NEW CENTURY BOOKS OF USEFUL SCIENCE

THE NEW STONE AGE

HARRISON E. HOWE

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The
Century Books of Useful Science
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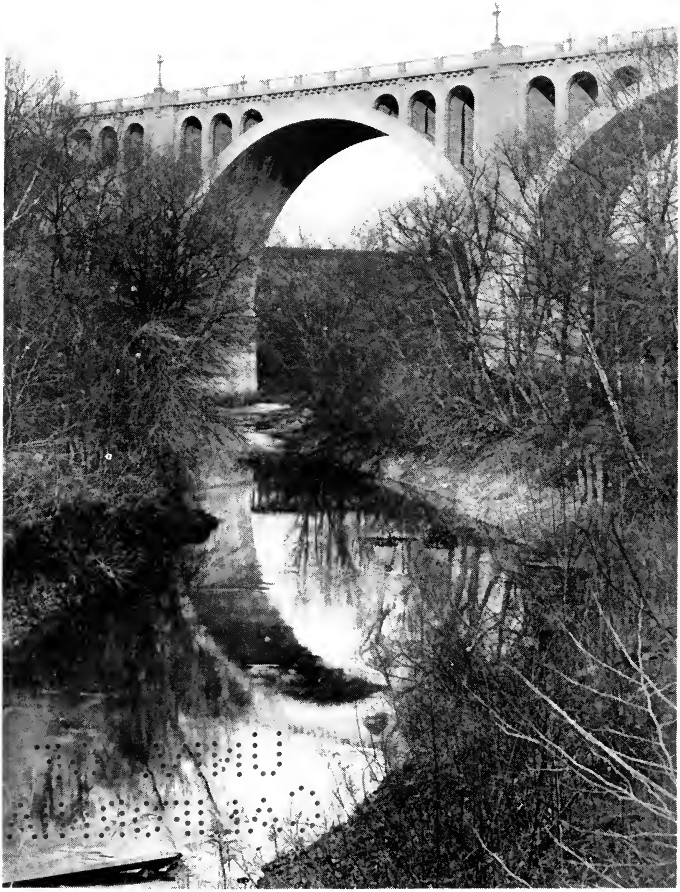

Photograph by C. A. Phillips

CONNECTICUT AVENUE BRIDGE, WASHINGTON, D. C.

An ornamental concrete bridge in which precast blocks are used in the arches for decorative effect. Length, 1341 feet, width of roadway, 35 feet, width of each sidewalk, 7 feet, 11 inches. The spans are 170 feet between pier centers and reach a height of 115 feet in places, including the foundation piers

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BY

HARRISON E. HOWE

ILLUSTRATED WITH
DIAGRAMS AND PHOTOGRAPHS

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ACKNOWLEDGMENT

Whenever an industry experiences a comparatively short period of rapid development and its products are attractive for a very wide variety of uses there is almost sure to be a rich literature of considerable extent. In the case of cement and concrete much of the record concerns the application of the material and less of it than there should be is devoted to a discussion of the laws and principles underlying the whole industry.

In any direction an abundance of material is to be found on our subject. The newspapers record this or that unique application. The technical and scientific press frequently devotes pages to timely discussions and any periodical concerned with nearly any phase of engineering is almost sure to refer to cement and concrete in every issue.

The author has consulted and drawn from this store of information at every opportunity but obviously has not been able to review it all. He wishes to make acknowledgment for the assistance that has been received from Prof. Alfred H. White of the University of Michigan, H. Colin Campbell of the Portland Cement Association, Nathan C. Johnson and his old friend S. H. Salisbury, Jr. There should also be mentioned in particular the following publications which the reader will find to be of value if desiring to pursue the subject further:

Chemistry and Testing of Cement, C. H. Desch.
Portland Cement, R. K. Meade.
The Silicates in Chemistry and Commerce, W. & D. Asch.
Cement, Concrete and Bricks, A. B. Searle.
Concrete, Plain and Reinforced, Taylor and Thompson.
The Manufacture of Hydraulic Cements, Geol. Survey, Ohio.
Journal of the American Ceramic Society.
Portland Cement, by George A. Rankin, A.B.
Portland Cement Manufacture and Trade, by Edward D. Boyer.
Effect of Time and Mixing on the Strength of Cement, by Duff A. Abrams.
Chemical and Metallurgical Engineering. Various Staff Articles.
Cotrell Processes of Electrical Precipitations, by Walter Schmidt.
Effect of Curing Condition on the Wear and Strength of Concrete, by Duff A. Abrams.
Effect of Age on the Strength of Concrete, by Duff A. Abrams.
Structural Laboratory Investigation in Reinforced Concrete Made by Concrete Ship Section Emergency Fleet Corporation. By W. A. Slater.
Aberthaw Tests on Concrete in Sea Water.
Report of Committee on Contraction and Expansion of Concrete Roads at National Conference on Concrete Road Building.
Publications of the Associations of American Portland Cement Manufacturers.
Publications of the Portland Cement Association.
Publications of the Heltzel Steel Form and Iron Co.
Design of Concrete Mixtures, by Duff A. Abrams.
Publications of the American So. of Testing Materials.
Technical Papers and Bulletins of the U. S. Bureau of Standards, Dept. of Commerce.
Standardized Concrete, by E. A. Van Vleck.

Free Lime in Portland Cement, by Alfred H. White.
Volume Changes in Concrete, by Alfred H. White.
Effect of Vibration, Jigging and Pressure on Fresh Cement, by Duff A. Abrams.
Publications of Koehring Machine Co.
Publications of Western Wheeled Scraper Co.
Publications of Cement Gun Co., Incorporated.
Various Articles in Engineering News Record, by Messrs. R. J. Wig and S. C. Hollister, with reference to Concrete Ships.
Publications of the Colloseus Cement Co.
Publications of Universal Portland Cement Co.
Publication of the Trus-con Lab.
Concrete as a Structural Material, by Maxmillian Toch.
Patent Literature.
Concrete.
Cement Age.
Good Roads.
Concrete Steel Construction, by C. A. P. Turner.
Popular Hand Book for Cement and Concrete Users, by Louis W. Chandler.
American Concrete Pipe Association.
Journal of the Engineers Club of Philadelphia.
Concrete Products.
General Electric Review.
Circulars of the Paint Manufacturers Assn. of U. S.
Cements Producing Quick Hardening Concrete, by P. H. Bates.
Disintegration of Fresh Cement Floor Surfaces by the Action of Smoke Gases at Low Temperature, by Alfred H. White.
Publications of Department of the Interior, U. S. Geological Survey.

CONTENTS

CONTENTS

CONTENTS

LIST OF ILLUSTRATIONS

ILLUSTRATIONS

INTRODUCTION

It is said that when the Wrights brought the first heavier-than-air flying-machine to Washington for a trial flight, the newspaper reporters present, after examining the machine, cheerfully offered to eat it if it could fly. There is no record that they made good on this offer, but we know that today the airplane has become so common in many localities as to cause but a small percentage of the population to turn their eyes skyward when the characteristic roar of the powerful engine announces that one of these man-made birds of flight is passing overhead.

Similarly with most things about us today, familiarity has made us unappreciative. We give no consideration to the tedious and painstaking work without which things we now consider essential could not have been developed. A pair of eye-glasses is unfortunately so common an aid to human happiness and comfort that no one thinks of the tremendous care necessary to produce the lenses with accurate curve, to impart a high enduring polish, or indeed to manufacture the glass itself. There is little appreciation of the fact that there is a difference in glass, and this may be well illustrated by the intense interest displayed on the part of the public when the newspapers announced the success of American scientists in overcoming difficulties atttending the production of large quantities of less than a dozen needed varieties of optical glass during the war.

And so illustrations might be chosen from nearly every form of human activity to emphasize how we have come to take as a matter of course great numbers of products that have resulted from long periods of development. We owe too much to cement to be satisfied with a like condition, and in the following pages something of its development and history is given to remind those who use it of the work that cement and its products represent, and to leave the reader more appreciative of this modern construction material.

Much of our admiration for the ancients comes from an appreciation of their success in handling stone. We admire the design of ancient structures; the mass of many of them inspires awe; the decoration, whether carved or in some other form, has frequently served as our pattern: but most of all we wonder at their powers in overcoming many grave engineering problems. From an examination of such records as we can interpret, we have come to know that much of their building was possible only through a vast expenditure of human labor on a scale that with present conditions would be possible only under the necessities of war.

The human race found from experience that stone alone could be depended upon for permanence, and whenever it could be used the ancients employed this material in constructing their great monuments. Substitutes, such as the clay bricks used at Babylon, perished; and when the people became too indolent to undertake the difficulties of construction involving any massive stone structures, they degenerated into the use of materials easier to fabricate, and elaborate decoration took the place of permanence. For example, the great Temple of Diana of the Ephesians represented a great expenditure of wealth; but it was built principally of wood, and, according to tradition, was fired by one who chose that method of perpetuating his name, but in punishment his name has been erased from history.

We are now in a new stone age more wonderful because ways have been developed whereby stone, natural and artificial, may be used to the fullest extent and to the best advantage with the minimum expenditure of human labor. Engineering skill has provided mechanisms for cutting, engraving, and transporting such materials, making possible buildings quite out of the question otherwise. Added to this is the ability to form a stone-like material to meet a variety of special requirements. This has been achieved through a mastery of cement and the products possible by its use.

In this book an attempt is made to present in everyday language the story of this cement, in the hope that it may be better appreciated, more thoroughly understood by the non-technical user, and used with a due regard not only for its excellent characteristics but for its necessary limitations. It must always be borne in mind that for satisfactory results one needs not only good materials but proper design and conscientious workmanship. If any one of this trinity fails, then the structure itself may fail; but if the triangle is equilateral and all components good, then the builder can face the future with confidence.

THE NEW STONE AGE

CHAPTER I

HISTORICAL

Man has frequently been described as differing from other animals in his ability to construct, although it may be recognized that many men lack the tenacity and energy and resistance to discouragement that have made the beaver famous. Many animals that are somewhat distinguished from others by their ability to put things together are quite obviously far below the ability of even our most primitive man, and the interesting work of Yerkes with monkeys is one illustration of that point. In his experiments monkeys were tempted by food to assemble the necessary number of unit boxes to enable them to reach the bait; but usually they were unable to carry through the idea, even though they started to make the necessary pile.

We do not know just when man began to put materials together, but it must have been very early in his career. In some parts of the world we still have tribes that have remained virtually untouched by any civilization, and we have reason to believe that they very closely approximate primitive man. Where they find it necessary to put things together, vegetable fibers and the tendrils of vines are often employed as ties. Frequently thongs made from the skins of animals are used.

Some merely pile up material, depending solely upon the weight of the component parts for stability. But at some time a man more observing than his fellows may have lifted a stick from the wet earth and noted how the clay clung to it. This may have led him to try clay as a plastic material, using it as a binder, and more particularly to smear the wall of his hut, so that the wind and weather might be better excluded from his habitation, just as the Eskimo learned to throw water over his house built of ice blocks, thereby rendering it virtually air-tight.

When the storms washed this clay from the structure, it may have carried with it quantities of weathered fiber and splinters or twigs from the brush forming the framework. In replacing it, it was easier to re-use the clay washed to the base of the wall than to bring other material from a distance. By employing this material we can conceive that gradually man came to use these various fibers in the clay, which acted as a binder, and this may perhaps have been the forerunner of the practice of using hair or similar materials in modern mortar and plaster.

Meanwhile fire was doubtless discovered. It is difficult to see how man could make substantial progress without fire, for in its ashes he probably found the first bits of metal that started him on his metallurgical career. How great must have been the advantage of the man who first added metals to his working tools over his fellows who still relied solely upon hard wood and flint! He at once came into possession of superior tools for offense and defense against the materials and forces of nature, including his own fellows. Fire must have led also to the discovery of glass and, as we shall see, to the first improvements in cementitious materials.

John Mills, in his interesting work, "The Realities of Modern Science," indicates ways in which man probably came to know fire and how he turned it to his advantage. To be sure, we have no record of how man first learned to keep fire alive, and it must have been many thousands of years before he discovered how to make a fire when wanted. Students have come to believe that man first saw fire in dry seasons when lightning may have started it,—just as it starts forest fires today,—and some one with abundant courage may have approached such a fire and retrieved a burning stick from the outer fringes, perhaps after the fire had been partly checked by a rain. He must have wondered why he could hold one end of the stick while the fire progressed at the other; but seeing him unharmed may easily have led others of his tribe to become more familiar with fire and to experiment with it.

In time they learned how to keep the fire going and, as Mr. Mills points out, this may have resulted from observing that the fire lasted longest where heaps of brush or large trees were involved; or he may have learned that wood is combustible through the accident of throwing a blazing brand into dry brush. We can appreciate that with a gradual familiarity with fire it may have become one of his most cherished possessions, to be carried with the tribe upon its wanderings and gradually put to use. His first taste of cooked meat may have come from finding a partly burned animal at the edge of a forest fire, and if he liked it he undoubtedly experimented, and eventually, perhaps after many years, developed primitive ways of cooking.

It is little wonder that religious rites soon were developed around fire as a deity, or at least that it was used by man to express his worship of some deity. In constructing altars upon which fire could be used, or perhaps in arranging stones around a fire to conserve it, limestone came in contact with sufficient fire to produce burned lime. The lime thus calcined was crumbly, and it is easy to conceive how it might have been found that this material, when moistened, would harden. In this way the oldest cementatious material, mud, was gradually displaced by lime. It was but natural to try mixing other substances with lime, and sand was found not only to cheapen the mortar, that is, to provide a larger quantity with less labor, but also to improve it.

In the ordinary sand-lime mortar there is chemical action between the carbon dioxide of the air and the calcium hydroxide and the hardening of the mass must be preceded by a loss of water. The function of the sand in this mixture is to prevent undue shrinkage and the appearance of serious cracks as well as to give porosity, thus facilitating the action of the air. Such sand-lime mortar is, of course, older than history. It has been found that the pyramids were built with a mortar consisting of this burned lime, with which a partly burned gypsum or calcium sulphate was incorporated. Such mortar must have been used for many, many centuries.

In time the Romans learned how to mix volcanic ashes with the burned lime, and this material they found would harden or set under water. Obviously, until such a mortar was devised the wonderful aqueducts and maritime structures for which the Romans were famous were impossible. They obtained their volcanic ash from a place called Puzzuoli, and in our day a cement called puzzolan, made upon the same principles, derives its name from this Roman work.

It seems strange that this simple secret of mixing volcanic ash with burned lime to produce so good a cement should have become lost; but for ten centuries no one knew how to make the so-called Roman cement. There was no advance over ordinary cement or mortar until the last of the eighteenth century. That there may be no confusion as to the various kinds of cementitious materials, it may be well to describe briefly the more important varieties.

Common lime is produced from pure limestone by heating the latter until most of the carbon dioxide is driven from the calcium carbonate. When this material is moistened, it hardens by the loss of water; but it is non-hydraulic and is not water-resisting. Hydraulic lime is somewhat water-resisting and will set under water. It is made by burning an impure limestone at a low temperature, the impurity being clay. The next in the scale toward cement, as we know it, is the so-called natural cement, which results when the impure limestone, which nature has provided constituted of the right proportion of lime and clay for the purpose, is burned at a low temperature and the resulting material ground. These natural cements are hydraulic. Puzzolan was originally made from slaked lime and volcanic ash; but, as made today, it is more customary to substitute ground blast-furnace slag for the volcanic ash. It is, of course, a hydraulic cement. Then, there is the so-called plaster of Paris, used as such or as an ingredient in cement; and this is produced by driving off approximately 75 per cent. of the combined water in gypsum and finely grinding the resulting material. Then we have Portland cement, which does not slake but which is hydraulic when ground. As we shall see later, Portland cement may be made from a variety of materials.

The modern cement industry may be said to have begun with the work of John Smeaton, who built the Eddystone Light. He undertook to develop a water-resisting mortar that would set under water. Many light-houses had been built at Eddystone, only to be disintegrated and battered to pieces by the waves; and because of the dangerous locality, where many a ship was lost, Smeaton determined to erect a light-house that would endure at least to a far better degree than its predecessors. In his "Narrative of the Building of the Eddystone Light-house," he describes his experience in seeking the desired mortar. By 1756 he had found that an impure clayey limestone gave him a mortar far superior to that commonly in use. However, he had burned the mixture to but a low temperature, and had not departed from the customary practice of using only that part of the resulting material which would slake with water, very much as the customary mortar would do. His hydraulic lime thus prepared was the first distinct advance in many, many years, and awakened new interest in the development of better building materials.

In 1796 John Parker patented what he called a Roman cement, because it was an effort to reproduce this material that led him to his discovery and made possible an approach to the durable maritime works that had been built a thousand years before. In his work Parker had used a calcareous material. In 1802 in France, a similar cement was brought out, in which nodules of the same general composition were employed.

The next step in development was the work of one Edgar Dobbs, who in 1810 patented in England an artificial Roman cement which he prepared from lime and about 50 per cent. of clay. This he first formed into small briquets, and burned these just enough to expel the carbon dioxide, being careful not to carry the temperature to the vitrifying point. It is interesting to see by what gradual steps these early experimenters advanced the art of cement-making from the first stages, which have been described, toward the process for cement production as we know it today, involving high temperatures. It is curious also, from our point of view, to see with what hesitation these inventors undertook to use that portion of their material which reached incipient fusion. They were also fortunate in finding ready mixed the lime and clay which we now know to be necessary to produce a satisfactory cement.

Paisley in England and Vicat in France began independently a series of experiments, using clay and the chalk that is so abundant in those vicinities. It would seem that Vicat proceeded in a more systematic manner than his English contemporary, and made better use of the knowledge of the chemistry of the substances available for the type of cement that he sought. In England it appears that the work was more empirical, and therefore the chance of finding the proper substances to be used and the best methods of combining them into cement was less favorable.

In 1813 Vicat began the manufacture of an artificial hydraulic cement in France, and in 1822 James Frost began producing a similar material in England. By 1824 Joseph Aspdin, of Leeds, England, had discovered that if the dust from limestone roads, or failing that ground limestone, were mixed with clay and burned at a higher temperature than his predecessors had employed, the resulting mass when ground would produce a material that hardened when mixed with water. Further, this cement had a yellowish-gray color when hard, producing a stone-like substance very similar in appearance to the building stone quarried at Portland, England. He gave it the name Portland cement; and it was really of the old Roman type, since his burning was not quite to the fusion point, which is one of the distinguishing features between the two cements.

The first large use of the new Portland cement was in connection with the building of the Thames Tunnel in 1828; but even that piece of engineering did not serve to establish it in the market. It was sold below the price of other mortars and cements until 1859, when John Grant used it exclusively in constructing the London Drainage Canal. By this time the practice of burning to fusion had been established, and, while there must have been a great lack of uniformity, for there was no scientific control either in proportioning the materials or in burning, grinding, and storage, the product gradually made headway.

In 1852 the Germans had taken up the manufacture of Portland cement, and they were the first to apply science to its manufacture, with the result that they produced a considerably better product and momentarily obtained thereby an advantageous position.

CHAPTER II

IN AMERICA

As in England, cement in America was brought to the forefront in the construction of a canal. The first cement produced here was a natural cement from a rock found near Chittenango, New York, by an engineer employed on the Erie Canal. This was in 1818, and application was made for twenty-year rights for the sole production of this natural cement. While this was denied, the discoverer was rewarded by a bonus of $20,000, and this cement was used in large amounts along the Erie Canal.

Nearly all of the cement mills in those early days were to be found along the various canal projects that marked the first development of transportation facilities in our history; and this was natural, since the greatest market for cement was in their construction and the canals afforded the only economical means for transporting the product.

Beginning in 1818, the increase in the number of mills was fairly rapid, especially in view of the circumstances of those early days. Thus, in 1825, satisfactory rock was discovered in Ulster County, New York, followed in 1828 by a second mill in that county at Rosendale, which name is still applied to American natural cements. In 1829 cement rock was found near

Louisville, Kentucky, where work was in progress upon the Louisville and Portland Canal. Ten years later, when the Chesapeake and Ohio Canal was in process of construction, another mill was established.

The industry, in fact, may be traced with the development of the canal system. The Illinois and Michigan Canal led to the establishment of a mill in 1838. In 1848, in Virginia, a mill was put in operation near the James River. The Lehigh Coal and Navigation Company began operations in Pennsylvania in 1850. Akron, New York, came into production in 1840. A mill at Fort Scott, Kansas, began to produce in 1868. Buffalo followed in 1874 and Milwaukee in 1875.

All of these mills worked upon the natural cement rock, which varied greatly and must have led to difficulties in using so variable a product. The process was comparatively simple. The rock was broken into small pieces and dumped into small upright kilns, of masonry or brick, alternately with the fuel used to burn it. At first wood was employed, and the burning lasted for a week; but in a few years coal was substituted. During the day the rock was charged alternately with coal, and when the burned charge reached the base, it was drawn out. In the continuous coal-fired system the clinker was withdrawn daily. Later the kilns were constructed of iron plates and lined with fire-brick. Such kilns were approximately sixteen feet in diameter and forty-five feet in height. The clinker from these kilns was ground between burr-stones frequently turned by water-power. The product was screened and the coarse material returned to the mill. These burr mills were gradually supplemented with ball and other types of efficient grinding machinery particularly suited to this type of cement clinker, which is comparatively soft.

The production of natural cements continues to this day, and until 1899 increased in volume of production. That year the curve reached its maximum, the output being 9,868,179 barrels. Since that time the production has gradually decreased, although the total production of cement in the country has very gradually increased.

Analyses of natural cements show the following typical constitution: Rosendale cement—silica, 27.75; iron oxide and alumina, 9.78; magnesium oxide, 21.18; calcium oxide, 35.61; carbon dioxide, 4.05; leaving calcium sulphate, water, and undetermined, 1.30. The natural cement from Utica gave silica, 35.43; iron oxide and alumina, 9.02; calcium oxide, 33.67; magnesium oxide, 20.98.

The natural cement from the Lehigh Valley gave silica, 18.28; iron oxide and alumina, 7.43; calcium oxide, 51.53; magnesium oxide, 2.07; potassium and sodium oxides, 1.50; carbon dioxide, 16.20; undetermined, 2.93.

Portland cement was imported exclusively until the early seventies, when experiments were begun at Copely, Pennsylvania, by D. O. Saylor. His work was not commercially important until 1875, when the first Portland cement made its appearance and found its commercial way hard indeed, having to meet the competition of the imported material, which then, as now, seems to have a certain charm for many Americans. Today practically no Portland cement is imported.

It is true that the technique had not been so well developed and the materials used differed decidedly from those employed in England. A cement rock high in lime was used, together with ordinary cement rock, and it required many tedious trials to arrive at the right proportions. The kilns used were bottle-shaped and not of great size. Finally this cement won recognition through its use in two large engineering projects—one of which was the Eads Bridge and the other the Drexel Building in Philadelphia. The original mill produced about 1700 barrels a year; it now turns out that much cement in an average day.

In 1872 experiments were begun with a mixture of marl and clay found near Kalamazoo, Michigan, and for some time an excellent product was manufactured. Indeed, certain sidewalks made from that early cement are still giving satisfactory service and are reported to be in good condition. But the cost of producing cement from these materials proved to be too high, and the mill ceased operations in 1882.

Other mills that came into production in the same decade include one at Wampum, Pennsylvania, in 1875, limestone and clay being the raw materials; another in 1877 at South Bend, Indiana, working upon white marl and clay; and a third in 1879 at Rockport, Maine. Then in 1883 a small plant began at Egypt, Pennsylvania, which is near Copely, the scene of Mr. Saylor's first experiments, and from that time on plants have been largely concentrated in the Lehigh Valley, where ideal raw material is to be found in a deposit of stone of varying depth, lying in a wide strip extending for many miles in that valley.

The production of Portland cement has been as follows:

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES 1870–1919, IN BARRELS

Year	*Quantity*	*Year*	*Quantity*
1870–1879	82,000	1900	8,482,020
1880	42,000	1901	12,711,225
1881	60,000	1902	17,230,644
1882	85,000	1903	22,342,973
1883	90,000	1904	26,505,881
1884	100,000	1905	35,246,812
1885	150,000	1906	46,463,424
1886	150,000	1907	48,785,390
1887	250,000	1908	51,072,612
1888	250,000	1909	64,991,431
1889	300,000	1910	76,549,951
1890 [1]	335,500	1911	78,528,637
1891	454,813	1912	82,438,096
1892	547,440	1913	92,097,131
1893	590,652	1914	88,230,170
1894	798,757	1915	85,914,907
1895	990,324	1916	91,521,198
1896	1,543,023	1917	92,814,202
1897	2,677,775	1918	71,081,663
1898	3,692,284	1919 est.	80,287,000
1899	5,652,266		

It is remarkable that in this rapid growth of so important an industry a surprising minimum of science has been employed. The process invented by Aspdin is incapable of producing the cement that we now know

[1] The figures for 1890 and prior years were estimates made at the close of each year but are believed to be substantially correct. Since 1890 the official figures are based on complete returns from all producers.

as Portland cement, for it is not burned at a temperature sufficiently high to produce the one essential ingredient, since discovered through scientific research. In improving the process by raising the burning temperature to a point to produce incipient fusion, which was accomplished about the year 1825, this constituent was formed, and, while the superiority of cement so made was early demonstrated, no one knew why it was better, nor why such burning was necessary to make it better. As in many other industrial processes, the process for manufacturing a superior product was accidentally discovered, but no one gave sufficient thought to why the steps found necessary were taken. Development along really scientific lines, therefore, has been unfortunately slow, and the early development of the Portland cement industry depended upon the chance discovery by burning various mixtures and waiting to see what physical properties were obtained.

The improvements in mechanisms necessary for handling raw materials and finished product, and the preparation of raw materials, as well as every other step in manufacture, have been made with a great degree of perfection, so that improvements in the quality of cement have been due largely to this mechanical perfection rather than to the acquirement of any better knowledge of what cement actually is. Now, having learned something of the essential constituents of a successful cement, it remains to be seen whether there may not be other raw materials than those commonly employed which will make it possible to secure these necessary compounds more economically and perhaps in larger quantity. Improvements thus far are perhaps due more than anything else to the better grinding of both raw material and finished product, this grinding being more uniform, much finer and more economical than formerly. More uniform burning is another important factor.

CHAPTER III

RAW MATERIALS AND PROCESSES OF MANUFACTURE

While theoretically there is a wide choice in the raw materials that may be used for Portland cement, as a matter of fact the various combinations are made from comparatively few components. One of the first requirements is that the raw material must be in a physical state admitting of fine grinding with as low power consumption as possible. The finished product must contain silica, lime, and alumina in the right proportions, and must be free from excessive amounts of ferric oxide, magnesium, potash, and soda. The raw materials therefore must be so chosen as to provide the proper ingredients. The silica and alumina are customarily derived from clay or shale. The lime is obtained as limestone or marl, if it contains not less than eighteen per cent. of lime, and clay or chalk.

In compounding the raw material mix, due allowance is made for such clay as may be present in the marl. By-products, such as slag and caustic soda waste, are also used. In calcareous materials lime predominates, and this class is represented by limestone, marl, chalk, and alkali waste. Silica and alumina predominate in the agrillaceous materials, such as clay, shale, slate waste, and slag. Combinations having the right proportion of the three essential elements may be made up from cement rock and limestone, or from limestone with shale or clay, sometimes from slag and limestone, and frequently from marl or shale with clay. Less frequently, alkali waste is proportioned with clay.

A typical cement rock found near Copely, Pennsylvania, will analyze as follows: calcium carbonate, 67.14; magnesium carbonate, 2.90; silica, 18.34; iron oxide and alumina, 7.49; sodium and potassium oxides, 0.19; water and undetermined, 3.94. Cement rock from other localities usually runs somewhat less in calcium carbonate, with a corresponding increase in magnesium carbonate and with some variation in the other constituents noted. This is the same type of rock as that used in the production of natural cements. The other rock materials noted vary in their composition—hence the necessity of constant careful chemical control if the best possible results are to be obtained in the finished product. The alkali waste mentioned is the precipitated calcium carbonate derived from the Leblanc process.

There are three processes commonly employed for the production of Portland cement from the ingredients that have been noted. These are the wet process, the semi-wet, and the dry process. The wet and the semi-wet processes have as their principal advantage the greater facility with which the proper mixing of raw materials prior to burning can be obtained, and consequently the possibility of using marl, which occurs wet, with clay. The semi-wet process is simply the wet process applied to dry materials.

The proper raw materials having been decided upon, the first step is to crush and grind the materials to a fine powder. This may be done, as indicated, by either a wet method or a dry one. Where wet materials are brought into the mill, this may be done by any suitable dredging, pumping, and conveying machinery. Where dry raw materials are employed, the rock is either broken up at the quarry and conveyed to the grinders, or it may be brought to the crushers and passed by belt conveyors and other means to the different types of grinders.

There are, of course, many types of these powerful machines. The gyratory type of crusher has been popular, and a large crusher of this type is sometimes installed at the quarry, followed by a series of smaller crushers at the end of the conveyor at the mill. The largest gyratory crusher is nearly nineteen feet in height and weighs approximately 425,000 pounds. An idea of the capabilities of this machine is obtainable from the fact that it will crush 800 tons of rock an hour, and pieces as big as three by five by ten feet may be fed into it. This crusher is, in effect, a heavy hammer, swinging with great power, accentuated by centrifugal force, against a circumference that forms the anvil.

The product from such large crushers is then conveyed to smaller ones, which further reduce the size of the pieces. From this point in the semi-wet process the materials are mixed in the wash mill to form a thick suspension, or slurry, which contains about 40 per cent. of water. It is then ground in one of several types of special mills, some of which employ burr-stones. In the wet method the materials are similarly ground, and in both cases the slurry is then usually levigated and run into shallow bins or other containers, where much of the water drains away or evaporates.

The material, thus thoroughly incorporated and partly dried, may be made into briquets and dried by the waste heat coming from the kilns, after which it is fed into the cooler end of the ordinary kiln. The more modern practice provides for feeding the wet slurry direct to rotary kilns. In these, the first several feet from the stack or feed end is fitted with lifters, which elevate the slurry and allow it to drop through the heated gases. The material, after passing through this zone, carries about 10 per cent. of moisture.

One of the objections to both the semi-wet and the wet methods has been that sometimes sufficient initial set takes place in the slurry to interfere with its efficient subsequent handling by the apparatus ordinarily provided. More recent researches indicate that there are several types of organic material that may be added to the slurry to prevent this from taking place. Such a setting preventative must subsequently be destroyed during the burning process. Molasses, sugar in other forms, oxy-acids, oxy-aldehydes, and oxy-ketones are among the materials that have been patented for such use. About one fourth of one per cent. of sugar is sufficient, and this, of course, burns off without objectionable residue.

The more obvious advantages of the wet process are: first, the avoidance of dust, both in that portion of the plant where the grinding and the mixing of the raw materials are performed, and also nearly complete elimination of dust from the gaseous products of the kiln; second, the greater ease obtained in feeding the required composition to the kiln to give a satisfactory finished product. These advantages are in addition to that of better grinding and mixing, to which reference has already been made. The wet process may be said to be gaining in favor, and several of the recently built large mills employ it.

The cement plant of today is usually of reinforced concrete construction, and consists, in short, of a series of storage-bins, located between the few unit processes —grinding, burning, mixing, drying. A typical wet-process mill has in general the following types of equipment. Assuming that the raw materials will consist of limestone and clay, the coarse crushing plant will be located at the quarry. The rock is first crushed to pass an opening three inches in diameter, and in this condition is delivered to a storage-bin at the plant, using standard dump-cars to convey it. The clay will be transferred by a locomotive crane into special cars, which at the plant will be emptied by a bucket conveyor system operated from a traveling crane. This kind of equipment is also used to transfer the clay from its storage-bin to the wash mill. Such raw clay will contain approximately 30 per cent. of moisture, and an additional 30 per cent. will be required in the wash mill.

A mill of this type is ordinarily constructed of reinforced concrete, and it takes the form of a basin, say, twenty-five feet in diameter and six feet deep. In this, clay and water are added and thoroughly mixed by a revolving mechanism. The resulting suspension, or slurry, when thoroughly mixed, flows from the wash mill through a screen into either of two agitation basins, from which it is pumped as needed to receiving tanks so located as to feed comminuters by gravity.

The lime rock is elevated to hoppers also located above the comminuters, and is fed to them at a constant rate, this rate being controlled, as is that of the clay slurry, to give the desired proportions of clay, rock, and water. The feed to the comminuters contains about 18 per cent. dry weight of clay, 82 per cent. of rock, to which sufficient water is added to produce a 33 per cent. slurry.

The mixture so produced flows to a tube mill, seven by twenty-two feet, in which about eighteen tons of beach pebbles are employed to do the grinding. As this tube mill revolves, the material is hammered between the pebbles and the circumference of the mill. The product of the tube mill is fed into a second smaller mill, ten by six feet, in which seventeen tons of a specially designed iron slug, called cylpeb, serves still further to reduce the particles.

The next step is to pass through a Trix mill, where over-sized particles are screened out and returned to the comminuter. From these last mills the slurry goes to a storage-basin, where a mechanical agitator keeps the solids in suspension. The material has been ground so that between 90 and 95 per cent. of it will pass through a sieve having 200 openings to the inch. While in this storage-bin, the control laboratory makes an analysis and then a check analysis after the material has flowed to an agitation basin. Any corrections in composition are now made by adding the necessary ingredients, and the material is then finally pumped by air-lift pumps to storage-basins in the kiln building.

The rotary kiln of today is an impressive piece of mechanism. One recently installed is ten feet in diameter and two hundred and forty feet in length. For two hundred and ten feet of this distance a lining of high-grade fire-brick is provided, and the remaining distance is fitted with lifter plates. The rotary kiln is connected with a high stack, and may be fired either by gas or by powdered coal.

Much of the success attending cement manufacture as practised today is due to methods evolved for burning powdered coal. Natural gas and oil continue to be favored fuels, but without pulverized fuel the cement industry would be considerably limited. The use of pulverized fuel enables many otherwise waste fuels to be used, permits a temperature control that is very essential, and in well equipped mills affords considerable ease in handling. The preparation of pulverized fuel has been a problem in another field than that under discussion; but it may be said that, because of the recognized highly combustible and indeed explosive character of finely divided organic dust suspended in air, the safety factor has been one of the most important parts of the problem.

As long as pulverized fuel is at rest, it can be so conveyed and stored as to prevent it disseminating in the air, and it can be used with safety. One of the successful methods used in pulverizing the fuel provides an air suction, which constantly carries from the mill those particles of fuel that have been reduced to sufficient fineness, thereby eliminating much of the potential danger. Coal, as received, must be dried, and when pulverized more than 95 per cent. should pass through a sieve having 100 openings to the inch. A low-ash coal is desirable, since this ash necessarily becomes a part of the finished product.

Pulverized fuel is essentially an American invention, and upon its use depends the Portland cement industry in some other parts of the world.

From this point on the process is the same, whether the wet, semi-wet, or dry method for preparing the raw materials has been used. Returning for the moment to the dry process,—by which the larger portion of the Portland cement is still manufactured in the United States,—the crushed raw materials must be reduced to as fine a dust as is economically possible before burning. A great variety of mills, rolls, crushers, etc., are used for this purpose. These include ball mills, where flint pebbles or hardened balls perform the work. Tube mills, so arranged that satisfactorily reduced material is automatically discharged, are also installed. There are crushers where pulverization is accomplished between plates, very much as coffee is ground to powder in a small coffee-mill. Then there is the hammer-mill type, where a series of hammer-like devices pound the particles to dust. The iron slug, or cylpeb, is frequently used at the end of the tube mill, which feeds and discharges through its shaft, these slugs increasing the output and producing finer material. Again, the edge-runner mill may be employed. This is the same type of mill as is used in the manufacture of putty and many other substances, and consists of two heavy wheels running on a track around a center shaft. They are provided with suitable scrapers, which continually return material to the wheel path. In the case of raw materials for cement, the under plate is a perforated grid, the perforations being designed to let through only that portion which has been ground sufficiently fine.

This finely ground powder is dried and must be carefully analyzed before it is fed to the kiln, and additions of one or another of the ingredients made, as required to keep the material going to the kilns as uniform as possible. In all processes the hot clinker issuing from the kiln carries 10 or 11 per cent. of the heat supplied to the kiln in the burning of Portland cement. It has been suggested that this obvious loss of heat may be prevented by utilizing it to pre-heat the air brought in to support the combustion of the pulverized fuel in the kiln. The clinker leaves the kiln at a temperature approaching 1200° C. (2192° F.) and will give up to the air approximately 520 British thermal units [1] per pound of clinker. If the theoretical amount of air for complete combustion of the pulverized fuel enters the clinker cooler at atmospheric pressure, it has been calculated that 480° C. (896° F.) would be the maximum temperature to which the air is heated. Using this heated air, the highest theoretical temperatures may be obtained when the fuel consumption is lowest; and to reach this high kiln efficiency there should be a slight excess of air.

A great deal depends upon the proper temperature

[1] A British thermal unit is the amount of heat required to raise the temperature of one pound of water one degree F. The unit in the metric system is either the large caloric, which is the amount of heat required to raise the temperature of one kilogram of water one degree C., or the small calory, which is the amount of heat required to raise the temperature of one gram of water one degree C.

of the burning, for the tricalcic silicate that imparts to Portland cement its most valuable properties requires very high temperatures if it is to be formed from limestone and clay. There is a considerable shrinkage of the raw materials during burning, and a well burned clinker is a brown or grayish-green mass, semi-vitrified. The cooled clinker is elevated by a bucket conveyor or elevator to an inclosed clinker storage-bin, there to remain until it is required for the finishing process.

It is necessary to grind the clinker to as fine a powder as is economical, and for special purposes extra fine grinding is sometimes specified, as, for example, for cement used in the construction of concrete ships. The weight per cubic foot is less with the more finely ground materials. The finishing mill is ordinarily fitted with comminuters and tube mills, the latter containing a section supplied with beach pebbles, and a second part, about one third the length of the former, supplied with cylpebs. Cement must be ground so that at least 78 per cent. will pass through a sieve having 200 openings to the inch.

Gypsum is an important constituent, added with the clinker entering the comminuter in a percentage sufficient to produce the required retard in the setting time of the finished product. Sometimes plaster of Paris, which is gypsum from which 75 per cent. of its combined water has been removed, is added to the finished product. The finished cement is transferred from the finishing-mill room by belt conveyors to concrete damp-proof silos, where it is held until required for shipment. The packing is done on special machines, supplied from a hopper, to which the cement is delivered by a screw conveyor from the silos, and the filled bags, holding one cubic foot, or ninety-four pounds, are delivered, of course, by belt conveyors. For specially large operations cement has been successfully transported in bulk, being loaded directly into box-cars, carefully lined to avoid loss by sifting or other leaks, and also to exclude moisture. At one time it was customary to pack a large proportion of the cement output in barrels; but the use of cloth sacks has become more and more general, notwithstanding the annoyance involved in accounting for and crediting sacks returned by constructors and dealers for re-use.

Many millions of sacks are required annually to handle our cement production, and some plants maintain elaborately equipped departments where old sacks may be thoroughly cleaned and repaired for re-use. The packing of cement in bags is largely controlled by the corporation that has perfected the automatic machines used for the purpose; and, while the desirability of producing a one-time service, non-returnable bag is well recognized, none has so far been perfected. One of the difficulties in the way is the necessity of choosing a material that will work satisfactorily on the present bag-making machinery, or the alternative of interesting sufficient capital to develop a type of machine that will make a good bag from some of the cloth substitutes so far proposed.

One of these substitutes is an ingenious reinforced damp-proof paper, composed of two sheets of Kraft wrapping-paper (the crisp, brown sort so extensively used for wrapping packages) of weights chosen to render the required service. These two sheets of paper are held together by an asphaltic damp-proof compound, and, simultaneously with cementing these sheets of paper together, jute or cotton yarn is woven between the sheets. The space between these cords, which run diagonally in opposite directions, may be gaged to meet the great strain upon certain parts of the bag, and their size may be designated according to the service to be performed. There are several requirements to be met in designing a bag for cement, the pressure being greatly increased, for example, when bags are piled in tiers, as they usually are during construction operations.

The electric motor has accomplished a great deal for the cement industry, beginning with the movement of raw materials clear down to electrically driven conveyors that load the bags into trains. Motors have well recognized advantages in mills of this type, where they may be used directly connected or with short chain drives for operating the various mills, crushers, kilns, conveyors, and other units in a way to provide ample power at points where it will be required without the wastage so difficult to avoid in other systems of power transmission.

CHAPTER IV

BY-PRODUCTS IN THE CEMENT INDUSTRY

Until a few years ago the cement industry could not be strictly said to have by-products, although there were losses due to the escape of fine particles in the gases issuing from the stacks. In order to maintain a sufficiently high temperature in the long rotary kiln, it is necessary to blow the powdered fuel into it with considerable force; and this, together with the tall chimney through which hot gases rush, is sufficient to carry with it a considerable percentage of this dust. Smelters also have trouble with dusts and fumes, and in the manufacture of sulphuric acid there are mists that must be removed from the air. The removal of suspended particles from gases is a mechanical problem, and commercially such particles are either removed by settling in flues, expansion-chambers, baffle-houses, etc., or by filtration processes involving towers, bags, and the like, scrubbing methods, centrifugal, and more recently electrical precipitation.

The electrical precipitation process offers one of the best methods of separating individual particles of suspended matter from the gases without having to treat the gases themselves. It was while working upon the problem of removing sulphuric-acid mist from gases before they pass to the contact towers, in the contact process for the manufacture of sulphuric acid, that Dr. F. G. Cottrell became interested in the process that now bears his name, and developed commercial methods for accomplishing the purpose. The success there led later to installations of similar apparatus in other sulphuric acid plants, and more particularly in smelters, where restrictions had been placed relative to fume control because of damage done to vegetation in the surrounding country.

Not many cement plants are located in districts where the dust carried from the kilns can cause great damage. In southern California there is a factory in the heart of the fertile orange belt. It became the center of serious agitation that threatened the factory with extinction. There had been many demands made by complaining neighbors, whose land in some cases had been purchased in settlement of suits; and, notwithstanding the company's liberality in settling the complaints of the growers, it became increasingly apparent that either the dust must be prevented from escaping into the atmosphere or the plant definitely shut down. In this emergency the company turned to the Cottrell process as a possible solution.

This problem was quite different from the ones it had solved, due largely to the dryness of the gases, their high temperature, the great volume of gas, and the large quantity of dust that had to be removed.

In the Cottrell process the individual dust particles are given separate electrical charges, and are then caused to migrate under the electric force out of the current of advancing gases. The force that can be exerted upon the individual particle depends upon the construction of the apparatus, as well as on the electric characteristics of the gases under treatment. The gases, along with the suspended material, are passed into an apparatus comprising a system of electrodes. One of these systems facilitates the electric discharge from its surface, while the other is designed to minimize or prevent such discharge. These electrodes are so placed in the apparatus that the two types oppose each other, and a silent discharge is maintained between them by means of a high uni-directional electric potential.

The gases are now passed through this discharge, which in reality is composed of a stream of particles of electricity flowing from the electrode designed to discharge to the non-discharging electrode. As the suspended particles in the fumes come into this stream of electric particles, they are bombarded by the electric particles, which attach themselves to the suspended material and give them their electric charge. In this manner the particles gather sufficient electric charge to move under the force of the field between the electrodes, causing them to pass to the non-discharging electrode, where the suspended material is deposited. Meanwhile the gas in which the particles were originally suspended moves on.

This is a simplified description of what is really a very complicated mechanism. The process would seem very simple from what has been outlined above, but a great deal of skill is required in design to secure anything approaching theoretical results. For example, there is difficulty at times in freeing the electrodes from their attached particles, and care must be exercised if satisfactory efficiency is to be realized.

In the plant under discussion several large-sized treaters were built, and proved entirely successful. When it is remembered that nearly a million cubic feet of gas must be treated each minute, the temperature being 450° C. (842° F.), and that 90 tons of dust are collected, on the average, every twenty-four hours, the immensity of the undertaking may be better realized. The total power of consumption of such an installation, including the motors driving the electrical apparatus and the conveyors removing the dust, is 40 kilowatts. The collection of the suspended particles averages an efficiency of more than 95 per cent., the heavy dust being entirely removed. The apparatus is managed by one man on each eight-hour shift.

The collecting electrodes are of wire mesh, while the discharge electrodes are of iron wire. The removal of dust from the electrodes is effected by the simple method of jarring them by means of air-hammers, and the dampers are operated by means of air-cylinders. The dust falls into hoppers, thence to screw conveyors that feed automatic scales, from which the dust is carried to bins. By this arrangement the treaters can be cleaned hourly, the entire bank of twenty units requiring less than five minutes.

The operation of such an installation gives us, then, a by-product, saved in the first instance to avoid litigation and prolong the life of the cement plant in question. If we remember the constitution of the raw materials entering the kiln, we recognize at once that in the dust so collected there should be enough salts of potassium to make it worth while to treat it for the recovery of potash. The dust in the factory under discussion is from a calcined raw mix containing no cement as such, but carrying about 2 per cent. of potash. In the beginning this dust was sold as a soil dressing. Later a kiln was installed in which the collected dust is burned to cement, and when the dust from this kiln is collected, it is found that the potash has been concentrated and that the dust from this kiln carries from 12 to 21 per cent. of potassium oxide, depending upon whether the kiln is operating on all dust or on part dust and part raw material.

It is interesting to note that the only reason for installing the special kiln was that the character of the soil in the vicinity of the plant was not such as to utilize all of the dust collected as a soil dressing; and this circumstance may be said to have forced the discovery that potash could be recovered in a quantity to make it a very valuable by-product. Where the raw materials are high in potash, the dust is correspondingly high in this important substance, and frequently the raw material in a cement plant can be decomposed granite high in feldspatic material, which often contains one per cent. of potassium oxide. This makes the potassium oxide content of the raw mixture less than one fifth of 1 per cent., the potash in the dust from the main cement kilns 2 per cent., while that from the final kiln in which this dust is burned to cement, is something more than 20 per cent. potassium oxide.

Since 1915, this recovery plant has proved of unusual value, for the price of potash rose to unprecedented heights, making the recovery plant more profitable, under war conditions, than the cement plant itself. Indeed, it is stated that at the Riverside plant, where the climatic conditions make the storage of cement clinker comparatively easy, this clinker unground was stored against the time when building construction should increase the demand for cement. The plant operated on a satisfactory economic basis from the proceeds of the recovered potash.

Another means for recovering such dust is by the water-scrubbing method, which is preferred by some engineers. One method of application is to cause the dust-bearing gases to pass through sprays or curtains of mist, which weights down the particles and cools them enough to cause their precipitation while the gases pass onward.

The potassium salts recovered by either method are only partly soluble in water, and are customarily converted into one of the soluble potassium salts of commerce. While especially suitable for fertilizer purposes, these potassium salts may be refined or brought into such form as the market may demand.

While it is not true of the cement industry, it may be said of others that such methods of precipitation of dust from fumes have shown phenomenal profits, not alone because the device performs its functions efficiently, but because up to that time the plant had been operated with appalling losses of either raw material or finished product. In this instance a series of fortunate circumstances has shown a possible way to produce potash: that if necessary, mills can be operated with cement as the by-product and potash the thing most desired, should such production ever be so important.

This achievement in the cement industry is a conspicuous illustration of what frequently occurs upon the employment of scientific research upon an industrial problem. It is a curious fact that much of the industrial research in our country has been taken up under the pressure of threatened litigation and not with sufficient frequency because the industry desires to make the most of its opportunities.

CHAPTER V

THEORY OF PORTLAND CEMENT SETTING

To M. Vicat of France seems to belong the honor of first undertaking to correlate the opinions and sort out the facts, so far as they were known in 1812, regarding the scientific principles underlying cements. He was particularly concerned with any relation that might exist between the quality of cement and the chemical composition of the stone that went into it; the nature of the chemical compounds formed during the burning operation; and, lastly, the changes that take place when cement hardens, or sets.

His first theory stated that, in mortars, hardening was caused by chemical combination between a portion of the alumina and silica found in the sand with the lime; but he soon found that this theory could not be supported. He then proceeded to study the influences of cohesion, discarding the hypothesis of simple interlacement of crystals, and came to a consideration of whether adherence is stronger than cohesion, or *vice versa,* in cases where cement hardens without perceptible shrinkage and also where shrinkage is measurable. By a process of theorizing and experiment he came to have no doubt that an important influence was exerted by the presence of quartz upon the cohesion of the lime.

Taking it up point by point, Vicat concludes: "We persist in thinking, as we have always maintained till now, that the lime in cements of natural or puzzolanos, etc., enters into chemical combination with these substances"; and, as Rankin states in his address on "Portland Cement" in the Journal of the Franklin Institute, the theories that Vicat must have had in mind can be stated: "First, that the lime contained in cement mortars should be present in chemical combination with some material other than water; second, that this other material should be silica, preferably in a finely divided or gelatinous condition."

Le Chatelier examined thin sections of cement clinker under a microscope fitted with polarizing apparatus, and concluded that this clinker was a mixture of tricalcium silicate with tricalcium aluminate. He attempted to prepare silicates of calcium and aluminum in the laboratory, and then examined their hydraulic properties; but he failed to prepare tricalcium silicate directly from lime and silica. He also examined very thin sections of hardened cement, and found it to consist of crystallized calcium hydroxide, interlaced with crystals of hydrated monocalcium silicate in a white matrix. From these observations he concluded that tricalcium silicate, when mixed with water, forms calcium hydroxide and hydrated monocalcium silicate. He believed the hydroxide then reacts further upon the calcium aluminate of the cement, forming hydrated basic calcium aluminate.

As has been stated, Portland-cement clinker is formed by the chemical combination of three oxides, lime, silica, and alumina, with which magnesia and ferric oxide always occurs in commercial cement. The three principal oxides make up more than 90 per cent. of the cement, and, while ordinary chemical methods enable us to learn the percentage of each oxide present, it gives us nothing with reference to the condition or way in which these oxides combine.

Many persons have been at work upon this question, and most of the work resulted in a failure to appreciate the extent to which the principle known as the phase rule could be employed in deciding the question. To the Geophysical Laboratory of the Carnegie Institution of Washington belongs the credit of achieving the first considerable success in learning to what the cementitious character of Portland cement is due.

A long series of systematic, painstaking experiments led to the determination of the characteristic properties of the several solid substances containing only the oxides of calcium, alumina, and silica which may be expected to occur in Portland cement. In order to work out the ternary system, about 1000 different mixtures of the three oxides were investigated, involving 7000 heat treatments and microscopical examinations of the resultant products. Materials of known purity were used, and fusions were made in a platinum crucible to avoid contamination and to obtain a thoroughly combined product. In the article already quoted, the apparatus is both described and illustrated and the method given in some detail. Considerable ingenuity was displayed in the design of furnaces, methods for temperature measurement and control, and indeed methods of constant uniform heating.

The data obtained are interpreted most readily by plotting them in three dimensions. In this scheme the concentration of each mixture is represented by a point within an equilateral triangle, on which the pure components, calcium oxide, aluminum oxide, and silica, are represented by the apices of the triangle: the binary systems, calcium oxide with aluminum oxide, calcium oxide with silica, and aluminum oxide with silica, are represented by the sides of the triangle; while the ternary mixtures are indicated by points within the triangle located with reference to the percentages of each of the three components present. When the composition is represented by such a point within the equilateral triangle on the horizontal plane, the magnitude of the corresponding temperature can be indicated by the distance above this plane, and a model resembling a contour map of a mountainous region can be constructed, in which each melting-point corresponds to a peak on the model and the mountain slopes represent the melting temperatures of a compound in a ternary mixture.

The major constituents of Portland-cement clinker, made up only of the oxides of calcium, aluminum, and silicon, have been found to be the three compounds—tricalcic silicate, in which three molecules of calcium oxide combine with one of silica; dicalcic silicate, where two molecules of calcium oxide combine with one of silica; and tricalcic aluminate, in which three molecules of calcium oxide combine with one of aluminum oxide. Occasionally a compound consisting of five molecules of calcium oxide with three of aluminum oxide occurs, as does also free lime or calcium oxide.

By exhaustive study of these several compounds, their optical and crystallographical properties were determined. These are of great assistance when examining commercial Portland-cement clinker under the microscope; and, while the mixtures are too finely grained to permit of certain identification, nevertheless something of the optical nature can be seen.

From all this work, it would appear that the value of Portland cement as a cementing material when mixed with water is due principally to one or more of the compounds dicalcic silicate, tricalcic silicate, and tricalcic aluminate. Now, if the clinker has been perfectly burned and pure oxides have been used, the clinker will consist of about 36 per cent. of the tricalcic silicate, 33 per cent. of the dicalcic silicate, 21 per cent. of the tricalcic aluminate, and 10 per cent. of the minor constituents. But in the actual manufacture of cement this is not achieved; for the raw materials are rarely ground fine enough nor heated sufficiently high to complete this chemical reaction, and in our commercial cement the proportions of the essential ingredients will be altered from the percentages given above. The work done at the Geophysical Laboratory, however, makes it possible to state which constituents will not be completely formed. Tricalcic silicate is the last one to form completely, being the compound resulting from the combination of a molecule of calcium oxide with one of dicalcic silicate. Consequently, there will be less tricalcic silicate and more dicalcic silicate and free lime, or calcium oxide, in the commercial clinker than in the one possible under laboratory conditions.

In the manufacture of the best Portland cement, it is necessary to carry the reaction as nearly to completion as possible; and this is more necessary when the action of free lime on the physical properties of Portland cement is understood. Actual experience has shown that concrete made from cements in which there is much free lime will disintegrate with relative rapidity, because of the expansion of this uncombined lime when it reacts with moisture, forming calcium hydrate. The necessity, therefore, of carrying out the reaction by which the calcium oxide combines with the dicalcic silicate, is apparent; and for some time cement manufacturers have striven to devise ways of insuring the combination of lime during burning, so that a better product with increased strength might be secured. As shown below, it seems certain that the essential cementing material in Portland cement is tricalcic silicate, although, unfortunately, this is the compound of the three that is formed with the greatest difficulty under commercial conditions.

There is still a great deal to learn as to the scientific principles underlying the complete hardening of Portland cement; yet enough data has been secured to furnish a knowledge of the gradual hardening, and to answer the query whether there is an increase in strength within the time that is frequently required to produce full strength in cement. The first change in cement mortar is usually described as setting, and this takes place rapidly. It sometimes requires a year for cement that has hardened to attain its maximum strength.

The hydration of the three major constituents, tricalcic aluminate, tricalcic silicate, and dicalcic silicate, will throw light upon what transpires in cement. Quoting again from Mr. Rankin's discussion: "When pure tricalcic aluminate is mixed with water, an amorphous hydrated material is first formed. This material sets and hardens very rapidly. The compound tricalcic silicate, when mixed with water, also sets and hardens rather rapidly. In the case of this compound, as in the case of tricalcic aluminate, the setting and hardening are due to the formation of an amorphous hydrated material on the individual grains, which are thus cemented together. The extent of the hydration or the percentage of amorphous material which each grain will yield depends upon the percentage of water used and the time. With a given percentage of water, the amount of amorphous material formed from the compound tricalcic aluminate in a given time is much greater than for the compound tricalcic silicate; that is, the compound tricalcic aluminate reacts with water much more rapidly than the tricalcic silicate. The compound dicalcic silicate reacts very slowly with water, and it is only after a long period of time that sufficient amorphous hydrated material is formed to cement together the grains of this compound and so form a hard mass.

"The amorphous hydrated material formed by the action of water on the constituents of cement does in time no doubt crystallize to some extent. From the data available it would appear that the crystals formed are calcium hydrate and some crystalline hydrate derived from tricalcic aluminate. Apparently no crystalline hydrate of the calcium silicates is formed.

"From this brief description of the action of water on the constituents of Portland cement, it will be seen that the settling and hardening involve the formation of an amorphous hydrated material which subsequently partially crystallizes; that the initial set is probably due to the hydration of tricalcic aluminate; that the hardness and cohesive strength at first are due to the cementing action of the amorphous material produced by the hydration of this aluminate and of the tricalcic silicate; and that the gradual increase in strength is due to further hydration of these two compounds together with the hydration of the dicalcic silicate."

From this it is obvious that the essential constituent of Portland cement is the compound tricalcic silicate, for it is the only one of the three compounds occurring in Portland cement that will set and harden within a reasonable time to form a mass having the physical characteristics of Portland cement. The other compounds either require too long a time to set and harden or form a mass too soluble in water and lacking both durability and strength.

Older theories, which stipulated gelatinous silica as the essential cementing substance, have been overthrown; for, while some of the particles may thus have been cemented together to form our most durable rocks, such silica does not occupy a correspondingly important place in Portland cement.

The question will at once arise as to why cement kilns are not operated so that tricalcic silicate will be produced. The answer is found in the difficulty with which this compound is formed from calcium oxide and silica. To begin with, the temperature of burning required would be 1700° C. (3092° F.), much too high for economic industrial practice. To form any considerable percentage of the desired compound, it is necessary to use a flux that will materially reduce the required temperature, and this to a considerable extent is furnished by the lower melting calcium aluminates. The best cement-making practice today produces a Portland cement containing from 30 to 35 per cent. of tricalcic silicate, which approaches the maximum possible yield with the present percentage of flux, and gives as good results as could be expected from the proportions of the components in an average Portland cement. The only conditions under which a larger percentage of lime can be used to convert more of the dicalcic silicate to the tricalcic silicate involves fineness of grinding and temperatures that are uneconomical, working with our present raw material.

Alumina below 10 per cent. renders cement more quick setting; but there is a noticeable decrease in tensile strength when more than that amount is present. Ferric oxide is believed to act similarly on alumina in promoting the combination of silica and lime. Ordinarily less than 5 per cent. of ferric oxide is present, which quantity apparently has no bearing upon the value of the cement in construction. It is to the presence of iron compounds that cement owes its dark color, and the white Portland cements are manufactured from materials selected with reference to their freedom from iron.

Potash and soda, which are always present, are not believed to promote the combination of lime, silica, and alumina; and calcium sulphate always delays the setting. Two per cent. is the usual allowance in specifications, and when 4 or 5 per cent. is reached, the result is injurious to the cement. It is popularly believed that any considerable percentage of magnesia will give rise to expansion and cracking.

CHAPTER VI

OTHER TYPES OF CEMENT

PUZZOLAN, COLLOS, SOREL, AND GYPSUM

As has been indicated, the Romans found it advantageous to mix volcanic ash with slaked lime in the preparation of their cement. This ash was conveniently found at a place named Pozzuoli, near which quantities of volcanic ash may be found even today. One such accumulation, a hill 440 feet high, called Monte Nuovo, was formed by an eruption in September, 1538. It has been mentioned by several classical writers. Because of the origin of this ash, the name "puzzolan" has been applied to cements employing somewhat similar materials. Diatomaceous earth has been found an excellent substitute for volcanic ash, but the nearest approach commercially is the slag from blast-furnaces. The temperatures reached in blast-furnaces are considerably higher than those obtained in rotary cement kilns, with the result that complete fusion is obtained. The process of manufacture consists in granulating the slag by running it, while still molten, into a reservoir of water. The fine particles thus formed are then dried and ground, very much as is cement clinker, with varying proportions of hydrated lime and a little gypsum to regulate the time of setting. Sometimes a little Portland-cement clinker is intimately ground with slag.

The first cement of this character was produced by the Clinton Cement Company at Pittsburgh in 1897, and in 1900 one of the steel companies began the manufacture of a similar cement. This activity has been assigned to a subsidiary corporation, which now manufactures true Portland cement from slag and limestone by the dry process.

It should be noted that if limestone and blast-furnace slag are ground together and burned by the usual method for making Portland cement, a true Portland cement results; but if the slag is granulated, as noted above and ground with slaked lime without burning, the resulting product is puzzolan cement. It will be seen at once that there is an economic advantage in manufacturing puzzolan as contrasted with Portland cement; for in using slag, a considerable part of the desired reaction has already taken place, and of course there is a saving in the number of heat units required, for the slag is a waste product of an operation against which the entire charge for fuel required can properly be made. There is a debit against this saving, however, because of the necessity of drying following granulation.

One limitation in the manufacture of puzzolan is that only slag from pure iron ores, which have been fluxed with limestone low in magnesium, can be used. In blast-furnace operations it is necessary to mix the fuel with the material to be fused, and in consequence there is likely to be a larger percentage of sulphur compounds in the resulting material than is desirable, unless precautions are taken in the use of fuel. There is also very likely to be a fairly large percentage of sulphur compounds in the iron ore itself, and it is considered difficult to operate a blast-furnace to produce the most desirable quality of iron and at the same time puzzolan-cement clinker.

It is desirable to avoid an excess of lime in Portland cement beyond that required to satisfy the chemical ratio of complete fusion; yet a high percentage of lime appears necessary if the material is to be expected to pass through the kiln at the proper rate. If a low percentage of lime is used, the mass tends to become too fluid; and when attempts have been made to produce a Portland cement by complete fusion of the original raw materials, the product has not had immediate cementitious qualities, and considerable calcium sulphide has been present. If the blast-furnace could be operated primarily for cement and its by-products, the difficulties, so far as sulphur is concerned, might be overcome, and an excess of lime in the resulting cement could be avoided.

Puzzolan cements are excellent for many purposes, particularly where the concrete made with it is kept moist. It does exceptionally well in sea water, and in this respect approaches very nearly the characteristics of its historical ancestor. However, when it becomes thoroughly dry, it seems to lose much of the strength shown while moist, and apparently oxidation by the atmosphere causes ultimate crumbling as the reaction progresses inward from the surface, being evidenced by a green coloration. Because a comparatively small quantity of cement is used where the concrete is kept moist, the production of puzzolan is a very small fraction of the total cement made.

There is another cement also made from slag which is somewhat different in character from puzzolan cement. It is made by a process called "collos" after its inventor, Heinrich Colloseus. To appreciate the difference between this and Portland cement, the following analyses are given. The composition of Portland cement varies, but in general lies between the extremes quoted:

Silica	19.8 –26.25
Alumina	4.16– 9.45
Iron oxide	2.19– 4.47
Lime	58.22–65.59
Magnesia	trace– 2.89
Alkalis	0.19– 2.83
Sulphuric anhydride	0.19– 2.19
Loss in ignition	0.26– 2.67
Undetermined residue	0.12– 1.28

Collos cement differs from the average rotary-kiln Portland cement in the presence of calcium sulphide and in the very much lower percentage of lime.

A typical collos cement contains:

Silica	33.04
Alumina	13.90
Iron oxide	1.23
Lime	42.86
Calcium sulphide	2.18
Magnesia	3.74
Alkalis	1.93
Sulphuric anhydride	1.11

Whereas the puzzolan cements undergo certain changes due to oxidation by the atmosphere, the change that affects collos seems to consist principally in the transformation of calcium sulphide into calcium sulphate, due to the method by which it is manufactured. Briefly stated, this consists in granulating the slag by running it upon a rapidly revolving corrugated cylinder, which granulates it while sprayed with a relatively small amount of a dilute solution of magnesium sulphate or similar salt of one of the oxide-bearing earth metals. The cooled and collected granules, when ground to a fine powder, constitute the finished product, to which nothing is added except a little plaster of Paris to control the setting time.

Customarily a blast-furnace is operated with cement as the first consideration, and may be the usual 40- or 50-foot stack familiar in the production of pig iron. The charge is proportioned very much as in the operation of iron blast-furnaces, where the calcium oxide and magnesium oxide in the resulting material will run from 40 to 50 per cent. Such a silicate has a melting-point between 1200° C. and 1300° C. (2192° and 2372° F.), which fortunately is about the melting temperature of the orthoclase from which potassium salts may be recovered. When such temperatures as those customary in iron production are used, the melt flows satisfactorily, is easily granulated to the desired cement clinker, and something more than 90 per cent. of the potash salts are volatilized and may be recovered by some such process as has been mentioned.

The molten mass is tapped from the base of the furnace into large iron ladles, from which the slag runs at a constant rate on to the periphery of a revolving cylinder. The slots, three inches apart, run longitudinally, breaking up the molten mass into fine globules, while the drum or cylinder revolves at a speed of 600 revolutions a minute. Simultaneously a 5 per cent. solution of magnesium sulphate is supplied under pressure through the interior of the cylinder, at a rate to use approximately sixty gallons of solution to a ton of molten slag. Under these circumstances the magnesium sulphate actually penetrates the granules, and both a physical and a chemical change takes place in the molten silicates. The oxy-salts of magnesium sulphate are formed on the surface and also on the interior of the finely divided material as it is suddenly chilled and then more slowly cooled. This is actually a dry granulation process, for the only water used is the amount necessary to carry the magnesium sulphate to the molten particles, and, by the time these fall upon a slowly revolving table beneath the cylinder, they are quite dry. This table, which may be 25 feet in diameter, carries the granules for two thirds or three fourths of a turn, so that they are almost cooled when scraped off by a conveyor which takes them to clinker storage.

As is customary in blast-furnace operation, a hot-air blast is employed in melting the charge, and this excess of air actually oxidizes virtually all of the sulphur present in the fuel, permitting it to pass off with the gases as sulphur dioxide, leaving only the small amount of calcium sulphide given in the previous analysis. If low sulphur fuels could always be used, the presence of sulphides might be avoided altogether.

There are several advantages claimed for this type of cement. It is somewhat slower in attaining its initial set, but in practical work this has not been detrimental in construction work. It attains high strength and is never too quick setting. It sets equally in air and water, and in general complies with the standard specifications for Portland cement. Indeed, where a quicker setting cement is required, the omission of gypsum and the addition of from 5 to 10 per cent. of a high-lime clinker to the collos type, will produce the desired results. The specific gravity is 2.88, as compared with 3.10 for Portland cements.

In Portland cement specific gravity is one indication of proper calcination, the density usually preferred being 3.10; but there is nothing to show that the denser cements have any advantage. In fact, in some special work, for example concrete ships, an effort was made to obtain a lower specific gravity without sacrificing strength, in this case by extremely fine grinding. Collos cement is said to be almost constant in volume, and as there is no excess lime, there is lessened danger of unsoundness. Portland cements sometimes expand, because of the outward thrust of certain crystals that grow in the mass, or perhaps the formation of a colloidal cement; but tests in carefully calibrated glass tubes indicate a lack of expansion in the case of these other types.

Being a completely fused material, it may be assumed that all the elements of collos cement are in permanent chemical combination, and that it therefore should resist sea water, alkaline fluids, and even fire to an unusually satisfactory extent. But perhaps the characteristic most appreciated in building operations is the non-staining character of the collos type of cement.

The iron in this type of cement seems to be in chemical combination with the other constituents and in the ferrous condition. The cement has been proved to be non-staining, and tests, in which polished copper and iron have been embedded in concrete made with this cement, have been found to be free from discoloration and to be uncorroded at the end of many months. In a number of instances, white marble and other stone have been laid up in various buildings with this cement with entire satisfaction, both as to the strength of the mortar and particularly because no staining resulted.

With more than 90 per cent. of the potassium present in the raw materials volatilized in this process, it has been suggested that it could be profitably operated for the cement and potash with but little consideration for the iron to be made; and if ore of low iron content is used, the cement is improved in color. The potash may be recovered in the usual manner.

Sorel cement is another variety, distinct in materials, methods of manufacture, chemical reactions, and uses from those previously described. It has come into prominence more recently, especially for flooring and various artificial stones. Chemically speaking, sorel cement is magnesium oxy-chloride, which is formed in the mass when magnesium oxide and magnesium chloride are brought together in the right proportions.

The source of magnesium is usually magnesite, the carbonate ore of magnesium. In one process for the production of carbonic-acid gas familiar in charged waters and soda-fountain beverages, magnesite is heated or calcined to drive off the carbon dioxide to the point at which from 2 to 4 per cent. of the gas remains in the mineral. This temperature is about 870° C. (1600° F.), and the resulting oxide is suitable for the cement described. Magnesite may be calcined at different temperatures, and that now under discussion is called caustic burning.

The hardening of the cement being due to the formation of magnesium oxy-chloride, it is obviously necessary so to proportion the magnesium oxide and the magnesium chloride as to form the oxy-chloride exclusively, leaving no excess of either constituent. This is usually controlled by the specific gravity of the magnesium chloride solution with which the oxide is to be mixed. Commercially, the preparation is offered in dry form containing the ingredients in proper proportions, so that, upon stirring with the prescribed quantity of water, a plastic mass will be produced with the setting time regulated to permit its being spread in place.

This type of cement is dense, hard, and tough—especially when suitable fillers are incorporated with it, as in the manufacture of composition flooring. Such fillers may be fibers or powdered minerals, which also serve to impart the desired color. Properly troweled and finished, this cement has a surface so satisfactory that it may be used for table-tops and other similar applications. The material has abundant strength for flooring, and, unlike Portland cement, it is possible to cut, saw, nail, or force screws into the magnesite flooring, as it is customarily called. Further, it has the ability to resist fire to a reasonably satisfactory degree, and acts as a heat insulator. Fortunately, its comparatively low cost permits its use in competition with other types of permanent flooring, leading to its installation in hospitals and other public buildings, as well as in the kitchens, pantries, etc., of houses.

When used for flooring or for step-treads on railway cars and on ship decks, the composition is advantageously worked into the surface or foundation provided with ribs, set at such an angle as to give anchorage for the material and yet to permit it to be chiseled out in strips, blocks, or other sections when repairs are required for those portions subjected to the greatest wear. Magnesite flooring has come into almost general use as a satisfactory insulator and covering for the floor of the modern steel railway coach, where it is subjected to extraordinarily hard usage.

Although known for some twenty years, this type of flooring has become prominent commercially only in the last six or eight years. Some two hundred concerns are now producing it, and 10 per cent. of our magnesite ore production is required for the manufacture of this type of cement. Where it has not been successful, the cause has nearly always been a failure to appreciate the necessity of balancing the chemical reaction. Good results cannot be obtained with either too little or too much of either ingredient. As is the case with every structural material, a certain number of failures can be traced to poor design and poor workmanship.

Another important series of plasters is that utilizing gypsum as a raw material. Gypsum for this purpose is usually mined from the granular masses of the mineral in which it occurs more or less stained by iron.

When gypsum is of especially fine grain, mottled in pale colors or white, it is called alabaster. Gypsum is also deposited from solution in salt lakes, where it forms compact fibrous beds looking like limestone, but very much softer. When it is transparent, it is called selenite. The chemical composition of gypsum is calcium sulphate, with which two molecules of water crystallize out for each molecule of calcium sulphate. Calcium sulphate is a by-product in several chemical operations, and the pure compound thus obtained is variously termed terra alba, mineral white, pearl hardening, crown filler, etc., and is used for such purposes as a filler in paper-making, finishing cloth, wall-paper printing, and as a pigment.

When gypsum is heated to the point where 75 per cent. of this water of crystallization has been driven off and is then finely ground, plaster of Paris results. For the finer plasters the raw material is washed free from iron. In the process of burning, which may be carried on in kilns, furnaces, or muffles, direct contact with the fuel must be avoided, so that the sulphide will not be formed from a part of the sulphate. Consequently the burning operation requires considerable care. The most favorable temperature for burning is about 125° C. (257° F.), and if the temperature is carried to 200° C. (392° F.), all the water is expelled, and the resulting product will combine with water very slowly, the property of rapid setting having been destroyed.

Gypsum plasters, of which plaster of Paris is perhaps the best known, set or harden on recombination of water with the burned plaster to form hydrated calcium sulphate. As soon as a part of the plaster, which according to Le Chatelier is really two molecules of calcium sulphate with one molecule of water of crystallization, begins to dissolve, a combination takes place with some of the water with which it is mixed, forming the same chemical combination as the mineral gypsum. This is much less soluble than the plaster, and begins to crystallize at once with a network of crystals. This process continues as more of the plaster dissolves, becomes hydrated, and crystallizes, so that the set rapidly increases, due to the interlacing of newly formed crystals with those that have been formed. This train of events continues until the plaster is fully hydrated.

Recent experiments by Keane show that the ability of a plaster that has been heated to a high temperature to set is directly due to differences in the fineness of the particles. Thus so-called dead-burned plaster, resulting when gypsum had been heated for some time at 600° C. (1112° F.), was unable to set when the average diameter of the particles was 0.05 millimeters; but the same product ground until the average diameter had been reduced to 0.005 millimeters, formed a hard mass, setting rather rapidly. In investigations on metals it has been learned that the boundaries between neighboring crystals are surfaces of considerable strength, due to surface tension or perhaps the presence of a layer of amorphous material. This may also account for the early strength developed in the network of calcium sulphate crystals that form to give us the familiar hard, dense mass of plaster.

As in the use of many other good materials, errors are frequently made in the use of plaster of Paris, particularly failures to get the right proportion of plaster and water. Where plaster is used in considerable quantity, a safe method is to add the plaster to the water, for reasons that the above theory of setting makes clear. If the desired proportion of water can be placed in a suitable container, above which a sieve can be so placed as to deliver the plaster in a fine shower, it can then be sifted into the water until some dry plaster remains on the surface. The sifting should be done slowly, giving the plaster time to hydrate. The presence of a fair layer of dry plaster on the surface of the water is an indication that enough plaster has been added. It is then well thoroughly to work up the mass with the hands; and, while those unfamiliar with working plaster of Paris in this way are pretty sure to consider the mixture too thin, it will be found entirely satisfactory when the mold or other article has hardened. The plaster in this condition is homogeneous, readily flows into place, and sets with satisfactory density, strength, and service.

Portland cements, particularly the white cements, magnesium oxy-chloride and plaster of Paris, are used with a great variety of substances to form all kinds of artificial stones. Granites and that type of material are usually secured by facing cement or concrete slabs and blocks, as will be described later; but in fashioning artificial marble, onyx, and other types of decorative stone, these materials are used for their cementatious qualities, their durability, compressive strength, hardness, and ease of working. Special plaster of

Paris is the basis of the hard cement used in place of wall tile.

The distribution of color required is obtained by a great variety of fillers, extending from minerals and waste materials to masses of silken threads. These are embedded in the surface, which, after the mass has set, is turned or rubbed down to the specified size and shape, and then finished according to the desired effect. This may consist in producing a high polish, after which glue, size, wax, stearin, etc., may be applied in a solution of petroleum ether. This tends to fill the pores, and gives a smooth surface to which dirt does not adhere readily and which can be washed without injury. Again, the surface may be washed with a barium hydroxide solution designed, through the formation of insoluble barium sulphate, to render the object water-proof.

CHAPTER VII

CONCRETE

Concrete is the term applied to mixtures of coarse and fine rock particles, called aggregate, and water with Portland cement, which acts as a mortar and when it hardens produces a solid mass. An effective mixture is one in which there is enough cement of good grade to coat every particle, small and large, and in addition to fill the spaces, called voids, that exist between the grains of sand or larger particles of aggregate. Enough of the small aggregate, or fine particles, must be used to form a mortar with the cement when it is hydrated, and this mortar must fill the spaces or voids between the larger pieces called coarse aggregate. At the same time, the coarse aggregate must be graded and distributed through the mass in a manner to leave the minimum number of unoccupied spaces.

This entire mass must be workable and sufficiently plastic to allow concrete to be placed in a practical and economical manner. As has been noted in discussing the factors affecting permanence, only enough water should be used to make the mass plastic, this being sufficient, usually, to effect a reasonably complete hydration of the cement, and to provide water which the dry aggregates will absorb to the point of their saturation.

To a small degree, water in concrete acts as a lubricant for the particles of aggregates, and makes it possible thoroughly to work into place both large and small particles, producing a more compact mass. Mention has also been made of the detriment that an excess amount of water causes, and its influence upon strength is due to the excessive porosity of the concrete, which follows the evaporation and drying out of the excess water, which has occupied spaces that otherwise would have held cement mortar, and because this water tends to wash away from the surfaces of the aggregate a portion of this mortar, which otherwise would act to bind the mass into a true, artificial stone. Further, excess water may easily cause a separation of the heavier and lighter portions of the aggregate by permitting large fragments to sink rapidly to the bottom of the layer, giving the appearance of a deposit of stratified rock, in which the boundary between successive layers of the concrete may be easily distinguished because the larger aggregates lack sufficient cement mortar to bind them properly and are frequently porous to a great degree.

It is believed, also, that the crazing and cracking of surfaces, and the ease with which corners of concrete may sometimes be knocked off, is traceable to excess water, which carries with it the lighter particles of the cement and any dirt that may have been introduced with sand or the larger aggregates. This, the pulpy material, often rises in the form of a scum, varying in thickness from just enough to be noticed to a matter of inches. This foam-like material often marks the completion of a day's work. It has no binding qualities, and therefore in good construction is carefully removed before the next layer of concrete is added. Unless this is done, there is sure to be a line, of varying width, that will be easily penetrated by moisture, and in time enough water may creep in to produce a slimy mass from this laitance, which is therefore a constant source of danger and a probable cause of ultimate failure. Some experts contend that this efflorescent substance has its origin in the soluble sulphides and chlorides that may be present in some cements.

In the design of concrete it is customary to use a bag of cement as the unit. This weighs approximately ninety-four pounds, and is also so near a cubic foot that it is so considered in most calculations. In a series of tests on the proper proportion of water, results were obtained which are given here to emphasize the importance of having just the right amount of moisture in the mixture.

The best way of determining the influence of excess water is to make up a series of test pieces, which can be subjected to stresses at the same period in the life of each test specimen. The resistance to compression is a test chosen in this instance, and when using 0.6 pints of water per cubic foot of dry materials, this resistance equaled, in one series of tests, 4090 pounds per square inch when the specimen was one month old and 4970 pounds at the end of sixty days. This was stiff, pasty concrete, probably too stiff to be worked economically in large masses. A test at one month with a freely flowing mixture, which would be easy to place in large masses, gave averages of 3380 and 4012 pounds, with these values increased to 4920 and 5160 at two months. In this case 5.3 pounds of water had been used. When this amount of water was increased to 6.5 pounds per cubic foot, the resulting consistency was at once recognized as that so often used on highways and in reinforced concrete construction. At the end of one month, averages on this class of concrete gave 2920 and 3280 pounds per square inch; these averages rising to 3820 and 3990 pounds per square inch at two months.

The tests were not carried beyond the use of 7.8 pounds of water per cubic foot of dry material, for this gave a watery mixture that should never be used, and produced strengths of but 2730 at one month and 3050 per square inch at two months. As a result of this work, the committee directing investigations concluded that in road-making not more than six pounds of water should be used per cubic foot of dry material, including the cement as well as the aggregate. Due allowance must be made for wet aggregate, such as stone exposed to the rain, and also for the excessive dryness of materials used in hot weather.

Work of this nature has given rise to three terms often found in engineering specifications: "quaky" is used to describe a mass that will not flow readily, that is rather stiff, and upon which water can be brought to the surface if it is tamped slightly; a "mushy" mixture is one that can be readily worked into place by spading, but it is not watery; a mixture that flows into place and requires no manipulation in the forms is a "fluid" mixture. It seems certain that the most desirable consistencies for concrete, where satisfactory strength and durability are expected, are those that are quaky or mushy.

From all this, it is evident that proper mixing is another essential, and much research has been expended upon mixing-drums to provide designs that will insure complete and thorough mixing during the minute which is the length of time usually required. Such mixing-drums cause the material to shower from the top of the drum through the material which is being lifted by interior plates and discharged by pick-up buckets to different points of the drum. One of the mixers claims no fewer than five mixing actions, which follow one another in rapid succession until the contents are finally discharged.

Since the cement in concrete is there as a binder, much attention has been given to the aggregates, for they must bear the brunt of the wear. Coarse and fine aggregates have been defined. It is important that, in choosing fine aggregates, organic impurities be excluded, and before any sand can be used it must be determined to what extent organic materials are present.

The important characteristics of sand for use in concrete are durability, cleanness, and grading. Obviously, particles that are soft cannot satisfactorily withstand wear; and, unless satisfactory grading is carried on, the proportions required by our definition of a satisfactory mixture cannot be secured.

Experience in concrete construction has shown that it is not safe to judge the cleanness of a sand by its superficial appearance. It has been found, for example, that, if durability and grading are satisfactory, a sand that may appear dirty will give good results, providing only that this dirt is not composed of organic material. Then, too, sand that appears clean may in fact have its granules filmed over with enough organic material to prevent satisfactory bonding.

The commonest tests that have been used in judging a sand have been the determination of silt and the loss of weight upon igniting the sand, in which test the sand is heated to redness to destroy organic materials. The silt test gives no information concerning organic impurities, and has to do only with loam; while loss on ignition is not a satisfactory method. Organic impurities not only prevent suitable bonding, but they actually prevent the setting and hardening of cement. When present in large quantities, or even in very small quantities, they produce a decidedly injurious effect by retarding hardening. Clay, on the other hand, will simply cause a reduction in strength.

Fortunately, researches have developed a simple colorimetric test which anyone can apply for the purpose of determining the presence of humus or similar organic matter in sands. This research has been conducted conjointly by the American Society for Testing Materials, the Structural Materials Research Laboratory, and the Portland Cement Association. These tests are of two characters—one that is useful in field work; and another, giving more accurate results, to be employed in the laboratory. These two methods really differ only in the accuracy with which the colors obtained are measured, the laboratory affording methods for comparing the results with definite color standards.

The sand under consideration is shaken thoroughly in a dilute solution of sodium hydroxide, which is easily obtainable at any drug-store. The solution is 3 per cent. sodium hydroxide, and is conveniently made by dissolving one ounce of sodium hydroxide in enough water to make 32 ounces of solution. The mixture is allowed to stand a few hours and the color is noted. A convenient apparatus is to be found in 12-ounce graduated prescription bottles, and the recommended procedure is to fill such a bottle to the 4½-ounce mark with the sand to be tested. The 3 per cent. solution of sodium hydroxide is then added until the volume of the sand and solution, after thorough shaking, makes 7 ounces. After again shaking very thoroughly, the stoppered bottle is allowed to stand for twenty-four hours, and, while a good idea of the result can be gained sooner, it is recommended that, when possible, this interval of time be allowed to elapse for the most reliable results.

The results are interpreted on a basis of experience. It has been found that if the solution remains colorless, or if only a slight yellow color develops, the amount of organic impurities present is small enough to cause no concern. On the other hand, if a dark-colored solution is developed, the sand should not be used in highways or pavement, or in building construction. Those sands producing the deeper shades of yellow colored fluids are useful only for lighter work; and if approaching a brown shade it may be concluded that such sand is not only unsuited for any type of concrete, but that a small quantity of such material might render a considerably larger volume of sand unsuitable for any application in concrete construction.

This test has been found so satisfactory that it is sometimes introduced in the specifications. To make such dirty sands useful, they are sometimes washed. When properly done this should reduce the percentage of organic impurities to a point where the sand can be employed; but a second test should invariably be made with the washed sand. That washed sand is frequently suitable, and is often available in quantity where other materials are hard to obtain, has led to the design of special plants for washing and grading sand.

In the case of a dam, gravel from an adjacent pit was conveyed by special cars and a belt conveyor to the top of a series of screens combined with devices for washing the material, and thence to bins where it was stored prior to conveyance to the mixer. This washing plant was favorably located, both with reference to the source of raw materials and also to the mixer, and could use quantities of water from the river across which the dam was being thrown. Satisfactory coarse and fine aggregates resulted from this contrivance. The sand delivered was less than ¼ inch in size, the fine gravel from ¼ inch to 1½ inches, and the coarse aggregate from 1½ to 3 inches.

While organic impurities directly affect the strength of concrete, silt that may be contained in sand or mixed with aggregates produces no effect upon this characteristic. It does, however, have a tendency to rise to the surface when the concrete is compacted in place, forming a sort of film on the top, which is objectionable and which must be removed when placing concrete in layers.

Although silt can be determined with accuracy only in the laboratory, it can at least be detected in the field. A volumetric test is usually made whereby, with washing methods, the amount of silt by volume in a given sand or small aggregate can be roughly determined.

In judging the suitability of sands, the coarse clean Ottawa, Illinois, sand has been taken as the standard, and most of the work in testing goes back to the Ottawa sand. Thus a fine aggregate should be of such quality that mortar made by mixing one part of Portland cement with three parts of the fine aggregate by weight when made into briquets, described in the chapter on testing, or into cylinders, should show a tensile or a compressive strength at seven and at twenty-eight days, equal at least to the strength of similar briquets or cylinders made from one part of the same cement and three parts of standard Ottawa sand by weight. Care must be taken in such tests to have the consistency of the test mix and the standard mix the same.

The coarser aggregates, which, like the finer ones, are often specified by the size of opening in a sieve which they must pass and the size of mesh identical in form upon which they are retained, should consist of clean, durable broken rock or pebbles, graded in size and free from dirt and organic matter. In ordinary concrete it is customary to use fragments graded from 1½ inches down, with not more than 5 per cent. passing a screen having four meshes to the linear inch. For reinforced concrete the grading may be from 1 inch down. However, in large masses of concrete larger stones are often embedded, providing they do not come nearer than 6 inches to the outer surface of the mass and are not placed nearer than 6 inches between their surfaces. It is customary to limit the amount of such stone that can be embedded, 30 per cent. being a usual allowance. In the use of this rubble stone a phrase has become established in the industry, the maximum usable stone often being described as "a one-man stone," indicating that stones too great for one man to manage are considered too large for this purpose.

In the early development of concrete there was a belief that only certain types of aggregates could be used with safety, and on many a piece of construction a contractor has been compelled to bring from a distance aggregates that would meet the specifications. It has been found that the older specifications can be considerably modified. One investigator, in determining the resistance to blows, learned that such resistance depends directly upon the elasticity and toughness of the aggregate primarily, and on the hardening period of the concrete in the second place, rather than upon the cement. It is assumed, of course, that in any case sufficient cement would be used to form a good binder. This experimental work was done upon small cubes arranged under a miniature pile-driver. Wearing qualities are the first consideration in selecting an aggregate, and the next step is to devise a method for combining material of different sizes to produce concrete mixtures that will develop predetermined strength. In cases to which reference has been made, where contractors have brought their aggregates from afar, this has frequently been necessary merely to suit the grading stipulated for the coarse aggregate, and not because local material did not have proper wearing qualities.

It was to determine a rational method for combining aggregates differing widely in size and grading so as to produce concrete equaling in strength that made of aggregates heretofore approved, that the sieve analysis method was devised.

The experimental work has given rise to the term "fineness modulus of the aggregate." This furnishes a method for measuring the size of the aggregate and grading it, and for determining what mixture can be made with it to produce concrete of satisfactory strength. The sum of the percentages in the sieve analysis of the aggregate, divided by 100, gives the fineness modulus. In determining this value, standard sieves of square-mesh wire cloth are used, the sieves being chosen so that the square opening of each succeeding sieve is exactly double that of its predecessor. Beginning with the finest, these sieves have 100, 48, 28, 14, 8, 4 meshes per linear inch, and then meshes ⅜, ¾, and 1½ inch.

Many different series of tests have shown that for a given plastic condition of concrete there is an intimate relation between the fineness modulus of the aggregate and strength and other properties of the concrete. This is due, really, to the fact that the fineness modulus indicates what changes are necessary in the amount of water to be used in proportion to the dry material, to give a plastic condition to the mixture. Professor Duff A. Abrams, in discussing the steps in the design of concrete mixtures, points out that when the compressive strength of the concrete has been decided upon, reference may be made to a curve, plotted as a result of his researches, indicating the relation between strength of concrete and water content, and the maximum water ratio which may be used determined by such reference. From this point on the problem is simply that of securing a workable concrete, using this water ratio and a minimum quantity of cement. To accomplish this the aggregate must be graded as coarse as permissible. Experience or trial is the only guide in determining the relative consistency of concrete necessary for the work at the moment, and the driest workable consistency should be used. It follows that the size of aggregate available—or which must be used—and the other factors will furnish a guide as to the mixture which can be employed. It is customary to express this mixture as one volume of cement to a given number of volumes of fine aggregate and of coarse aggregate.

The next step is to make a sieve analysis of the fine and coarse aggregates, using such sieves as have been described and expressing the results in terms of percentages of material by weight, coarser than each of the standard sieves. The values so found are added and divided by one hundred, giving the fineness modulus of the fine and of the coarse aggregates.

Now, if more than 20 per cent. of the aggregate is coarser than a given sieve, the maximum size shall be taken as the next larger sieve in the standard set; if between 11 and 20 per cent. is coarser than a given sieve, the maximum size is arbitrarily taken as the

Abrams' Table of Proportions and Quantities for One Cubic Yard of Concrete

Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12-inch cylinders, 3,000 pounds per square inch.

SIZES		FINE AGGREGATES, SCREEN OPENINGS PER INCH														
COARSE AGGREGATES Inches	Cement in Barrels Aggregates in Cubic Yards	0-28			0-14			0-8			0-4			0-⅜ In.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
No. 4 Screen to ¾	Proportions	1	1.3	2.4	1	1.6	2.4	1	1.8	2.3	1	2.0	2.3	1	2.7	1.5
	Quantities	1.96	.37	.69	1.85	.44	.66	1.82	.48	.62	1.75	.52	.59	1.79	.72	.40
No. 4 Screen to 1	Proportions	1	1.3	2.7	1	1.6	2.6	1	1.8	2.6	1	2.0	2.5	1	2.6	1.8
	Quantities	1.90	.36	.76	1.77	.42	.68	1.72	.46	.66	1.67	.50	.62	1.72	.66	.46
No. 4 Screen to 1½	Proportions	1	1.2	3.1	1	1.6	3.2	1	1.7	3.1	1	2	3	1	2.4	2.4
	Quantities	1.82	.32	.84	1.68	.40	.79	1.63	.41	.75	1.61	.47	.72	1.62	.57	.57
No. 4 Screen to 2	Proportions	1	1.2	3.5	1	1.5	3.5	1	1.6	3.7	1	1.9	3.6	1	2.2	3.1
	Quantities	1.75	.31	.90	1.63	.36	.85	1.55	.36	.85	1.52	.43	.81	1.53	.50	.70
No. 4 Screen to 2½	Proportions	1	1.1	3.8	1	1.4	3.9	1	1.6	4.0	1	1.8	4.0	1	2.1	3.5
	Quantities	1.72	.28	.97	1.58	.33	.91	1.51	.35	.89	1.49	.40	.88	1.50	.46	.78
No. 4 Screen to 3	Proportions	1	1.1	3.9	1	1.4	4.1	1	1.5	4.1	1	1.7	4.1	1	2.0	3.7
	Quantities	1.69	.28	.97	1.58	.33	.97	1.49	.33	.90	1.49	.37	.90	1.49	.44	.81
⅜ to ¾	Proportions	1	1.3	2.3	1	1.7	2.3	1	1.9	2.3	1	2.2	2.2	1	2.8	1.4
	Quantities	1.96	.37	.67	1.85	.46	.63	1.82	.51	.62	1.75	.57	.57	1.79	.75	.37
⅜ to 1	Proportions	1	1.3	2.6	1	1.7	2.6	1	1.9	2.5	1	2.2	2.4	1	2.7	1.7
	Quantities	1.90	.36	.74	1.77	.44	.68	1.72	.48	.64	1.67	.54	.59	1.72	.68	.43
⅜ to 1½	Proportions	1	1.3	3.0	1	1.7	3.0	1	1.9	3.0	1	2.1	2.9	1	2.6	2.2
	Quantities	1.82	.35	.80	1.68	.43	.75	1.63	.46	.73	1.61	.50	.68	1.62	.63	.53
⅜ to 2	Proportions	1	1.3	3.3	1	1.7	3.4	1	1.8	3.5	1	2.0	3.4	1	2.4	2.9
	Quantities	1.75	.34	.86	1.63	.41	.83	1.55	.42	.80	1.52	.45	.77	1.53	.62	.66
⅜ to 2½	Proportions	1	1.3	3.7	1	1.6	3.7	1	1.7	3.9	1	2.0	3.8	1	2.3	3.3
	Quantities	1.72	.33	.95	1.58	.37	.87	1.51	.37	.87	1.49	44	.84	1.50	.51	.74
⅜ to 3	Proportions	1	1.2	3.8	1	1.6	3.9	1	1.7	4.0	1	1.9	4.0	1	2.2	3.5
	Quantities	1.68	.30	.95	1.58	.37	.91	1.49	.37	.88	1.49	.42	.88	1.49	.48	.77
½ to ¾	Proportions	1	1.5	2.3	1	1.9	2.2	1	2.1	2.2	1	2.3	2.1	1	2.8	1.3
	Quantities	1.96	.44	.67	1.85	.52	.61	1.82	.56	.59	1.75	.59	.54	1.79	.75	.34
½ to 1	Proportions	1	1.5	2.5	1	1.9	2.5	1	2.1	2.4	1	2.3	2.4	1	2.8	1.6
	Quantities	1.90	.42	.70	1.77	.50	.66	1.72	.53	.61	1.67	.57	.59	1.72	.72	.41

Abrams' Table of Proportions and Quantities for One Cubic Yard of Concrete

Based upon laboratory investigations, using approved materials, compressive strength, 28 days, with workable plasticity, 6 by 12-inch cylinders, 3,000 pounds per square inch.

SIZES		FINE AGGREGATES, SCREEN OPENINGS PER INCH														
COARSE AGGREGATES Inches	Cement, in Barrels; Aggregates in Cubic Yards	0-28			0-14			0-8			0-4			0-3/8 in.		
		Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse	Cement	Fine	Coarse
1/2 to 1 1/2	Proportions	1	1.4	2.8	1	1.9	2.9	1	2.1	2.9	1	2.2	2.8	1	2.7	2.1
	Quantities	1.82	.37	.75	1.68	.47	.73	1.63	.51	.69	1.61	.52	.66	1.62	.65	.51
1/2 to 2	Proportions	1	1.4	3.3	1	1.9	3.3	1	2.0	3.4	1	2.2	3.3	1	2.7	2.7
	Quantities	1.75	.36	.86	1.63	.46	.79	1.55	.46	.78	1.52	.50	.74	1.53	.62	.62
1/2 to 2 1/2	Proportions	1	1.4	3.6	1	1.8	3.6	1	1.9	3.7	1	2.1	3.7	1	2.6	3.1
	Quantities	1.72	.35	.91	1.58	.43	.85	1.51	.42	.83	1.49	.46	.81	1.50	.57	.69
1/2 to 3	Proportions	1	1.3	3.7	1	1.8	3.8	1	1.8	3.9	1	2.1	4.0	1	2.4	3.3
	Quantities	1.68	.33	.92	1.58	.42	.89	1.49	.40	.86	1.49	.46	.88	1.49	.53	.63
3/4 to 1	Proportions	1	1.7	2.4	1	2.1	2.4	1	2.4	2.1	1	2.6	2.2	1	3.1	1.5
	Quantities	1.90	.48	.68	1.77	.55	.63	1.72	.61	.53	1.67	.64	.55	1.72	.79	.39
3/4 to 1 1/2	Proportions	1	1.7	2.7	1	2.0	2.8	1	2.3	2.7	1	2.5	2.7	1	3.0	2.0
	Quantities	1.82	.46	.73	1.79	.50	.70	1.63	.55	.65	1.61	.59	.64	1.62	.73	.48
3/4 to 2	Proportions	1	1.7	3.1	1	2.0	3.1	1	2.3	3.1	1	2.5	3.0	1	3.0	2.4
	Quantities	1.75	.44	.80	1.63	.48	.75	1.55	.53	.72	1.52	.56	.67	1.53	.68	.55
3/4 to 2 1/2	Proportions	1	1.7	3.3	1	2.0	3.5	1	2.3	3.4	1	2.4	3.4	1	2.9	2.8
	Quantities	1.72	.43	.84	1.63	.47	.83	1.51	.52	.76	1.49	.53	.75	1.50	.64	.62
3/4 to 3	Proportions	1	1.7	3.5	1	2.0	3.7	1	2.3	3.7	1	2.4	3.6	1	2.8	3.1
	Quantities	1.68	.43	.88	1.58	.47	.87	1.49	.51	.81	1.49	.53	.79	1.49	.62	.68
1 to 1 1/2	Proportions	1	1.7	2.8	1	2.0	2.9	1	2.3	2.7	1	2.6	2.6	1	3.1	2.0
	Quantities	1.82	.46	.75	1.68	.50	.73	1.63	.55	.65	1.61	.62	.62	1.62	.75	.48
1 to 2	Proportions	1	1.5	3.2	1	1.9	3.5	1	2.2	3.3	1	2.4	3.3	1	3.0	2.6
	Quantities	1.75	.39	.83	1.63	.46	.85	1.58	.51	.76	1.52	.54	.74	1.53	.68	.59
1 to 2 1/2	Proportions	1	1.4	3.4	1	1.9	3.8	1	2.0	3.7	1	2.3	3.7	1	2.7	3.1
	Quantities	1.72	.35	.86	1.58	.45	.89	1.51	.44	.83	1.49	.51	.81	1.50	.59	.69
1 to 3	Proportions	1	1.3	3.6	1	1.8	4.0	1	2.0	3.9	1	2.2	3.9	1	2.7	3.3
	Quantities	1.67	.33	.90	1.58	.42	.94	1.49	.44	.86	1.49	.48	.86	1.49	.59	.73

next larger half-sieve; if less than 10 per cent. is coarser than certain sieves, the smallest of these sieve sizes is considered the maximum size.

The next step is to determine from the table the maximum value of fineness modulus which may be used for the mix, kind, and size of aggregate and the work under consideration. The percentages of fine and coarse aggregates required to produce the fineness modulus desired for the final aggregate are computed by applying this formula: When p is the percentage of fine aggregate in the total mixture, A the fineness modulus of coarse aggregate, B the fineness modulus of final aggregate mixture, and C the fineness modulus of fine aggregate, then $p = 100 \frac{A\text{-}B}{A\text{-}C}$.

It will be seen then that, based upon such analyses and the use of diagrams and curves which have been plotted as the result of experimental work for the use of those responsible for the design of concrete mixtures, it is easily possible to choose proper proportions of available aggregates by sieving to make the concrete of desired strength, as has been indicated above. This necessitates choosing the strength that the contemplated structure must have, the water ratio that can be trusted to give that strength, and the proportion and grades of available aggregates that, with the Portland cement to be used, will produce a plastic mixture capable of giving the required service.

It is often considered desirable to subject aggregates to wearing tests; but changes are being made in the maximum resistance that must be shown by such material before it is used. This is known as French coefficient of wear, an arbitrary scale long familiar to those concerned in highway construction.

Assuming that a properly designed concrete mixture has been prepared, the next problem is that of so placing it as to produce the best results. Forms play an important part in this procedure, and the function of reinforcement is discussed elsewhere. Much depends upon so placing the forms that there will be no yielding; as the pressure exerted by the fresh concrete increases, forms must also be tight enough to prevent the leakage of mortar, and designed so that they can be easily removed when setting has progressed far enough. This is frequently accomplished by bevels. It is desirable to have the exposed surface of the forms made of sound lumber of uniform thickness, with edges tongued and grooved or beveled to make tight joints, and in the case of beams, arches, and the like, care must be taken to permit the completion of the work without any sagging or deformation of the member. Floor supports, arches, and the like should remain in place for a considerable time, affording not only maintenance but also protection during the balance of construction.

The workman is often forgetful of the fact that the form for concrete is a mold that will impart to the finished material the same character of surface as is given the mold. It is sometimes possible to trowel over or otherwise treat the green concrete surface or other formed material; but in many cases the character of the lumber used is all too visible. It must be remembered that concrete cannot be easily twisted about to straighten out the kinks or to erase unsightly or irregular lines, and care put into the forms is usually a good investment.

Wooden forms are treated to prevent concrete from adhering to them, a satisfactory preparation for this purpose being boiled linseed oil or a coat of ordinary whitewash. Crude oil will discolor concrete and therefore is objectionable.

On large construction projects it is customary to elevate concrete to towers from which chutes and gutters radiate to carry the material to different parts of the structure. In some instances this method is disadvantageous. The placing of large amounts of concrete at one time may interfere with properly working the material into all parts of the form by the process called spading; when smaller quantities are deposited at one time it facilitates spading and insures a proper distribution of the concrete in the mixture. Then, too, where such chutes are employed there is liable to be an excess of water. This not only produces a more fluid mixture, which readily flows on gradual grades, but serves as a lubricant as well, wetting the iron surface of the chute. If a grade is sufficiently steep to permit the ready flow of a satisfactory mixture, it will be found that it is rarely less than thirty feet in one hundred, which necessitates a height of tower expensive to erect.

That compacting and thorough working of the concrete into all recesses of the forms is important is indicated by the effect of vibration and jigging upon the strength of concrete. Here again we must resort to laboratory tests to give us the foundation for our conclusion, and in this case cylinders six by twelve inches were employed. While these cylinders were still in steel forms, violent vibration was produced by holding an electric motor against the side of the form, and to increase the vibration the motor was equipped with an eccentric fly-wheel weighing about twelve pounds, running a thousand revolutions a minute. Jigging was accomplished by the use of a table raised and dropped by cams, the drop being about one tenth of an inch, and usually one hundred drops a minute were secured.

With these tests tamping or hand puddling was carried on for comparison. The results clearly indicated that jigging, tamping, and vibration are of value for getting concrete into place, particularly in complex forms and about reinforced bars; but that, after the concrete is in place, severe vibration or such continual agitation as tamping produces does no good and may prove harmful. Obviously, dryer concrete could be worked into place with the help of vibration to better advantage than otherwise, and therefore would show better strength, which, it must be remembered, is primarily due to the fact that less water has been used in the mixture. Therefore, if some feasible method could be devised for the use of vibration on a commercial scale, it might lead to the use of somewhat dryer concrete and, at the same time, aggregates of a somewhat coarser grading, here again making possible the use of smaller quantities of water.

These tests further showed that, whatever the method used to compact concrete, including the use of the roller in finishing roadways, excess water brought to the surface must be removed.

In depositing concrete, it should be placed in its final position as soon after mixing as is possible, and it is good practice to roughen and clean the surface of one layer before a second is put in place. After cleaning and wetting, it is customary to go over such a surface with a cement mortar made of one sack of Portland cement mixed with two and a half cubic feet of fine aggregate. The finishing of concrete surfaces, after the forms have been removed, has become an art and is discussed in Chapter XI. Usually a float, or trowel, is employed to give a surface a color as nearly uniform as possible; but there are a variety of ways for treating the surface to produce effects that approach the artistic.

By reference to the discussion on the chemistry involved in the hardening of cement, it will be seen that the curing process is one to be considered carefully, and steps should be taken to provide sufficient moisture for ten days, at least, after the forms have been removed. In this way hydration can proceed and assist in the development of desired strength.

The possibility of using an almost limitless variety of aggregates with Portland cement as a binder makes it clear that no structural material offers quite so many advantages as does concrete. It can be made to take forms nearly as delicate as can be fashioned in wood. These can be obtained at a cost far less than in any other medium equaling or approaching the permanence of concrete, and with the skilful manipulation of concretes, together with the treatment of surfaces, a variety of results can be produced which are not to be found in any other material. Evidences of this confront us on every hand, and special attention is called to certain achievements recited in other chapters.

It has been indicated elsewhere that maximum strength in cement and concrete structures is realized only after a considerable period of time, during which the hydration of the cement takes place slowly, necessitating a minimum curing period of ten days in most cases. It has also been pointed out that certain types of concrete reach their maximum strength in not less than a year's time; and yet, it is frequently necessary to have concrete that will harden very much more quickly, and this can be accomplished only with cements designed on somewhat different lines from standard Portland cement.

For example, in military operations it is frequently desirable to have as great a portion of the strength that a concrete is able to develop to be reached within twenty-four hours. This would be the case in laying foundations for heavy guns and in preparing a newly acquired position for defense against early attack. The problem of cements that will produce quickly hardening concrete has been attacked by the Bureau of Standards, and in an experimental kiln of semi-commercial size a number of cements have been prepared that do develop very high early strength. To make such cements commercial it has been necessary to consider ordinary methods of manufacture in their preparation, leaving variations to fall upon the compositions of materials and certain details in the operation of apparatus to be found in all cement plants.

The composition of the materials making up the raw mixtures embraced limestones and calcined alumina, while in other causes the alumina was replaced partly by kaolin, the high-grade clay used in pottery, or bauxite—a clay that is high in compounds of alumina and affords us our raw material for the preparation of the important metal aluminum.

In studying the possibilities, Sorel cement, which has been described elsewhere, was of course considered, for it had been unofficially reported that concrete made with such a cement had been used in military operations. Work with the magnesium oxide and magnesium chloride, which was first used in 1853 by Sorel, at least indicated that impurities are permissible to a degree, but that the resulting cement becomes of better and better quality as the ingredients used become more pure.

Working with compositions similar to those used in flooring—such as 50 per cent. magnesia, 12 per cent. asbestos, 10 per cent. sawdust, 22 per cent. ground sand, and 6 per cent. iron oxide, all by weight, mixed with 52 per cent. of a solution of magnesium chloride having a gravity of 1.885—tension and composition tests were made. These were applied at twenty-four hours, seven days, twenty-eight days, and ninety-eight days. Results obtained indicated strengths that showed the possibility of producing strong concretes with such a cement; but in the design of such a mixture due allowance had to be made for the difference in the volume occupied by the same weight of Portland cement and Sorel cement. Magnesia weighs but 51 pounds to the cubic foot, whereas Portland cement averages about 94 pounds. Using gravel and coarse sand as aggregates, the specimen showed that the Sorel cement concretes have a strength at forty-eight hours greater than that obtained by Portland cement in seven days; but there is little increase in the strength of the Sorel cement concrete after the forty-eight-hour period.

One advantage in the use of Sorel cement is that concrete made with it cannot be frozen, for the freezing-point of the magnesium chloride solution used in its production is so low that no care need be taken to prevent damage caused by low temperatures. To be sure, low temperature will retard its setting.

By referring to the chapter on the principles underlying the hardening of cement, it will be noted that tricalcium aluminate has the ability to set quickly, and in the experiments under discussion it was decided to try calcium aluminate cements. When aluminates react with water, hydrated alumina must be formed, as it is this colloid that furnishes the greater part of the cementitious material in such compounds. It is further desirable to have as large a quantity of alumina present as possible.

The compound that has four molecules of calcium oxide combined with five of alumina oxide will, of course, give the most, while that of five molecules of calcium oxide with three of aluminum oxide will give the minimum. With the higher alumina content the reaction with water is slower, and consequently the time of setting will be slower. This is especially true where a considerable quantity of silicate, which reduces the amount of alumina, is present, and such silicate also retards the setting time. It will be recalled that some compounds of the oxides of calcium alumina and silica react so slowly with water that no cementing material is formed. A comparison of eight of these experimental cements shows that a standard sand mortar made from calcium aluminate cement developed a compressive strength of 8,610 pounds to the square inch at seven days. This was the greatest strength produced, and the composition of this material was as follows:

Silicon oxide	0.68 per cent.
Aluminum oxide	74.11 per cent.
Iron oxide	0.40 per cent.
Calcium oxide	23.82 per cent.
Magnesium oxide	0.81 per cent.

Of course, the high early strengths shown by such cements are due entirely to the more rapid and thorough hydration of the cement.

The greater the amount of the alumina present as an aluminate of lime, the greater will be the early strength, and, under certain conditions of curing, a marked increase may be obtained in strength with aging, which does not extend over a long period. An excess of water during the curing stage is to be avoided; but moisture, usually present in the air, is not sufficient to be detrimental.

CHAPTER VIII

REINFORCEMENT

In discussing the development of the cement-gun, the point is made that improvements in engineering do not always originate with engineers. The use of reinforcement in concrete arose from the work of a French gardener who introduced metal parts in the manufacture of flower-pots. The early reinforced concrete was called armored concrete, and, from the introduction of the first system by Monier in 1867, down to the present time, there has been a wide variety of systems developed with the idea of securing greater elasticity and resistance to shock in concrete structures.

While 1867 has been given as the date of the first system for reinforcing, it must not be supposed that those ancient engineers who understood the use of cement overlooked the introduction of rods and wire to strengthen their own structures. Numerous evidences of reinforcing have been found in the work, and the Romans particularly were in the habit of using bronze rods, crossed and otherwise placed, to take the stress due to tension.

The use of reinforced concrete began by following various types of frame construction in using concrete, and endeavoring to support the concrete members in such a way that they would safely carry imposed loads.

Some of the early work consisted in constructing an arched floor between T-shaped iron joists. This was introduced by Dennett at Nottingham in 1857. These arches were of short span, and little if any reinforcement was used in the various members. The year 1867 saw the patenting of Scott's method of reinforcement, and a span of one hundred and thirty-two feet was used in a bridge in the Paris aqueduct.

Fortunately, the coefficients of expansion of concrete and iron and steel are practically the same, and the two classes of materials can be used together with decidedly beneficial results to each. It has been pointed out, in the discussion of mortar applied by the cement-gun or other mechanical means, that a thin layer of cement mortar over a metallic surface constitutes one of the best means of protecting the metal against corrosion and fire. It has also been indicated that the compressive strength of concrete is many times its ability to resist stresses due to tension. Iron and steel resist these stresses unusually well, and by suitably placing the right amount of metal reinforcement in the concrete member it is enabled to resist shock and has instituted in it the desired characteristic—elasticity.

Whatever the placement of the reinforcing members, one of the prime considerations is that of a suitable bond between the metal and the cement. This bond is due to friction, to molecular adhesion, and to the grip that the concrete has upon the metal due to shrinkage, which takes place during the hardening of the mass. It is not believed that simple twists in the rods and bars, or special corrugations, tend to improve the bond.

and of course paints and similar materials used to protect metal surfaces cannot be used on the reinforcing metal for fear that a proper bond cannot be secured. Where the metal should be given extra protection, as in concrete ships, zinc or galvanizing has been employed, this being an effective method for protecting iron and steel against oxidation, while at the same time affording a bonding surface for the cement. As has been said, reinforced concrete design has followed timber construction of the mill type, using columns and various methods for supporting piers from these columns. There has been a continual effort to reduce the number of members and to simplify the construction. This not only contributes toward lessening the cost incident to placing and supporting intricate forms, but strives to eliminate any obstructions that would interfere with proper lighting, especially in lofts.

A type of construction popularly known as mushroom construction derives its name from the arrangement of the reinforcing rods and the rapidity with which a building can be erected by this method. The structure is practically monolithic. Under this method the floor slabs in reality form a continuous concrete structure with the top of the column, from which the reinforcing rods flare out radially to support the floor. Some unusual records for speedy construction have been made, particularly on buildings of unusual size. The spans in mushroom construction are from fourteen to thirty feet, and the ceilings are flat, obstructing the light little if at all.

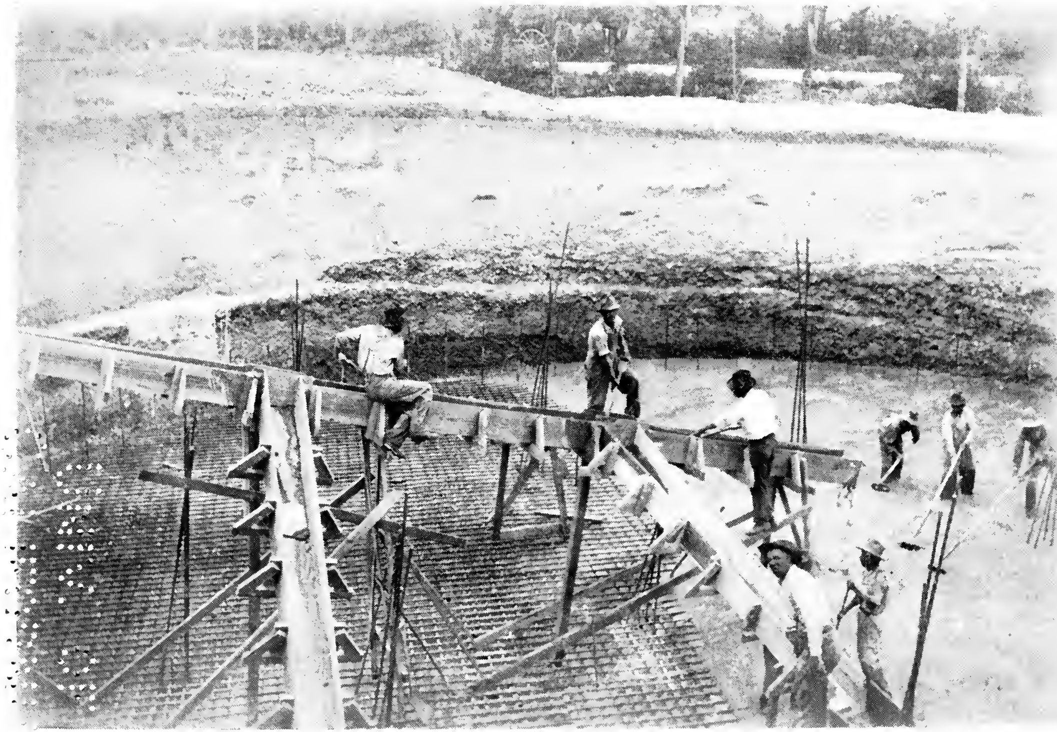
The position and arrangement of the reinforcement is all-important, and several failures of reinforced concrete structures have been due to errors in this respect. Hence the strict specifications with regard to lapping reinforcement, and to the weight of metal per one hundred square feet in special material such as reinforcing wire mesh, and the precaution constantly sounded of securely tying in place all reinforcing members, especially where they cross. Corrugations in bars assist materially in wiring them in place.

Welding may often be advantageously employed, and in ship construction electric welding has been found most advantageous.

The desirability of knowing just how the reinforcement is distributed after the concrete has been poured, has led to the development of special tests, some of which involve the use of the X-ray, with which concrete joints may be examined and any displacement of the reinforcement located. There have been numerous designs, which depend upon some peculiar shape of the reinforcing bar to distribute the load evenly and secure the necessary strength at given points. Many of these peculiar bars have failed to substantiate in practice the claims made for them.

Reinforcement may be used wherever concrete is employed, and often concrete cannot be installed unless reinforcement is included. The design of the structure comes down, on the whole, to the special requirements in accordance with which the amount of reinforcement, its shape and placement, must be decided.

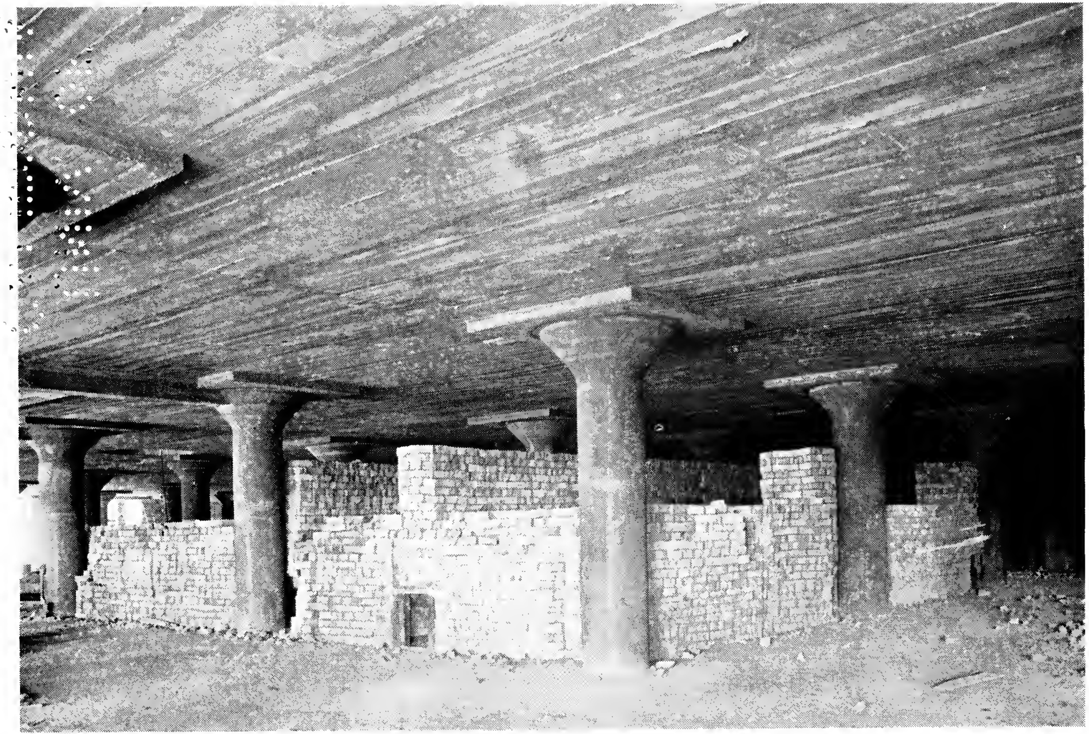
Some of the fundamentals of reinforced concrete design may be recalled here. We may repeat that all materials employed are so disposed, with regard to posi-



Courtesy of G. W. Smith, San Antonio Public Utilities

POURING THE BOTTOM OF A 400,000 GALLON TANK AT SAN ANTONIO, TEXAS

Note reinforcement



A CONCRETE BUILDING DESIGNED FOR HEAVY LOADS

Floor shown under a test load of 650 lbs. per square foot tion and amounts, that each resists stresses that it is best fitted to resist, and the column performs, therefore, as a homogeneous unit. In columns, posts, etc., the compression or ability to sustain loads is borne principally by the concrete, although some assistance is rendered by the steel; but when tension takes place and any bending occurs, this must be borne by the vertical steel. In reinforced beams three forces are at work—namely, compression, tension, and shear.

In square columns the reinforcing bars are set in the concrete at such a distance from the surface as to protect the steel in case of fire. The concrete outside the steel assists in carrying the load, but it cannot be depended upon after a severe fire, and consequently is neglected in calculating the load that it can safely bear. In a column eight by eight inches, four bars, each half an inch square, may be used, placed so that they form corners of an area five by five inches; and in calculations this area of twenty-five square inches will be reckoned as the size of the column.

The maximum per cent. of steel permitted in columns of this type is four, and some building ordinances limit it to three per cent. When a load is applied to the top of the column and the steel bars bear their share, they may bend, because in a fifteen-foot column the slenderness ratio is large. Suitable ties, therefore, are placed around upright bars, and spaced at intervals not exceeding twelve times the thickness of the vertical bars. This means that, in such a column as we have described as an illustration, the ties will be six inches apart, and these ties are held in place by iron, the ends of which are turned in far enough to be gripped by the concrete so that they cannot be pulled out.

The point was made in an earlier paragraph that the reinforced column must act as a homogeneous unit. This means that steel capable of carrying greater loads than the concrete must not be used, or the concrete will be stripped from the reinforcement and the column will fail. The amount of steel used must not give a stress exceeding concrete stresses multiplied by the ratio of deformation. Each square inch of steel is equal to fifteen square inches of concrete, as has been shown by careful measurements of the decrease in the length of a piece of steel and that of concrete of the same size loaded with equal loads. Both materials shorten under these conditions. Steel shortens one-fifteenth as much as does the concrete.

This is a very simple example of the precautions that must be taken in designing all kinds of reinforced concrete members. Concrete has ten times greater strength in compression than in tension. The stresses on beams affect concrete somewhat differently than in the case of columns. In a column a high compressive stress on the concrete may strip it from the steel, and in beams the high tensile stress in the concrete does nothing more than crack it, leaving the concrete between cracks, to cling to the steel and to protect it from corrosion.

In columns hooped reinforcement is sometimes used, the iron being wound spirally around the core of the concrete. Vertical steel is used, and the steel spiral is wound around it. A spiral of this type does not begin to give until the concrete is on the point of failing.

Therefore, in effect it is the same as increasing the strength of the concrete in compression, and in the form of a spiral, steel is more than twice as effective as the same amount would be in a vertical position.

Owing to the different behavior of mixtures entering in the construction of composite concrete blocks, it is often necessary to use reinforcement, even in so small a unit. Barbed wire has been found satisfactory for this purpose, tending to hold different parts of the block in position. Stirrups act to enable concrete to bear shearing stresses, just as spikes and bolts used in a number of timbers prevent the slipping of one plank past the adjoining plank in a horizontal movement. Stirrups should be fastened to the steel placed to bear the tension, and not simply looped around it. Stirrups must extend far enough above the axis to develop bond. There are a number of excellent hand-books for engineers, and texts intended for self-taught men, which go into detail on all factors entering into reinforced concrete design. This data would be out of place here, since it is our purpose to explain the purpose of reinforcement and to indicate how necessary it is to use the right amount in the right place, and not to make every man his own concrete engineer. It can be pointed out, however, that, if for any reason concrete cracks, the steel in the reinforcement will carry all the tension with a stress of twelve thousand pounds to the square inch. Cracks are likely to occur where occasionally a poorly mixed batch of concrete has been deposited, where construction joints are defective, where forms have been removed too roughly, or where excessive temperature changes have taken place. In-adequate foundation is also a possible seat of trouble.

So much has been made of the point that reinforced concrete columns are fire-proof that some time ago co-operative tests on full commercial-scale columns were arranged by the Underwriters' Laboratory, the insurance interests, and the manufacturers of the materials under test. A special furnace was constructed, in which the member under test could be heated in a way to duplicate the action of fires of different intensity, and at the same time loads could be applied. Water was played upon the hot column to duplicate the conditions present in a conflagration, and other physical tests were applied by subjecting the burned column to impact and similar stresses that it might have to undergo in actual service.

These tests have since been extended to include the usual hollow iron or steel column and the twelve-by-twelve mill timber that preceded these other structural materials. It is interesting to note that the hollow metal columns under load failed before any of the others, and that the wooden timbers capable of supporting the same weight lasted six or seven times as long as these metal columns. It was found that the ultimate failure of the wood was due to the failure of the metal cap rather than to the destruction of the wood, notwithstanding the high temperature. A newly designed cap of reinforced concrete has proved itself equal to the requirements, and can be so made as to endure as long as the column does.

The reinforced concrete columns have done well indeed under conditions approaching those of a conflagration. The fire tests have included different types of reinforced columns using the same aggregate, several aggregates with the same type of column, and experiments to devise methods for safeguarding columns made from gravels high in their per cent. of quartz or granite. This has taken the form of plastering the column, of using a plaster in place of protective concrete outside the steel, and of casing the columns in gypsum forms, which should take the place of protective concrete.

The columns used were those having vertical and spiral reinforcement, the columns being cylindrical; cylindrical columns with vertical reinforcement; spiral reinforced cylinders; and vertical reinforced square columns.

Results have shown that the character of the aggregate determines the tendency of the concrete to spall or crack away from the reinforcement. Trap-rock, limestone, slag, and gravel containing ninety per cent. of limestone pebbles are non-spalling. Granite and quartz, on the other hand, expand rapidly at 575° C., and give trouble. Where the concrete failed because of spalling, the failure occurred earlier in those columns possessing spiral reinforcements.

In four-hour tests non-spalling columns retained fifty per cent. of their strength, which indicates that there would be small likelihood of their failure under full loads in practice, due to the safety factors that are allowed in engineering calculations. Columns that retained their protective covering, which is from one and one-half to two and one-half inches thick, came through severe tests satisfactorily. It is to be concluded that if existing columns that are not protected were given a one-inch coat of Portland cement plaster, held in place with chicken-fence wire reinforcement, they would be amply safeguarded. The only question is, will the protective coating stay in place under fire conditions?

It must not be concluded that plasters of one type or another will replace protective concrete coatings. The placement of such a protective coating on existing columns by means of a cement-gun or similar mechanical device is not to be considered plaster in this connection. Plasters that have been tried include Portland cement and crushed cinders and a mortar composed of gypsum, lime, and sand. If plasters are to be used, obviously those that are heat-insulating are to be preferred.

CHAPTER IX

SOME FACTORS INFLUENCING PERMANENCE

There are few building materials in which so many factors can affect permanence as in cement, and no attempt will be made to discuss all of them. It seems important that some of them should be considered, more particularly since many persons look upon concrete as a permanent material, regardless of certain limitations that should be recognized without in any way detracting from the desirability of using cement and its product universally.

One of the apparent characteristics of concrete is that it changes volume. There has been a great deal of discussion among authorities as to whether this change of volume is due wholly to expansion and contraction that come with fluctuations in temperature, or whether alternate wetting and drying of the mass may not contribute largely toward this behavior. Evidence of the expansion and contraction of pavements may be seen in the expansion joints, which are to be found at regular intervals across concrete roads, and in the practice of leaving a thin wooden strip between the concrete slabs in sidewalks, these strips being later removed to allow for the expansion of the hardened walk. To be sure, these changes in volume are not always great, but they need not be to cause considerable damage unless some room for movement is allowed in designing whatever structure may be under consideration.

In the earlier investigations, measurements were made on test bars, and later refinements involved constructing the forms in such a way that a column of concrete, measuring 4 by 4 inches in cross-section and, say, 3 to 4 feet in length, was left free, except at the ends, where the outer iron frame, on which the test was conducted, was provided with serrations, or teeth, so arranged that the bars were restrained at both ends. While still plastic, it was an easy matter to place metallic plugs at fixed distances apart, so that measurements of change in length could be made with great accuracy. With such bars, either restrained or not, according to the desire of the experimenter, it has been comparatively easy to prove that cement is subject to expansion and contraction, to measure the amount of this change, and, by comparing the conditions, to learn something of the causes of this change in volume. This work has not been confined to freshly prepared materials, but sections of walk that has been in place for twenty years and is still in good condition have been observed by White at the University of Michigan, who sawed sections for observation from such material.

Now, when Portland cement is subjected to changes of temperature, it has been found that, on the average, the richness of the cement—that is, the proportion of cement used with relation to sand and gravel—has an important bearing on expansion and contraction and, consequently, upon the life of concrete pavements and walks. Changes take place more rapidly and more extensively with an increase in the amount of Portland

Courtesy Prof. A. H. White

STUCCO LOOSENING FROM THE BRICKS

A result believed to be due to volume changes

Courtesy Prof. A. H. White

AN ILLUSTRATION OF WHAT MAY TAKE PLACE WHERE INSUFFICIENT SPACE IS LEFT TO CARE FOR VOLUME CHANGES cement used, and this explains why the top coat so often breaks away from the base of old cement sidewalks in which it was customary to finish the surface with a comparatively rich mortar of cement and sand. This may also occur if the top is spread on a hardened base. The average figures show that for each degree Fahrenheit there is an expansion or contraction in concrete of 0.0000055 or for each degree Centigrade, 0.00001. The coefficient increases in the case of concrete until it is seven months old; but after that time and for all practical purposes the value quoted above is fairly accurate.

In the laboratory, work has been done at high temperatures, heating experimental blocks to 1500°. It was found that this material, upon cooling, did not return to its original dimensions, but retained an elongation of nearly 75 per cent. of the maximum gained during the heating experiment.

When Portland cement, which has hardened, reacts with water, it seems that a colloidal cement is formed. This theory was first advanced by Michaëlis in 1893, and has been developed by him later and supported in part by the work of other investigators. Some of these experiments have been carried on in glass flasks where the bulbs were filled with the cement and then the stems of the flasks were filled to a given mark with clear water. It was observed that in the early stages of setting there was an actual decrease in the absolute volume of the cement, for the water in the column fell a little in the first three hours, then three times as much in the next twenty-four. It had decreased one third of an ounce at the end of seven days, and nearly half an ounce at the end of twenty-eight days. Presently the cement began to expand, and this expansion would actually have forced the column of water into the necks of the flasks an even greater distance than it had fallen, but for the fact that, being no longer plastic, the cement could not flow in the direction of least resistance, but instead burst the flasks.

In a discussion before the International Engineering Congress in 1915, A. H. White explains this strange behavior by the action of colloidal cement, to which reference has been made.

Cement first reacts with the water to form a colloid of greater volume than the cement, but of less volume than the cement plus the water; but as soon as the cement has begun to set and has taken on rigidity, the process of hardening starts, because water diffuses through the hardened cement to fresh surfaces on the interior, this being indicated by the fall of the water-level in the neck of the flask. In other words, hardening cement requires water, as we have found in practice and we cover freshly laid cement with damp earth and burlap. After the cement has begun this part of the cycle, the newly formed colloid has a larger volume than the cement, and the pressure is exerted on the walls of the flask just as in practice it is exerted against any object with which it comes in contact. Presumably, this action of water on the hardening cement continues until the colloid developed in the interior layers becomes so dense that water can no longer diffuse through it. In the laboratory this condition is found to exist after about twelve months, when no further extension in test pieces is measurable.

The difference in the degree and rate of expansion between cement and concrete may be explained by the larger number of voids or spaces not occupied in the concrete mass by the solid substances. These voids provide a place to be filled by colloid cement, and if concrete is sufficiently porous to accommodate such cement as is formed, there will, of course, be relatively little or no expansion; but the concrete will remain porous permanently, and this is not desirable, under most circumstances.

This same phenomenon has been cited as explanation for the behavior of concrete dams. These often permit water to seep through them when first put in service, but after a time they become watertight, due, we may suppose, to the increasing density of the colloidal cement formed on the side of the dam permanently in contact with water.

If concrete is hardened in dry air, or after hardening is kept dry, it contracts or shrinks, and this shrinkage is greater than would have been the expansion if the same material had been kept in water. It is believed that the removal of water from the colloid by air drying or by heating causes contraction, just as the burning of clay causes it to contract. Experiments have, of course, been tried with alternate wetting and drying of cement bars, some of the work extending over a period of six years, and there has not been a single exception noted.

Beginning with a new set of test bars, they have been found to expand in the first year in the water, and then to remain at a constant volume for the next two years. If then taken from the bath and dried, a contraction of 0.15 per cent. on the average, was noticed, and on being immersed again in water these bars again expanded slightly more than their original length. These facts repeat themselves with each cycle, the bars gradually becoming longer, showing that with each immersion for a long period more colloid cement develops, so that in such a series of tests the fluctuations gradually become greater and greater.

Another curious fact is that the reaction to immersion in water and drying in air progresses more rapidly with the increase in the number of cycles, owing, no doubt, to the fact that the colloid responds more quickly to rehydration than does the original unhydrated cement. An experiment is reported in which 90 per cent. of the expansion noted for the first twelve months of continuous immersion in water was accomplished in twenty-four hours in the second immersion, after a two months' interval of drying.

One other point should be noted in this connection, and that is that with short immersions in water the strength of concrete falls off rapidly, reaching the lowest point at the end of two days. At that time the strength is less than two thirds that of similar material that has remained dry. But after two days the strength increases rapidly, and after twenty-five days in water it is decidedly greater than that of the dry bars. This is explainable again by the behavior of the colloid cement. In those first two days only the outer shell was penetrated, and the resulting expansion unquestionably set up a strain between it and the core, which the water had not reached.

Where high temperatures have been withstood, as in a conflagration, the gravel and sand of the concrete may expand, even though the dehydration should cause the colloid cement to contract. These expanded solid particles do not return to their original dimensions, so that a test bar does not return to its original length, and a second heating will cause little variation. Such a bar can be made to expand by rehydrating, so that the colloid will again fill the spaces and cause expansion, which will again be retained by the expansion of sand and gravel if heated to a high temperature.

This has an important bearing on the treatment of concrete structures that have suffered high temperatures. This heating, which may be very intense for a short time, frequently causes the outer portion of a concrete column or beam to break off or spall; but the dehydrated colloid in the cement that remains in place is capable of again taking up water and filling the spaces caused by expansion of the aggregate, so that in many instances such concrete can be wetted down to advantage after it has cooled. Unless an aggregate, such as limestone, has been used, a considerable percentage of the original strength may be regained; but if limestone has made up the aggregate, an element of weakness is introduced, because it may have been burned to free lime, which is considered one of the possible weaknesses in cement.

The other extreme—freezing cement and concrete—depends for the extent of its effect upon the quantity of liquid water contained in the material at the time. It has been noted that cement contracts upon freezing at a rate almost the same as in the case of cast iron, and a series of successive thawings and freezings, in which the thawing is under water, left the test bars unaffected.

All of this work relative to the change in volume, whether due to temperature fluctuations or the action of heat and moisture, of course has a direct bearing upon the permanence of concrete structures in service. It is evident, from what has been said, that concrete expands when heated, and contracts when cooled; and it may either expand or contract when frozen, depending upon the proportions of the cement in the concrete and on its previous history. This also affects the extent of the change when the concrete is alternately wetted and dried.

It has been found, further, that if concrete has been exposed to water for a long time, the colloid developed resists freezing, and therefore helps to preserve the bar. It is believed by many experts that the volume changes due to variations in moisture are considerably greater than those taking place when we pass from winter to summer. This being true, it is obvious that it is better to place concrete where it is continually wet or always dry, rather than to expose it to extreme changes.

This expansion demonstrates its power in the occasional buckling of squares in the sidewalk; sometimes it is a dished condition or a series of concavities in which pools of water gather after the rain. At times the sidewalk abutting against a cement curbing may actually push a section from the sub-base upon which it is laid. Sidewalks and pavements are usually subject to rather severe conditions; for concrete is sufficiently porous actually to absorb rain, and it also gathers moisture from the ground upon which it rests. This has been demonstrated by a series of measurements made under the auspices of the Bureau of Standards upon concrete highway slabs, beginning the work very shortly after they had been placed.

Actual conditions under which concrete may shrink are those obtaining in a dry climate, in which case it is customary to allow the contraction of the hardening cement or concrete to cause cracks which serve as expansion cracks, for it is quite unlikely that enough moisture will ever be present to enable it to expand to a dangerous extent. There have been examples of contraction even in a more moist atmosphere, but this was apparently due to the fresh concrete having been laid upon an old base of the same material, which prevented the passage of water from the ground to the new material, whereas the surface allowed ready evaporation.

Such data also indicate the desirability of using the same composition throughout a particular piece of work. The cracking that has been observed in the older methods of applying concrete to walls was probably due to the difference in expansion of the outer coating and the base, remembering that the cause of the expansion may have been changes in moisture to an even greater extent than changes in temperature.

It must not be overlooked that the slight transverse longitudinal or diagonal cracks that appear from expansion and contraction may become a source of grave trouble, particularly in roadways and walk; for they are often filled with water, and in winter the freezing produces larger cracks, which may further increase by this process. This will ultimately destroy a structure unless maintenance, such as is suggested in the chapter on roadways, is carried on.

Laboratory study on the effect of volume changes in concrete has been carried on at the Royal Engineering Academy in Petrograd. A summary of the results may be stated as follows: The smallest changes are found in porous concretes made from good aged cements and stone aggregates such as granite and limestone. If desired uniformity in massive concrete structures is to be obtained and horizontal cracks prevented, the concrete must be deposited continuously, and provision made to have the surfaces of any necessary layers well interlocked. The maximum blocks that should be attempted vary, of course, with the properties of the concrete, the structural conditions, and the influence of moisture and temperature. If the conditions that permit free expansion and contraction of concrete can be minimized, it means that greater blocks can be safely used.

In some concrete structures the design should provide for the use of single monoliths, separated by horizontal and vertical planes giving these single parts a great measure of independence, especially when subjected to varying loads and fluctuating atmospheric conditions. It is recommended that provision be made to protect structures from destructive atmospheric influences, either by the use of a heavy facing or extraordinary wall surfaces or some type of water-proof cover.

An example cited in proof of the seriousness of continually wetting and drying concrete is that of docks and piers, where that portion always under the water will be found in good condition, as will the portion above high tide; but, where the material is frequently wetted and dried alternately, deterioration begins, and may be helped along by the erosive action of the tides.

Chemical composition indicates a few sources of possible weakness, free lime being a compound to be avoided. Owing to the action of the carbon dioxide of the air upon free lime, calcium carbonate may be formed and expansion come by the slaking of such unslaked lime. The result is the appearance of cracks or even more rapid disintegration. The presence of the compounds of sulphur is another indication of possible unsoundness, and even cinders or ash high in sulphur, used as an aggregate in concrete, may give an unsatisfactory result.

In cold weather it is often necessary to protect hardening cement or concrete and maintain a higher temperature over the curing material by the use of braziers or other devices in which fuel is burned in proximity to the concrete. The inspection of one floor under such conditions indicated that the results achieved were unsatisfactory, and, upon seeking for the cause, the laboratory was brought into play in order that conditions might be accurately duplicated. It was surprising to find that the carbon dioxide present in the products of combustion had exerted a harmful influence on the Portland cement, setting at a temperature below 40°. This was due to the formation of a hydrated calcium carbonate quite unstable and capable of efflorescing at a temperature slightly higher than that obtaining during the curing.

With efflorescence this unstable hydrated calcium carbonate loses its bonding properties; and, while the effect is merely on the surface, and, therefore, could not affect the strength of the floor, it is apparent that it could easily disintegrate with unpleasant dusting and rapid wearing of the surface.

If curing must be done in cold weather, the temperature should be maintained well above 45°, under which circumstances the objectionable carbonate is not so apt to form, and the initial setting of the cement will proceed more rapidly. It has been contended that concrete hardened in the cold is not so permanent; but there is no reason to disbelieve that, if sufficient time is given, remembering that the hardening of concrete is a chemical process not directly dependent upon temperature except for speed, ultimate satisfactory strengths can be reached. The only provision is that actual freezing of the uncombined water should be avoided.

Permanence is directly related to the strength of concrete, and strength, in turn, has been found to depend upon the quantity of water used, the time the batch is mixed, and the care with which curing is carried on.

It is doubtful whether any one thing has contributed so much to dissatisfaction with concrete as the use of too much water. Excess water is used at times because of the belief that a freely flowing mixture can be placed to better advantage in the forms. Sometimes it is because excess water lubricates spouts and gutters through which the concrete mix is conveyed from mixer to forms. Again, in mixing, it may appear to the worker that a more homogeneous batch can be obtained if much of water is used. In order to obtain fundamental information, the Structural Materials Research Laboratory, in coöperation with the Portland Cement Association, undertook a series of tests to devise a method whereby the proper consistency could be determined at the time concrete was being placed.

Many different methods have been used for indicating the consistency of concrete. The total amount of water to be used has been expressed as a percentage of the weight of the dried materials, as a percentage of the weight of the finished concrete, and as a percentage of the weight of the cement. These methods of expression have not given satisfactory results, for all of the water used is not required by the cement, some of it being absorbed by the aggregate. The amount of water that affects the cement may be varied in different ways: Varying degrees of wetness can be produced with the same grading of aggregates and amount of cement by simply using different quantities of water. Then the quantity of cement may be varied, and the richer mixtures will require a smaller percentage of water to give the same plasticity. If the nature of the aggregate be changed from coarse to fine, those carrying the finer materials will need more water. Any of these combinations can be changed, and every factor has its bearing.

The water in a cement or concrete mixture not only furnishes the necessary moisture for the chemical reaction, but serves to help coat each of the particles of sand, gravel, or broken stone with a film of cementitious material. The real reason a mixture, rich in cement, is of greater strength than one with less cement is not that more cement is used, but because the concrete can be, and usually is, mixed with a quantity of water that is relatively lower for the richer mixtures than for the lean ones. If water were used in proportion to the cement employed, there would be no gain in strength by the addition of more cement. Whereas the use of more cement is usually believed to afford more strength, in many cases nothing more has been done than to waste cement in using an excess amount of water.

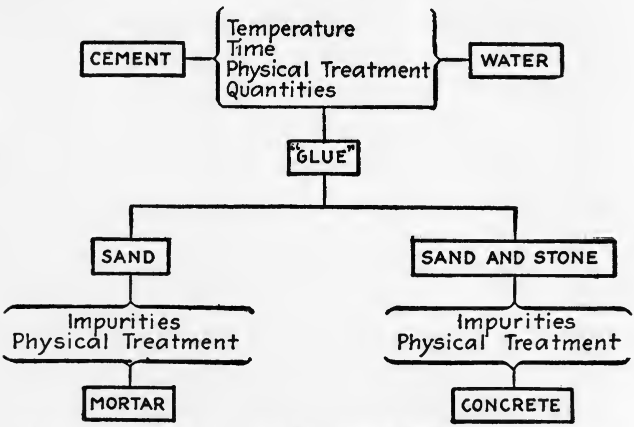
A long series of tests has shown, without question, that well graded aggregates and binding cement can perform their true function only when the right amount of water is used—and this should be the minimum with which a plastic, workable concrete can be prepared. The mixture must be workable, and to this requirement can be ascribed the use of Portland cement and water in quantities that are not the minimum. These could be reduced but for that consideration. Any method of mixing, handling, placing, and finishing concrete that will enable the amount of water used to be reduced to a minimum is advantageous. It must be remembered, however, that mixtures that are so dry as not to be plastic will develop low strength. It has been found that in working upon a unit of one bag of cement, one pint more water than is necessary has the same effect upon the strength of the resulting concrete as if 91 pounds instead of 94 pounds of Portland cement had been used.

The best practice has been reduced to formulae, useful to engineers; and in general it may be said that a mixture should not be so wet that it cannot retain all the water used, that it must be plastic, and that care should be exercised not to use aggregates too coarse with the quantity of cement and water employed.

The arguments are frequently advanced that excess water is not harmful, for it will evaporate and disappear; and that wet concrete, while weak in the early stages, gains strength more rapidly than dryer mixtures; and that, where plenty of cement is used, there need be no excess water. The experiments that have been cited all go to prove that the point at which water stands on the surface is just 200 per cent. of the water that should be used for concrete developing maximum strength; and that, while wet concrete does gain strength more rapidly than dryer mixtures, it has from one third to one quarter the ultimate strength of the proper mixtures. The only safe rule to follow is to use the smallest quantity of water that will give a plastic or workable mixture and use the remainder of the moisture in the curing.

Doubtless the fundamental cause for the detrimental influence of excess water is that it prevents the particles of cement from adhering to the surface of the aggregate particles, where they belong if maximum strength is to be realized; and if this excess water is still further increased, a point is reached where the strength is negligible and the cement cannot harden, for the cement, though fully hydrated, can offer no resistance to stresses.

Not only is the strength of concrete greatly increased with a decrease in the mixing water used, but there is a direct influence upon wear; and here again equations have been evolved that enable the engineer to estimate the probable wearing resistance of a concrete of known strength. These wearing tests may be conducted by a machine described as a "rattler," in which blocks of concrete under test are placed, being wedged tightly about the periphery of a revolving metal drum; some 200 pounds of cast-iron balls are placed in the interior, and a wooden head is then clamped in place. The device is then rotated at about 30 revolutions a minute until 1800 complete turns have been made. At



GENEOLOGY OF MORTAR AND CONCRETE. N. C. JOHNSON.

the end of the run the surfaces of the blocks are carefully examined, noting not only the amount of wear, but its character.

The depth of abrasion may be readily measured. A very poor concrete may be entirely destroyed, and a high-grade concrete will seldom wear as much as half an inch. Such tests are of much importance in choosing cement aggregates and suitable mixtures for roadways and other types of pavements.

"Quaky" is a term applied to concrete of the proper consistency. A favorite method for determining whether the proper amount of water has been used is to fill a truncated cone, having a base 8 inches in diameter, a height of 12 inches, and a top 4 inches in diameter, with freshly mixed concrete, lightly tamped with a rod into place in the mold. As soon as the mold is filled and struck off with a trowel, it is removed, and the height of the concrete after removal is measured. For concrete in road work a practical consistency is obtained when the slump is between one half inch and one inch. If the surface of the concrete is to be worked by hand, it may be necessary to use a consistency that would give a slump of one and one half inches.

Next to surplus water, under-mixing may be convicted as the greatest evil in defective concrete. There are numbers of batch-mixing machines from which to choose, and on smaller operations hand mixing must still be practised. What should be the minimum time of mixing? In every instance strength increases with increased time of mixing, and the problem has been to strike a proper economical average, being the minimum time that the mixer can be run and produce satisfactory strength. In experiments with the same mixture, varying the mixing time from sixteen seconds to ten minutes, it has been found that, on the average, with an efficient design of mixing-machine one minute is sufficient time for mixing—and that, especially, with the proper constitution of the mixture. This means using the optimum percentage of water. The same strength was found after one minute's mixing that was obtained with ten minutes' mixing where the amount of water had been increased 15 per cent. No reasonable increase in the period of mixing, however, could compensate for the use of excess water in the batch.

The rate of rotation of the mixing-drum is another factor that has been investigated, and it has been found that between twelve and twenty-five revolutions a minute does not produce results indicating material influence on the strength of the finished material. For the very slow and the very rapid rotation a slight reduction of strength is noted, and a peripheral speed of 150 feet a minute for the maximum diameter of the inside of the mixing-drum has been found a satisfactory average.

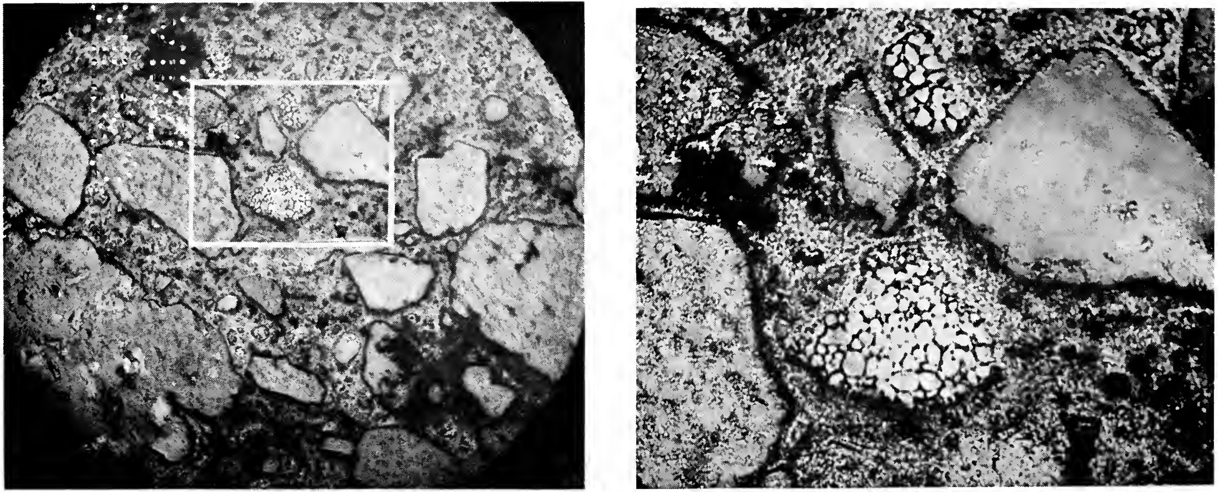
Nathan C. Johnson after extensive work in which photomicrographs have played an important part has pointed the way for securing far better service from the cement in concrete. This is to be secured by a better distribution of more concentrated cementing materials and a study of our present mixing methods convinces that new mixing principles must be introduced if this is to be accomplished. Mr. Johnson urges the use of a centrifugal mixer for this purpose.

When cement clinker is thoroughly ground the powdered cement is capable of reacting so rapidly with water that if used as much it would set too quickly. The hydrous gypsum that is added to hot cement has its water of crystallization driven off through the mass thus forming a tiny film of hydrated cement on the grains of cement. Storage of ground cement under average conditions also promotes the formation of this protective coating. By referring to the photomicrographs and diagram this film can be identified. It is

Courtesy Prof. A. H. White

"DISHED" SLABS PHOTOGRAPHED AFTER RAIN

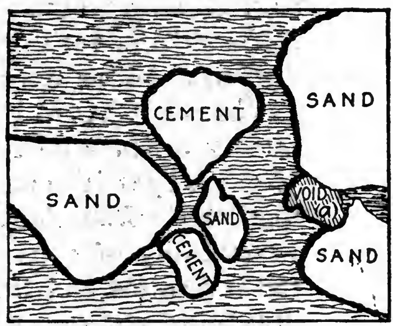
Irregularities largely due to volume changes



PHOTOMICROGRAPHS OF COMMERCIAL CONCRETE SHOWING SAND GRAINS, UNUSED CEMENT AND AIR VOIDS

The area within the square at the left is enlarged from 60 to 180 diameters in the view at the right. The diagram in the text gives the identification of the various constituents. Negatives, etc., by N. C. Johnson.
See *Journal of the Engineers Club*, Philadelphia, September, 1919

this hydrated film which causes the deterioration of cement in average storage. Experiments at the Bureau of Standards have shown that such cement can be used if sieved to remove all lumps and proportioned to aggregate with due allowance for the fact that a part of the cementing material has already been used or hydrated.



IDENTITY OF AREAS IN THE PHOTOGRAPH

Note hydrated film, the heavy line, around each particle

Now when we add water to cement hydration progresses only after moisture has penetrated this already hydrated film and may not reach all the cement owing to the formation of dense films of hydrated cement. Meanwhile the "glue" formed by cement and water diffuses through the water and gradually coats the particles of sand with a cementitious material much more dilute than is desirable. Further, sand particles and grains are able to hold many air bells and in concrete the surfaces of the aggregate hold an appreciable quantity of air. To properly dislodge these air bells so that the surface may be coated with cementitious materials means the most thorough stirring possible. If the air remains trapped in the cement and concrete voids are produced just as when an excess of water is present.

What is involved in properly mixing concrete is indicated by Mr. Johnson's calculations. In a cubic yard of concrete having the proportion of 1 part cement to two parts of sand and four parts of coarse aggregate there are approximately one million pieces of stone up to and including $1\frac{1}{2}''$, twenty-five billion sand particles if commercial coarse sand is used or two hundred billion if the sand is very fine and from two hundred to three hundred billion cement particles. And all of these must be really mixed in commercial time preferably in a way to leave no air or water voids and no clumps of cement particles undistributed over sand and coarse aggregate. Experiments so far conducted indicate the possibility of accomplishing this result with the centrifugal mixer and the changes in the mixture itself, these being made possible by the more complete utilization of the cement and water.

Assuming that proper design, good materials, and competent workmanship all have had their part, that the right proportions of materials have been used, properly placed and finished, it remains to effect curing in such a way that the cement or concrete may be made as permanent as possible.

It is believed that most of the fault found with concrete floors may be traced to either improper consistency or careless curing. Excessive wear and dusting are certain to result if the concrete is not permitted to have the curing water necessary for the hydration of the cement. The effect of the curing condition on the compressive strength of concrete has been determined accurately. Samples stored for long periods in damp sand, and tested while damp, developed strength from two and a half to three times as great as similar samples that had been exposed to room temperature for the same period.

Supplying concrete, which has set, with sufficient moisture to carry on the hydration of the cement and the formation of the colloidal cement, and then protecting the material from drying out for at least ten days, gives an increase in strength of at least 50 and probably 75 per cent. over dry material. In the case of concrete and cement products, it has been found advantageous to use curing-tunnels in which the cement products are kept for days in a moist atmosphere, and even in steam, in which latter condition hardening progresses satisfactorily with greater rapidity. One series of tests shows that concrete cured under eighty pounds steam pressure might be considered advantageous in the time saved in curing and in the strength developed in the finished article.

In the chapter on highways, the precautions used to best advantage in guaranteeing a proper curing of freshly laid cement is discussed in greater detail; but it should not be forgotten that such curing is required if high compressive strength and resulting resistance to wear are to be expected.

CHAPTER X

SOME PHASES OF CEMENT AND CONCRETE TESTING

The first testing of cement and concrete was probably done by John Grant, of London, in 1859. He molded small briquets, and subjected them to stresses in an effort to determine in advance what type of service could be expected from the new material. The engineer is always confronted with the problem of how to determine in advance what the quality of the structural material will be at that time in the future when it will develop its maximum strength or will be subjected to unusual stresses. He must also know the effects of such influences as may cause disintegration or decay. There is a demand for accelerated tests which will give such information with a sufficient degree of accuracy to permit the use of materials with a fair degree of confidence as to their performance and service. To this end, a variety of tests have been applied to concrete. Some of these have to do with determining the influence of new factors upon concrete structures, and others have to do with determining data that can be compared with standards set after practical experience with materials, the previous history of which is known.

Usually concrete is subjected to one or both of two physical tests, namely, tension and compression tests.

Besides these, the time of setting is important; the soundness or liability to volume change is determined; fineness is a consideration, as is also specific gravity and, of course, the chemical analysis.

In most specifications, Portland cement is given a definition that in reality describes a particular process of manufacture. Thus, in the specifications prepared by the American Society for Testing Materials, collaborating with government departments and engineering bodies, Portland cement is defined as "the product obtained by finely pulverizing clinker, produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined, or uncalcined gypsum." The limits within which chemical and physical properties must fall have been agreed upon, and, in the case of chemical characteristics, the loss on ignition must not exceed 4 per cent., insoluble residue, not more than 0.85 per cent.; no more than 5 per cent. of magnesia nor 2 per cent. of sulphuric anhydride is allowable.

So much depends upon the quality of cement that arrangements for inspection and analysis are perhaps more complete, especially where large quantities of material are involved, than is the case with most things entering into construction. It is customary for an inspector to be stationed at the mill where samples are taken as the cement is being prepared for shipment; and the cars are sealed by the inspector after sampling has been completed. Contracts for cement specify all details with respect to sampling, testing, acceptance, and refusal, and suitable time is allowed for the completion of the necessary tests. More than this, the size of the sample that shall be taken for each unit is usually stipulated, and it is customary to take a sample from each fifty barrels or fraction thereof—if the cement is in cars at the time of sampling—and one sample for every one hundred barrels, if sampled from storage-bins. Composite samples are frequently used.

Where cement in bulk is sampled, it is customary to withdraw eight pounds for each hundred barrels passing over a conveyor, or to use long sampling-tubes for drawing material from depths up to ten feet over the face of the cement in bins. Great care is used in storing and shipping samples in air-tight containers, and, in mixing samples, a sieve is usually employed.

To assure uniformity in method, and to eliminate, as far as possible, personal errors that may be involved, every step in the testing of cement has been standardized. The care thus exercised may be indicated by citing directions for determining the loss on ignition:

"One gram of cement shall be heated in a weighed, covered, platinum crucible of 20 to 25 cubic centimeter capacity as follows, using either method as may be agreed upon:

"The crucible shall be placed in a hole in an asbestos board, clamped horizontally so that about three fifths of the crucible projects below, and blasted at a full red heat for fifteen minutes with an inclined flame; the loss in weight shall be checked by a second blasting for fifteen minutes. Care shall be taken to wipe off particles of asbestos that may adhere to the crucible when withdrawn from the hole in the board. Greater neatness and shortening of the time of heating are secured by making a hole to fit the crucible in a circular disk of sheet platinum and placing this disk over a somewhat larger hole in an asbestos board.

"Or the crucible shall be placed in a muffle at any temperature between 900° and 1,000° C. for fifteen min-

..... Sample.. of .... Cement, marked .... Test No. .... Lab'y No. ....

Submitted / Collected by .... for .... Contract No. .... Sampled ....

Received ....

To be used .... Reported ....

Brand .... Mf'd by ....

CHEMICAL ANALYSIS.

Lab. Nos.

SiO_2 ......

Fe_2O_3 ......

Al_2O_3 ......

CaO ......

MgO ......

SO_3 ......

Loss ......

Insoluble Residue......

PHYSICAL TESTS.

Specific Gravity	Fineness. % Passing Sieves—		Soundness.						Time of Setting.	
	100-Mesh.	200-Mesh.	% Water.	— Days. Air.	— Days. Water.	28 Days. Air.	28 Days. Water.	5 Hrs. Steam.	Initial. Hr. Min.	Final. Hr. Min.

	7-Day Briquettes.					28-Day Briquettes.			
	% Water.	1st.	2d.	3d.	4th or Average.	1st.	2d.	3d.	4th or Average.
Neat									
Mortar									

REMARKS:

11—4675 CEMENT RECORD. Form 216.

RECORD CARD AS USED BY THE BUREAU OF STANDARDS

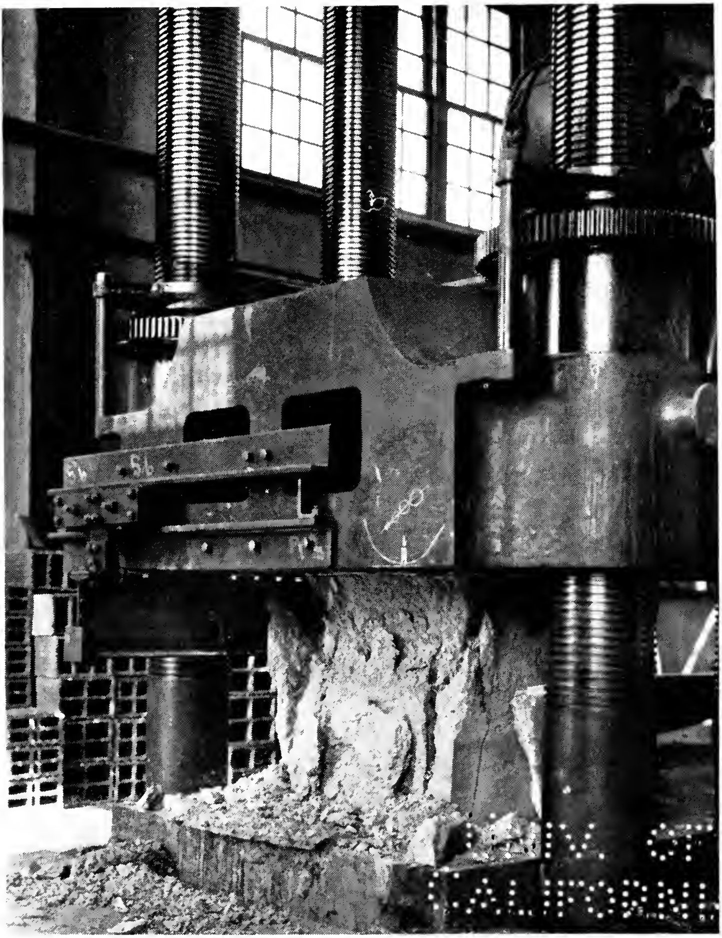
utes, and the loss in weight shall be checked by a second heating for five minutes.

"A permissible variation of 0.25 will be allowed and all results in excess of the specified limit, but within this permissible variation, shall be reported as 4 per cent."

To La Chatelier belongs the credit for having designed an apparatus used in determining the specific gravity of cement. This is a flask of peculiar shape, having two calibrated portions, separated by a bulb, in the neck of the flask. The flask is filled with kerosene free from water, or with benzine to a predetermined point on the stem. Sixty-four grams of cement is slowly introduced, and the level of the liquid, after the addition of the cement, is noted. The specific gravity is then calculated from a simple formula in which the volume of the liquid displaced by the cement is the determining factor.

The fineness of cement is determined by a set of standard sieves, for the use of which detailed instructions are provided to guide those inspecting the material. Of course, methods for mixing cement pastes, and mortars, and concretes prior to physical testing are also standardized, an apparatus being provided to determine the consistency. Tables have also been worked out showing the percentage of water to be used when preparing cement in various forms for testing.

Soundness is a characteristic of cement that should always be determined. The method consists of forming a little pat of cement paste of normal consistency and about three inches in diameter and half an inch thick at the center, tapering to a thin edge. This is made upon a clean glass plate and stored in moist air for twenty-four hours, during which time hydration takes place. The pat is then placed in an atmosphere of steam with a temperature between 98° and 100° C. upon a suitable support holding the plate an inch above boiling water; and this steaming continues for five hours. Any distortion that takes place can be determined by means of a straight edge brought in



A CUBIC YARD OF CONCRETE UNDER COMPRESSION IN TEST FOR THE PENNSYLVANIA STATE MINE CAVE COMMISSION AT THE BUREAU OF STANDARDS

This testing machine is the largest in the world and develops ten million pounds. The head weighs 25 tons and the screws 10 tons each

CEMENT TESTING LABORATORY, U. S. BUREAU OF STANDARDS, WASHINGTON, D. C.

contact with the surface of the part that had been next the plate, and failures in soundness are indicated by varying degrees of shrinkage, cracks, checking, distortion, and occasionally disintegration.

It is desirable to know to what extent there may be free lime in a cement, for it is a general belief that a good Portland cement should not contain free lime. Free lime is nearly always present in under-burned cement, due largely to the lack of grinding to sufficient fineness in preparing the raw materials for burning. It has also been shown that free lime may result from over-burning.

The boiling test is ordinarily used, but, as indicated above, this necessitates the works chemist being at least twenty-four hours behind the progressive work of his mill, and prevents an inspector from reaching as prompt a decision as is frequently desirable.

With a view to improving this condition, White devised a method, some years ago, that depends upon the rapidity and extent to which crystals of calcium phenolate will form on a microscopic slide under observation at a magnification of about eighty diameters. The method consists in using polarized light, so often found useful in determining the constants of materials. The ordinary light is vibrating in all directions; but, when this light is passed through a Nicol prism, it is divided into what is called the ordinary and extraordinary rays.

The Nicol prism is a piece of Iceland spar, cut along a certain plane and cemented with Canada balsam. This layer of balsam, which runs diagonal to one axis of the prism, causes one of these rays to be diverted, and the emergent ray is made up of light, all parts of which are vibrating in one plane.

If a second Nicol prism is placed so that it crosses the first, all light is excluded, and in the microscope a nearly black field appears. When certain substances are placed between these crossed Nicols, they appear as white or colored objects on a black field, and often show markings or other characteristics that are constants for that particular material. Thus grains of starch from various sources have distinctive markings when viewed under polarized light, and it was by the use of polarized light that the scientists at the Geophysical Laboratory were able to establish methods for identifying the components of Portland cement.

In the present method a reagent is prepared by dissolving crystallized phenol in xylol and adding two drops of water to five cubic centimeters, in which five grams of phenol have been dissolved. Too much moisture in the solution prevents the formation of good crystals and also tends to react with the cement. In making a test, a little of the finely powdered material is placed on the slide in a way to have a fair quantity in the center, with a diminishing amount toward the edges. This will leave a sort of nucleus where the crystals of calcium phenolate will appear and from which they will grow.

Fortunately, there is a distinct difference in the refracting power of the calcium phenolate and the cement, so that the crystals of phenolate appear with a sort of halo, due to their strong double refracting power, leaving the cement practically invisible. The crystals then become specks of white, and, if a large amount of free lime is present, masses in which the outlines of individual crystals are difficult to distinguish may be formed. Calcium carbonate and other compounds of calcium do not give this reaction; it is characteristic only of calcium oxide, which is free lime, or the hydroxide formed when water is applied.

The crystals begin to appear as small dots, and within two hours have reached a size that makes them prominent in the field of the microscope. In commercial cements they have been noted within six minutes after applying the test. Comparing this microscopic method with boiling tests, a very good agreement has been obtained, and it has been determined that cements which show no crystals of calcium phenolate under this test within an hour have no more than a negligible and a harmless trace of free lime.

The miroscopical test is more delicate than the steam test, and it should be remembered that a cement which through aging has much free lime changed to hydrate might be condemned by the microscopic test alone, although such a cement may have become perfectly sound. Also, through the hydration of sound cement by wetting, such a cement might be judged unsound from a microscopic test.

It is considered certain that cement which comes from the kiln containing more than a trace of free lime will not pass the boiling test, and the microscopic test would seem to have particular value in the mill, besides being useful in the hands of the inspector, who can always refer certain samples to the laboratory for the usual boiling test.

The time of setting is usually found by the use of two weighted needles, one being one-twelfth inch in diameter and loaded to weigh one-fourth of a pound, while the other is but one-twenty-fourth of an inch in diameter and is made to weigh one pound. Using such Gillmore needles, a pat of neat cement paste, mixed to a normal consistency, half an inch in thickness and having a flat top, is kept in moist air at a temperature of 21° C. (70° F.). The initial set is considered to have been reached when the quarter-pound needle will be borne by the pat without appreciable indentation; the final set is when the heavier needle will be so borne. Of course, needles are held in a vertical position.

Another method of determining the same thing involves the use of a special apparatus where the depth to which a needle penetrates the cement paste is measured half a minute after the needle is released. The final set occurs when the needle does not penetrate the paste.

The time of setting is important in determining whether a cement should be used for a given purpose. For maritime works quickly setting cements are wanted, and this means those that will set in less than two hours. The beginning of this set is sometimes noticed within a few minutes after mixing.

The basis for most comparative work is the resistance to compression, determined with testing machines upon small cubes or upon cylinders, usually six inches in diameter and twelve inches in length, and tension tests for which the standard briquette is used. This briquette has the general outline of the figure eight or hour-glass, with the narrow portion having a cross-section exactly one inch square. The briquette molds are usually of brass, and are constructed in such a way as to prevent the parts separating during molding. Since several briquettes must be broken to obtain a fair average, the molds are usually in gangs, provided with levers to lock the halves in position. The exact size as well as the shape of the briquettes is specified; their total length is three inches and, as indicated above, their thickness one inch.

In order to have results comparable, care must be exercised in making such briquettes. The water used is at 60° F., and the sand is that obtained from Ottawa, Illinois. This must be sieved so that the portion that passes a No. 20 sieve is considered standard, when not more than five grams of a 500-gram sample pass a No. 30 sieve after one minute of continuous sieving. The sieves themselves are standardized, and machines have been designed so that sieves placed in them will always be subject to the same degree of shaking during the preparation of the sand. When one part of cement is used with one part of sand, about 15 per cent. of the total weight of water is used, and this is reduced to 12 per cent. when the proportions call for one part of cement with three parts of sand.

On preparing a briquette in the mold, the latter is placed on a glass plate, the material is filled in, pressed down, and struck off evenly with a trowel. The mold is then turned over, and the operation of heaping, pressing down with the thumbs, and smoothing off is repeated. It is customary to allow these briquettes to remain in the molds for twenty-four hours, covered with a damp cloth, and they are then variously treated and aged, depending upon the data sought. Usually, briquettes are broken at the end of twenty-four hours, seven days, and twenty-eight days. During that time they may be stored in the air, in moist closets, or under water, and are frequently subjected to unusual conditions, all depending upon the ultimate use of the cement in question.

The breaking is done in a special cement-testing machine provided with grips that fit over the ends of the briquettes, exerting a straight pull. Levers are so arranged that shot allowed to flow into a small bucket applies tension to the briquette and this flow of shot automatically ceases with the breaking of the specimen. By the simple process of weighing this bucket of shot on a special beam, the tensile strength in pounds per square inch may be read off. A number of briquettes are broken and the average taken as the basis of any report.

The desirability of decreasing the dead weight of concrete without detriment to its strength, when used in concrete shipping construction, also led to a search for an aggregate peculiarly adapted to this requirement and ways of testing materials from which to make it. It was finally decided to use clay, fired in a way to produce a light vesicular mass containing such a large volume of porous material that when they are fired samples float upon water.

Evidently, shales and clays are most suitable; but care must be taken not to over-burn them, and it became necessary to find a way to test clays in the laboratory.

It has been found that rapid firing in rotary kilns is the best method of preparing such unusual aggregates, so that the laboratory test is reduced to a quick firing of the material under heavily reducing conditions.

The method devised by the Bureau of Standards consisted in grinding, if necessary, and then sieving the sample through a thirty-mesh sieve and bringing the material to a condition of optimum plasticity. Cubes, molded by hand, were dried, first at room temperature and then at 60° C. (140° F.). They were then fired in a test kiln, gradually raising the temperature according to a definite time schedule.

The outline of the cubes was carefully observed during the firing, and, after 900° C. (1,650° F.) had been reached, two specimens were removed for examination each thirty minutes. As soon as the cubes gave evidence of fusion, the firing was stopped and the furnace allowed to cool. Materials that failed to float in a solution of common salt having a specific gravity of 1.1, or that consisted of large cavities inclosed by a film of vitrified clay were considered unsuitable. Those that float and upon breaking the specimen show a fine, uniform cellular structure have been found most suitable.

Cement is ten times stronger in compression than it is in tension. That is, it resists crushing, or will support loads put directly upon it to a far greater extent than it will withstand a bending or deflecting action.

Wherever possible, such laboratory tests as have been described are checked by observation of cement and concrete in actual service over long periods of time. Reasonably extensive research has been undertaken on a variety of new factors. Thus the effect of time on the strength of concrete, the influence of the amount of water used, the results when aggregates of different grading and quality are employed, the relation between compressive strength and resistance to wear, the effect of consistency on the strength of concrete, and the effect of age on strength, all have been investigated. Other factors are discussed elsewhere in this book. One of the most important points that have been made is that as long as concrete does not dry out it continues to gain strength until strength equalizing that of the aggregate itself is reached.

Such data as are presented in discussing special uses of concrete have, in most instances, resulted from tests conducted on a scale that justifies the use of the term "practical." Thus, in determining the effect of sea water upon concrete, sixteen-foot specimens were employed; and, in the work upon the behavior of reinforced concrete columns when subjected to high temperatures, commercial size columns were prepared for the tests.

CHAPTER XI

ART IN CEMENT AND CONCRETE

There will be some who will question the statement that there can be art in concrete, basing their opinion on what they have seen rather than on the possibilities. If it is remembered that cement may be considered simply as a mortar or binding material, into which all sorts of things can be placed, its artistic possibilities will be appreciated. Occasionally there appears a cement worker with the skill and vision to undertake specialties, and this gives him a commanding position in his locality. Such a man becomes a contractor for work requiring a high degree of artistic skill.

It is both the color and texture of surfaces that add much to the beautiful appearance of an article, quite aside from its good design, proper proportions, and artistic lines. Some of the first attempts, therefore, to beautify concrete structures had to do with a change in the ordinary texture of the material, and in an attempt to introduce variations to relieve the monotony of a concrete wall. It gradually came to be realized that if a way could be devised to have the embedded aggregate give the texture and color to the mass, a long step would have been taken toward the ideal treatment of concrete surfaces.

It will be recalled that an ideal concrete has each of the particles of aggregate coated with the cement and sand mortar, which is sufficiently opaque, even in thin films, to obscure the color of the aggregate and give the whole surface a gray appearance. It was a small matter to apply water at just the right time, in the setting of stucco or other concrete material, to remove this mortar film. The work is facilitated by the use of a stiff brush, and today it is common practice thoroughly to brush the surface, using the minimum amount of water to expose the aggregate carefully worked to the surface during the placing of the concrete.

It is remarkable what beautiful effects can be obtained even by the use of local aggregate. And in Washington, for example, there are many pieces of work that depend for their beauty upon the variation in the shades and tints of the washed Potomac River gravel. Granite chips can be depended upon for pink, yellow, brown, tan, red, green, white, black, and gray shades. Slate color depends upon the use of lampblack mixed with the cement. Corborundum gives the characteristic sparkle and glisten due to the hard particles of which it is composed, and it has been used in treads and floors to produce a very hard surface that will stand the wear due to heavy traffic. Marble, quartz, silica sand, and micaspar give beautiful whites, and with them white cement may also be used.

Frequently these various color aggregates are too expensive to be used through the mass, but are either confined to the face of concrete blocks or are applied in the stucco upon the foundation or scratch coat. More ordinary materials, such as crushed brick and local gravel, have been used through the mass, and in many instances material has been pressed into the surface of green concrete just before its initial set.

In the list of specially prepared surfaces must be mentioned the vitrified or glass-faced cement tiles that have been prepared to take the place of various types of structural tiles. Such an enameling process permits the introduction of all types of colors, including those used in ceramics and in glass.

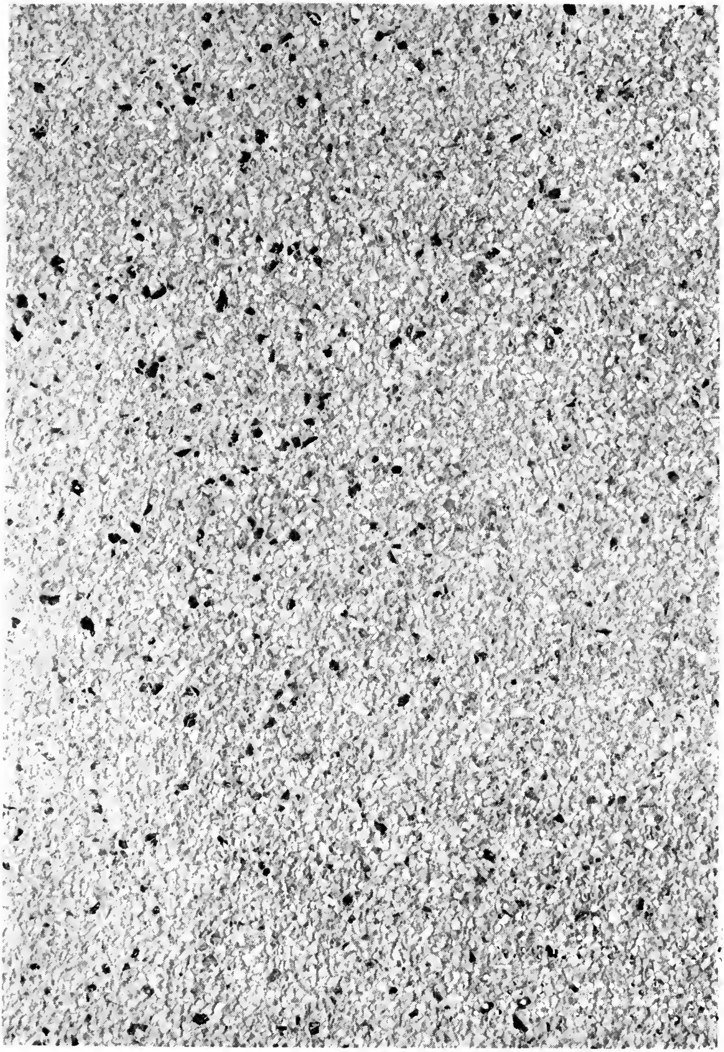
Another method of preparing the surface consists of tooling, either horizontally or vertically, which has the same appearance to be found in cut stone similarly treated. This may be accomplished, where blocks are concerned, by providing a tooled surface in the mold, and in the case of monolithic construction it can be secured either through the design of the form or by the use of the same sort of gang cutting wheels that have come into use on natural stone. Other pleasing effects are created by the artistic use of brick about doors and windows and elsewhere in a structure, to introduce a difference in the texture of the surface as well as in the color. The wide variety obtainable in brick is evident everywhere, and it will be seen how suitable these specialties are toward obtaining unusual effects in cement and concrete construction. Terra-cotta tiles are frequently set into concrete walls for decorative purposes with very good effects.

By the use of very well made molds, some of which make use of gelatine to obtain the desired reproduction of particularly fine lines, the casting of beautiful columns, with capitals almost as well grooved as those to be found in natural stone, have been made possible.

Decorative statuary is now to be found made of cement, and in this class of work the gelatine mold again plays a very important part. The concrete products shops are making a specialty of pre-casting such decorative materials, and attempt many things, heretofore considered impossible as cement and concrete products. Outdoor vases, fancy flower-pots, bird-baths, and the like are frequently executed in good taste and exquisite form from cement products. Park and lawn benches, sun-dials, and similar articles are limited in variety only by the ingenuity of the maker. Here, again, artistic effects are produced by the shape of the article, by the use of colored sands in the mortar, and by the use of crushed marble, granite, micaspar, and other special aggregate.

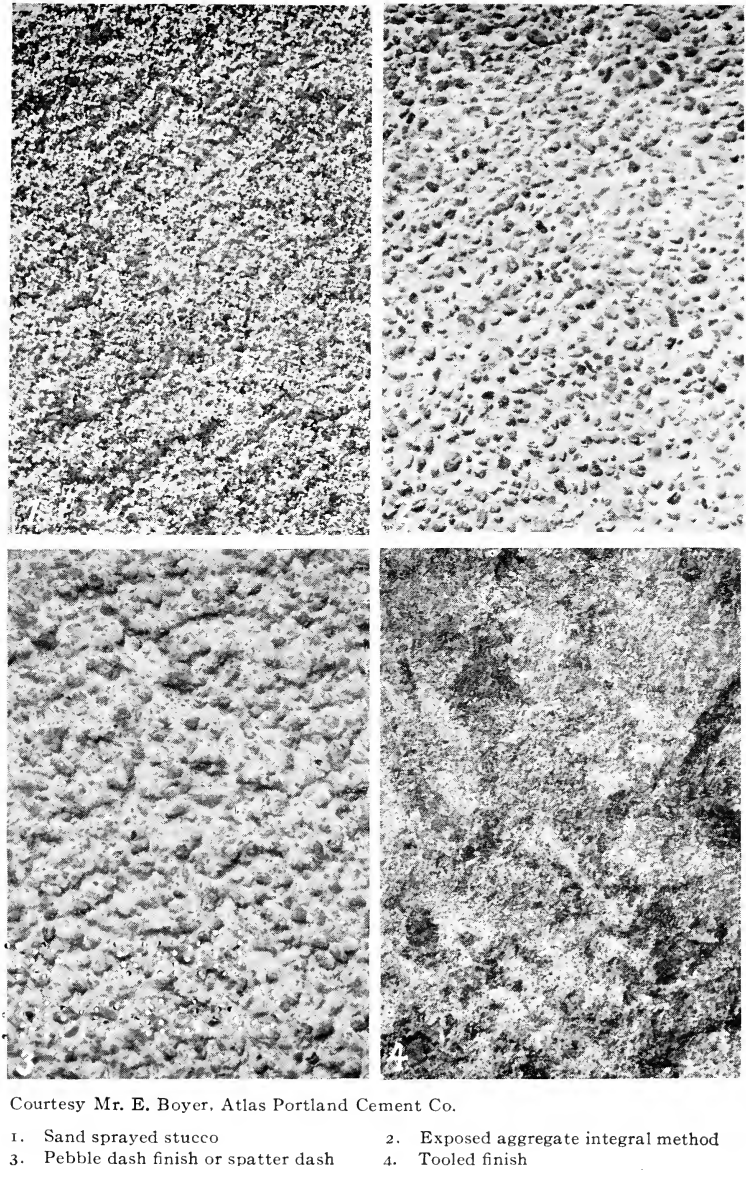
Larger units for ornamental purposes are to be found in concrete architectural trim, which has become a standard product, almost regardless of the material of which the wall itself is built. A great many expensive houses built of brick, etc., are now to be found in which this concrete trim has been extensively employed with satisfaction. Being a cast product, it can be prepared more cheaply than natural stone can be cut, and when due regard is paid to the factors involved, the resulting product is as durable and will be as satisfactory for the purpose as the more expensive article for which it is substituted.

In the employment of stucco, now to be found nearly everywhere, there are several standard finishes. These are stippled, sand-floated, sand-sprayed, rough-cast, pebble-dash, and the exposed aggregate to which reference has been made. These finishes are applied



DETAIL OF SURFACE TREATED STUCCO

Fort Lincoln Cemetery, Washington, D. C. Horace W. Peaslee, architect; John J. Earley, sculptor



Courtesy Mr. E. Boyer, Atlas Portland Cement Co.

1. Sand sprayed stucco
2. Exposed aggregate integral method
3. Pebble dash finish or spatter dash
4. Tooled finish

to the ground coat, and are produced in the following ways. The stippled finish results when the finishing coat is troweled smooth with a metal trowel with as little rubbing as possible. It is then lightly patted with a brush of broom-straw, which gives an even stippled surface that is very pleasing. When a sand-floated finish is desired, the finishing coat, after being brought to a smooth even surface, is rubbed with a circular motion, with the addition of a little sand to roughen the surface slightly, this treatment being given when the mortar is partly hardened.

If, after the finishing coat has been brought to an even surface, it is sprayed by means of a long, wide fiber brush, such as a whisk-broom, dipped into the creamy mixture of equal parts of cement and sand, the sand-sprayed finish is produced. The cement-and-sand mixture must be prepared not more than thirty minutes before using, and kept stirred. The coating is thrown forcibly against the surface, and is applied while the finishing coat is still moist and before it has attained its early hardening. This means that sand-spray must be done within from three to five hours of the time when the finishing coat has been applied. If lighter shades are desired in the spray coat, hydrated lime is added to an amount not to exceed ten per cent. of the weight of the cement.

The rough-cast finish is also known as spatter-dash. The finishing coat is brought to a smooth, even surface, as before, with a wooden float, and before it has finally hardened it is uniformly coated with a mixture of one sack of cement to three cubic feet of fine aggregate thrown forcibly against it to produce a rough surface of uniform texture when viewed from a short distance, say twenty feet. Especial care must be taken to prevent the rapid drying out of this finish by means of spraying thoroughly at intervals after the stucco has hardened sufficiently, so that the spray water will not wash away the mortar.

Pebble-dash results when clean round pebbles or other solid material between one quarter inch and three quarters of an inch in size, and previously wetted, are thrown with sufficient force against the wall to embed themselves in the fresh mortar. The finishing coat is brought first to a smooth surface, and care must be taken to obtain a uniform distribution of the pebbles over the surface. Sometimes the pebbles are put into the mortar with a clean wooden trowel, but it is not possible to roughen the surface after the pebbles are embedded.

In addition to what has been said concerning exposed aggregates, it may be added that a solution of one part of hydrochloric acid in four parts of water by volume is used in place of clear water. This treatment leaves a clean aggregate surface, and the walls should be well washed with water applied with a hose after such acid treatment.

Besides the various colored aggregates to which reference has been made, it is sometimes desirable to color the cement mortar, so that, in addition to a variation in the color of the aggregate, further contrasts may be obtained. These inorganic coloring materials are used in quantities not to exceed twenty per cent. of the weight of the Portland cement, and must be very finely ground. A proper amount by weight of color is usually added to each batch of fine dry aggregate before the cement is added; the color and the aggregate is first thoroughly mixed, and after the cement is mixed in, the whole mass is shoveled from one pile to another over a mesh screen until a uniform color denoting uniform mixing appears. Water is then added to bring the mortar to the consistency desired for plastering or for concrete. The depth and the shade depend upon the proportion of the color used, and also on the color of the cement with which it is mixed, as well as the relative sizes of the cement and color material particles.

If grays, blue-black, and black are wanted, use Germantown lampblack, carbon black, or black oxide of manganese. Ultramarine blue will give varying degrees of blue. The red oxide of iron produces a color that may vary to a dull brick-red. Mineral dark red gives a bright red to vermillion. The red sandstone shading to purplish red is obtained by the commercial color known as Indian red. Brown to reddish brown is derived from what is known as metallic brown, which is one of the mineral oxides. Yellow ocher accounts for buff, colonial tint, and yellow. Beautiful greens can be obtained with the aid of chromium oxide.

Perhaps no better indication of the possibilities in the proper use of cement and concrete can be given than the fact that in many expensive monument buildings cement has been used for interior finish in the walls above the height of, say, ten feet. This extends beyond the artificial onyx, marbles, etc., to which reference has been made in the application of Sorel and oxychloride cements, to the reproduction of particular types of building-stone. There is at least one great structure in which an odd type of porous building-stone is used for the interior finish to a height of twelve or fifteen feet; but above that the concrete blocks are employed, and these duplicate so correctly the color, texture, and general appearance of the natural stone used in the first courses that very few know that there is this variation in the finish.

Artistic effects are often obtained in unusual places by the use of concrete materials. There is recorded the construction of artificial falls and rocks in a city park where this bit of beauty could not have been added to the scenery so well by any other method. These rocks have been made and placed in a manner to deceive the very elect, and there is reason to believe that the material will prove durable and entirely well suited for its purpose. Pergolas are now to be obtained complete from pre-cast units, made with great care in the shop and finished with white cement. Pleasing designs are obtainable, and the plastic material is well adapted to the execution of the various artistic designs.

CHAPTER XII

APPLYING CEMENT MORTAR

Cement and concrete must be placed in such a way as to secure a proper bond, uniform in strength and wearing qualities, and a density that will make it possible for the material to resist adverse agencies. The bond with underlying material is usually secured by thoroughly cleaning the old surface, wetting it or sometimes washing it over with a cement mixture or a mortar prepared for the purpose.

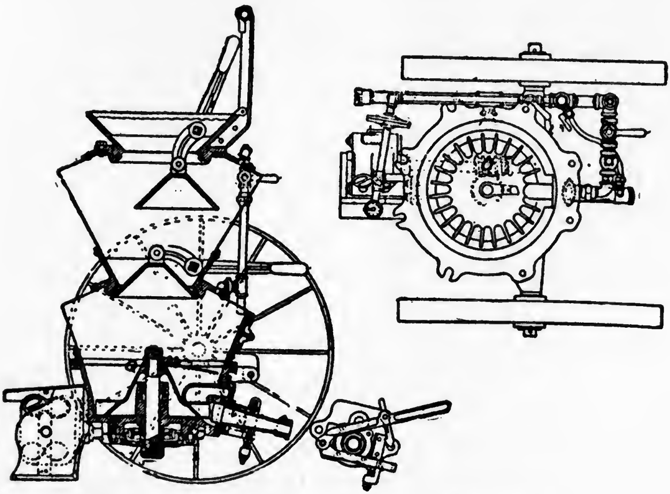
Bond between courses is assured by a similar method. Uniformity in physical characteristics results from a standardization of the materials used, and uniformity in methods of mixing and placing. Density is also afforded by the character of materials and their treatment, particularly tamping and spading material into place. This allows entrapped air to escape, brings excess water to the surface, and helps to fill the places between the coarse aggregate with the fine aggregate and cement mortar. Mechanical devices have been perfected for both tamping and bringing green concrete to the desired contour. Rolling and belting is employed as described in the chapter on highways.

It has been customary to depend upon hand working for compacting cement mortar on surfaces, particularly such vertical surfaces as the sides of buildings and horizontal overhead, like girders and ceilings. It is obvious that ideally uniform results are not to be obtained by such hand methods, and it was while coating forms upon which to mount the skins of animals for museum purposes that Carl E. Akely felt the need of a more flexible and easier way of spreading plaster of Paris. He turned to compressed air as an aid, and finally perfected the mechanical device now known as the cement-gun.

The cement-gun is not the first attempt to deposit cement mortar by mechanical means. It differs from its predecessors, however, in that it does not endeavor to convey wet material from a reservoir to the surface to be coated. This was tried some years ago; but it was found that lumping in the machine could not be avoided, and that the frequent shut-downs required to clean out the apparatus so greatly increased the cost of operations as to render the mechanism impractical. The cement-gun is a decided advance in engineering, and will doubtless come to play as important a part in future work as the mechanical concrete-mixer plays in construction projects. There are more than three hundred thousand concrete-mixers in use today, and, while it may be some time before so many cement-guns are in use, their number is steadily increasing.

Akely hit upon the simple scheme of conveying the dry material to the nozzle by means of compressed air, and of introducing in the nozzle a spray of water under pressure twenty pounds greater than the air-pressure. In this way hydration and deposition is secured coincidently, making it possible not only to spray as thin a coat as may be desired, but also to build up this coat to any desired thickness. The cement-gun is not confined to the application of cement mortars, but has been used with lime, plaster of Paris, magnesite, fire-clay, and other materials.

In order to make applications continuous, the princi-



CROSS SECTION DRAWING OF CEMENT GUN

ple of the air-locked caisson is employed, and the device consists of two hoppers, one feeding into the other, and each provided with an air-tight conical valve so designed that it seats against a gasket when the air is applied, rendering the chamber air-tight. Air-pressure is maintained in the lower chamber, and in addition a jet of air is introduced to drive the small quantities of dry material, brought to the discharge-tube by a revolving plate, out into the hose leading to the nozzle.

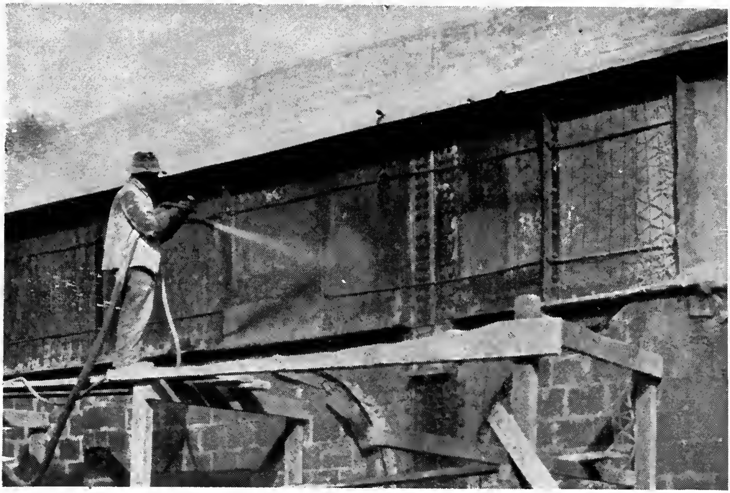
The pressure in the upper chamber is broken and applied alternatingly as the reservoir is charged with new material, the frequency depending upon the speed of operation. In this manner the proportion of sand and cement may be kept uniform, and the amount of water employed can also be nicely regulated.

In the lower chamber there is a conical-shaped feed wheel provided with pockets on the periphery, and this wheel is revolved by an air motor. In this way small quantities are brought under the air, admitted through a gooseneck, thus forcing the material through the outlet valve. The nozzle is chambered, and has needle holes in the inner wall through which the water is admitted. When the material thus hydrated is placed under pressure against a surface, there is a rebound composed of material virtually free from cement, so that the initial bond with the surface is through the medium of a very rich mortar and very dense, neat cement. The sand particles now drive against this first layer, each grain serving as a tiny tamp still further compacting the mortar. The sandy particles are driven by pressure into this coating, and a continually larger percentage of the mixture adheres to the coating thus built up. The sand that falls can be collected and re-used. The percentage of sand rebound is from fifteen to twenty per cent.

An air-pressure of thirty-five pounds is preferred under normal conditions when from fifty to one hundred feet of hose between reservoir and nozzle is in use. The water-pressure must always be at least twenty pounds greater than the air-pressure. When working with reinforcement there must be sufficient pressure to give the material velocity such that any rebound will clear the reinforcing wires. If the rebound does not

DETAIL OF SECONDARY PORCH, POTOMAC PARK FIELD HOUSE, WASHINGTON, D. C.

Balustrade columns and cornice were precast; walls are stucco on terra cotta tile; all are of the same color and texture. Designed and built by the Bureau of Public Buildings and Grounds, Washington, D. C.
John J. Earley, sculptor



ABOVE: SHOOTING "GUNITE" INTO PLACE

AT THE LEFT: THE CEMENT GUN

clear the wires it will fall into loose piles and form what has been called sand pockets. If the water-pressure is not greater than the air-pressure, the needle jets will fail to puncture the stream of flowing dry material, and will fail to secure satisfactory hydration. The action of the air helps to atomize the water, thus spraying the dry particles as they pass by.

A number of tests have shown that the proper proportions of cement and sand for the gun is one part of cement to three parts of sand, which, in view of the rebound, means that the mortar in place will be equivalent to a one to two and a half mixture. Careful tests have been conducted comparing the strength of gun-placed mortar with the best hand-placed mortar, and it has been found that not only could material be placed with a gun much more economically, but that it also has much greater strength. In one comparison a ditch that was being covered to the thickness of one inch had a depth of four feet and a bottom width of six feet with side slopes of one to one. Seventeen linear feet of this ditch was covered in one hour by the gun, three men being employed in its operation. Practically the same amount of material was used as was required by five men to cover the same distance by hand. They applied a coating one and a half inches thick, which is an indication of lower density; and it took the five men two hours and forty minutes. This means a saving of 40 per cent. in the cost of machine-placed mortar as compared with hand-placed mortar.

To determine whether there was any appreciable difference in the water-tightness of the two coatings, holes were dug behind the walls to a depth of a foot below the bottom of the ditch. These holes were then filled with clay and water. When the puddle reached the height of three and a half feet above the bottom, the hand-placed mortar broke up from the hydrostatic pressure and the permeation of the moisture. The gun-placed material was able to withstand a height of five feet without any effect other than a $3/8$ inch rising of the bottom. Samples of gunite, as cement-gun placed mortar is called, have been tested in the laboratories to determine the imperviousness of the mortar, and at the University of California samples one inch thick were subjected for two hours and twenty minutes to a pressure equivalent to that of a column of water 1,610 feet high, with no indication of moisture coming through. At 3,400 feet the specimen broke on bending, after having leaked a little just before breaking.

Still another series of tests has been made to determine how effective is the bond between the gunite and any underlying material. When the surfaces have been cleaned and thoroughly wetted, there is very little variation in strength between masses of gunite. There is reason to believe, therefore, that the adhesion between new and old surfaces is substantially perfect. Where a tensile strength and compressive test has been made, gunite has shown a strength 30 per cent. greater than hand-placed materials of the same kind.

Another important point is the reduction in volume which must be due to the filling of all the voids, and with this decrease in porosity there is a marked increase in water-proofness. The decrease in volume of units of given strength and the method of working indicate that forms as ordinarily employed can be eliminated to a great extent; and as there is no hydrostatic head to be withstood, as is the case with concrete, no heavy bracing is needed. In built-up walls cement has been shot from the inside against movable panels near which the reinforcing material is suspended, so that the desired thickness can be built up, and, when properly set, the panel moved on for the next section. At times tarred paper has been found a sufficient backing against which to shoot gunite through wire reinforcement, which soon becomes embedded in the mortar.

That thin slabs of this character have unusual strength is proved by tests made at Lehigh University, and also by engineers of the Quartermaster's Department of the United States Army. Thus a slab two and a quarter inches thick and seven feet wide was reinforced with triangular mesh woven wire reinforcement, and when ten days old was loaded with sand-bags until the loaded portion bore a weight of two hundred and seventy-eight pounds to the square foot. A deflection of one and five eighths inches occurred, and a crack appeared; but when the load was removed at a later date the normal position was resumed by the slab, and the crack appeared as a hair crack. It is evident from this that with the use of gunite the load on supporting piers could be somewhat reduced. Another series of slabs were tested by the United States Shipping Board, having in mind the development of beams and other units to be used for concrete barges. The failure of these slabs was by tension in the reinforcement, and in no case was there sufficient tension reinforcement to develop a high compressive stress before the steel had passed the yield point.

It has been shown that gunite has very close adhesion to steel reinforcement, and that its high density prevents the absorption of more than small amounts of moisture. These features, together with high strength, has resulted in successful use in concrete ship and barge work. In the case of barges, interior panels have been set up, against which gunite is shot from the outside. The walls are thus built up in one operation, and afterward troweled to true surface. The ribs are then built up directly against the completed walls, again using the gun. One such barge, upon having her side stove in, was completely repaired in about two hours, again using the cement-gun.

The several advantageous features that have been outlined above have brought the cement-gun into use in a wide variety of applications, and have introduced cement as a protective coating in places where it could not have been used otherwise, since a film less dense would have failed. A few of these special applications can be mentioned.

Railroads have had considerable difficulty with the corrosion of iron and steel that comes into frequent contact with smoke and gas from locomotives. The sulphurous and sulphuric-acid vapors in the products of combustion come into contact with these metals in a way to cause great corrosion. Steel can be preserved from this destruction by coating it with cement, which has been found to be one of the best preservatives for this purpose. Before cement can be applied the metal must be sand-blasted clean, and the cement-gun can be used as a sand-blast apparatus for this purpose. The machine allows the application of the mortar under pressure in a way that fills all pores in the surface of the steel and eliminates the air that always accompanies hand-placed mortar. In one of the great terminals more than one million square feet of steel surface has been covered with an almost unbelievable saving in the dead load, and at a cost less than that of the forms that would have been necessary had the concrete been poured.

Previous to application of cement in this fashion to protect steel, careful tests were made with special coated pieces to ascertain to what extent a change in temperature and atmospheric conditions would be detrimental. A piece of four-by-four-inch angle-iron, two feet long, was sand-blasted, and in one hour after cleaning was coated with a one-to-three mixture of cement and sand, the thickness of the coating varying from one-quarter to one-half inch. After setting, the sample was stored in moist sea air for three days, and then immersed in salt water for three days. It was then held at five degrees below zero for forty-eight hours, but not a particle of cement flaked off. It was coated with ice, allowed to thaw out overnight, and again examined, but no flaking occurred. The sample was then placed on top of a boiler and left there for three days. Careful examination with a microscope failed to show any unsoundness. The piece was then cooled and afterward dropped two feet, first on a wooden floor and then on a concrete floor. There were no cracks or checks. The sample was then dropped ten feet on a cement floor, and this broke the coating from the outside but not from the inside of the angle. The metal so exposed was examined for rust spots which would have indicated penetration of the water, but the metal was as clean as when sand-blasted.

Following this series of tests, the steel structure was protected, and after several months' wear, during which time very heavy loads were moved over it, no cracks had appeared, and a ringing sound when struck with a hammer indicated a perfect bond with the metal.

Severe tests have been made with gunite on levees in the Mississippi River area, where it was found that if a two-inch layer of gravel is first spread on the bank and afterward treated with very wet gunite, an impervious dense mixture can be built up. With a mixture of one part of cement to three parts of sand, the cost is about one third less than when an ordinary one: three: five concrete mixture four inches thick is employed. The tests have demonstrated the superiority of the protected levees of small sections over the larger standard sections of earth alone. Very little seepage occurred, and where gunite and sheet piling were used together no seepage occurred. The levee itself and the fields behind it remained dry. Such protection is particularly valuable where there is much wave wash, or where the land on which the levee can be built is expensive, since a smaller bank protected with gunite will give even better service than the large standard earthen bank.

The water-proof character of cement mortar, placed with the aid of compressed air, has made it a favorite medium for the repair, water-proofing, and indeed construction of various dikes and reservoirs. Where masonry has been used, the old mortar is very apt to become fragile or disintegrated, and no method of placing new mortar excels the cement-gun. The material shot from it penetrates all crevices and covers up every crack. On one reservoir where a section was carried away, the old masonry was prepared for surfacing while the new was being put in place. The old mortar was taken out to depths varying from one to three inches, and the walls were then cleaned and sand-blasted, and sprayed with water immediately in advance of the gun. The whole interior of the wall, including new masonry, was then coated, and the final result is a complete success. There has been no seepage. In this case the plaster was applied to an average thickness of three inches in a band about three feet in height above the floor-line, and carried on up with a thinner coating at the top of the wall.

In another case, a brick-lined reservoir showed so many leaks that it was relined with cement mortar shot in place, using a reinforcing mesh. An impervious condition was thus secured. In still another instance the ordinary concrete walls of a reservoir had disintegrated to such an extent that in five years the surface had disappeared to a depth to expose the reinforcement of triangular mesh wire. More recently the reservoir has been lined entirely with gunite, and without stone, using double reinforcement of triangular mesh wire. The use of heavy equipment was avoided, and indications are that the work will be entirely successful.

In Nevada an irrigation canal four thousand feet in length, five feet at the bottom, from eight to ten feet wide at the top, and with an average depth of four feet, has been lined with gunite, using a woven wire reinforcement. The cement coating is two inches thick, and, notwithstanding high costs because of the inaccessible location, the saving in water through cessation of seepage has indicated the wisdom of doing the work. The saving of water has been strikingly shown by the fact that vegetation which formerly flourished at the sides of the flume and beneath it on hillsides is now withered.

Dams have also been surfaced with gunite. In repairing dams, cracks on the upstream side are usually opened up with chisels to a depth of five inches or so, and then poured nearly full with hot asphalt, after which three layers of heavy burlap are painted over the crack with heavy coats of asphalt, so that they extend several inches each side of the crack. After repairing the cracks in this manner, the entire surface of the dam is covered with reinforcing wire mesh secured in place by spikes let into the masonry or concrete, after which the whole face is ready to be coated with gunite to a thickness of about three inches.

The necessity of thoroughly cleaning out old joints and cracks in masonry is illustrated by the experience of repairing the sea-wall at Governor's Island, New York. Although it was shown that the cement mortar had penetrated many crevices over two feet, failures have occurred where the seaweed and debris had not been thoroughly removed, thereby interfering with a proper bond. The joints in 4,300 linear feet of this wall were filled in one month, working between tides.

Masonry in places other than in contact with water often needs repointing and general repair to joints and surfaces. This has been successfully done with the cement-gun. The joints are washed, cleaned, and otherwise made ready, after which the surface is covered with light reinforcement and the mortar shot into place. The piers of a railroad bridge sixty-three years old had become disintegrated; but in 1917 these were restored and covered with an impervious coating of gunite, at a cost of only forty-seven cents a square yard, although the work was done under disadvantageous conditions.

In building construction exterior stucco and interior plaster are often placed with the gun. Frame dwellings are frequently made new by this process, and no better method has been developed for covering brick or old concrete buildings, as well as hollow tile. When covering frame buildings, it is customary first to make sure that the frame will carry the additional load; that the window-frames and other parts are in proper place and condition; and, since wood shows a tendency to absorb moisture, it must be protected from the mortar, from which it would otherwise shrink. A layer of tar-paper is therefore tacked in place. A light reinforcement of mesh is then put on with staples, and the mortar shot into place.

Where frame-work is used, the most satisfactory method of wall construction is obtained by placing the reinforcing wire directly upon the frames, and covering this with from three quarters of an inch to two inches of cement mortar. The reinforcement mesh must be furred away from the frame in order to be sure that it is entirely covered, and, as in all reinforced concrete, the reinforcement should be near the inner side of the slab. In carrying out this work, a panel may be placed along the plane of the outer surface of the wall, to be removed when the wall is finished; or tar-paper may be placed on the frame, where it acts as a form. The tar-paper serves the twofold purpose of insulation and a backing for the gunite.

There are a few principles to be observed in this method of construction. The tar-paper must be drawn tight, and firmly held in place; and the wire must be drawn to as near a true plane as possible. All reinforcement should be mesh of not less than one and a half inches. Reinforcement should never break at the corners, but should be carried around the corner for at least a foot. In a sharp bend the mesh should be doubled and strengthened by the addition of a small strip under and over the corners of windows and doors.

Some contractors use some type of fiber, such as old rope cut in very short lengths, claiming that this is an aid against checking. Others find that one part of cement, to which ten per cent. hydrated lime has been added, to three parts of sand is the best mixture.

Sometimes air-spaces are desired for insulation. This is accomplished best with three thin walls. The first can be shot against a movable panel set the proper distance beyond the reinforcement; the center wall can be built up against tar-paper over which a light reinforcement is hung; and the third or inner wall built up on reinforced tar-paper with reinforcing mesh hung against it after the first layer of gunite has been sprayed upon the paper. In this way, three thin walls are constructed, providing a double air-space. This was accomplished in one instance where an all-steel form was used, the outer and inner walls being supported directly on the channels, with the center wall supported by the tie-rods.

Roofs may be placed with the gun, just as well as other parts of the building. Edges and valleys must be doubly reinforced. Where expansion joints are to be included, these are made by turning the reinforcement mesh upward at the proposed joints, and placing between them several layers of tar-paper or felt. These vertical joints can afterward be capped with either metal or an inverted U of reinforced gunite. It is customary to shoot roofs from underneath against movable panels and light boards. The lower coat is shot to the thickness necessary to insure stability, and the finishing coat is then put on from above, after the panels have been removed.

Gunite has found useful application in treating railroad cuts to prevent falling of earth, and the right of way has been kept free through this system of sealing. It finds extensive application in tunnel, subway, and tube construction. It is equally important in mines, where it can be used to prevent the atmosphere from coming in contact with the strata making up the mine roof. It is the weathering of this material that often leads to the falls that cause continual expense for maintenance and repairs. Where timbers in mines are covered with cement mortar, they are also made weather-proof and fire-proof, and besides this there is less opportunity for dangerous floating coal-dust to lodge, so that the explosion hazard is decreased. Another important thing is the extent to which the circulation of air can be stopped, for in efforts to control fires in mines with ordinary equipment the ease with which air permeates coal, etc., makes it difficult to build up gas-tight protection walls.

At the experimental mine of the Bureau of Mines, extensive coating of entry and of passages has been done by way of experiment, and this lining comprises something more than one thousand linear feet of entry. The roof coating is from one-quarter to three-quarters of an inch thick, with the sides from one to two inches thick. In this work the dry-mixed material has been conveyed a distance of four hundred feet to the nozzle, and the following differences between cement mortar, applied by hand and mechanically, have been noted. In tensile strength the gun work excelled the hand work from twenty to two hundred and sixty per cent.; in compressive strength, from twenty to seven hundred and twenty per cent. The percentage of voids in gunite are only fifty-two to seventy-five per cent. of those in the hand-made product. The adhesion of the gun-applied mortar was, on the average, twenty-seven per cent. better than by hand work. The hand work absorbed from 1.4 to 5.3 times as much as the gun-made mortars and, as far as surface permeability was concerned, the gun work absorbed from one twentieth to seven tenths as much water per hour per unit area as hand-made surfaces.

The fire-proofing of timbers with gunite coating has been taken up very seriously by a number of the larger mines where shafts have been gunited. Notwithstanding the wide differences in temperatures to which gunite may be subjected in mining operations, it has stood well. On one property the temperature at the collar of the shaft is frequently far below zero, while in the pump-house the temperature near the roof exceeds 100° F.

Virtually all of the work in mine-shafts is done with light reinforcing material. With respect to mine operations the conclusions that have been reached are that the method of applying cement-sand coating in entries or tunnels in coal-mines with weak roofs is entirely successful, that the results of weather-proofing are very promising, that steel supports can be protected from rusting and wood timbers from fire. Fire-walls can be made gas-tight, can be quickly placed and repaired, and the method of applying the mortar with the gun is of the greatest advantage in fire-proofing wood mine timbers, covering adjacent porous formations, and making them air-tight.

Another field of usefulness is in highway repair work.

All in all, the cement-gun bids fair to become one of the most useful appliances in modern construction, and in maintaining and repairing various types of structures. In it a great number of advantages are combined, and it is another illustration of what can be done with the proper control of air. It belongs well up in the list comprised of such items as the pneumatic drill, the pneumatic painting-machine, the pneumatic hammer, and several other achievements of engineering that depend for their efficient operation upon the compression or expansion of air.

CHAPTER XIII

HIGHWAYS

The primary purpose of highways is to promote commerce and, incidentally, to facilitate ready contact between the individuals of communities that may be fairly distant. Sooner or later, possible emergencies call for types of construction that will carry more than the normal load and will be sufficiently permanent to repay the additional cost that such construction may entail. The famous highways of ancient times, which are still used in some parts of the world, were those built for military purposes, and the less important ones were not so built as to endure to our day. The present state of repair of these old roadways depends, in part, upon the climate in which they are found, the care exercised in the original design, construction, amount of traffic, and their maintenance.

The endurance of our own roads depends, of course, on the same factors, and our good roads, begun as an aid to trade bringing the producer nearer the market centers and affording the advantage of community life, have now become great lines for transportation under all conditions. Man being naturally a social animal, the first roads improved in the community are generally the main highways to the village, the church, and the school-house, and, because these bear most of the travel, they are usually the first to be made more permanent.

Changes in transportation facilities, as to the number of vehicles, the kind, and their speed upon the highway, together with the increased load carried, have made it necessary to extend our good roads program. This had already begun when it became necessary to turn at once to motor transportation to relieve congested railways and to gain time in serving the military establishment.

Thus experience has taught the country at large the value of good roads as a part of a national transportation system and the necessity of still better building to withstand modern traffic. The military roads of old could hardly have had such an important peace-time usefulness as do our roads, because of the smaller areas covered by them and the smaller population concentrated in greater proportion about certain centers. The ancient roads did involve the use of cement and concrete, according to the views of many who have examined the remaining materials and find upon them the marks remaining from the wooden forms which, it is believed, were used somewhat after the fashion in which we use wood or metal forms today.

In this chapter it is desired to indicate something of the care that should be used in constructing a standard highway, and to indicate some of the particulars in which the concrete highway qualifies as a structure comparable to the Appian Way or any of the roads of old that have won our admiration. The point is that it is not so difficult to build a good road, but that the extra precautions which, if taken, will make a good road still better certainly repay cost.

The rapidity with which the good roads movement has brought concrete into prominence is shown by statistics, which indicate the cumulative increase of concrete roads, streets, and alleyways in the United States from 1909 to 1918. Using the square yard as the unit of measurement, the total in 1909 was less than five million square yards. This increased slowly, reaching ten million yards in 1912, since which year the increase has been rapid, reaching as much as fifty-three million square yards in a single year, fifteen million in each of several years, and in 1919 the cumulative total was more than one hundred and thirteen million square yards. Of this, between seventy and seventy-five million can be attributed to roads, something more than thirty-five million to streets, and nearly five million to alleyways.

This development has been so gradual in some localities as to indicate clearly the policy of putting down a few miles, watching its behavior, and then perhaps trying a few more. In many states and communities definite plans have been worked out, and these plans are being followed as rapidly as events will permit. A few localities have adopted the plan of laying one half of the road, so that many more miles may be covered with enough concrete to give a width that answers the greater part of the time, leaving the other longitudinal half to be laid when more funds are available. While there are some objections from a construction standpoint to this method, there is something to be said in favor of it, since its use makes possible the more rapid extension of the good road system, and thus has a direct bearing upon the effort to make life on the farms comfortable and attractive.

In many communities concrete roads have developed wayside markets, and increasing numbers of people take delight in driving into the country to buy from improvised stands. Good roads also effect a great saving of time and power, whether the vehicle is horse-drawn or motor-driven.

This point has been well tested, and the results may be expressed in any one of several ways. If the number of pounds necessary to pull a ton is used as the basis for comparative figures, then it can be shown that the loose-gravel new road requires 263 pounds to pull a ton, over a level stretch. This is reduced to 218 pounds if it is an earth road with a soft mud surface, and a further improvement is to have the earth road covered with fine dust, when 92 pounds is required. A good gravel road makes it possible to move the same load with 78.2 pounds. A water-bound macadam, when in good condition, requires 64.3 pounds. Using a concrete base upon which asphaltic oil, with which screenings have been mixed, forms a top cover three eighths of an inch thick, this power is reduced to 49.2 pounds; but concrete itself unsurfaced gives the best figure reported, namely, 27.6.

In these days of motors, it is popular to express such results in the number of miles that can be traveled upon a gallon of gasoline. This test was made by a motor-truck company, using five two-ton vehicles. The experiment was conducted in 1918 during cool weather, and the trucks were loaded to capacity in each of the tests. The earth road made 5.78 miles to the gallon possible; fair gravel, 7.19; good gravel, 9.38; fair bituminous macadam, 9.48; fair brick, 9.88; good brick, 11.44; and concrete, 11.78 miles to the gallon. Thus, if all of our roads were paved with concrete, it would be possible to save 50 per cent. of the motor fuel now used, thereby greatly lengthening the time for which the present visible supply would suffice.

The high first cost involved in installing any good road is frequently used as an argument against its installation; but it can be proved that differences in cost of maintenance and repairs, calculated over the life of a modern highway made with concrete, are enough less than the sums required in other instances to make such highways an item of economy. Three roads of other grades will not outwear a single concrete roadway, and, when maintenance and interest upon bonds are added to the first cost in both instances, there is a distinct gain in favor of the concrete highway.

The reports of the State Commissioner of Highways in each of several States show maintenance of concrete roads to be approximately four mills ($0.004) per square yard per annum. Using the average width of the concrete road as a basis for calculation and the actual cost figures in the several highway departments, we find first-class concrete costing about $115 a mile annually for all types of maintenance; good gravel roads run between $800 and $900, while macadam is above $950 per mile per annum.

This, of course, directly affects the tax-payer, but people are beginning to see the fairness of not asking the tax-payer to assume the total cost of a roadway that we now have reason to believe will last for many, many years. Surely the coming generation should, in all fairness, be expected to pay a part of the cost, and therefore the bonding system of finance is coming into general use.

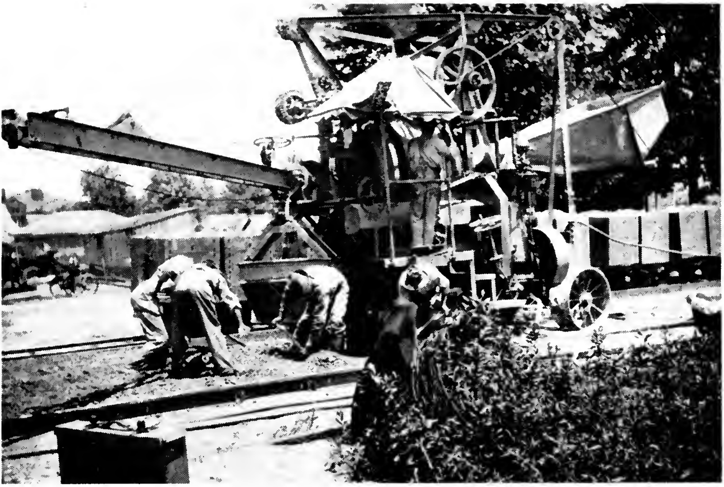
Another way in which good roads affect the tax-payer is in the maintenance of his vehicles that travel over various types of roads. We are rapidly approaching the eight million mark for automobiles and trucks of various classes licensed in the United States, so that something approaching thirty-five million tires are involved when we speak of increased mileage and a decrease in wear and tear upon tires and vehicles.

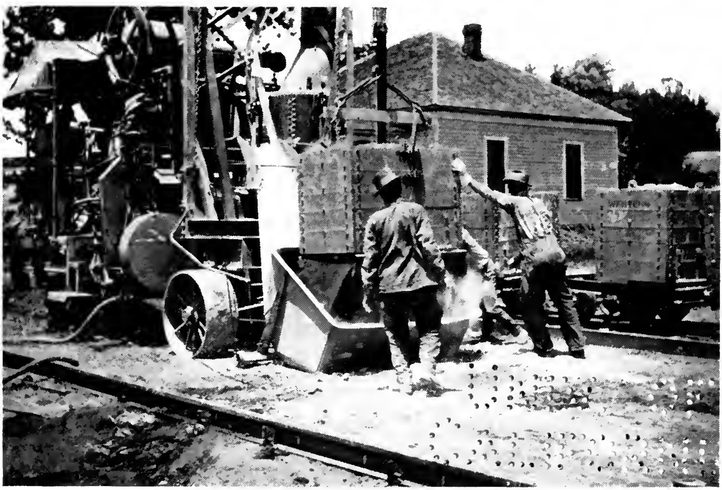
The material under discussion—concrete—has been found satisfactory on unusually steep grades, some of which are as high as 29 per cent. there being such a grade in Los Angeles. There are many examples of grades running from 9 to 20, and the less steep are common to all who drive. Perhaps more important is the ability of the concrete road to withstand all sorts of requirements. Any other road that could be built for anything like the price of building first-class concrete would be certain to fail soon under loads now commonly carried over considerable distances. Note, for example, the tests made upon certain types of trucks that are loaded to their maximum to show what they will hold, without a second thought being given to the ability of the roadway to support such a load; for experience has shown that concrete, if laid according to the best engineering practice, will sustain it. The practice in the Northwest of hauling great timbers on trucks especially designed for the purpose is another example.

In the design of concrete roadways, it must be borne in mind that as soon as the improvement has been completed the traffic it will be required to carry is sure to increase many per cent. This may demonstrate that the road is too narrow, or that it is too thin to bear comfortably all that is required of it. A good two-track roadway should not be less than eighteen feet in width, and if many trucks are to use the roadway twenty feet is much better. By light traffic is meant that which will provide no two vehicles to pass which will weigh more than six tons gross. Roads for this type of traffic are now made six inches thick at the edges and eight inches thick at the center for the eighteen to twenty-foot roadway. Where single, three-track, and four-track roads are to be put down, the design is naturally amended. The streets and roads bearing heavy traffic, with a width up to forty feet, customarily have a thickness at the side of eight inches, with ten to twelve inches at the center.

These roads are designed with a crown that need not exceed one hundredth of the width, and at times it is satisfactory to design such roads without a crown, especially if a finishing-machine is to be used in construction. Alleys, for the sake of drainage, are usually designed with a reverse crown or a concave surface, and the thickness of the concrete is dependent upon the maximum load that it is expected an alley must bear.

Good design now calls for a decided widening of the roadway at the turns, and these are frequently banked as well. The extent of both widening and banking is dependent upon the radius of the curve. As a matter of safety, it has been argued that no highway or street be paved around a curve of less than 150 feet radius at the inside edge, and where possible the radius should

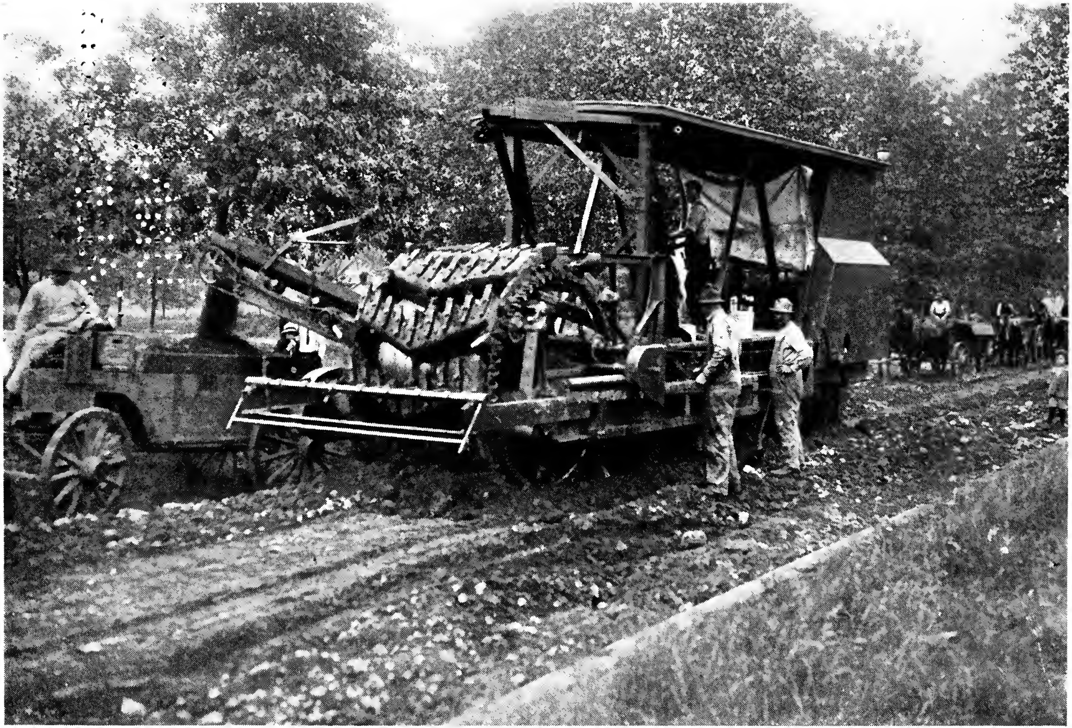




Courtesy Koehring Machine Co.

A TYPE OF MODERN CONCRETE MIXER USED EXTENSIVELY IN ROAD BUILDING

Note forms at the road side, the unit boxes of aggregates and cement on the industrial railway, the skip which conveys the mixture to the rotary mixer and the beam with traveling bucket to deliver the concrete where wanted



Courtesy Koehring Machine Co.

A ROTARY GRADER

A machine that cuts the subgrade to the required depth and conveys the material as removed to waiting dump wagons or be increased in order that better vision can be had and ample width provided for safe passage of vehicles.

The sub-grade, or earth, upon which the concrete is to be laid is a very important factor. The essential point is that as nearly a uniform condition as possible should be secured in the sub-grade. It does not make much difference whether this is wet or dry, so long as it is fairly constant. Sometimes extra reinforcement is used in swamps, or where the sub-grade is unstable for any reason. It is not uncommon to find the soil on a hilltop considerably more porous than is the case part way down the hill. Where soils of differing texture join, there is almost sure to be an accumulation of water that follows along such a seam, and this in wet seasons will produce a soft, seepy area. In such cases drains must be provided, and these usually reach into the more porous soil, so that the accumulation of water may be avoided. In a flat country drains are usually provided for the shoulder of the road.

The principal difference between the country road and the city street is the curb extending above the pavement level. A great deal of pavement has been laid with separate curbs placed adjacent to the pavement after it has hardened sufficiently to bear the workmen and the forms with safety. This necessitates a second operation, and does not give as satisfactory a job as the more recent integral form of curb. This system allows the curb to be laid at the same time as the pavement itself, and the saving in time and labor indicates that the integral curb is 50 per cent. more economical than either the separate curb or the combined curb and gutter. Besides this, the job is finished as the work progresses, and, in general, streets can be opened for complete use a considerable time in advance over that possible by any other method.

Aside from these construction advantages, it can be shown that the curb with a rounded intersection, such as the integral curb provides, is a difficult place for dust and dirt to collect, that it is practically self-cleaning, and that it actually serves to increase the width of the road, since vehicles are parked close to such a curb without injury to tires or rims. One of the objections to the usual concrete curb has been the abrasion from vehicles, which might soon cause chipping and disintegration; and this is obviated by the integral curb. There have been cases where gutters have broken through, but this can also be avoided by using suitable thickness of concrete at such points. Since as the name indicates, the integral curb is an actual part of the roadway, the joints in it are made in perfect alignment with the joints of the pavement, and expansion joints may be allowed to remain open, no filler being used.

Occasionally it is economical to use two-course construction, especially in laying a road through an area where local aggregates may be available in quantity, but where their physical character, such as resistance to abrasion and wear, is such as to make it necessary to bring better aggregates for the top or wearing coat. Where this practice is followed, it has been recommended that the lower course, using the less desirable aggregate, be a concrete in which one part of cement is used to two and a half parts of fine and four parts of coarse aggregate. The top course must be laid immediately after the lower course is placed and rolled.

Area of Cross Section, Cubic Yards, *Quantities of Materials Required per Linear Foot and Square Yards of Surface for Concrete Roads for Various Widths and Thicknesses Shown

*Based on 1 bbl. cement equal 4 cu. ft.; voids in stone, 45%. Factors used from Taylor and Thompson "Concrete, Plain and Reinforced."

Width Feet	Thickness Sides Inches	Thickness Center Inches	Thickness Average Inches	Area of Cross Section Square Feet	Cubic Yards Concrete per Linear Foot of Pavement	Square Yards per Mile	Cement Barrels 1:2:3	Cement Barrels 1:1½:3	Sand Cubic Yards 1:2:3	Sand Cubic Yards 1:1½:3	Rock or Pebbles Cubic Yards 1:2:3	Rock or Pebbles Cubic Yards 1:1½:3
9	6	8	7.333	5.500	.204	5280	.355	.389	.106	.086	.157	.173
10	6	8	7.333	6.111	.227	5867	.394	.433	.118	.095	.175	.193
18	6	8	7.333	11.000	.407	10560	.708	.777	.212	.171	.313	.346
18	7	9	8.333	12.500	.463	10560	.806	.884	.241	.194	.357	.394
18	8	10	9.333	14.000	.519	10560	.903	.991	.270	.218	.400	.441
20	6	8	7.333	12.222	.453	11733	.788	.866	.235	.190	.349	.385
20	7	9	8.333	13.888	.514	11733	.887	.974	.265	.214	.393	.434
20	8	10	9.333	15.555	.576	11733	1.002	1.100	.300	.242	.444	.490
24	6	8	7.333	14.667	.543	14080	.945	1.037	.282	.228	.418	.462
24	7	9	8.333	16.667	.617	14080	1.074	1.178	.321	.259	.475	.524
24	8	10	9.333	18.667	.691	14080	1.202	1.320	.359	.290	.532	.587
26	6	8½	7.667	16.611	.615	15253	1.070	1.175	.320	.258	.474	.523
26	7	9½	8.667	18.777	.695	15253	1.208	1.327	.361	.292	.535	.591
26	8	10½	9.667	20.944	.776	15253	1.350	1.482	.404	.326	.598	.660
27	6	9	8.000	18.000	.667	15840	1.161	1.274	.347	.280	.514	.567
27	8	11	10.000	22.500	.833	15840	1.449	1.591	.433	.350	.641	.708
30	6	9	8.000	20.000	.741	17600	1.289	1.415	.385	.311	.571	.630
30	8	11	10.000	25.000	.926	17600	1.611	1.769	.482	.389	.713	.787
36	6	9½	8.333	25.000	.926	21120	1.611	1.769	.482	.389	.713	.787
36	8	11½	10.333	31.000	1.148	21120	1.998	2.193	.597	.482	.884	.976
40	6	10	8.667	28.888	1.070	23467	1.862	2.044	.556	.449	.824	.910
40	8	12	10.667	35.555	1.317	23467	2.292	2.515	.685	.553	1.014	1.119

Cement for 1 cu. yd. concrete: 1-1½-3 Mix. : 1.91 bbls.; 1-2-3 Mix. : 1.74 bbls.
Sand for 1 cu. yd. concrete: 1-1½-3 Mix. : 0.42 cu. yds.; 1-2-3 Mix. : 0.52 cu. yds.
Stone for 1 cu. yd. concrete: 1-1½-3 Mix. : 0.85 cu. yds.; 1-2-3 Mix. : 0.77 cu yds.

FROM SPECIFICATIONS FOR CONCRETE ROADS, STREETS, ALLEYS, ETC., AMERICAN CONCRETE INSTITUTE. 1918.

This upper course should be not less than two inches in thickness, and aggregates exceeding one inch in size should not be used. The mixture should be one part of cement to one and a half parts of fine and two and a half parts of coarse aggregate.

The materials used are the ones familiar in concrete construction. All of them must be thoroughly tested, the mixture being designed in accordance with the strength desired and the aggregates available. In extensive work, samples of the concrete are often cast in the field from the material, as it is being placed, and results from such tests not only indicate the types of materials employed, but give information regarding manipulation.

It is nearly always desirable to use local sand, and this must be examined for organic impurities and silt, and aggregate should also be tested with respect to the organic material that it may carry. By clean sand in all concrete constructions, one that is free from clay, loam, silt, or organic matter is meant. Care is necessary in grading aggregates, and where stone screenings are used for fine aggregate there must be no dust with it. In the coarse aggregate it is essential to have tough, hard stone. Brittleness is to be avoided, and unless the aggregates are much harder than the mortar they afford no advantages whatever.

Too few look upon highway construction as an undertaking of the magnitude it really is. To be carried on successfully, careful organization and efficient equipment are needed. Care has been taken not only in working out the proper organization of a crew for highway and pavement construction, but diagrams and blueprints are made available indicating efficient methods for placing raw materials with reference to the work as it progresses, devices for conveying materials to the mixer and from the mixer to the roadway.

Work may be calculated on the capacity of the mixer, using, as is customary in concrete construction, the bag or cubic foot of cement as the unit. Supposing that a pavement twenty feet in width is to be laid with two-course construction and an integral curb, labor will be distributed somewhat as follows; assuming that there will be a boom-and-bucket delivery of the concrete to the point where it is placed: The foreman will divide his crew under the headings of forms, mixing and placing, finishing and curing, and protection. The forms will require a man to set them, and he will have a helper. Under mixing and placing, fourteen shovelers and wheelers will be needed, four cement handlers, one engineer, the mechanical mixer batch operator, and a fireman who will also wet down the sub-grade before the concrete is placed. Then there will be two concrete distributors, two men who will install any reinforcing and joint filling material, a man to attend to details of the sub-grade, and of course the ever-present water-boy. The finishing calls for a working foreman, two finishing helpers, and a luter, who also assists in rolling and belting the roadway. Two shovelers attend to details of curing and protection.

Since concreting of this type is a continuous operation, it will be seen that, even with this division of labor, there must be close coöperation if efficiency is to be attained.

The equipment needed includes a variety of materials, from the big batch-mixer to the stakes to be driven to hold the forms in place.

An examination of the catalogues of companies specializing in equipment for laying concrete roadways will indicate at once that a great deal of ingenuity is displayed in providing this equipment. Design has done well in keeping up with improvements resulting from scientific studies, and this progressiveness is indicated all the way from machinery to be used in preparing the sub-grade to devices for finishing the roadway itself. The contractor today can command, wherever the extent of construction justifies, rotary graders that dig and load from sixty to one hundred cubic yards every hour. These are motor-driven machines, moving forward on their own power, cutting out the road-bed, and loading the material so removed into trucks that take position alongside the conveyor. The digging is done by a rotating cylinder carrying herring-bone shaped buckets provided with teeth on their cutting edges. This cutting wheel is adjustable, so that a cut from one inch to two feet can be made, and these are more than five feet in width. The device moves forward as the cutting is being done, so that a tremendous amount of work is possible with a minimum of manual labor—quite in contrast with the old horse grader gang with its plows and picks and shovels.

There are also machines that can be adjusted to cut the sub-grade to the exact contour desired, and this device is sometimes designed to ride upon the edges of the heavy steel forms, used not only to support it, but to confine the concrete while it is setting. There are many mixers, some of which can be located so that the mixing action will continue without interruption for the time mentioned in the specifications. There may also be a measuring device for the water to be used with each batch; and, having once determined the quantity of water required to give the best consistency with the materials in hand, this device may be locked so that concrete of uniform quality is sure to be delivered.

It is a long step from the old mixing platform where a number of workmen constantly turned the batch with shovels until it was uniform in appearance to the labor-saving machines that are available today for extensive work. These mixers are self-driven; some have caterpillar traction, and the more complete ones include a boom designed to serve as a track for a bucket operated by a cable and under the control of the engineer. With this device there is a great saving in labor and a marked increase in the yardage that can be placed daily. The bucket opens automatically at whatever point it may be stopped on the boom, and thus partially spreads the concrete delivered. This bucket automatically closes when it returns for the next load. At the other end of the machine is a skip into which the raw materials may be delivered by wheelbarrow, or into which they are sometimes dumped from special boxes delivered alongside by a little industrial railway. The crane lifts these boxes from the trucks and quickly dumps their contents into the skip. This type of box has a further advantage in that proper proportions can be placed in it at a central plant adjacent to the stores of raw materials. Boxes are also used without the skip.

Another method for conveying raw materials to the mixer is the use of a belt conveyor over which measuring bins are mounted on rollers that enable the workmen to place them in a position accessible to the materials. The number of bins depends upon the capacity of the mixer, and they can be adjusted to give the required quantity of material. The belt moves at the rate of 450 feet a minute, and quickly carries the proper proportion of raw materials to the mixer. This eliminates the wheelbarrow, and makes possible a marked increase in the amount of concrete that can be placed daily.

Some mixers are provided with heating systems, so that asphalt can be mixed with aggregate. These heating systems are also useful when placing concrete in cold weather.

Thus far, the storage of raw materials on the ground has been considered; but frequently portable material bins of large capacity are set up in a way to allow the batch-boxes, previously described, to be run under them on the portable railway. These material bins are filled by mechanical loaders from railway cars, so that there is no rehandling of material. Sometimes such portable bins are so designed that a standard flat-car can be used to transport them, and by the use of jacks they can be easily reset in any desired location.

Any contractor, bidding upon the construction of a roadway, will give careful consideration to the water supply, which must be free from oil, acid, alkali, or vegetable matter. The supply must be ample, and sometimes it is necessary to sink special wells.

Small reservoirs, or stand-pipes, have been constructed in order to furnish water under pressure. The size and type of the pumping plant depends upon the length and grade of the pipe line and the size and condition of the pipe. A minimum of twenty-five gallons of water to the square yard is usually required, and this may run up to very much larger figures. For the curing process from twenty-five to thirty gallons to a square yard is needed, and this may increase in hot weather. About eight gallons a square yard are needed for mixing, and another gallon or two will be used in preparing the sub-grade.

Another important accessory is the forms, which may be of either wood or metal. Wooden forms are of heavy timbers, usually two inches in thickness, held in place by suitable stakes. More recently steel forms have come into use, and some of these are designed to cast the integral curb with the base. The devices for finishing the sub-grade and also for completing the pavement, which have been mentioned, frequently are carried upon forms of this description.

Without going into details relative to the actual placing of machinery, forms, and the like, the process of placing the road may be considered. The sub-grade is preferably prepared with the same contour as the finished road is to have. It must be carefully prepared, and sometimes steps are taken to make it more firm and of uniform density. If very dry it is usually sprinkled. The concrete is distributed by a template, or, on pavements more than twenty feet in width, it is sometimes spread with a lute, which resembles a toothless rake.

The distribution of the material to the proper depth is controlled by pins so placed that no more than slight irregularities will be left in the surface of the pavement, and these are removed by the finishing operations. The pins are withdrawn as soon as the concrete has been placed about them. Expansion and contraction joints are left at definite intervals, and these joints are occasionally designed to be invisible. Joints have been used in which metal plates provided with bolts embedded in the concrete protect the slab, and between such plates asphalt felt may be used as a filler. In general, expansion joints extend entirely through the pavement and through the intergral curb, if it is used. The concealed joint is customarily employed as a contraction joint.

Reinforcement is often used in roadways and particularly in city pavements. An expanded metal or reinforced wire mesh, weighing about twenty-five pounds to one hundred square feet, is often recommended; and such reinforcement is placed not less than two inches below the finished surface of the pavement, and extends to within the same distance of joints, but of course is not permitted to cross them. At times steel bars five-eighths inch square or three-quarters inch round have been laid around the circumference of a concrete block. This plan has been suggested because cracks that occur are very likely to originate about the edges. The same care in using reinforcement in a condition that will insure a good bond with the cement is observed here as elsewhere.

In finishing concrete roadways a machine may be used, or a roller and belt are employed. The machine has been found to give good results where a stiff mixed concrete has been used; but if the machine requires a concrete with considerable water to work properly, it cannot be recommended. The roller method is extensively used. It has for its object to compact the mass and to work any excess water to the surface, where it can be removed. Such rollers weigh not more than one hundred pounds, and are operated either with a handle or with ropes and two bails, by which it may be pulled across the pavement. In use the roller is so manipulated that about two feet of the pavement is covered each time the roller crosses it. After once applying the roller, an interval of from fifteen to forty minutes is allowed to pass, and the operation is then repeated a second and a third time.

Following the rolling, a canvas or rubber belt, at least six inches wide, is applied with a crosswise and longitudinal motion. This gives a smooth, homogeneous surface, upon which a wooden float may be used at such points as is thought necessary—for example, at the joints.

The material used in the joints is a plastic compound of such a character that it does not become brittle in cold weather nor excessively soft in hot weather. A bituminous material with a fiber matrix is customarily used. This is from one-quarter to one-half inch in thickness, and in laying the pavement a quarter inch or more of the filler is allowed to protrude above the pavement. When the pavement has hardened, the excess filler is quickly trimmed, sometimes by using a shovel upon which metal strips have been fastened to give it proper height, so that not more than three-eighths of an inch of the joint filler will extend above the pavement.

Much of the strength and wearing qualities of a concrete road may be lost unless proper curing conditions are maintained for a minimum period of at least ten days. All consistencies of concrete show great increases in strength under favorable curing conditions. As compared with concretes that have been allowed to dry out immediately, the affect upon wear is quickly apparent. Unfortunately, too little care has been given to the maintenance of proper curing conditions, and many faults of concrete floors, such as excessive wear and dusting, may be traceable to an insufficient supply of water for the hydration of the hardening cement. Dusting is not likely to occur in concrete pavements if sufficient water is gradually supplied by the elements; but if it is allowed to dry out prematurely, it may have low wearing resistance in the first periods of its life, and may be badly worn even before the rain or snow has had an opportunity to supply the desired moisture. A variety of practices has grown out of this effort properly to cure pavement concrete.

The method that has been used more than any other is to keep pavements covered for at least ten days with a minimum layer of two inches of moist earth, which is sprinkled morning and night. Following the belt finishing, the concrete is covered with canvas to prevent rapid evaporation, and as soon as earth can be applied with safety it is spread over it. At the end of ten days this covering is removed; but the pavement must be kept closed to traffic for at least another four days, and preferably from ten days to two weeks, especially if the temperature is not much above 50° F. When the temperature is lower than this, the earth is sometimes omitted, as evaporation is not so rapid, and frequent sprinkling substituted. An effort is always made to allow hardening to progress slowly and uniformly. Nothing is to be gained by the premature opening of such a roadway to traffic.

Another method, followed particularly in warm weather, is called ponding. In this method about two inches of water is kept over the concrete for ten days, earth being formed into dikes around areas of such size that they will easily hold the depth of water desired. At the end of the day these areas are flooded with water not required for the mixer. This, of course, is applicable only to level stretches of pavement. When the curing has progressed to the desired stage, the water is easily drawn away and the pavement swept clean.

There have been cases where water under pressure is supplied to sprinkler heads, the pipe being supported on small blocks, and with this arrangement it is easy to furnish enough moisture without the necessity of any one going out upon the pavement day after day. On road work, each morning the previous day's pavement is covered with earth, and the canvas used to protect it while it was setting is rolled up to be used during the new day. Frames to support the canvas are often provided, so that immediately after a section has been finished, especially if it is hot or windy, it can be given protection.

Winter brings another problem. The hardening of concrete proceeds very slowly at low temperature, and the water necessary for hydration must not be allowed to freeze. Sometimes the aggregates are heated in rotary heaters on large construction work, or by jets of live steam directed into the piles as the material is loaded into the batch-boxes, cars, or wheelbarrows. The mixing water must also be heated, and chemicals are sometimes added for the purpose of either accelerating the hardening or preventing freezing. In general, engineers disapprove of the use of chemicals that would harden concrete; but under some circumstances, where other protective measures cannot be readily employed, calcium chloride is sometimes employed. This material possesses the property of lowering the freezing-point of the water and also of accelerating the setting of the cement. It is a crystalline material readily dissolved in the mixing water, and the quantity used should be about 3 per cent. by weight of the mixing water. It can be used safely if the temperature is only slightly below freezing.

Ordinary salt is commonly used in concrete mixtures. It lowers the freezing-point of the water, but it seriously retards the setting of cement, which is quite the opposite of the condition desired when placing concrete in cold weather.

As pointed out elsewhere in this book, as long as water does not actually freeze, the only difficulty in placing concrete in cold weather is the slowness with which it hardens. Warmth tends to accelerate the initial setting; and that this may go forward with some rapidity, the recommended practice is to take steps to enable the concrete mass to be placed upon the subgrade when the temperature is not less than 80° F.

In cold weather, immediately after placing concrete it must be protected either by canvas on frames, or covered with hay, straw, etc. Sometimes steam is blown under canvas covers; occasionally braziers are kept burning underneath canvas or other covering, and such other steps as are expedient are taken to maintain a temperature as much above 45° as is possible for at least ten days.

If sawdust is used for protective covering, it should be determined in advance whether or not it will stain the pavement surface.

If concrete roadways are to yield the long life of service of which they are capable, they must be maintained in a systematic manner; and nowhere does the old adage that a stitch in time saves nine prove to be true to a greater extent than in this connection. As will be cited below, cracks are certain to form in such blocks of concrete; and no matter how small these may be, they gradually widen, due principally to the action of freezing water that collects in the smallest cracks. Sometimes the whole system of cracks is made up of individual members so small that they tend to preserve the pavement, since the expansion and contraction take place with more or less uniformity throughout the surface; and these small cracks may prevent the formation of a few very large ones. This is particularly true of stucco, in which there is little opportunity for free water to collect.

However, there are pretty sure to be a few cracks large enough to merit special attention, and joints are also likely to become more or less separated. The necessity of attending to such cracks has led to the development of practically standard equipment in use by highway departments. Sometimes a light automobile truck or roadster, remodeled into such a conveyance, is used to carry the few tools required, and a kettle for heating the tar used in filling cracks is attached at the rear. One-horse wagons are often used in the same manner.

The first step in effecting repairs is thoroughly to clean the crack or joint; and for this a sharp hook, a small pick, and a stiff brush are usually employed. Loose particles must be removed, and, where openings are too narrow to permit this method of cleaning, air is sometimes used, obtaining compression by means of an automobile tire pump of the usual hand-operated variety or one attached to the motor. When thoroughly cleaned, enough tar is poured into the crack to flush over the edges; the tar is then covered with dry coarse sand.

In repairing joints it is good practice to remove the old joint material to a depth of from a quarter to a half inch below the surface of the concrete, thus affording an opportunity for the new material to effect a good bond. Good workmanship calls for the manipulation of the hot tar in a way not to disfigure the pavement, and, to avoid unsightly wide lines, the spout of the pot from which the tar is poured is bent so that a very thin stream can be secured.

The tar used is refined coal-tar having a melting-point of about 100° F. This melting-point can be determined by heating a half-inch cube in water and noting the point at which melting occurs. In order to secure a very free flowing material, the tar is heated from 225° to 250° F. at the time of application.

Next in importance to cracks and joints come surface pockets, which are usually due to the use of aggregates

STREET WITH INTEGRAL CURB AND EASY SIDEWALK APPROACH

CONCRETE PAVEMENT FINISHING WITH STRIKE-OFF BOARD, CANVAS BELT AND ROLLER

Belt used to remove surface water ahead of roller and used again behind roller that are too soft, or to the occurrence of a lump of clay that has disintegrated in the pavement; and sometimes a piece of coal or wood, inadvertently mixed with the concrete, gives rise to such a pocket. It is a matter of common knowledge that most of these pockets begin with a little depression, perhaps not more than one inch in diameter; but this easily becomes a source of trouble, not only because of possible freezing, but because edges easily broken by traffic are thus provided, and the pocket soon becomes a hole that is worn in all directions and can easily become the starting-point for serious repairs unless handled in time.

Such pockets, after a thorough cleaning, should be filled with hard, small aggregates from one-quarter to three-eighths of an inch in size, and hot tar is then poured into the opening until it is flush with the surface. Very coarse dry sand is sprinkled on the tar while it is still hot. Recently, emulsified asphalt has been successfully used with small aggregates for this type of repair work.

Sometimes slight depressions appear in a pavement. These may be due to a variety of causes, and frequently it is desired to fill them. If the depressions are not of great extent, layers of tar may be used, applying dry coarse sand between them until a sufficient depth has been placed.

Sometimes replacements must be made to such an extent that it is necessary to cut through to the base and form a compact mass on which to place the new concrete. Gravel is placed in the sub-base for this purpose, and thoroughly rammed, after which the sides of the opening should be painted with a mixture of neat cement and water before placing the new concrete. If, in the interim between cutting through the pavement and placing the new material, water should collect in the opening, this should be removed and the sub-grade again compacted by tamping before completing the repair. It is desirable to use a stiff mixture in repairs of this character, and one that requires considerable tamping to bring water to the surface in the process of ramming the mixture into place will be satisfactory. It is particularly desirable to have the concrete thoroughly rammed into place about the edges of the patch.

The surface is carefully struck off to the same level as the remainder of the pavement, is kept moist for several days, and is protected from traffic a sufficient time, usually ten days, to allow it to harden. If the area is large it can be treated almost as a new piece of work, and should be cured and protected similarly.

When old concrete pavements are to be resurfaced, every effort must be made to secure a good bond between the old layer and the new concrete. Following the practice used in repair work, the old street is thoroughly cleaned and brushed over with grout of wet consistency. After this, the new material is placed, finished, and cured, just as if a two-course pavement were being laid, and the methods recommended are followed. Any joints in the new layer should come directly over those in the old pavement, and it is customary to assure this by the use of thin wooden strips over the old joints. When the pavement is hardened, these are removed, and joint filler or the kind of tar used in making repairs is filled in.

In resurfacing old concrete, the new layer should not be less than three inches thick and the coarse aggregate should consist of particles not more than one inch in size. A satisfactory preparation has been found to be one part of cement, one and one half parts of fine aggregates and two and one half parts of coarse aggregate. The reinforcement is placed in the middle of the new layer, and if any holes are found in the old pavement these should be filled before placing the new material.

When old pavements are to be widened, the first operation is to lay down a concrete foundation for the new part along the edges of the old slab of the same thickness as the old slab, brought to the same level, and with precautions taken to secure good bond with the edge of the old pavement. The mixture of one part of cement to two parts of fine aggregate and four parts of coarse aggregate has been found suitable for this work. The extension thus laid should be allowed to cure for two days, during which time it must be kept wet, and the surfacing layer may then be placed on this widened slab. Such resurfacing is not confined to old concrete pavements, but is often used upon worn-out pavements of other kinds. When undertaking improvements of this type, the best engineering advice should be sought with reference to the condition of the sub-grade and the suitability of the worn-out material properly to support the new pavement.

The sidewalk problem is closely related to city pavements, and may be considered in connection with them. The loads to be borne are obviously much less, and, while the same principles of construction apply, it is manifest that thinner slabs can be laid, that finer aggregates are more suitable, and that usually a smoother surface is required. The character of the surface has been a matter of development. It will be recalled that formerly it was customary to finish a pavement with a richer mixture that gave a very smooth surface, but that unfortunately provided two dissimilar layers having different coefficients of expansion and sooner or later liable to separate. This has been gradually replaced in some communities by a one-layer pavement with surface finished in some modification of a stippled treatment. Still more lately, lighter aggregates have been used, and manipulated in a way to have them form the surface of the walk and bear the wear. Here and there a city requires the use of lampblack to avoid glare, giving a slate color.

It is always desirable to lay pavement, curb, and sidewalk at the same time, for then proper provision can be made for driveways and crossings and many details included, which are appreciated by all kinds of traffic, including pedestrians. In some instances, an inclined sidewalk approach has been installed. This means simply that at the point where the sidewalk comes to the street the curb, walk and pavement are so molded that in place of a curb there is an incline from roadway to walk. This has no disadvantageous features, but provides an easy transit from one level to the other. Such construction is sure to have the approval of those who walk with difficulty or those desiring to cross streets with perambulators, as the five- or six-inch vertical step at the curb line is entirely eliminated.

This subject cannot be passed without emphasizing how desirable it is for the tax-payer to insist on the employment of a contractor who has made a record in successfully installing roadways, pavements, alleys, walks, or whatever the structure under consideration may be. So much is involved, considering the number of years that mark the life of such a pavement, that it does not pay to experiment with amateurs or to intrust such improvements to those who, while thoroughly honest, do not have the experience to make them capable of putting into the concrete pavement the qualities that it must have to make it permanent, and that it can have if all details receive proper attention.

The contraction and expansion of concrete roadways has received very careful consideration, and committees composed of eminent authorities have made exhaustive investigations. There is no question about the expansion and contraction of concrete as affected by the moisture content, this point having been definitely established as applying to concretes of all ages. An increase in moisture gives rise to expansion, and when the concrete dries out contraction takes place. Obviously, an ideal condition would be that which would provide for a decrease in the moisture content with a temperature increase, so that drying might compensate for the slight expansion due to a rise in temperature and an increase in the moisture content when the temperature decreases. To be sure, a variation in the quality of the concrete has something to do with the tendency to expand and contract, as dense mixtures absorb water less rapidly than do porous ones. Consequently, if concretes of different qualities are used in road construction, there will be a variation in the behavior of the mass; the more porous of two concretes will have a tendency to expand, and will also have less resistance to the stresses that will be set up. This difference in the quality of concretes might easily cause separation under certain conditions, whether one-course or two-course work had been used.

From this it will be seen also that the amount of moisture that is held in the sub-base is an important factor, since concrete has the ability to absorb moisture from the ground. The action of frost in a sub-base containing moisture can occur only in localities where the temperature drops to a point so low as to freeze to the depth of the sub-base. The effect of freezing and thawing in the sub-base is that the slab becomes subjected to forces that may cause cracking. The ability of the sub-base to freeze depends upon the porosity of the material, the ease with which it takes up moisture, and the average distance below the sub-base at which water remains in the ground. The movement of the slab on the sub-base, while actually very slight, may still cause friction, which is a factor affecting expansion and contraction.

The Committee of the National Conference on Concrete Road-Building, after discussing the factors that cause some of the cracks in roadways, present data indicating how our present knowledge can be used to prevent the formation of such cracks. It is believed that, with a proper understanding of the physical phenomena involved, much of the cracking can be eliminated. Longitudinal cracks usually occur only after some seasonal change, while transverse cracks may occur at any time—but usually during the first drying season—when the pavement indicates marked contraction. Longitudinal cracks are believed to be caused by the unstable condition of the earth beneath the pavement. They may, however, be caused by a combination of factors, involving the moisture content in the concrete, the temperature of the atmosphere, and stresses caused by condition of the sub-grade. Diagonal cracks may be caused similarly, and occasionally result from the action of stresses that are at right angles to each other. This would be the case, for example, when longitudinal stresses were set up along one side of a pavement in contact with some rough structure that would tend to hold the pavement in place.

The best mixture to be used, if cracks are to be reduced to a minimum, is a dense one that will tend to reduce the absorption of moisture. A test specimen of such a concrete should show a minimum strength of 1500 pounds to the square inch at the twenty-eighth day test.

Some experimenters have thought that cracks might be due to the use of concrete slabs of improper length; but it has been shown that on level roadways the size of the slab will depend almost directly upon climatic conditions. Where there is little rainfall the slab should not exceed twenty-five feet, this length being chosen as the result of observations upon roads in California and measurements made by investigators at the Bureau of Standards. Where rainful is intermittent and conditions are similar to those found east of the Mississippi River, the ground water rising in cool seasons and sinking lower in warm ones, it has been found feasible to use a slab varying from thirty feet in length to one that is practically continuous.

The length of the slab does not appear to have any effect upon longitudinal cracking, but it should be varied with the quality of the concrete. Thus a dense concrete absorbing less moisture will have a lessened tendency to move, and at the same time will have greater strength to resist stresses introduced by restraint of the sub-base. The character of the sub-soil is also a factor, and, where unstable, shorter slabs should be used. Also, if the sub-grade is very smooth, so that frictional resistances will be more or less uniform throughout its length, longer slabs can be used than where a rough sub-grade obtains. Under such conditions shorter lengths can care for a proportionate share of the stresses. If a so-called smooth sub-grade has a number of rough places, these, through the tendency of the slab to move, may easily cause cracking.

The season at which the road is constructed also has some bearing on the length of slabs that can be used. These may be longer if placed in the fall or winter, particularly where they are not subjected to freezing, than if put down during the spring or summer. When laid in the fall, the tendency to increase due to absorption of moisture is somewhat counterbalanced by the decrease due to lower temperature, so that in the first few months of its life the slab is not subjected to so great stress.

In general, the length of slab may be increased in proportion to an increase in its thickness. The added weight assists in overcoming friction, and slabs of greater thickness have an increase in ability to resist stress which is greater than any increase in friction caused by the added weight.

It will occur to many that, if variations in moisture content have a direct bearing upon the expansion and contraction of concrete, a more stable condition could be obtained if a bituminous material were applied upon the surface. There are those who argue that the ordinary concrete surface has the same action upon a tire as would be the case if it were held against an abrasive stone; but opposed to this statement is the one that the sandy surface of concrete gives greatly increased traction; that the concrete surface resists skidding to a far greater degree; and that there is never any trouble from a soft surface in hot weather, which may even give rise to stickiness or to the creeping of the pavement, due to the actual flow of the covering on certain grades.

As far as the prevention of cracks is concerned, the experimental results indicate that there is a greater movement of concrete that has been covered than with that upon which no bituminous material has been placed. The reason for the movement has been laid to the power of the black surface to absorb and retain the heat from the sun, while, at the same time, any moisture that enters concrete at the sides or from beneath is held in it a much greater length of time.

Reinforcement is used in pavement to increase its strength and also to prevent cracking. It has been shown that reinforcement is of value when the width of the pavement exceeds twenty-five feet, when a decided change in grade occurs, or whenever a thin slab is required. In some regions there is a lack of water for curing, and reinforcement improves the quality of pavements constructed under such conditions. If the foundations are uncertain, if extra long or wide slabs are wanted, or if there is very little rainfall in the region, then reinforcement will be of value. If there is difficulty in placing joints or if a decided change in grade occurs, here again the necessity for reinforcement is indicated.

Obviously, joints installed in ways that have been described have for their principal purpose the relief of the stress due to changes in the volume of the concrete mass. Since there is only an occasional slab that fails because of a crushing action, joints are usually reckoned as providing for contraction. Sometimes roads are constructed without joints, with the idea that cracks will develop where there is the greatest need for expansion joints. When filled with tar or other resilient material, these will perform the same service. To be sure, the cracks will appear, but only after the concrete has been weakened in a way that may lead to partial disintegration of the road and demand for more extensive early repairs. The joints are usually designed to provide only for contraction, upon the theory that all stresses developed by reason of expansion will be absorbed by the concrete, which is able to withstand considerable compression. At street intersections and sharp, open curves there should be free movement of the concrete wherever it is restrained, and therefore joints should be placed at such points.

There have been objections raised to the extensive use of concrete roads, and it may be well to indicate some of them. The glare of light-colored pavement has been found objectionable by some. To overcome this glare the surface may be roughened so that the light is broken up, or in extreme cases enough of the concrete and sand mortar may be brushed out to expose the aggregate which, under wearing conditions, will be free from glare. As far as city pavements and sidewalks are concerned, mineral pigments may be added to the mortar, thereby producing virtually any color that may be desired. In some instances, lampblack has been used for this purpose.

As far as noise is concerned, no one has as yet shown how a road that will be permanent can be made of hard materials which do not give rise to noise. This objection does not have the force it once did, for noise today is quite independent of the road surface, being produced by the explosion of the internal combustion motor rather than by horseshoes upon hard pavement.

At one time there was an objection to concrete roads as being slippery. It is known that they aid in preventing sidewise slipping,—which we call skidding in the case of automobiles,—and that the gritty surface of a concrete road prevents the side-slipping of horses, which is considered more harmful than either forward or backward slipping. To prevent the road being too slippery for the use of horses, the green concrete is sometimes brushed over with a broom to produce roughness, or the aggregates brought near the surface to give a more secure footing. In this connection it should be pointed out that the same load is more easily moved over concrete than over most other pavements, so that hundred per cent. traction is less important.

The fact that a concrete road is free from loose stones and has an even surface practically overcomes any objection that might be raised to the hardness of the road. It is loose stones on the surface of ordinary roads, and the small holes to be found in them, that cause the most injury to the horse.

CHAPTER XIV

CONCRETE IN RAILROADING

Perhaps the first appearance of concrete in the railroad field was in the shape of culverts and small bridges. Later it came to be used in station structures and freight-houses. A few years ago we began to see the standardized type of small shelter provided for trackmen, switchmen, and others whose work carries them along the right of way. The familiar old wooden shanty at railroad crossings is giving way to a neatly designed monolithic house, which is sometimes cast at a central point and conveyed on a flat-car to the point where its service is to begin.

In many districts where losses of posts and poles by fire have been serious, concrete has replaced wooden materials formerly employed. The slowness with which this permanent type of pole or post has displaced wood on the right of way is in part due to the cost of transporting these reinforced members to different parts of the system. In considering any railway problem it must not be overlooked that railroads cannot haul their own materials entirely free of charge. Where the roadway crosses the railroad, concrete lumber has come into somewhat extensive use. Most of the maintenance expense of highway grade crossings is due to the loosening and destruction of the planks by the traffic; and in time respiking new planks to the ties, together with alternate wetting and drying where the two pieces of wood come in contact, causes rotting and decay, so that the ties then have to be replaced. Any type of construction that will reduce this item of material and labor cost is desirable.

This has led to the use of monolithic concrete crossings, and also to the use of pre-cast slabs to which the name concrete lumber is applied. Some of the slabs are laid directly on sawn track-ties, or on strips nailed to ordinary ties. The track is prepared by thoroughly tamping the ties. The weight of the slab is sufficient to hold it in place, but in some instances malleable iron sockets have been placed in the slab when cast, so that they may be anchored more securely with screw-bolts that pass through the sockets. Reinforcement is used in slabs of this type, and because of the service to be performed the edges are protected by metal angles and by handling sockets, which makes easier the work of placing or removing the slabs.

A convenient pre-cast unit is nine inches in width, from six to eight feet in length, and of a thickness equal to the depth of the rail. Where mesh or expanding metal reinforcement is used with bars, the heavier metal should extend lengthwise in the unit.

Where the solid or monolithic concrete crossing is installed, it not only replaces the usual wooden planks, but acts as ballast for the road. The crossing outside the rails is completed with pre-cast slabs having sockets to facilitate their removal when rail renewals are required, and gutters must be provided to drain water from about the rail. A high-grade aggregate should be used, and the crossing cured and protected in the usual manner during that time, just as with any other part of the highway, in order to secure maximum strength and durability.

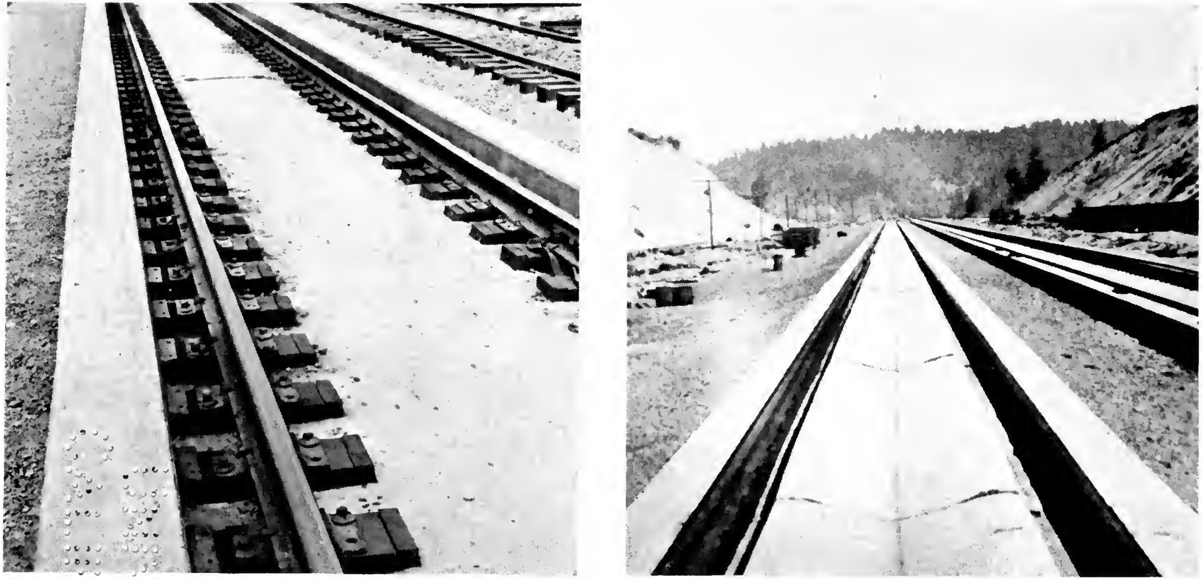
The suggestion has been made that the casting of concrete lumber is a profitable rainy-day occupation for the section gang, thereby effecting economy in two directions. It has been reckoned that the annual saving in maintenance where concrete crossings are used in place of wood will pay for the installation in from two to three years.

Another important point is the approach to highway grade crossings. In most instances the railroad is somewhat above the highway, making it necessary for a vehicle to negotiate a little grade before crossing the rails. If this grade could be placed somewhat more than the length of the average vehicle away from the crossing, it is thought that many accidents might be avoided; for the vehicle, in case of emergency, would be in a position to make the crossing under very much more favorable circumstances.

Concrete supports for storing rails along the right of way are coming into more general use, and the same utilization of this building material for coal-bunkers, reservoirs, bank supports, bumpers at the end of a track, and general building is to be found on the property of progressive railroads, just as in other industries. The use of cements, both Portland and Sorel, in laying the floors of cars and the treads of car-steps, has been mentioned elsewhere. No doubt some experiments have been made looking to the future utilization of concrete in different sections for some types of railroad-car sidings and roofs. One of the attractive utilizations of the material for railroads has been in connection with the road-bed itself.

There is still a great diversity of opinion as to how useful concrete can be made in this connection. There is ample evidence that concrete pavements between street-car tracks is successful. No special concrete is required, and the usual procedure is followed in placing the concrete, providing expansion joints, etc., but the design of the pavement may vary considerably. A concrete base may be laid, and, after hardening, the portion upon which the pavement section is to be placed, is covered and brought to an even surface by spreading a mat of bitumen and sand. The concrete pavement section placed upon this extends from web to web of the rail, and is given a thickness that brings the surface of the concrete about half an inch below the top of the rails. This method of road construction gives a permanence of road-bed that makes for the comfort of passengers and the longevity of rolling stock, which is not so subject to vibration as it is with other types of road-bed. This becomes more important with greater traffic concentration, and indeed expenditures relative to improvement of railroad vehicles and equipment may be traced to the necessity of caring for the steadily increasing traffic concentration.

This has led to greater speed on railroads, the use of heavier and still heavier steam and electric locomotives, and marked increase in the size and weight of the passenger- and freight-cars with correspondingly heavier loads. The unfavorable comments often heard concerning American as compared with foreign



TWO TYPES OF CONCRETE RAILWAY TRACK SUPPORT

POSSIBILITIES WITH CONCRETE

A roof with arches 103 feet $7\frac{1}{2}$ inches over all, constructed during cold weather, and cured with the aid of heat from salamanders roads are due, in some measure, to the different loads concerned in the two cases, and the problems of road-bed maintenance are quite different.

Heavier rails have come into use, and in an effort better to distribute increased weight, ties have been placed closer together. More ballast has been used, but in the minds of many engineers improvements in road-building and maintenance have not kept pace with the requirements.

Great stresses are found in tracks and road-beds, and these stresses are increased many times with the passage of each train. Stresses as high as 40,000 pounds to the square inch have been noted on cinder-ballasted track, and even 25,000 pounds to the square inch have been found in 85-pound rails with 12 inches of stone ballast and the track in perfect condition.

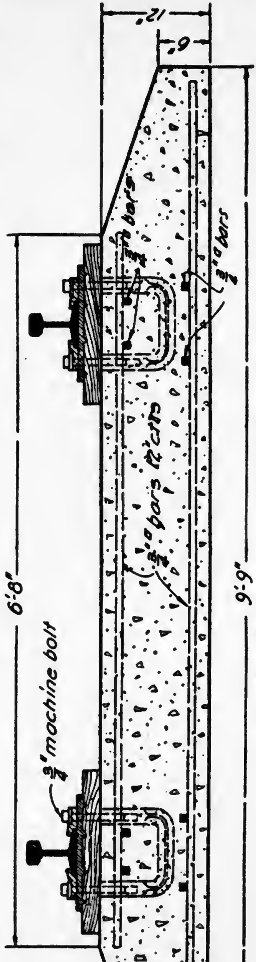
Increase in stresses leads sometimes to rail breakage, so that under present methods of construction it is customary frequently to replace rails, sometimes without regard to the apparent condition of the rails in order to be on the safe side. Rail replacement is a serious question, and, with that of ties, is requiring more and more attention on the part of maintenance engineers. These ties, once plentiful, are now difficult to obtain, while the increased traffic necessitates their more frequent renewal. It seems apparent, therefore, that there must soon come some form of permanent track foundation that will be sufficiently strong to withstand the stresses to which it is subjected, and provide for the placing of rails so that they may be easily adjusted or replaced.

Some experts think that concrete has in it the possibilities for meeting these severe requirements, and for years engineers have experimented with different types of design. As long ago as 1899 the technical papers that print engineering news published designs for permanent tracks. These designs began with the use of pier-like concrete members ten feet in length, ten inches in width at the top and twenty-six inches at the bottom, and about twelve inches in thickness. Another design involves the use of a heavy concrete slab upon which stone ballast and then the usual wooden tie is placed. This type has been under severe trial for several years on the Long Island Railroad, where as many as 1300 train movements a day must be accommodated. The use of concrete slabs in this position gives a bearing surface on the sub-grade or supporting earth which is increased at least three times over the usual method. In the experiment, slabs only eight inches thick were used, without reinforcement. The results obtained indicate clearly the practicability of such construction, but it is believed that it is better to use reinforcement and to provide the slab with a curb-like protection to prevent the stone ballast from spreading.

Still another design that has been used primarily for street-car tracks provides anchor-plates in the concrete, and with these the rails are secured in place; a tie-rod is used between the webs of the rails, and the concrete foundation is made practically monolithic by the pavement between the rails.

The earlier suggestions for concrete track support took into consideration the earlier type of rail ballast-ing, and also subscribed to the belief that there must be some elastic medium between the track rail and any hard base that may be provided. Lately, however, engineers have come to experiment with tracks placed directly upon the concrete foundation, using wooden planks in various ways to secure the track in place, and perhaps also to provide something of a cushion.

The chief engineer of one American railway has gone on record as saying that, with the perfect rigid surface, there should be no bending and no serious damage to the railroad track, unless a defect such as a flat wheel exists. In a number of more recent designs special attention is given to reinforcement, and to improved methods for anchoring creosoted tie blocks to which rails are secured. The Northern Pacific Railroad has installed experimental lengths of track, using three types of concrete track support, and these are now under test.



SUGGESTED TYPE OF TRACK SUPPORT

Undoubtedly we have just begun our work in this field. Some still believe that there must be a stick of wood under the rail to give an elastic medium, without which it is argued both rolling stock and road-bed construction will go to pieces in a short time. Others believe that with concrete on a well compacted sub-grade the rail may be advantageously secured directly to the grade. The late Doctor Dudley gave it as his opinion that if the road-bed could be made absolutely unyielding, the springs of the vehicles providing elasticity, the best results would be had.

If the track could be as smooth and relatively as stiff as a planer or machine bed, there would be a saving in the cost of maintenance and track and machinery. The stiffer the rails, the less the creeping due to the wave that runs ahead of the wheels, the less the wear to the ties due to this motion, the less the destruction of the track and running gear due to the pounding of the wheels, and the easier the handling of the trains. It is admitted that there is an appreciable resistance to the passage of trains due to the deflection of the track, for the wheels are constantly trying to climb to an ever receding crest. There is a large amount of power required to produce the deflection on the rails, ballast, ties, and road-bed. If an unyielding road-bed could be provided, it might be possible to save this power, which for a 3,000-ton train has been calculated as sixteen hundred horsepower hours to one hundred miles, which, at one and a half cents per horsepower hour, gives a charge of twenty-four dollars against track deflection in moving a 3,000-ton freight train over an ordinary hundred-mile division.

Whatever the experience may have been to date with reference to concrete track support, there is reason to believe that the future will find its advantages so marked that heavy first costs will be entirely justified, particularly when the saving of time, labor, wear and tear on equipment, and maintenance are considered. It is believed that concrete railroad-track support will greatly reduce the expense of track maintenance through the conservation of ballast, the long life of rails, rail fastenings, and the possibility of using lighter rails and the decrease in tie renewals. This is not all, for there would be reduced operating expenses because of the economy of fuel, labor, rolling-stock equipment, and longer trains, with greater tonnage moved by the same motive power. Higher train speeds should be obtained because of the smooth train motion without rocking, and because of the reduced liability of rail-spreading.

CHAPTER XV

BRIDGES

It has been truly said that no highway is more permanent or serviceable than its weakest bridges, and the most satisfactory roadways are those provided with durable bridges, easy to construct, easy to maintain, and permanent in proportion to the care used in construction.

Not long ago a freight train passing over a bridge caused the ties to become smeared with oil, due to a leaking tank-car in the train. Presently a second train crossed this bridge, and, as is customary, dumped ashes as it went along. Soon afterward fire was discovered, and before any steps could be taken to extinguish it the blaze had reached such proportions that the fire-fighters could not venture upon the structure and it had become too hot to risk pouring water upon it. The ties burned off the bridge, but it was one built of reinforced concrete, so that as soon as it cooled it was possible to relay the track and to reopen the bridge to traffic within a few hours after the fire. There was no warping of small parts or bracing which would require replacement, as might have been the case with some types of metal bridges; and, obviously, had the structure been of wood the delay in transportation over this main line would have been a matter of weeks. The concrete bridge, therefore, possesses the desirable property of indestructibility to a high degree.

Concrete bridges do not rust, rot, or burn. They need no painting, no repair of masonry joints, no rebuilding after floods, no tightening of bolts or rivets, and can be maintained at very low cost. They can be built, usually, from local materials, merely necessitating the transportation of a few bags of cement and the necessary steel rods or bars to provide required reinforcement.

Concrete, being a plastic material, is easily molded, and lends itself so readily to different types of ornamentation that the decorative treatment that may be given a bridge is limited only by the skill and ingenuity of the designer and workmen. So desirable has the concrete bridge and culvert become that most highway departments have evolved standards for which plans and specifications are at hand, so that the installation of such bridges is greatly facilitated. Notwithstanding this provision, it must be remembered that nearly every bridge location involves a special study if the needs of a situation are to be met. All the advantages that are accorded concrete can naturally be obtained only when it is used consistently, and this involves proper design to meet a special need.

It is always desirable to have the bridge placed where the river follows a straight course both above and below the bridge. Such a position reduces the danger that the bridge may be undermined, or that its approach or adjoining embankments may be washed away by high water. The abutments of the bridge should be designed not only with reference to supporting the bridge, but to retaining in place the roadway embankment. The wing walls should be monolithic with the abutment, and vertical expansion joints may be required to prevent cracking due to expansion and contraction. The earthen fill behind the abutment and wing walls must be provided with suitable drainage.

In addition, foundations must extend below a possible frost line and to firm bearing soil or other material. The bearing power of soil, etc., may be rated as follows (expressing this power in tons per square foot): loam, ½ ton; clean dry sand, 2 tons; sand that is compact and well cemented, 4 tons; gravel and coarse sand, well cemented, 8 tons; soft clay, 1 ton; moderately dry clay in thick beds, 2 tons; clay that is always dry and occurs in thick beds, 4 tons; and bedrock in naturally thick layers, 200 tons to a square foot.

Low-water bridges are now being regularly built of concrete. They are particularly adapted to those parts of the country where rainfall usually occurs in the form of a cloudburst, giving rise to great volumes of surface water that must be carried off quickly. Such low-water bridges are often entirely submerged, and, because concrete is not damaged by such an experience, it can be used in a way to permit debris to be washed along by the stream, rather than piled up against the upstream side of a bridge, to cause damage and trouble. In some places, bridges of this type have been used in fords, for they serve even though entirely under water, to provide a safe level passage through the stream at any time.

As in other concrete construction, the placement of forms should be done with care. Forms for bridge work are almost always of two-inch plank, securely fastened to two- by six-inch uprights and so braced as to be substantial and unyielding. Lumber that is tongued and grooved is recommended for the surfaces coming in contact with the concrete in order that a smooth surface finish may be obtained. There are some standard metal forms to be had for small bridge and culvert construction, but on larger work special designs are usually used, and it is more economical to build up suitable wooden forms.

Great care must be taken to secure the perfect alignment of beam and girder forms, remembering that any small irregularities cannot be removed from the hardened concrete, and that irregular lines are so unsightly as to bring adverse criticism to an otherwise satisfactory structure. The supports for the floors and arches should remain in place until the concrete is strong enough to be safely self-supporting, and sometimes it is left in place as an additional support during the time the rough filling is completed, for during such filling unequal loads must occasionally be borne by the bridge.

Reinforcement must be placed in the exact location shown on the plans, and so secured, particularly at intersections, that during the deposit of the concrete there will be no disarrangement of the metal. Welding may sometimes be used to advantage. It is inadvisable to place steel directly upon the forms with the intention of raising it while concrete is being placed. It is far better to support the steel on pieces of aggregate or even small blocks of concrete, which become a part of the structure, and in general all steel should be securely placed before any concrete is deposited.

The proportion of materials for abutments and wing walls are one cubic foot of cement to not more than two and one-half cubic feet of fine aggregate and five cubic feet of coarse aggregate. Sufficient water is used to produce the consistency usually described as quaky, which is one that will permit the aggregate slowly to find its place in the forms, and which can be spaded or worked into place without undue separation of the coarse aggregate from the mortar. In the edges, bridge floors, etc., care is taken to insure a smooth surface next the forms, and the material should be thoroughly spaded and worked in around the metal reinforcement. Whenever possible the concrete for an arch should be deposited in a single run; but where the span is too great to permit this the spans are divided into sections, which are deposited in turn radially. Care must be taken to maintain a load as nearly balanced as possible, so that distortion, not only of the framework but also of the reinforcement and supports, may be prevented.

It is considered good practice to place an entire floor of a concrete bridge in a single day. The full thickness of the floor should be deposited at one time, and if for any reason the floor cannot be completed in one day, the dividing line is made in a vertical plane perpendicular to the main reinforcing rods.

Concrete should never be placed in running water, and in still water only when precautions are taken to insure placing the material in a way to prevent separation of cement and aggregate. In important work engineers are justified in going to additional expense to avoid placing concrete in water, since it is difficult otherwise absolutely to prevent the formation of an injurious amount of laitance.

When the forms have been removed from the concrete bridge, any projection or irregularity should be removed at once and cavities filled with mortar. This is usually done with a cement and sand mortar composed of one part of cement to two parts of sand. Plastering is never permitted, but exposed surfaces are finished to give a smooth appearance. It is sometimes necessary to scrape the surface to obtain the desired effect or a cement-gun is used. Concrete floors in bridges are finished very much as other pavements, and are protected and guarded while curing in the usual approved fashion.

There are many bridges in the country that, in turn, have had claimed for them the distinction of being the longest or the highest or the one with the greatest arch span. Such records are seldom held for long, and the occurrence of serviceable bridges of this type is so frequent that a discussion of dimensions is hardly required. In a number of instances steel structures have been replaced by concrete ones, particularly in difficult positions, as for example where one abutment is much higher than another, causing the floor of the bridge to be an inclined plane. The other extreme is the multitude of bridges so small as to be little more than culverts, and for this type of bridge there are a number of standard designs in different States. Such a bridge of fourteen-foot span for a twenty-foot roadway requires only thirty-five cubic yards of excavation, sixty cubic yards of concrete, and thirty-one hundred pounds of reinforcing steel.

Concrete culverts are as advantageous for the service required of them as are concrete bridges. A table of standards has been compiled showing the various designs of waterway required for the areas to be drained. This waterway is provided either by a box type of culvert or, sometimes, by a special culvert pipe. These have been made of large diameter, and above twenty-four inches in diameter it is the custom to provide such pipe with metallic reinforcement. Sometimes pre-cast units are assembled in various ways in the construction of culverts, metal fittings being cast in place in the concrete at the time the unit is manufactured, and so arranged as to interlock with other units.

Closely allied with bridges and culverts are the structures used to convey and control water, as in irrigation projects. The ditches that convey the water from the source of supply to the point where it is needed are often the source of serious loss, owing to seepage through porous soil, and in addition require constant maintenance. Then there is a series of locks to be provided, and other structures to control the flow and transportation of water. In the West it has recently been found that concrete lumber can be prepared and placed as cheaply as redwood, heretofore the favorite material for this construction. This concrete lumber is frequently poured in trays, in which it is comparatively simple to place any reinforcement required. As soon as one tray has been poured, another form is placed above it, and the second slab cast. In this way time and space have been economized and the cost of production reduced. With pre-cast units of this character construction can be standardized and the labor of placing the material in the field substantially reduced. In order to secure a tight joint in concrete lumber placed vertically, the edge of the slab is designed with a type of square-cornered corrugation which fits in the corresponding recess in the slab placed above. It is not difficult to cast in place various metal plates, bolts, etc., with which to secure the lumber to such supporting columns or other structures as are provided.

Masses of concrete are sometimes used as counterbalance weights for the jack-knife type of bridge used over navigable waters. This may be a monolithic block or small units cast with holes to assemble them on steel supporting rods.

CHAPTER XVI

CONCRETE IN WATERWAYS

Among the miscellaneous uses of concrete in the improvement of waterways, the first striking example that comes to mind is the Panama Canal, the building of which had several curious economic results. These included a slight advance in the price of glycerine, due to the quantities of explosives used in making the excavations, and the influence upon the cement market. It is estimated that the concrete required for the canal construction exceeded five million cubic yards. It is doubtful whether the canal, with its locks, could have been constructed in so short a time or so economically but for Portland cement. The various docks, warehouses, etc., that accompany maritime improvements of this character must also depend upon concrete for their efficient construction, and in controlling future land slides concrete and cement will doubtless play an important part.

Elaborate details concerning the canal are to be found in so many works that further description may be omitted here. The same might be said for the numerous dams built in this country in connection with conservation and irrigation projects. Many of these have been in relatively inaccessible places to which it would have been very difficult and expensive to transport the usual masonry materials that would otherwise have been used. In some instances both fine and coarse aggregate have been obtained on the spot, the size of the work justifying the erection of special crushing and washing plants. These have furnished clean and satisfactorily graded material from which concrete of uniform quality could be prepared with facility. Some sites have made it necessary to prepare large masses of monolithic concrete to which to anchor one end of the dam, where natural conditions have demanded some such action.

The colloidal material that forms upon the hydration of cement is thought to be responsible for the closure of small cracks and the filling of voids in dams, allowing a small amount of seepage when the water is first brought in contact with them, but afterward became virtually water-tight. More recently the cement-gun has been utilized to cover the water side of the dam with a very dense and highly compacted mixture of rich cement mortar, with or without reinforcement. This is proving excellent practice and has rendered such dams water-proof.

Concrete piling has been extensively used for work at the sea-front, and also in the construction of underpinning for foundations. When used at the sea it is subjected not only to the adverse conditions of alternate wetting and drying, but in some latitudes to freezing and thawing and further to the erosive action of material floating with the tides. It is therefore subjected to conditions about as strenuous as can be contrived for structural material of this character. Some piers that have been built with concrete piling have suffered because of insufficient reinforcement in the piles, improper design of the concrete mixtures, and blows from drifting wood, which in time have destroyed the corners of the piles and exposed the reinforcing metal to the active corrosion of sea-water.

During the world war, in order to save time, some of the warehouses at seaports were supported on concrete piles, which in turn rested upon wooden piles so driven that the wood will always be immersed. In this position the wood is not subject to deterioration and may be considered reasonably permanent. By the use of metal corners the concrete piling placed upon the wood may be protected, and sufficient reinforcing imparts a measure of elasticity and increased tensile strength that is helpful in resisting stresses. If the concrete is water-proofed and made as dense as possible, there is reason to believe that good results may be obtained.

Some years ago one of the construction companies undertook to determine whether concrete could be made in a manner to resist the effects of sea-water when placed in a northern climate where many of their operations take place. In 1909 a number of piers were constructed with different proportions of cement, sand, stone, and water, varying the material to cover the field fairly well. The cement employed was from different sources and involved commercial Portland cements, cement practically free from iron, that made from blast-furnace slag, commercial cement low in alumina, some that was high in alumina, and others that were from iron ore but practically free from alumina.

In pouring the piers, which were reinforced, a core-hole eight feet long was made, so that the seepage of water through the concrete piers might be observed. In sectional area these piers average about 1.8 square feet. They are sixteen feet long, and are still undergoing the action of the air and tides, being supported from the cap-log of a wharf. The salt water rises nearly to the top of each pier once in twelve hours, and subsides again, thus allowing the surface to dry. It will be a number of years before definite results can be obtained, but already some of the specimens have gone to pieces. Others are so badly eroded and partially disintegrated as to render them useless if they were in actual service supporting loads. But a few still show little or no signs of deterioration. Of the twenty-four specimens, seventeen have shown no water in the core-holes.

Many breakwaters have been constructed of concrete, and older ones of masonry have in several instances received a new facing of cement mortar. In repairing and reinforcing one breakwater, concrete piles twelve by twelve inches were cast, with recesses into which concrete slabs could be fitted. The pre-cast slabs were twenty-eight by thirty inches and four inches in thickness. The piles were driven in direct contact with the face of the old wall, and when in place the slabs were allowed to slide down the slot provided by the recess in the piles. This gave a hard continuous face, and the space behind the slabs and between the piers could be filled with grout and other supporting material that further protected the breakwater.

On river-banks, where washing is apt to be affected by currents, mattresses of concrete have been used for protection. These have consisted of blocks or slabs fitted with iron rings or chains mounted in the concrete, so that units can be joined in a way to provide a flexible covering sufficiently continuous to afford the desired protection, and at the same time so flexible as to conform to the contour of the bank.

Successful experiments have been conducted with cement mortar concrete as protective material for levees such as are common along the lower Mississippi. Here the function of the coating is not only to add strength to the bank, but to render it sufficiently water-proof to allow a considerable portion of the bank to remain dry. Experience has shown that a bank that can remain dry due to the evaporation of any water that seeps into it can be relied upon to hold, whereas a bank that is saturated may give way at any moment, even though it may have a large mass.

In special cases, blocks of concrete have been cast and afterward thrown into the water to protect banks and shore lines and to assist in diverting currents. In one unusual case the character of the underlying rock made it possible for a great volume of water wanted for power purposes to seep through the river-bed and disperse in other directions. To increase the volume of water behind the dam, a considerable quantity of cement mortar and concrete was used to fill up the cracks in the river-bed, and when treated in this fashion very satisfactory results were obtained.

As has been previously indicated, the small cracks that develop are not so serious a menace as might be thought—first, because of the tendency of hydrated cement to form a colloidal material in the open spaces of the concrete, and also because of the tendency of silt to lodge in these cracks and voids. If the cracks are very small at the time of their formation and develop slowly, it is possible for the silting to keep pace and in this way to prevent leakage. Experiments with hollow beams filled with water under pressure indicate that cracks one thousandth of an inch or less will permit the passage of enough water to cause moisture to be indicated on the outside around the crack. If the crack has widened rapidly, so that there is no time for the deposit of any kind of sediment, leakage also increases rapidly, and a crack one hundredth of an inch in width is capable of allowing water to spurt from it. On the other hand, observations have been made on reservoirs, dams, concrete ships, and barges that had cracks of sufficient width to cause leakage but in which there was no leakage, prevented doubtless from one or the other, or perhaps both, of the agents to which reference has been made.

CHAPTER XVII

CONCRETE SHIPS

So much has appeared in the press in the last few years relative to concrete ships, what is expected of them, and their advantages in times of emergency, that it is unnecessary to cover the subject from that point of view. Besides the comparative rapidity with which such vessels can be fabricated, there is the additional consideration that in times of war iron and steel are demanded in such quantities that any plan for saving them is worth consideration. Obviously, concrete ships, notwithstanding the large amount of steel reinforcement they must have, require only a part of the steel used in an all-steel vessel.

The engineers who undertook the design and construction of concrete ships faced a set of problems for the solution of which there were no precedents, and in their preliminary calculations the best they could do was to interpret data on past performances in the light of entirely novel requirements.

It is recognized at once that the concrete used must be both light and strong, that the densest possible mass must be used, and that concrete of high density has always had a high unit weight. The problem involved securing durable concrete impermeable to water, developing high compressive strength of not less than four thousand pounds to the square inch when tested at twenty-eight days, and a minimum weight.

Extraordinarily strong and plastic concrete was secured by the use of cement ground especially fine. The cement specified provided that at least 90 per cent. must pass a sieve having 200 openings per linear inch. Such cement is constant in volume, has high strength, and gives a plastic mixture.

The aggregates used must not exceed half an inch in size; and, beginning with sand or gravel or volcanic ash, especially burned clay was ultimately devised. It was found that clay fused in a rotary cement kiln could be so burned as to have a porous structure and general characteristics that would give the desired strength to the concrete. One part of cement to one part of specially fused clay below one quarter of an inch in size, and two parts of this clay between one quarter and one half inches in size, gives a concrete with compressive strength of 3,380 pounds to the square inch after a seven-day period and 4,350 pounds at twenty-eight days. This concrete weighed only 106 pounds to a cubic foot, and made it possible to obtain a ratio of 62 per cent. of the dead weight of the total displacement for a 3,500-ton ship, as compared with 65.68 per cent. for a steel ship and 53 per cent. for a wooden vessel.

A 3,500-ton concrete ship of the standard 150-pound concrete contains about 1,761 tons of concrete, 400 tons of reinforcing steel, and 811 tons of wood fixtures, machinery, and equipment. It is seen, therefore, that the total weight of the ship without load is 2,970 tons, and that a reduction in the weight of the concrete per cubic foot from 150 to 106 pounds is of decided advantage. The per cent. dead weight to full-load displacement of a concrete ship, with standard concrete weighing 150 pounds a cubic foot, is 52, so that the achievement in preparing the special aggregate needed added a clear ten per cent. to this ratio.

One of the outstanding problems is that of forms, which are constructed and placed for virtually the entire ship before the pouring of the concrete begins. The accuracy required is much greater than for ordinary concrete operations. There must be no increase in the thickness of the hull walls. Due regard must be had for proper balancing, while the comparatively thin covering of the reinforcement makes necessary more than ordinary accuracy in form construction.

A number of suggestions have been made, all the way from plaster to metal, including metal-lined wood forms. There was also one suggestion that involved placing sections of the forms on wheels, so that they could be quickly removed when the concrete had hardened, and, following the launching of the ship, immediately rolled back into place to begin the construction of a second vessel. Some engineers have advocated placing inside forms, then fabricating the steel reinforcement, and finally setting up the outside forms. More often the reverse method has been followed; that is, the outside forms have been set up, then the steel, and then the inside forms. Abroad small barges have been cast upside down, with the concrete placed by hand or with the cement-gun.

The reinforcement constitutes another important problem, for its parts must be accurate to within a fraction of an inch, even though at least 60 per cent. of

CONCRETE SHIPS AND BARGES IN THE UNITED STATES AND CANADA IN 1918

	Dead weight tonnage
Completed:	
S.S. *Faith*	5,000
S.S. *Concretia*, Montreal	350
Ocean Barge & Transport Co., Seattle, scow	550
J. W. Thompson Co., New Orleans, 2 barges	1,100
Louis L. Brown Co., New York, 1 barge	700
Louis L. Brown Co., 1 barge for Navy Department	500
Fougner Concrete Shipbuilding Co., New York, 1 oil barge for Standard Oil Co.	370
American Chain Co., Bridgeport, Conn., 1 barge	100
Harrison Barge, Long Beach, N. Y. (800 tons, estimated)	800
Marl Barge, Union City, Mich.	300
	9,770
Government work under contract:	
Concrete Ship Department:	
Fifty 3,500-ton cargo ships, Liberty Shipbuilding Co., Brunswick, Ga.	175,000
Five 3,500-ton cargo ships, Fougner Concrete Shipbuilding Co., Flushing, L. I.	17,500
Forty-two vessels, forty 7,500-ton oil tankers, with two 3,500-ton cargo ships to be built at five Government and two private yards	307,000
Navy Department:	
Eleven 500-ton coal barges (one completed by L. L. Brown Co.)	5,500
Twenty-one 500-ton barges	10,500
War Department-Army Transport Service:	
Twelve 265-foot car-ferry floats, 1,100 tons	13,200
Five 100-foot water-tank boats (285 tons, estimated)	1,425
Fourteen 130-foot river steamers (390 tons, estimated)	5,450
	535,575
Private contracts:	
One 2,000-ton cargo ship, Houston, Tex.	2,000
One cylindrical oil tanker, New Orleans, La. (estimated)	1,500
One oil tanker, Newburgh, N. Y.	2,800
One seagoing barge, Vancouver	1,500
Two 225-foot cargo ships, Cleveland, Ohio (estimated)	6,000

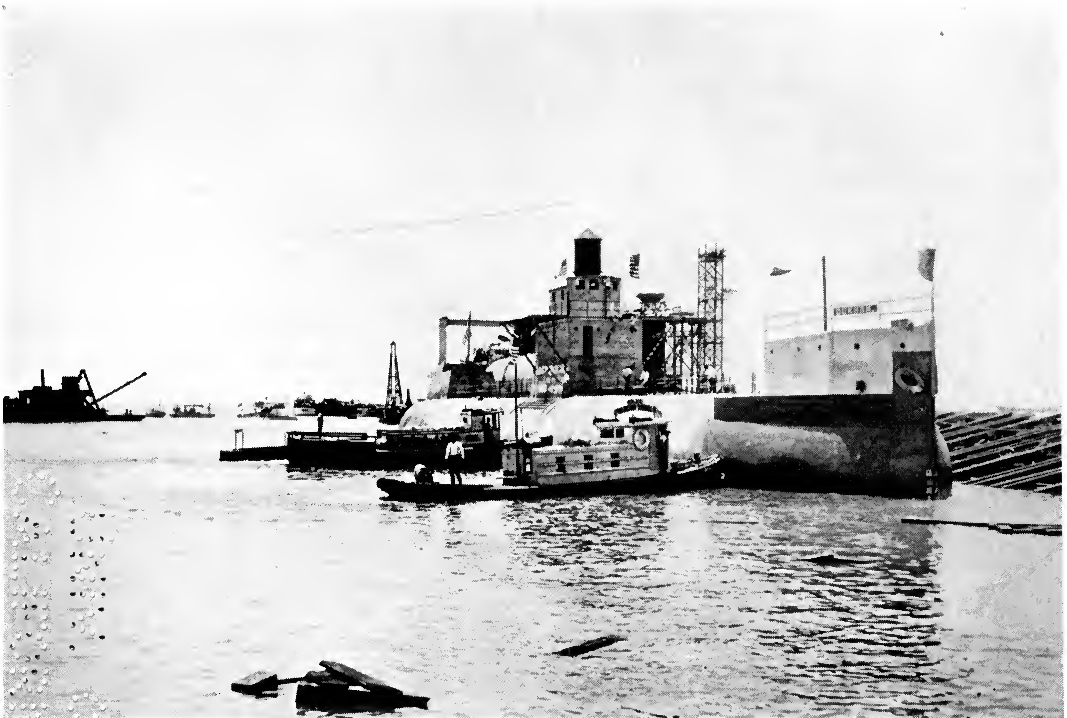
Private contracts (continued):	*Dead weight tonnage*
Two 150-foot tow barges, Cleveland, Ohio (estimated)	1,200
One barge, 400 tons, Concrete Boat Co., San Francisco, Calif.	400
One 600-ton barge, Chas. O. Heyworth, Chicago, Ill.	600
One tugboat, 25 tons; 10 barges, 130 tons, International Constructors, Chicago, Ill.	1,325
Three oil barges, 400 tons (estimated), Fougner Shipbuilding Co.	1,200
	18,525

Summary:	
Completed	9,770
Government work under contract	535,575
Private contracts	18,525
	563,870

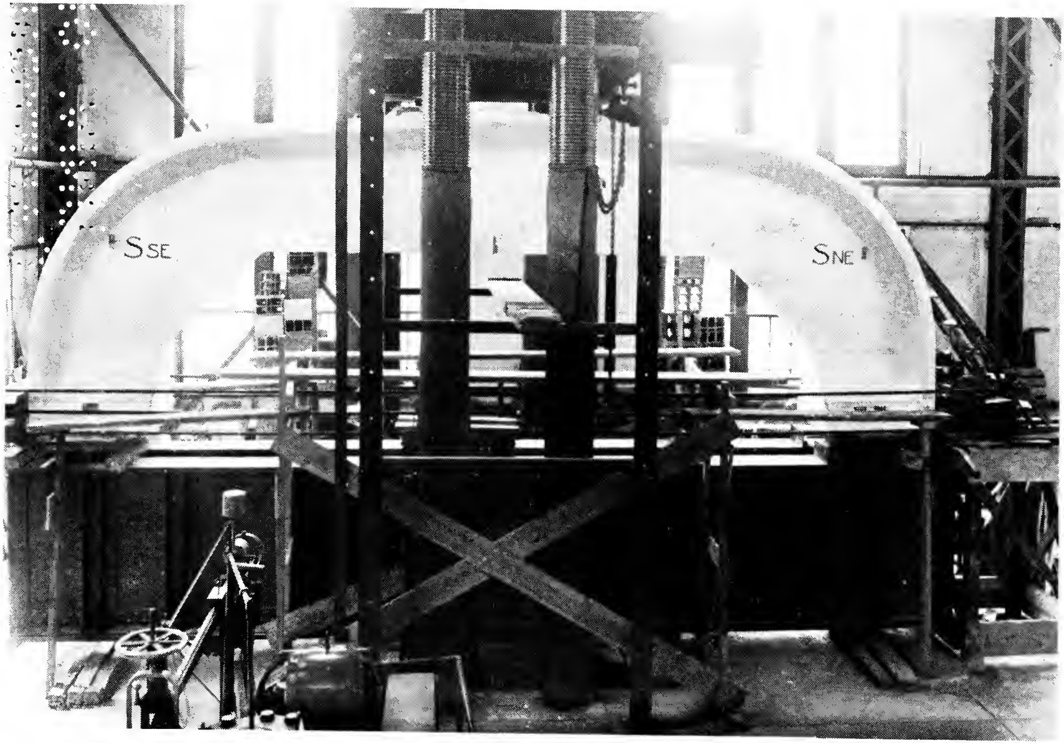
(From "Concrete Ships in 1918" by Robert W. Lesley, in "Cement in 1918," Department of the Interior, U. S. Geological Survey.)

the ship's length necessitates frames constantly changing shape. Virtually all of the metallic members are of small dimensions, and, with a total hull thickness of three and one half or four inches, it is apparent that any bending of the steel must be corrected, and that the curvatures that change forward and aft must be true. To avoid lapping the steel reinforcing material, a study of welding has been made, and this has involved tests of the various welding methods and the devising of special welding-machines. Electric resistance welding has given very satisfactory results.

In considering the durability of concrete ships, the corrosion of this steel reinforcement constitutes one of the most serious elements of the problem. Much of the steel is covered by little more than five eighths of an inch of concrete, and this cannot be relied upon entirely



A CONCRETE OIL TANKER



TESTING A CONCRETE SHIP MEMBER AT THE BUREAU OF STANDARDS

The test piece is full-size vertically and half-size horizontally to prevent moisture reaching the metal. The steel may be protected by galvanizing or by being covered by some protective medium of a character not to effect bonding between the steel and the concrete. Again, the surface of the concrete may be given a coating that will prevent air and water from reaching the steel, or a density of sufficient magnitude may be secured in the concrete to make it impervious to water.

It will be obvious that placing concrete in such forms as have been described and around complicated metal reinforcement presents still another difficulty. It is highly desirable that the concrete be placed continuously to avoid construction joints, and for a 3,500-ton ship this means continuous concreting for three days of twenty-four hours each. A 7,500-ton ship means six days. By using a rich mortar mixture carefully prepared, a fairly fluid concrete can be obtained without the use of excessive moisture, and by taping the forms it can be made to settle satisfactorily around the steel. Since small aggregate is used, the danger of segregation, with which an engineer must reckon when working other types of concrete, is avoided. Also, by placing this mixture in small batches that are shoveled into the forms, a thorough working into place around the reinforcement is assured.

The treatment of the hull involves providing a coating that will resist barnacles, which show no discrimination against concrete ships in fastening themselves upon anything that floats. The same difficulty with paint involving oils is met here as elsewhere, since concrete is a chemically active material, and its alkali tends to saponify the paint oils, thus causing their speedy disintegration. An anti-fouling bituminous coating appears to be one of the best for concrete ship-bottoms.

In the design of the concrete ship the difference in weight of the hull allows certain changes in the proportions of the vessel, as compared with the standard steel or wooden craft. Concrete being capable of much higher compressive stresses than tensile stresses, the design takes the greatest possible advantage of this compression. In experimental work, pressure-recording instruments and recording strain gages have been placed at many points to record the pressure exerted upon the vessel, and the effect of the engine vibration upon the concrete structure has been the subject of much discussion.

Persons who felt that concrete ships would be short-lived, and even dangerous, based their contention upon the assumption that engine vibration would cause a shattering of the material or the development of large cracks. This has not proved to be the case with those vessels that are in service. The *Faith,* which was constructed upon the Pacific coast, has made several trips in different seas, in which she was subjected to many adverse trials and all kinds of unfavorable weather conditions. She behaved satisfactorily under all circumstances, and because of her rigidity her engines developed a surprising efficiency.

The rigidity attainable for shafting and propeller supports proved to be as much of an advantage as in any location where heavy machinery is set up, and in general vibration apparently causes no more deterioration in concrete vessels than in land structures of this material. The foundations and emplacements for the machinery equipment must, of course, be placed with great care, always remembering that metal parts embedded in concrete are not subject to change in position later on. Any fitting that is likely to require adjustment must be attached in a manner to make this possible, and those parts that must be subject to renewal or replacement must likewise be attached with this in view.

Many of the attachments for the deck and the interior of the vessel may be made by molding anchor-bars permanently in the concrete, and special attention must be given in casting any part of the water-tight bulkheads or members which must penetrate the outer shell of the vessel. The frame supporting the rudder to the outer end of the stern-tube is of cast steel, and a part of the all-steel stern of the vessel. The frame may be designed so that the whole stern may be detached from the hull, this being accomplished by means of plates extending on either side along the sides of the ship. Plates may be cast as flanges and attached to the reinforcing bars of the concrete properly placed.

Concrete ocean-going ships are new, and we must wait a number of years for performances in actual practice to demonstrate to what extent they are efficient and reliable. Theoretically, the concrete ship can be designed with far more accuracy than is customary with a steel ship. At least one ship has been successfully built and has given satisfactory performance thus far in ocean service. We must expect some failures with vessels made of concrete, just as we have had failures with vessels of other types. It is expected that concrete of the necessary strength will have sufficient density to make it impermeable to water, so that the steel will be protected. Ways for protecting concrete from the sea water have been devised. Those parts that are subject to abrasion are above the waterline, where frequent inspections and repairs can be made. After all, the life of a ship depends upon something that cannot be forecast, and that is its ability to withstand suddenly applied stresses and great loads, which come with the strain and wrenching of the sea, causing reversals of great stresses within such a rigid structure. As has been noted, the ship that has been watched most carefully has thus far proved satisfactory in this respect.

Some of the other factors that may determine the durability of a concrete ship involve care in the type of cargo and the kind of electric current employed on shipboard. We know that various vegetable oils and sugar will so react with concrete as to cause disintegration. If concrete vessels are to be employed in this sort of trade, then the inner surface of the hull will need to be especially protected.

The possibility of electric current leaking makes it necessary that direct current be not used on concrete ships. At the Bureau of Standards it has been shown that a very small leak will cause weakening of the mortar at the cathode, if the action continues an appreciable time, with the result that the bond strength will decrease. If the leak is large, steel at the anode may oxidize resulting in the concrete splitting away from the reinforcement. With alternating current these troubles are avoided.

The troubles that may arise from electrolysis indicate the inadvisability of using brass or bronze castings adjoining steel reinforcement, since in the presence of an electrolyte there is at once the possibility of local electrolytic action.

Experiments with concrete in storage-tanks for oil indicate that the kind of concrete being used in ship construction makes special provision for the heavier fuel oils unnecessary, and if any further trouble should develop from this storage it is anticipated that research work now in progress on protective linings will have found ways for forming protective coatings.

Whatever may be the result from the use of concrete as a shipbuilding material, it seems certain that barges for inland waterways, small lakes, canals, etc., will be successful. On such waterways they will not be subjected to sagging and hogging, nor to conditions that are responsible for the greatest stresses. Concrete tow-boats have been built for the New York State Canal, these being of five hundred tons capacity. These barges are made from the same type of concrete as is used in shipbuilding, and are provided with four-inch wooden plank floors and a three-inch plank lining of the vertical walls. The hatch-covers are of wood, with the timber frames bolted to the reinforced concrete girder that forms the hatch. These barges are a little less than one hundred and fifty feet in length and twenty-one feet in width, so that their construction is decidedly less complex than in the case of an ocean-going vessel of far greater size.

Concrete has been found very useful in another phase of shipping. Reports record at least one case in which a hole stove in the side of a vessel was repaired with concrete in a manner satisfactory until dry-dock could be reached. The work may be said to have been improvised, and consequently lacking some of the finer points of detailed construction, but, in view of what has been said concerning concrete ships themselves, one can readily see how plates and timbers used as part of the repair could be made to constitute forms, and a rich hydraulic cement mortar used to make the repair watertight. Similarly cement and concrete have been used in salvaging sunken vessels.

Also, since concrete ships have been a reality, cement mortar has been used to resurface old hulls, following the practice devised for converting old frame houses into modern stucco-covered structures. Suitable reinforcement can be attached to the old hull and the mortar put in place, preferably with the aid of the modern cement-gun. (See Chapter XII.)

The requirements of interior construction in steel or wooden vessels can also be met in some particulars by concrete. As a surfacing material, as a protection against fire, it is unsurpassed. Cement flooring is not new in some types of vessels; and, just as the material finds application in innumerable ways in land structures, so it finds itself afforded a usefulness on board ship, being limited principally by the resourcefulness of those who wish to use it.

CHAPTER XVIII

BUILDING FOR A THOUSAND YEARS

We have plainly indicated that stone properly prepared, erected, and protected will give us buildings that will last a thousand years; and, now that scientists have learned much of the true nature of cement and what takes place when it sets, we have by far the best opportunity of our career to build enduring structures. Add to this the ability to apply accelerated tests and there seems to be little reason why we should not be able to erect reinforced concrete structures, with or without embellishment, with equally enduring materials, which would last more than a thousand years.

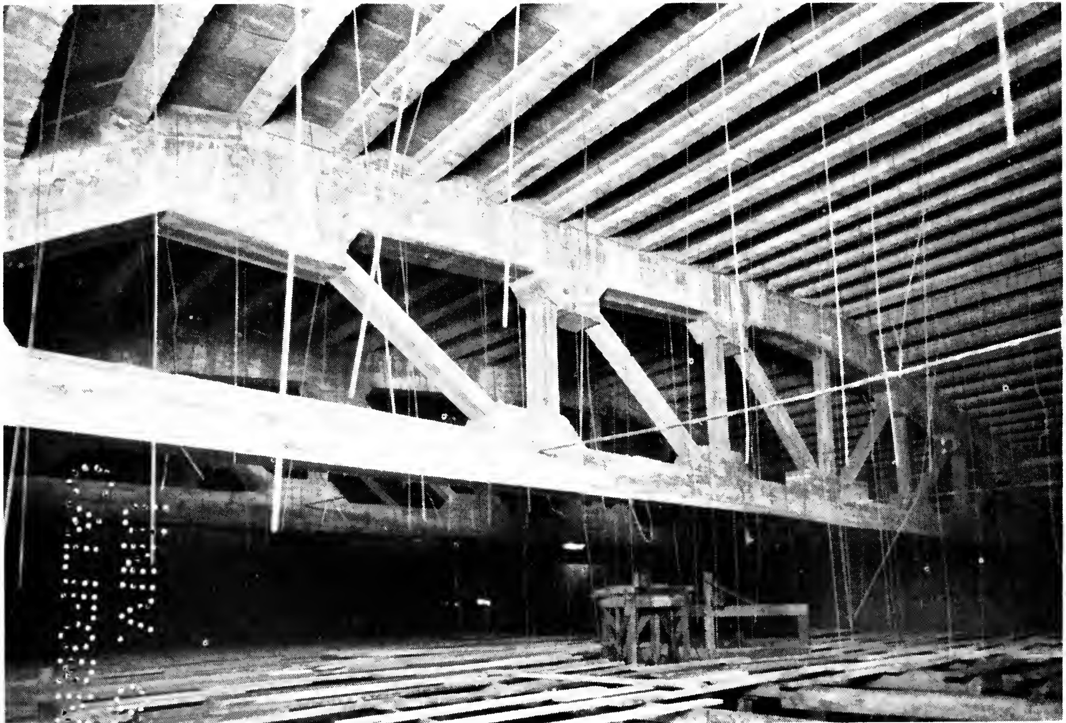
The concrete structures of today show how much has been accomplished in a comparatively short time, for it has only been within the last century that stucco houses of the better class have been erected. We still have about us examples of how not to build concrete houses, but with them there are many beautiful examples that indicate the possibilities.

In mercantile and industrial concrete building it has been shown that efficiency of manufacturing operations can be obtained without lessening attractiveness in exterior appearance. Reinforced structures save space, because thin walls can be used. The reinforcing increases carrying capacity, and, the building being monolithic, vibrations are resisted to a remarkable degree. Properly designed and erected, buildings of reinforced concrete have low maintenance costs, are endowed with many hygienic factors, and can be erected rapidly. Their principal disadvantage is the difficulty of altering them should a further increase in load beyond that allowed by the safety factor later be found desirable.

But there are other advantages in concrete construction. Much of the material needed for the construction is to be found near at hand, thus dispensing with the uncertainty of transportation and conditions that may obtain in distant labor centers. The materials for erecting such a building are brought to the spot in bulk, and, aside from protecting the cement from the weather, require no special treatment or handling. Most of the labor required is of the less highly specialized variety, and the equipment needed is relatively simple. These factors give the following rating as to first costs for factory buildings, beginning with the least expensive: mill structures, concrete floor slab, concrete beam and slab, and structural steel fire-proof. Conditions that now obtain tend to diminish the difference between mill construction and work involving concrete.

Speed of construction is often important, and on large contracts two months' time has been saved by the use of concrete. The ability to resist fire needs no further comment, excepting to point out that insurance rates on contents are also affected. Then, all concrete floors being water-tight, there is less likelihood of damage to goods on floors below when the sprinklers let loose or the fire-hose is turned on.

Maintenance, depreciation, and obsolescence have



CONCRETE CEILING UNDER CONSTRUCTION

Illustrating how reinforced concrete may be used in accordance with the same principles of design employed with other building materials

CONCRETE IN PUBLIC AND MONUMENTAL BUILDING

Westchester County Court House

little terror for owners of concrete structures. Germicidal and cleansing preparations in general can be used without fear of injury. In machine-shops shafting stays in line, and there is no sagging or warping of beams, floors, and stairways. It has also been found that concrete buildings are adaptable, and with the changing centers of specialized industrial activity they are comparatively easy to refit for the new service. While it is not a simple matter to increase the strength so that additional loads may be borne, it is usually the case that so large a safety margin has been used in the calculation that new loads may be borne with safety. There is on record the case of a building originally intended to bear two hundred pounds to the square foot, which is now a warehouse for the storage of sheet metal, and the floor loads are six times as great.

The adaptability of a building is important, and in concrete structures this adaptability is found to an unusually large degree. They can be made warm and dry, for concrete is a poor conductor of heat. They are considered exceptionally secure against loss of life from tornados, earthquakes, or explosions; and in the San Francisco earthquake, the fire at Baltimore, the tornado at Fergus Falls, Minnesota, and the munition-ship explosion in Halifax harbor concrete structures gave examples of their great resistance to the destructive forces of nature. In concrete buildings the corners can be rounded to facilitate cleaning, and in one mercantile establishment the practice of painting the corners white assists in keeping them clean.

The vibration of some buildings is a serious factor that can be expressed in dollars and cents, and the rigidity of concrete structures is important in this connection. As the yearly turnover of a business often amounts to several times its first cost, an increase in production of from fifteen to twenty per cent. may equal a large proportion of the total first cost of the building. There is on record a case in which a first-class mill-constructed building was completed at a cost of three thousand dollars below the bids submitted by reinforced concrete contractors on the same plans. Since the completion of the building twenty-two thousand dollars has been spent in an effort to stiffen it so as to eliminate vibration. This amounted to approximately fifty per cent. of the original contract. Machines may be anchored and shafting supported in fixed positions without difficulty in concrete. Where requirements cannot be foreseen, such equipment can be put in place with bolts set in drilled holes. That this supplies adequate anchorage is indicated by the fact that the many balconies of the Traymore Hotel at Atlantic City are built of reinforced concrete, supported by brackets stone-bolted to concrete columns.

The American habit of filling in land, building subways, and doing all sorts of things that call for special foundations, has developed that feature of engineering to a very high degree. The use of piles has been supplemented by the practice of casting concrete piers resting upon bed-rock, and from this has developed the concrete-pile industry. Some of these have been patented, and in general they consist of a conical shell, or nose, that penetrates, and this is followed by a thin sheet-metal shell that holds the concrete poured into it, or some type of collapsible form that acts as a support for some type of shell and is then withdrawn before the concrete is poured. Another plan uses a thin sheet-iron perforated shell on the outside of a second shell used only for driving, and the effect is to place concrete projections of different sizes and shapes in the surrounding soil, thus greatly increasing the anchorage.

A foundation should be in the form of a continuous wall rather than small piers, even if a building of small proportions must be supported. Continuous foundation gives the structure proper support to all areas, and aids in preventing the entrance of rodents. Where the entire structure is of concrete there is virtually nothing to attract rats and mice, and the fact that it is vermin-proof constitutes one of its attractions.

In concrete foundations bolts or other forms of support for wooden superstructure, where used, can be put in place by suspending them on cleats resting upon the forms, thereby securing an unusually firm anchor in the hardened wall.

Concrete blocks are rarely used in commercial buildings excepting in those of small size; but occasionally a special block prepared with a peculiar type of facing is used to give decoration to the structure. Again pre-cast blocks or slabs may be set up with cement mortar to give the appearance of natural stone construction, and in most large cities there are public buildings, banks, etc., built of this material. Where the building itself is of monolithic concrete, it is frequently trimmed wth pre-cast blocks, which appear around doors and windows, at the corners, and elsewhere. Concrete blocks, as such, have found their greatest use in small structures such as dwellings, small mercantile buildings, garages, and the like. Their manufacture is described in the chapter on concrete products. They can be used effectively, notwithstanding the monstrosities to be found about the country, which have resulted from the use of plain blocks by persons of no artistic sense.

Of late years small concrete blocks, more properly called concrete bricks, have been employed. The smaller size afforded a better opportunity of securing walls without that deadly regularity which has been characteristic of some block structures. Perhaps the greatest advantage, next to durability, in concrete structures of block construction, is the opportunity afforded for one or more continuous air-spaces in the wall. This permits efficient insulation, which provides against the changes of temperature out of doors. There have been patented designs for blocks that allow of continuous air-space in both directions.

A mean size of concrete building block is eight inches thick, with a face eight by sixteen inches. These dimensions are subject to wide variations, and blocks have been made up to thirty-two inches in length. Fractional blocks must be made in order to secure breaking joints, and the faces of these blocks may be variously treated, as described in the chapter on art in concrete.

In dwelling-houses concrete has been used in combination with nearly every other building material, and by itself in monolithic construction, as slabs, as blocks, and as rough walls surfaced with a variety of stuccos. Many houses are built entirely of concrete, with the exception of floors laid upon concrete bases, and the necessary trimmings, which may be metal finished to resemble wood.

A great deal of publicity was given a few years ago to the small house to be cast monolithically, or to be poured as concrete slabs, one for each side, and then erected into the final structure. It has been argued that this type of dwelling is uneconomical to construct, unless the number involved is sufficient to pro-rate the cost of forms. To overcome this difficulty, houses have been designed to use large pre-cast units, usually slabs of a length equal to the height of the house, and of a width giving a total weight not difficult to transport. These slabs are joined and held securely by means of concrete poured into matched openings left for this purpose.

Any masonry wall may cause the condensation of moisture upon it, regardless of the extent to which it may be damp-proof or water-proof. It is considered advisable, therefore, to furr out from the inner wall and in this way provide small additional air-spaces between the outside wall and the plastered wall upon which decorations are to be placed. This prevents warm air in the room from coming in direct contact with the cold outside wall, and no moisture will form to give unsightly evidence that moisture has been present.

Occasionally a metal form is erected, metal lath or fabric is fastened to it, and the exterior is then covered with Portland cement or stucco. Metal lath is also attached to the inner side of the form and is then plastered with ordinary plaster. Partitions are built up in the same fashion, or sometimes hollow cement tiles or other fire-proof partition material is employed. Floors and roofs may be similarly made, or reinforced concrete slabs may be put in place.

Abroad it has become customary to cast the house with metal window casements in place. But large slabs when employed are composite, clinker aggregate being used in the inner surface to give more porosity and consequently better insulation. Where special blocks are cast, a stone concrete forms the outside face and coke breeze aggregate is used on the inside. In all this composite work, barbed-wire reinforcement is used to overcome unequal shrinkage.

Local aggregates frequently give desirable color to concrete walls, which are brushed with water at just the right time to remove the surface film of concrete mortar from the colored bits of stone. The surface may be variously treated as mentioned in the chapter on art in concrete.

The requirements in a home are comfort, pleasure, sanitation, and durability. We should like a house cool in summer and easily heated in winter. We want to feel it is fire-proof, and has no place for vermin, rats, and mice. We wish to use a material that possesses individuality and with which a pleasing artistic effect can be secured, free from damage without and within, sanitary to the utmost, proof to a remarkable degree against the destructive forces of nature. Concrete houses can be made to answer these specifications, and when so built constitute an asset in every sense of the word and make it possible for us to build for a thousand years.

CHAPTER XIX

WATER-PROOFING AND SURFACE PROTECTION

Throughout the discussion in this book, emphasis has been placed upon the necessity of obtaining concrete as dense as possible, in order that there may be a minimum of voids to hold moisture that may lead to disintegration and ultimate failure. The point has also been made that moisture absorbed by the porous concrete not only works to disadvantage by causing volume changes, but is liable to disrupt the mass through freezing and thawing. The only method of placing cement mortar, which reduces the water in excess of that required for hydration to the minimum, involves mechanical appliances such as the tamper, the roller, and especially the cement-gun.

Very early in this era of concrete construction, it became apparent that means must be devised for damp-proofing and water-proofing all masonry building materials, which are more or less porous and permit the absorption of water by capillary action. In many instances, water that thus permeates material dissolves alkali sometimes present, and unfortunately brings this to the surface, where it deposits as a white crystalline substance when the water evaporates. How often one sees otherwise attractive buildings discolored and marred by such a white deposit, most prominent at those seasons of the year when there is abundant moisture in the air! This may often be avoided by the proper selection of brick, etc., having a minimum of free alkaline salts.

The term damp-proofing should be confined to the means used for keeping water and dampness out of the structure above the ground-line, and water-proofing as applying to foundations, tunnels, and other work below grade.

Early in the development of damp- and water-proofing, the problem was not well understood, and reliance was placed upon materials that experience has shown to be ill suited for the work. This has been particularly unfortunate, since a prejudice against present scientifically combined materials arose, and today some engineers refuse to employ substances that are really efficient, basing their objections upon the performance of coatings that should never have been employed.

There are two main subdivisions, one involving coatings familiarly termed membrane treatment, and the other integral water-proofing, which, as the name implies, makes a water-proof material an integral part of the concrete mass. In particular work, both methods are sometimes employed. Turning now to the problem of damp-proofing, the methods may be considered under processes that are designed to deposit water-resistant compounds in the pores of the material, and the treatment of surfaces with some form of wax as such or in solution.

The use of wax was made popular by the work on the obelisk called "Cleopatra's Needle" in Central Park, New York, in 1885. The rapidity with which this ancient monument began to disintegrate under conditions of modern civilization lends emphasis to the statement that the necessity for protection of structures may be traced to the influence of civilization. Cleopatra's Needle had stood for some four thousand years in the climate of Egypt without appreciable effect upon the stone; but under conditions obtaining in New York its porous surface became shattered as a result of water freezing in the pores, and of the sulphurous and sulphuric acid as found in the atmosphere of any modern industrial city. A similar experience has been met in London, where old buildings have begun to show the effect of this acid moisture following the burning of soft coal. The habit of the people in South Italy of continuing to use wood for fuel largely accounts for the absence of disintegration in the masonry of the Roman Empire.

Referring again to the obelisk, this was carefully cleaned and the loose stones removed. Some of these crumbled, and the total debris weighed nearly seven hundred and eighty pounds. The entire surface of the Needle was then carefully heated, bit by bit, with blowtorches, and the surface of nearly two hundred and seventy square yards was then treated with hot paraffin. This is a very effective type of damp-proofing, but quite obviously is limited in application to special cases where cost is entirely secondary and where the surface can be heated and coated in a manner to procure satisfactory work.

Virtually all of the early proprietary damp-proofing products were transparent, and were based upon solutions of paraffin or waxes, all designed to produce no change in color of the treated surface, and all being easy to apply. It is well known that only a small per cent. of wax can be dissolved in a given volume of solvent, so that this method was not very successful, since upon evaporation an insufficient coating remained. Manufacturers did not always recognize this limitation, and cheerfully advertised effective results with a minimum number of applications. This did not leave a sufficient quantity of solids upon the surface to be effective.

Another large group of damp-proofing coatings involves the use of cement washes and coatings, based upon the employment of common oils. The application of cement washes assists in damp-proofing; since the treatment fills a part of the pores; but these washes involve the use of water, which must occupy a definite space, leaving pores when this water evaporates. Water easily enters these microscopic openings. Sometimes there is difficulty in obtaining a satisfactory bond between the wash and the concrete, and equally serious is the coefficient of expansion between those mixtures containing different proportions of cement.

When coatings based upon oils, meaning our ordinary paints, are put upon wood or metallic surfaces, there is no reaction between the surface and the coating, and if good practice is followed the result is satisfactory. Concrete, however, is chemically active, and is nearly always alkaline in nature. It will be recalled that soaps result when alkalis react with fatty acids, commonly called fats. We have, then, a reason why oil-base coatings so often fail as protective films for concrete. There is a tendency to saponify the coatings, which reduces them to an ineffective mass.

Where paint has been used either as a damp-proofing medium or to decorate cement and concrete surfaces, these surfaces should be treated by the Macnickol method, designed to neutralize the alkali and render the surface inert. This method consists in priming and filling the surface with a twenty-five per cent. water solution of zinc sulphate, prepared by dissolving three pounds of zinc sulphate crystals in a gallon of water. Tests conducted by the Paint Manufacturers' Association of the United States indicate that, when cement surfaces have been treated in this manner, they may be painted with even more enduring results than wooden surfaces. The same type of paint may be used, having a lead or a zinc base. The most satisfactory results have been obtained with paints made of linseed oil or mixtures of bodied and heat-treated linseed and Chinese wood oil. Such opaque white pigments as basic sulphate white lead, basic carbonate white lead, zinc white lithopone, and such inert pigments as barytes, silica, white China clay, and asbestine have been found satisfactory.

The brush application of an acid resin is also used to damp-proof concrete. This procedure is based upon the fact that such acid resins will combine with the lime of the concrete, and will form an integral material on the surface only. Sodium silicate has also been widely used for surface treatment, the relatively insoluble calcium silicate being formed in the pores of the surface; but if wear must be withstood, as is the case with floors, this material is not very durable. Another treatment applied to floors is designed to prevent excessive dusting, and involves the use of chemical hardeners. Experiments are now under way at the Bureau of Standards with such compounds as magnesium fluosilicate and zinc sulphate, as well as sodium silicate and aluminum sulphate. Of these, the aluminum sulphate treatment is giving promising results, and a floor under test for nine months has still remained in a satisfactory condition.

Another method is damp-proofing with opaque materials that are also decorative. These materials are usually proprietary compounds designed with a knowledge of the physical and chemical character of the surface to be treated, and the kind of raw materials that can be treated in a way to have them combine with the cement to produce an efficient protective coating.

There is another important class of damp-proofing coatings that are in no way decorative, but that are designed first to seal the pores of the wall and at the same time to facilitate bonding the coating of cement or other mortar to the surface of the damp-proofing material. Such materials are built upon a bituminous base, and, as indicated, are applied to the inside of the wall. They are black, viscous, and are applied with a brush. They provide a continuous coating, which remains tacky for an indefinite period and forms a sort of insulating layer in the wall which effectively prevents moisture from passing beyond it.

Silicofluoride, which precipitates silica into the pores of the concrete and thereby makes it water- and air-resistant, is applied with a brush, or, when large areas are concerned, may be sprayed on the surface.

Another method, which really involves surface treatment and is more than damp-proofing, may be considered before water-proofing is discussed. It does not attempt to treat the concrete or cement, but undertakes to protect the structure from contact of moisture by enveloping it in a membrane. This membrane is continuous, and consists of a bituminous shield with which some sort of fiber is employed. As compared with other coatings, the membrane method has the advantage that it is not affected by any movement of the wall or protected member, and cracks that develop in the concrete have no effect upon it. It was the early practice to put asphalt, coal-tar, pitch, or special bituminous composition directly upon the concrete; but it was found that, notwithstanding its elasticity, the coat was liable to crack with any movement of the wall.

By employing burlap, coal-tar felt, special water-proofing felts, and the like, reasonably perfect membranes, possessing strength and toughness sufficient to withstand small stresses, can be applied. Asphalts are favored when the membrane is to be exposed to the air, since they are not so liable to be affected by oxidation as are the coal-tar products. The latter have been given preference for work below ground, which has to be covered with earth. Whenever a bituminous material is employed, it should be selected with reference to a low melting-point, which not only insures greater elasticity, but is easier to apply.

Special asphalts are frequently made up from such hard hydrocarbons as Gilsonite made into a viscous fluid with petroleum residues which give the necessary elasticity.

When it comes to integral water-proofing, it must be remembered that such density and water-resistant characteristics as cement mortar and concrete have are partially due to the colloidal cement, which permeates the pores of the material upon hydration and which becomes so dense as to render the mass almost water-tight if sufficient moisture remains in contact with it. Chemically this colloidal cement is a calcium silicate formed by the reaction between the silica and lime of the cement, and technically known as colloidal calcium hydrosilicate. Fundamentally, a most successful integral water-proofing material would be a colloid that would entirely fill the voids and pores in the cement or concrete mass, leaving no spaces between the crystals that are formed in the process of hardening. Such a colloid should expand and develop only enough to perform this function; for, obviously, if such an integral expansive force continued, cracks might develop due to internal strains that would be set up. Further, an ideal colloid for the purpose should not tend to lose its character should the concrete mass become dry, and should always quickly revert to its colloidal state upon wetting after having been thoroughly dried.

Hydrated lime, clay, and aluminum hydroxide are examples of colloids that are slow in reverting to their colloidal state after drying. With this understanding of what a water-proofing compound should be, the development of integral materials for the purpose may be considered.

These may be either dry compounds to be mixed with the cement, or materials to be added to the water used in mixing the mortar and concrete. Some compounds are composed of materials known to be repellent to water, of which class the metallic soaps are examples. A lime salt of a fatty acid is a popular repellent for this use. It is efficient, but only when uniformly mixed with the material and evenly distributed throughout the mass. It will be apparent that such materials, upon coming in contact with water added to the dry cement with which they are mixed, will have a tendency to leave the mass and float upon the surface. The more water added, the greater the separation of the repellent powders that are thus afforded a greater opportunity to rise through the mass. Occasionally, as in the facing of concrete blocks and artificial stone, methods can be developed that tend to hold the repellent in place; but in general there has been difficulty in the application of dry repellent powders.

Another natural development arising from experience with repellent powders has been the effort to provide something that would accomplish the purpose so far as water-proofing is concerned, and yet be of a nature that would make possible the mixture of such a non-repellent material uniformly throughout the dry cement and sand. Such products have been built up about hydrated clay, aluminum hydroxide, or other inorganic colloidal material as a basis. This involves grinding such substances extremely fine, but it has not been found that such materials will develop colloidal characteristics to the ideal extent required to fill the voids completely. Some also hold that when these materials once become dried out they are not likely quickly to return to their volume in the colloidal state when again wetted.

In chemical engineering, integral powders are also used to render the structure more resistant to acids or alkalis, as the case may require.

There is still another class of materials that have been applied in integral water-proofing. They are metallic in nature, and nearly always consist of iron reduced to a very high state of subdivision and intimately mixed with the concrete mass. Theoretically, this metallic iron is changed into iron oxide, as common rust is called; and this oxide occupies a larger volume than does its equivalent of metallic iron. The voids should be filled and the concrete rendered so dense as to be impervious to water. A great deal of concrete has been placed with this type of water-proofing, and much of it has been successful. Some contend that the conditions under which the iron is placed in the concrete mass renders its oxidation very slow, if not impossible, particularly in the interior of the mass, and that it therefore cannot attain maximum efficiency. It depends, obviously, upon the conversion into the oxide, and where both air and moisture are present this is rapidly formed, but not under other conditions.

Finely ground metallic iron, with the addition of certain chemicals, is also used in surface applications in which an effort is made to fill all surface pores with the iron, which can there form a void-filling oxide.

There is still a class of water-proofing materials to be considered, namely, those that are added to the mixing water rather than to the dry cement. Such compounds, either as pastes or powders, should be evenly distributed throughout the mass with greater facility if mixed with water than if confined to the dry materials. Colloids must supply the effective substance,

A PRETENTIOUS CONCRETE BLOCK COUNTRY HOUSE

A CONCRETE BLOCK HOUSE WITH CEMENT TILE ROOF remembering that it is now agreed that it is colloidal cement that assists in making untreated concrete as water-proof as it is.

One type of this material is the unsaturated fatty acids, which react with the elements of the cement to produce a water-proofing compound. The calcium hydroxide of the cement used in this way is thought by some to decrease that available for the initial setting and hardening of the cement to such a point that the strength of the concrete may be affected, and they therefore prefer to use colloids that are efficient on account of their own characteristics, and that do not depend upon the reaction with the cement for their efficiency.

The present tendency is to furnish this type of colloidal material in concentrated form, so that there may be sufficient colloid present to close all pores and fill voids.

It seems particularly important that stucco should be water-proof, for it is a common thing to see otherwise handsome buildings disfigured by great cracks and occasional bare spots where the stucco has fallen away due to moisture, or where moisture destroys such a surface by including volume changes, manifested either by expansion and contraction or freezing and thawing, sometimes from both causes. The integral water-proofing of stucco is not difficult, and certainly should be more universally practised. Experiments have been conducted in the laboratory with cubes of different kinds of stucco, some water-proofed effectively, some untreated, and others that show the waterproofing to have been imperfectly done. The results indicated without any question the relative absorbent qualities of the specimens, and showed how readily untreated concrete will absorb comparatively large quantities of moisture.

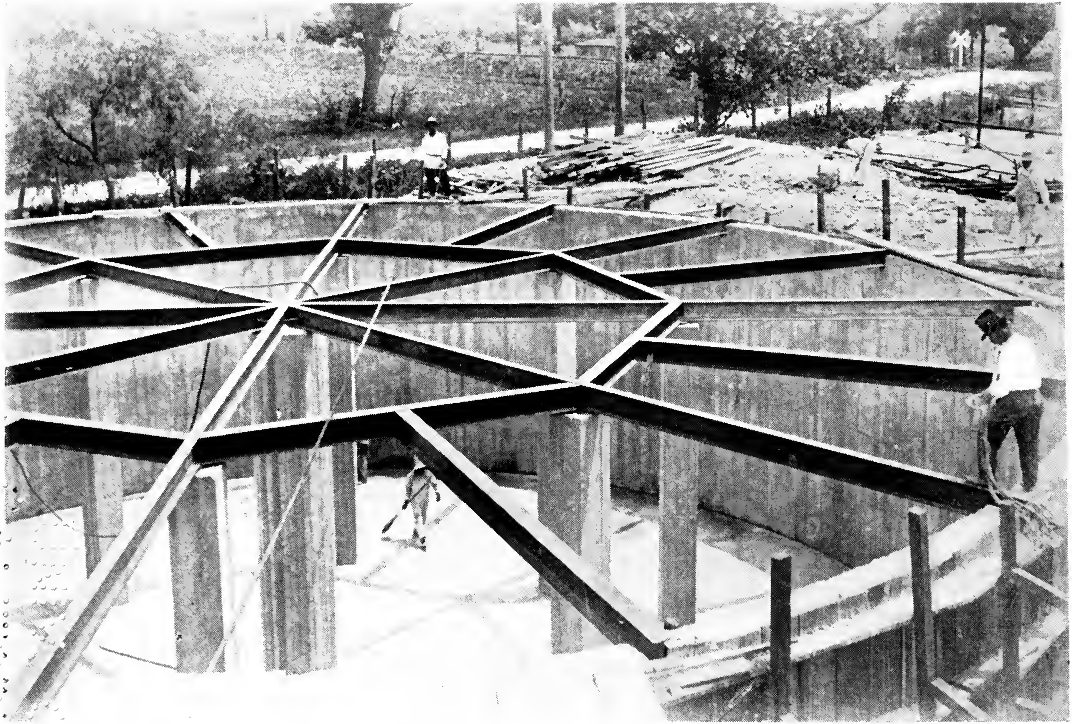
Where any type of damp-proofing or water-proofing surface treatment is followed, it is essential that the masonry surface be as dry as possible; for this coating depends to some extent upon the absorption of the wall to secure adequate penetration, which insures a good bond. Continuity in such surface treatments is essential, and where ceilings make it impossible to carry the surfacing treatment of side walls continuously between floors, it is recommended that the coating be carried out some distance upon the ceiling.

Where coatings are used below grade, or over places where there is apt to be pressure from water behind the wall, it is quite essential that this pressure be relieved through drain-pipes, sometimes carried through the wall itself, these drains being closed after the remainder of the wall has been treated. Experience has shown that with buildings satisfactory results are obtained by placing ordinary drain tile of sufficient capacity outside the wall at the foundation footing, so that water accumulating outside the wall and running down may be rapidly carried away and pressure avoided. Walls provided with such drainage, and properly coated with a bituminous film, seldom allow moisture to enter the basement. This treatment is obviously applicable only in those instances where the excavation does not go beyond the line that will permit sufficient fall to be given the tile to drain into existing sewage systems.

Mr. H. D. Hyman, in a discussion of integral water-proofing, emphasizes six points, the neglect of any one of which may lead to unsatisfactory water-proofing. These six points are as follows:

1. The ingredients for the concrete must be standard in every respect; the sand must be clean and coarse, and the gravel or broken stone of the best quality.
2. The integral compound must be of tested merit, incorporated in accordance with the manufacturer's directions, and thoroughly diffused throughout the mass.
3. The ingredients must be so proportioned that the cement mortar will fill the voids of the aggregate.
4. Mixing must be thorough to obtain uniform density and the consistency known as quaky used. Tie-forms well braced are an essential to good results. Care must be assumed in placing the concrete, with particular attention to the spading at the faces, and to the horizontal joints between material placed on different days. No wood of any kind can be allowed to remain in the concrete.
5. Ground water must be kept from the mass until it has reached a point at which it is capable of resisting the destructive action of the water. Draining, and even pumping, must be resorted to when necessary.
6. Each member of the structure must be designed and constructed so that the water-pressure will be resisted without exceeding the structural strength of the member. The foundation must be able to support the structure without excessive settlement of the structure, and the whole must possess sufficient weight to counteract the lifting pressure.

Concrete is so good a structural material that these various processes designed to make it ideal should be considered with reference to special needs as they arise in the application of concrete in our modern structures. The comparatively slight added cost constitutes insurance against the little things, as well as the great, which often mar walls, give rise to stains, and otherwise displease and aggravate the occupant, if indeed they do not lead to inconvenient extensive and expensive repairs. When scientifically undertaken, waterproofing and damp-proofing of cement and concrete can be effected to a remarkably satisfactory degree.



Courtesy of G. W. Smith, San Antonio Public Utilities

STEEL WORK FOR COVER OF 400,000 GALLON TANK

Note concrete supporting columns

A GREAT GRAIN ELEVATOR AFTER A FIRE WHICH DESTROYED THE PLANT FROM THE CONCRETE BINS TO THE CONCRETE CHIMNEY

CHAPTER XX

CONCRETE TANKS

Concrete tanks, especially for industrial purposes, are being used to a constantly increasing extent. Many of these tanks are underground, and, since it is comparatively easy to mold a tank in place, it has been found possible to put concrete tanks where they will be of maximum service, frequently in out-of-the-way places in which it would be difficult to fit a metal tank or to construct a satisfactory tank of any other material. Concrete tanks can be built in batteries or groups, as plant conditions require. Compartments can be made monolithic with the general structure. Suitable inlet and outlet pipes can be provided, and when it is considered that various types of treatment can be given the concrete, either integral or surface, it will be recognized that they can be made to serve an almost endless variety of purposes. Indeed, many concrete tanks are performing service that no other structural material can give so satisfactorily.

We need not stress the adaptability of concrete for the storage of water, except to say that water-tanks, often made beautiful by the design and general treatment, have been set in doors and out of doors, both above and under ground.

Where mineral oils are to be stored, concrete tanks are not an experiment. Many such tanks have fifteen years of service behind them, and tanks for the storage of eight hundred million gallons of mineral oil are now available in the United States. The size of the tank depends almost entirely upon the skill and perfection of workmanship employed in its construction. To be proof against the leakage of liquids, high density must be secured, and it pays to use precautions that are well understood in the selection of materials, in their proper proportioning and mixing, and in the careful placing of concrete tank walls, bottom, and cover.

Perhaps the greatest advantages of the concrete tank are to be gained when they are placed underground and covered with two or three feet of earth. This makes it possible to maintain a comparatively even temperature, reduces losses from evaporation, and provides the greatest protection from fire, lightning, and other destructive agencies. When tanks are so placed, insurance is reduced, and the fire hazard for buildings in the vicinity is brought to a minimum.

The storage of vegetable and animal oils has not been so simple, and it is believed that concrete designed to hold such materials should be given at least a surface treatment with some such substance as magnesium fluosilicate. Such a treatment for tanks designed to hold the heavier or crude petroleum oils is a wise precautionary measure, and even tanks that are to hold water only should be given a coating of rich mortar to be sure that all pores are closed. The advantage of using cement for this application will be apparent.

When molasses is stored in concrete, a complication is introduced due to the fact that there may be a tendency to fermentation, requiring frequent cleaning of the tank. This can be largely overcome by using underground tanks. Any reaction between the calcium salts in the concrete and the sugar solutions can be retarted or prevented by suitable treatment of the tank surface. A number of molasses storage-tanks are in use by a company having over a half million gallon capacity in concrete storage. A portion of these tanks received inside treatment of flexible coal-tar, which afforded complete protection.

The storage of miscellaneous chemical solutions has presented a variety of problems in concrete tank construction. Steel or wood tanks will not withstand the chemical action involved, and progress has been made in lining such tanks with lead, glass, or other types of enamel. It is difficult to apply an enamel that will be entirely free from pin-holes, which become at once the center of considerable trouble, and the harder enamels are at times subject to abrasion or injury from impact. These conditions have led to experiments with concrete tanks for a great number of purposes, and in most cases these have been satisfactory in their performance.

Stock chests in paper-mills and other tanks in the same industry have been satisfactory, although the concrete is not given any special treatment. Calcium-chloride solutions have also been stored, the untreated walls showing slight wear only. Bisulphide-of-lime solution has been stored in tanks built in 1904, and acid towers of concrete lined with vitrified tile have proved entirely suitable. Silicate of soda stored in concrete tanks has no effect upon the material, as is to be expected.

A sulphuric-acid solution in a concrete digester used for treating wood chips, and lined with brick laid in litharge, has given no trouble whatever. A tank in which sulphuric and hydrochloric acid has been stored from time to time, the surface of the tank having been treated with special coatings, has given no trouble. Tar-coated tanks have been used with complete success for storing ammoniacal liquors. Zinc chloride and various types of electrolytic solutions have also been stored in tanks, some of which have been treated with asphalt coating. Tanning liquors stored in concrete tanks have had no effect upon the vats, which have given their owners satisfactory service, and concrete tanks for this type of storage have been in use since 1905. Tanning liquors include leaching, bark solutions, hemlock liquors, quebracho, and other extracts, and it is the opinion of many in the tanning industry that no other material for vats could have been so successfully used as reinforced concrete, with or without special surface treatment.

Log boiling previous to the cutting of veneer has also been successfully carried on in concrete tanks, where no effect other than the natural abrasion incident to the boiling of logs has been noticed.

The dairy industry has also extensively used tanks of this material. Whey, buttermilk, and many other dairy products are satisfactorily stored in such tanks, which have decided advantages in being non-absorptive and easily cleaned.

In the gas industry, purifying boxes of large capacity, scrubbers, and other units have been installed. The mining and metallurgical industry also uses tanks for slimes and various types of storage with great success. In the recovery of many materials, concrete tanks find a place, and for the storage of liquids used for cleaning in electroplating and similar specialties, concrete is an appreciated item of equipment.

It must be apparent that such tanks are called upon to bear considerable stresses, and it is necessary carefully to design and construct such apparatus, paying especial attention to satisfactory reinforcement. The number of construction joints or seams should be reduced to a minimum, and any speeding up of the work necessary to accomplish this is fully justified. Where joints must be used, precautions should be taken to secure as tight a joint as possible. To do this, it is sometimes good practice to embed a metal plate in the freshly placed concrete, so that it will extend some distance into the concrete next to be placed. In addition to this, the surface of that material placed last must be roughened before the work has stopped, and cleaned and painted with cement grout before the new layer is poured. Also, because great strength may be demanded of concrete tanks, precautions should be taken to secure the maximum strength, which is attained only when the material is well cured and protected during the time it is going through the initial setting and the hardening period. As soon as strength has been sufficiently developed to withstand the pressure of water, it is advisable partly to fill the tank, so that there may be abundant moisture easily available to facilitate proper hardening.

Concrete water-storage tanks must often be elevated on some type of supporting structure. This structure may be of the same material, but where metal is used for any reason it is a good practice to protect it from corrosion by embedding it in concrete or covering it with a dense coating of cement mortar, best applied by some such mechanical device as the cement-gun. Where the height is not too great, the conduit through which the water is pumped to the tank and the exit pipes may be made a part of the supporting structure, and encased in a wall of concrete sufficiently thick to bear the weight of the full tank, thereby simplifying the support of the structure and making it somewhat less conspicuous.

Swimming- and wading-pools are in effect sunken concrete tanks. They have come into general use because they are easy to construct, easy to keep clean, and may be built of any desired shape without difficulty. The surrounding houses can be made of the same material, as may also sliding-boards, platforms, and other accessories. Where a white surface is desired in a swimming-pool, a white cement wash may be applied, and if special markings are desired, tile can easily be set into the concrete at the time of placement. The wading-pool has recently appeared in increasing numbers in various public parks, such pools usually having a maximum depth of twelve inches. With concrete they may be constructed with a sloping pavement, to permit an easy entrance, and the surface can be sufficiently roughened to add the safety of walking without any discomfort. Such pools form ideal skating-ponds for winter sports.

The grain-elevator and storage-bin is really a tank under another name. The fire hazard, ever present in adjoining structures where organic dust may become suspended in air in such a proportion as to give rise to spontaneous combustion, makes the use of fire-proof materials important in their construction. Another source of considerable loss in mills is from insects and rats, which not only destroy quantities of grain annually, but gnaw their way through walls and floors, thus giving rise to a considerable percentage of loss through leakage.

Concrete bins and elevators are obviously proof against these destructive agencies, and in addition are dry and water-tight. They have come to dot the landscape in all those areas where grain is the basis of a considerable portion of the industrial activity. Along the Great Lakes and the great grain-carrying railroads, numerous elevators have sprung up, these usually being built as a series of circular towers having incredible capacity, and making it possible to expand the plant to suit the requirements as they arise.

Acting upon this suggestion, some farmers have put in small tanks or bins in which to store their crops, awaiting favorable market conditions. On one farm four such bins, each of a diameter of twenty feet and a height of fifty-six feet, have been erected, with a total capacity of 45,000 bushels, and an annual saving considerably in excess of ten per cent. of the cost has been effected since their installation.

In many instances, upon the farm, in the small elevator, and in the elevator of enormous capacity, fires on adjoining property have left these bins intact and the grain within them undamaged. One of the most striking examples of this was in connection with the Baltimore fire, where the concrete grain bins of the Pennsylvania Railroad and the chimney of the same material were the only parts of that great plant which survived the conflagration.

A CONCRETE FLOWER POT

Showing the use of exposed aggregate. John J. Earley, sculptor

ARTISTIC CONCRETE PRODUCTS

CHAPTER XXI

CONCRETE PRODUCTS

While cement is very nearly a universal construction material, there is, as in most cases, a great advantage in experience in its manipulation. This point has been made repeatedly in other chapters, and in no way detracts from the many advantages that the material has. It is simply the case of making a good thing better by the application of the skill which comes only with experience. There is a further advantage in the use of concrete products, and that is that where a plant has been properly established and managed it is possible to install the very best apparatus to secure results to specifications, and materials are produced with a great deal of uniformity, homogeneous in texture, accurate in dimensions, true to form, and made in a way to have high strength. Concrete products can be made under fairly uniform and standardized conditions. Proper facilities for curing can be installed, involving tunnels or other devices where curing is carried out even under steam pressure and out of the ordinary temperatures with a view to securing special results. The employment of units pre-cast gives great flexibility in construction, and enables one to secure the utmost that is desirable in contrast.

Perhaps the best known concrete products are blocks that have been recommended in times past for all sorts of purposes, many of them unfortunately being not well suited for execution with blocks as they were first produced. It took a little time to develop the idea of special shapes and lengths of blocks that could be laid artistically and in a way to approach the appearance of stone masonry. Then, too, it has been found undesirable to attempt the reproduction of cut-stone blocks in concrete. However, molds might be sufficiently tooled and finished to give the type of break on the surface that is obtained by chiseling natural rock, but it seems far better to create for concrete blocks a type of special surface that shall be characteristic of the material.

The concrete block is the product of a machine that discharges the blocks in various gangs or numbers, dependent upon the capacity of the plant. Greater density is obtained by the use of vibrating-machines, so designed that vibration is applied before the initial set of the mass. When concrete begins to harden, nothing should be done to disturb it, and never should any attempt be made to retemper partially set concrete or to use it in new batches of freshly mixed concrete.

Reference has been made to the possibility of combining different mixtures into concrete block. Thus crushed coke, familiarly known as coke breeze, may be used for the inside of the block, because it is porous and not so liable to permit the condensation of moisture upon its surface. The outer surface of the block may be varied in its composition, producing many types of special facing.

Such blocks usually require careful reinforcement, barbed wire being a popular material for the purpose, in order that the uneven volume changes, due to differences in the mixtures used, may be counteracted and kept from destroying the structure. Great strength can be obtained, with a decrease in the gross weight, by the use of well placed webs, which at the same time provide the much desired air-space. Where metal fittings are required for any purpose, such as hinges, they can be either stone-bolted into the concrete block or actually cast in place at the time the block is made.

Closely related to concrete blocks are the slabs usually designated as concrete lumber. This is made with or without provision for joints, which must be obtained by recesses in one edge of the slab placed to fit over a corresponding projection in an adjacent slab. To facilitate carrying and placing heavy units of lumber, it is customary to provide metal eyes for carrying, but in some cases threaded metal sockets have been cast in place, so that screw-bolts can be inserted when it is necessary to transport the slab. Some cement-products plants carry such reinforced slabs in stock, the size being determined by the local demand. Frequently it has been found possible to provide and place concrete lumber at a total cost not in excess of duplicating the work with first-rate timber. In such cases the advantage is without question usually with the concrete, because of its fire-, water-, and vermin-proof qualities. It is easy, also, to cast in place such metal corners and edges as may be thought desirable to protect the material from blows that may disfigure the corners and lead to the ultimate disintegration by abrasion and the entrance of water.

Another material is concrete tile or shingles, which so far have not been extensively used, probably because of a lack of familiarity with their good qualities. Obviously, roofing of this character must be made with great care, since it is intended to last indefinitely when once in place. Due regard must be given to the support of the roof-frame, for concrete shingles are much heavier than wooden shingles, and cement may be compared with large Spanish tiles in this particular. When well made they stand the impact of materials ordinarily falling upon them, and if the angle or slope of the roof is made sufficiently steep they can be relied upon to be water-proof. Such shingles are usually flat, with a ridge that interlocks with a corresponding depression in another shingle, so that a tight fit can be obtained in all directions, and inorganic or mineral pigment is used in the surface to provide the desired color.

Posts of all types have been made of reinforced concrete in the concrete-products industry. They are permanent, and for this reason they have become extremely popular. The increasing scarcity and rapidly advancing cost of wood posts of the types of wood known to withstand rotting and decaying satisfactorily has done much to increase the demand for concrete posts, and today many corporations and farmers are making such posts in those seasons of the year when other work is slack. The average farm of one hundred and thirty-eight acres requires seventy-five posts each year to replace ordinary breakage and wear of wooden posts. If all farms availed themselves of the advantages of concrete fence-posts, there would be a possible market of nearly half a million posts a year until the farms had become entirely refenced with concrete posts. Such posts can be made to have the same advantages as the wooden ones, and are becoming a stable product of the concrete-products plants. Mileposts of this character are to be found in some parts of the country, and highly ornamental posts are used, especially at the corners of city property.

Concrete guide-posts have been installed through some areas, and years ago combined supports for trolley wires, electric lighting wires, and letter-boxes were installed in various parts of the world. These same posts have also been made to carry the lighting units for streets, and later on the letter-boxes themselves were made of concrete. The concrete lighting standard is now familiar in most cities. It has been made very attractive, is economical to install, involves a low maintenance cost, and all in all would seem to solve the lighting standard problem for many a city. Provision is made for the conduit in the design of the post, so that the wires of various types are both hidden and protected. Such conduit is usually led into iron pipes embedded in the concrete and thus protected from corrosion. Concrete grape-vine posts have also been widely used, and special posts supporting concrete beams have been used in a protecting fence on narrow roads, on curves, and on embankments. These structures are sufficiently massive and heavy to prevent vehicles from plunging into dangerous places.

Another extensive specialty of the concrete-products plant is the tile for land drainage and for sewerage purposes. One of the essential advantages of concrete tile is its uniformity of size, for the volume of water that will flow through a tile line is limited to the capacity of the smallest tile in the line. Since concrete tile is machine-made, the diameter and length may be depended upon to be uniform. The curing of the tile is not likely to bring about any such changes as are experienced in the burning of the older clay tile. Another point is that circular tile has a greater capacity for its diameter than has oval tile. The four-inch circular tile may carry as much water as a five-inch tile that is not a true circle. Here, again, the machine-made product has a marked advantage, and, since concrete tile is always cylindrical, there is no variation that would prevent the free and rapid movement of water. Rough places on the inside of the tile serve to retard the flow of the water. Consequently the smooth interior finish that characterizes all machine-made concrete tile is a marked advantage.

The ends of the tile are smooth and run parallel, so that the tile may be fitted closely together. This is an important point, for, while it is through such joints that water to be carried away enters the tile line, it is also through poor joints that silt and earth enter, sometimes in sufficient quantity to block a tile line, necessitating labor and expense of digging it up and cleaning and relaying the line. In a well regulated concrete-products plant tile is produced of uniform strength because a uniform mixture is utilized and molded under uniform conditions. The cycle is completed by the proper curing, so that the tile in the line will be of uniform strength.

It is not customary to use reinforcement until a diameter of twenty-four inches has been reached; but tile of this and larger diameter is usually reinforced, partly to enable safe handling of such a heavy unit.

Besides its use in drainage systems, reinforced concrete tile or pipe made in large quantity has been employed as conduits for water under high pressure, and also for sewers. This pipe is constructed with edges designed to give tight joints, and has been made at least as much as one hundred and eight inches in diameter. Such a pipe has a thickness of nine inches, and, being in fifteen-foot sections, weighs fifty-five thousand pounds a section. Such pipe has been laid by divers working in fifteen feet of water and has given very satisfactory service. High pressures are withstood by such reinforced pipe, and it is known that under fifty pounds pressure to a square inch a mile of such material leaked only three hundred and thirty-five gallons in twenty-four hours.

The manufacture of such pipe involves a careful grading of aggregate, the careful proportioning of all ingredients, thorough mixing, and the proper placing of materials in the mold. Usually one sack of cement is used to one and a half cubic feet of well graded sand and two and a half cubic feet of clean pebbles or broken stone ranging from one quarter to not more than three quarters of an inch in the greatest dimension. The additional strength required is secured by embedding reinforcement in the concrete. For this purpose steel bars of cold-drawn wire mesh are used. This reinforcement is capable of resisting strains of from ten thousand pounds to twelve thousand pounds per square inch.

The use of concrete pipe for sewerage purposes dates back a number of years, the first sewers of this kind having been laid about 1850. Since that time many miles of such sewers have been put down because of its low cost and general satisfaction. It is particularly necessary to build such pipe with care, as no leakage is the ideal condition. A deficiency in fine material in the aggregate may cause pin-holes through which water may be forced when the pipe is exposed to internal pressure.

While an excess of such fine material will cause low strength and in general produce a pipe that will show seepage when internal pressure is applied, all such pipe used for sewerage purposes should be tested. Two indications of good quality are a high supporting strength and a low percentage of absorption. In determining absorption it is the practice to dry the pipe out at a temperature of 212° F. to constant weight. The pipe will absorb its full amount of water within twenty-four hours after being immersed, and upon being reweighed the percentage of absorption can be readily calculated. Tests have clearly shown that high strength and low absorption are inseparable. It is believed that in the few cases where fault has been found with concrete pipe for sewerage purposes, the difficulty has been due to poor workmanship rather than to any faults inherent in the material itself.

Concrete burial vaults have been a specialty of some product plants, and easily replace the brick and stone masonry so often used in cemeteries. Hot-beds and cold-frames have also been constructed of concrete products, having obvious advantages over wooden structural material for the same purposes.

The market to be reached by a cement-products plant is somewhat restricted by freight rates and the radius through which materials must be transported economically by motor-truck or team. Favorable freight rates are usually accorded cement products, and units such as silo staves, building block, drain-tile, wall-tile, and the like are often shipped great distances, especially to dealers who arrange to stock car-load lots for distribution in their own communities. The cement-products manufacturer can usually operate the entire year, and the business is one that ordinarily does not require a great outlay of capital at the start.

It is essential that such a plant maintain a high standard of workmanship, and that those in charge give constant study to their work, with the idea of developing new applications that will tend to stabilize their business and make it more permanent. When it is considered that the miscellaneous products are almost endless in variety, it would seem that there is a continual opportunity for the application of cement and concrete. Many ornamental objects are already in demand, including park and garden lawn seats, fountains, sun-dials, bird-baths, pedestals for supporting a variety of objects, vases, urns, and statuary. More commonplace, but equally important, are the lawn-rollers, waste-incinerators, laundry-tubs, garbage-boxes, and numerous other cement products yet to be developed.

CHAPTER XXII

CONCRETE ON THE FARM

There are so many applications for concrete upon the farm that it is difficult to select the most impressive example; but, since health is so essential, we will begin with a consideration of the concrete septic tank. This affords a central method of sewerage disposal wherever the advantages of a city or town sewerage system are not available. The concrete septic tank solves the problem of disposal of house waste. While it is not intended that this be substituted for the modern sewerage system, yet it is the best plan that has been proposed for use where such a system is not available.

Such tanks are not difficult to build, nor are they expensive, and when once in operation they require practically no maintenance or special attention. Concrete is particularly well adapted to this application. The tank itself can be cast monolithic in place, and concrete slabs used to form a tight, substantial, strong cover. The principle upon which septic tanks operate is that of decomposition for the solids and semi-solids enter the first compartment from the house drain, and as they become liquified the liquid is discharged through a second and similar chamber, from which it siphons into a tile system, having open joints through which the liquid finds its way into the soil at such a distance from the house as to guarantee absence of contamination in the domestic water supply.

Once started, the septic tank is self-operating, and, being discharged at intervals from the siphon compartment, the tile line, which may also be of concrete, is constantly flushed, then emptied by leakage, and the soil is allowed to rest until the next discharge. This system of intermittent discharge keeps the soil from clogging and insures efficient disposition.

The concrete fence-post already mentioned offers many advantages to the farm. It is fire-proof (an important consideration along railways), will not rot or decay, and when properly made possesses great strength. It may be made at home on the farm in commercial molds of metal, which last indefinitely, or in homemade molds built of lumber. Such homemade molds usually provide for a post four inches square at the top, five inches square at the bottom, and seven feet in length. Sometimes a recess is provided for a block of wood into which to drive a staple for the wire fence, or a heavily galvanized staple is embedded at the time when the concrete is poured.

There are various other methods of providing for the attachment of the fence, but one of the most popular is the use of an inserted strip of concrete of such composition that staples may be driven directly into the post, or a series of holes of small diameter are cast into the post so that tie wires may be used in them. This makes it possible to adjust the height of the fence regardless of the depth to which the post must be placed in the earth. Another method discards the attaching of the fence permanently by any kind of special feature, and uses what is known as the Western Union twist, this being the form of attachment used to tie wires to glass insulation. The wire is tied around the three sides of the post, and is made long enough for the ends that project beyond the post to be wrapped around the line wire. This simple method holds the fence well in place and disposes of any annoyance due to the uncertainty of special means of fastening.

The placement of reinforcement in posts is an important detail. Reinforcing rods must be placed at the points of greatest stress. It must be remembered that concrete, like stone, is very strong in bearing loads placed directly upon it, but will not stand great strains that tend to bend it or pull it apart. We rely upon the metal reinforcement to protect it in this regard. It is not enough to put a rod or piece of metal pipe in the post, because the strains upon it may come from any one of several directions as the result of numerous efforts to break the fence from every side or from sudden strains put upon it in a direction parallel with the fence. Reinforcement in a square post should, therefore, be placed near the surface of the four corners—if the post is round, at the points in the concrete near the face that would correspond to the corners of a square; if the post is triangular, there should be a reinforcement bar in each corner.

The usual precautions must be taken in properly proportioning, mixing, placing, and curing concrete. If wooden molds are used, they should be thoroughly wet before the post is poured, and have their surface treated to facilitate an easy removal of the finished product. The partially hardened concrete must not be damaged when the molds are removed, and to this end it is well to design the molds so that only wedges are necessary to hold the parts together. Hammering to remove molds should be reduced to the minimum.

Corner posts, end posts, and the posts used for gateways are usually cast in place to advantage. Whether so made or cast in molds, they should be provided with braces unless the mass is so great and so thoroughly reinforced as to make bracing unnecessary. Braces are usually more economical than any increases in the size of the post or the depth of its setting. Such bracing may be secured by a concrete beam running to the base of the next post, and this brace can be monolithic with the post or a separate unit pre-cast. Sometimes these braces take the appearance of wings, being cast solid to the ground with the corner post. There is a great strain upon a corner post, and it is essential that it does not become loosened. The bracing itself is often reinforced with small bars or with woven mesh.

Attractive surface finish can be given to gate and corner posts by using special facing materials such as those mentioned in the chapter upon art in concrete. Gate-hinges can be embedded in the concrete at the time the post is constructed, or other devices for hanging the gate may be included in the design. It is not difficult to include some ornamental top in the design of the corner or gate post, and the unit may be finished to any extent deemed desirable by the owner.

Tile for land drainage is always secured from a cement-products plant, for it must be machine-made to secure proper uniformity. The usual clay products tile has a porous wall, and it has been argued that such tile is more efficient in carrying away surplus water than is the dense concrete units, which can admit water to the line only through the openings between the ends of the tile. Experience has proved, however, that land may be rapidly and thoroughly drained with concrete tile, which must be carefully laid, with the same attention to essential details as in the use of any other drain-tile. These factors include the area to be drained; for, with other conditions the same, the tile must increase in size with the increase in area, and tile lines placed far apart naturally require a larger tile than one whose lines are nearer together.

The fall or slope is another consideration, for where the water flows rapidly and the slope is steep, smaller tile will carry the same volume of water than where the slope is gradual. Concrete tile-drains will operate on a fall as little as half an inch in one hundred feet. But, where the gradient is so small, large tiles should be used and great care paid to their proper installment. The effect of slope on the carrying capacity of different-sized tile is indicated by the fact that a four-inch tile will drain three acres of land when the fall in a hundred feet is only one and one quarter inches. This area increases to nine acres if the fall becomes six inches in one hundred feet, thirteen acres with a twelve-inch fall, and eighteen acres where the fall is twenty-four inches in one hundred feet.

The texture of the soil is another consideration, for water quickly passes through porous sandy soil, and larger tile is required to carry the water than if a dense clay is being drained. It also affects the depth at which the tiles must be laid and the distance between laterals; for, since the water can travel easily through sandy soil, sandy loam can have laterals one hundred feet apart; but a dense, close clay makes it impossible to space them more than thirty or forty feet. Where the rainfall is heavy or where sudden rain-storms of

SIZE OF WATERWAY REQUIRED FOR VARIOUS AREAS TO BE DRAINED

AREA DRAINED	AREA OF WATERWAY NEEDED (in Sq. Ft.)		
	Steep Slopes	Rolling Country	Flat Country
Acres			
10	5.6	1.9	1.1
20	9.4	3.1	1.9
30	12.8	4.3	2.6
40	15.9	5.3	3.2
50	18.8	6.3	3.8
60	21.6	7.2	4.3
80	27	8.9	5.4
100	32	10.6	6.3
125	37	12.5	7.5
150	43	14	8.6
200	53	18	10.6
300	72	24	15
400	89	30	20.
Square Miles			
1	127	42	25
2	214	71	43
3	290	97	58
4	359	120	72
5	425	141	85
7	548	183	109
10	716	239	143
15	970	323	194
20	1204	401	241
30	1630	543	326
50	2390	797	478
75	3240	1080	648
100	4020	1340	805

considerable magnitude are frequent, drainage must be designed to carry away the surplus water quickly, and large tile is required.

The same trenching machines and tools used in grading the bottom of the ditch, preparing its sides, etc., are used in laying the concrete tile. The essentials of a good drain-tile are met satisfactorily by concrete in the particulars that have been emphasized in reference to concrete products. It is hardly necessary to urge suitable tile drainage in the present discussion, for the practical results have been clearly demonstrated in nearly every farming community and on a scientific basis by the various agricultural experiment stations and agricultural colleges. It is interesting to note that at the present time farm products have reached a price level quite beyond any advance in price in the cost of concrete tile. In 1914 a bushel of wheat would buy twenty-two feet of a given size of concrete drain-tile, while in 1919 a bushel of wheat would purchase forty-one linear feet of the same tile.

In many localities improvements in the countryside have been concurrent with the increase in the number of silos. Largely through the research conducted by the agricultural experiment stations and the Federal Department of Agriculture, farmers have learned how to convert soft immature corn into valuable feed for feeding many animals. Corn in the silo is worth more to them than corn in the crib. At the Indiana Experiment Station figures were compiled over an eight-year period, and the average showed that if corn is selling for one dollar a bushel silage is worth $9.22 a ton as a food on the farm. If corn is $1.25 a bushel, silage is worth $10.21, and if $1.50, $11.30 per ton. At the Missouri Experiment Station tests were made in 1918 which showed that steers fed on silage without grain made almost three times the profit made by steers receiving 16½ pounds of shelled corn a day with the silage, both lots of animals being sold in the same market.

The cases in favor of silage have been so thoroughly proved on a number of occasions that progressive farmers no longer require conversion. It is simply a question of how to erect the silo in which to keep the material in the best possible condition for feeding.

A silo, to keep silage in good condition, must be built so that the natural moisture in the silage will be retained. Air must be excluded, and the silage must be allowed to settle in a manner to prevent the forming of air-pockets. The silo must give its owner a long period of service at low cost, and must be wind-proof, vermin-proof, fire-proof, reasonable in first cost, and as free as possible from maintenance costs. To enable free settling to the utmost compactness, a cylindrical form has been found preferable.

From these requirements it will be seen that, of all materials used, the concrete silo has the most points in its favor. The cylindrical form is most readily constructed in concrete. It is a fire-proof structure, and its weight makes it so stable that no concrete silo has ever blown down. Its permanence is much in its favor, and, with the help of some one familiar with the proper mixing of and placing of concrete, no skilled labor is needed. The farm-hands can do practically all the work, and in most cases the only material that needs to be purchased by the farmer is the cement and reinforcement. Homemade forms are frequently utilized, and complete specifications for the making of such forms, together with a list of materials required for concrete silos based upon the number of animals to be fed, are easily available through the firms offering cement for sale.

Reinforcement must, of course, be used, but it is simple to place and presents no difficulty even to the most inexperienced. Round or square steel rods or some form of woven mesh wire are usually used as hoops in the concrete, embedded in the center of the wall. Ordinary woven wire fencing should not be used in the place of the steel mesh fabric that is specially made for this purpose. Vertical reinforcement is also needed in all monolithic concrete silos, and this consists of steel rods three-eighths or one-half inch in diameter, spaced thirty inches apart. The square twisted rod is usually preferred for this type of service, since the horizontal rods can be attached to them more securely.

Where a monolithic structure is put up, the concrete is usually mixed by hand on a water-tight platform. This is usually constructed of two-inch planks, tongued and grooved so that the tight joints will prevent the cement being carried away by the leakage of mixing water. The sides are provided with a strip to prevent materials from being washed or carried away. Since proportioning the ingredients is an important part of the job, a measure-box is necessary. This is usually made to hold one cubic foot or four cubic feet, and in the latter case marks are made at proper levels to indicate one and two and one-half cubic feet. The measuring-box is bottomless, and is set on the mixing platform, where the required amount of sand or gravel is shoveled in. When the box is raised, this is spread in an even layer over the platform and the cement spread over it. The cement does not need to be measured, since it is put up in bags holding approximately one cubic foot.

After the foundation has been laid and the first course of concrete has been placed, uprights are erected in the square holes provided in the inner frame to guide and support this inner form as it is raised course by course. These uprights must be carefully plumed after each layer, or the walls may not be truly vertical. Each day the outside form is raised up within four inches of the top of the concrete last placed, the vertical reinforcing rods spliced if necessary, and the horizontal rods attached securely for the next course. Next the inner form is raised level and plumed, and the concrete placed to fill the forms for that course.

The concrete must be carefully spaded into the forms if a dense smooth wall is to be obtained, and a spading tool may be made from a piece of thin board beveled at the end and shaped to provide a handle. This is used to work the pebbles or broken stone back from the form, so that the cement mortar may have an opportunity to form the dense smooth surface desired. Particular attention must be given to the inside of the wall, for there must be no obstructions to prevent the free settling of the silage. At the end of each day's work the top surface of the concrete forms must be roughened so that a good joint can be possible with the next day's course. Each morning, before placing the next course, the top of the walls must be washed with water and painted over with a mixture of Portland cement and water having the consistency of thick cream.

Metal forms are on the market, and in some communities farmers have found it to their advantage to purchase such forms for use in the community. These metal forms are easy to handle, can be used repeatedly, and are preferable to homemade forms. They are provided with clamps for holding them firmly together, and, owing to the accuracy with which sections may be set, result in a smooth even silo wall. Such forms usually include scaffolding, jacks with which to raise them, and derricks for elevating the concrete. They, therefore, effect a saving of both time and labor.

There are two other types of concrete silos. These are the block and the stave. Each of them, if properly built, give satisfaction and avoid the use of forms. The blocks are curved so that when laid up the course conforms to the curvature of the silo, and these blocks, being made in simple machine molds, may be either homemade or purchased at the cement-products plant. It generally pays to purchase the blocks from those who are experienced in the handling of concrete and who are in a position to provide more homogeneous blocks of greater strength and better appearance. One form of concrete block for silos has air-spaces, and is provided in the top with a groove to take reinforcement. The other type is solid, and has embedded in it steel rods with hooked ends, so that each block can be securely fastened to the adjoining one. The best mixture for a block made by the wet process is one part of cement, two parts of sand, and three parts of pebbles. And where the tamped block is made, one part of cement is used to three parts of sand.

In laying up the blocks, great care must be taken to get tight joints, the blocks being well cemented together, putting them on about half an inch of a cement mortar composed of one part of cement to two parts of clean sand. Blocks should be arranged in each course, so that an even number of blocks or half blocks complete the circle.

It is usually best to plaster the inside wall of the cement block silo, using cement mortar to secure a surface sufficiently smooth to allow the proper settling of the silage. Before plastering, the walls are thoroughly scrubbed, and should be wet when the plaster is applied.

Ease of construction and the rapidity with which concrete stave silos can be erected have made them popular in many communities. Many built from ten to fifteen years ago are still in a condition virtually as good as new. Four men are usually required to erect the stave silo, two working above, one to set the staves and the other to follow and plum them, while two men below hoist the staves and assist with the scaffolding. Common types of concrete silo staves are about thirty inches long, ten or twelve inches wide, and from two and a half to three inches in thickness. A considerable variety of methods is used to join the staves together, but all types appear to produce air-tight and water-tight walls, which are absolutely essential.

A solid concrete foundation is first installed and the first course of staves set upon it, alternating full-length with part-length staves so as to secure a breaking of joints. This breakage is maintained until the top row of staves has been put in place, when part-length staves are again used to finish the structure. A steel hoop is put on and tightened as each course of staves is placed in position. The inside wall is painted with a wash of cement and water, which fills the surface of the staves and assists in sealing the joints between adjoining staves, as well as providing a smooth, even, air-tight surface.

There has been no difficulty in providing suitable door-frames of the continuous or other type in silos, the design varying slightly with the requirements.

Water-tanks, cisterns, troughs, and many other concrete structures find their place on the farm. They provide sanitary, cleanly structures which are durable, and can be placed with great facility wherever wanted. The temptation to use a run of bank gravel or sand must be put aside if the best possible structure is to be erected. Feeding-troughs and watering-troughs are often built, with projections into the ground that serve as foundations if they rest upon well compacted soil, and this makes the use of a special sub-base unnecessary. In such cases the walls are started in a trench below ground, where forms are not usually required. And when the ground-level is reached the forms are set up. In the larger size, reinforcement in the shape of quarter-inch round rods bent in U shape are usually employed.

It is very desirable to provide all watering-troughs or tanks and feeding-troughs in the barn-yard with a concrete pavement to avoid the transformation of the surroundings into an unsightly mud-hole. Tanks are often supplied with covers to prevent refuse from blowing into the water and fouling it.

Another desirable application of concrete on the farm is in the building of milk-cooling tanks. These can be designed in a variety of ways, including partitions and baffles about which the water may flow from one compartment to another. The tank is usually constructed with the bottom such a distance below the milk-room floor level as to make it easier to lift the cans into and from the tank, and the floor should have corrugations at least an inch in depth, so that there may be a free circulation of water beneath the cans. Such tanks are usually of a depth to permit the milk-can being surrounded by water up to the neck of the standard size.

Silo forms are sometimes used to build a circular watering-tank, which can be provided with a concrete cover with wooden doors placed at intervals.

Cisterns are preferably constructed with a filter, which may be above or below ground as desired. The filter has two compartments, one receiving the water that comes from the house gutters which enters by a six-inch tile set in the wall. This first compartment is provided to allow any material that enters with the water to settle before the water flows to the second compartment, which contains the filter proper. A baffle-board is provided between the inlet of the water supply and the inlet into the filter apartment, so that any strong current will be broken and an opportunity given materials to settle. A sudden rush of water might also disturb the filter-beds and force a direct path through them, thus destroying their efficiency.

The filter compartment has a concrete slab cover, and is provided with a layer of sand and gravel, beneath which is a layer of charcoal raised on a perforated slab of reinforced concrete. Such a perforated slab is made by setting tapered wooden plugs into the concrete when it is soft, or by nailing such plugs on the bottom of the form. A filter of this simple type insures clean water at all times, and the renewal of the filter-bed as may be needed is a comparatively simple matter.

Suitable tanks for dipping animals are usually installed of reinforced concrete, and upon many farms hog-wallows are also built of concrete. It has been said that a hog wallows in the mud, not with the idea of getting dirty, but in an effort to take a bath, and uses the mud simply because his keepers do not provide him with a suitable tub. A concrete hog-wallow constitutes such a tub, and not only adds to the comfort of the hog, but insures an opportunity to use medicated solutions with the water supply or to add oils of a germicide nature, which float upon the water and accomplish very desirable purposes. Corners in hog-wallows should be slightly rounded, so that the pool can be cleaned, and at one side the wall should be sloped and corrugated to provide a better foothold for the hogs when they enter and leave. If a concrete apron be provided it will be impossible for the hogs to root beneath the wallow.

The circular wallows are structures easily built, using the silo form just as in the construction of the water-tank, and the corrugated runway is built at any convenient point.

Another valuable concrete structure on the farm is the manure-pit, built with a sump, which tends to conserve all of the fertilizing values in the manure. On some farms such concrete pits are covered, and are provided with a carrier which connects the pit with the stable. Such concrete pits are also screened to prevent them from becoming a breeding-place for flies and other insects. For convenience in packing manure into pits, the inside faces of the walls are usually sloped. In building large pits, one side is inclined and corrugated so that teams may be provided with a good footing when starting a heavily loaded wagon out of the pit. The liquid that gathers in the sump is pumped out and sprinkled on the land.

Entire farm structures are often built of monolithic concrete or of concrete blocks, and all modern dairy barns are provided with concrete floors and drains, and some of them use concrete feeding-troughs with a view to facilitating the thorough and frequent cleaning. The use of concrete roadways in barn-yards is to be highly recommended, and on some farms it has been found economical to surface the entire barnyard with concrete. The barn-yard is no longer used solely as a place to concentrate the stock, but is considered a part of the farm work-room, and anything that will tend to leave its usefulness unimpaired at all seasons of the year, regardless of weather conditions, constitutes true economy and efficiency. Where stock is fed in the barn-yard the concrete constitutes a feeding-floor into which material will not be tramped and destroyed.

CHAPTER XXIII

MILITARY AND MISCELLANEOUS USES

In the World War cement and concrete had its first extensive trial as a material for military uses, and in virtually every instance proved itself equal to the emergency. There are two or three outstanding characteristics which make cement an invaluable material for such purposes. First, its quick setting and hardening is greatly in its favor; second, its use involves the transportation of material in compact small units; third, when protected by a few feet of earth, concrete has been found better than brick or stone as a material for defense construction. Add to this the rapid placement of cement with the cement-gun or other mechanical device, and its ability to set under water, and it will be seen that, wherever strength and hardness are desirable, it perhaps has no equal for the uses of the military establishment. Besides all this, local materials nearly always form the bulk of the structure.

We are familiar with the so-called pill-box, which was an easily constructed protection for machine-guns, the use of concrete and cement in trenches and for the construction of underground compartments, which is now an old story. Many of the military roads in this country, as well as abroad, would have been out of the question but for the use of this ready-made material.

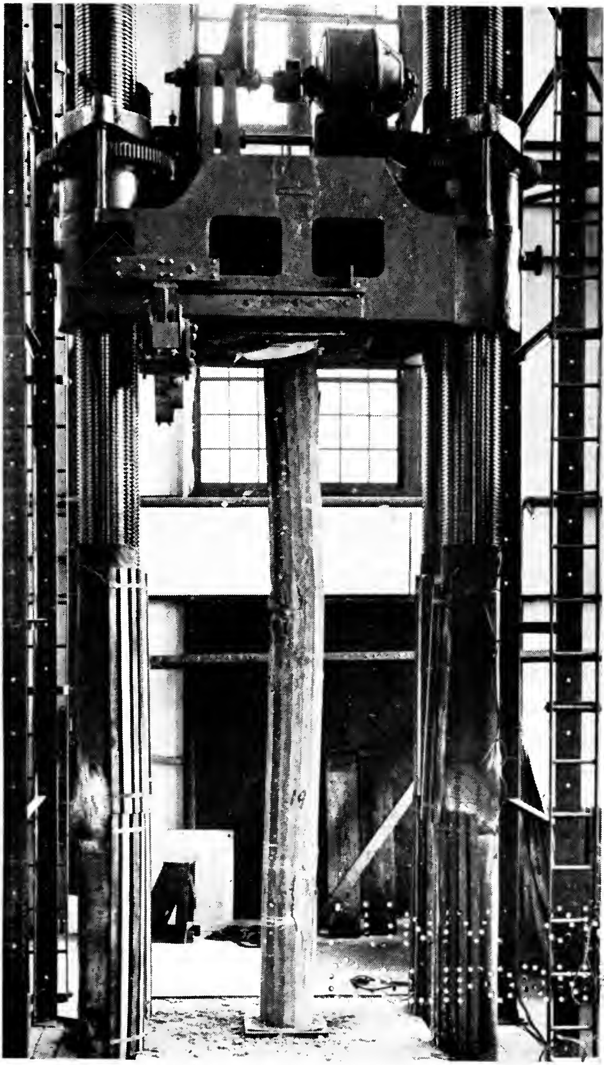
Our most extensive warehouses, docks, piers, and temporary buildings were of reinforced concrete, built hurriedly, but having such permanence as to fit them for a long period of service under peace conditions. It was found that reinforced concrete could be put up as cheaply as less desirable temporary buildings. One of the most spectacular uses of cement was in the attack upon Ostend and Zeebruge, where old war vessels filled with cement, were towed into place, and sunk. Under these conditions the water penetrating the mass caused it to set and to form an obstruction to incoming ships very difficult to remove. The repairs to ship hulls, often including considerable construction, were made with cement and concrete, and the concrete ship itself, described elsewhere, is really an outcome of military necessity, although certain small barges had been constructed of this material and successfully used previously.

Cement was particularly useful in the housing of explosives, for it was possible with it to quickly prepare a compartment for ammunition that would be water-tight, air-tight, and, when covered with earth, of a reasonably uniform temperature. When so covered, they also afforded ample protection and became the standard structure for such purposes. Closely allied with this is the preparation of foundations for ordnance of various sizes, leading to a careful study of the quickly hardening cements to which reference has been made in another chapter.

If the diverse requirements of war are considered, as well as the great variety of applications to which cement lends itself, it will be seen without further elaboration that it will be in the future one of the most important raw materials in time of war. In this connection, it is well to recall that it was the cement-mill that contributed so much toward the relief of the potash shortage through the recovery of potassium salts from the dust in the cement kiln gases.

Among the many miscellaneous items now built of concrete may be mentioned the hundreds of concrete chimneys in successful use through the world. These have withstood high winds and cyclones, and have shown that the ideal material for chimney construction, which must have strength to resist the bending and overturning effect of such winds, is to be found in the monolithic concrete chimney. These great reinforced structures are often required to stand high temperatures, the fumes of acids, and the corrosive influence of the products of combustion. In exceptional cases, as in some smelters, it has been thought desirable to provide a lining, sometimes slightly separated from the stack walls to provide an air-space, and under such conditions insulation is provided to maintain stack temperatures, while at the same time the corrosive influence of gases is avoided. To be sure, especial conditions require special study and treatments designed to facilitate the economical handling of strong acid fumes which cause very great damage at the point of condensation upon the walls.

Several concrete chimneys have been struck by lightning, but have suffered no damage. At times they alone in a group of other structures have withstood the devastating influence of fires. They produce a good draft, have not developed leaks through their walls,



REINFORCED CONCRETE COLUMN UNDER COMPRESSION TEST IN THE WORLD'S LARGEST TESTING MACHINE, U. S. BUREAU OF STANDARDS

Columns have also been similarly tested while subjected to fire, the majority of such tests having been made at the Bureau

CONCRETE AND CEMENT ARCHITECTURAL TRIM

are free from maintenance, and if properly designed and constructed do not need to be insured. There is no other material that may be used so advantageously for high chimney construction and that permits of a design including so many of the actual factors of safety. The smooth interior offers no obstruction to the flow of the stack gases, and the heat losses in concrete chimneys are low. This is important in obtaining the stack draft.

Unique methods are often employed in the construction of concrete chimneys. An example is taken from San Francisco, where a tower was built through the center of the chimney and provided with an electric elevator for conveying the building materials. Upon the tower two outriggers were carried, and from the end of each outrigger the block and tackle required to handle the outside forms was suspended. The forms were three feet high, and there were five sets of forms in use. When the concrete was poured in one set of forms, the bottom form was removed and placed on top. Since only one set of forms were poured daily, this gave the concrete four days in which to set. At the completion of the work it was a simple matter to take down the interior tower, bit by bit.

Concrete chimneys are of various dimensions, the tallest in the world being at Kaganoseki, Japan. This chimney was built for a copper company, and withstands frequent earthquakes. It has an inside diameter of twenty-three feet and three inches, and a height of five hundred and seventy feet.

Often there are parts of machines so large as to be difficult to transport and set in place. This has led to the use of concrete parts for such huge machines as generators. With our present knowledge of aggregate-cement-water and the methods of combining them, it is possible not only to get uniform strength in all parts of a concrete structure, but also to produce duplications of that structure. We have also learned how to reinforce the concrete for various classes of work, and to obtain increased strength and density by the special preparation of the cement, as in using that of unusual fineness. This has led to experiments with concrete masses for the stator frame and thrust-bearing support of large size electric generators of hydroelectric installations where the vertical shaft operates at low speed. The use of concrete in place of metal for these parts introduced no problems of suitability or strength. Beaters in paper-mills have also been made in place with concrete.

Ceilings have been made as good as new by pouring cement mortar or concrete from above, supporting the form upon the ceiling from the floor below. The largest initial letter is at Salt Lake City, where the initial U, one hundred feet by one hundred feet, was constructed by the university students. This is of concrete. Cement mortar and such mortar with reinforcement is essential in modern tree surgery. The daily press, as well as the technical press, constantly reminds us of the possibilities with this plastic strong material. And no discussion of what is done with it can be complete. It is the sort of thing that goes on and on, and its use really seems to be limited only by the skill and imagination of those who employ it. The few instances of use that have been indicated paves the way for the flight of the imagination, and if there is something you would like to build of concrete, but have not yet been able to accomplish, let us resolve the problem into its essential features and concentrate our efforts upon these component parts, solving them one by one.

The future problems in concrete and cement construction would seem to concentrate about the ways of obtaining the highest percentages of tri-calcium silicate in the cement and in reducing the items of labor and fuel. The first problem doubtless involves extensive research to find other materials from which cement can be made economically and satisfactorily, at the same time producing the highest quantity of tri-calcium silicate, upon which it depends for its setting properties and strength.

The cost of labor in the production of cement has been greatly reduced by the use of ingenuous mechanical devices at all stages in its manufacture. Labor costs in the placement of cement and concrete are constantly being reduced by design of forms, mixing and conveying machinery, and devices for such finishing operations as cutting to grade and contour, and tamping. Reference has already been made to the advance in design and construction of excavating and sub-grade preparing machinery. As far as economy in the use of fuels in the burning of cement is concerned, this is something that has already seriously engaged the attention of the leaders in cement manufacture.

The vertical kiln is known to require less fuel, but it requires much more labor. Mr. Robert W. Lesley, long known in cement fields, proposes that the gases derived from the distillation of coal be used in the burning of cement, rather than the powdered coal itself, and that the by-products be recovered from such destructive distillation of the fuel. He would go a step further, and grind coke derived from the distillation process, and burn it powdered in the kiln probably mixed with the raw materials, so that higher temperatures can be obtained in the mass itself.

Another phase of the problem is the increase in the rate of reaction in the clinkering zone. The fuel problem has always been before cement manufacturers, being perhaps the greatest single item of expense. A few plants have been favorably located, but in 1905 only two plants could avail themselves of natural gas, while fifteen plants burned oil and eighty-four plants relied upon powdered coal. In 1914 the cement industry used 226,474 long tons of anthracite, 6,731,438 short tons of bituminous coal, 20,072 tons of coke, 2,502,065 barrels of fuel-oil and gasoline, and $5,525,894,000 cubic feet of gas. These figures are applicable to the United States. The fuel problem is not peculiar to the cement industry, for many of our industrial activities depend upon reactions that go forward at high temperatures. Those concerned in the manufacture of cement will doubtless contribute the best they have toward the solution of the fuel question in general, but it stands as one of the difficulties that must be overcome if we are to continue expanding the use of so ideal a structural material as cement and its products.

INDEX