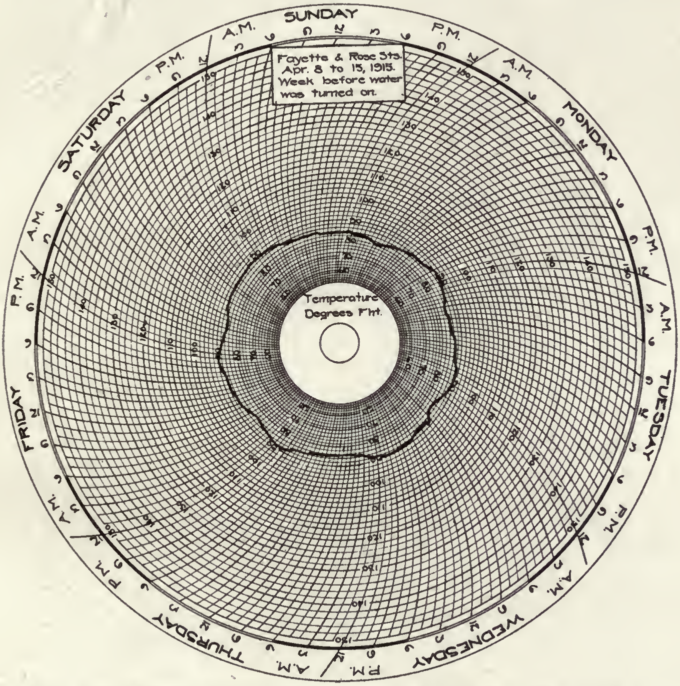


FIG. 92.—Duct temperature before installing cooling system.

was to a great extent dried out and it seemed logical to conclude that some method of supplying water to the duct line would improve conditions. Studies were made of the temperatures existing in the duct line under regular operating conditions. The conduits which were used principally for carrying 13,000-volt cables were laid in made earth with some ash. Thermometers were placed in an idle duct some distance from a manhole and the observations showed that the temperatures in the duct line responded to the variations in load and to atmospheric temperatures. The response to the changes in load followed within a few hours, but atmospheric temperature variations produced no effect for some days.

The records as has been stated were taken as a result of repeated cable failures. During the year 1912 there were 15 failures; during 1913, 7; and during 1914, 19. Nearly all the troubles occurred during the summer months, and most of them were in the section of the duct where the temperature records were observed.

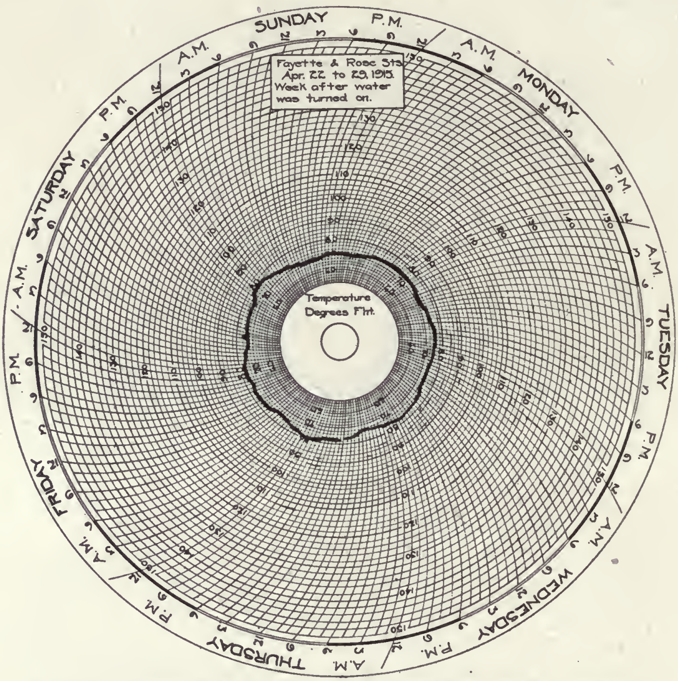


FIG. 93.—Duct temperature after installing cooling system.

During the summer of 1915, a sprinkler system was installed in the three sections where the greatest number of burnouts had occurred. The cooling system consisted of a ¼-in. iron pipe with 1/64-in. perforations at a 3-ft. spacing installed in a vacant duct. About 4,000 gal. of water per day at a temperature of about 55°F. were supplied to the system and it was found that the duct temperature was reduced about 10°F. Some trouble appears to have been experienced due to plugging up of the perforations. The charts shown in Figs. 92 and 93 show the temperature conditions before and after the sprinkler system was installed. The results are not conclusive and serve merely to show the possibilities of this method of cooling.

In some instances, transmission cables run through manholes containing transformers and heavily loaded cables both of which tend to raise the temperature of the duct line. In such special cases it may be cheaper to provide a cooling system rather than additional cables in order that the existing cables may be operated at their maximum rating during the summer peak-load period.

The radiation of heat from a duct line differs from that from other classes of electrical apparatus around which the air is free to circulate; therefore, changes in the temperature of a duct line will not follow changes in load as closely as in the case of station apparatus, but instead will lag to such an extent that the line may not reach its final temperature for several days. This is especially true during certain seasons of the year when the earth around the duct line is drying out.

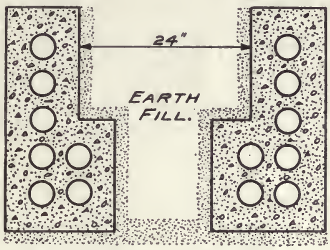


Fig. 94.—Method of separating ducts.

The drying out of the earth in summer when the atmospheric temperature is around 90°F. affects the carrying capacity of cables quite materially, since the maximum copper temperature at which it is safe to operate high-voltage cables is something like 150°F. A number of companies change the rating of the cables according to the seasons of the year. In one case where there are a number of cables in a duct line it has been necessary to limit the rating of the cables in summer to about half the winter rating.

In order to facilitate radiation from cables, duct lines have been constructed, as shown in Fig. 94, so that earth would be in direct contact with each duct.

Connections to Overhead Lines.—In most primary distribution systems in which part of the lines are underground, there are connections made between the underground cable and overhead aerial wires. It is usual to run feeders and important mains underground for some distance from the station in large cities and then connect with overhead lines in the more scattered area.

Where back-yard and alley distribution is general, the main lines are placed underground in streets, and the local distributing taps taken off the overhead lines. It is quite frequently necessary that underground lines be carried across railroads, main boulevards and streams. This class of distribution was for many years very troublesome because of the difficulty of properly caring for the cable ends which are brought up the pole to the overhead line.

Plain joints, made up by stripping the lead back a few inches and covering by tape and compound, were succeeded by lead joints filled with compound and left open at the end where the live wire came out. In some cases joints were protected by enclosing them in boxes. All of these various forms were susceptible to the action of the sun and rain, and were sooner or later located by lightning flashes, or potential surges, as the weak spots in the line.

In recent years many of the large distributing systems have been equipped with potheads or pole terminals designed to meet such conditions. Outdoor potheads for pole connections should serve the double function of connecting the insulated conductor of the underground cable to the overhead aerial wire, and of sealing properly the end of the lead-covered cable to protect the insulation from moisture. Protection of the cable insulation from moisture requires a structure which will not only prevent the direct action of water in the form of rain, snow or sleet, but will also prevent the indirect action of moisture in the form of fog and water vapor.

Effective devices of this kind are today an absolute necessity in every underground cable system. A single-conductor form of terminal is shown in Fig. 95. This terminal consists essentially of three parts: a conducting stem (*a*) which acts as a continuation of the underground cable conductor; an insulator (*b*); and a connecting pin (*c*) between the insulator and lead sheath (forming, in reality, an expanded extension to the lead sheath), which may be called the bell.

The advantages claimed for this type of terminal are as follows:

1. Protection of the insulation from injury by electrostatic discharges, or by any deteriorating influence, such as moisture,

either held in suspension in the air or in the form of rain, snow or sleet.

2. Separation of, and efficient insulation of, conductor from conductor, and conductor from grounded lead sheath, when exposed to usual weather conditions.

3. Connection of underground conductor with aerial conductor in an approximately straight line, thus avoiding bending heavy conductors or wasting cable in goose-necks or rain loops.

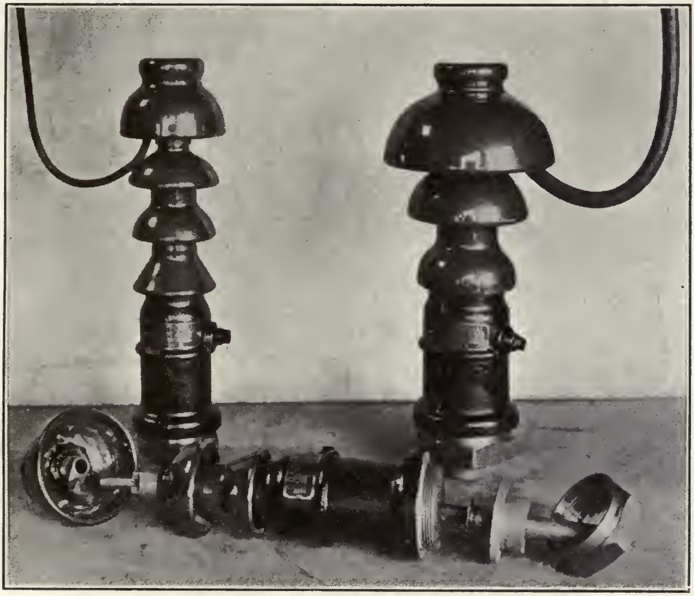


FIG. 95.—Single-conductor terminal.

4. Facility in connecting and disconnecting the aerial extension.

5. Rigid structural unity—the terminal, the cable conductors and the lead sheath being tied together in a rigid mechanical union.

6. Ease of installation, the lead bell being adaptable to any diameter of cable.

7. Connection of current-carrying parts in an effective manner, securing good electrical and convenient mechanical connection between the conductors of the cable and their aerial extensions.

Another form of single conductor terminal is shown in Fig. 96. This terminal consists of a porcelain sleeve which, when filled with compound, serves to seal the end of the cable insulation from moisture, and a porcelain cap which fits over the top and has ample overlap, excluding water in a driving rain and when submerged. The cap carries a copper plug which is attached

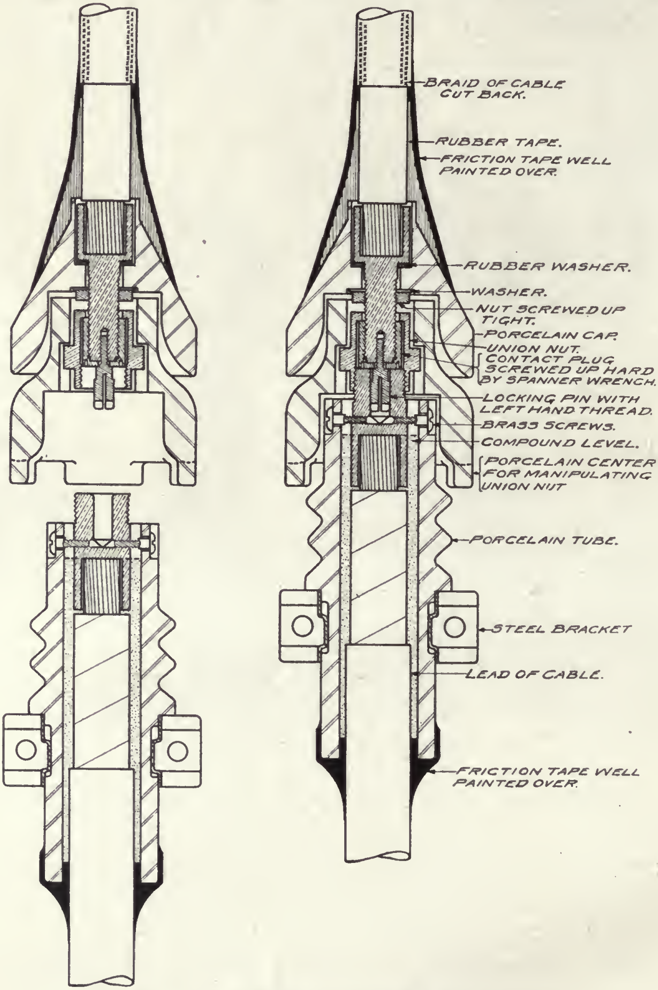


FIG. 96.—Single-conductor terminal.

to the outgoing terminal. The tube carries a recessed member in which the plug seats, and this member is soldered to the cable conductor. The circuit is thus opened and closed by merely removing and replacing the cap.

This type of pothead is made in various forms for voltages up to and including 30,000 and with either wiping sleeves, stuffing boxes, or plain entrances for the cable. It has a very wide application to distribution work and in many instances the device is used merely as a disconnector in place of a blade or oil switch. Because of its small unit form, it permits the installation of any complicated switching arrangement in a safe, neat and complete manner.

A form of multi-conductor terminal is shown in Fig. 97. This type of terminal is particularly suitable for heavy power-transmission cables. Some companies using multi-conductor terminals made of iron have experienced trouble due to heating caused by eddy currents set up when the terminal is used on cables carrying alternating currents. This trouble, however, has been overcome by making the metal forked cap of the terminal of non-magnetic material such as aluminum or brass.

Fig. 97.—Three-conductor pot head.

The pole shown in Fig. 98 is of particular interest on account of the considerable number of 13,200-volt, three-conductor cables which terminate at this point; and while it may not be good practice to bring out so many cables on one pole, it shows what can be done when the conditions require it.

In all cases where underground cables are connected to overhead lines, some suitable covering should be provided at the end of the lateral pipe to prevent the entrance of water. There are several devices on the market which are arranged to fit around the cable and slip over the pipe. A very satisfactory pipe cap can be made of sheet lead from the cable sheath which is formed into a bell shape soldered to the cable and hammered over and around the pipe, as shown in Fig. 99. Unless the top of the pipe is covered, water will enter during rain storms, and in winter weather will freeze and damage the cable.

The National Electric Light Association line-construction specification for joint use of poles provides that connection to

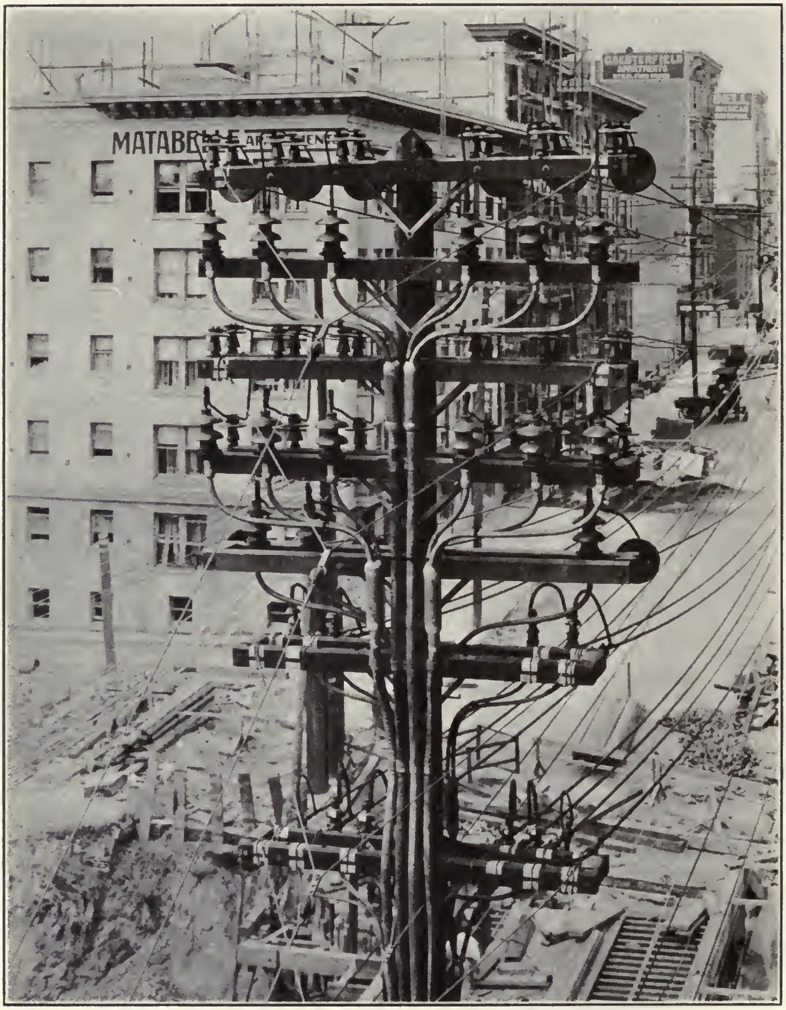


FIG. 98.—Terminal pole.

electric-light lines for supplying service, or for street lamps, transformers, fuses, switches or lightning arresters or connections to underground wires and, in general, connections forming a part of the electric-light system may be run vertically upon a pole, and, if necessary, through telephone wires, provided such electric-light wires and connections are so constructed, placed and maintained as to conform to the following requirements:

Lead-sheathed cable shall be inclosed within a pipe or conduit of solid insulating material wherever such cable shall be run upon

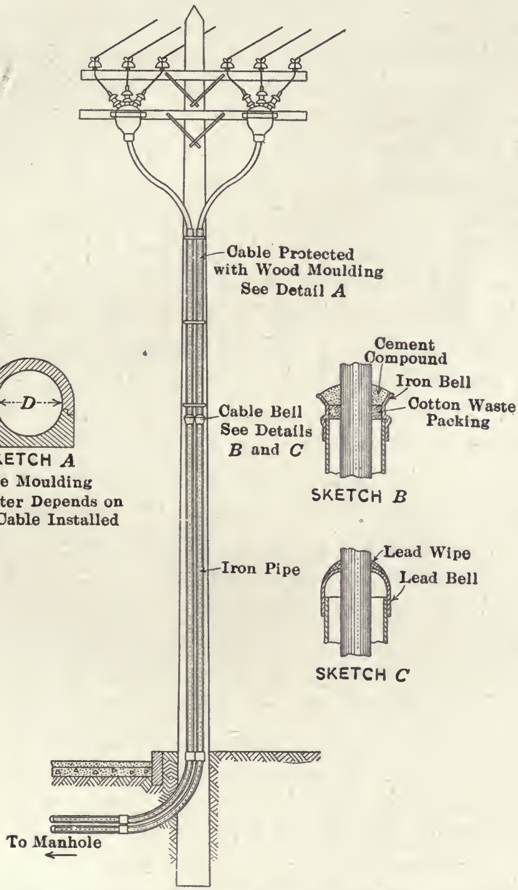


Fig. 99.—Terminal pole, showing methods of protecting cable.

the pole between a point not less than 40 in. above the highest telephone wire, connection or attachment, and a point not less than 6 ft. below the lowest telephone wire, connection or attachment.

Ground wires or wires throughout the entire length of attachment to the pole shall be inclosed within an insulating conduit, or otherwise effectually insulated and protected. All cables, wires, connections and conduits forming a part of the electric-light system and carried vertically upon a pole within the terms of this article shall be placed upon the same circumference of the pole on the crossarm side or face of the pole, it being further provided that the poles jointly used and having such vertical attachment shall be furnished with pole steps and that no vertical attachment shall be so placed as to interfere with the use of pole steps. Where vertical attachments of the lighting company pass telephone crossarms, they shall be run behind the telephone crossarm and not across the face of such arms.

Lightning Arresters.—Where underground cables connect with overhead wires, protection of cables against lightning is necessary; and suitable arresters and fuses should be installed for this purpose as well as to protect the station apparatus. Resonance invariably produces high potentials at the junction of overhead and underground lines, and these potentials are often of sufficient value to break down the insulation of the cables and also the insulation of apparatus installed on the system.

Whenever lines contain both inductance and capacity in appreciable amounts, high voltages, which endanger the insulation of the whole system and which it is impossible to detect on ordinary switchboard instruments, may exist. Abnormal voltages are, therefore, often found in circuits containing a combination of underground and overhead circuits.

It is difficult, however, to determine the proper arresters for such circuits on account of the various conditions to be met. Where it is necessary to install lightning arresters, the accessibility, ease of inspection, voltage and power of the system, as well as the length of underground and overhead lines, will be important factors in the selection of a proper type. In all lightning-arrester installations it is of the utmost importance to make proper ground connections, as many lightning-arrester troubles can be traced to bad grounds.

For grounding pole arresters, one or two 1-in. or 1¼-in. iron pipes should be driven into the ground at the base of the pole and connected to the arrester by means of a copper wire not less than No. 2. The ground wire should be protected for some distance up the pole to prevent its being injured. The pipes should be driven far enough from the pole so that movement of the pole will not loosen them.

Splicing Equipment, Tools and Safety Devices.—In the laying, splicing and connecting of cables, certain tools and accessories are necessary and useful; and every cable splicer should be supplied with a kit of tools, as follows:

Gasoline furnace.	10-in. flat file.
Solder pot and ladle.	10-in. round file.
3- or 4-lb. soldering iron.	Hacksaw frame and blades.
8-in. side-cutting pliers.	Wiping cloths.
Gas pliers.	Kettle for compound.
Chipping knife.	Small and large pan.
Pein hammer.	Mason's bag.

As a great many accidents of a minor character are constantly occurring due to methods employed in raising and lowering tools and material from manholes, these accidents occurring principally from want of particular kinds of devices to prevent the spilling of solder and the tipping over of tool and material pans, the following tools or devices which have been found very effective are suggested for use.[1]

(*a*) A very effective and useful rope for lowering the solder pot, compound kettle, tool pan, etc., consists of a small hemp rope on one end of which is fastened a snap hook for engaging in the handles or bails on the compound kettle and solder pot. On the other end of this rope there is a "sister-hook" which is useful in forming a loop or safety belt which may be used in emergency cases, Fig. 100.

The sister-hook, as shown in the figure, consists of two separate hooks turned in opposite directions. The flat sides fit snugly together, forming a complete ring about the bail of a kettle, or anything which is placed within the hook, and make it practically impossible to jolt it out accidentally. The iron rod at the other end is used when lowering hot solder pots or anything which may burn or cut the rope.

(*b*) A solder pot which has eliminated many accidents due to the spilling of solder is provided with a flange on the inside which allows the pot to be tipped at a considerable angle without spilling the contents. This pot also has a ring turned in the handle which prevents it from losing its balance by the handle slipping in the hook of the lowering rope.

[1] N.E.L.A. Underground Report, 1915.

(*c*) The compound kettle may also have a ring turned in the handle to prevent slipping in the lowering hook and consequent spilling of the contents on the workmen below.

(*d*) A great deal of trouble has been experienced by the use of the ordinary baking pan as a means for lowering into the manhole small tools, tape, etc., which are commonly used on cable-splicing work. To prevent the pan from tipping over, handles may be put on each corner of the pan and joined together in the

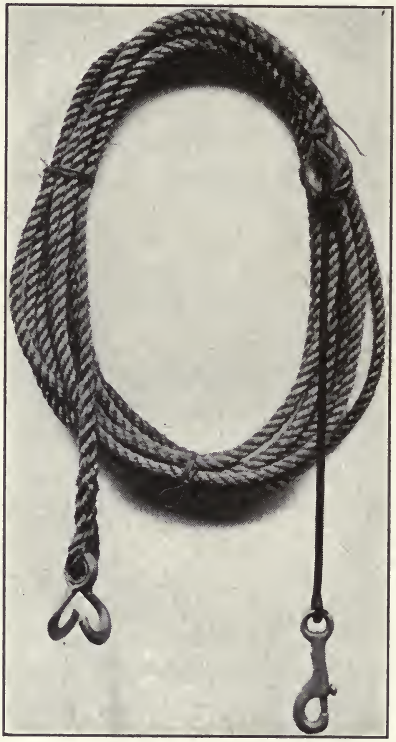


Fig. 100.—Tool lowering rope.

center, forming a ring in which the snap hook on the lowering line engages. This form of handle for the material pan will always keep the pan in balance and prevent spilling the contents.

(*e*) An effective cable-sheath knife has recently come into use. This knife is very much the same as the sheath knife formerly used, except for the provision of a fiber shield on each side of the blade. These shields are set back just far enough from the cutting edge to permit the sharp edge of the knife to penetrate the lead sheath only, without cutting the insulation beneath.

(*f*) A new type of cable-sheath cutter for cutting around the cable has recently been introduced. It has proved very effective and where used has reduced the number of short-circuits due to the old style of cutting wheel, which cut through both lead sheath and insulation. This cutter is of the plier type, the cutting blades being mounted on the sides of the plier jaws extending only far enough beyond the inside edge of the jaws to allow the cutter to cut through the lead sheath without disturbing the insulation beneath.

(*g*) Hacksaw frames used on cable work may be insulated in several different ways, one of which is to wind the metal parts

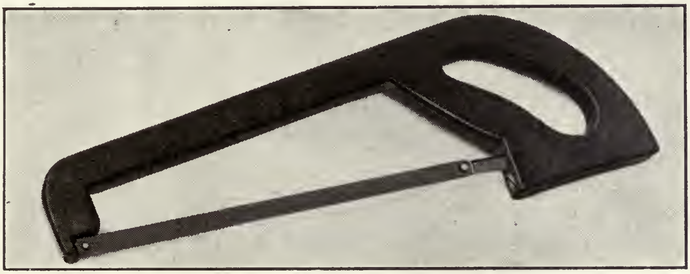


Fig. 101.—Hacksaw frame.

of the frame with insulating tape. Another method is to have the metal parts covered with rubber and vulcanized. A very satisfactory form of hacksaw frame is one made entirely of fiber, Fig. 101. The all-fiber hacksaw frame has been used by one of the larger companies for some time and has proved very satisfactory.

(*h*) To prevent the many short-circuits which occur by junction-box catch nuts and bolts falling across terminals of opposite polarity, insulated wrenches may be used with good effect. These wrenches are of the socket type and have a setscrew with a fiber head which may be tightened on the nut of screw bolt which is to be removed. This holds the nut or bolt tightly in the head of the wrench and permits its safe removal from the junction box. Another very successful form of wrench for removing junction-box catch nuts and bolts is one in which the nut or bolt head is held tightly in the wrench by a set of springs.

(*i*) For removing the compound in low-voltage service boxes, a hard-fiber chisel has been found very effective and should form part of the equipment of every service wagon.

(*j*) The ship-auger type of socket wrench for removing the nuts on the inside cover of junction boxes is a very satisfactory tool, as it permits the workman to tighten the nuts or bolts in a very easy position, and it also allows him to be on his guard against being struck by vehicles or pedestrians.

TOOLS FOR HANDLING FUSES AND CATCHES

(*a*) The use of wooden pliers in handling fuses has eliminated a great many accidents which occur from the careless handling of fuses.

(*b*) A safe and useful tool for removing catches in junction boxes under short-circuit conditions consists of a long insulated

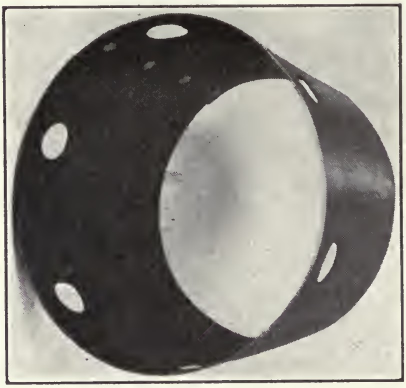


Fig. 102.—Furnace shield.

handle with a clamp and setscrew on the end for holding the catch. By using this device the workman may stand some distance from the catch when it is withdrawn.

(*c*) A useful instrument for tracing the cause of blown fuses consists of an insulated handle on which is mounted a fuse wire. This fuse wire bridges the fuse terminals, and by blowing indicates which of the wires of the circuit is short-circuited or grounded.

FURNACES AND ACCESSORIES

(*a*) Kerosene furnaces for melting solder and compound, and for the heating of soldering irons, are recommended in place of the gasoline furnace which has caused many accidents on account of the inflammability of the gasoline. To prevent furnaces from tipping over, it is the practice of some of the companies to fill the bottom of the furnace with lead, giving it a heavy base.

(*b*) A very efficient device which allows the compound kettle to be heated at the same time the solder pot is on the furnace, consists of a shield which envelops the solder pot and carries the compound kettle on top at the same time. A hole may be cut in the side of the shield in which a soldering iron may be heated. Many of these shields are now in use with very satisfactory results, Fig. 102.

(*c*) When it is necessary to use gasoline, a very safe can or container is one that cannot be exploded by igniting the gasoline at the filling hole. A can of this type is on the market in several different styles and thicknesses of material.

TEST LAMPS

Several styles of test lamps are in use.

(*a*) In one of these the lamps are enclosed in a small wooden frame which prevents the lamps from being broken and is easily packed in the tool kit. The contact points in connection with this type of test lamp are made of common brad awls, the wires being soldered to the awl points at the wooden handles, forming not only an insulated handle but at the same time allowing the workmen a firm grip on the contact points which is much more desirable than having loose and flabby wires in his hand.

(*b*) Another form of test lamp has metal guards, but this is found to be undesirable on account of the number of short-circuits that have occurred by these guards falling across live wires.

OPENING AND GUARDING MANHOLES

(*a*) Hooks for removing and replacing manhole covers, which engage in a hole in the manhole cover, are found to be very convenient. On the end opposite the hook there is a ring handle. In using these hooks the covers are dragged from the manhole, which is preferable to prying them up and turning them over by hand, as this method frequently results in injury to the hands and feet on account of the covers slipping or falling.

(*b*) A guard rail may be made either of pipe, Fig. 103, or angle

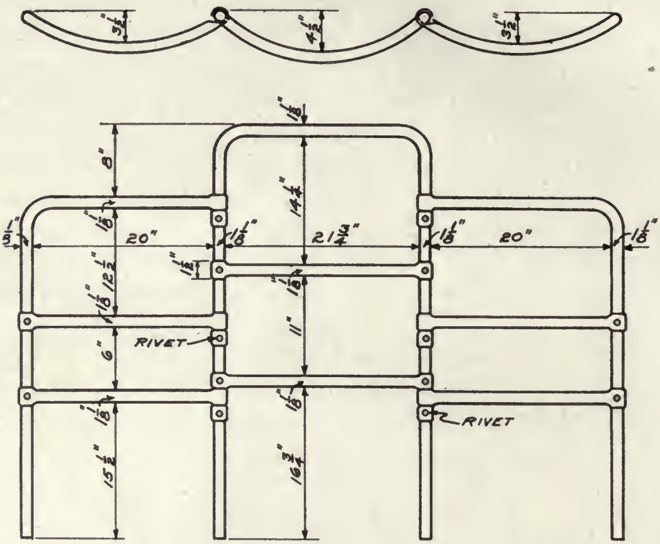


FIG. 103.—Wrought-iron pipe manhole guard.

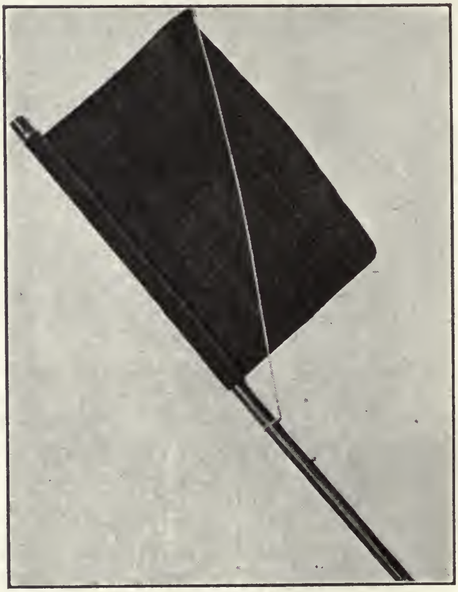


FIG. 104.—Warning flag.

iron, both forms of which are used extensively. The guard rail should be made collapsible so that it may be stored in a tool cart or wagon.

(*c*) It is customary to have a red flag displayed, and it seems advisable to have, as a further safeguard, a danger sign, as in many places very little attention is paid to a red flag. A flag which is kept extended at all times by a wire device which folds back against the staff when the flag is furled is shown in Fig. 104.

(*d*) Several types of gratings are used to cover open manholes. Covers made of flat bar iron or heavy wire mesh are commonly

Fig. 105.—Manhole grating.

used. An excellent type of grating is one which is hinged in the center, allowing one side of the grating to be raised for lowering tools and materials into the manhole, as shown in Fig. 105. Gratings for manholes are especially useful near railroad tracks and places where the regular manhole railing cannot be kept in place.

TESTING FOR LIVE CABLES

(*a*) There are several devices for testing cables to determine whether they are alive before working on them. The first is a pointed tool on the end of an insulated handle. The tool is provided with a short piece of cable and clamp for attaching to the cable sheath, Fig. 106. This insures the passage of the cur-

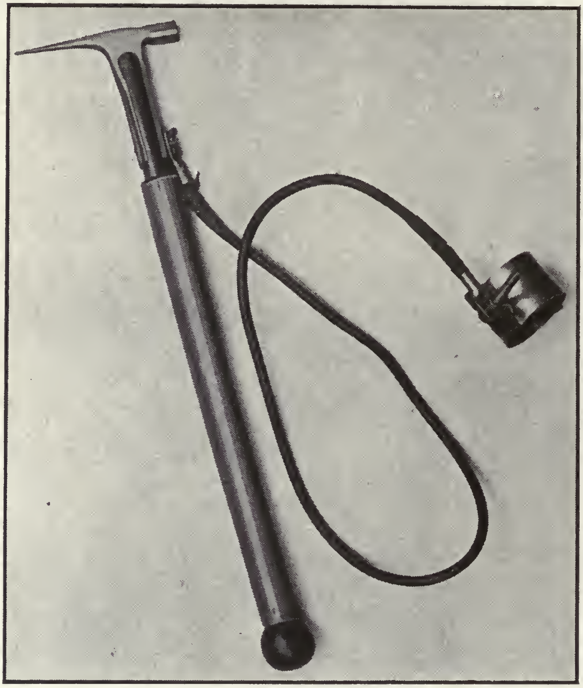


Fig. 106.—Tool for testing cable.

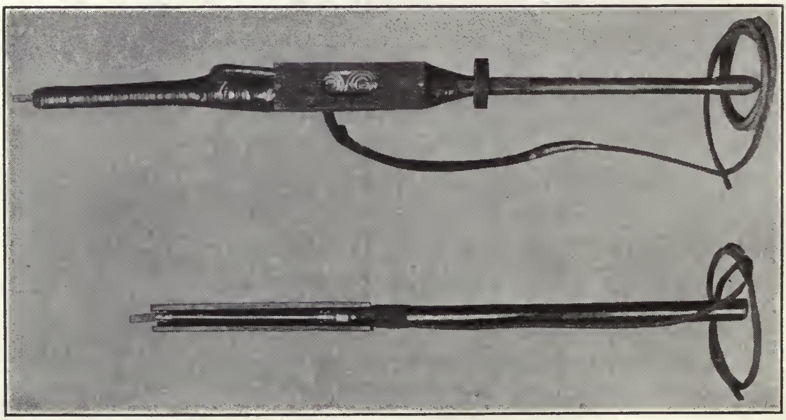


Fig. 107.—Geissler tube.

rent through to ground if the cable is alive when the tool is driven into it.

(*b*) A similar device, but of different form, is the spear type which, on account of the length of the handle, may be driven into the cable from the street surface.

(*c*) Another method for determining the cable to be worked on is to put a current of high frequency through the cable, and this cable may be readily detected in the manhole by the use of an exploring coil and telephone headpiece. The high-frequency note that is struck when the exploring coil comes into contact with the high-frequency cable is readily distinguished from the note of the cables of lower frequency.

(*d*) The electroscope is sometimes used for detecting the presence of a live conductor. The electroscope is used by high-tension cable splicers to test a line after the lead sheath has been removed.

(*e*) Recently the Geissler tube has been used for work of this kind. The tube is connected between conductor and ground, and if the cable is alive it is denoted by the illumination given off by the tube, Fig. 107.

VENTILATION OF MANHOLES

(*a*) The most effective method of ventilating manholes containing illuminating or other gases is by the use of either a motor-driven fan or one operated by hand.

(*b*) There is another very efficient device for ventilating manholes which, however, is not recommended for removing gases. This device consists of a canvas shield hung on the handrail and passing down to a point near the bottom of the hole. This canvas is always placed facing the wind, which passes down in front of it and comes out of the hole on the opposite side of the shield. This device has been found to give entire satisfaction and is highly recommended for this work.

MISCELLANEOUS

(*a*) A very effective lamp guard made of fiber is found useful around live low-tension work, as it eliminates the danger of short-circuits should the lamp fall from the man's hand upon a live terminal.

(*b*) Smoke helmets and respirators are very useful in manholes that are full of gas. There are several satisfactory respirators in use today. Some of the less complicated types of smoke helmets are very effective for rescue work in manholes, as it is possible to wear them for periods of 30 min. or more without the operator suffering any inconvenience.

(*c*) Storage-battery lamps for illumination of manholes should be used when current from the mains is not available. The use of open-flame lamps or torches should be avoided.

(*d*) On account of the many cases of employees getting dirt in their eyes, and receiving other injuries to their eyes while working in manholes, the wearing of an approved type of safety goggle is advisable.

(*e*) It is good practice to display red lamps upon piles of material and around openings at night and also on dark days, as a great many accidents have been caused by employees and others stumbling over material in dark places and also falling through unprotected openings.

(*f*) Emergency wagons equipped with smoke helmets, pulmotors, and first-aid outfits, along with tools for quick repairs, etc., have proven very efficient.

(*g*) To prevent short-circuits between conductors of Edison tube joints and prevent undue heating of conductors adjacent to the one being worked on, the use of sheets of asbestos between conductors has met with considerable favor.

(*h*) The use of rubber mats in manholes and junction boxes has recently come into use. By their use the cable to be worked on can be isolated, and the workman does not need to be as careful as formerly, not having to consider burning the sheaths of the adjoining cables while using solder; and, furthermore, the possibility of live cable ends falling on the other cable sheaths is eliminated, the rubber shield completely blanketing all cables with the exception of the one being worked on.

CHAPTER VII

TESTING OF CABLES

International Electrical Units.—The following resolutions were adopted by the International Congress of Electricians, held at Chicago in 1893. They were legalized by act of Congress and approved by the president on July 12, 1894, and are now recognized as the International Units of value for their respective purposes.

Resolved, That the several governments represented by the delegates of the International Congress of Electricians be, and they are hereby, recommended to formally adopt as legal units of electrical measure the following:

1. As a unit of resistance, the International Ohm, which is based upon the ohm equal to 10^9 units of resistance of the c.g.s. system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at a temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area, and of the length 106.3 cm.

2. As a unit of current, the International Ampere, which is one-tenth of the unit of current of the c.g.s. system of electromagnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, in accordance with the accompanying specification (*A*) deposits silver at the rate of 0.001118 gram per second.

3. As a unit of electromotive force, the International Volt, which is the e.m.f. that, steadily applied to a conductor whose resistance is one International Ohm, will produce a current of one International Ampere, and which is represented sufficiently well for practical use by $\frac{1,000}{1,434}$ of the e.m.f. between the poles or electrodes of the voltaic cell, known as Clark's cell, at a temperature of 15°C., and prepared in the manner described in the accompanying specification (*B*).

4. As the unit of quantity, the International Coulomb, which

is the quantity of electricity transferred by current of one International Ampere in one second.

5. As the unit of capacity, the International Farad, which is the capacity of a conductor charged to a potential of one International Volt by one International Coulomb of electricity.

6. As the unit of work, the joule, which is 10^7 units of work in the c.g.s. system, and which is represented sufficiently well for practical use by the energy expended in one second by an International Ampere in an International Ohm.

7. As the unit of power, the watt, which is equal to 10^7 units of power in the c.g.s. system, and which is represented sufficiently well for practical use, by the work done at the rate of one joule per second.

8. As the unit of induction, the henry, which is the induction in the circuit when the e.m.f. induced in this circuit is one International Volt, while the inducing current varies at the rate of one International Ampere per second.

NOTE.—Specifications (*A*) and (*B*), omitted here, may be found in the original publication and in the electrical handbooks.

Standardization Rules.—In the Standardization Rules of the American Institute of Electrical Engineers, approved June 30, 1915, the following recommendations are made in regard to cable tests:

HEATING AND TEMPERATURE OF CABLES

677. *Maximum Safe Limiting Temperatures.*—The maximum safe limiting temperature in degrees C. at the surface of the conductor in a cable shall be:

For impregnated-paper insulation	(85–*E*)
For varnished-cambric insulation	(75–*E*)
For rubber insulation	(60–0.25*E*)

Where *E* represents the r.m.s. operating e.m.f. in kilovolts between conductors.

Thus, at a working pressure of 3.3 kv., the maximum safe limiting temperature at the surface of the conductor or conductors, in a cable would be:

For impregnated-paper insulation	(81.7°C.)
For varnished-cambric insulation	(71.7°C.)
For rubber insulation	(59.2°C.)

ELECTRICAL TESTS.

678. *Lengths Tested.*—Electrical tests of insulation on wires and cables shall be made on the entire lengths to be shipped.

679. *Immersion in Water.*—Electrical tests on insulated conductors not enclosed in a lead sheath, shall be made while immersed in water after an immersion of 12 hr., if insulated with rubber compounds, or if insulated with varnished cambric. It is not necessary to immerse in water insulated conductors enclosed in a lead sheath.

In multiple-conductor cables, without waterproof overall jacket of insulation, no immersion tests should be made on finished cables, but only on the individual conductors before assembling.

680. *Dielectric-strength Tests.—Object of Tests.*—Dielectric tests are intended to detect weak spots in the insulation and to determine whether the dielectric strength of the insulation is sufficient for enabling it to withstand the voltage to which it is likely to be subjected in service, with a suitable factor of assurance.

The initially applied voltage must not be greater than the working voltage, and the rate of increase shall not be over 100 per cent. in 10 sec.

681. *Factor of Assurance.*—The factor of assurance of wire or cable insulation shall be the ratio of the voltage at which it is tested to that at which it is used.

682. *Test Voltage.*—The dielectric strength of wire and cable insulation shall be tested at the factory, by applying an alternating test voltage between the conductor and sheath or water.

683. *The magnitude and duration of the test voltage* should depend on the dielectric strength and thickness of the insulation, the length and diameter of the wire or cable, and the assurance factor required, the latter in turn depending upon the importance of the service in which the wire or cable is employed.

684. *The following test voltages* shall apply unless a departure is considered necessary, in view of the above circumstances. Rubber-covered wires or cable for voltages up to 7 kv. shall be tested in accordance with the National Electric Code. Standardization for higher voltages for rubber-insulated cables is not considered possible at the present time.

Varnished-cambric and impregnated-paper insulated wires or cables shall be tested at the place of manufacture for 5 min. in accordance with the Table XXX below:

TABLE XXX.—RECOMMENDED TEST KILOVOLTS CORRESPONDING TO OPERATING KILOVOLTS

Operating kv.	Test kv.	Operating kv.	Test kv.
Below 0.5	2.5[1]	5	14
0.5	3.0	10	25
1.0	4.0	15	35
2.0	6.5	20	44
3.0	9.0	25	53
4.0	11.5		

[1] The minimum thickness of insulation shall be 1/16 in. (1.6 mm.).

Different engineers specify different thickness of insulation for the same working voltages. Therefore, at the present time the test kilovoltage corresponding to working kilovoltage given in Table XXX are based on the minimum thickness of the insulation specified by engineers and operating companies.[1]

685. *The frequency of the test voltage* shall not exceed 100 cycles per sec., and should approximate as closely as possible to a sine wave. The source of energy should be of ample capacity.

686. *Where ultimate breakdown tests* are required, these shall be made on samples not more than 6 meters (20 ft.) long. The maximum allowable temperature at which the test is made for the particular type of insulation and the particular working pressure, shall not be greater than the temperature limits given in paragraph 677.

687. *Multiple-conductor Cables.*—Each conductor of a multiple-conductor cable shall be tested against the other conductors connected together with the sheath or water.

INSULATION RESISTANCE.

688. *Definition.*—The insulation resistance of an insulated conductor is the electrical resistance offered by its insulation, to an impressed voltage, tending to produce a leakage of current through the same.

[1] The Standards Committee does not commit itself to the principle of basing test voltages on working voltages, but it is not yet in possession of sufficient data to base them upon the dimensions and physical properties of the insulation.

689. *Insulation resistance* shall be expressed in megohms for a specified length (as for a kilometer or a mile or) 1,000 ft., and shall be corrected to a temperature of 15.5°C., using a temperature coefficient determined experimentally for the insulation under consideration.

690. *Linear insulation resistance,* or the insulation resistance of unit length, shall be expressed in terms of the megohm-kilometer, or the megohm-mile, or the megohm-1,000 ft.

691. *Megohms Constant.*—The Megohms Constant of an insulated conductor shall be the factor (K in the equation)

$$R = K \log_{10} \frac{D}{d}$$

where R = the insulation resistance, in megohms, for a specified unit length.

D = the outside diameter of insulation.

d = the diameter of conductor.

Unless otherwise stated, K will be assumed to correspond to the mile unit of length.

692. *Test.*—The apparent insulation resistance should be measured after the dielectric strength test, measuring the leakage current after a 1-min. electrification, with a continuous e.m.f. of from 100 to 500 volts, the conductor being maintained positive to the sheath of water.

693. *Multiple-conductor Cables.*—The insulation resistance of each conductor of a multiple-conductor cable shall be the insulation resistance measured from such conductor to all the other conductors in multiple with the sheath or water.

CAPACITANCE OR ELECTROSTATIC CAPACITY.

694. *Capacitance* is ordinarily expressed in microfarads. Linear Capacitance or Capacitance per unit length, shall be expressed in microfarads per unit length (kilometer, or mile, or 1,000 ft.). and shall be corrected to a temperature of 15.5°C.

695. *Microfarads Constant.*—The Microfarads Constant of an insulated conductor shall be the factor K in the equation:

$$C = \frac{K}{\operatorname{Log}_{10} \frac{D}{d}}$$

where C = the capacitance in microfarads per unit length.
D = the outside diameter of insulation.
d = the diameter of conductor.

Unless otherwise stated, K will be assumed to refer to the mile unit of length.

696. *Measurement of Capacitance.*—The capacitance of low-voltage cable shall be measured by comparison with a standard condenser for long units of high-voltage cables, where it is necessary to know the true capacitance the measurement should be made at a frequency approximating the frequency of operation.

697. *Paired Cables.*—The capacitance shall be measured between the two conductors of any pair, the other wires being connected to the sheath or ground.

698. *Electric Light and Power Cable.*—The capacitance of low-voltage cables is generally of but little importance. The capacitance of high-voltage cables should be measured between the conductors and also between each conductor and the other conductors connected to the lead sheath or ground.

699. *Multiple-conductor Cables* (Not Paired).—The capacitance of each conductor of a multiple-conductor cable shall be the capacitance measured from such conductor to all of the other conductors in multiple with the sheath or the ground.

NOTE.—The paragraph numbers refer to sections in the American Institute of Electrical Engineers Standardization Rules.

CAPACITY OF TESTING APPARATUS.

The size of electrical apparatus necessary in voltage testing, with alternating current is not generally appreciated. This may be due to the fact that as these tests are made on open circuits, many persons assume no current is required. However, there is current flowing and the amount is shown by the formula:

$$I = \frac{2\pi fCE}{1,000,000}$$

where

I = current flowing into the cable.
E = testing voltage.
f = frequency.
C = electrostatic capacity of cable in microfarads.

But the size of apparatus is dependent upon the watts required or

$$\text{Size} = \text{Watts} = I \times E$$

$$= \frac{2\pi fCE}{1{,}000{,}000} \times E = \frac{2\pi fCE^2}{1{,}000{,}000}$$

This means that the watts are proportional to the frequency capacity and the square of the voltage, and on high-voltage tests this means large apparatus. For instance, 1,000 ft. of a 500,000-cm. cable with 6/32-in. wall of 30 per cent. Para has a capacity of about 0.33 microfarads. With a frequency of 25 cycles, this formula shows that 1.3 kw. capacity is required to test at 5,000 volts. If this cable were to be tested at 30,000 volts, apparatus 36 times as large, or of about 47 kw., would be required. If 60 cycles instead of 25 were used, a 30,000-volt test would mean that the apparatus would have to have a capacity of about 113 kw.

According to the best information available, there appears to be no appreciable difference in severity between testing at 25 or 60 cycles on ordinary factory tests.

Locating and Repairing Cable Failures.—Numerous methods have been tried for locating faults in underground transmission cables, some companies depending upon the use of an intermittent current on the damaged cable, which is then explored by means of an induction coil and telephone receiver, while other companies make use of the Murray loop test. Most companies avail themselves more or less of the method of inspection when locating faults by sending men over the route of the cable.

As stated by W. A. Durgin, in a paper presented before the National Electric Light Association in 1910, fault location in high-tension power cables requires quite a different procedure from that usually outlined in texts upon cable testing, due to the wide difference in the characteristics of construction between power and intelligence transmissions. The "cut-and-try" method is applicable to both, but if a quicker and less expensive system is desired testing equipment of special design must be provided.

Most of the larger companies have provided themselves with a testing transformer which is used in connection with a motor-driven generator to supply current of varying voltage for the purpose of breaking down a faulty cable or applying a high-tension test. For the purpose of expediting, as much as possible, the work of locating and repairing a cable fault, specific rules should be prepared governing the procedure of station, substation and underground men in such cases.

In the *Proceedings* of the National Electric Light Association, Underground Committee, 1911, the report of two companies gives the various methods by which the cable breaks are located, and the percentage of breaks which are discovered by each method as follows:

Method	Company *A*, per cent.	Company *B*, per cent.
Loop test	15.0	46
Examination	36.5	8
Cut-and-try	17.5	28
Reported	24.3	11
Exploring coil	1.3	7
Miscellaneous	5.4	

Most companies, before applying the loop test, attempt to obtain a dead ground on one phase of the cable by breaking it down with a special transformer or generator. Following a cable breakdown, and while the location of the break is being determined it is customary to assemble a gang of underground repair men, with tools and proper means of transportation at some convenient location where they may be hurried to the place of the burnout as soon as this is determined.

Loop Test.—Where one conductor of a multiple-conductor cable is grounded and another conductor is clear, the following adaption of the loop test can be used to advantage. This method also applies to single-conductor cable where another conductor is available for the return. The two conductors must be of the same size or corrections will have to be made for the difference in the resistance of the two sizes.

The grounded conductor is jointed to the good conductor at the end opposite that at which the test is to be made. A resistance wire is used, made up in the form of a straight wire bridge or wound on a threaded drum. The wire is calibrated throughout its length. Contact *C*, referring to Fig. 108, is arranged that it can be moved along the resistance wire throughout its entire length. A battery is connected between the contact *C*, and the galvanometer between the terminals *A* and *B*. In making test, *C* is set preferably at the middle point of the resistance to start with. When contact is made, the galvanometer will swing to either one side or the other, depending on the location of the ground. Contact C is then moved along the resistance wire until no deflection is obtained upon the galvanometer. It will be evident that the distance from A to C of

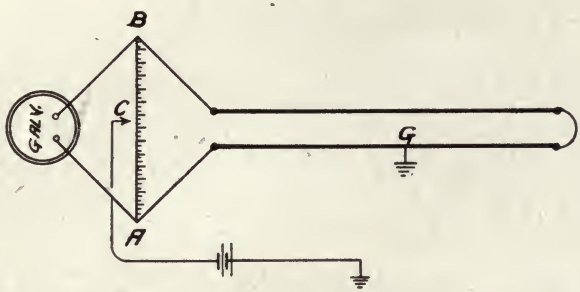


FIG. 108.—Loop method of locating grounds on underground cables.

the resistance wire will represent the distance from A to G on the conductor which is grounded.

This can be represented by the following formula, wherein L represents the total length of the conductors joined together,

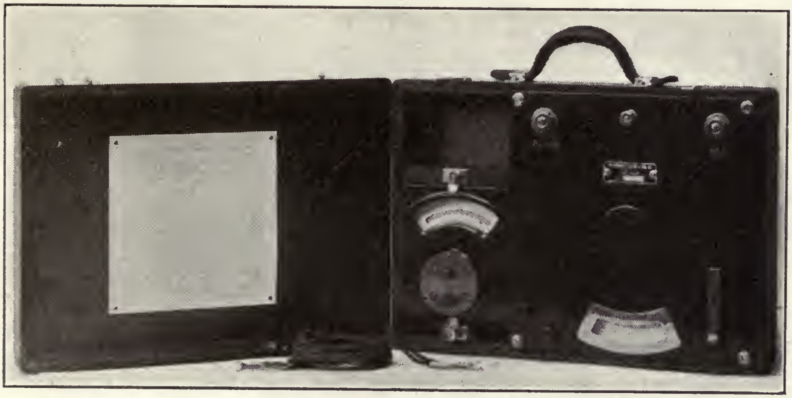


FIG. 109.—Portable fault localizer.

and AC and BC represents the relative distance measured on the resistance arm.

$$\frac{AC}{BC} = \frac{AG}{BG}; \text{ or } \frac{AC}{BG} = \frac{AG}{L - AG}.$$

Solving,

$$AG = \frac{AC\ (L - AG)}{CB}.$$

A portable fault localizer is illustrated in Fig. 109.

It is an application of the Wheatstone bridge with all the necessary apparatus contained in one portable case wired for connection to the circuit to be tested.

Its use assumes that the cable is grounded at only one point and that a parallel conductor of the same length and resistance as the faulty cable is available.

After all electrical connections to the defective feeder have been removed and before the fault localizer has been connected to the cable, the cable is tested by means of a temporary connection through a lamp bank or battery for the grounded conductor. If the lamps do not burn brightly, a high-resistance ground is

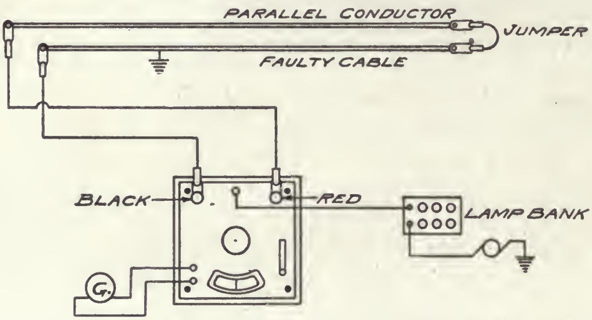


FIG. 110.—Diagram of connections for cable fault localizer.

indicated and should be broken down by applying a sufficiently high voltage.

The fault localizer is connected as shown in the diagram (110) and the dial revolved by means of the knob in the middle of the localizer until the galvanometer shows no deflection when the key is closed. The reading of the instrument then shows the per cent. of length of the feeder from the point where the test is being made to the location of the ground, assuming the total length of the feeder to be 100 per cent.; the red scale indicating that the ground is on the conductor connected to the binding post marked red, and the black scale indicating that it is on the conductor connected to the binding post marked black.

Only direct current is used in these tests.

In this instrument all necessary apparatus is contained in one case and it has the further advantage of easy adjustment. The position of the ground may be read directly on the dial in terms of per cent. of length of cable.

Fault-locating Equipment.—In any central-station system the most important work in connection with trouble finding is the quick and accurate location of a break in a three-phase transmission cable. With the advent of high-tension cables came a problem which hitherto had not obtained to any great extent, namely, the difficulty of obtaining a closed circuit for testing current across the break, as on this closing of the signaling circuit through the fault hinges the success of all methods employing interrupted or varying current, with the exploring coil and telephone receiver. Almost invariably in high-tension cable breaks, there is no metallic path between conductors, or between conductor and sheath; a thick wad of paper or other insulation intervening, through which a path must be carbonized to complete the testing circuit. With the application of sufficient pressure and current this path through the insulating medium can be made and maintained, while the fault is being located with the exception of cases where the break is submerged in water, or where the cable is burned completely open.

There is a wide variation in the resistance in faults in high-tension cables; a cable may break down with a working pressure of 13,000 volts, and upon applying a 100-volt test show practically a short-circuit through the fault. The next breakdown in the same cable may take 5,000 volts to even indicate the existence of trouble. It is, therefore, obvious that it is necessary to have a test set of sufficient pressure to obtain a flow of current across the break. It is also desirable to be able to vary this pressure as in the use of signaling currents; the best results are obtained with the testing voltage as low as possible. Again, on account of the electrostatic capacity of long cables, a certain amount of current-carrying capacity in the apparatus is required. While it is unnecessary that this be as large as is required for a breakdown test on a sound cable, yet it should be of a considerable value depending upon the length and working voltage of the line in trouble.

There are some cable faults through which it is necessary to maintain a steady flow of current at a certain pressure in order to hold the conducting path across the break. This current should be of a small value so as to obviate the danger of damaging the adjacent cable and also to reduce the prospect of destroying the conducting path by combustion. These conditions are met by the use of the method and apparatus herein described which has been used for a number of years in a large central-station system. With this device it is possible to locate quickly and accurately grounds, short-circuits, crosses and opens in underground and overhead lines, whether the lines are carrying working current or not, also to identify for tagging different wires and cables alive or dead, and to pick out the phase wires of an alternating circuit on the poles, in the manholes, or on the customer's premises, without any interruption or interference whatever in the operation of the system.

The test set comprises two parts, the apparatus for the reduction of the fault resistance and carbonizing of the path across the insulation medium, and the signaling device with exploring coils and telephone receivers.

For the location of faults in No. 4/0 paper-insulated cables of 5 miles and under, the capacity of the set is 7.5 kw. and for over 5 miles in length, 15 kw. In general, the maximum pressure of the apparatus should be one-half the greatest working pressure of the underground system, and in the set in question the pressures obtainable are 115–230–575–1,150–2,300–3,450–4,600–5,750–6,900 volts. These voltages are derived from standard lighting transformers connected in different combinations to obtain varying pressures. The signaling part of the apparatus consists of a very powerful sound-producing device which takes current directly from either alternating current or direct current mains. A specially designed motor-driven interrupter produces a signal current of a frequency to which the telephone receiver and the human ear are most responsive and which, though extremely small in value, produces signals which are easily heard. The voltage, current, and tone of the signaling circuit can be varied at will. It will interrupt either alternating current or direct current giving a distinctly different tone on each. Wherever alternating current is available it is used in preference to direct current as the apparatus is somewhat simpler.

This interrupter is of rugged construction, can be used on the system voltage, in conjunction with the ordinary transformer, and will run for hours without any attention whatever, giving out a never-varying signal.

While this outfit is designed to be set up permanently in the station, a portable set of about 3 kw. capacity can be used where necessary. This is capable of handling practically all faults except those submerged in water or of very high resistance.

The apparatus is designed to be used by the ordinary trouble hunter without the use of laboratory instruments, and it can be used to advantage in conjunction with the power bridge loop and capacity instruments, etc., to locate faults exactly without opening any joints in cables.

The signaling system can be adapted to any existing type of breakdown apparatus.

It is often desirable to be able to pick out the different legs or phases of an alternating circuit, at some point distant from the source of supply. This can be done by superposing the interrupted currents on the primary line through an ordinary transformer without any interference in the working of the circuit. By applying the exploring coils to the different wires of the circuit it can be determined to which pair the interrupter is connected. Likewise, if it is desired to know which phase supplies a certain customer, by attaching a plug to a lamp socket and listening through a telephone receiver connected to a special type of coil, this can be readily determined.

A diagnosis and a somewhat predictive location of faults can be made with a little experience in working the apparatus. Faults in water show certain characteristics and the wet holes being known, some idea is given of the location of the breaks. Experience in carbonizing a fault shows whether it is in a section of cable or in a joint by measuring the charging current the distance to an open end can be approximately figured. If there is a cross between the live side of a grounded secondary and a primary or street-lighting circuit, this can be shown in advance. Advantage can be taken of the phenomenon of resonance to discriminate between the natural leakage and charging current of a circuit, and fault current, all of which makes it much easier to locate trouble.

For secondary networks, and breaks in low resistance, on isolated lines and cables, a portable vibrating interrupter, which will operate on two dry cells, has been developed. This interrupter gives a very good signal and can be heard through 1,000 ohms resistance. While the foregoing apparatus is intended primarily for underground cables it can be used with the same success on overhead lines.

The method and apparatus was devised by James A. Vahey, of the Edison Electric Illuminating Co. of Boston, Mass.

Periodic High-potential Testing of Transmission Cables.—There is a great variation of opinion in regard to the advisability of periodically testing transmission cables. It is the practice of most companies to apply a breakdown test of 150 to 200 per cent. of working voltage on new lines for an average time of 5 min. In some cases cables are subjected to high-potential test only after meager tests show a low value or after a series of breakdowns.

The following regarding high-potential testing is taken from the National Electric Light Association, Underground Committee report.

Some companies subject their cables to a high-potential test, once, twice and even three times a year, with pressures as high as three times normal working voltage. Other companies make insulation tests only, unless the record of any cable should show a gradual decrease in insulation resistance, in which case it would be subjected to a high-potential test to break down the developing defect. Several cases of incipient trouble have been discovered and eliminated by this method, but it has not always proved successful.

One large company started to make high-potential tests on all of its cables twice a year, but for various reasons this practice was soon abandoned. With the numerous changes in its underground system and the practice of subjecting cables to a high-potential test after any changes have been made on them, many of the lines thus obtained a test indirectly. A few cases occurred in which lines withstood the test but broke down shortly afterward, notably one case in which the lead sheath of the cable was damaged by electrolysis. This cable burned out a few days after the high-potential test, and an examination of the cable showed that there must have been a hole in the lead sheath for several weeks previous to the test.

Several companies are now installing apparatus with the view of making periodic high-potential breakdown tests on all of their transmission lines, while other companies which already have the necessary equipment have abandoned the practice of making such test.

In general, it might be said that high-potential tests increase the liability to subsequent breakdowns and often do not disclose existing points of weakness.

CHAPTER VIII

DISTRIBUTION SYSTEMS AND AUXILIARY EQUIPMENT

General.—In dealing with systems of distribution, no attempt will be made to take up the solution of all of the electrical problems involved, numerous text-books and reports of engineering associations having covered this subject in considerable detail. Modern three-wire direct-current distributing systems consist essentially of a three-wire network of distributing mains with numerous cable feeders delivering current at different points in the network, the current being supplied by a system of substations. Since the direct-current system of underground distribution is confined so largely to the Edison system, which has been developed to a high degree of perfection and in which most of the problems in handling low-potential current have been solved, it is thought unnecessary to include this subject in the discussion.

Alternating-current Distribution.—The secondary network in an alternating-current system is practically identical in its essential details with its predecessor, the direct-current network, and, therefore, had a number of its problems already solved. However, the higher voltages employed in the alternating-current system brought about difficulties which have been satisfactorily overcome only after years of experience and effort.

The distribution of alternating current for general commercial purposes is accomplished in America almost universally by 2,200-volt mains supplying step-down transformers located near groups of consumers who are served by secondary mains at 110 to 220 volts. Lighting service is quite generally single-phase; while power service is more frequently two-phase or three-phase. Two-phase systems are in use chiefly where this method of distribution was established in the early period of development and is too extensive to warrant changing to the three-phase system. Three-phase systems are now standard for nearly all new power installations. Alternating-current underground distribution in general conforms to established overhead practice so far as voltage, character of service and regulation are concerned. Alternating-current systems are divided into primary and secondary distribution, which may be subdivided into single-phase, two-phase (three- and four-wire), and three-phase (three- and four-wire) systems.

Single-phase.—In the early days of the industry all distribution was single-phase. This system is very simple to install and maintain but has the serious disadvantage of not being well adapted for power loads except where the motors are of small rating. Single-phase motors are not, as a rule, manufactured in large sizes because their design is complicated and expensive and,

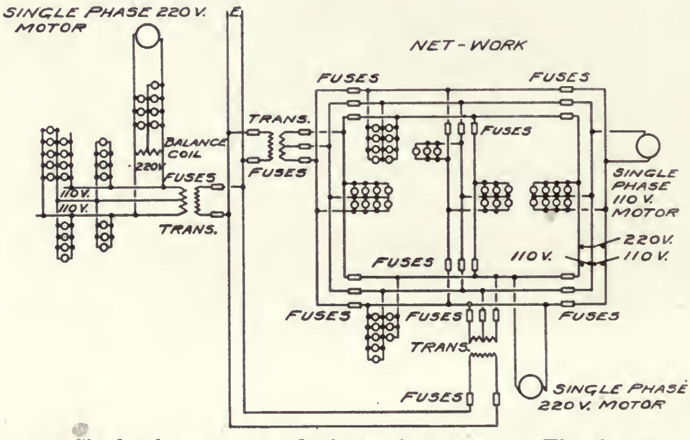


Fig. 111.—Single-phase two and three-wire system. The fuses on the secondary side of the transformer may be omitted.

since they are not self-starting, a costly split-phase starting control is a necessary part of the motor equipment.

As a rule, straight single-phase primary distribution is not employed except in scattered districts where the diversity factor is such as to make the loading of a single-phase circuit more economical than that of a polyphase circuit.

A single-phase, two-, and three-wire system is illustrated in Fig. 111.

Two-phase.—A two-phase system is supplied by a generator which generates two voltages which are in quadrature, *i.e.*, one voltage is a quarter cycle behind the other. This system possesses the same advantages as the single-phase system as regards economical loading of circuits but has, in addition, the important advantage that it may be used to take care of motor loads without the use of the expensive starting apparatus required by a single-phase motor.

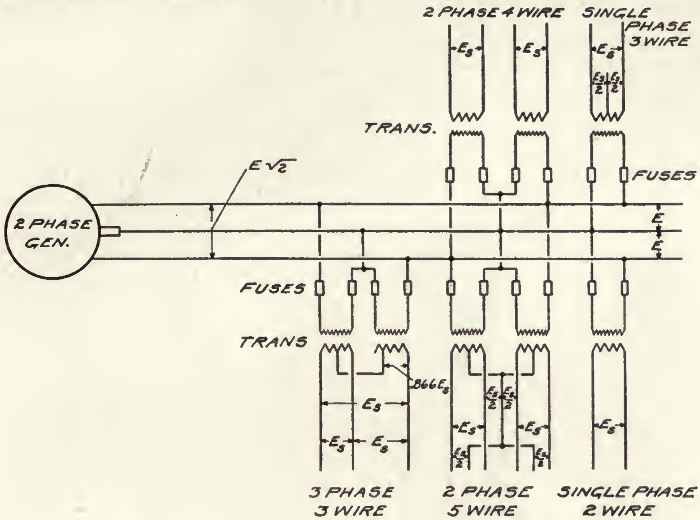


Fig. 112.—Two-phase, three-wire system.

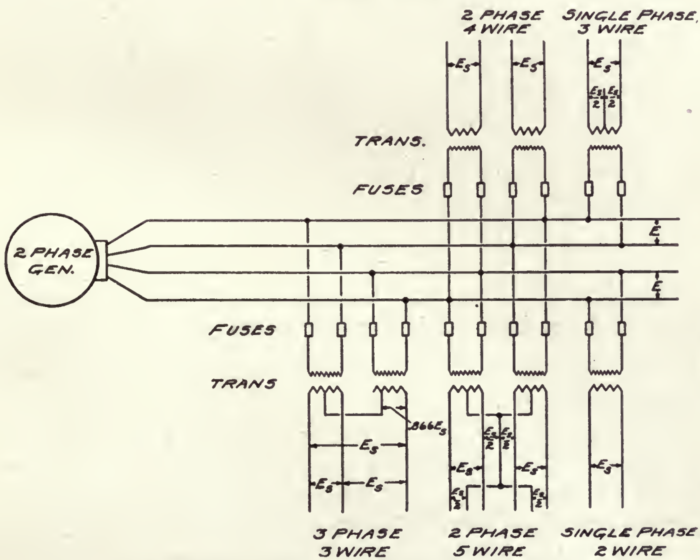


Fig. 113.—Two-phase, four-wire system.

The two-phase system may be either three or four-wire. Where used as a four-wire system, the transmission of energy is in effect single-phase. The distribution of energy, however, is a combination of single- and two-phase, since the lighting load is taken care of on a number of single-phase taps made in such a way that the load is balanced between *A* and *B* phases, while the motor load makes use of both phases.

In the two-phase, three-wire system, two of the four wires are replaced by a single wire called the neutral, the cross-section of which is theoretically 41.4 per cent. greater than either of the other two. The three-wire system requires less copper than the

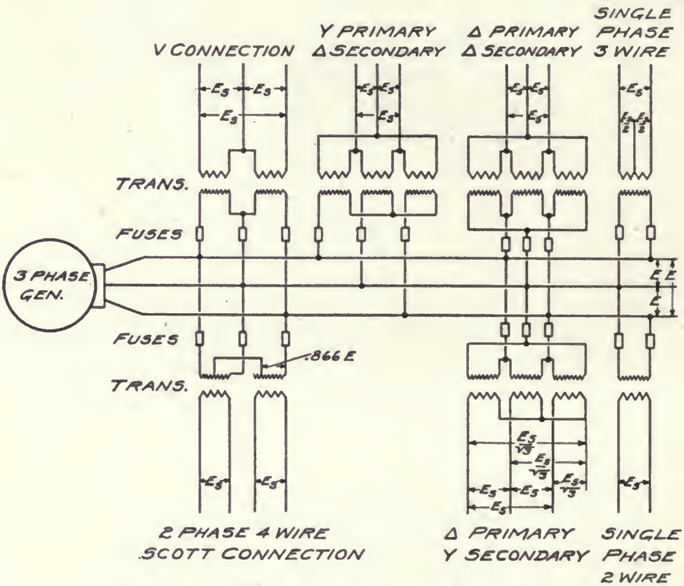


Fig. 114.—Three-phase, three-wire system.

four-wire for the same current-carrying capacity but it is less flexible, and good regulation is difficult because load conditions on one phase will affect the other phase, thereby producing unbalanced voltages.

Two-phase, three-wire, and two-phase, four-wire systems are shown in Fig. 112 and 113.

Three-Phase.—The three-phase system may be used with either three or four wires. The three-wire system may be either Δ- or *Y*-connected; and where good load balances may be obtained, it is very satisfactory. However, a balanced load is difficult to obtain; and where the load is unbalanced, there is a shifting of the neutral, with the result that voltage regulation is difficult. For this reason the four-wire system has many advantages over the three-wire system and has been adopted in many of the best installations. In this system, which is Y-connected, a neutral wire carries the unbalanced current, making it possible to obtain good voltage regulation on all three phases even when a condition of considerable unbalance exists. Since this neutral wire is at approximately ground potential; it will be seen that it is possible to transmit at considerably higher voltage between phases without increasing the potential of the system with respect to ground. For instance, a three-phase,

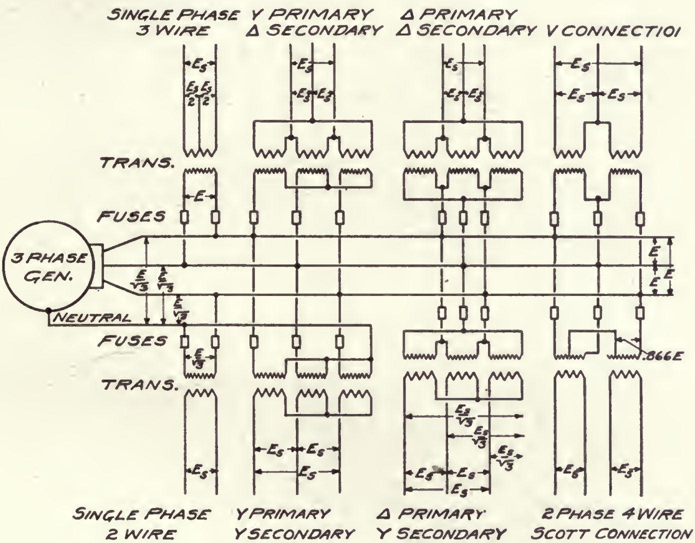


FIG. 115.—Three-phase, four-wire system.

three-wire system with 2,400 volts between phases may be replaced by a three-phase, four-wire system with approximately 4,100 volts between phases without raising the voltage to ground. This results in a reduction in the size of the conductors, which is only partly offset by the increased cost of the neutral wire.

Three-phase, three-wire, and three-phase, four-wire systems are shown in Figs. 114 and 115.

The following table gives a comparison of the weights of wire required by the various systems based on the single-phase system as 100 per cent. transmitted load and other conditions being equal.

TABLE XXXI

System	Size of wire	Per cent. of single-phase, two-wire
Single-phase, two-wire........	....	100.00
Two-phase, three-wire........	Neutral equal to outside......	75.00
Two-phase, three-wire........	Neutral 1.41 times outside....	72.90
Two-phase, four-wire	....	100.00
Three-phase, three-wire......	....	75.00
Three-phase, four-wire	Neutral equal to outside......	33.30
Three-phase, four-wire	Neutral one-half outside......	29.16

Secondary Mains.—The arrangement of secondary mains depends largely upon the density of the load. In outlying districts where the load runs from 1 to 10 kw. in each block, the

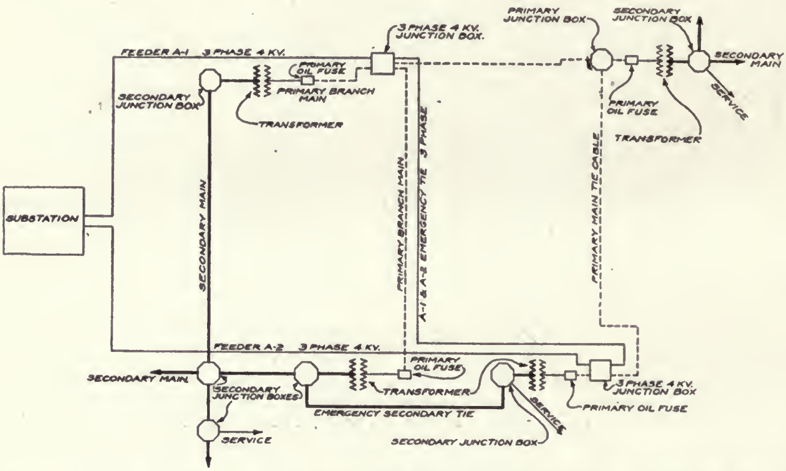


FIG. 116.—A. C. primary and secondary distribution system, showing use of junction boxes and fuses.

size of secondary wires is comparatively small and the distance between transformers is such that the interconnection of adjacent secondary mains is not commonly considered desirable. In the denser parts of a city, where business buildings are served, a cross-connected network is frequently developed. The interconnection of secondary mains has the advantages of making use of spare capacity, by equalizing loads on adjacent transformers. The network is the last step in the development of a system of secondary mains, the gradual extension of mains on all intersecting streets resulting in a system of lines which is interconnected thus forming a network. In the design of networks, the selection of sizes of secondary cable is restricted by the practical conditions in each locality. The smaller and more widely distributed consumers are carried on mains of proper size to deliver the total energy demanded. Large consumers, such as theatres and department stores are usually more economically cared for by a separate installation of transformers in the immediate vicinity of the consumer's premises.

The desirability of establishing centers of distribution to which a circuit is run directly from the substation without other

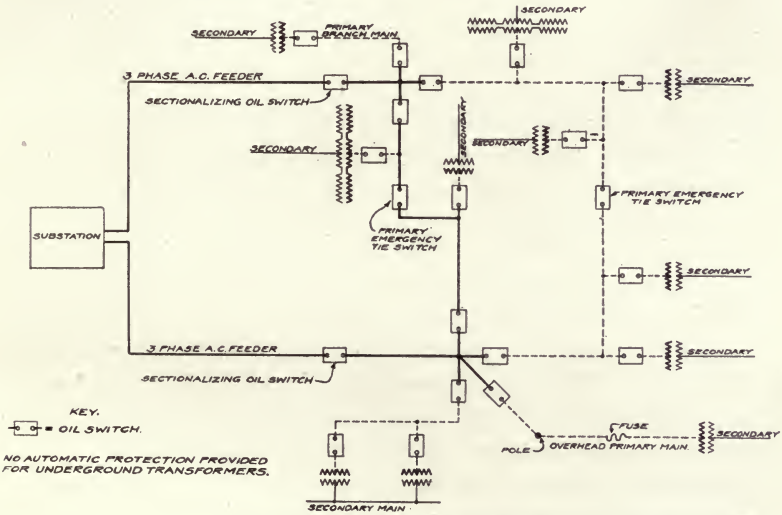


FIG. 117.—A. C. distribution system, showing use of oil switches.

connections has led to the development of several schemes for interconnecting or disconnecting circuits at central distributing points, as may be required in the operation of the system. Among these methods attention is called to the use of junction boxes equipped with fuses or solid connectors, adapted for easy removal or manipulation in order to accomplish the desired result. Another scheme includes the use of manual non-automatic oil switches connected in distributing circuits for sectionalizing and disconnecting purposes. In a few instances recourse has been had to automatic switches, or special forms of high-tension fuses of either the oil or cartridge type, arranged to automatically disconnect faulty sections of primary circuits from the main circuit.

Typical arrangements of these schemes are outlined in Figs. 116 and 117, which show the method of applying the various devices referred to for sectionalizing and interconnecting purposes, as well as for disconnecting circuits to improve working conditions.

Underground Transformers.—The method of installing transformers, standard subway types of which are on the market, plays a very important part in the successful operation of an alternating-current underground distribution system. Transformers as now manufactured, when properly installed and cared for, will give reasonably reliable service without automatic protection. The practice, however, varies with different companies, some using fuses or automatic protection in connection with every manhole transformer, and others connecting them solid. Transformers for underground installation must possess certain features in order successfully to meet all service conditions. The following may be mentioned as especially important.

They must be water-tight, as subways are not always dry. They must be properly proportioned for the limited space available in manholes, and they must have small iron losses because they are continuously connected to the mains. The radiating surface must be large and the temperature rise small, since the manholes are practically air-tight, limiting the dissipation of heat. While in the past manufacturers have considered that underground transformers should be provided with emergency relief valves or vents in order to prevent the creation of dangerous pressures within the transformer cases, it may be definitely stated that the use of such devices is entirely unnecessary and their omission is recommended in all cases. An exhaustive study of underground transformer troubles by the National Electric Light Association Committee on Underground Construction reveals the fact that many troubles may be traced directly or indirectly to the use of relief devices or to poor electrical connections resulting from careless or improper installation methods. Troubles caused by the occasional flooding of transformer manholes where relief devices have been in use may be emphasized as a reason for their omission, as many cases of transformer failures are directly traceable either to water or moisture entering the relief device or the transformer case through loose covers or other points of entrance which have not been properly sealed at the time of installation.

The importance of maintaining the oil in underground transformers in perfect condition, free from moisture or sediment, cannot be too strongly emphasized, as the life of the transformer depends on the elimination of these conditions.

Precautions should be taken by operating companies to insure proper installation and operation of transformers, and in addition to an inspection of the oil at least once a year, air pressure should be applied to the transformer cases after installation to detect leaks. Transformers should be so placed in the underground chamber that the oil gage and oil drain are readily visible and accessible.

The transformer should be subjected to an air pressure of about 6 lb. per sq. in. when full of oil and after the line and feeder connections have been made. To make the air-pressure test, any convenient device, such as a small air pump used to inflate automobile tires, can be used to establish the required pressure.

The chief transformer difficulties which most companies encounter are caused by the flooding of subways and manholes. Occasional failures in the cable connections to the transformers have also contributed to the list of troubles in this class of service. If water gets into the transformer tank, it will be necessary to dry out the transformer before it is again placed in service. The simplest method of doing this is as follows: Drain off all the oil from the transformer. Then, with the cover off, circulate sufficient current through the coils to maintain a temperature of about 80°C. With the secondary coils short-circuited, about 1½ to 3 per cent. of the rated voltage applied to the primary windings should be sufficient to produce the required heating. The temperature may be determined by a thermometer between the coils and in good contact with them. During the first hour of this operation the temperature should be carefully observed so that the coils will not attain a temperature exceeding the above-mentioned value. Under ordinary circumstances 10 or 12 hr. should be a sufficient length of time to properly drive out all moisture from the coils. If, however, there are evidences of moisture at the end of this time, the heating should be continued several hours longer.

Transformers should be provided with cutout subway boxes on both primary and secondary sides if they feed an underground distribution network. If they feed only isolated sections, the cutout on the secondary side may be omitted. These boxes need not necessarily be fused, as a number of companies consider that fuses give more or less trouble. Several companies recommend the omission of fuses on both the primary and secondary sides, and depend for protection entirely upon the automatic devices in the station. Fuses, where used, are between 150 and 200 per cent. of cable capacity. The neutral is connected solid in all cases, and is usually not brought into the junction box. The secondary neutral of the transformer should be a solid copper conductor where it enters the transformer case. If stranded wire is used, water is apt to be siphoned into the transformer when manholes are flooded, and special precaution should, therefore, be taken to see that this connection is made water-tight.

The location of transformers at street intersections is especially desirable as it permits of the supply of electricity in four directions from one unit. With alley lines, where the high-tension distribution is overhead, it is sometimes preferable to locate the transformers for the underground secondaries on poles. In large installations, transformers are usually located in separate manholes or in vaults on the customer's premises.

It is usual in subway systems to connect transformers in multiple so that in case of a transformer failure the service may not be interrupted, although there may be a temporary drop in voltage until part of the load can be transferred to an adjacent transformer bank.

Some trouble has been experienced due to transformers not operating satisfactorily in parallel and it has been necessary in some instances to install reactors in the transformer cases so that the load may be properly shared by the different units. The operation of subway transformers in multiple, however, has proved a valuable means of safeguarding service, and many failures of transformers or transformer bushings have resulted in no interruption of service, the only indication of trouble being a slight lowering of voltage at the immediate load supplied by the defective transformer.

No particular precaution seems to be necessary to conduct heat away from transformer manholes except with large installations, where a cold-air intake is provided at the bottom of the manhole and a vent at the top, as illustrated in Fig. 118. These are usually placed alongside of an adjoining building where such arrangements can be made.

In temperate zones, transformers of moderate capacities may be safely installed in manholes where 3 cu. ft. of space per kva. is provided, without installing any special means of ventilation other than that afforded by a perforated manhole cover. When the concentration of transformer capacity in a single manhole reaches 200 kva. or more, under conditions where the space

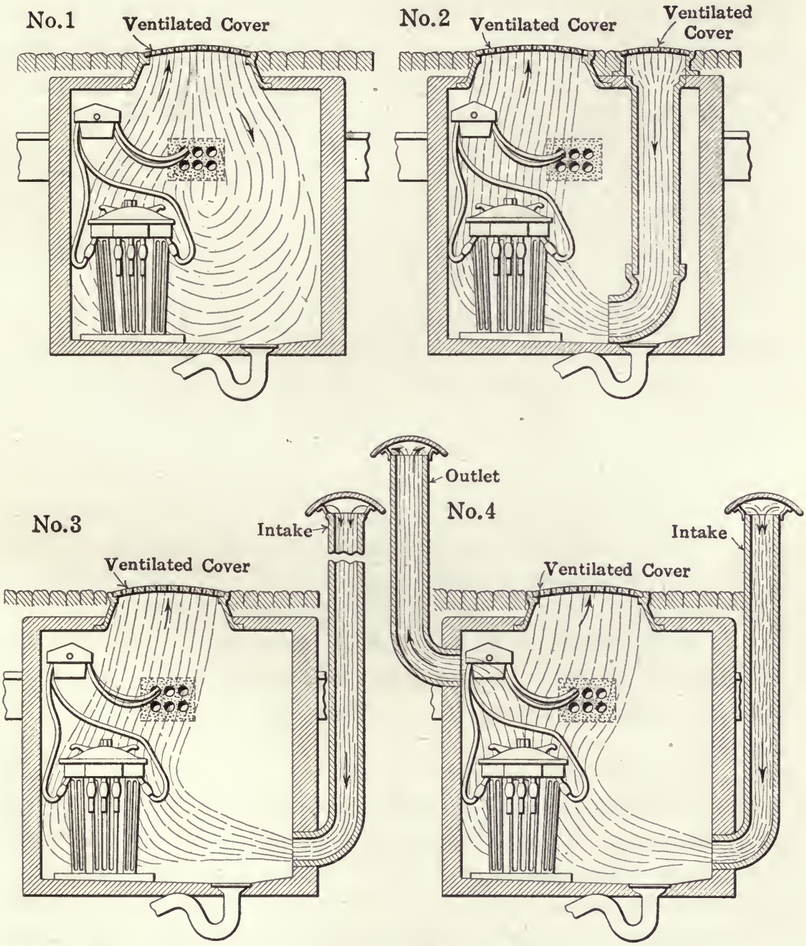


Fig. 118.—Methods of ventilating transformer manholes.

factor must be reduced below the limit given above, some special facilities for ventilation must be provided to avoid temperature rises in excess of those allowed and guaranteed as permissible by manufacturers. Natural ventilation is to be preferred in all cases where conditions are favorable for the installation of suitable means for promoting a rapid circulation of air through the manhole. In some cases recourse may be had to artificial circulation by placing small blowers in manholes to draw air in or out, as may be convenient.

In general, it may be said that 8 watts of transformer losses may be allowed per sq. ft. of wall surface. In moist soil with ventilated chamber, 12 watts may be allowed; while under unfavorable conditions not more than 6 watts per sq. ft. would be permissible. The total surface, including roof and floor, should be included when determining wall surface.

It is recommended that transformers be installed directly in contact with the bottom of manholes, and not blocked up off the bottom in any case unless the transformer case is reliably grounded.

Some of the most serious accidents on record have been either indirectly or directly the results of shocks received from transformer cases placed on wooden blocks in manholes, all of these accidents being primarily due to a failure of the transformer or wiring connections, whereby high potential was impressed upon the ungrounded transformer case.

Cable Junction Boxes.—Due to the wide extent of territory covered by alternating-current feeders and mains, and to the large load connected to same, suitable emergency ties, junction boxes, oil fuses, etc., must be provided to sectionalize the portions of the system which may be affected or upon which work must be performed. The necessity of these auxiliary devices is apparent when one considers the high potential of the alternating-current system as compared with the low potential of the direct-current system.

Undoubtedly the greatest difficulty has been in the development of primary fuses and junction boxes. If one is to judge by the widely differing types of these devices in use, engineers are not agreed as to the best solution of this problem. Underground alternating-current distribution would probably now be more extensively used but for lack of confidence in the primary fuse and means for quickly and safely cutting in and out portions of a primary network in case of trouble.

Low-voltage cable junction boxes for 250- and 500-volt operation have been in general use for a number of years, but the development of the alternating-current underground system of distribution has brought about a demand for similar subway boxes for use at higher voltages. Primary fuse boxes in which the fuses were immersed in oil have been used by some companies, but in a number of cases their operation has been very unsatisfactory. One general defect of a number of oil fuse boxes which have been on the market in the past is that little or no effort had been made to dampen the effect of the explosion when the fuse was blown, the explosion of the fuse often bursting the box casting itself, and also at times throwing the oil over the workmen. Boxes of recent design, however, have been constructed to

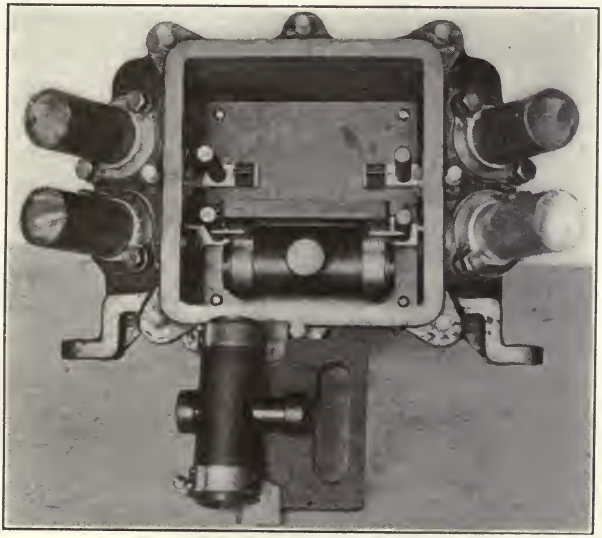


Fig. 119.—Subway box with fuse immersed in oil.

operate successfully by the use of a special form of fuse holder, which has been able to withstand satisfactorily the explosion and arc of a blowing fuse without damage to the box and without disturbing the oil contained therein to any noticeable extent. This form of box, which is shown in Fig. 119, is not provided with a relief valve, but the fuse holder consists of a special form of cartridge holder with an insulating handle which carries the wire fuse through the center and connects the ends to the fuse clip by ordinary knife blades. The fuse wire itself is so built that the overload current blows it at the center, and the result of the explosion is greatly dampened by means of a cushion of air trapped in the upper part of the horizontal tube mounted in the center of the fuse holder. Tests with this type of box made close to a source of power of 2,000 kw. failed to cause any explosive action or throwing of oil under short-circuit.

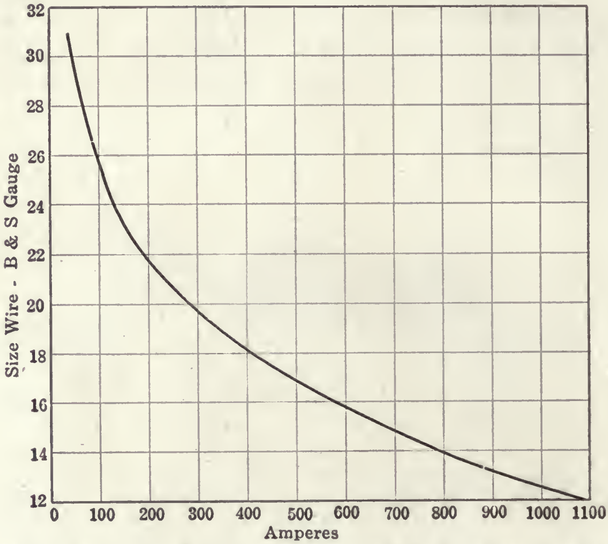


Fig. 120.—Fusing current of copper wire immersed in oil.

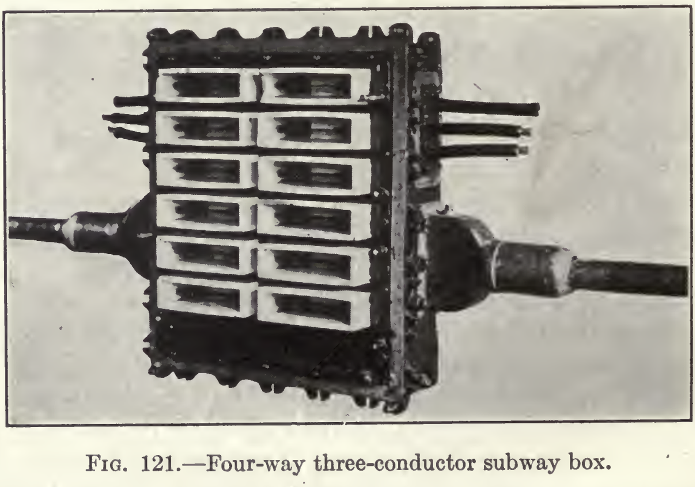


Fig. 121.—Four-way three-conductor subway box.

The boxes are usually fused for short-circuit and not for overload protection. The curve shown in Fig. 120 shows the relation between fusing current and size of wire.

The first essential in the successful operation of any system is continuity of service. While all systems are more or less subject to interruptions; each system should be so designed that these interruptions will be reduced to a minimum, both as to duration and area affected.

Fig. 121 shows a four-way, three-conductor interconnecting junction box suitable for 4,500 volts working pressure. All live

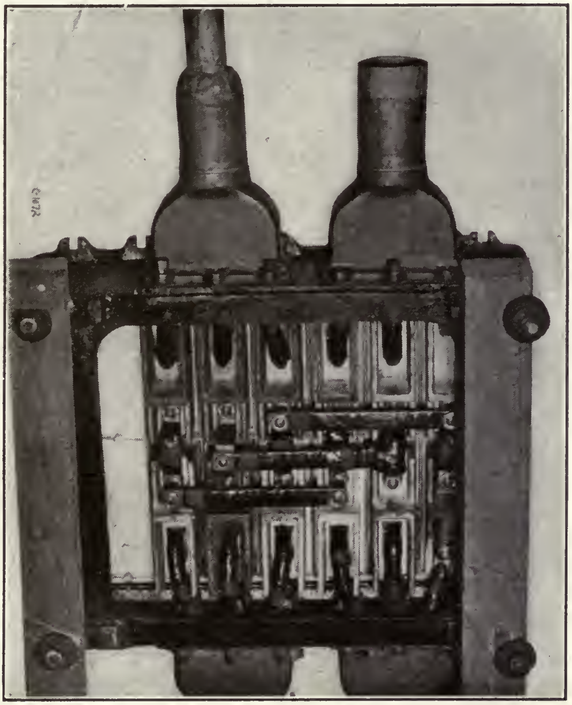


FIG. 122.—Backview four-way three-conductor subway box.

parts are mounted in porcelain cells, one cell taking care of one cable conductor. The bus connections are made on the rear by copper straps connecting from the various studs to give the desired combination. Flexible insulated cable leads are extended through the side of the box from the other stud of each individual porcelain cell, thereby making it possible to assemble all current-carrying parts in the porcelain cells which are mounted in a frame.

Fig. 122 shows a rear view of the arrangement and electrical connections, which, when the box is assembled, are all imbedded

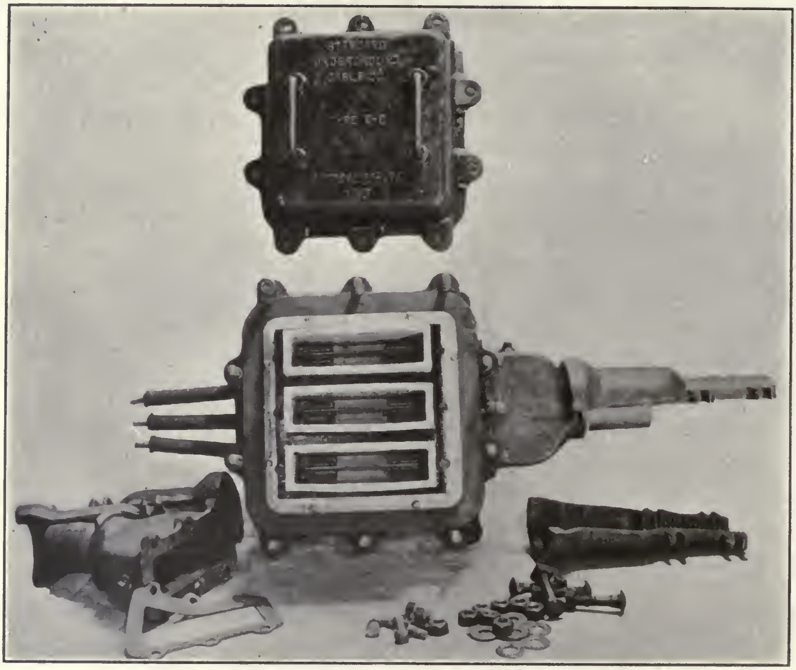


FIG. 123.—Two-way three-conductor sectionalizing box.

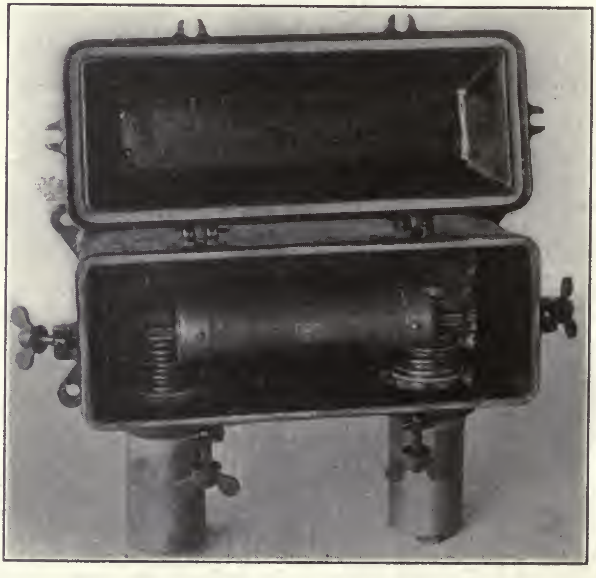


FIG. 124.—Single-pole primary cutout box.

in insulating compound. A two-way sectionalizing box of the same construction, built for three-conductor cable operated at 4,500 volts, is illustrated in Fig. 123.

A single-pole primary cutout box for fusing 2,500-volt cables is shown in Fig. 124. In this particular design the ends of the cable are sealed and thoroughly protected from moisture by a nipple terminal which extends through the wall of the box casting and at the same time acts as a support for the spring clip which takes the enclosed fuse.

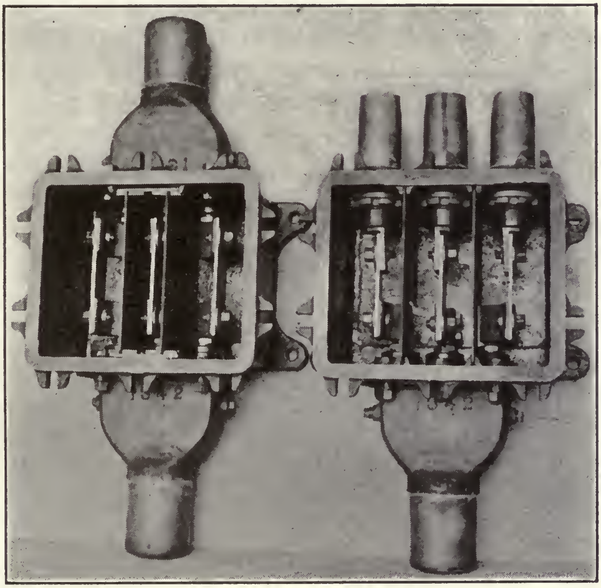


Fig. 125.—Three-pole low-voltage sectionalizing box.

Fig. 125 shows a three-pole sectionalizing box, designed for low voltage. The box may be arranged for multiple- or single-conductor cables, depending upon local conditions. All cables whether single or multiple form are terminated by sealed nipple terminal structures; and disconnecting straps extend between the stems in these nipples so that all slate or other bases may be entirely eliminated.

In some installations spare feeders have been provided to be used in case of emergency. These feeders are usually equipped with suitable subway boxes so that they may be connected to any of the feeders in trouble and supply service while repairs are being made. Practice seems to have demonstrated that the fusing of mains is unsatisfactory; and in most installations no fuses are used in the primary system except on transformers.

Safety to workmen and continuity of service demand the use of more reliable apparatus on an alternating-current system than is required on a direct-current system. The additional cost of sectionalizing devices for the alternating-current underground system is small as compared with the cost of the direct-current system. Load and service will be important factors in the choice of the system.

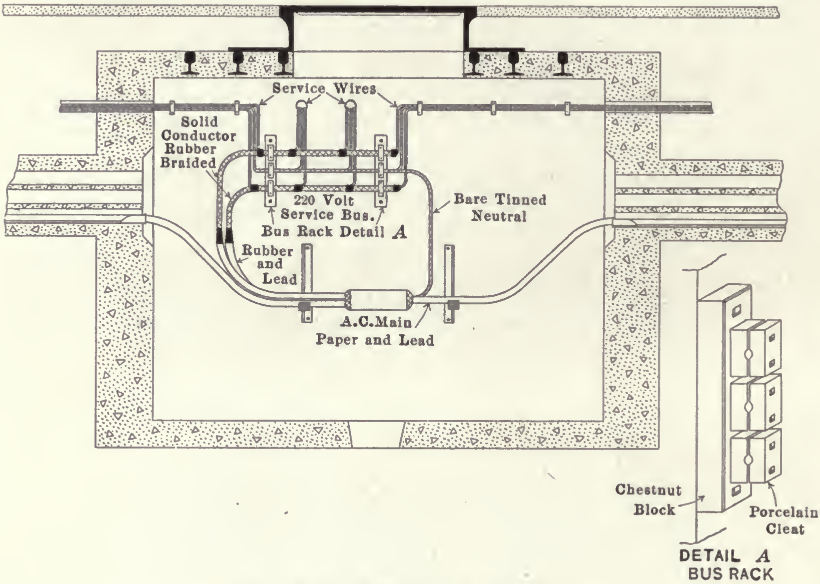


Fig. 126.—Manhole service bus.

Service Bus.—In many systems, subway branch boxes are used on the main cable for taking care of the service connections to consumers. These boxes add considerably to the cost of the service installation, and it is frequently necessary to install additional boxes in cases where the number of outlets in the original box installation is insufficient to take care of the ultimate number of service connections. A novel method of taking care of service connections is by the use of a rubber-insulated bus mounted on the wall of the manhole or distribution hole, as shown in Fig. 126. In this type of construction a hand splice is made on the main paper-insulated lead-covered cable with rubber-insulated lead-covered cable; the lead sheath on the branch cable terminating a short distance below the bus rack. Service connections are made to the bus with rubber-insulated cable covered with weatherproof braid, the bus cable being a solid conductor in order to avoid any moisture siphoning into the paper cable in case the rubber insulation or service-connection joints become defective while the manhole is filled with water. Installations of this character have proved very successful and have been in operation on 220-volt alternating-current systems for a period of about 10 years without failure. The principal advantage with

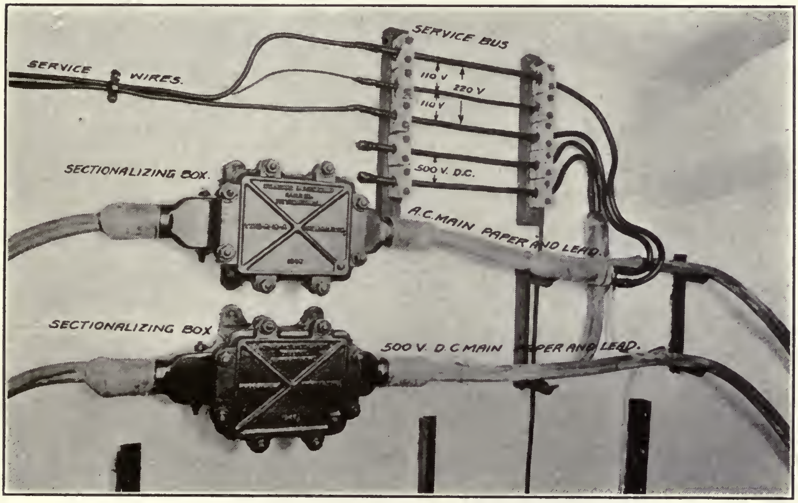


FIG. 127.—A.C. and D.C. service bus with sectionalizing box in manhole.

this form of construction is that the services of a lead jointer are not required to make connections to the service bus; and any number of services up to the capacity of the bus may be installed as the occasion requires. In Fig. 127 is shown a bus arrangement as just described, with sectionalizing boxes on the secondary alternating-current and 500-volt direct-current mains mounted on the wall of the manhole.

Manhole Oil Switches.—Manhole oil switches have been used quite extensively by a number of companies for disconnecting sections of cable when failures occur or when it is desired to work on a feeder without interrupting the service. Multiple-pole hand-operated oil switches of various capacities and potentials up to 10,000 volts are in successful operation.

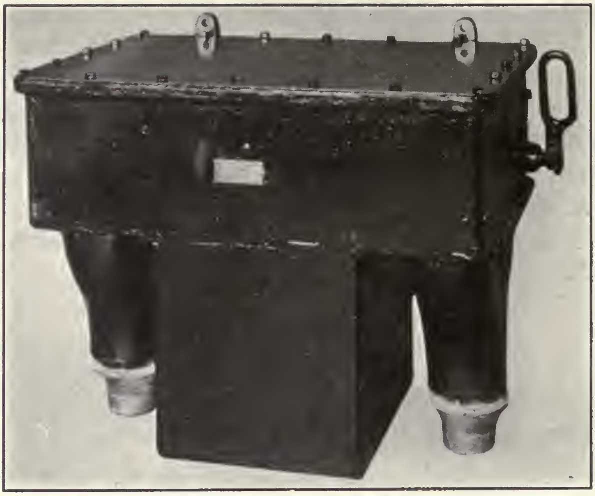


FIG. 128.—Triple-pole 10,000-volt manhole oil switch.

FIG. 129.—Triple-pole 2,500-volt manhole oil switch.

These switches are made for mounting on flat vertical surfaces in manholes or in locations where there is danger of flooding. The frame, cover and oil vessel are cast iron, and by means of gaskets, all joints are made water-tight. The switch is provided with an operating handle on the outside of the frame of such design that the switch can be operated with a hook.

Manhole automatic overload switches are not recommended due to the effect of low temperature on the automatic features and the tendency of the oil to congeal or thicken at extremely low temperatures. While the thickening of the oil would not interfere with the opening and closing of a non-automatic hand-operated switch, automatic switches must depend in a large measure upon gravity as the actuating force in opening, and the thickened oil would have a tendency to delay or entirely prevent the opening of the switch. Further, the gases generated by an automatic switch in opening the circuit under short-circuit conditions would, in spite of any vent which might be provided, have a deteriorating effect upon the gaskets, with consequent danger of water getting into the switch and causing serious damage. In Figs. 128 and 129 two types of manhole oil switches are shown.

Alternating-current Network Protector.—The use of the alternating-current network has become standard practice in sections where the load is dense. This system has the advantage of permitting the use of a smaller number of transformers, a more economical loading of the transformers and a greater flexibility in the distribution system.

The principal difficulty which has attended the interconnection of transformer secondaries has been the progressive blowing of fuses when a defect developed in any of the transformers. In the case of a failure not only does the transformer drop its load but the defect develops into a short-circuit into which all the other transformers feed, with the result that the fuses blow progressively, starting with those nearest the fault, until the whole network is shut down.

To eliminate the disadvantages of the network there has been developed commercially a device known as the "A.C. Network Protector" designed to disconnect automatically a faulty transformer.

This device, which has no moving parts to stick or get out of order, consists of a small transformer with primary and secondary

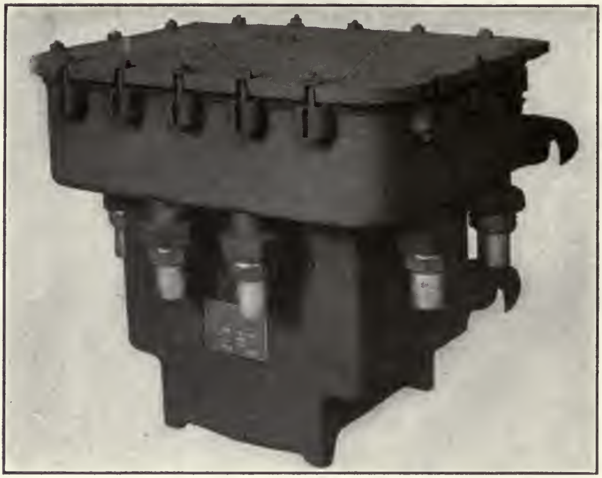


FIG. 130.—A.C. network protector.

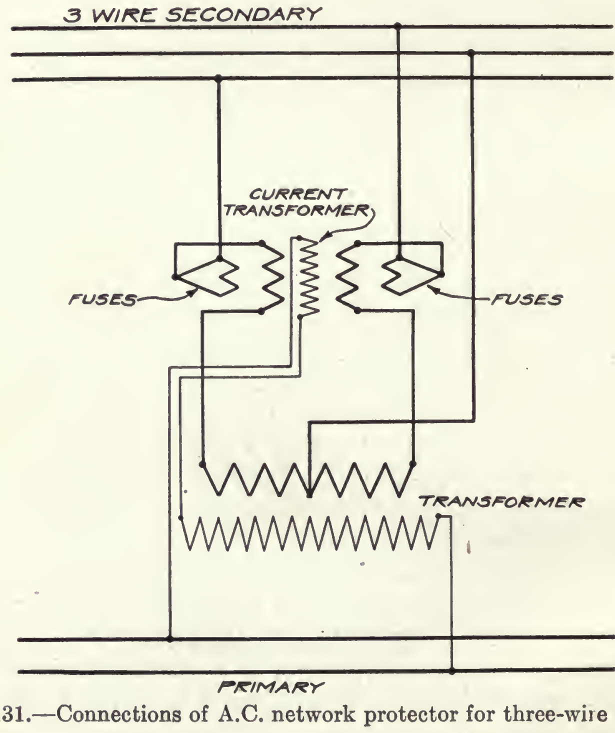


FIG. 131.—Connections of A.C. network protector for three-wire network.

windings in series with the corresponding windings in the power transformer, and a third coil wound on the iron core. The windings are so designed that under normal conditions the ampere-turns in one coil neutralize those in the other and the flux in the core is zero. When a defect develops and there is a reversal of current in the secondary, the ampere-turns add their effects together, producing a heavy flux in the iron core, upon which is wound the third coil consisting of a few turns of heavy-wire short-circuited through a V-fuse. This flux sets up in the local circuit a heavy current which instantly blows the fuse and isolates the faulty transformer.

Fig. 130 shows the general appearance of the protector; and Fig. 131 shows a diagram of connections for use on a three-wire system.

Service Connections from Underground Mains.—The central station, in furnishing service to all classes of consumers under varying conditions, is required in many installations to change existing overhead services to an underground system of distribution. In some cases the entire cost of making the change from overhead to underground is borne by the customer, and in other cases the company bears the entire cost, the practice followed being dependant on local conditions. It is the practice of some of the larger central-station companies to issue "Rules and Regulations for Wiring" to the end that wiring contractors doing construction work for customers to be connected to the company's mains will so arrange and carry out their work as to protect the interests of customers and at the same time conform to such regulations as experience has shown are necessary in order for the company to supply uniform and satisfactory service.

Wherever it is desired to supply current from underground mains, the customers' wiring should terminate and the meter-board be placed at the front wall of cellar or vault nearest the street. In some cases where wiring is done by local contractors and service is not actually being supplied from subways at the time service is desired, the central station companies require an additional temporary overhead service to be installed until the underground system is provided.

Armored Services.—In the early periods of underground construction, the service end of the system was somewhat neglected and very little thought was given to the real importance of an ideal service installation. Services were usually treated as an adjunct to the main system and no special attention was given to the installation as long as the connection was made with the property to be served.

As the underground system increased, the matter of adequate protection at the consumer's end of services was taken up by the underwriters with the result that certain rules and regulations were formulated governing the methods of installation. At first many companies made their service connections with lead-covered cable which was buried in the ground. This, of course, proved impractical, as a failure in the cable necessitated the tearing up of both the street and sidewalk in effecting repairs. Another method of furnishing service was to bring the feed into a building at a street intersection extending it to adjacent buildings through the various cellars. The objections to this type of service were that it materially increased the fire hazard and the danger of interruptions to service and afforded ample means for the unscrupulous to obtain current by theft.

There are many other arguments against the installation of such services but the three previously mentioned were sufficient to condemn such practice and to show clearly the need for individual service connections. The next step was the installation of individual services consisting of iron pipe or duct through which the cable was drawn. Fire risk, however, was not materially reduced until a few years ago when it was realized that the old type of terminal block was inadequate. These terminal blocks consisted of an ordinary fuse block which was not protected against dampness nor against short-circuits caused by accidental contact.

The writer recalls a case in a large eastern city where an investigation of service trouble showed that a serious short-circuit had been caused by the piling against the fuse block of a number of steel-banded packing cases filled with fireworks. There are still such services in existence but central-station companies are gradually eliminating them, and with the advance in design of equipment for underground services to meet the severe operating conditions, a water-tight service box with enclosed fuses was produced. This equipment was installed adjacent to the duct holding the service wires which were carried by knobs or cleats to the service box where porcelain-bushed holes provided an entrance for the wires. After leaving the service box, the main wire ran to the meter, usually located on the board.

After a time the underwriters revised the rules governing wiring, condemning the practice of using moulding in cellars. This left conduit or open wiring as alternatives. Conduit was more generally accepted, as the underwriters had also ruled that all switches and cutouts be enclosed in iron boxes. With the increased number of consumers came an alarming number of current thefts, and the larger percentage of these occurred at services which were more or less obscured. The underground box which was located in basements afforded a temptation to the unscrupulous, and a constant watch was necessary to detect

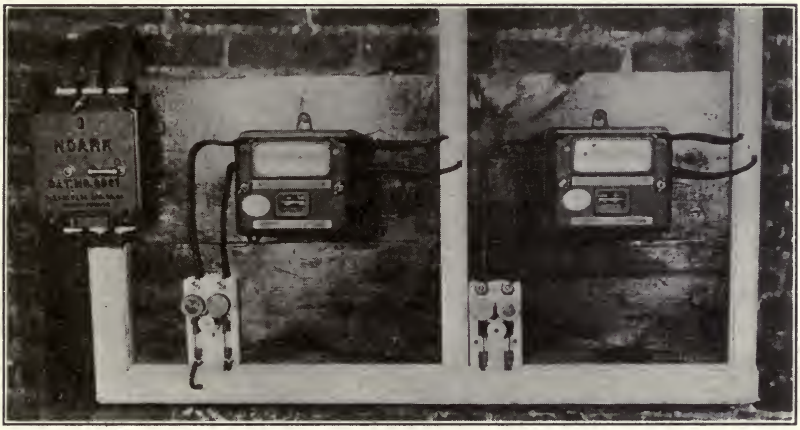


Fig. 132.—Service box with meter loop in wood moulding.

cases of theft. The plans for full meter and service protection have been taken up within the past few years and now nearly all of the larger operating companies have been equipping their underground services with protective devices. As most underground districts had been primarily supplied by overhead services, whose entrance was usually above the first floor, considerable expense is incurred in changing the location of meters from upper floors to basements. This involves an entire new meterboard and necessary wiring to connect the same with original distributing centers. The old method was as shown in Fig. 132. This is inadequate in preventing theft of current and does not furnish an absolute protection to the wires. Devices are now on the market by the use of which it is possible to get full protection from theft as well as to provide an absolutely iron-clad service at a very slight cost over that of open-wired boards. Such boards have many additional features for facilitating the handling and testing of meters in service. An ideal board, as used by some of the larger operating companies, can be constructed at a very reasonable cost.

In changing over from the old overhead to new underground installations, considerable wiring is necessary to connect new services to points of distribution. When making such changes in large buildings it is advisable to bring all meters to a point adjacent to the service. The following is an outline of the method employed by a few of the companies making extensive changes from overhead to underground systems.

Prior to starting the actual work, a service inspector is sent out to select the most advantageous point to make the service entrance. In making this selection attention must be given to the physical conditions outside of the building, such as location of hydrants, poles and other obstructions which would interfere with service pipes. After having familiarized himself with the outside, he selects the most desirable point for the location of the service entrance, choosing the point, where possible, which is least likely to be obstructed by an accumulation of material usually found in cellars. If sufficient wall space can be secured at the point of entrance of service, the meterboard will be located at that point unless a large amount of interior wiring is involved. Should this be the case, a meter location is selected which will allow a more economical installation by eliminating some of the wiring. Such a case would be where there are a number of meters located at various points in a building.

After the service pipe is installed, the interior wiring changes are started. Service wire is pulled in as the first step, and the service board is mounted at the point selected. The best form of meterboard is constructed of angle iron made up in the form of a frame, upon which may be mounted backboards to support meters. If service and meters are to be located at the same point, an approved water-tight service box is bolted to the side of the frame. Service wires are calked in the service pipe with oakum soaked in a sealing compound to exclude gases. Service wires are then incased in a flexible-steel conduit, one end of which is pushed back in the service pipe until it reaches the calking. To the other end is attached a connector which is made up to a fitting on the service box and wires are then soldered into the service box. This method gives a full armored protection to the service and is highly recommended by the fire underwriters.

The service box should be of a type which will be accepted by the underwriters as a switch and cutout. The usual type of box used is that which provides for extraction of fuses when the cover is opened. The load side of the service box is equipped with a fitting similar to that which receives the flexible conduit on the service side of box, and from this the wires are carried to the switch

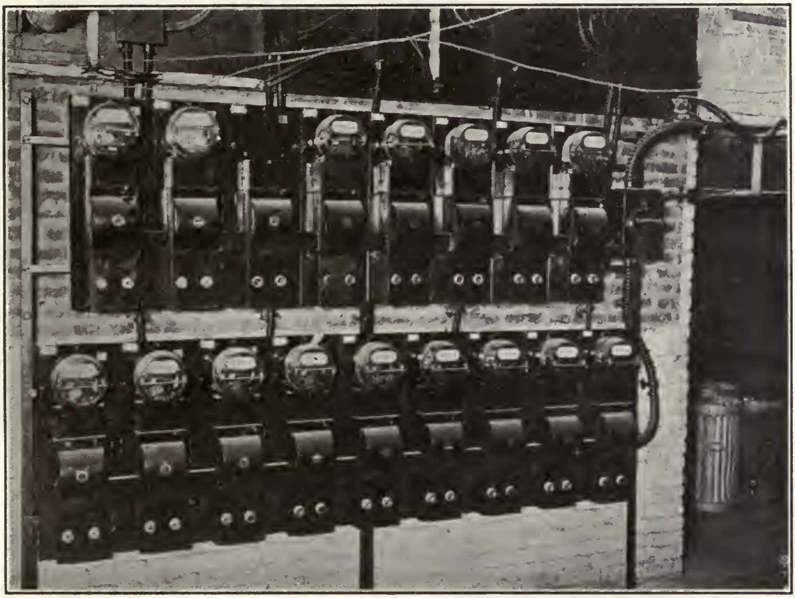


Fig. 133.—Apartment house meter installation.

cabinet of the first meter and then on through the various cabinets until the end of the bank has been reached. Each meter has an independent switch and cutout located between the service and the meter. These are placed in a steel cabinet which is sealed and effectually protects the service against tampering. As most companies use a three-wire bank form of distributing through their underground system, it becomes necessary to balance the load on each service as far as practical, as many of the overhead services are apt to be two-wire. It has been found that where an office or other similar building has a number of meters, the installation may be practically balanced by using all two-wire meters and connecting these in staggered position on a three-wire service. This does not apply to larger two-wire installations, as in the larger installations the periods of consumption do not occur simultaneously. Installations of 1,000 watts or larger should be changed to three-wire. This invariably means a larger amount of rewiring but can usually be done by extending

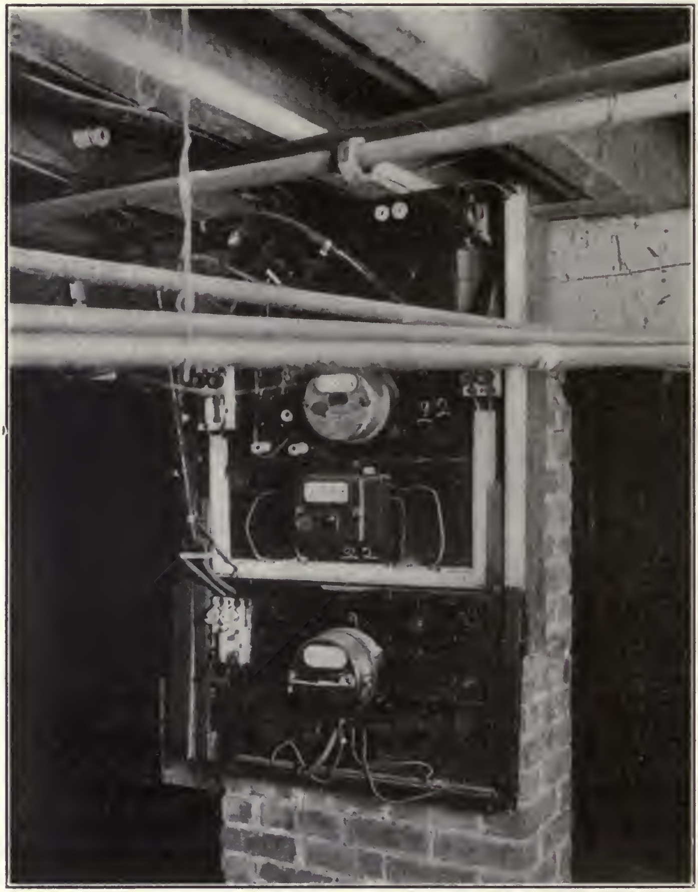


FIG. 134.—Improper meter installation.

the three-wire mains from the meter to the center of distribution and there balancing one subcircuit against another.

In all such three-wire systems, it is recommended that the neutral wire be made solid from the manhole or transformer to the point of distribution. Solid or dummy fuses should be installed in the service box and so arranged as not to be removed when cover is opened and other fuses are extracted. This has one distinct advantage in changeover jobs, especially where the old jobs have had a grounded service. Such services are apt to have local grounds on the building, and in changing over if no secondary ground was on the original service these local grounds are apt to appear on the live leg of the distributing main and blow fuses. The current will then find a path back through load, and owing to the resistance of the ground, will probably cause a fire. With the solid neutral, this difficulty may be overcome safely by

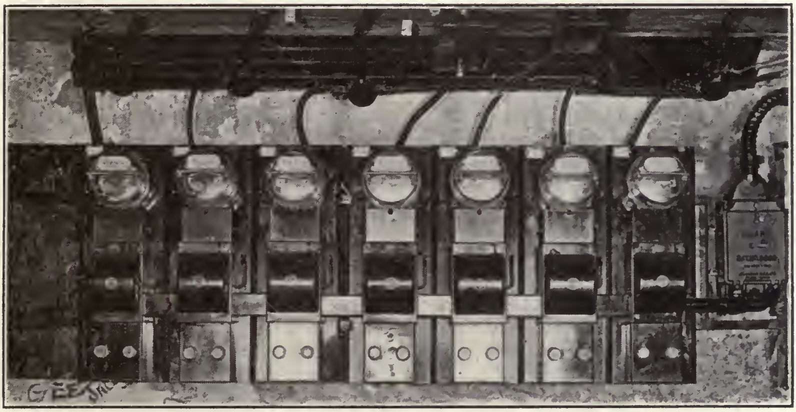


Fig. 135.—Iron-clad meter installation.

transposing the circuit wires on which the ground appears. The best form of neutral wires to install from street to service box is a stranded bare tinned copper of not less capacity than that of the outside wires, and in no case should this be less than No. 6 B. & S. gage. Fig. 133 shows a model service installation for apartment houses and large buildings. The service is installed in iron conduit from the manhole to the service box as described before. This installation is equipped with meter protective and testing devices in which are also incorporated consumer's fuses and switch control. This represents an iron-clad installation in which there are no wires or current-carrying parts exposed from the manhole to the first point of distribution. The features of the testing devices are that a meter may be tested, replaced if necessary, or repaired, without interruption of service to the consumer. Shunting arrangements are made by which meters may be entirely isolated from the line for purpose of repairs or changes, thus eliminating danger to the operator. It is also possible to discontinue service for non-payment or other causes and lock same out until such time as it becomes desirable to reinstate service. This is very convenient where there is a change of tenants and it is desirable to make a meter transfer. Fig. 134 shows a job which was changed over and shows the hazardous condition of wires both from a fire and theft of current standpoint. Many old installations have reached such a condition and should be rebuilt.

Fig. 135 shows a service equipped with armor. Such installations as are shown in Fig. 135 can be made for less than $2.50 per meter, which includes complete outfit installed as shown.

Protection of Transmission Systems.—The growth in the central-station industry and the use of high-voltage transmission cable has brought about numerous problems which have made it necessary to resort to various methods for protection of the system.

The increase in size of generating and substation equipment, together with the increase in size and voltage of the connected cables, has made it exceedingly difficult to handle short-circuiting values. The change from engine-driven units of comparatively small capacity and slow speeds to turbine-driven units of large capacity and high speeds is perhaps one of the largest factors in the problem.

Experience has shown that no single part of an electrical system is free from the possibility of injury, and that it is incumbent upon operating and designing engineers to protect their systems as far as possible from such occurrences through the use of protective devices suitably designed to afford such protection.

Relays.—Oil-break switches and carbon-break circuit-breakers are commonly used to open electrical circuits at some given overload and on short-circuit. To secure additional protection under a variety of abnormal conditions or to provide for a certain predetermined operation or sequence of operation, relays may be advantageously employed. The connections between the relays and circuit-opening devices are usually electrical and are extremely flexible since they admit of the use of a number of devices, each having a different function, with a single oil switch or circuit-breaker as well as with one or more switches to secure the desired operation or protection.

Relay protection for transmission lines varies with the type and method of operating different systems, but, in general, either instantaneous, inverse time-limit or definite time-limit types of

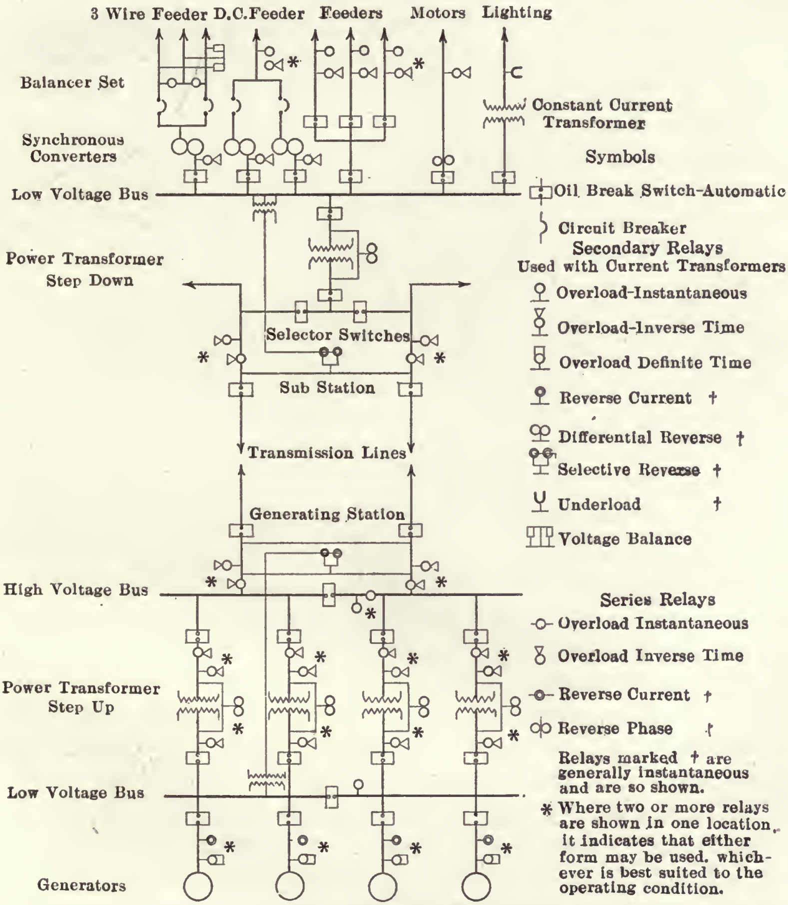


FIG. 136.—Diagram of modern power house wiring and busses showing location of relays.[1]

relays have been used according to engineering judgment. The arrangement of relays on a feeder or transmission line must be such that the occurrence of a short-circuit between any two wires will open the breaker. On single-phase circuits one relay is

[1] G. E. Co. Bulletin 4857-A.

sufficient to accomplish this. One of the fundamental conditions beginning to be more fully appreciated by engineers is that each particular line should be treated individually with respect to its relay setting instead of having a certain definite setting for the relays of all lines in a given class.

In order to determine the proper setting of instantaneous overload, time-limit and inverse time-limit relays which are more commonly used on a system of distribution, it is necessary to know the characteristics of the system as well as the characteristics of the generators, automatic apparatus, circuit-breakers, regulators, etc.

In systems operating radial feeders, with each feeder connecting to only one substation and not operating in parallel at substation ends, reasonably satisfactory service has been rendered by the type of relays referred to.

In systems operating ring systems of feeders, or radial feeders with several substations in tandem on a single feeder, where selective action is required in order to prevent interruption of service from all stations between a fault and the source of power, satisfactory results have rarely been continuously attained with any of the types of relays mentioned.

In Fig. 136 is shown a one-line diagram which will be of assistance in making a selection from the various types of relays to meet the requirements of power-house and substation layouts.

It should be noted that the selection of relays to meet actual operating conditions is an important problem and should receive careful attention when a new system is being laid out or extensions are being made to a system already installed.

The successful operation, selective cutting out of trouble, and the continuity and safety of service, depend entirely on the operation of automatic oil switches and circuit-breakers, which in turn must be tripped by means of relays. There are many types of relays, each type designed to perform certain functions, and before any of these types are installed, a careful study should be made of the conditions under which they must operate.

Current-limiting Reactance Coils.—When short-circuits occur in the cable system, a tremendous current flow is set up which reaches its maximum during the first cycle. When it is realized that for this first cycle every generator connected to the bus is able to assume a short-circuiting value of at least ten times its rated capacity, it is readily seen that heavy stresses are imposed on the switches, cables and apparatus. The stresses on the feeder switches at such times are enormous, and it has become necessary of late years to lock knife switches in position and to take steps to protect the oil switches against these effects. To relieve this condition and protect the system, various types of apparatus have been employed. The use of reactances, both external and internal, on generators, as well as on the bus and feeder circuits, has perhaps been one of the most effective means of protecting the central station and cable system.

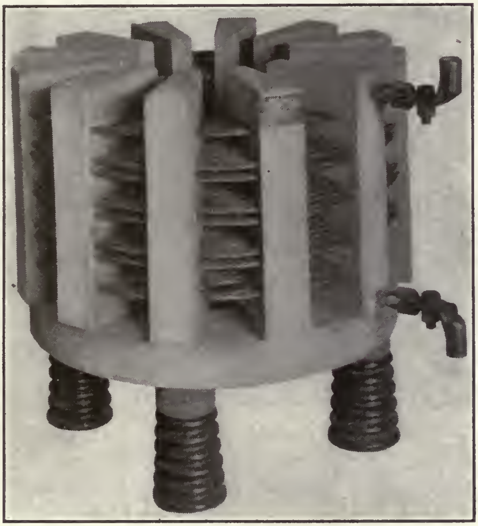


FIG. 137.—Cast-in-concrete type of current-limiting reactance.

In general, it may be said that in stations of large capacity, external current-limiting reactance coils, in one form or another, have become a necessity for the protection of oil switches and service. Local conditions will govern the type of reactances to be used, but wherever possible, it is now generally admitted that the best protection to service is obtained from the use of reactances on the individual feeder circuits.

A large company, which has recently completed the installation of 5 per cent. reactance coils on all 13,200-volt, 60-cycle feeders has noticed a very material improvement in the selective operation of relays, with the resultant benefit to the system. Short-circuits, which formerly caused an interruption to service on several multiple feeders, have now become minimized to such an extent that only the short-circuited feeder releases and the synchronous apparatus in the system is not affected.

No combination of generator and bus reactances will give this protection to service, as their installation is intended primarily to protect station apparatus. The percentage of reactances to be used is still an open question and cannot be standardized as it depends largely upon operating conditions. The practice is to have a total reactance of 8 to 12 per cent. on generator circuits and about 2 to 5 per cent. on feeder circuits.

Current-limiting reactances should be of the air-core type, and their capacity should correspond to the full-load capacity of the

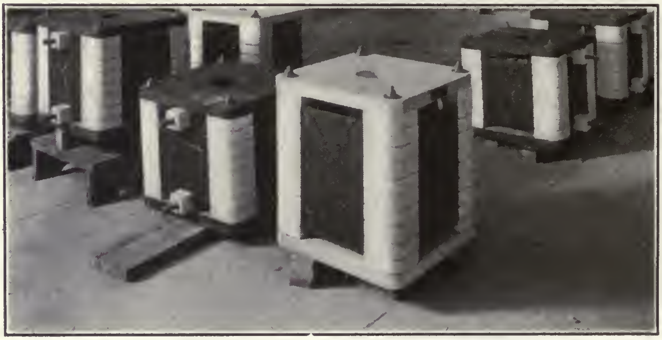


Fig. 137*a*.—Semi-porcelain-clad type of current-limiting reactance.

line which they are intended to protect. They are generally built with a core of non-magnetic material such as wood, concrete, porcelain, or of several such materials in combination. Two types of feeder reactance coils are illustrated in Figs. 137 and 137*a*. In general, they are so bulky that it is difficult to find room for their installation in a station already built. In some cases separate structures adjacent to the generating station or the switch-house have been found necessary for their proper housing. When these reactance coils are properly constructed and placed, their installation involves no additional hazard.

Selective Fault Localizer.—The localizer is designed primarily to indicate on which feeder a ground occurs when there are a number of radial lines connected to a high-tension busbar. The device necessitates a relay for each feeder. One of these relays is shown in Fig. 138. They are connected to the respective current transformers of the lines on which it is desired to localize, in such a manner that all load currents are balanced out, as shown in Fig. 139. The various relays are interconnected in such a way that only the relay on the grounded line is operative. All the

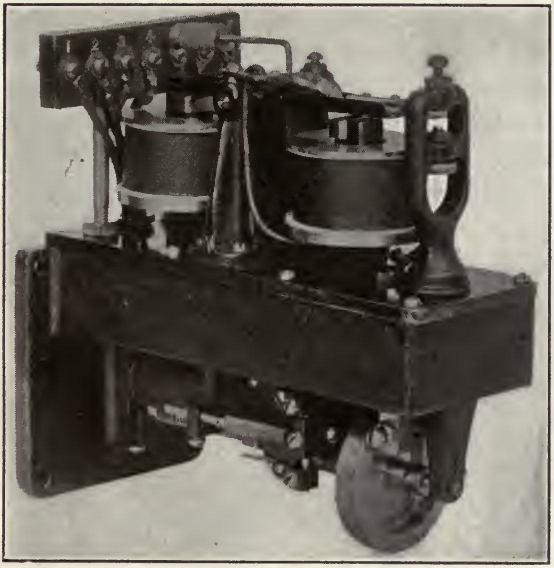


FIG. 138.—Relay for localizer of faulty feeders.

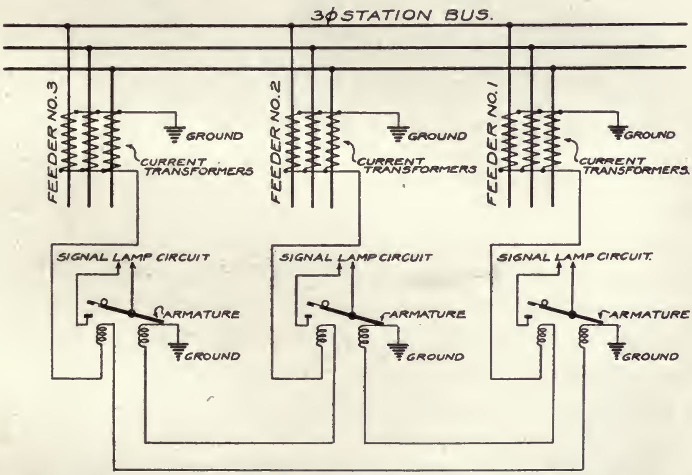


FIG. 139.—Connections of feeder-localizer apparatus as applied to a three-phase system.

other relays are rendered non-operative by balancing the magnetic pulls, one against the other in successive pairs. When a ground occurs on a high-tension system, the proper relay operates and illuminates its signal lamp to indicate the grounded feeder.

This device is used as an auxiliary appliance to the arcing-ground suppressor. When the two devices are used in combination, it is possible to have a ground occur upon a system without interrupting the service. As soon as a ground develops, the localizer operates being followed immediately by the arcing-ground suppressor, which automatically cuts out the arc to ground.

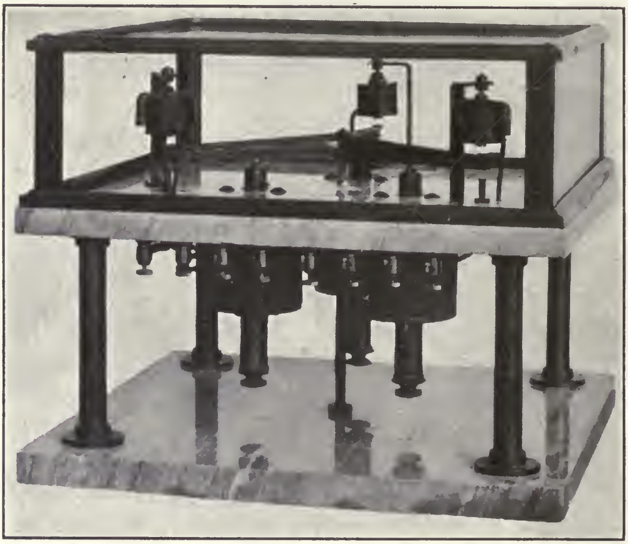


Fig. 140.—Three-phase electro-magnetic selective relay for arcing-ground suppressor.

If this arc were allowed to play for any length of time it would develop into a short-circuit in the cable system. With the accidental arc suppressed, the station operator can now substitute a good cable for the faulty one and open the switch of the arcing-ground suppressor, thus clearing the system.

Arcing-ground Suppressor.—There are two essential parts to the arcing-ground suppressor: first, a selector of a grounded phase, Fig. 140; and second, a single-phase switch between each phase of the busbar and ground. When an accidental ground takes place in the system, the potential of that phase to ground is reduced, which causes the selector to pick out and operate the corresponding single-phase switch. This single-phase switch extinguishes the arc no matter where it occurs on the system, and thus stops further development of the trouble as well as preventing surges which accompany an arcing ground. When a substitute cable is switched in, the faulty cable is taken out and then the switch of the arcing-ground suppressor is opened. The single-phase switches are designed with two contacts in series, with resistances between contacts. A circuit is never made nor broken without this resistance in series to damp out oscillations.

Grounded-neutral Systems.—Some companies in order to gain additional protection operate on a grounded-neutral system, while others resort to the use of various types of arcing-ground suppressors. The practice of grounding the neutral on transmission systems has not so far been standardized, and it is the practice of some companies to operate with the neutral free from ground, while others ground the neutral through varying amounts of resistance, and in still other cases the neutral is grounded without any resistance.

In a system with the neutral ungrounded, when one conductor becomes grounded, the arc may establish and extinguish itself in rapid succession, creating an arcing ground which would have been eliminated if the neutral had been grounded. The presence of an arcing ground of high-frequency oscillation is liable to create surges destructive to the cable and apparatus. Where the neutral is grounded through a resistance, the high-frequency voltage between two of the conductors and ground is minimized when the other conductor is grounded. This same result is accomplished also in an ungrounded system by the use of an arcing-ground suppressor, when the faulty conductor is grounded through the suppressor switch. This operation is accomplished in a fraction of a second and eliminates the arcing ground and with it the attending high-frequency voltage, thus leaving the cable with line voltage between the other two conductors and ground. This operation causes no interruption to the system, and the faulty feeder may be taken out of service at leisure. Another feature of the arcing-ground suppressor is that in cases of accidental contacts with the bus by employees working in the vicinity, the suppressor may act with sufficient promptness to prevent fatal accidents. A number of instances of this kind have been reported to the writer.

In the grounded system the voltage to ground decreases as the resistance between the neutral and ground decreases, and increases as the generator capacity increases. It is necessary to decrease the resistance in the neutral as the capacity of the system increases in order to confine the voltage strains to the same limits. But since the current that can flow over a short-circuit between one conductor and ground may be limited by the resistance in the neutral, most of the companies using the resistance prefer, in case one conductor becomes grounded, to use such resistance as will allow the necessary current to flow to operate the relays properly without regard to the voltage rise.

In expanding the idea of decreasing the resistance between the neutral and ground in order to minimize the voltage strains to ground, one large company, after operating with the neutral, grounded through a resistance for several years, has decided to ground the neutral without resistance. Under this condition, when one conductor becomes grounded, the current on that con-

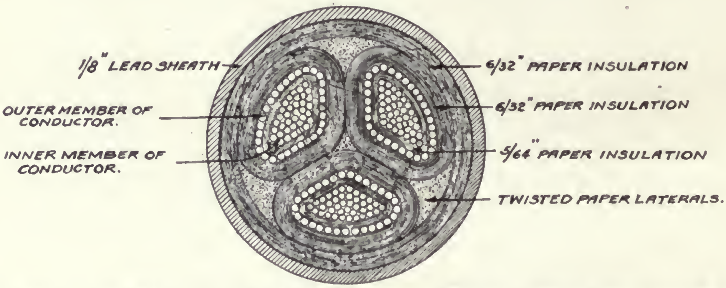


Fig. 141.—350,000 c.m. 13,200-volt split-conductor paper insulated-sector cable.

ductor approximates that flowing over a short-circuit between conductors, which will cause the selective relays to operate in the same manner as when a short-circuit occurs between conductors, the condition for which the relays are set.

There is considerable difference of opinion regarding the advisability of grounding the neutral and the relative advantages and disadvantages resulting therefrom. For more detailed information regarding the practice of grounding the neutral and the operation of arcing-ground suppressors, the reader is referred to the *Proceedings* of the American Institute of Electrical Engineers.

Merz System of Cable Protection.—The Merz system of cable protection consists of the usual equipment of current transformers, relays and oil switches, but the current transformers at opposite ends of the transmission line are connected in opposition through an independent pilot cable paralleling the main transmission line. By this arrangement no current will flow through the secondaries of the current transformers so long as the same amount of current flows in the same direction in each of their primaries; but should there be a breakdown of the cable insulation between the transformers, conditions would be so changed that current would flow through the secondaries of both transformers, actuate the relays and open the oil switches at both ends of the line. There would then be remaining in service the transmission-ring system with one section cut out but with a service to all substations unimpaired and supplied through the lines remaining in service.

The disadvantages of this method of protection are the complications of the additional three-conductor pilot cable and the fact that a short-circuit of the control cable would operate the relays of the section of the main cable it protects.

The objections to the installation of the pilot-wire cable and the difficulties encountered in its maintenance have led to the present development of split-conductor cables in the application of the balanced system of protection to transmission lines. In Fig. 141 is illustrated a sector type of split-conductor cable as manufactured and now used in this country by several large central-station companies.

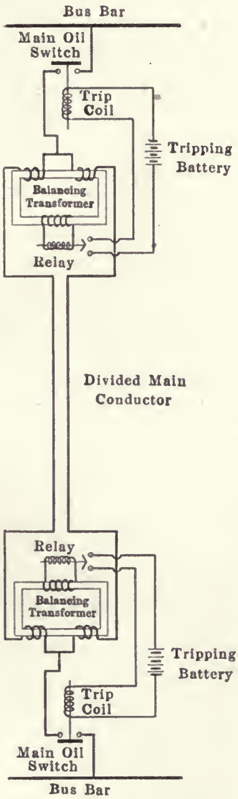


FIG. 142.—One-line diagram, illustrating the split-conductor scheme of feeder protection.

This balanced system of protection has been developed and patented by Mr. J. C. Hunter, of the firm of Merz & McLellan. In the balanced-current method of control in connection with main-line conductors, each conductor is divided into two parts of equal resistance and carrying capacity. The currents in these conductors are balanced against each other in the usual manner to operate secondary relays, thereby avoiding all necessity of using the pilot cable. A method of connecting a split-conductor scheme of feeder protection is shown in Fig. 142. The general adoption of this type of cable in many transmission undertakings abroad indicates that the advantages to be derived from its use are considered as effecting material improvements in the reliability of service and are, therefore, worthy of recognition in American practice.

CHAPTER IX

ELECTROLYSIS

General.—Electrolysis as here referred to is the chemical decomposition of metallic structures by electric currents. Soil, when entirely dry, has a very high resistance, but under normal conditions street soils contain varying amounts of water-holding salts in solution, thus making the earth a fair conductor of electricity. The specific resistance of soils varies widely, ranging from a few hundred ohms per $cm.^3$ for moist soils to 25,000 or 30,000 ohms per $cm.^3$ in the case of dry sandy soils.

Since it is to a large extent the moisture which makes soil a conductor, the passage of currents through the earth is by electrolytic conduction, and is accompanied by a decomposition of the metal at the point where the current leaves an underground structure to take a path of lower resistance through the earth. This is true of both direct and alternating currents except that the rate of decomposition by an alternating current is only about 1 per cent. of that caused by a direct current of the same value.

The rate of oxidation is proportional to the current strength, and from a consideration of the theoretical amount of metal changed into the oxide it will be seen that even though the decomposition of underground structures does not follow the electrochemical law exactly, the amount of metal oxidized in a year is very considerable. The constant for iron (converted into the ferrous condition) is 1.042, and for lead 3.858 grams per amp-hr. The amount of iron oxidized in a year will be $1.042 \times 8{,}760 \times 0.002205 = 20.2$ lb. per amp. The amount of lead will be $3.858 \times 8{,}760 \times 0.002205 = 74.1$ lb. per year per amp.

Either more or less (but generally less) than this theoretical amount is realized under actual conditions, depending upon soil conditions.

The effects of electrolytic action would be far less serious if this loss of metal were distributed evenly over the structure, but this unfortunately is not the case. Actually the currents discharge from a number of small areas, causing pitting. Thus the usefulness of a structure may be destroyed by being badly corroded in a few spots while the amount of oxidation over the rest of its surface is negligible.

Electrolytic corrosion in most cases is caused by stray currents which have leaked from grounded electrical systems. The stray currents from grounded telegraph and telephone lines and, in general, from direct-current distribution systems are so small as to be negligible.

Railway return conductors, since they carry comparatively heavy curents, are the only sources of stray currents which need be considered in connection with the problem of electrolysis.

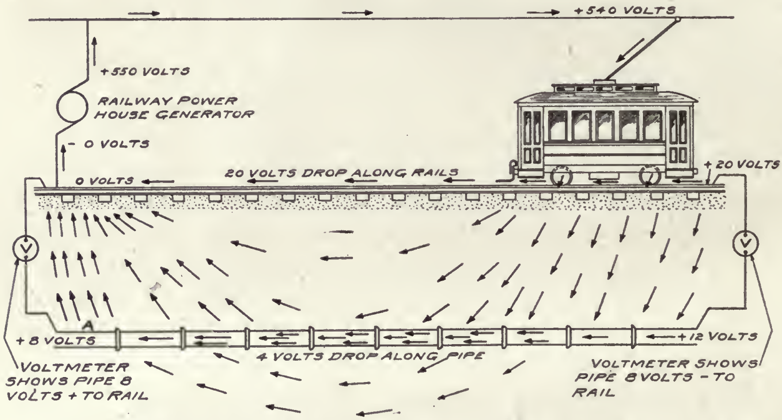


FIG. 143.—Diagram showing stray railway currents with assumed distribution of potentials caused by these currents.

Trouble from electrolysis followed close upon the introduction of electric traction. In the early days of the industry engineers did not foresee the danger, and very little attention was paid to the proper bonding of the track return, with the result that the greater part of the return current left the rails to take a path of lower resistance through the earth or along adjacent metallic structures. Even after the necessity of proper bonding came to be realized, a considerable part of the current returned to the negative bus through the earth. Fig. 143 shows a simple trolley system in which the return current divides, part returning along the rail, part through the earth, and part along the iron water main. The greatest damage to the main will occur at *A* where the current leaves the pipe to pass through the ground to the negative bus. Corrosion will also occur at the joints, due to the fact that where the joint resistance is high the current will by-pass the joint through the earth, returning to the pipe on the other side.

Before attempting to utilize any of the systems for the mitigation of electrolysis, attention should be given to the matter of proper rail bonding and the limiting of the distance between substations.

Rails may be bonded by the installation of copper ribbon or wire soldered or brazed to the webs of the rails or by welding together the ends so as to make practically a continuous rail.

In many installations not only are the separate rail sections bonded but the two rails or (in the case of a double-track road) all four rails are electrically connected.

The method of bonding rails by the use of a welding outfit has been used to a considerable extent and is apparently satisfactory since it provides mechanical reinforcement in addition to a good electrical connection.

A great deal of attention has been given to the matter of rail bonding; and since the methods in use to-day produce bonds which show a conductivity of about 80 per cent. as compared with an equivalent continuous rail, it is doubtful whether any further relief for electrolytic conditions can be expected from attempts to improve upon the present bonding methods.

The number of, and the distance between, stations or substations which supply a railway line will govern to a very large extent the amount of current which will leak to pipe lines or other foreign structures.

Where too small a number of stations are used to supply a railway line, the return current to the negative bus will be large and the distance between stations comparatively long. These two factors bring about the condition of excessive voltage drop along the rails and aggravate the tendency of current to return through the ground.

American engineers apparantly did not have as thorough a grasp of the situation as did engineers on the Continent. As soon as the problem of electrolysis became serious in Europe, regulations were adopted limiting the voltage drop between any two points in the track to about 7 or 8 volts. These regulations forced railway companies to install better bonds, to limit the distance between stations and, in some cases, to install insulated return feeders, with the result that troubles from electrolytic corrosion disappeared almost entirely.

American practice, on the other hand, has not sought to remove the underlying causes of electrolysis but has attempted merely to relieve acute local conditions. The measures adopted in this country, in addition to track bonding, have consisted of "pipe drainage" or bonds to other systems. It must not be inferred that the drainage system is inherently bad, for up to the present time it has undoubtedly relieved acute cases of electrolysis and has apparently imposed no serious hardship on the owners of structures tied in by the bonds. In spite of the results obtained by the drainage system, it does not cure electrolysis nor remove the fundamental causes, and it is to be regretted that the large investment necessary for the development of an adequate bonding system was not used to develop some positive cure such as the return-feeder system. It is true that where a large system has adopted drainage bonds as a remedy the cost of a change to the return-feeder system would be almost prohibitive; and the writer believes that in most cases the drainage system is very nearly as satisfactory a remedy as the return-feeder system, provided careful and systematic tests are made.

Drainage Systems.—The aim in all drainage systems is to lower the potential of the structure with respect to the earth by draining off the current through metallic bonds. The proper location for these bonds is determined by tests, and the drainage conductors are installed at points where the structure is dangerously positive to the adjacent track. The current is drained either to the track or else direct to the negative railway bus by means of return feeders. If all the current could be drained from the structure by means of bonds, the bonding system would be an excellent means of relieving conditions on the particular structure so drained. The problem is not solved, however, by indiscriminate bonding. Drainage of any one structure lowers its potential with respect to neighboring structures, with the result that the latter will drain through the ground to the bonded pipe line. It is, therefore, clear that while bonding may clear up conditions in one place it may work to the injury of structures not tied into the network.

Where the drainage bonds are so installed that a pipe line becomes a parallel return for the track circuit, it is practically impossible to control the amount of current carried on the pipe line, and serious overheating may result. If the pipe joints offer a high resistance, the current will leak around the joint and corrode the metal at the point where the current passes into the soil. The use of such bonds to a pipe line where high-resistance joints occur may place the line in a worse condition than would obtain in the absence of any bonds at all. In the unbonded condition the total yearly loss of metal would be greater but under some conditions of bonding the action is localized and intensified so as to cause the structure to corrode through in a number of places.

In addition to the above objection, the system is not permanent in that any radical change in conditions will necessitate a complete change in the bonding system in the locality affected.

In any system where the pipe parallels the track, the current will divide approximately in inverse proportion to the resistance; and in such a system, when the current carried by the pipe becomes excessive, the current on the pipe can be decreased only by an increase in rail conductivity. This method requires the use of a very costly installation of copper as an auxiliary return.

Excessive currents on pipe lines are a source of danger not only to the pipe itself but to buildings into which service connections are run. There are cases on record of very serious overheating of pipe connections inside buildings. However, this danger is remote, and is due not to the use of bonds but to the installation of bonds in the wrong place.

Probably the best way to drain a pipe line is by the installation of insulated drainage feeders running from the negative bus in the station to various points on the structure. It is possible by the use of such a system to control very closely the distribution of current on the pipe line by varying the resistance of the drainage leads.

This method is better than the preceding, but all drainage systems have the disadvantage that with growth in the railway system it may be necessary to drain very large currents from pipe lines, and that in many cases the trouble is merely transferred from one area to another.

Numerous attempts have been made to protect pipe lines from the effects of electrolysis by means other than the use of bonds.

Protective Coatings.—Protective coatings in the form of paint, dips of asphalt, coal tar or pitch, and wrappings of paper or cambric have been used to some extent, but tests have failed to show that any one method is universally satisfactory.

It is difficult to apply any coating so as to obtain a uniform smooth surface free from pinholes or bare spots. Where these exist, a pipe line may fail much more quickly than where the pipe is uncoated due to the fact that corrosion will be localized in a small number of areas, the effect of electrolytic action being intensified.

Even if the coating is very carefully applied, it is likely to be scratched in handling; and after the pipe is laid, blisters often form on the coating and expose the metal to corrosion.

Insulation in the form of wrappings of cloth or paper fail in most instances because they are not entirely impervious to moisture. The coating becomes damp in spots and affords a conducting path, with the result that the pipe fails.

Dips consisting of coal tar or pitch which are applied hot and allowed to cool and harden on the pipe surface are very likely to develop cracks. It is possible to make coatings absolutely impervious, but only at an excessive cost. Such an installation requires the construction of a trench in which the pipe is laid, the pitch being poured in and allowed to cool. This method is not recommended except in special cases where continuity of service is of such importance as to make the cost of the installation a minor consideration.

Cement coverings, even when several inches in thickness, will not afford certain protection because concrete is not impervious to moisture, and moist concrete is a fairly good conductor.

Electrolytic conditions on a pipe line could be cleared up if it were possible to cover the pipe with a conducting coating which would not be corroded when the current passed from the pipe line into the earth. Most of the non-corrosive metals are so expensive as to make their use commercially impracticable. Black oxide, or coke particles in a suitable binder, fulfill the requirement as regards non-corrosive properties, but the same difficulties are here encountered as in the use of paints and dips. It is very difficult to get a uniform surface free from flaws. In addition, black oxide is electronegative to iron and there is danger of local galvanic action being set up.

Insulating Joints.—Very beneficial results have attended the practice of breaking up the electrical continuity of pipe lines by the use of an insulating medium at every joint. If the installation cost is too great to warrant the insulation of every joint, the insulation may be used at greater intervals in the line provided test readings are taken to detect excessive potential drop between insulated sections. If the voltage difference between two sections is too great, there will be a shunting of the current around the insulation and a corrosion of the pipe on one side of the joint.

Cement is very commonly used as the insulating medium; and while it is not strictly an insulator, if used at intervals sufficiently frequent, its resistance will be high enough to reduce the current carried. Various special types of insulated joints using fiber, wood, leadite or other substances have been used with apparent success.

The use of insulating joints is especially recommended at the point where service connections are made to a building. These joints prevent loading up the pipes inside a building with stray current and minimize fire hazard.

Fig. 144.—Cable damaged by electrolysis.

Insulating joints are valuable as an auxiliary means of reducing trouble from electrolysis but should not be used as a substitute for some of the more positive methods, such as the limitation of voltage drop along railway returns.

Protecting Cable Sheaths.—Thus far the problem of electrolysis has been considered only with a view to protecting such structures as gas and water pipes. Where conditions are favorable to electrolysis, the destruction of the sheaths of lighting, power, and telephone cables is much more rapid and disastrous.

Since the electrochemical equivalent of lead is about four times that of iron, and the lead in the sheath is just thick enough to give sufficient protection and mechanical support to the insulation, it will be seen that a cable will fail in a much shorter time than a pipe line carrying the same current.

Fig. 144 is a photograph of a section of a three-conductor transmission cable which was damaged by electrolysis in a wet manhole.

The character of the duct construction will determine to a large extent the amount of current leaking from railway systems to the cable sheaths. All duct structures will admit moisture to a greater or less degree, but fiber duct laid in concrete admits less than other forms of construction. Where water does enter, there will in general be an exchange of current either from sheath to sheath through the concrete or between sheaths and external structures. It is, therefore, important that duct lines be so graded as to drain toward manholes, and that, as far as possible, manholes, be kept dry by drain connections to sewers.

The usual method of protecting cable sheaths is by the use of a drainage system similar to that used for the protection of pipe lines. The object of draining the sheaths is to make them slightly lower in potential than the surrounding earth or neighboring structures, thus preventing current flowing off the sheaths. Since there is danger of overdraining in making the sheath potential considerably lower that that of ground or adjacent grounded structures, it is sometimes necessary to insert suitable resistances in the drainage leads. Overdrained cable sheaths are a source of danger to neighboring pipe lines because of the tendency of these lines to be injured by the drainage of their current to the cable sheaths. To prevent electrolysis of the sheath of cables by an exchange of current between sheaths, it is standard practice to attach a common bond in every manhole which equalizes the sheath potential of all the cables in the duct line.

It is inadvisable to bond direct to the track or railway return, since this makes a cable system a parallel return to the railway system. Where bonds are so installed, an accidental high resistance in the railway return will throw upon the sheaths the burden of carrying a large part of the return current. This condition will result in serious overheating of the sheaths and, in the case of power cables, in a considerable reduction of current-carrying capacity.

To prevent excessive currents on cable sheaths, the use of insulating joints in a run of cable is sometimes resorted to. This method should be used only with great care since there is danger of setting up excessive potentials across the joint or between the sheath and ground. As in the case of insulated pipe joints, insulated sheath joints are used chiefly to prevent the entrance of stray currents into buildings through lateral connections.

The use of insulated return feeders provides the most satisfactory means of preventing electrolysis. The cost of this system compares favorably with those now in use, and except in cases where there exists a large investment in bonding or other systems, its use is recommended.

Where insulated return feeders are used, the connection between the tracks or other return conductors and the station negative bus is removed, and insulated leads are run out to various points in the track. By draining the track at numerous points, the potential gradient along the rail is reduced to any desired value, and high-current densities are avoided. It will be seen from Fig. 145 that the current flows from both directions into the return lead, thus preventing the existence of a high-

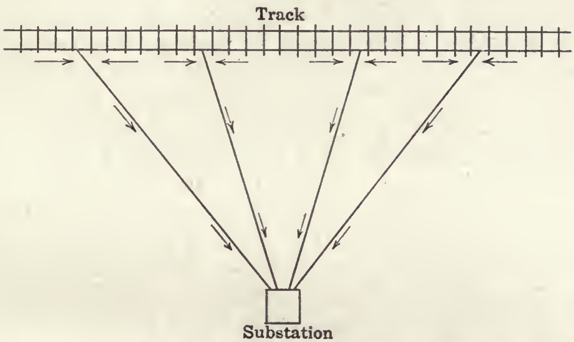


Fig. 145.—Reduction of track gradient by use of insulated return feeders.

voltage difference between any two points in the track. It is possible to obtain practically any desired reduction in potential gradient along the track and to eliminate excessive drop between foreign structures and rails by proper design of the return feeders. It is true that by the use of this system some of the conductivity of the track is sacrificed, but this sacrifice seems justified by the excellent results obtained in practice.

Insulated return-feeder systems are in use in New York City, Springfield, Ohio, and St. Louis, Mo. For a complete description of this system and of the methods of calculating, the number and size of feeders, the reader is referred to *Technologic Paper* No. 52 of the Bureau of Standards. The simple insulated return-feeder system will serve the purpose in most cases but where long or heavily loaded railway lines are used, it is sometimes necessary to make use of either direct or inverted boosters.

Another remedial measure has been proposed for the relief of electrolysis. This consists in a periodic reversal of polarity on the railway system; and while this method would theoretically reduce materially the corrosion, in a large and complicated system, the operating difficulties would make the scheme impractical even if the reversal were as infrequent as once in 24 hr.

Other schemes such as the double-trolley and negative-trolley systems have been proposed. The first is open to the objection of excessive cost and increased operating difficulties. The second, while it would undoubtedly delay the ultimate destruction of other structures, would impose a serious hardship on companies which had installed drainage systems.

General Practice.—A canvass of 56 of the larger lighting companies operating about 200,000 miles of underground lighting and power cables yielded the following information as to practice as regards electrolysis mitigation.

Conduits

Vitrified-clay tile, of both single and multiple type, is used exclusively by 43 per cent. of the companies. Vitrified tile and indurated fiber is used by 43 per cent. of the companies. In recent years the use of vitrified tile has been abandoned in favor of fiber in most of these systems. Indurated fiber is being used exclusively by 12.5 per cent. of the companies. The remaining 1.5 per cent. is made up of companies who either have not specified the type of conduit used or else have in use a type which is not yet standard.

The tendency to abandon the use of sectional tile conduit in favor of fiber is significant. Not only does fiber conduit afford a continuous runway, but its waterproofing and insulating properties must inevitably serve to minimize the danger of electrolytic corrosion at some point outside of a manhole where the destruction action might continue undetected until the cable failed.

Electrolysis

Electrolysis was reported as existing on the cable system by 64 per cent. of the companies. Evidence that the trouble is confined to isolated cases is furnished by the fact that in only three instances was electrolysis reported as generally existent throughout an entire system. The cause of the electrolytic action was in most cases attributed to stray railway currents leaving the cable sheaths to select paths of lower resistance to the railway return systems. Two companies state that attempts have been made to remedy the condition by insulating sections of the cable. Of these, one appears to have been successful, and the other reports that the trouble still exists in spite of the fact that each insulated section is drained to a driven ground connection.

Bonding of Cable Sheaths

The practice of bonding the cable sheaths together as a means of equalizing sheath potentials and of preventing electrolysis between sheaths of adjacent cables is shown to be quite general.

Bonds are used by 89 per cent. of the companies, leaving only 11 per cent. which use no bonds. Except in the case of three companies, which employ lead strip, the universal practice is either to use copper wire or copper ribbon sweated directly to the cable sheaths. In one instance a company reports sweating the bonding ribbon into one end of the cable joint sleeve, a method which is at once unique and effective.

The necessity of insulating cable sheaths from their supporting racks in manholes appears to be doubtful.

Of the replies received, 60 per cent. of the companies do not insulate. It would appear that the companies who do attempt to insulate have more trouble from electrolysis where cables are insulated from racks than where they are not. This is probably due rather to local conditions than to the method of racking cables.

Of those using some form of rack insulation, 23 per cent. use porcelain saddle blocks. Slate, brick, alberene or concrete shelves are used by 14 per cent. Wood blocks, old rubber hose or fiber sections cut from old lengths of conduit are employed by 35 per cent. An unintentional insulation is obtained by 27 per cent. which use a non-conducting form of cable fireproofing.

Except in the case of those who use porcelain saddle blocks, the value of such forms of insulation for establishing conditions adverse to the action of electrolysis appears very doubtful.

Probably the only real value of any of these materials is to furnish a form of mechanical support which protects the lead sheaths against the rough edges of the manhole racks. A more effective protection would be obtained by the use of a piece of sheet lead cut from the cable strippings.

The practice of draining a cable system to the street railway return system at the negative bus in substations, or to negative conductor or tracks at points close to substations is rapidly becoming standard.

That the drainage system affords real protection to cable sheaths is proved by the fact that 66 per cent. use this system and have noted that electrolysis under this method of bonding is negligible.

Many companies connect also to other grounded systems. Connections to gas or water pipes are made by 25 per cent. of the companies, to system neutrals by 16 per cent., and to cable sheaths of other systems by 7 per cent. Bonding direct to street-railway tracks is practised by 18 per cent.

The fear that such apparently indiscriminate connections to other systems would result in loading up the cable sheaths with return currents from other systems has been dispelled by the results obtained by companies using the drainage system.

It would appear that the troubles from electrolysis are in inverse proportion to the number of drainage connections employed. This is borne out by the experience of two companies which report that severe electrolytic conditions have almost entirely disappeared from their systems as a result of the free use of drainage bonds. This improvement in conditions has not been obtained at the expense of the adjacent systems since tests show a marked decrease in electrolytic action on neighboring structures tied into the drainage network.

A large company operating in a city of about 500,000 population, and which reports no drainage taps of any kind, appears to be suffering severe damage by electrolytic corrosion. On the other hand, a company which bonds both to its own grounded neutral conductors and to street railway negative return cables notes absolutely no electrolysis in spite of the fact that much of its system is permanently submerged in salt water.

In several cases the drainage connections used consist of a network of conductors paralleling the cable system. One report states that a network of this kind was installed by the railway company for the purpose of protecting adjacent cables and structures.

There appears to be no ground for the belief that sheath currents may reach such a value as to result in serious overheating. Forty-two companies making up 75 per cent. of the systems reporting state that they allow their cable sheaths to carry return currents. Of these, four limit the currents by the use of resistance inserted in the drainage leads; four make periodic inspection and test, limiting the current when necessary by the installation of additional drainage bonds. The rest make no attempt to limit the current. It is worthy of note that not a single case of damage to a cable or a limiting of capacity due to overheating has been reported.

Uninsulated Neutral

An uninsulated neutral or return conductor is used on either their high- or low-tension distribution systems, or both, by 54 per cent. of the companies reporting. Of the companies using this system, 53 per cent. use their cable sheaths either wholly or in part for carrying these neutral currents. Where this practice is followed, it appears that in most cases the neutral wire itself is used chiefly as a common bond to which all cable sheaths are connected. The return currents divide inversely as the resistance of the paths, and, except in cases where there are few cables in a duct line, the cable sheaths carry the major portion of the neutral return currents.

One company reports the use of the cable sheaths as a neutral for a transmission system, and several use their sheaths as the neutral of their 2,300-volt or 4,000-volt distribution feeders.

Only five cases of trouble are reported as resulting from the use of cable sheaths as neutral return conductors. In one instance bond wires were burned off and cable sheaths damaged due to the use of bonds of insufficient size. The trouble was cleared up by the installation of bonds of larger cross-section. The second case was the destruction of a neutral by electrolytic action. This neutral was a service connection tapped off from an old Edison iron-tube system and carried through a wooden plug into a joint-box. A bond between the neutral and the iron tube caused a disappearance of the dangerous condition.

The remaining three cases of trouble consisted of a distortion of neutral potentials on Edison three-wire direct-current networks by earth-potential gradients caused by street-railway return currents. In two instances the difficulty was overcome by installing additional feeder copper, but in the third case it was found necessary to run insulated neutral wires from the load center affected back to the substation.

Coöperation of Utilities

Coöperation with the railway companies is reported by 36 per cent. of the companies; with the telephone companies by 28 per cent.; and with water companies or municipalities by 25 per cent. Only 11 per cent. report any coöperation on the part of the gas interests. It should be noted that in many cases the reporting companies are connected either directly or indirectly with the railway systems.

Since there is no reported instance of failure to cure electrolytic action where proper coöperation existed between utilities, it seems clear that there should be little difficulty in correcting conditions favorable to electrolytic corrosion. The advantages of the standard methods in use have been proved conclusively, and there is no reason to believe that the protection gained by their use could not be extended to the underground structures of other utilities provided these utilities were willing to take up the problem in a real spirit of coöperation.

Electrolysis Surveys.—Where trouble from electrolytic corrosion is suspected, accurate data as to the intensity and extent of the trouble may be obtained from an electrolysis survey. Such a survey is made by reading, at intervals along the streets on which railways are located, the potential difference between one structure and all the others. Where an electric central-station company is making the survey it is usual to assume the cable sheaths as the datum or potential zero. The potential difference between the cables in each manhole and neighboring tracks, water pipes or gas pipes is read by means of a high-resistance voltmeter. A meter well-adapted for electrolytic work is the Weston duplex instrument illustrated in Fig. 146.

For the potential readings, contact is secured by means of rods for the cable sheaths and a screw-driver point for other structures or the earth.

The rods are approximately 6 ft. long and are usually in two parts so that they can be easily carried about. Heavy reinforced lamp cord is used for the leads from the rods to the instrument. In Fig. 147 rods are shown which have been used to advantage by the testing department of the Brooklyn Edison Co. In taking current readings, flexible rubber-covered wire of the proper resistance is used to give the correct millivolt reading. The bare ends of these leads are held on the cable sheaths by one man while another reads the meter.

The field notes should be copied on cards similar to that shown in Fig. 148 and made a part of a special electrolysis file. These cards, in addition to the voltage readings, have space for a general description of the conditions existing at the time of the test. After the collection of the field data a skeleton map of the city or district affected is used to give a graphic presentation of the existing conditions. The railway lines, duct lines, water pipes, and other structures are drawn in their proper location and the potential difference between the cable sheaths and other structures are platted normal to the direction of these structures. Positive voltages are laid off in one direction and negative voltages in the other.

Fig. 146.—Weston duplex electrolysis instrument.

Since the Weston test meter is a duplex instrument, it is possible also to measure the current carried on the cable sheaths by obtaining the millivolt drop over a given length. The amperes per millivolt is a constant for a given cable, and by using the constant as a multiplier, the value of sheath current is obtained.

By measuring the current carried on the cables in every manhole, it is possible to learn the approximate location of the point

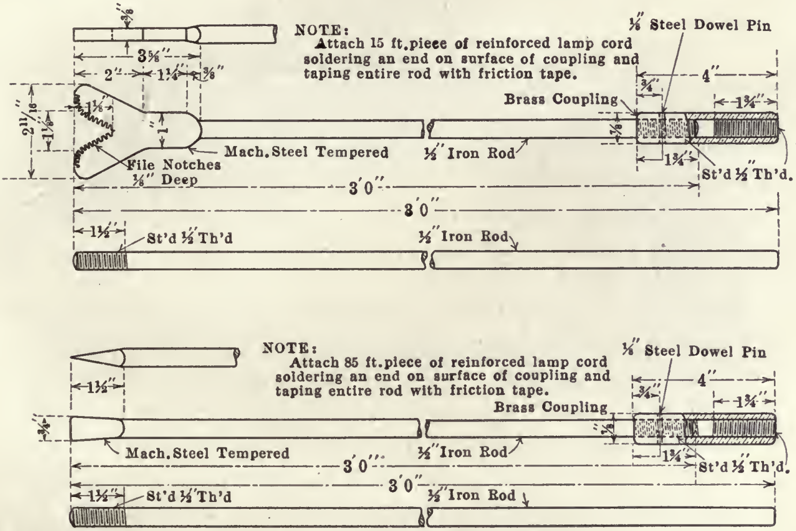


FIG. 147.—Electrolysis testing rods.

where the current is leaving. Where a marked discrepancy exists in the sheath currents in adjacent manholes, an investigation should be made with a view to installing metallic drains to prevent the current leaving through the ground.

		PUBLIC SERVICE ELECTRIC CO. ELECTROLYTIC TEST																					
○	Time	Date: Tested by Municipality Street	POTENTIAL, CABLE TO														Direction of Current on Cables	Electrolysis Pittings on Cables	Cables Bonded Together	Water in Manhole	Cables Protected	Cables Supported	Remarks
			Track		Water		Gas		Earth		Tel.												
			+	−	+	−	+	−	+	−	+	−	+	−	+	−							
○																							

FIG. 148.—Electrolysis record card.

The value of the electrolysis survey is to show the danger points in a cable system and to indicate the places where drainage bonds should be installed.

CHAPTER X

OPERATION AND MAINTENANCE

Records.—One of the essential things in connection with the operation of an underground system is the keeping of detailed permanent records. It should be the duty of every cable and underground engineer to keep a system of records which will enable him to tell at any time the exact amount and the location of the cable installed.

Suitable forms should be provided to make it an easy matter for the foreman on the work to make the necessary notes, and these foremen's reports should be carefully transferred to the permanent office records. A good system of records will be found of great value in locating and taking care of trouble and in laying out new work. Such records will also be of assistance to the commercial department in considering new business. It frequently happens, where complete records are not kept, that the company depends to a large extent upon the memory of certain employees, and if these employees leave the company the information is lost.

Diagrammatic layouts of the conduit system and manhole system are most conveniently kept in loose-leaf or card form. These records are not drawn to scale, but show a diagram of the street with a line to represent the conduit, while manholes are indicated in their proper location by rectangles or other figures corresponding to the shape of the manhole. Measurements are indicated, showing distances between centers of covers and also their location with respect to curb lines. The latter is quite important, particularly in locations where, during the winter months, snow covers the ground. Knowing the exact location of the center of a cover will save considerable time for the cable men when inspecting manholes on locating trouble. In Fig. 149 is illustrated a system of conduit record, while a manhole record card is shown in Fig. 150. The number of records necessary will depend on the size of the company and the nature of the work. For a comparatively small expense, however, records will be made which will always be accessible.

Identification of Cables.—All cables should be properly tagged in every manhole, these tags to indicate the size, voltage, and cable number. With a view to ascertaining the general practice and experience of the larger companies in regard

PUBLIC SERVICE ELECTRIC COMPANY

CABLE RECORD

MANHOLE NO. *401-S.E. Corner* LOCATION *Main & First Strs.* CITY *Newark, N.J.*

DATE INSTAL'D	DUCT	NO. OF CABLES	CIRCUIT NO.	SIZE	MAKE	INSULATION KIND	INSULATION THICK	VOLTAGE	DATE INSTAL'D	DUCT	NO. OF CABLES	CIRCUIT NO.	SIZE	MAKE	INSULATION KIND	INSULATION THICK	VOLTAGE
7-8-14	N-31	1	2401	2/0	S.U.	P	5/32	2400	7-8-14	S-31	1	2401	2/0	S.U.	P	5/32	2400
7-8-14	N-32	1	2402	2/0	S.U.	P	"	"	7-8-14	S-32	1	2402	2/0	S.U.	P	"	"
5-4-16	N-33	1	2403	4/0	S.I.W.	P	"	"	5-4-16	S-33	1	2403	4/0	S.I.W.	P	"	"
5-4-16	N-21	1	2404	4/0	S.I.W.	P	"	"	5-4-16	S-21	1	2404	4/0	S.I.W.	P	"	"
6-1-16	N-11	1	2405	2/0	A.S.W.	P	"	"	6-1-16	S-11	1	2405	2/0	A.S.W.	P	"	"

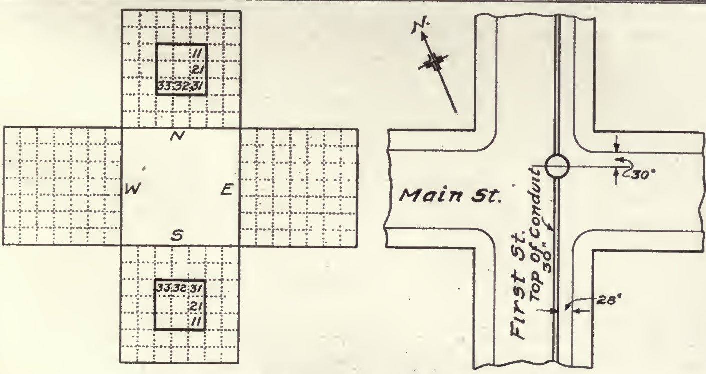


FIG. 149.—Conduit and cable record card.

to cable tagging and numbering scheme, the Underground Committee of the National Electric Light Association sent out to member companies a series of questions relating to cable tagging. The replies received indicated a great diversity of opinion and practice. With the exception of a few of the companies, who embody some very good features in their methods of tagging and numbering, it appears that the matter has received very little attention.

Tags have been made of various metals, including brass, lead, zinc, aluminum, copper and galvanized iron; brass being the most common in use. Usually symbols or figures are stamped into the metal. A good form of tag is one in which the figures are cut

Special 53 E. 1000-5-15

PUBLIC SERVICE ELECTRIC COMPANY

MANHOLE. INSPECTION CARD

MANHOLE No. *401-S.E.Corner* LOCATION *Main & First Strs.* CITY *Newark, N.J.*

BUILT *MAY-1914* KIND *CONCRETE* SIZE *6 Ft. x 8 Ft. And 6 Ft. Deep.*

INSPECTED		POTENTIAL OF CABLE TO			WATER PRESENT	GAS PRESENT	NECESSARY REPAIRS OR CHANGES
DATE	BY.	RAIL	WATER MAIN	GAS MAIN			
8-10-14	C.A.D.	-1.2	-0.8	—	No	No	All Cables in good Condition.
8-12-16	C.S.D.	-1.0	-0.6	—	No	No	2 hangers required on west Wall.

TRANSFORMER AND BOX RECORD

INSPECTED		TRANSFORMERS		BOXES		REMARKS
DATE	BY	TYPE	SIZE	TYPE	SIZE	
8-12-16	C.S.D.	H.5834	50 KW.	2 Pole	400 A	O.K.
				S-Pole	30 A	O.K.

FIG. 150.—Manhole record card.

through the middle in the form of a stencil. With the figures or symbols punched through the metal, the legibility should not be affected by any ordinary corrosion. The punching should form plain open figures without any frail bars of metal left to cause confusion. A tag as just described is shown in Fig. 151, the shape of the tag illustrated indicating the class of service for which the cable is used.

A tag made of sheet lead, similar to the lead sheath of the cable and subject to the same exposure, would not be seriously affected by corrosion, and when made in the form of a strap, as shown in Fig. 152 can be passed around the cable like a collar. Glass tags made to receive a card bearing the cable number have been used by some companies, but as far as is known to the writer have nowhere been in service long enough to have thoroughly demonstrated their usefulness.

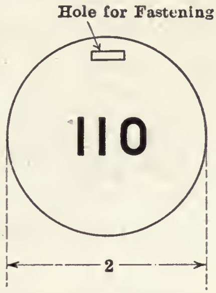


FIG. 151.—Round-cable tag.

Tags were formerly fastened to the cables with copper wire in pendant fashion; but due to corrosion, tags frequently became detached from the cable. For this reason a tinned copper bonding ribbon is now used for fastening the tags to the cable. As shown in Fig. 153, two holes are punched in the tag to allow an additional wire to be

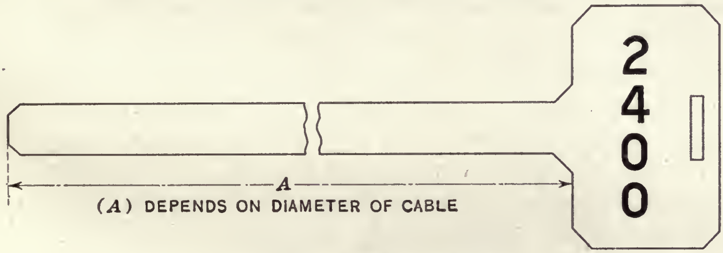


FIG. 152.—Lead-cable tag.

used in supporting the tag, thus insuring its proper fastening to the cable. Tags should be fastened to the cables at or close to the joint. This makes them easier to find in congested manholes.

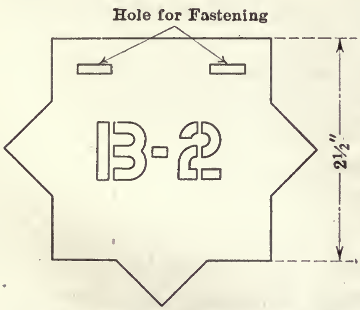


FIG. 153.—High-tension-cable tag.

There are various numbering schemes in use for designating cables and in some cases attempts have been made to indicate, in addition to the serial number of the cable itself, the voltage, class of service, source and destination. Tags of different shapes have been used to advantage and some companies have adopted sharp-pointed tags, Fig. 153, for marking high-tension feeders. By choosing different ranges of numbers for different classes of distribution, distinction can be made as to the class of service. Letters of the alphabet are sometimes combined with numerals to show class distinction. The following method of numbering is submitted as a simple and ready means of identification.

Secondary mains, 110-volt.............	numbers 100 to 199 inclusive.
Secondary mains, 220-volt.............	numbers 200 to 299 inclusive.
Primary feeder, single-phase, 2,400-volt.	numbers 2,400 to 2,499 inclusive.
Primary feeder, two-phase.............	numbers 4,800 to 4,899 inclusive.
Series-arc circuits.....................	numbers 7,500 to 7,599 inclusive.

From the foregoing it is noted that a number may be used which readily indicates the voltage of the circuit. While numbering schemes are good, it must be remembered that, as a rule a given method is applicable only to its particular cable system. The design and development of any scheme is influenced by so many local factors that each must be worked out independently to suit the requirements. Whether the numbers are placed on tags or in record books, they must be simple, capable of expansion without complications, and they should preferably be indicative to some degree of some function the cable performs.

The use of loose-leaf cable-record books in which duct locations are given and which can be used as a reference in the field to check the cable tagging is very desirable. This form of record has proved highly satisfactory for both field and office use.

In addition to proper tagging some additional safeguard is usually desirable in order to remove every possibility of workmen cutting into a live cable. An exploring coil has been used to advantage in the field to pick up a signal on the desired cable which has a special signal current impressed upon its conductor terminals. This same exploring coil and interrupter is also used in many cases in the field to phase out the conductors of a multiple-conductor cable. Spiking is often resorted to as a last precaution before cutting into a supposedly dead cable, but is not recommended as good practice, because of its unreliability as it is done by some cablemen.

In Chapter VI, under the heading "Testing for Live Cable," several methods which are considered good practice are described.

Record of Cable and Equipment Failures.—A system of recording cable failures and subway troubles is of considerable value. Interruption to service caused by the failure of a cable or other equipment should be thoroughly investigated by the foreman or cableman in charge, and a complete report giving full details should be kept on file for future reference. If the troubles are numerous a detailed record will greatly assist in determining what changes are necessary to improve the system.

PUBLIC SERVICE ELECTRIC COMPANY

________________19______

REPORT OF HIGH TENSION FEEDER TROUBLE

Date__________ Time__________ Feeder No__________ From__________
To__________ Size__________ Operating voltage__________ Frequency______
Insulating material__________ Insulation thickness__________ Condition______
Made by__________ Installed, date__________ by__________
Length of underground portion__________ ft. overhead__________ ft.
First indication of trouble__________
Nature of trouble__________ Reported by__________
Trouble occurred during test__________ or feeder in service__________
Previous to breakdown, load on feeder__________ Max. air temperature______

LOCATION OF FAULT

Fault located by:

Inspection__________
Report of__________
Loop test__________
Fault detector__________
Cut and try______ No. of cuts______
Time required to locate__________
Section of conduit__________

Fault located in:

Manhole in joint__________
in bend__________
in straight length__________
Duct______ ft. from duct edge.
Repairs completed at__________
Feeder ready for service at
Location of duct occupied__________

PROBABLE CAUSE OF TROUBLE

(*a*) Mechanical injury:
1. Extraneous mechanical__________
2. Electrolysis__________
3. Sharp bend__________
4. Overheating__________
(5 Surge on system)__________

(*b*) Defect in cable:
1. Defective insulation__________
2. Defective sheath__________
3. Defective joint__________ Made by__________

(*c*) Cause unknown__________

Resulting damage in conduit or manhole__________
" " " station or substation__________
Detail report of trouble of__________ on cable No.__________

On reverse side give detailed report

Fig. 154.—Cable-trouble sheet.

In order to secure comparative information it is desirable that reports be made up on a standard form such as that submitted herewith, Fig. 154, for reporting high-tension feeder trouble. This form which has been drawn up to cover all ordinary cases of trouble, may be made up in card form for convenience in filing.

If this is done, some reduction may be made in the size of the report. It is very desirable, however, that in entering the information under the headings "Location of Fault" and "Probable Cause of Injury" the foreman should have the accompanying form of report at hand and make entries on the form under one of the several subheadings. The back of the report should be used for describing previous troubles on the same line or in the same conduit, which may possibly have had a bearing upon the fault, as well as other items of interest which cannot be readily tabulated.

Cleaning Manholes.—Underground systems require much less attention than overhead lines, but it is a mistake to suppose that when lines are once underground they will care for themselves. There is always a chance for trouble. Provision should be made for cleaning manholes at regular intervals, these cleanings being sufficiently frequent to prevent insanitary conditions in manholes. A number of companies maintain portable pumping equipments which are used by a regular inspection and cleaning division employed solely in maintaining the underground system in a satisfactory condition. Before beginning work in manholes where obnoxious odors or other disagreeable conditions exist, an effort should be made to supply forced ventilation or adopt other expedients which will make the conditions in the manhole tolerable for the workmen. Increasing interest in the welfare of employees is daily becoming more evident both on the part of the operating companies and the public authorities having to deal with such matters. In a large system a considerable saving in the cleaning of manholes can be affected by a systematic procedure in the use of large dump wagons and a small gang of men, who, when work on the cleaning of manholes is slack, join the various conduit and cable gangs.

Care of Cables.—If a large number of loaded cables pass through one manhole it is well to take temperature readings in the manhole to determine when a temperature unsafe for the cable is reached; these can be taken either with a recording thermometer or one giving maximum temperature. In cold weather, or when the streets are muddy, it is sometimes advisable to have an inspector go over heavily loaded conduit lines to make sure that the ventilating holes in the manholes covers are open.

In Fig. 155 are shown curves of manhole temperature, temperature of outside air and load on the cables passing through a manhole. The hole, which is 7 by 7 ft., and 7 ft. deep, contains two 50-kw. transformers. It will be noted from the size of the manhole that there are 3.43 cu. ft. of space per kw. of transformer capacity. This is considered conservative and in this particular case did not result in excessive manhole temperatures.

Periodic insulation resistance tests are valuable, as they furnish indications of abnormal conditions and often lead to the detection of faults on the system. A new cable should not be connected to the main busbars without being previously tested with full working pressure. This is usually accomplished through a suit-

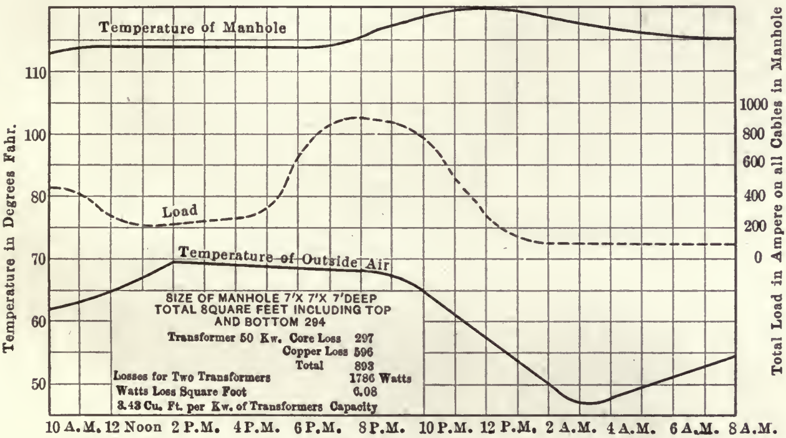


FIG. 155.—Manhole-temperature chart showing comparison of temperature with load on cables.

able transformer properly fused, or by inverting a rotary converter with a fuse on the low-tension side.

The feeder readings, taken in stations and substations, should be carefully followed up to make sure that no feeders are overloaded and the load on the mains should also be noted. For the purpose of checking the load on single-conductor cables, particularly transformer leads, a split-core current-testing transformer will be found convenient. This instrument, which is illustrated in Fig. 156, consists of a special transformer having a hinged magnetic circuit and a standard portable ammeter. Flexible duplex leads are supplied with each set, of sufficient length so that the transformer can be clamped in position around the conductor and the ammeter removed to a more convenient place for reading. When a test is to be conducted, the terminals of the duplex leads should be inserted in the ammeter binding posts and the transformer jaws firmly clamped in position around the cable. The transformer will maintain within commercial limits its ratio accuracy from one-eighth to 25 per cent. overload. Occasions constantly arise for using this set in determining the load on feeders and in the case of distribution networks, where it has been found particularly valuable.

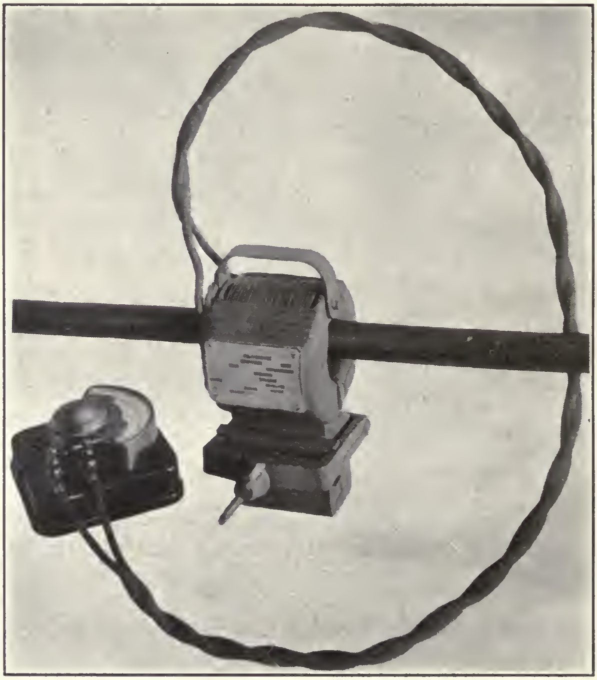


Fig. 156.—Split-core cable-testing transformer.

A regular inspection of the manholes, covers, cables, junction boxes and other equipment should be made from two to four times a year depending on the size of the system, and a record kept of such inspection, together with all necessary work done to maintain the entire system at maximum efficiency.

Cables should not be disturbed after once in place, if it is possible to avoid it. If they must be moved, it should be done with the greatest care, one cable at a time and without any strain on the cable joints.

Cables should never be used as steps for entering or leaving manholes. A small portable ladder should always be used for this purpose.

It is not possible to estimate accurately the life of cables and what will be the cost of maintenance after several years' installation. The cost of repairs for the first year is usually very low and the other items of maintenance are the expenses for periodic inspection and testing.

Bonding Cables in Manholes.—The following recommendations are made by the Underground Committee of the National Electric Light Association in the matter of the bonding of all cables in each manhole.

It is of prime importance when faults occur in underground cables, that the current flowing in the short-circuit should be sufficient to operate the safety devices or in the absence of safety devices to make a sufficient disturbance so that the existence of the trouble will be quickly brought to the attention of the station operator. In the case of single-conductor cables, whether for use on Edison three-wire systems having a normal voltage of 115 or 230, or on railway systems having a normal voltage of about 600, it is entirely possible that a short-circuit may occur between the conductor and the lead at a point remote from the power supply station without a sufficient rise in the current to enable the operator to distinguish it from some unusual load. The lead sheaths of 1,000,000- and 1,500,000-cm. cables, which are the sizes frequently used, are equivalent to about 70,000 and 80,000 cm. in copper, respectively, so that if the current which passes through the short-circuit from the conductor to the lead is required to traverse only a few blocks of the lead of that particular cable before it can find other paths to the station, the resistance may be sufficient to limit the current to the normal carrying capacity of the copper. The radiating surface of the lead is so great that this large amount of current may be carried for quite an appreciable time without seriously overheating the lead. The result is that the arc at the point where the trouble started has in series with it sufficient resistance so that it burns quite steadily and without the knowledge of the station operator. This is probably the most dangerous trouble that can occur on an underground system and every effort should be made to avoid the occurrence of such a condition.

The use of concentric cable eliminates the above-mentioned difficulty, as an arc of this kind, even if it starts in the outer conductor, is very quickly communicated to the inner, and enough current will flow in the short-circuit to eliminate any doubt on the part of the operator as to the nature of the trouble. Where single-conductor cables are already installed, the condition can generally be improved by bonding the lead sheaths of all cables in each manhole. This will, in general give sufficient conductivity in the return path to cause enough current to flow at the point of the trouble so that the existence of the trouble is immediately apparent. The calculations to determine the possible amount of current that will flow are, however, very simple and should always be made as a check whenever there is any doubt on this point.

The bonding of the cables in all manholes also reduces the liability of damage due to electrolytic action by stray currents of electric railways, as well as similar damage due to leaky joints and other troubles on the lighting cables. While there is some difference of opinion among experts on the subject as to the exact scheme of protection that should be adopted for lead-covered cables operated by a lighting company, they are in accord on the proposition that the lead sheaths of all cables be bonded together in all manholes.

When bonding cables the important feature, necessary for good results, are a positive low-resistance connection to the lead sheath and a conducting medium from one cable sheath to the other. Experience has proved that either copper ribbon or copper-tinned wire give the best results. A choice between the two is simply a matter of opinion and minor manhole requirements, the wire having the advantage of a more flexible bond than the ribbon, when such is an advantage.

Rules and Requirements.—In large systems it is important to devise a set of rules for the guidance of the men in the different departments. These rules must be rigidly complied with so as to eliminate any danger of injury to men making tests or repairs to cable or switchboards. While it is impossible to include in a brief summary complete instructions covering every detail in connection with underground work, the following rules are intended to lay down certain fundamental principles, which should be observed in all cases. To avoid accidents to employees or the public, the following rules and cautions are recommended.

Subway Rules

Every splicer, inspector, and helper, must observe the following:

Look Out for Gas

Immediately upon opening a manhole or vault and before entering same, make a careful examination for illuminating, sewer, or other harmful gas. Never enter a manhole where poisonous gas is found, but report same promptly to foreman or superintendent in charge.

If it is necessary to work in a manhole which does not ventilate properly after the cover has been removed, an air pump must be used. A rope must be attached to the body of the workman in the manhole and fastened above, so that in case of necessity, he can be drawn to the surface. Work of this character must be done only when expressly ordered by the foreman or superintendent and under his direct supervision.

Avoid Explosions

Do not use matches, lamps or candles in or near manholes. If artificial illumination is required use only incandescent lamps or approved safety lanterns.

Never carry a gasolene or other furnace or torch into or near a manhole.

Do not smoke or carry lighted cigars, cigarettes or pipes into or near a manhole.

Avoid sparks in connecting or disconnecting cables or apparatus in manholes.

Exercise care in soldering and wiping joints so as not to ignite the flux.

Watching and Guarding

After removing a cover from a manhole, place around the opening the guard provided, to which should be attached a red flag. When working at night, substitute a red light. Always have a man at the surface to guard the opening. Replace cover, noting that it is properly seated, upon completion of work. If excavations are made, see that they are properly fenced, lighted and guarded.

Gloves, Boots, Etc.

When working on any cable or piece of apparatus, wear rubber gloves and rubber boots, and before beginning work satisfy yourself that these are in good condition. Do not wear boots with nails in the heels. Use a dry board to stand on, and an insulating barrier around live parts where possible. All conducting parts of tools or appliances that need not be exposed must be insulated. Be sure your tools are in good condition. Never leave tools lying around loose where they may come into accidental contact with live parts. Keep sleeves down and avoid contact between any part of your body and live cable or apparatus.

Be Sure You Have the Right Cable

When sent out to do any work, be positive you understand exactly what you are to do. Be sure you have the right cable before beginning any work. If tags are missing or if from any cause, there is difficulty in locating the proper cable, report promptly to the foreman or superintendent.

Live Work

Treat every cable and piece of apparatus as alive until you have satisfied yourself that it is dead and until then observe all precautions.

High-voltage Work

Do not work on live high-tension cable or apparatus, without express and definite orders from the foreman or superintendent. Never attempt to splice a high-voltage cable alive. When instructed to have the current disconnected before beginning work, make certain that the switchboard attendant understands upon which circuit you are to work and do not begin until he tells you the circuit is dead. As soon as you have notified the station to put the current on, consider the circuit alive. Make certain that no other workman is engaged on the same circuit before having current connected.

Report Defects

Report without delay to the foreman or superintendent the presence of gas or water in manholes, or any defect or unusual condition you may observe.

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