MASONRY CONSTRUCTION

PHILLIPS - BYRNE

AMERICAN SCHOOL of CORRESPONDENCE
CHICAGO ILLINOIS

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Masonry Construction

A Guide to

APPROVED AMERICAN PRACTICE IN THE SELECTION OF BUILDING STONE, BRICK, CEMENT, AND OTHER MASONRY MATERIALS, AND IN ALL BRANCHES OF THE ART OF MASONRY CONSTRUCTION

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Foreword

IN recent years, such marvelous advances have been made in the engineering and scientific fields, and so rapid has been the evolution of mechanical and constructive processes and methods, that a distinct need has been created for a series of *practical working guides*, of convenient size and low cost, embodying the accumulated results of experience and the most approved modern practice along a great variety of lines. To fill this acknowledged need, is the special purpose of the series of handbooks to which this volume belongs.

¶ In the preparation of this series, it has been the aim of the publishers to lay special stress on the *practical* side of each subject, as distinguished from mere theoretical or academic discussion. Each volume is written by a well-known expert of acknowledged authority in his special line, and is based on a most careful study of practical needs and up-to-date methods as developed under the conditions of actual practice in the field, the shop, the mill, the power house, the drafting room, the engine room, etc.

¶ These volumes are especially adapted for purposes of self-instruction and home study. The utmost care has been used to bring the treatment of each subject within the range of the common understanding, so that the work will appeal not only to the technically trained expert, but also to the beginner and the self-taught practical man who wishes to keep abreast of modern progress. The language is simple and clear; heavy technical terms and the formulæ of the higher mathematics have been avoided, yet without sacrificing any of the requirements of practical instruction; the arrangement of matter is such as to carry the reader along by easy steps to complete mastery of each subject; frequent examples for practice are given, to enable the reader to test his knowledge and make it a permanent possession; and the illustrations are selected with the greatest care to supplement and make clear the references in the text.

¶ The method adopted in the preparation of these volumes is that which the American School of Correspondence has developed and employed so successfully for many years. It is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best method yet devised for the education of the busy working man.

¶ For purposes of ready reference and timely information when needed, it is believed that this series of handbooks will be found to meet every requirement.

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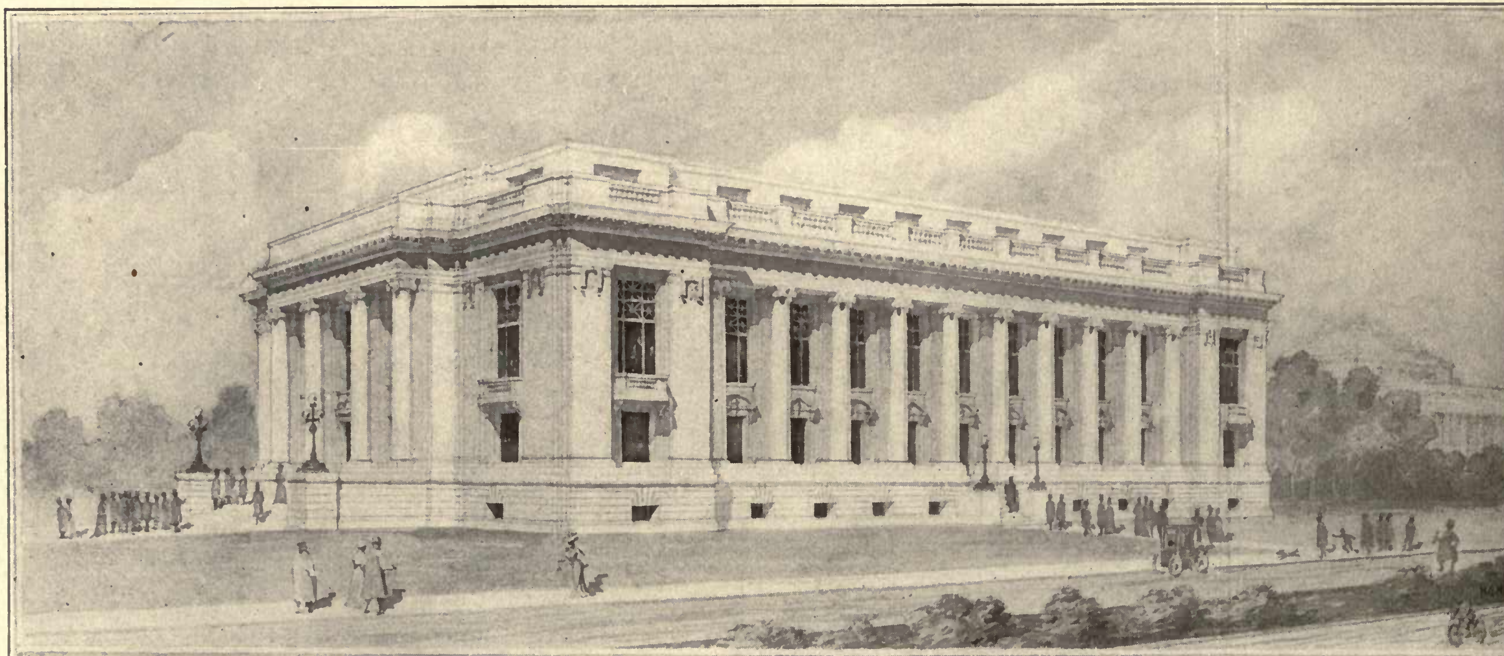


SUPREME COURT BUILDING AT SPRINGFIELD, ILL.

W. Carbys Zimmerman, Architect, Chicago, Ill.

Built of Bedford Stone. Cost, $300,000. Classic, Influenced by Modern French School. To be Completed in Winter of 1907.

MASONRY CONSTRUCTION.

PART I.

STRUCTURAL MATERIALS.

Classification of Natural Stones. The rocks from which the stones for building are selected are classified according to (1) their geological position, (2) their physical structure, and (3) their chemical composition.

Geological Classification. The geological position of rocks has but little connection with their properties as building materials. As a general rule, the more ancient rocks are the stronger and more durable; but to this there are many notable exceptions. According to the usual geological classification rocks are divided into three classes, viz.:

Igneous, of which greenstone (trap), basalt, and lava are examples.

Metamorphic, comprising granite, slate, marble, etc.

Sedimentary, represented by sandstones, limestones, and clay.

Physical Classification. With respect to the structural character of their large masses, rocks are divided into two great classes: (1) the unstratified, (2) the stratified, according as they do or do not consist of flat layers.

The *unstratified* rocks are for the most part composed of an aggregation of crystalline grains firmly cemented together. Granite, trap, basalt, and lava are examples of this class. All the unstratified rocks are composed as it were of blocks which separate from each other when the rock decays or when struck violent blows. These natural joints are termed the *line of cleavage* or *rift,* and in all cutting or quarrying of unstratified rocks the work is much facilitated by taking advantage of them.

The *stratified* rocks consist of a series of parallel layers, evidently deposited from water, and originally horizontal, although in most cases they have become more or less inclined and curved by the action of disturbing forces. It is easier to divide them at the planes of division between these layers than elsewhere. Besides its principal layers or strata, a mass of stratified rock is in general capable of division into thinner layers; and, although the surfaces of division of the thinner layers are often parallel to those of the strata, they are also often oblique or even perpendicular to them. This constitutes a *laminated* structure.

Laminated stones resist pressure more strongly in a direction perpendicular to their laminæ than parallel to them; they are more tenacious in a direction parallel to their laminæ than perpendicular to them; and they are more durable with the edges than with the sides of their laminæ exposed to the weather. Therefore in building they should be placed with their laminæ or "beds" perpendicular to the direction of greatest pressure, and with the edges of these laminæ at the face of the wall.

Chemical Classification. The stones used in building are divided into three classes, each distinguished by the predominant mineral which forms the chief constituent, viz.:

Silicious stones, of which granite, gneiss, and trap are examples.

Argillaceous stones, of which clay, slate, and porphyry are examples.

Calcareous stones, represented by limestones and marbles.

REQUISITES FOR GOOD BUILDING STONE.

The requisites for good building stone are durability, strength, cheapness, and beauty.

Durability. The durability of stone is a subject upon which there is very little reliable knowledge. The durability will depend upon the chemical composition, physical structure, and the position in which the stone is placed in the work. The same stone will vary greatly in its durability according to the nature and extent of the atmospheric influences to which it is subjected.

The sulphur acids, carbonic acid, hydrochloric acid, and traces of nitric acid, in the smoky air of cities and towns, and the carbonic acid in the atmosphere ultimately decompose any stone of which either carbonate of lime or carbonate of magnesia forms a considerable part.

Wind has a considerable effect upon the durability of stone. High winds blow sharp particles against the face of the stone and thus grind it away. Moreover, it forces the rain into the pores of the stone, and may thus cause a considerable depth to be subject to the effects of acids and frost.

In winter water penetrates porous stones, freezes, expands, and disintegrates the surface, leaving a fresh surface to be similarly acted upon.

Strength is generally an indispensable attribute, especially under compression and cross-strain.

Cheapness is influenced by the ease with which the stone can be quarried and worked into the various forms required. Cheapness is also affected by abundance, facility of transportation, and proximity to the place of use.

Appearance. The requirement of beauty is that it should have a pleasing appearance. For this purpose all varieties containing much iron should be rejected, as they are liable to disfigurement from rust-stains caused by the oxidation of the iron under the influence of the atmosphere.

TESTS FOR STONE.

The relative enduring qualities of different stones are usually ascertained by noting the weight of water they absorb in a given time. The best stones as a rule absorb the smallest amount of water.

Some stones, however, come from the quarry soaked with water and in that condition are very soft and easily worked. Upon exposure to the atmosphere they gradually dry out and become very hard and durable. The Bedford limestone of Indiana forms an example of this kind of stone, and the stone in many of the public buildings throughout the United States may be seen in the process of "weathering", indicated by the mottled appearance of the walls.

To determine the absorptive power, dry a specimen and weigh it carefully, then immerse it in water for 24 hours and weigh again. The increase in weight will be the amount of absorption.

TABLE 1.

Absorptive Power of Stones.

	Percentage of Water Absorbed.
Granites	0.06 to 0.15
Sandstones	0.41 " 5.48
Limestones	0.20 " 5.00
Marbles	0.08 " 0.16

Effect of Frost (*Brard's Test*). To ascertain the effect of frost, small pieces of the stone are immersed in a concentrated boiling solution of sulphate of soda (Glauber's salts), and then hung up for a few days in the air. The salt crystallizes in the pores of the stone, sometimes forcing off bits from the corners and arrises, and occasionally detaching larger fragments.

The stone is weighed before and after submitting it to the test. The difference of weight gives the amount detached by disintegration. The greater this is, the worse is the quality of the stone.

Effect of the Atmosphere (*Acid Test*). Soaking a stone for several days in water containing 1 per cent of sulphuric and hydrocholric acids will afford an idea as to whether it will stand the atmosphere of a large city. If the stone contains any matter likely to be dissolved by the gases of the atmosphere, the water will be more or less cloudy or muddy.

A drop or two of acid on the surface of a stone will create an intense effervescence if there is a large proportion present of carbonate of lime or magnesia.

PRESERVATION OF STONE.

A great many preparations have been used for the prevention of the decay of building stones, as paint, coal-tar, oil, beeswax, rosin, paraffine, soft-soap, soda, etc. All of the methods are expensive, and there is no evidence to show that they afford permanent protection to the stone.

ARTIFICIAL STONES.

Brick is an artificial stone made by submitting clay, which has been suitably prepared and moulded into shape, to a temperature of sufficient intensity to convert it into a semi-vitrified state. The quality of the brick depends upon the kind of clay used and upon the care bestowed on its preparation.

The clays of which brick is made are chemical compounds consisting of silicates of alumina, either alone or combined with other substances, such as iron, lime, soda, potash, magnesia, etc., all of which influence the character and quality of the brick, according as one or the other of those substances predominates.

TABLE 2.

Specific Gravity, Weight and Resistance to Crushing of Stones.

Kinds of Stone	Specific Gravity	Weight, pounds per cubic foot	Resistance to crushing, pounds per sq. in.
Granite—			
minimum	2.60	163	12,000
maximum	2.80	176	35,000
Trap—			
minimum	2.86	178	19,000
maximum	3.03	189	24,000
Gneiss, average	2.70	168	19,600
Syenite, average	2.64	167	30,740
Sandstones—			
minimum	2.23	137	5,000
maximum	2.75	170	18,000
Limestones—			
minimum	1.90	118	7,000
maximum	2.75	175	20,000
Marbles—			
minimum	2.62	165	8,000
maximum	2.95	179	20,000

Iron gives hardness and strength; hence the red brick of the Eastern States is often of better quality than the white and yellow brick made in the West. *Silicate of lime* renders the clay too fusible and causes the bricks to soften and to become distorted in the process of burning. *Carbonate of lime* is at high temperatures changed into caustic lime, renders the clay fusible, and when exposed to the action of the weather absorbs moisture, promotes disintegration, and prevents the adherence of the mortar. *Magnesia* exerts but little influence on the quality; in small quantities it renders the clay fusible; at 60° F. its crystals lose their water of crystallization, and cold water decomposes them, forming an insoluble hydrate in the form of a white powder. In air-dried brick this action causes cracking. The *alkalies* are found in small quantities in the best of clays; their presence tends to promote softening, and this goes on the more rapidly if it has been burned at too low a temperature. *Sand* mixed with the clay in moderate quantity (one part of sand to four of clay is about the best proportion) is beneficial, as tending to prevent excessive shrinking in the fire. Excess of sand destroys the cohesion and renders the brick brittle and weak.

MANUFACTURE OF BRICK.

The manufacture of brick may be classified under the following heads:

Excavation of the clay, either by manual or mechanical power.

Preparation of the clay consists in (*a*) removing stones and mechanical impurities; (*b*) tempering and moulding, which is now done almost wholly by machinery. There is a great variety of machines for tempering and moulding the clay, which, however, may be grouped into three classes, according to the condition of the clay when moulded: (1) soft-mud machines, for which the clay is reduced to a soft mud by adding about one quarter of its volume of water; (2) stiff-mud machines, for which the clay is reduced to a stiff mud; (3) dry-clay machines, with which the dry or nearly dry clay is forced into the moulds by a heavy pressure without having been reduced to a plastic mass. These machines may also be divided into two classes, according to the method of filling the moulds: (1) those in which a continuous stream of clay is forced from the pug-mill through a die and is afterwards cut up into bricks; and (2) those in which the clay is forced into moulds moving under the nozzle of the pug-mill.

Drying and Burning. The bricks, having been dried in the open air or in a drying-house, are burned in kilns; the time of burning varies with the character of the clay, the form and size of the kiln, and the kind of fuel, from six to fifteen days.

Color of Bricks depends upon the composition of the clay, the moulding sand, temperature of burning, and volume of air admitted to the kiln. Pure clay free of iron will burn *white*, and mixing of chalk with the clay will produce a like effect. Iron produces a tint ranging from *red* and *orange* to *light yellow*, according to the proportion of the iron.

A large proportion of oxide of iron mixed with pure clay will produce a *bright red*, and where there is from 8 to 10 per cent, and the brick is exposed to an intense heat, the oxide fuses and produces a *dark blue* or *purple*, and with a small volume of manganese and an increased proportion of the oxide the color is darkened even to a *black*.

A small volume of lime and iron produces a *cream color*, an increase of iron produces *red*, and an increase of lime *brown*. Magnesia

YOUNG MEN'S CHRISTIAN ASSOCIATION BUILDING, OAK PARK, ILL.

Pond & Pond, Architects, Chicago, Ill.

Walls of Cherry Red Paving Brick, Trimmed with Purple Red Paving Brick. Columns, String-Courses etc., of Bedford Stone. Built in 1905.

in presence of iron produces *yellow*, and clay containing alkalies and burned at a high temperature produces a *bluish green*.

The best quality of building brick and probably the majority of paving brick or block, are manufactured from shale. The process of manufacture is similar to that of clay-brick, the shale being first ground very fine. If the shale is nearly free from impurities, the resulting product will be a cream colored brick. To give the brick any desired color, the shale is mixed with clay containing the proper proportions of lime, iron, or magnesia, giving almost any shade from a cream to a dark wine color or even a black.

Classification of Brick. Bricks are classified according to (1) the way in which they are moulded; (2) their position in the kiln while being burned; and (3) their form or use.

The method of moulding gives rise to the following terms:

Soft-mud Brick. One moulded from clay which has been reduced to a soft mud by adding water. It may be either hand-moulded or machine-moulded.

Stiff-mud Brick. One moulded from clay in the condition of stiff mud. It is always machine-moulded.

Pressed Brick. One moulded from dry or semi-dry clay.

Re-pressed Brick. A soft-mud brick which, after being partially dried, has been subjected to an enormous pressure. It is also called, but less appropriately, pressed brick. The object of the re-pressing is to render the form more regular and to increase the strength and density.

Sanded Brick. Ordinarily, in making soft-mud brick, sand is sprinkled into the moulds to prevent the clay from sticking; the brick is then called sanded brick. The sand *on the surface* is of no advantage or disadvantage. In hand-moulding, when sand is used for this purpose, it is certain to become mixed with the clay and occur in streaks in the finished brick, which is very undesirable.

Machine-made Brick. Brick is frequently described as "machine made"; but this is very indefinite, since all grades and kinds are made by machinery.

When brick was generally burned in the old-style up-draught kiln, the classification according to position was important; but with the new styles of kilns and improved methods of burning, the quality is so nearly uniform throughout the kiln that the classification is less important. Three grades of brick are taken from the old-style kiln:

Arch or Clinker Bricks. Those which form the tops and sides of the arches in which the fire is built. Being overburned and partially vitrified, they are hard, brittle, and weak.

Body, Cherry, or Hard Bricks. Those taken from the interior of the pile. The best bricks in the kiln.

Salmon, Pale, or Soft Bricks. Those which form the exterior of the mass. Being underburned, they are too soft for ordinary work, unless it be for filling. The terms *salmon* and *pale* refer to the color of the brick, and hence are not applicable to a brick made of a clay that does not burn red. Although nearly all brick-clays burn red, yet the localities where the contrary is true are sufficiently numerous to make it desirable to use a different term in designating the *quality.* There is not necessarily any relation between color, and strength and density. Brick-makers naturally have a prejudice against the term *soft brick,* which doubtless explains the nearly universal prevalence of the less appropriate term salmon.

The form or use of bricks gives rise to the following classification:

Compass Brick. Those having one edge shorter than the other. Used in lining shafts, etc.

Feather-edge Brick. Those of which one edge is thinner than the other. Used in arches; and more properly, but less frequently, called *voussoir* brick.

Front or Face Brick. Those which, owing to uniformity of size and color, are suitable for the face of the walls of buildings. Sometimes face bricks are simply the best ordinary brick; but generally the term is applied only to re-pressed or pressed brick made especially for this purpose. They are a little larger than ordinary bricks.

Sewer Brick. Ordinary hard brick, smooth, and regular in form.

Kiln-run Brick. All the brick that are set in the kiln when burned.

Hard Kiln-run Brick. Brick burned hard enough for the face of outside walls, but taken from the kiln unselected.

Rank of Bricks. In *regularity of form* re-pressed brick ranks first, dry-kiln brick next, then stiff-mud brick, and soft-mud brick last. Regularity of form depends largely upon the method of burning.

The *compactness and uniformity* of texture, which greatly influence the durability of brick, depend mainly upon the method of moulding. As a general rule, hand-moulded bricks are best in this respect, since the clay in them is more uniformly tempered before being moulded; but this advantage is partially neutralized by the presence of sand-seams. Machine-moulded soft-mud bricks rank next in compactness and uniformity of texture. Then come machine-moulded stiff-mud bricks, which vary greatly in durability with the kind of machine used in their manufacture. By some of the machines the brick is moulded in layers (parallel to any face, according to the kind of machine) which are not thoroughly cemented, and which separate under the action of frost. The dry-clay brick comes last. However, the relative value of the products made by different processes varies with the nature of the clay used.

TABLE 3.

Size and Weight of Bricks.

The variations in the dimensions of brick render a table of exact dimensions impracticable.

As an exponent, however, of the ranges of their dimensions, the following averages are given:

Baltimore front	
Wilmington front	$8\frac{1}{4}$ in. × $4\frac{1}{8}$ in. × $2\frac{3}{8}$ in.
Washington front	
Croton front	$8\frac{1}{2}$ in. × 4 in. × $2\frac{1}{4}$ in.
Maine ordinary	$7\frac{1}{2}$ in. × $3\frac{3}{8}$ in. × $2\frac{3}{8}$ in.
Milwaukee ordinary	$8\frac{1}{2}$ in. × $4\frac{1}{8}$ in. × $2\frac{3}{8}$ in.
North River, N. Y.	8 in. × $3\frac{1}{2}$ in. × $2\frac{1}{4}$ in.
English	9 in. × $4\frac{1}{2}$ in. × $2\frac{1}{2}$ in.

The Standard Size as adopted by the National Brickmakers' Association and the National Traders and Builders' Association is for common brick $8\frac{1}{4} \times 4 \times 2\frac{1}{4}$ inches, and for face brick $8\frac{3}{8} \times 4\frac{1}{8} \times 2\frac{1}{4}$ inches.

Re-pressed Brick weighs about 150 lb. per cubic foot, common brick 125, inferior soft 100. Common bricks will average about $4\frac{1}{2}$ lb. each.

Hollow Brick, used for interior walls and furring, are usually of the following dimensions:

Single,	8 in. long,	$3\frac{5}{8}$ in. wide,	$2\frac{1}{4}$ in. thick.
Double,	8 " "	$7\frac{1}{2}$ " "	$4\frac{1}{2}$ " "
Treble,	8 " "	$7\frac{1}{4}$ " "	$7\frac{1}{4}$ " "

Roman Brick, 12 in. long, 4 to $4\frac{1}{2}$ in. wide, $1\frac{1}{2}$ in. thick.

TABLE 4.

Specific Gravity, Weight, and Resistance to Crushing of Brick.

Designation of brick.	Specific gravity.	Weight per cubic foot, pounds.	Resistance to Crushing, pounds per sq. in.
Best pressed..........	2.4	150	5,000 to 14,973
Common hard;.......	1.6 to 2.0	125	5,000 to 8,000
Soft.................	1.4	100	450 to 600

Fire-Brick are used wherever high temperatures are to be resisted. They are made from fire-clay by processes very similar to those adopted in making ordinary brick. Fire-clay is also used in the manufacture of paving-blocks or pavers, especially in Western Indiana; and many of the streets of our Western cities are laid with fire-clay block, forming a smooth and durable roadway.

Fire-clay may be defined as native combinations of hydrated silicates of alumina, mechanically associated with silica and alumina in various states of subdivision, and sufficiently free from silicates of the alkalies and from iron and lime to resist vitrification at high temperatures. The presence of oxide of iron is very injurious; and, as a rule, the presence of 6 per cent justifies the rejection of the brick. The presence of 3 per cent of combined lime, soda, potash, and magnesia should be a cause for rejection. The sulphide of iron—pyrites—is even worse than the substances first named.

A good fire-clay should contain from 52 to 80 per cent of silica and 18 to 35 per cent of alumina and have a uniform texture, a somewhat greasy feel, and be free from any of the alkaline earths.

Good fire brick should be uniform in size, regular in shape, homogeneous in texture and composition, strong, and infusible and break with a uniform and regular fracture.

A properly burnt fire-brick is of a uniform color throughout its mass. A dark central patch and concentric rings of various shades of color are due mainly to the different states of oxidation of the iron and partly to the presence of unconsumed carbonaceous matter, and indicates that the brick was burned too rapidly.

Fire-brick are made in various forms to suit the required work. A straight brick measures $9 \times 4\frac{1}{2} \times 2\frac{1}{2}$ inches and weighs about 7 lb.

or 120 lb. per cubic foot; specific gravity 1.93. One cubic foot of wall requires 17 9-inch bricks; one cubic yard requires 460. One ton of fire-clay should be sufficient to lay 3000 ordinary bricks. English fire-bricks measure $9 \times 4\frac{1}{2} \times 2\frac{1}{4}$ inches.

To secure the best results fire-brick should be laid in the same clay from which they are manufactured. It should be used as a thin paste, and not as mortar: the thinner the joint the better the furnace wall. The brick should be dipped in water as they are used, so that when laid they will not absorb the water from the clay paste. They should then receive a thin coating of the prepared fire-clay, and be carefully placed in position with as little of the fire-clay as possible.

CEMENTING MATERIALS.

Composition. All the cementing materials employed in buildings are produced by the burning of natural or artificial mixtures of limestone with clay or siliceous material. The active substances in this process and the ones which are necessary for the production of a cement, are the burned lime, the silica and the alumina, all of which enter into chemical combination with one another under the influence of a high temperature.

Classification. Owing to the varying composition of the raw materials, which range from pure carbonate of lime to stones containing variable proportions of silica, alumina, magnesia, oxide of iron, manganese, etc., and the different methods employed for burning, the product possesses various properties which regulate its behavior when treated with water, and render necessary certain precautions in its manipulation and use, and furnishes a basis for division into three classes; namely, common lime, hydraulic lime, and hydraulic cements, the individual peculiarities of which will be taken up later.

Common lime is distinguished from hydraulic lime by its failure to set or harden under water, a property which is possessed by hydraulic lime to a greater or less degree.

The limes are distinguished from the cements by the former falling to pieces (slaking) on the application of water, while the latter must be mechanically pulverized before they can be used.

The hydraulic cements are divided into two classes, namely, *natural* and *artificial*. The first class includes all hydraulic substances produced from natural mixtures of lime and clay, by a burning process which has not been carried to the point of vitrification, and which still contain more or less free lime.

The artificial cements are generally designated by the name "Portland" and comprise all the cements produced from natural or artificial mixtures of lime and clay, lime and furnace slag, etc., by a burning process which is carried to the point of vitrification.

The hydraulic cements do not slake after calcination, differing materially in this particular from the limes proper. They can be formed into paste with water, without any sensible increase in volume, and little, if any, production of heat, except in certain instances among those varieties which contain the maximum amount of lime. They do not shrink in hardening, like the mortar of rich lime, and can be used with or without the addition of sand, although for the sake of economy sand is combined with them.

All the limes and cements in practical use have one feature in common, namely, the property of "setting" or "hardening" when combined with a certain amount of water. The setting of a cement is, in general, a complex process, partly chemical in its nature and partly mechanical. Broadly stated, the chemical changes which occur may be said to afford opportunity for the mechanical changes which result in hardening, rather than themselves to cause the hardening. The chemical changes are, therefore, susceptible of wide variation without materially influencing the result. The crumbling which calcined lime undergoes on being slaked is simply a result of the mechanical disintegrating action of the evolved steam. In some cements of which plaster of Paris may be taken as the type, water simply combines with some constituent of the cement already present. In others, of which Portland cement is the most important example, certain chemical reactions must first take place. These reactions give rise to substances which, as soon as formed, combine with water and constitute the true cementitious material. The quantity of water used should be regulated according to the kind of cement, since every cement has a certain capacity for water. However, in practice an excess of about 50 per cent must be used to aid manipulation.

The rapidity of setting (denominated activity) varies with the character of the cement, and is influenced to a great extent by the temperature, and also, but in less degree, by the purity of the water.

Sea water hinders the setting of some cements, and some cements, which are very hard in fresh water, only harden slightly in sea water or even remain soft. Cements which require more than one-half hour to set are called "slow-setting", all others "quick-setting". As a rule the natural cements are quick- and the Portlands slow-setting. None of the cements attain their maximum hardness until some time has elapsed. For good Portland 15 days usually suffices for complete setting, but the hardening process may continue for a year or more.

The form and fineness of the cement particles are of great importance in the setting of the cement, and affect the cementing and economic value. Coarse particles have no setting power and act as an adulterant. In consequence of imperfect pulverization some cements only develop three-fourths of their available activity, one-fourth of the cement consisting of grains so coarse as to act merely like so much sand. The best cement when separated from its fine particles will not harden for months after contact with water, but sets at once if previously finely ground.

In a mortar or concrete composed of a certain quantity of inert material bound together by a cementing material it is evident that to obtain a strong mortar or concrete it is essential that each piece of aggregate shall be entirely surrounded by the cementing material, so that no two pieces are in actual contact. Obviously, then, the finer a cement the greater surface will a given weight cover, and the more economy will there be in its use. The proper degree of fineness is reached when it becomes cheaper to use more cement in proportion to the aggregate than to pay the extra cost of additional grinding.

Use. Common lime is used almost exclusively in making mortar for architectural masonry. Natural cement is used for masonry where great ultimate strength is not as important as initial strength and in masonry protected from the weather. Portland cement is used for foundations and for all important engineering structures requiring great strength or which are subject to shock; also for all sub-aqueous construction.

LIMES.

Rich Limes. The common fat or rich limes are those obtained by calcining pure or very nearly pure carbonate of lime. In slaking they augment to from two to three and a half times that of the original mass. They will not harden under water, or even in damp places excluded from contact with the air. In the air they harden by the gradual formation of carbonate of lime, due to the absorption of carbonic acid gas.

The pastes of fat lime shrink in hardening to such a degree that they cannot be employed for mortar without a large dose of sand.

Poor Limes. The poor or meagre limes generally contain silica, alumina, magnesia, oxide of iron, sometimes oxide of manganese, and in some cases traces of the alkalies, in relative proportions which vary considerably in different localities. In slaking they proceed sluggishly, as compared with the rich limes—the action only commences after an interval of from a few minutes to more than an hour after they are wetted; less water is required for the process, and it is attended with less heat and increase of volume than in the case of fat limes.

Hydraulic Limes. The hydraulic limes, including the three subdivisions, viz., *slightly hydraulic*, *hydraulic*, and *eminently hydraulic*, are those containing after calcination sufficient of such foreign constituents as combine chemically with lime and water to confer an appreciable power of setting or hardening under water without the access of air. They slake still slower than the meagre limes, and with but a small augmentation of volume, rarely exceeding 30 per cent of the original bulk.

Lime is shipped either in bulk or in barrels. If in bulk, it is impossible to preserve it for any considerable length of time. A barrel of lime usually weighs about 230 lb. net, and will make about three tenths of a cubic yard of stiff paste. A bushel weighs 75 lb.

NATURAL CEMENT.

Rosendale or *natural* cements are produced by burning in draw-kilns at a heat just sufficient in intensity and duration to expel the carbonic acid from argillaceous or silicious limestones containing less than 77 per cent of carbonate of lime, or argillo-magnesian limestone containing less than 77 per cent of both carbonates, and then grinding the calcined product to a fine powder between millstones.

Characteristics. The natural cements have a porous, globular texture. They do not heat up nor swell sensibly when mixed with water. They set quickly in air, but harden slowly under water, without shrinking, and attain great strength with well-developed adhesive force.

Setting. A pat made with the minimum amount of water should set in about 30 minutes.

Fineness. At least 93 per cent must pass through a No. 50 sieve.

Weight. Varies from 49 to 56 pounds per cubic foot.

Specific Gravity about 2.70.

Tensile Strength. Neat cement, one day, from 40 to 80 pounds. Seven days, from 60 to 100 pounds. One year, from 300 to 400 pounds.

PORTLAND CEMENT.

Portland Cement is produced by burning, with a heat of sufficient intensity and duration to induce incipient vitrification, certain argillaceous limestones, or calcareous clays, or an artificial mixture of carbonate of lime and clay, and then reducing the burnt material to powder by grinding. Fully 95 per cent of the Portland cement produced is artificial. The name is derived from the resemblance which hardened mortar made of it bears to a stone found in the isle of Portland, off the south coast of England.

The quality of Portland cement depends upon the quality of the raw materials, their proportion in the mixture, the degree to which the mixture is burnt, the fineness to which it is ground, and the constant and scientific supervision of all the details of manufacture.

Characteristics. The color should be a dull bluish or greenish gray, caused by the dark ferruginous lime and the intensely green manganese salts. Any variation from this color indicates the presence of some impurity; blue indicates an excess of lime; dark green, a large percentage of iron; brown, an excess of clay; a yellowish shade indicates an underburned material.

Fineness. It should have a clear, almost floury feel in the hand; a gritty feel denotes coarse grinding.

Specific Gravity is between 3 and 3.05. As a rule the strength of Portland cement increases with its specific gravity.

Tensile Strength. When moulded neat into a briquette and placed in water for seven days it should be capable of resisting a tensile strain of from 300 to 500 pounds per square inch.

Setting. A pat made with the minimum amount of water should set in not less than three hours, nor take more than six hours.

Expansion and Contraction. Pats left in the air or placed in water should during or after setting show neither expansion nor contraction, either by the appearance of cracks or change of form.

A cement that possesses the foregoing properties may be considered a fair sample of Portland cement and would be suitable for any class of work.

Overlimed Cement is likely to gain strength very rapidly in the beginning and later to lose its strength, or if the percentage of free lime be sufficient it will ultimately disintegrate.

Blowing or Swelling of Portland cement is caused by too much lime or insufficient burning. It also takes place when the cement is very fresh and has not had time to cool.

Adulteration. Portland cement is adulterated with slag cement and slaked lime. This adulteration may be distinguished by the light specific gravity of the cement, and by the color, which is of a mauve tint in powder, while the inside of a water-pat when broken is deep indigo. Gypsum or sulphate of lime is also used as an adulterant.

TESTING CEMENTS.

The quality or constructive value of a cement is generally ascertained by submitting a sample of the particular cement to a series of tests. The properties usually examined are the *color, weight, activity, soundness, fineness* and *tensile strength.* Chemical analysis is sometimes made, and specific gravity test is substituted for that of weight. Tests of compression and adhesion are also sometimes added. As these tests cannot be made upon the site of the work, it is usual to sample each lot of cement as it is delivered and send the samples to a testing laboratory.

Sampling Cement. The cement is sampled by taking a small quantity (1 to 2 lb.) from the center of the package. The number of packages sampled in any given lot of cement will depend upon the character of the work, and varies from every package to 1 in 5 or 1 in 10. When the cement is brought in barrels the sample is obtained by boring with an auger either in the head or center of the barrel, drawing out a sample, then closing the hole with a piece of tin firmly tacked over it. For drawing out the sample a brass tube sufficiently long to reach the bottom of the barrel is used. This is thrust into the barrel, turned around, pulled out, and the core of cement knocked out into the sample-can, which is usually a tin box with a tightly fitting cover.

Each sample should be labelled, stating the number of the sample, the number of bags or barrels it represents, the brand of the cement, the purpose for which it is to be used, the date of delivery, and date of sampling.

FORM OF LABEL.

Sample No..
No. of Barrels....................................
Brand ....
To be used..
Delivered................ *Sampled*................
By...................

The sample should be sent at once to the testing office, and none of the cement should be used until the report of the tests is received.

After the report of the tests is received the rejected packages should be conspicuously marked with a "C" and should be removed without delay; otherwise they are liable to be used.

Color. The color of a cement indicates but little, since it is chiefly due to oxides of iron and manganese, which in no way affect the cementitious value; but for any given kind variations in shade may indicate differences in the character of the rock or in the degree of burning. The natural cements may have almost any color from the very light straw colored "Utica" through the brown "Louisville", to chocolate "Rosendale". The artificial Portlands are usually a grayish blue or green, but never chocolate colored.

Weight. For any particular cement the weight varies with the degree of heat in burning, the degree of fineness in grinding, and the density of packing. The finer a cement is ground the more bulky it becomes, and consequently the less it weighs. Hence light weight may be caused by laudable fine grinding or by objectionable under-burning. Other things being the same, the harder-burned varieties are the heavier.

The weight per unit of volume is usually determined by sifting the cement into a measure as lightly as possible, and striking the top level with a straight edge. In careful work the height of fall should be recorded. Since the cement absorbs moisture, the sample must be taken from the interior of the package. The weight per cubic foot is neither exactly constant, nor can it be determined precisely. The approximate weight of cement per cubic foot is as follows:

Portland, English and German	77 to 90 lb.
" fine-ground French	69 "
" American	92 " 95 "
Rosendale	49 " 56 "
Roman	54 "

A bushel contains 1.244 cubic feet. The weight of a bushel can be obtained sufficiently close by adding 25 per cent to the weight per cubic foot.

Fineness. The cementing and economic value of a cement is affected by the degree of fineness to which it is ground. Coarse particles in a cement have no setting power and act as an adulterant.

The fineness of a cement is determined by measuring the percentage which will not pass through sieves of a certain number of meshes per square inch. Three sieves are generally used, viz.:

No. 50, 2,500 meshes per square inch.
No. 74, 5,476 " " " "
No. 100, 10,000 " " " "

Activity denotes the speed with which a cement begins to *set*. Cements differ widely in their rate and manner of *setting*. Some occupy but a few minutes in the operation, and others require several. Some begin setting immediately and take considerable time to complete the set, while others stand for a considerable time with no apparent action and then set very quickly. The point at which the set is supposed to begin is *when the stiffening of the mass first becomes perceptible,* and the end of the set is when cohesion extends through the mass sufficiently to offer such resistance to any change of form as to cause rupture before any deformation can take place.

Test of Activity. To test the activity mix the cement with 25 to 30 per cent of its weight of clean water, having a temperature of between 65° F. and 70° F., to a stiff plastic mortar, and make one or two cakes or pats 2 or 3 inches in diameter and about $\frac{1}{2}$ inch in thickness. As soon as the cakes are prepared, immerse in water at 65° F., and note the time required for them to set hard enough to bear respectively a $\frac{1}{12}$-inch wire loaded to weigh $\frac{1}{4}$ pound, and a $\frac{1}{24}$-inch wire loaded to weigh 1 pound. When the cement bears the light weight, it is said to have begun to set; when it bears the heavy weight, it is said to have entirely set. The apparatus employed for this test is shown in Fig. 1, and is called "Vicat's Needle apparatus".

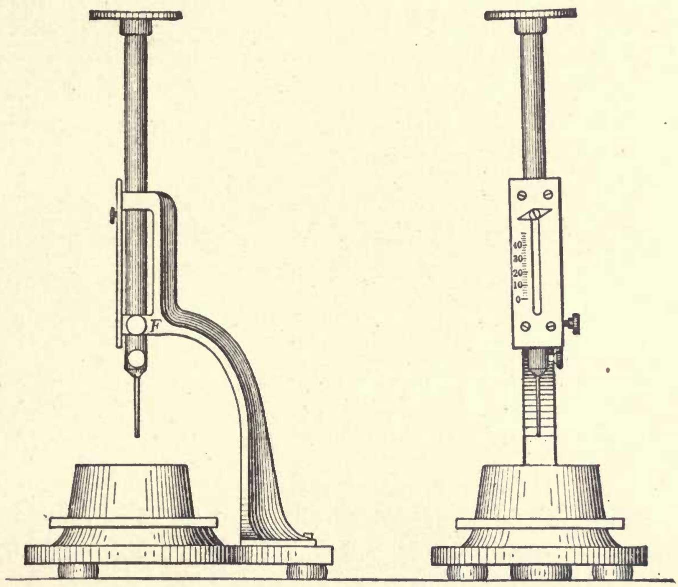


Fig. 1. Vicat's Needle Apparatus.

Quick and Slow Setting. The aluminous natural cements are commonly "quick-setting," though not always so, as those containing a considerable percentage of sulphuric acid may set quite slowly. The magnesian and Portland varieties may be either "quick" or "slow". Specimens of either variety may be had that will set at any rate, from the slowest to the most rapid, and no distinction can be drawn between the various classes in this regard.

Water containing sulphate of lime in solution retards the setting, This fact has been made use of in the adulteration of cement, powdered gypsum being mixed with it to make it slow-setting, greatly to the injury of the material.

The temperature of the water used affects the time required for setting; the higher the temperature, within certain limits, the more rapid the *set*. Many cements which require several hours to set when mixed with water at a temperature of 40° F. will set in a few minutes if the temperature of the water be increased to 80° F. Below a certain inferior limit, ordinarily from 30° to 40° F., the cement will not set, while at a certain upper limit, in many cements between 100° and 140° F., a change is suddenly made from a very rapid to a very slow rate, which then continually decreases as the temperature increases, until practically the cement will not set.

The quick-setting cements usually set so that experimental samples can be handled within 5 to 30 minutes after mixing. The slow-setting cements require from 1 to 8 hours. Freshly ground cements set quicker than older ones.

Soundness denotes the property of not expanding or contracting or cracking or checking in setting. These effects may be due to free lime, free magnesia, or to unknown causes. Testing soundness is, therefore, determining whether the cement contains any *active* impurity. An inert adulteration or impurity affects only its economic value; but an active impurity affects also its strength and durability.

For the purpose of determining the amount of contraction or expansion the "Bauschinger" apparatus, Fig. 2, is used. A mould is used in which the test bars of cement are formed.

Tests of Soundness. The soundness of a cement may be determined by cold tests, so-called, the cement being at ordinary temperature; or by accelerated or hot tests.

To make the cold tests, prepare small cakes or pats of neat cement, 3 or 4 inches in diameter and about one-half inch thick at the center, tapering to a thin edge. Place the samples upon a piece of glass and cover with a damp cloth for a period of 24 hours and then immerse glass and all in water for a period of 28 days if possible, keeping watch from day to day to see if the samples show any cracks or signs of distortion.

The first indication of inferior quality is the loosening of the pat from the glass, which usually takes place in one or two days. Good cement will remain firmly attached to the glass for two weeks at least.

The ordinary tests, extending over a proper interval, often fail to detect unsoundness, and circumstances may render the ordinary tests impossible from lack of time. Under such circumstances resort must be had to accelerated tests, which may be made in several ways.

Warm-Water Test. Prepare the sample as before, and after allowing it to set, immerse in water maintained at a temperature of from 100° to 115° F. If the specimen remains firmly attached to the glass and shows no cracks, it is probably sound.

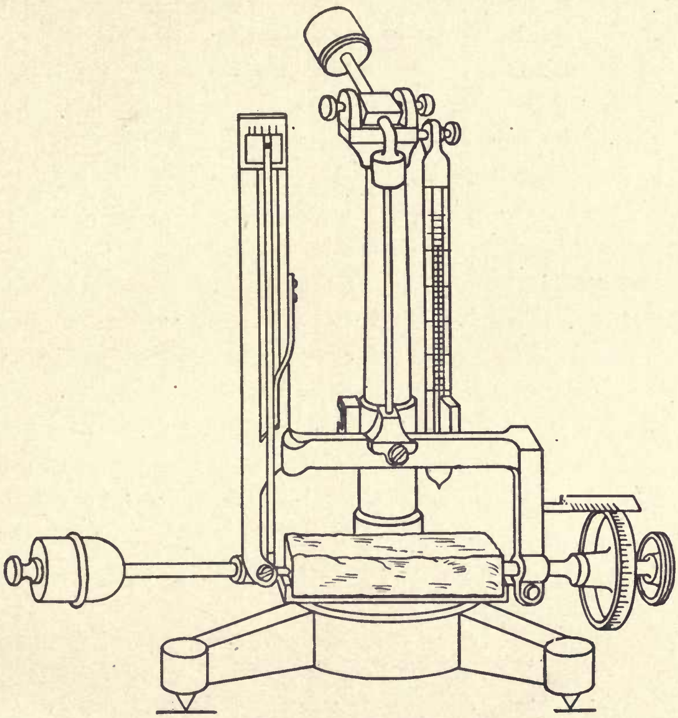


Fig. 2. Bauschinger's Apparatus.

The hot-water test is similar to the last, but the water is maintained at a temperature of from 195° to 200° F.

The boiling test consists in immersing the specimen in cold water immediately after mixing and gradually raising the temperature of the water to the boiling point, continuing the boiling for three hours.

For an emergency test, the specimen may be prepared as before, and after setting may be held under a steam cock of a boiler and live steam discharged upon it.

The results of accelerated tests must not be accepted too literally, but should be interpreted in the light of judgment and experience.

The cracking or contortion of the specimen (sometimes called "blowing"), is due to the hydration and consequent expansion of the lime or magnesia. If the effect is due to lime, the cement can be improved by exposure to the air, thus allowing the free lime to slake. This treatment is called "cooling the cement". The presence of uncombined magnesia is more harmful than that of lime.

Some idea of the quality of a cement may be gained by exposing to the air a small cake of neat cement mortar and observing its color. "A good Portland cement should be uniform bluish gray throughout, yellowish blotches indicate poor cement".

Tests of soundness should not only be carefully conducted, but should extend over considerable time. Occasionally cement is found which seems to meet the usual tests for soundness, strength, etc., and yet after considerable time loses all coherence and falls to pieces.

Strength. The strength is usually determined by submitting a specimen of known cross-section (generally one square inch) to a tensile strain. The reason for adopting a tensile test is that since even the weakest cement cannot be crushed, in ordinary practice, by direct compression, and since cement is not used in places where cross strain is brought to bear upon it, torsion being out of the question, the only valuable results can be derived from tests for tensile strength. In case of a cracking wall the strain is that of tension due to the difference of the direction of the strain caused by the sinking of one part of the wall.

In comparing different brands of cement great care must be exercised to see that the same kind and quality of sand is used in each case, as difference in the sand will cause difference in the results. To obviate this a standard sand is generally used. This consists of crushed quartz of such a degree of fineness that it will all pass a No. 20 sieve (400 meshes to the square inch; wire No. 28 Stubbs' gauge) and be caught on a No. 30 sieve (900 meshes to the square inch; wire No. 31 Stubbs' gauge).

Valuable and probably as reliable comparative tests can be made with the sand which is to be used for making the mortar in the proposed work. Specimens of neat cement are also used for testing, they can be handled sooner and will show less variation than specimens composed of cement and sand.

The cement is prepared for testing by being formed into a stiff paste by the addition of just sufficient water for this purpose. When sand is to be added, the exact proportions should be carefully determined by weight and thoroughly and intimately mixed with the cement in a dry state before the water is added; and, so far as possible, all the water that is necessary to produce the desired consistency should be added at once and thereafter the manipulation with the spatula or trowel should be rapid and thorough. The mortar so obtained is filled into a mould of the form and dimensions shown in Fig. 3. These moulds are usually of iron or brass. Wooden moulds, if well oiled to prevent their absorbing water, answer the purpose well for temporary use, but speedily become unfit for accurate work. In filling the mould care must be exercised to complete the filling before incipient setting begins.

The moulds while being charged and manipulated, should be laid on glass, slate, or some other non-absorbent material. The specimen, now called the "briquette", should be removed from the mould as soon as it is hard enough to stand it, without breaking. The briquettes are then immersed in water, where they should remain constantly covered until tested. If they are exposed to the air, the water may be carried away by evaporation and leave the mortar a pulverant mass. Also, since the mortar does not ordinarily set as rapidly under water as in the air (owing to the difference in temperature), it is necessary for accurate work to note the time of immersion, and also to break the briquette as soon as it is taken from the water. Cement ordinarily attains a greater strength when allowed to set under water, but attains it more slowly.

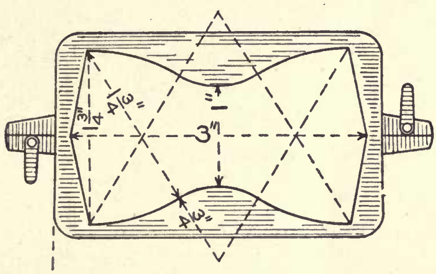


Fig. 3. Briquette Mould.

Age of Briquette for Testing. It is customary to break part of the briquettes at the end of seven days, and the remainder at the end of twenty-eight days. As it is sometimes impracticable to wait twenty-eight days, tests are often made at the end of one and seven days, respectively. The ultimate strength of the cement is judged by the increase in strength between the two dates. A minimum strength for the two dates is usually specified.

Testing the Briquettes. When taken out of the water the briquettes are subjected to a tensile strain until rupture takes place in a suitably devised machine. There are several machines on the market for this purpose. Fig. 4 represents one which is extensively used.

To make a test, hang the cup *F* on the end of the beam *D*, as shown in the illustration. See that the poise *R* is at the zero mark,

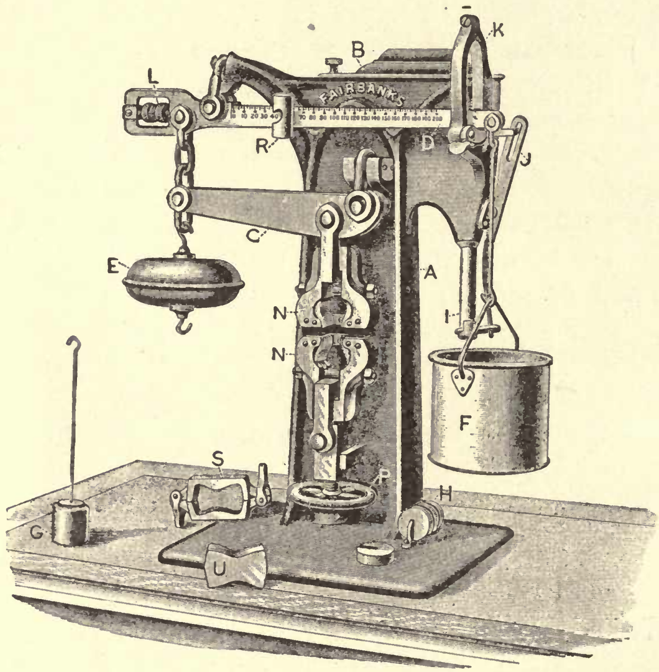


Fig. 4. Cement Testing Machine.

and balance the beam by turning the ball *L*. Fill the hopper *B* with fine shot, place the specimen in the clamps *N N*, and adjust the hand wheel *P* so that the graduated beam *D* will rise nearly to the stop *K*.

Open the automatic valve *J* so as to allow the shot to run slowly into the cup *F*. Stand back and leave the machine to make the test.

When the specimen breaks, the graduated beam *D* drops and closes the valve *J*, remove the cup with the shot in it, and hang the counterpoise weight *G* in its place.

Hang the cup *F* on the hook under the large ball *E*, and proceed to weigh the shot in the regular way, using the poise *R* on the graduated beam *D*, and the weights *H* on the counterpoise weight *G*. The result will show the number of pounds required to break the specimen.

TABLE 5.

Tensile Strength of Cement Mortar.

Age of mortar when tested.	Average tensile strength in pounds per square inch.			
	Portland.		Rosendale.	
	Min.	Max.	Min.	Max.
CLEAR CEMENT.				
One hour, or until set, in air, the remainder of the time in water:				
1 *day*	100	140	40	80
One day in air, the remainder of the time in water:				
1 *week*	250	550	60	100
4 *weeks*	350	700	100	150
1 *year*	450	800	300	400
1 PART CEMENT TO 1 PART SAND.				
One day in air, the remainder of the time in water:				
1 *week*	......	......	30	50
4 *weeks*	......	......	50	80
1 *year*	......	......	200	300
1 PART CEMENT TO 3 PARTS SAND.				
One day in air, the remainder of the time in water:				
1 *week*	80	125	......	......
4 *weeks*	100	200	......	......
1 *year*	200	350	......	......

CEMENTS—MEMORANDA.

Cement is shipped in barrels or in cotton or paper bags.

The usual dimensions of a barrel are: length 2 ft. 4 in., middle diameter 1 ft. $4\frac{1}{2}$ in., end diameter 1 ft. $3\frac{1}{2}$ in.

The bags hold 50, 100, or 200 pounds.

A barrel weighs about as follows:

Rosendale, N. Y.	300 lb. net
Rosendale, Western	265 "
Portland	375 "

A barrel of Rosendale cement contains about 3.40 cubic feet and will make from 3.70 to 3.75 cubic feet of stiff paste, or 79 to 83 pounds will make about one cubic foot of paste. A barrel of Rosendale cement (300 lb.) and two barrels of sand ($7\frac{1}{2}$ cubic feet) mixed with about half a barrel of water will make about 8 cubic feet of mortar, sufficient for

192	square	feet	of	mortar-joint	$\frac{1}{2}$	inch	thick.
288	"	"	"	"	$\frac{3}{8}$	"	"
384	"	"	"	"	$\frac{1}{4}$	"	"
768	"	"	"	"	$\frac{1}{8}$	"	"

A barrel of Portland cement contains about 3.25 to 3.35 cubic feet—100 pounds will make about one cubic foot of stiff paste.

A barrel of cement measured loosely increases considerably in bulk. The following results were obtained by measuring in quantities of two cubic feet:

1 bbl.	Norton's Rosendale gave	4.37 cu. ft.
"	Anchor Portland gave	3.65 "
"	Sphinx Portland gave	3.71 "
"	Buckeye Portland gave	4.25 "

Preservation of Cements. Cements require to be stored in a dry place protected from the weather; the packages should not be placed directly on the ground, but on boards raised a few inches from it. If necessary to stack it out of doors a platform of planks should first be made and the pile covered with canvas. Portland cement exposed to the atmosphere will absorb moisture until it is practically ruined. The absorption of moisture by the natural cements will cause the development of carbonate of lime, which will interfere with the subsequent hydration.

MISCELLANEOUS CEMENTS.

Slag Cements are those formed by an admixture of slaked lime with ground blast-furnace slag. The slag used has approximately the composition of an hydraulic cement, being composed mainly of silica and alumina, and lacking a proper proportion of lime to render it active as a cement. In preparing the cement the slag upon coming from the furnace is plunged into water and reduced to a spongy form from which it may be readily ground. This is dried and ground to a fine powder. The powdered slag and slaked lime are then mixed in proper proportions and ground together, so as to very thoroughly distribute them through the mixture. It is of the first importance in a slag cement that the slag be very finely ground, and that the ingredients be very uniformly and intimately incorporated.

Both the composition and methods of manufacture of slag cements vary considerably in different places. They usually contain a higher percentage of alumina than Portland cements, and the materials are in a different state of combination, as, being mixed after the burning, the silicates and aluminates of lime formed during the burning of Portland cement cannot exist in slag cement.

The tests for slag cement are that briquettes made of one part of cement and three parts of sand by weight shall stand a tensile strain of 140 pounds per square inch (one day in air and six in water), and must show continually increasing strength after seven days, one month, etc. At least 90 per cent must pass a sieve containing 40,000 meshes to the square inch, and must stand the boiling test.

Pozzuolanas are cements made by a mixture of volcanic ashes with lime, although the name is sometimes applied to mixed cements in general. The use of pozzuolana in Europe dates back to the time of the Romans.

Roman Cement is a natural cement manufactured from the septaria nodules of the London Clay formation; it is quick-setting, but deteriorates with age and exposure to the air.

MORTAR.

Ordinary Mortar is composed of lime and sand mixed into a paste with water. When cement is substituted for the lime, the mixture is called *cement mortar.*

Uses. The use of mortar in masonry is to bind together the bricks or stones, to afford a bed which prevents their inequalities from bearing upon one another and thus to cause an equal distribution of pressure over the bed. It also fills up the spaces between the bricks or stones and renders the wall weather tight. It is also used in concrete as a matrix for broken stones or other bodies to be amalgamated into one solid mass; and for plastering and other purposes.

The quality of mortar depends upon the character of the materials used in its manufacture, their treatment, proportions, and method of mixing.

Proportions. The proportion of cement to sand depends upon the nature of the work and the necessity for the development of strength or imperviousness. The relative quantities of sand and cement should also depend upon the nature of the sand; fine sand requires more cement than coarse. Usual proportions are:

Lime mortar, 1 part of lime to 4 parts of sand.

Natural cement mortar, 1 part cement to 2 or 3 parts of sand.

Portland cement mortar, 1 part cement to 2, 3, or 4 parts of sand, according to the character of the work.

Sand for Mortar. The sand used *must be clean,* that is, free from clay, loam, mud, or organic matter; *sharp,* that is, the grains must be angular and not rounded as those from the beds of rivers and the seashore; *coarse,* that is, it must be large-grained, but not too uniform in size.

The best sand is that in which the grains are of different sizes; the more uneven the sizes the smaller will be the amount of voids, and hence the less cement required.

The *cleanness* of sand may be tested by rubbing a little of the dry sand in the palm of the hand, and after throwing it out noticing the amount of dust left on the hand. The cleanness may also be judged by pressing the sand between the fingers while it is damp; if the sand is clean it will not stick together, but will immediately fall apart when the pressure is removed.

The *sharpness* of sand can be determined approximately by rubbing a few grains in the hand or by crushing it near the ear and noting if a grating sound is produced; but an examination through a small lens is better.

To determine the presence of Salt and Clay. Shake up a small portion of the sand with pure distilled water in a perfectly clean stoppered bottle, and allow the sand to settle; add a few drops of pure nitric acid and then add a few drops of solution of nitrate of silver. A white precipitate indicates a tolerable amount of salt; a faint cloudiness may be disregarded.

The presence of clay may be ascertained by agitating a small quantity of the sand in a glass of clear water and allowing it to stand for a few hours to settle; the sand and clay will separate into two well-defined layers.

Screening. Sand is prepared for use by screening to remove the pebbles and coarser grains. The fineness of the meshes of the screen depends upon the kind of work in which the sand is to be used.

Washing. Sand containing loam or earthy matters is cleansed by washing with water, either in a machine specially designed for the purpose and called a sand-washer, or by agitating with water in tubs or boxes provided with holes to permit the dirty water to flow away.

Water for Mortar. The water employed for mortar should be fresh and clean, free from mud and vegetable matter. Salt water may be used, but with some natural cements it may retard the setting, the chloride and sulphate of magnesia being the principal retarding elements. Less sea-water than fresh will be required to produce a given consistency.

Quantity. The quantity of water to be used in mixing mortar can be determined only by experiment in each case. It depends upon the nature of the cement, upon that of the sand and of the water, and upon the proportions of sand to cement, and upon the purpose for which the mortar is to be used.

Fine sand requires more water than coarse to give the same consistency. Dry sand will take more water than that which is moist, and sand composed of porous material more than that which is hard. As the proportion of sand to cement is increased the proportion of water to cement should also increase, but in a much less ratio.

The amount of water to be used is such that the mortar when thoroughly mixed shall have a plastic consistency suitable for the purpose for which it is to be used.

The addition of water, little by little, or from a hose, should not be allowed.

Cement Mortar. In mixing cement mortar the cement and sand are first thoroughly mixed dry, the water then added, and the whole worked to a uniformly plastic condition.

The quality of the mortar depends largely upon the thoroughness of the mixing, the great object of which is to so thoroughly incorporate the ingredients that no two grains of sand shall lie together without an intervening layer or film of cement. To accomplish this the cement must be uniformly distributed through the sand during the dry mixing.

The mixers usually fail to thoroughly intermix the dry cement and sand, and to lighten the labor of the wet mixing they will give an overdose of water.

Packed cement when measured loose increases in volume to such an extent that a nominal 1 to 3 mortar is easily changed to an actual 1 to 4. The specifications should prescribe the manner in which the materials are to be measured, *i.e.*, packed or loose.

The quantity of sand will also vary according to whether it is measured in a wet or dry condition, packed or loose. On work of sufficient importance to justify some sacrifice of convenience the sand and cement should be proportioned by weight instead of by volume.

In mixing by hand a platform or box should be used; the sand and cement should be spread in layers with a layer of sand at the bottom, then turned and mixed with shovels until a thorough incorporation is effected. The dry mixture should then be spread out, a bowl-like depression formed in the center and all the water required poured into it. The dry material from the outside of the basin should be thrown in until the water is taken up and then worked into a plastic condition, or the dry mixture may be shovelled to one end of the box and the water poured into the other end. The mixture of sand and cement is then drawn down with a hoe, small quantities at a time, and mixed with the water until enough has been added to make a good stiff mortar.

In order to secure proper manipulation of the materials on the part of the workmen it is usual to require that the whole mass shall be turned over a certain number of times with the shovels, both dry and wet.

The mixing wet with the shovels must be performed quickly and energetically. The paste thus made should be vigorously worked with a hoe for several minutes to insure an even mixture. The mortar should then leave the hoe clean when drawn out of it, and very little should stick to the steel.

A large quantity of cement and sand should not be mixed dry and left to stand a considerable time before using, as the moisture in the sand will to some extent act upon the cement, causing a partial setting.

Upon large works mechanical mixers are frequently employed with the advantage of at once lessening the labor of manipulating the material and insuring good work.

Retempering Mortar. Masons very frequently mix mortar in considerable quantities, and if the mass becomes stiffened before being used, by the setting of the cement, add water and work it again to a soft or plastic condition. After this second tempering the cement is much less active than at first, and will remain for a longer time in a workable condition.

This practice is condemned by engineers, and is not usually allowed in good engineering construction. Only sufficient quantity of mortar should be mixed at once as may be used before the cement takes the initial set. Reject all mortar that has set before being placed in the work.

Freezing of Mortar. It does not appear that common *lime mortar* is seriously injured by freezing, provided it remains frozen until it has fully set. The freezing retards, but does not entirely suspend the setting. Alternate freezing and thawing materially damages the strength and adhesion of lime mortar.

Although the strength of the mortar is not decreased by freezing, it is not always permissible to lay masonry during freezing weather; for example, if, in a thin wall, the mortar freezes before setting and afterwards thaws on one side only, the wall may settle injuriously.

Mortar composed of one part *Portland cement* and three parts sand is entirely uninjured by freezing and thawing.

Mortar made of *cements* of the *Rosendale type*, in any proportion, is entirely ruined by freezing and thawing.

Mortar made of overclayed cement (which condition is indicated by its quicker setting), of either the Portland or Rosendale type, will not withstand the action of frost as well as one containing less clay, for since the clay absorbs an excess of water, it gives an increased effect to the action of frost.

In making cement mortar during freezing weather it is customary to add salt or brine to the water with which it is mixed. The ordinary rule is: Dissolve 1 pound of salt in 18 gallons of water when the temperature is at 32° F., and add 1 ounce of salt for each degree of lower temperature.

The use of salt, and more especially of sea-water, in mortar is objectionable in exposed walls, since the accompanying salts usually produce efflorescence.

The practice of adding hot water to lime mortar during freezing weather is undesirable. When the very best results are sought the brick or stone should be warmed—enough to thaw off any ice upon the surface is sufficient—before being laid. They may be warmed either by laying them on a furnace, or by suspending them over a slow fire, or by wetting with hot water.

TABLE 6.

Amount of Cement and Sand Required for One Cubic Yard of Mortar.

Composition of mortar by volumes.		Cement.* Number of barrels.		Sand, cubic yards.
Cement.	Sand.	Portland or Ulster County Rosendale.	Western Rosendale.	
1	0	7.14	6.43	0.00
1	1	4.16	3.74	0.58
1	2	2.85	2.57	0.80
1	3	2.00	1.80	0.90
1	4	1.70	1.53	0.95
1	5	1.25	1.13	0.97
1	6	1.18	1.06	0.98
		Cement. Number of Pounds.†		
1	0	2675	2140	0.00
1	1	1440	1150	0.67
1	2	900	720	0.84
1	3	675	540	0.94
1	4	525	420	0.98
1	5	425	340	0.99
1	6	355	285	1.00

* Packed cement and loose sand.
† Loose cement and loose sand.

CONCRETE.

Concrete is a species of artificial stone composed of (1) the matrix, which may be either lime or cement mortar, usually the latter, and (2) the aggregate, which may be any hard material, as gravel, shingle, broken stone, shells, brick, slag, etc.

The aggregate should be of different sizes, so that the smaller shall fit into the voids between the larger. This requires less mortar and with good aggregate gives a stronger concrete. Broken stone is the most common aggregate.

Gravel and shingle should be screened to remove the larger-sized pebbles, dirt, and vegetable matter, and should be washed if they contain silt or loam. The broken stone if mixed with dust or dirt must be washed before use.

Strength of Concrete. The resistance of concrete to crushing ranges from about 600 to 1400 pounds per sq. in. It depends upon the kind and amount of cement and upon the kind, size, and strength of the aggregate. The transverse strength ranges between 50 and 400 pounds.

Weight of Concrete. A cubic yard weighs from 2,500 to 3,000 pounds according to its composition.

PROPORTIONS OF MATERIALS FOR CONCRETE.

To manufacture one cubic yard of concrete the following quantities of materials are required:

Broken-stone-and-gravel Concrete.

Broken-stone 50% of its bulk voids....	1 cubic yard
Gravel to fill voids in the stone........	$\frac{1}{2}$ " "
Sand to fill voids in the gravel.........	$\frac{1}{4}$ " "
Cement to fill voids in the sand........	$\frac{1}{8}$ " "

Broken-stone Concrete.

Broken stone 50% of its bulk voids....	1 cubic yard
Sand to fill voids in the stone.........	$\frac{1}{2}$ " "
Cement to fill voids in the sand........	$\frac{1}{4}$ " "

Gravel Concrete.

Gravel $\frac{1}{3}$ of its bulk voids.............	1 cubic yard
Sand to fill voids in the gravel.........	$\frac{1}{3}$ " "
Cement to fill voids in the sand.......	$\frac{1}{6}$ " "

Concrete composed of 1 part Rosendale cement, 2 parts of sand, and 5 parts of broken stone requires:

Broken stone	0.92 cubic yard
Sand	0.37 " "
Cement	1.43 barrels

The usual proportions of the materials in concrete are:

ROSENDALE CEMENT CONCRETE.

Rosendale cement	1 part
Sand	2 parts
Broken stone	3 to 4 "

PORTLAND CEMENT CONCRETE.

Portland cement	1 part
Sand	2 to 3 parts
Broken stone or gravel	3 to 7 "

To make 100 cubic feet of concrete of the proportions 1 to 6 will require 5 bbl. cement (original package) and 4.4 yards of stone and sand.

Mixing Concrete. The concrete may be mixed by hand or machinery. In hand-mixing the cement and sand are mixed dry. About half the sand to be used in a batch of concrete is spread evenly over the mortar-board, then the dry cement is spread evenly over the sand, and then the remainder of the sand is spread on top of the cement. The sand and cement are then mixed with a hoe or by turning and re-turning with a shovel. It is very important that the sand and cement be thoroughly mixed. A basin is then formed by drawing the mixed sand and cement to the outer edges of the board, and the whole amount of water required is poured into it. The sand and cement are then thrown back upon the water and thoroughly mixed with the hoe or shovel into a stiff mortar and then levelled off. The broken stone or gravel should be sprinkled with sufficient water to remove all dust and thoroughly wet the entire surface. The amount of water required for this purpose will vary considerably with the absorbent power of the stone and the temperature of the air. The wet stone is then spread evenly over the top of the mortar and the whole mass thoroughly mixed by turning over with the shovel. Two, three, or more turnings may be necessary. It should be turned until every stone is coated with mortar, and the entire mass presents the uniform color of the cement, and the mortar and stones are uniformly distributed. When the aggregate consists of broken brick or other porous material it should be thoroughly wetted and time allowed for absorption previous to use; otherwise it will take away part of the water necessary to effect the setting of the cement.

When the concrete is ready for use it should be quite coherent and capable of standing at a steep slope without the water running from it.

The rules and the practice governing the mixing of concrete vary as widely as the proportion of the ingredients. It may be stated in general that if too much time is not consumed in mixing the wet materials a good result can be obtained by any of the many ways practised, if only the mixing is thorough. With four men the time required for mixing one cubic yard is about ten minutes.

Whatever the method adopted for mixing the concrete, it is advisable for the inspector to be constantly present during the operation, as the temptation to economize on the cement and to add an excess of water to lighten the labor of mixing is very great.

Laying Concrete. Concrete is usually deposited in layers, the thickness of which is generally stated in the specifications for the particular work (the thickness varies between 6 and 12 in.). The concrete must be carefully deposited in place. A very common practice is to tip it from a height of several feet into the trench. This process is objected to by the best authorities on the ground that the heavy and light portions separate while falling, and that the concrete is, therefore, not uniform throughout its mass.

The best method is to wheel the concrete in barrows, immediately after mixing, to the place where it is to be laid, gently tipping or sliding it into position and at once ramming it.

The ramming should be done before the cement begins to set, and should be continued until the water begins to ooze out upon the upper surface. When this occurs it indicates a sufficient degree of compactness. A gelatinous or quicksand condition of the mass indicates that too much water was used in mixing. Too severe or long-continued pounding injures the strength by forcing the stones to the bottom of the layers and by distributing the incipient "set" of the cement.

The rammers need not be very heavy, 10 to 15 lb. will be sufficient. Square ones should measure from 6 to 8 in. on a side and round ones from 8 to 12 in. in diameter.

After each layer has been rammed it should be allowed sufficient time to "set", without walking on it or in other ways disturbing it. If successive layers are to be laid the surface of the one already set should be swept clean, wetted, and made rough by means of a pick for the reception of the next layer.

Great care should be observed in joining the work of one day to that of the next. The last layer should be thoroughly compacted and left with a slight excess of mortar. It should be finished with a level surface, and when partially set should be scratched with a pointed stick and covered with planks, canvas, or straw. In the morning, immediately before the application of the next layer, the surface should be swept clean, moistened with water, and painted with a wash of neat cement mixed with water to the consistency of cream. This should be put on in excess and brushed thoroughly back and forth upon the surface so as to insure a close contact therewith.

Depositing Concrete Under Water. In laying concrete under water an essential requisite is that the materials shall not fall from any height through the water, but be deposited in the allotted place in a compact mass; otherwise the cement will be separated from the other ingredients and the strength of the work be seriously impaired. If the concrete is allowed to fall through the water its ingredients will be deposited in a series, the heaviest—the stone—at the bottom, and the lightest—the cement—at the top. A fall of even one foot causes an appreciable separation.

A common method of depositing concrete under water is to place it in a V-shaped box of wood or plate iron, which is lowered to the bottom with a crane. The box is so constructed that on reaching the bottom a latch operated by a rope reaching to the surface can be drawn out, thus permitting one of the sloping sides to swing open and allow the concrete to fall out. The box is then raised and refilled.

A long box or tube, called a *tremie,* is also used. It consists of a tube open at top and bottom built in detachable sections, so that the length may be adjusted to the depth of water. The tube is suspended from a crane or movable frame running on a track, by which it is moved about as the work progresses. The upper end is hopper-shaped, and is kept above the water; the lower end rests on the bottom. The tremie is filled in the beginning by placing the lower end in a box with a movable bottom, filling the tube, lowering all to the bottom, and then detaching the bottom of the box. The tube is kept full of concrete by more being thrown in at the top as the mass issues from the bottom.

Concrete is also successfully deposited under water by enclosing it in paper bags and lowering or sliding them down a chute into place. The bags get wet and the pressure of the concrete soon bursts them, thus allowing the concrete to unite into a solid mass. Concrete is also sometimes deposited under water by enclosing it in open-cloth bags, the cement oozing through the meshes sufficiently to unite the whole into a single mass.

Concrete should not be deposited in running water unless protected by one or other of the above-described methods; otherwise the cement will be washed out.

Concrete deposited under water should not be rammed, but if necessary may be levelled with a rake or other suitable tool immediately after being deposited.

When concrete is deposited in water a pulpy, gelatinous fluid is washed from the cement and rises to the surface. This causes the water to assume a milky hue. The French engineers apply the term *laitance* to this substance. It is more abundant in salt water than in fresh. The theory of its formation is that the immersed concrete gives up to the water, free caustic lime, which precipitates magnesia in a light and spongy form. This precipitate sets very slowly, and sometimes scarcely at all, and its interposition between the layers of concrete forms strata of separation. The proportion of laitance is greatly diminished by using large immersion-boxes, or a tremie, or paper or cloth bags.

Asphaltic Concrete is composed of asphaltic mortar and broken stone in the proportion of 5 parts of stone to 3 parts of mortar. The stone is heated to a temperature of about 250° F. and added to the hot mortar. The mixing is usually performed in a mechanical mixer.

The material is laid hot and rammed until the surface is smooth. Care is required that the materials are properly heated, that the place where it is to be laid is absolutely dry and that the ramming is done before it chills or becomes set. The rammers should be heated in a portable fire.

CLAY PUDDLE.

Clay puddle is a mass of clay and sand worked into a plastic condition with water. It is used for filling coffer-dams, for making embankments and reservoirs water-tight, and for protecting masonry against the penetration of water from behind.

Quality of Clay. The clays best suited for puddle are opaque, and not crystallized, should exhibit a dull earthy fracture, exhale when breathed upon a peculiar faint odor termed "argillaceous," should be unctuous to the touch, free from gritty matter, and form a plastic paste with water.

The important properties of clay for making good puddle are its tenacity or cohesion and its power of retaining water. The tenacity of a clay may be tested by working up a small quantity with water into a thoroughly plastic condition, and forming it by hand into a roll about 1 to 1½ inches in diameter by 10 or 12 inches in length. If such a roll is sufficiently cohesive not to break on being suspended by one end while wet the tenacity of the material is ample.

To test its power of retaining water one to two cubic yards should be worked with water to a compact homogeneous plastic condition, and then a hollow should be formed in the center of the mass capable of holding four or five gallons of water. After filling the hollow with water it should be covered over to prevent evaporation and left for about 24 hours, when its capability of holding water will be indicated by the presence or absence of water in the hollow.

The clay should be freed from large stones and vegetable matter, and just sufficient sand and water added to make a homogeneous mass. If there is too little sand the puddle will crack by shrinkage in drying, and if too much it will be permeable.

Puddling. The operation of puddling consists in chopping the clay in layers of about 3 inches thick with spades, aided by the addition of sufficient water to reduce it to a pasty condition. After each chop and before withdrawing the spade it should be given a lunging motion so as to permit the water to pass through.

The spade should pass through the upper layer into the lower layer so as to cause the layers to bond together.

The test for thorough puddling is that the spade will pass through the layer with ease, which it will not do if there are any dry hard lumps.

Sometimes in place of spades, harrows are used, each layer of clay being thoroughly harrowed aided by water and then rolled with a grooved roller to compact it.

The finished puddle should not be exposed to the drying action of the air, but should be covered with a layer of dry clay or sand.

FOUNDATIONS.

The foundation is the most critical part of a masonry structure. The failures of masonry work due to faulty workmanship or to an insufficient thickness of the walls are rare in comparison with those due to defective foundations. When it is necessary, as so frequently it is at the present day, to erect gigantic edifices—as high buildings or long-span bridges—on weak and treacherous soils, the highest constructive skill is required to supplement the weakness of the natural foundation by such artificial preparations as will enable it to sustain the load with safety.

Natural Foundations. The soils comprised under this head may be divided into two classes. (1) Those whose stability is not affected by water, and which are firm enough to support the structure, such as rock, compact gravels, and hard clay, and (2) soils which are firm enough to support the weight of the structure, but whose stability is affected by water, such as loose gravels, sand, clay and loam.

Foundations on Rock. To prepare a rock foundation, all that is generally necessary is to cut away the loose and decayed portions and to dress the surface so exposed to a plane as nearly perpendicular to the direction of the pressure as practicable; or, if the rock forms an inclined plane, to cut a series of plane surfaces, like those of steps, for the walls to rest upon. If there are any fissures in the rock they should be filled with concrete.

Foundations on Gravel, Etc. In dealing with soils of this kind usually nothing more is required than to cover them with a layer of concrete of width and depth sufficient to distribute the weight properly.

Foundations on Sand. Sand is almost incompressible so long as it is not allowed to spread out laterally, but as it has no cohesion, and acts like a fluid when exposed to running water, it must be treated with great caution.

Foundations on Clay. Clay is much affected by the action of water, and hence the ground should be well drained before the work is begun, and the trenches so arranged that water does not remain in them. In general, the less a soil of this kind is exposed to the action of the air, and the sooner it is protected from exposure, the better for the work. The top of the footings must be carried below the frost line to prevent heaving, and for the same reason the outside face of the wall should be built with a slight batter and perfectly smooth. The frost line attains a depth of six feet in some of the northern states.

The bearing power of clay and loamy soils may be greatly increased: (1) By increasing the depth. (2) By drainage. This may be accomplished by a covering of gravel or sand, the thickness depending upon the plasticity of the soil, and by surrounding the foundation walls with a tile drain as in Fig. 5. If springs are encountered the water may be excluded by sheet pilings, puddling or plugging the spring with concrete. (3) By consolidating the soil. This may be done by driving short piles close together, or by driving piles, then withdrawing them and filling the space immediately with damp sand well rammed. If the soil is very loose and wet, sand will not be effective, and concrete will be found more satisfactory.

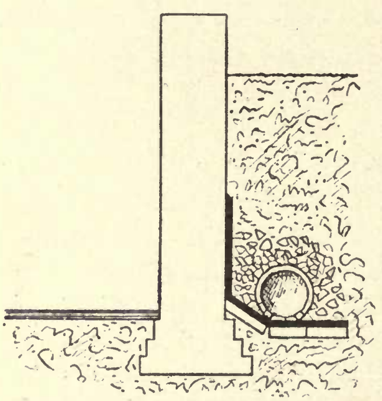


Fig. 5. Drainage of Foundation Walls.

Artificial Foundations. When the ground in its natural state is too soft to bear the weight of the proposed structure, recourse must be had to artificial means of support, and, in doing this, whatever mode of construction is adopted, the principle must always be that of extending the bearing surface as much as possible.

Foundations on Mud, silt, marshy or compressible soils are generally formed in one of three ways: (1) By driving piles in which the footings are supported. (2) By spreading the footings either by layers of timber, steel beams, or concrete, or a combination of either. (3) By sinking caissons of iron or steel, excavating the soil from the interior, and filling with concrete.

Foundations in Water are formed in several ways: (1) Wholly of piles. (2) Solid foundations laid upon the surface of the ground by means of cribs, caissons, or piles, and grillage. (3) Solid foundations laid *below* the surface, the ground being made dry by cofferdams or caissons. (4) Where the site is perfectly firm, and there is no danger of the work being undermined by scour, foundations are started on the surface, the inequalities being first removed by blasting or dredging. The simplest foundation of this class is called "Random" work or *Pierre perdue.* It is formed by throwing large masses of stone upon the site until the mass reaches the surface of the water, above which the work can be carried on in the usual manner. Large rectangular blocks of stone or concrete are also used, the bottom being first simply leveled and the blocks carefully lowered into place.

PILE FOUNDATIONS.

Timber Piles are generally round, the diameter at the butt varying from 9 to 18 inches. They should be straight-grained and as free from knots as possible. The variety of timber is usually selected according to the character of the soil. Where the piles will be always under water and where the soil is soft, spruce and hemlocks are used. For firm soils the hard pines, fir, elm and beech are preferable. Where the piles will be alternately wet and dry, white or black oak and yellow pine are used. Piles exposed to tide water are generally driven with the bark on. It is customary to fix an iron hoop to the heads of piles to prevent their splitting, and also to have them shod with either cast- or wrought-iron shoes.

Timber piles when partly above and partly under water, decay rapidly at the water line owing to the alternations of dryness and moisture. In tidal waters they are destroyed by the marine worm called the "teredo navalis." To preserve timber in such situations several processes are in use. The one most extensively employed is known as "creosoting," which consists of injecting creosote or dead oil of coal tar into the pores of the timber.

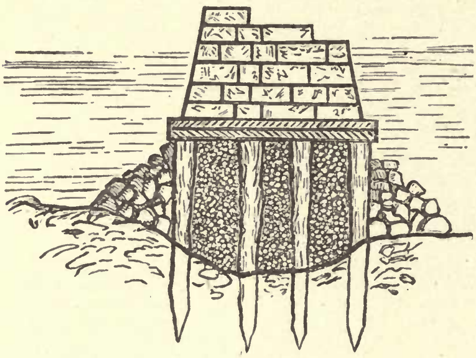


Fig. 6. Timber Pile Foundation.

The frame of timbers placed on the top of the piles is called the grillage. The piles are sawed off square below low water, a timber called a cap is placed on the ends of the piles and fastened with drift bolts, and transverse timbers called strips are placed on the caps and drift-bolted to them. As many courses as necessary may be added, each at right angles to the one below it, the top courses being either laid close together to form a floor or else covered with heavy plank to receive the masonry.

In some cases the grillage is omitted, a layer of concrete being used instead, with the heads of the piles embedded therein, as shown in Fig. 7. The name grillage is also applied to a combination of steel beams and concrete.

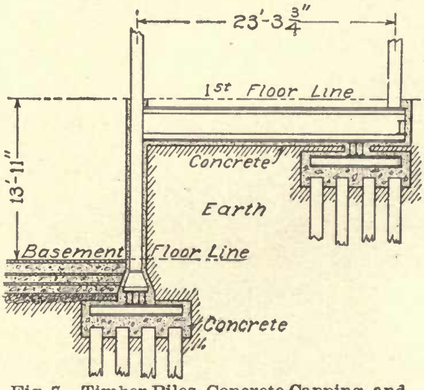


Fig. 7. Timber Piles, Concrete Capping, and I-Beam Grillage.

Iron and Steel Piles. Cast iron, wrought iron, and steel are employed for ordinary bearing piles, sheet piles, and for cylinders. Iron cylinders are usually sunk either by dredging the soil from the inside or by the pneumatic process.

Cast-iron piles are used as substitutes for wooden ones. Lugs or flanges are usually cast on the sides of the piles, to which bracing may be attached for securing them in position. A wooden block is laid on top of the pile to receive the blows of the hammer, and after being driven a cap with a socket in its lower side is placed upon the pile to receive the load. Solid rolled-steel piles are driven in the same manner as timber piles, either with a hammer, machine or water-jet.

Screw Piles are piles which are screwed into the stratum in which they are to stand. They are ordinary piles of timber or iron (the latter usually hollow), to the bottom of which a screw disk, consisting of a single turn of the spiral, similar to the bottom turn of an auger, is fastened by bolts or pins. Instead of driving these piles into the ground they are forced in by turning with levers or machinery suitable for the purpose. The screw disks vary in diameter from 1 to 6 feet. The water jet is sometimes employed by applying it to the under, upper, or both sides of the disk for the purpose of reducing the resistance.

Concrete Piles. Two methods of forming these piles are in use. (1) The piles are made in moulds and carried to the place of use and driven in the same manner as timber piles. (2) Holes are made in the ground and filled with concrete.

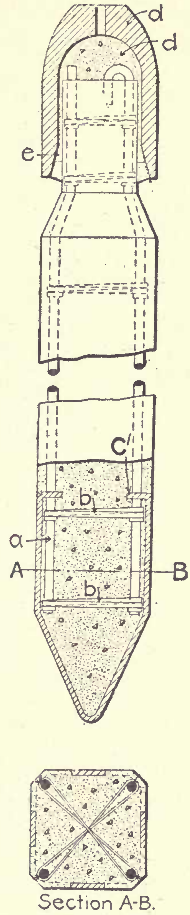


Fig. 8. Moulded Concrete Pile.

Moulded Concrete Piles. Fig. 8 shows the moulded pile. This pile is made in moulds and contains four vertical rods *a* at the corners, the rods are stayed by loops or hooks *b* of large wire sprung into place across the sides of the pile and held transversely by horizontal strips of thin metal. The feet of the piles are either wedge shaped or pyramidal and are protected by cast-iron points with side plates which turn in at *c* to lock with the concrete. The upper ends of the piles are shouldered in to give clearance for the driving cap *d*. This is a cast steel hood which fits loosely around the neck of the pile, and is filled with dry sand or a bag of sawdust *d'* retained by a clay ring and hemp jacket *e* at the bottom of the cap.

The sand absorbs the impact of the hammer so as to permit the piles to be driven safely, and it raises the hood sufficiently above the top of the pile to permit the reinforcement rods to extend beyond the concrete for connection with the superstructure.

Concrete Piles Formed in Place. Fig. 9 shows this type of pile. The hole is made by driving with an ordinary pile-driving apparatus, a sheet steel tube tapering from 20 inches at the top to 6 inches at the bottom, the tube is driven by means of a collapsible core which is withdrawn. When the desired depth is reached, the tube is then filled with concrete. Fig. 10 shows another method of forming this type of pile. A sheet steel shell is formed by telescopic sections, each section is 8 ft. long and has at its upper end projections which engage with projections on the lower end of the next section. To the bottom section is attached a cast iron point with a ¾-in. jet hole or nozzle, to which is fitted a 2½-in. pipe, this pipe is held in place by spreaders and remains in place in the finished pile, to which it adds lateral strength. The shell is sunk by water jet and filled with concrete.

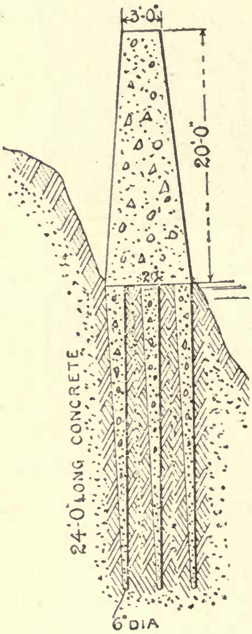


Fig. 9. Concrete Pile.

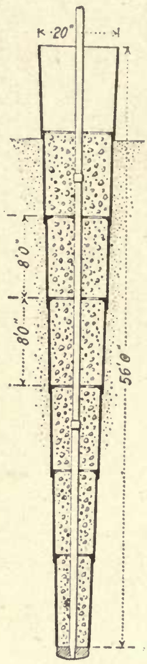


Fig. 10. Concrete Pile.

PILE-DRIVING.

Timber piles are driven either point or butt end down; the latter is considered the better method. When piles are directed to be sharpened the points should have a length of from one and a half times to twice the diameter.

To prevent the head of the pile from being broomed or split by the blows of the driving-ram it is bound with a wrought-iron hoop, 2 to 3 inches wide and $\frac{1}{2}$ to 1 inch thick. Instead of the wrought-iron band a cast-iron cap is sometimes used. It consists of a block with a tapering recess above and below, the chamfered head of the pile fitting into the one below, and a cushion piece of hard wood upon which the hammer falls fitting into the one above.

When brooming occurs the broomed part should be cut off, because a broomed head cushions the blow and dissipates it without any useful effect. Piles that split or broom excessively or are otherwise injured during the driving must be drawn out.

Bouncing of the hammer occurs when the pile refuses to drive further, or it may be caused by the hammer being too light, or its striking velocity being too great, or both. The remedy for bouncing is to diminish the fall.

Excessive hammering on piles which refuse to move should be avoided, as they are liable to be crippled, split, or broken below the ground. Such injury will pass unnoticed and may be the cause of future failure.

As a general rule, a heavy hammer with a low fall drives more satisfactorily than a light one with a high fall. More blows can be made in the same time with a low fall, and this gives less time for the soil to compact itself around the piles between the blows. At times a pile may resist the hammer after sinking some distance, but start again after a short rest; or it may refuse a heavy hammer and start under a light one. It may drive slowly at first, and more rapidly afterwards, from causes difficult to discover.

The driving of a pile sometimes causes adjacent ones previously driven to spring upwards several feet. The driving of piles in soft ground or mud will generally cause adjacent ones previously driven to lean outwards unless means of prevention be taken.

A pile may rest upon rock and yet be very weak, for if driven through very soft soil all the pressure is borne by the sharp point, and the pile becomes merely a column in a worse condition than a pillar with one rounded end. In such soils the piles need very little sharpening; indeed, they had better be driven butt end down without any point. Solid metal piles are usually of uniform diameter and are driven with either blunt or sharpened points.

Piles are driven by machines called pile drivers. A pile driver consists essentially of two upright guides or leads, often of great height, erected upon a platform, or on a barge when used in water. These guides serve to hold the pile vertical while being driven, and also hold and guide the hammer used in driving. This is a block of iron called a ram, monkey, or hammer, weighing anywhere from 800 to 4,000 pounds, usually about 2,000 to 3,000 pounds. The accessories are a hoisting engine for raising the hammer and the devices for allowing it to drop freely on the heads of the piles.

The steam hammer is also employed for driving piles, and has certain advantages over the ordinary form, the chief of which lies in the great rapidity with which the blows follow one another, allowing no time for the disturbed earth, sand, etc., to recompact itself around the sides and under the foot of the pile. It is less liable than other methods to split and broom the piles, so that these may be of softer and cheaper wood, and the piles are not so liable to "dodge" or get out of line.

When piles have to be driven below the end of the leaders of the pile driver a follower is used. This is made from a pile of suitable length placed on top of the pile to be driven. To prevent its bouncing off caps of cast iron are used, one end being bolted to the follower and the other end fitting over the head of the pile.

Piles are also driven by the "water jet." This process consists of an iron pipe fastened by staples to the side of the pile, its lower end placed near the point of the pile and its upper end connected by a hose to a force pump. The pile can be sunk through almost any material, except hardpan and rock, by forcing water through the pipe. It seems to make very little difference, either in the rapidity of sinking or in the accuracy with which the pile preserves its position, whether the nozzle is exactly under the middle of the pile or not.

The efficiency of the jet depends upon the increased fluidity given the material into which the piles are sunk, the actual displacement of material being small. Hence the efficiency of the jet is greatest in clear sand, mud, or soft clay. In gravel or in sand containing a large percentage of gravel, or in hard clay the jet is almost useless. For these reasons the engine, pump, hose, and nozzle should be arranged to deliver large quantities of water with a moderate force rather than smaller quantities with high initial velocity. In gravel, or in sand containing gravel, some benefit might result from a velocity sufficient to displace the pebbles and drive them from the vicinity of the pile. The error most frequently made in the application of the water jet is in using pumps with insufficient capacity.

The approximate volume of water required per minute, per inch of average diameter of pile, for penetrations under 40 feet is 16 gallons; for greater depths the increase in the volume of water is approximately at the rate of 4 gallons per inch of diameter of pile per minute, for each additional 10 feet of penetration.

The number and size of pipes required for various depths are about as follows:

TABLE 7.

Depth of penetration, feet.	Diameter of pipe, inches.	Number of pipes.	Diameter of nozzle, inches.
20	2	1	1
30	$2\frac{1}{2}$	1	$1\frac{1}{4}$
40	$2\frac{1}{2}$	2	$1\frac{1}{8}$
50	$2\frac{1}{2}$	2	1
60	$2\frac{1}{2}$	2	$\frac{7}{8}$

When the descent of the pile becomes slow, or it sticks or "brings up" in some tenacious material, it can usually be started by striking a few blows with the pile-driving hammer, or by raising the pile about 6 inches and allowing it to drop suddenly, with the jet in operation. By repeating the operation as rapidly as possible the obstruction will generally be overcome.

It is an advantage to use an ordinary pile-driving machine for sinking piles with the water jet. The hammer being allowed to rest upon the head of the pile aids in accelerating the descent, and light blows can be struck as often as may appear necessary. The efficiency of the jet can also be greatly increased by bringing the weight of the pontoon upon which the machinery is placed to bear upon the pile by means of a block and tackle.

Splicing Piles. It frequently happens in driving piles in swampy places, for false works, etc., that a single pile is not long enough, in which case two are spliced together. A common method of doing this is as follows. After the first pile is driven its head is cut off square, a hole 2 inches in diameter and 12 inches deep is bored in its head, and an oak treenail or dowel-pin 23 inches long is driven into the hole; another pile similarly squared and bored is placed upon the lower pile, and the driving continued. Spliced in this way the pile is deficient in lateral stiffness, and the upper section is liable to bounce off while driving. It is better to reinforce the splice by flattening the sides of the piles and nailing on with, say, 8-inch spikes four or more pieces 2 or 3 inches thick, 4 or 5 inches wide, and 4 to 6 feet long.

CONCRETE WITH STEEL BEAMS.

The foundation is prepared by first laying a bed of concrete to a depth of from 4 to 12 inches and then placing upon it a row of

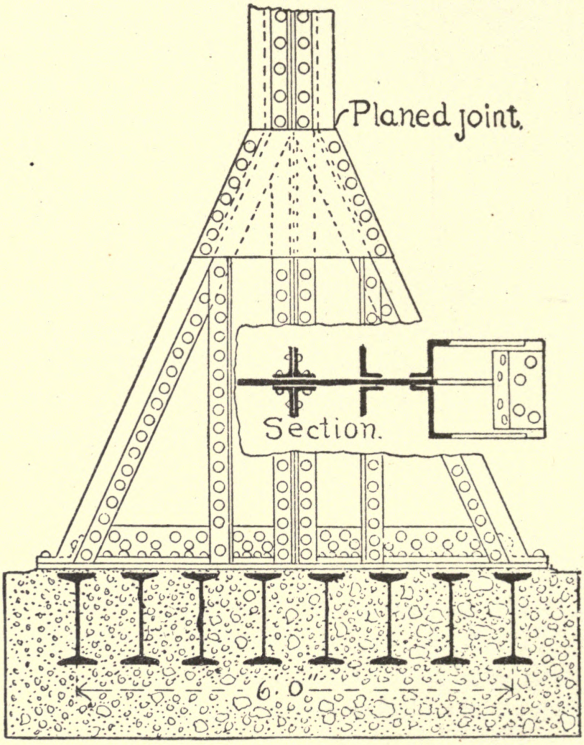


Fig. 11. Concrete, and Steel I-Beams.

I-beams at right angles to the face of the wall. In the case of heavy piers, the beams may be crossed in two directions. Their distance apart, from center to center, may vary from 9 to 24 inches, according to circumstances, *i.e.*, length of their projection beyond the masonry, thickness of concrete, estimated pressure per square foot, etc. They should be placed far enough apart to permit the introduction of the concrete filling and its proper tamping.

Hollow Cylinders of cast iron or plate steel, commonly called *caissons*, are frequently used with advantage. The cylinders are made in short lengths with internal flanges and are bolted together as each preceding length is lowered. They are sunk by excavating the natural soil from the interior. When the stratum on which they are to rest has been reached they are filled with concrete.

Cofferdams. There are many circumstances under which it becomes necessary to expose the bottom and have it dry before commencing operations. This is done by enclosing the site of the foundation with a water-tight wall. The great difficulties in the construction of a cofferdam in deep water are, first, to keep it water-

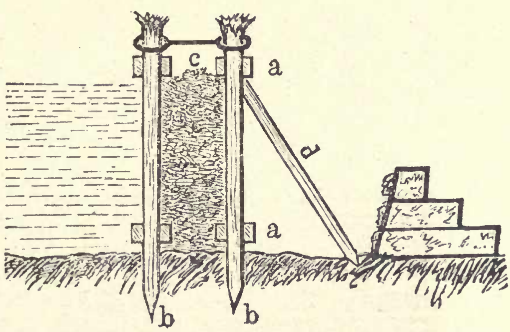


Fig. 12. Cofferdam,

tight, and, second, to support the sides against the pressure of the water outside. Fig. 12 shows the simplest form; it consists of two rows of piles driven closely and filled with clay puddle. In shallow water and on land sheet piling is sometimes sufficient.

Sheet Piles are flat piles, usually of plank, either tongued and grooved or grooved only, into which a strip of tongue is driven; or they may be of squared timber, in which case they are called "close piles," or of sheet iron. The timber ones are of any breadth that can be procured, and from 2 to 10 inches thick, and are shaped at the lower end to an edge wholly from one side; this point being placed next to the last pile driven tends to crowd them together and make tighter joints (the angle formed at the point should be 30°). In stony ground they are shod with iron.

When a space is to be enclosed with sheet piling two rows of guide piles are first driven at regular intervals of from 6 to 10 feet, and to opposite sides of these near the top are notched or bolted a pair of parallel string pieces or "wales," from 5 to 10 inches square, so fastened to the guide piles as to leave between the wales equal to the thickness of the sheet piles.

If the sheeting is to stand more than 8 or 10 feet above the ground, a second pair of wales is required near the level of the ground. The sheet piles are driven between the wales, working from each end towards the middle of the space between a pair of guide piles, so that the last or central pile acts as a wedge to tighten the whole.

Sheet piles are driven either by mauls wielded by men or by a pile-driving machine. Ordinary planks are also used for sheet

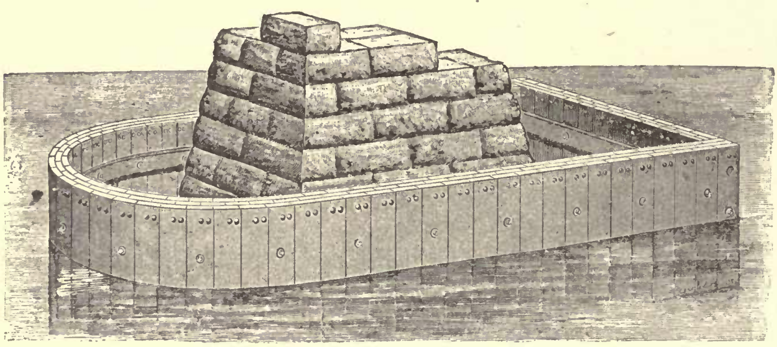


Fig. 13. Sheet Piling.

piling, being driven with a lap; such piling is designated as "single lap," "double lap," and "triple lap." The latter is also known as the "Wakefield" triple-lap sheet piling, shown in Fig. 13.

Cribs are boxes constructed of round or square timber, divided by partitions of solid timber into square or rectangular cells. The cells are floored with planks, placed a little above the lower edge so as not to prevent the crib from settling slightly into the soil, and thus coming to a full bearing on the bottom. After it has been sunk the cells are filled with sand and stone. On uneven rock bottom it may be necessary to scribe the bottom of the crib to fit the rock. In some cases rip-rap is deposited outside around the crib to prevent undermining by the current. A crib with only an outside row of cells for sinking it is sometimes used, with an interior chamber in which concrete is laid under water and the masonry started thereon. Cribs are sometimes sunk into place and then piles are driven in the cells, which are afterward filled with concrete or broken stone. The masonry may then rest on the piles only, which in turn will be protected by the crib. If the bottom is liable to scour, sheet piles or rip-rap may be placed outside around the base of the crib. Cribs with only an outer row of cells for puddling may be used as a coffer-dam, the joints between the outer timbers being well calked, and care taken by means of outside pile planks to prevent water from entering beneath it.

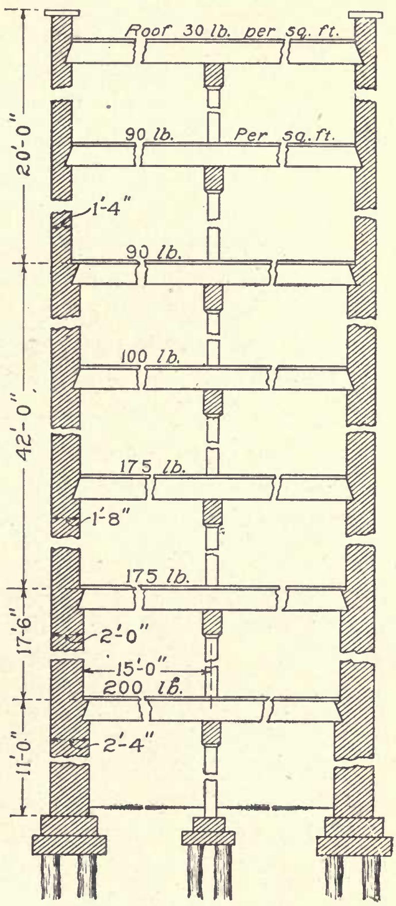


Fig. 14. Building on Pile Foundation.

Caissons are of two forms, the "erect" or "open" and the "inverted." The former is a strong water-tight timber box, which is floated over the site of the work, and being kept in place by guide piles, is loaded with stone until it rests firmly on the ground. In some cases the stone is merely thrown in, the regular masonry commencing with the top of the caisson; which is sunk a little below the level of low water, so that the whole of the timber is always covered, and the caisson remains as part of the structure. In others, the masonry is built on the bottom of the caisson, and when the work reaches the level of the water the sides of the caisson are removed. The site is prepared to receive the caisson by dredging and depositing a layer of concrete, or by driving piles, or a combination of both.

The *inverted caisson* is also a strong water-tight box, open at the bottom and closed at the top, upon which the structure is built, and which sinks as the masonry is added. This type of caisson is usually aided in sinking by excavation made in the interior. The processes employed to aid the sinking of the inverted caissons are called the "vacuum" and the "plenum."

The vacuum process consists in exhausting the air from the interior of the caisson, and using the pressure of the atmosphere upon the top of it to force it down. Exhausting the air allows the water to flow past the lower edge into the interior, thus loosening the soil.

The plenum or compressed-air process consists in pumping air into the chamber of the caisson, which by its pressure excludes the water. An air lock or entrance provided with suitable doors is arranged in the top of the caisson, by which workmen can enter to loosen up the soil and otherwise aid in the sinking of the caisson vertically by removing and loosening the material at the sides. If the loosened material is of a suitable character it is removed with a sand pump; if not, hoisting apparatus is provided and, being loaded into buckets by the workmen, it is hoisted out through the air lock.

Freezing Process. This process is employed in sinking foundation pits through quicksand and soils saturated with water. The Poetsch-Sooysmith process is to sink a series of pipes 10 inches in diameter through the earth to the rock; these are sunk in a circle around the proposed shaft. Inside of the 10-inch pipes 8-inch pipes closed at the bottom are placed, and inside of these are placed smaller pipes open at the bottom. Each set of the small pipes is connected in a series. A freezing mixture is then allowed to flow downwards through one set of the smaller pipes and return upwards through the other. The freezing mixture flows from a tank placed at a sufficient height to cause the liquid to flow with the desired velocity through the pipes. The effect of this process is to freeze the earth into a solid wall.

DESIGNING THE FOUNDATION.

Load to be Supported. The first step is to ascertain the load to be supported by the foundation. This load consists of three parts: (1) The structure itself, (2) the movable loads on the floors and the snow on the roof, and (3) the part of the load that may be transferred from one part of the foundation to the other by the force of the wind.

The weight of the building is easily ascertained by calculating the cubical contents of all the various materials in the structure. The following data will be useful in determining the weight of the structure.

TABLE 8.

Weight of Masonry.

Kind of Masonry.	Weight in lb. per cu. ft.
Brickwork, pressed brick, thin joints	145
" ordinary quality	125
" soft brick, thick joints	100
Concrete	130 to 160
Granite or limestone, well dressed throughout	165
" rubble, well dressed with mortar	155
" roughly dressed with mortar	150
" well dressed, dry	140
" roughly dressed, dry	125
Mortar dried	100
Sandstone, $\frac{1}{10}$ less than granite	....

Ordinary lathing and plastering weighs about 10 lb. per sq. ft.

Floors weigh approximately:

Dwellings ....10 lb. per sq. ft.
Public buildings ....25 lb. per sq. ft.
Warehouses......................40 to 50 lb. per sq. ft.

Roofs vary according to the kind of covering, span, etc.

Shingle roof weighs about 10 lb. per sq. ft.
Slate or corrugated iron..............25 lb per sq. ft.

The movable load on the floor depends upon the nature of the building. It is usually taken as follows:

Dwellings ....10 lb. per sq. ft.
Office buildings.......................20 lb. per sq. ft.
Churches, theatres, etc..............100 lb. per sq. ft.
Warehouses, factories........100 to 400 lb. per sq. ft.

The weight of snow on the roof will vary from 0 in a warm climate to 20 lb. in the latitude of Michigan. The pressure of the wind is usually taken at 50 lb. per sq. ft. on a flat surface perpendicular to the wind, and on a cylinder at about 40 lbs. per sq. ft. over the vertical projection of the cylinder.

Bearing Power of Soils. The best method of determining the load which a particular soil will bear is by direct experiment and examination—particularly of its compactness and the amount of water it contains. The values given in the following table may be considered safe for good examples of the kind of soil quoted.

TABLE 9.

Bearing Power of Soils.

Kind of soil.	Bearing power, tons per square foot.	
	Min.	Max.
Rock, hard	25	30
" soft	5	10
Clay on thick bed, always dry	4	6
" " " " moderately dry	2	4
" soft	1	2
Gravel and coarse sand, well cemented	8	10
Sand, compact and well cemented	4	6
" clean, dry	2	4
Quicksand, alluvial soil, etc	0.5	1

Area Required. Having determined the pressure which may safely be brought upon the soil, and having ascertained the weight of each part of the structure, the area required for the foundation is easily determined by dividing the latter by the former. Then, having found the area required, the base of the structure must be extended by footings of concrete, masonry, timber, etc., so as to (1) cover that area and (2) distribute the pressure uniformly over it.

Bearing Power of Piles. Several formulas have been proposed and are in use for determining the safe working loads on piles. The three in general use are:

Sander's formula.

$$\text{Safe load in lb.} = \frac{\text{Weight of hammer in lb.} \times \text{fall in inches.}}{8 \times \text{Sinking at last blow.}}$$

Trautwine's formula.

Extreme load in tons of 2240 lbs. =

$$\frac{\text{Cube root of fall in feet} \times \text{Weight of hammer in lb.} \times 0.023}{\text{Last sinking in inches.}}$$

Safe load to be taken at one-half of extreme load when driven in firm soils, and at one-fourth when driven in river mud or marshy soil.

Engineering News formula is the latest and is considered reliable.

$$\text{Safe load in lb.} = \frac{2\,wh}{S + 1}$$

in which w = weight of hammer in lb., h = its fall in feet, S = average sinking under last blows in inches.

Example of Pile Foundation. As an example of the method of determining the number of piles required to support a given building, the side walls of a warehouse are selected, a vertical section of which is shown in Fig. 15. The walls are of brick, and the weight is taken at 110 pounds per cubic foot of masonry.

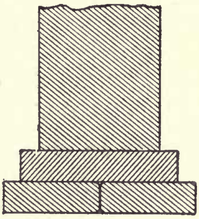


Fig. 15. Stone Footing.

The piles are to be driven in two rows, spaced two feet between centers, and it has been found that a test pile 20 feet long and 10 inches at the top will sink one inch under a 1,200-pound hammer falling 20 feet after the pile has been entirely driven into the soil. What distance should the piles be placed center to center lengthwise of the wall?

By calculation it is found that the wall contains $157\frac{1}{3}$ cubic feet of masonry per running foot, and hence weighs 17,306 pounds. The load from the floors which comes upon the wall is:

From the 1st floor	1500 lb.
" " 2nd "	1380 "
" " 3rd "	1380 "
" " 4th "	790 "
" " 5th "	720 "
" " 6th "	720 "
" " roof	240 "
Total	6730 lb.

Hence the total weight of the wall and its load per running foot is 24,036 pounds.

The load which one pile will support is, by Sander's rule

$$\frac{1200 \times 240}{8 \times 1} = 36{,}000 \text{ pounds.}$$

By Trautwine's rule, using a factor of safety of 2.5, the safe load would be

$$\frac{\sqrt[2]{20} \times 1200 \times 0.023}{2.5 \times (1 + 1)} = 15 \text{ tons or } 33{,}600 \text{ lb.}$$

Then one pair of piles would support 72,000 or 67,200 pounds according to which rule we take.

Dividing these numbers by the weight of one foot of the wall and its load, it is found, that, by Sander's rule, one pair of piles will support 3 feet of the wall, and, by Trautwine's rule, 2.8 feet of wall; hence the pile should be placed. 2 feet 9 inches or 3 feet between centers.

DESIGNING THE FOOTING.

The term *footing* is usually understood as meaning the bottom course or courses of concrete, timber, iron, or masonry employed to increase the area of the base of the walls, piers, etc. Whatever the character of the soil, footings should extend beyond the fall of the wall (1) to add to the stability of the structure and lessen the danger of its being thrown out of plumb, and (2) to distribute the weight of the structure over a larger area and thus decrease the settlement due to compression of the ground.

Offsets of Footings. The area of the foundation having been determined and its center having been located with reference to the axis of the load, the next step is to determine how much narrower each footing course may be than the one next below it.

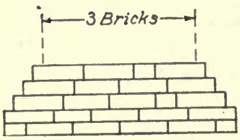


Fig. 16. Brick Footing.

The proper offset for each course will depend upon the vertical pressure, the transverse strength of the material, and the thickness of the course. Each footing may be regarded as a beam fixed at one end and uniformly loaded. The part of the footing course that projects beyond the one above it, is a cantilever beam uniformly loaded. From the formulas for such beams, the safe projection may be calculated.

Stone Footings. Table 10 gives the safe offset for masonry footing courses, in terms of the thickness of the course, computed for a factor of safety of 10.

TABLE 10.

Kind of stone.	R* in lb. per sq. in.	Offset for a pressure in tons per sq. ft. on the bottom of the course of 0.5	1.0	2.0
Bluestone flag	2,700	3.6	2.6	1.8
Granite	1,800	2.9	2.1	1.5
Limestone	1,500	2.7	1 9	1 3
Sandstone	1,200	2.6	1.8	1.3
Slate	5,400	5.0	3.6	2.5
Best hard brick	1,500	2.7	1.9	1.3
Hard brick	800	1.9	1.4	0.8
Concrete 1 Portland, 2 Sand, 3 Pebbles — 10 days old	150	0.8	0.6	0.4
Concrete 1 Rosendale, 2 Sand, 3 Pebbles — 10 days old	80	0.6	0.4	0.3

* Modulus of rupture.

To illustrate the method of using the preceding table, assume that it is desired to determine the offset for a limestone footing course when the pressure on the bed of the foundation is 1 ton per square foot, using a factor of safety of 10. On the table, opposite limestone, in next to the last column, we find the quantity 1.9. This shows that under the conditions stated, the offset may be 1.9 times the thickness of the course.

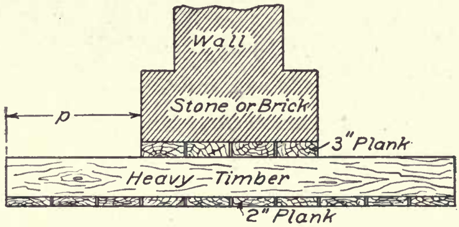


Fig 17. Timber Footing.

Timber Footing. The rise of the transverse timbers (Fig. 17) may be calculated by the following formula:

$$\text{Breadth in inches} = \frac{2 \times w \times p^2 \times s}{D^2 \times A}$$

in which w = the bearing power in lb. per sq. ft.;

p = the projection of the beam in feet;

s = the distance between centers of beams in feet;

D = the assumed depth of the beam in inches;

A = the constant for strength which is taken for Georgia pine at 90, oak 65, Norway pine 60, white pine or spruce 55.

Steel I-Beam Footings. The dimensions of the I-beams, Fig. 18, can be calculated by the usual formulas, by means of the strain

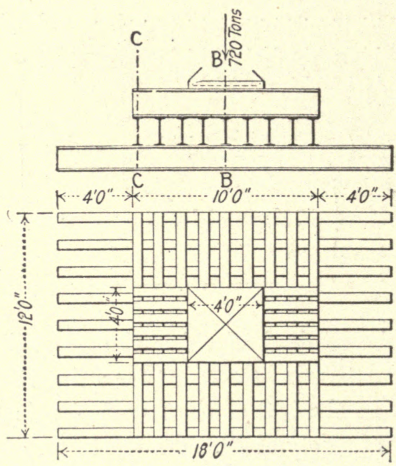


Fig. 18. Steel I-Beam Footing.

to which the part of the beam in cantilever is submitted. The safe load per running foot is given by the expression

$$W = \frac{S\,I}{6\,m} \times \frac{1}{z^2}$$

in which W = load in pounds per running foot;

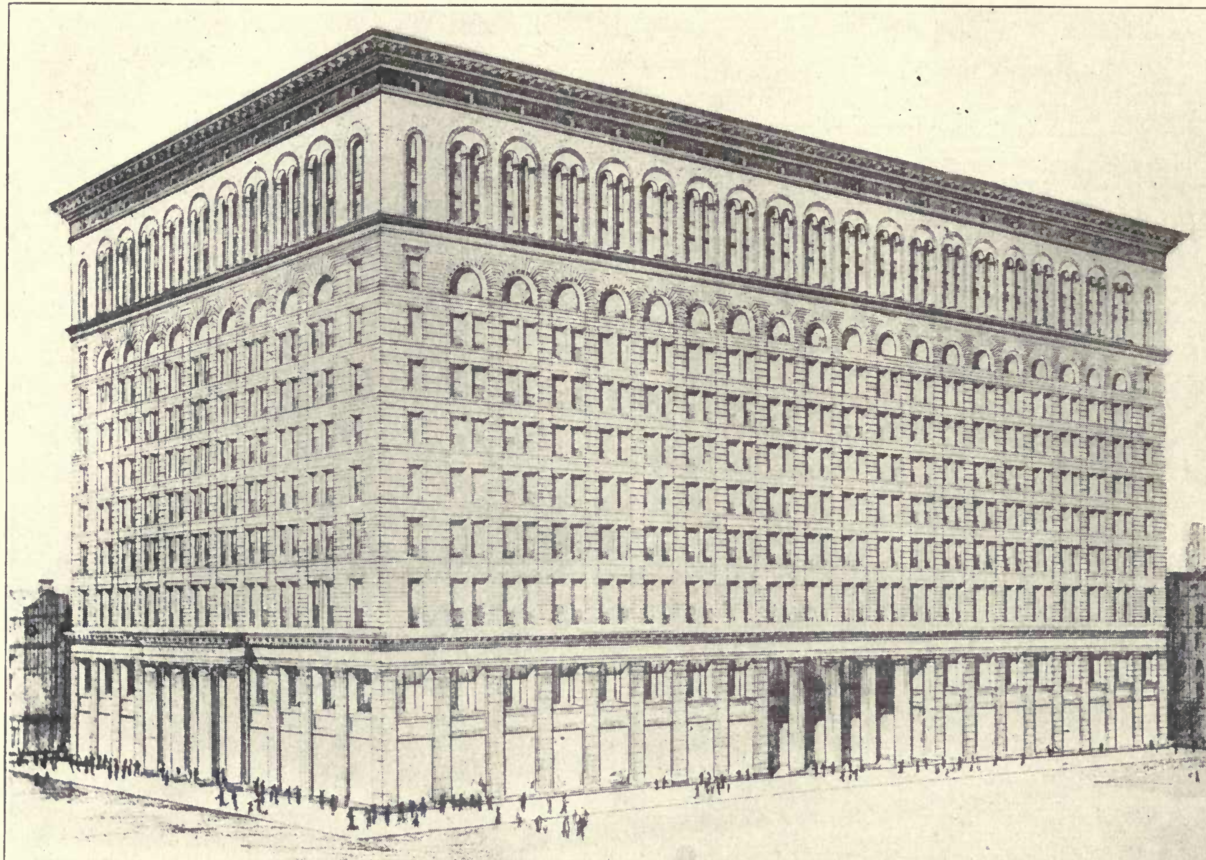
S = 16,000 lb. per sq. in., extreme fibre strain of beams;

m = distance from center of gravity of sections to top or bottom;

I = moment of inertia of section, neutral axis through center of gravity;

z = span in feet.

A ready method of determining the size of the beams is by computing the required *coefficient of strength,* and finding in the tables furnished by the manufacturers of steel beams the size of the beam



WANAMAKER'S STORE IN PHILADELPHIA, PA.

D. H. Burnham & Co., Architects.

Granite Exterior. The Roman Doric Order is Used as a Decorative Feature in the Lower Portion of the Building. Part of Building Completed in 1906. The People's "Shopping Palace."

which has a coefficient equal to, or next above, the value obtained by the formula. C, the coefficient, is found by the following expression:

$$C = 4 \times w \times p^2 \times s$$

in which w = bearing power in pounds per sq. ft.;
p = the projection of the beam in feet;
s = the spacing of the beam, center to center, in feet.

Table 11 gives the safe projection of steel I-beams spaced on I foot centers and for loads varying from 1 to 5 tons per sq. ft.

TABLE 11.

Safe Projection of I=Beam Footings.

Depth of beam, in.	Weight per foot, lb.	b (Tons per Square Foot).										
		1	1¼	1½	2	2¼	2½	3	3½	4	4½	5
20	80	14.0	12.5	11.5	10.0	9.0	9.0	8.0	7.5	7.0	6.5	6.0
20	64	12.5	11.0	10.0	8.5	8.0	8.0	7.0	6.5	6.0	6.0	5.5
15	75	11.5	10.5	9.5	8.0	7.5	7.5	6.5	6.0	6.0	5.5	5.0
15	60	10.5	9.5	8.5	7.5	7.0	6.5	6.0	5.5	5.5	5.0	5.0
15	50	9.5	8.5	8.0	7.0	6.5	6.0	5.5	5.0	5.0	4.5	4.5
15	41	8.5	8.0	7.0	6.0	6.0	5.5	5.0	4.5	4.5	4.0	4.0
12	40	8.0	7.0	6.5	5.5	5.5	5.0	4.5	4.0	4.0	3.5	3.5
12	32	7.0	6.5	5.5	5.0	4.5	4.5	4.0	4.0	3.5	3.5	3.0
10	33	6.5	6.0	5.5	4.5	4.5	4.0	4.0	3.5	3.5	3.0	3.0
10	25.5	5.5	5.0	4.5	4.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5
9	27	5.5	5.0	4.5	4.0	4.0	3.5	3.5	3.0	3.0	2.5	2.5
9	21	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.0
8	22	5.0	4.5	4.0	3.5	3.5	3.0	3.0	2.5	2.5	2.5	2.0
8	18	4.5	4.0	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
7	20	4.5	4.0	3.5	3.0	3.0	3.0	2.5	2.5	2.0	2.0	2.0
7	15.5	4.0	3.5	3.0	2.5	2.5	2.5	2.0	2.0	2.0	2.0	1.5
6	16	3.5	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5
6	13	3.0	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5
5	13	3.0	2.5	2.5	2.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5
5	10	2.5	2.5	2.0	2.0	1.5	1.5	1.5	1.5	1.5	....	....
4	10	2.5	2.0	2.0	1.5	1.5	1.5	1.5	....	....	....	....
4	7.5	2.0	2.0	1.5	1.5	1.5	1.5	....	....	....	....	....

SAFE WORKING LOADS FOR MASONRY.

Brick Masonry in Walls or Piers.

Tons per sq. ft.

Hard brick in lime mortar..............................5 to 7

Hard brick in Rosendale cement 1 to 3 .... 8 to 10

	Tons per sq. ft.
Pressed brick in lime mortar	6 to 8
Pressed brick in Rosendale cement	9 to 12
Pressed brick in Portland cement	12 to 15

Piers exceeding in height six times their least dimension should be increased 4 inches in size for each additional 6 feet.

According to the New York building laws, brickwork in good lime mortar 8 tons per sq. ft., 11½ tons when good lime and cement mortar is used, and 15 tons when good cement mortar is used.

According to the Boston building laws:

Best hard-burned brick (height less than six times least dimension) with

	Lb. per sq. ft.
Mortar, 1 cement, 2 sand	30,000
Mortar, 1 cement, 1 lime, 3 sand	24,000
Mortar, lime	16,000

Best hard-turned brick (height six to twelve times least dimension) with

Mortar, 1 cement, 2 sand	26,000
Mortar, 1 cement, 1 lime, 3 sand	20,000
Mortar, lime	14,000

For light hard-burned brick use ⅔ the above amounts.

STONE MASONRY.

	Tons per sq. ft.
Rubble walls, irregular stone	3
Rubble walls, coursed, soft stone	2½
Rubble walls, coursed, hard stone	5 to 16

Dimension stone in cement:

Sandstone and limestone	10 to 20
Granite	20 to 40

Dressed stone, with ⅜-inch dressed joints, in cement:

Granite	60
Marble or limestone	40
Sandstone	30

Height of columns not to exceed eight times least diameter.

MORTARS.

In ½ inch joints 3 months old:	Tons per sq. ft.
Portland cement 1 to 4	40

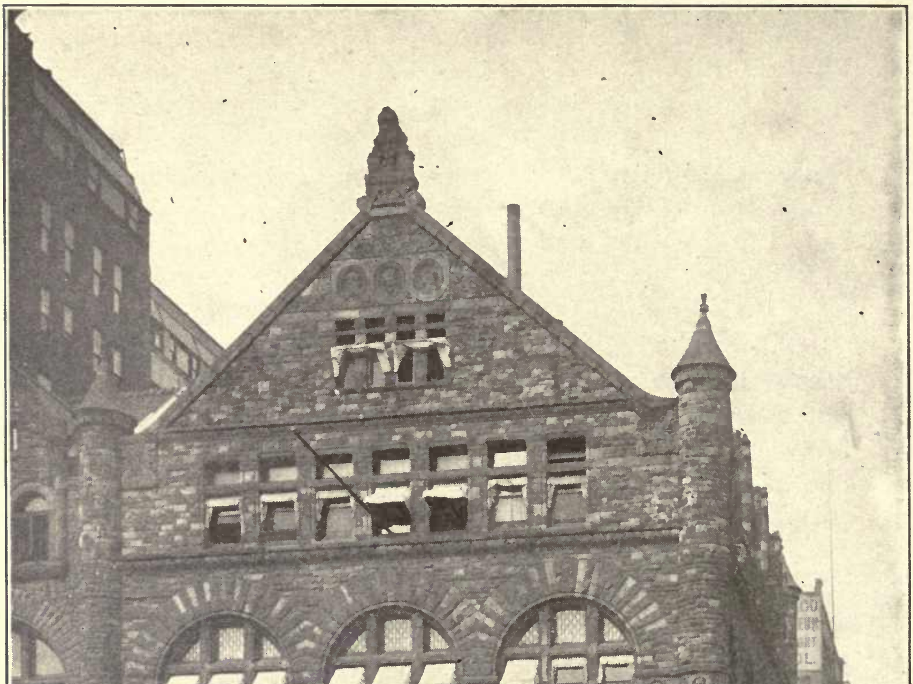
	Tons per sq. ft.
Rosendale cement 1 to 3	13
Lime mortar	8 to 10
Portland 1 to 2 in ¼-inch joints for bedding iron plates	70

CONCRETE.

	Tons per sq. ft.
Portland cement 1 to 8	8 to 20
Rosendale cement 1 to 6	5 to 10
Lime, best, 1 to 6	5

HOLLOW TILE.

	Pounds per sq. ft.
Hard fire-clay tiles	80
Hard ordinary clay tiles	60
Porous terra-cotta tiles	40
Terra-cotta blocks, unfilled	10,000
Terra-cotta blocks, filled solid with brick or cement	20,000



CHICAGO CLUB, FORMERLY THE ART INSTITUTE OF CHICAGO
Burnham & Root, Architects.
Exterior of Brownstone. Built in 1888.

MASONRY CONSTRUCTION.

PART II.

CLASSIFICATION OF MASONRY.

Masonry is classified according to the nature of the material used, as "stone masonry," "brick masonry," "mixed masonry," composed of stones and bricks, and "concrete masonry."

Stone masonry is classified (1) according to the manner in which the material is prepared, as "rubble masonry," "squared stone masonry," "ashlar masonry," "broken ashlar," and the combinations of these four kinds; and (2) according to the manner in which the work is executed, as "uncoursed rubble," "coursed rubble," "dry rubble," "regular-coursed ashlar,"' 'broken or irregular-coursed ashlar," "ranged work," "random ranged," etc.

DEFINITIONS OF THE TERMS USED IN MASONRY.

Abutment: (1) That portion of the masonry of a bridge or dam upon which the ends rest, and which connects the superstructure with the adjacent banks. (2) A structure that receives the lateral thrust of an arch.

Arris: The external angle or edge formed by the meeting of two plane or curved surfaces, whether walls or the sides of a stick or stone.

Backed: Built on the rear face.

Backing: The rough masonry of a wall faced with cut stone.

Batter: The slope or inclination given to the face of a wall. It is expressed by dividing the height by the horizontal distance. It is described by stating the extent of the deviation from the vertical, as one in twelve, or one inch to the foot.

Bats: Broken bricks.

Bearing Blocks or Templets: Small blocks of stone built in the wall to support the ends of particular beams.

Belt Stones or Courses: Horizontal bands or zones of stone encircling a building or extending through a wall.

Blocking Course: A course of stone placed on the top of a cornice, crowning the walls.

Bond: The disposing of the blocks of stone or bricks in the walls so as to form the whole into a firm structure by a judicious overlapping of each other so as to break joint.

A stone or brick which is laid with its length across the wall, or extends through the facing course into that behind, so as to bind the facing to the backing, is called a "header" or "bond." Bonds are described by various names, as:

Binders, when they extend only a part of the distance across the wall.

Through Bonds, when they extend clear across from face to back.

Heart Bonds, when two headers meet in the middle of the wall and the joint between them is covered by another header.

Perpend Bond signifies that a header extends through the whole thickness of the wall.

Chain Bond is the building into the masonry of an iron bar, chain, or heavy timber.

Cross Bond, in which the joints of the second stretcher course come in the middle of the first; a course composed of headers and stretchers intervening.

Block and Cross Bond, when the face of the wall is put up in cross bond and the backing in block bond.

English Bond (brick masonry) consists of alternate courses of headers and stretchers.

Flemish Bond (brick masonry) consists of alternate headers and stretchers in the same course.

Blind Bond is used to tie the front course to the wall in pressed brick work where it is not desirable that any headers should be seen in the face work.

To form this bond the face brick is trimmed or clipped off at both ends, so that it will admit a binder to set in transversely from the face of the wall, and every layer of these binders should be tied with a header course the whole length of the wall. The binder should be put in every fifth course, and the backing should be done in a most substantial manner, with hard brick laid in close joints, for the reason that the face work is laid in a fine putty mortar, and the joints consequently close and tight; and if the backing is not the same the pressure upon the wall will make it settle and draw the wall inward. The common form of bond in brickwork is to lay three or five courses as stretchers, then a header course.

Breast Wall: One built to prevent the falling of a vertical face cut into the natural soil; in distinction to a retaining wall, etc.

Brick Ashlar: Walls with ashlar facing backed with bricks.

Build or Rise: That dimension of the stone which is perpendicular to the quarry bed.

Buttress: A vertical projecting piece of stone or brick masonry built in front of a wall to strengthen it.

Closers are pieces of brick or stone inserted in alternate courses of brick and broken ashlar masonry to obtain a bond.

Cleaning Down consists in washing and scrubbing the stonework with muriatic acid and water. Wire brushes are generally used for marble and sometimes for sandstone. Stiff bristle brushes are ordinarily used. The stones should be scrubbed until all mortar stains and dirt are entirely removed.

For cleaning old stonework the sand blast operated either by steam or compressed air is used. Brick masonry is cleaned in the same manner as stone masonry. During the process of cleaning all open joints under window sills and elsewhere should be pointed.

Coping: The coping of a wall consists of large and heavy stones, slightly projecting over it at both sides, accurately bedded on the wall, and jointed to each other with cement mortar. Its use is to shelter the mortar in the interior of the wall from the weather, and to protect by its weight the smaller stones below it from being knocked off or picked out. Coping stones should be so shaped that water may rapidly run off from them.

For coping stones the objections with regard to excess of length do not apply; this excess may, on the contrary, prove favorable, because, the number of top joints being thus diminished, the mass beneath the coping will be better protected.

Additional stability is given to a coping by so connecting the coping stones together that it is impossible to lift one of them without at the same time lifting the ends of the two next it. This is done either by means of iron cramps inserted into holes in the stone and fixed there with lead, or, better still, by means of dowels of wrought iron, cast iron, copper, or hard stone. The metal dowels are inferior in durability to those of hard stone, though superior in strength. Copper is strong and durable, but expensive. The stone dowels are small prismatic or cylindrical blocks, each of which fits into a pair of opposite holes in the contiguous ends of a pair of coping stones and fixed with cement mortar.

The under edge should be throated or dipped, that is, grooved, so that the drip will not run back on the wall, but drop from the edge. Coping is divided into three kinds.

Parallel coping, level on top. *Feather-edged coping,* bedded level and sloping on top. *Saddle-back coping* has a curved or doubly inclined top.

Corbell: A horizontal projecting piece, or course, of masonry which assists in supporting one resting upon it which projects still further.

Cornice: The ornamental projection at the eaves of a building or at the top of a pier or any other structure.

Counterfort: Vertical projections of stone or brick masonry built at intervals along the back of a wall to strengthen it, and generally of very little use.

Course: The term course is applied to each horizontal row or layer of stones or bricks in a wall; some of the courses have particular names, as:

Plinth Course, a lower, projecting, square-faced course; also called the water table.

Blocking Course, laid on top of the cornice.

Bonding Course, one in which the stones or bricks lie with their length across the wall; also called heading course.

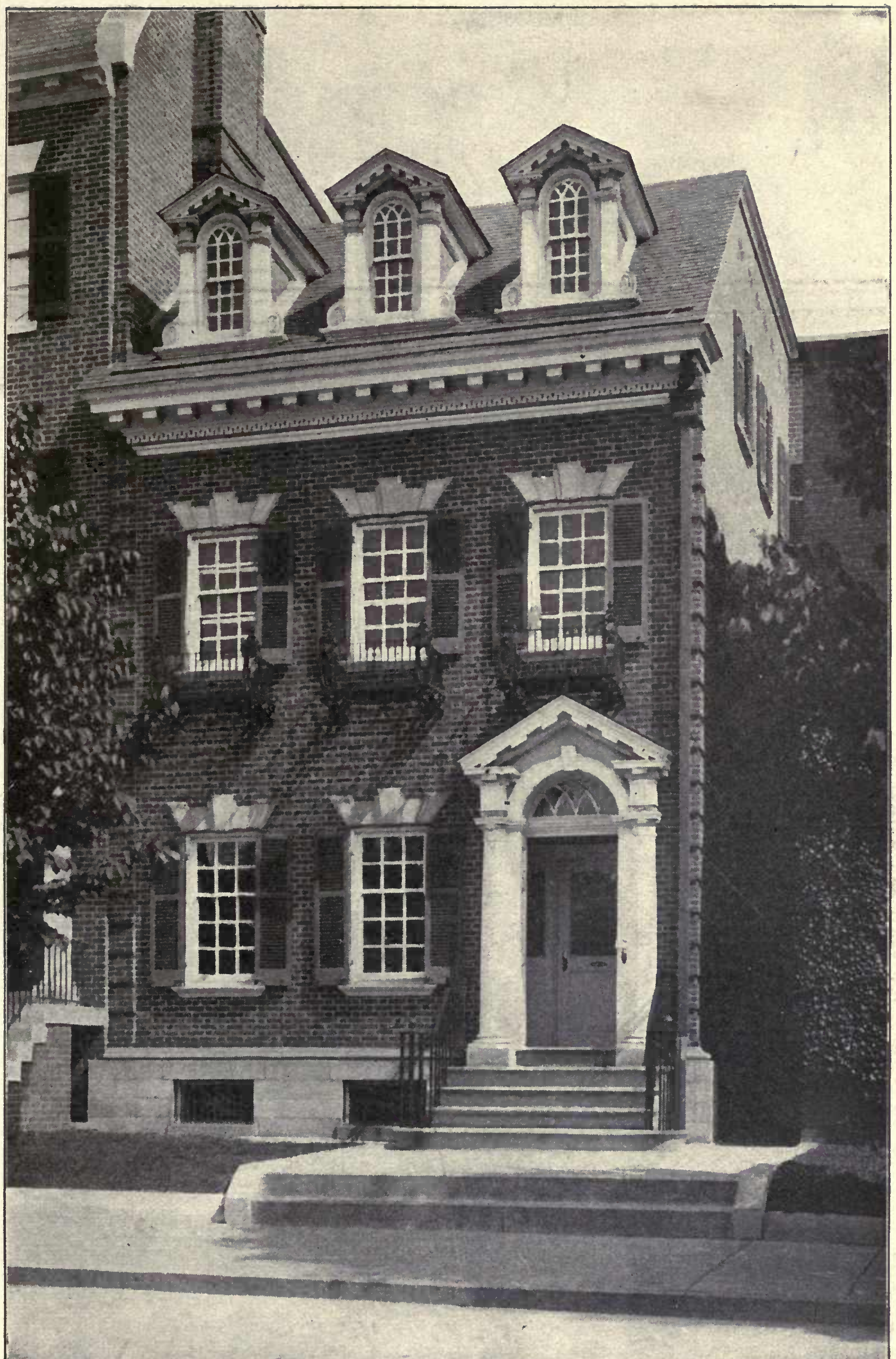
Stretching Course, consisting of stretchers.

Springing Course, the course from which an arch springs.

String Course, a projecting course.

Rowlock Course, bricks set on edge.

Cramps: Bars of iron having the ends turned at right angles to the body of the bar, and inserted in holes and trenches cut in the upper sides of adjacent stones to hold them together (see Coping).



HOUSE IN WASHINGTON, D. C.
Wood, Donn & Deming, Architects, Washington, D. C.
Doric Colonial Front.

Cutwater or Starling: The projecting ends of a bridge-pier, etc., usually so shaped as to allow water, ice, etc., to strike them with but little injury.

Dowels: Straight bars of iron, copper, or stone which are placed in holes cut in the upper bed of one stone and in the lower bed of the next stone above. They are also placed horizontally in the adjacent ends of coping stones (see under Coping). Cramps and dowels are fastened in place by pouring melted lead, sulphur, or cement grout around them.

Dry Stone Walls may be of any of the classes of masonry previously described, with the single exception that the mortar is omitted. They should be built according to the principles laid down for the class to which they belong.

Face: The front surface of the wall.

Facing: The stone which forms the face or outside of the wall exposed to view.

Footing: The projecting courses at the base of a wall for the purpose of distributing the weight over an increased area, and thereby diminishing the liability to vertical settlement from compression of the ground.

Footings, to have any useful effect, must be securely bonded into the body of the work, and have sufficient strength to resist the cross strains to which they are exposed. The beds should be dressed true and parallel. Too much care cannot be bestowed upon the footing courses of any building, as upon them depends much of the stability of the work. If the bottom course be not solidly bedded, if any rents or vacuities are left in the beds of the masonry, or if the materials be unsound or badly put together, the effects of such carelessness will show themselves sooner or later, and always at a period when remedial efforts are useless.

Gauged Work: Bricks cut and rubbed to the exact shape required.

Grout is a thin or fluid mortar made in the proportion of 1 of cement to 1 or 2 of sand. It is used to fill up the voids in walls of rubble masonry and brick. Sometimes the interior of a wall is built up dry and grout poured in to fill the voids. Unless specifically instructed to permit its use, grout should not be used unless in the presence of the inspector. When used by masons without instructions it is usually for the purpose of concealing bad work. Grout is used for solidifying quicksand.

Grouting is pouring fluid mortar over last course for the purpose of filling all vacuities.

Header. Also called a bond. A stone or brick whose greatest dimension lies perpendicular to the face of the wall, and used for the purpose of tying the face to the backing (see Bond). A trick of masons is to use "blind headers," or short stones that look like headers on the face, but do not go deeper into the wall than the adjacent stretchers. When a course has been put on top of these they are completely covered up, and, if not suspected, the fraud will never be discovered unless the weakness of the wall reveals it.

In facing brick walls with pressed brick the bricklayer will frequently cut the headers for the purpose of economizing the more expensive material; thus great watchfulness is necessary to secure a good bond between the facing and common brick. "All stone foundation walls 24 inches or less in thickness shall have at least one header extending through the wall in every 3 feet in height from the bottom of the wall, and in every 3 feet in length, and if over 24 inches in thickness shall have one header for every 6 superficial feet on both sides of the wall, and running into the wall at least 2 feet. All headers shall be at least 12 inches in width and 8 inches in thickness, and consist of good, flat stone.

"In all brick walls every sixth course shall be a heading course, except where walls are faced with brick in running bond, in which latter case every sixth course shall be bonded into the backing by cutting the course of the face brick and putting in diagonal headers behind the same, or by splitting the face brick in half and backing the same with a continuous row of headers."

Joints. The mortar layers between the stone or bricks are called the joints. The horizontal joints are called "bed joints;" the end joints are called the vertical joints, or simply the "joints."

Excessively thick joints should be avoided. In good brickwork they should be about $\frac{1}{4}$ to $\frac{3}{8}$ inch thick; for ashlar masonry and pressed brickwork, about $\frac{1}{8}$ to $\frac{1}{16}$ inch thick; for rubble masonry they vary according to the character of the work.

The joints of both stone and brick masonry are finished in different ways, with the object of presenting a neat appearance and of throwing the rainwater away from the joint.

Flush Joints. In these the mortar is pressed flat with the trowel and the surface of the joint is flush with the face of the wall.

Struck Joints are formed by pressing or striking back with the trowel the upper portion of the joint while the mortar is moist, so as to form an outward sloping surface from the bottom of the upper course to the top of the lower course. This joint is also designated by the name "weather joint." Masons generally form this joint so that it slopes inwards, thus leaving the upper arris of the lower course bare and exposed to the action of the weather. The reason for forming it in this improper manner is that it is easier to perform.

Key Joints are formed by drawing a curved iron key or jointer along the center of the flushed joint, pressing it hard, so that the mortar is driven in beyond the face of the wall; a groove of curved section is thus formed, having its surface hardened by the pressure.

White Skate or Groove Joint is employed in front brickwork. It is about $\frac{3}{16}$-inch thick. It is formed with a jointer having the width of the intended joint. It is guided along the joint by a straight edge and leaves its impress upon the material.

Joggle: A joint piece or dowel pin let into adjacent faces of two stones to hold them in position. It may vary in form and approach in its shape either the dowel or clamp.

Jamb: The sides of an opening left in a wall.

Lintel: The stone, wood, or iron beam used to cover a narrow opening in a wall.

One-Man Stone: A stone of such size as to be readily lifted by one man.

Parapet Wall is a low wall running along the edge of a terrace or roof to prevent people from falling over.

Pointing a piece of masonry consists in scraping out the mortar in which the stones were laid from the face of the joints for a depth of from $\frac{1}{2}$ to 2 inches, and filling the groove so made with clear Portland-cement mortar, or with mortar made of 1 part of cement and 1 part of sand.

The object of pointing is that the exposed edges of the joints are always deficient in density and hardness, and the mortar near the surface of the joint is specially subject to dislodgment, since the contraction and expansion of the masonry are liable either to separate the stone from the mortar or to crack the mortar in the joint, thus permitting the entrance of rainwater, which freezing forces the mortar from the joints.

The pointing mortar, when ready for use, should be rather incoherent and quite deficient in plasticity.

Before applying the pointing, the joint must be well cleansed by scraping and brushing out the loose matter, then thoroughly saturated with water, and maintained in such a condition of dampness that the stones will neither absorb water from the mortar nor impart any to it. Walls should not be allowed to dry too rapidly after pointing.

Pointing should not be prosecuted either during freezing or excessively hot weather.

The pointing mortar is applied with a mason's trowel, and the joint well calked with a calking iron and hammer. In the very best work the surface of the mortar is rubbed smooth with a steel polishing tool. The form given to the finish joint is the same as described under joints.

Pointing with colored mortar is frequently employed to improve the appearance of the work. Various colors are used, as white, black, red, brown, etc., different colored pigments being added to the mortar to produce the required color.

Tuck Pointing, used chiefly for brickwork, consists of a projecting ridge with the edges neatly pared to an uniform breadth of about $\frac{1}{8}$-inch. White mortar is usually employed for this class of pointing.

Many authorities consider that pointing is not advisable for new work, as the joints so formed are not as enduring as those which are finished at the time the masonry is built. Pointing is, moreover, often resorted to when it is intended to give the work a superior appearance, and also to conceal defects in inferior work.

Pallets, Plugs: Wooden bricks inserted in walls for fastening trim, etc.

Plinth: A projecting base to a wall; also called "water table."

Pitched-Face Masonry: That in which the face of the stone is roughly dressed with the pitching chisel so as to give edges that are approximately true.

Quarry-Faced or Rock-Faced Masonry: That in which the face of the stone is left untouched as it comes from the quarry.

Quoin: A cornerstone. A quoin is a header for one face and a stretcher for the other.

Rip-Rap. Rip-rap is composed of rough undressed stone as it comes from the quarry, laid dry about the base of piers, abutments, slopes of embankments, etc., to prevent scour and wash. When used for the protection of piers the stones are dumped in promiscuously, their size depending upon the material and the velocity of the current. Stones of 15 to 25 cubic feet are frequently employed. When used for the protection of banks the stones are laid by hand to a uniform thickness.

Rise: That dimension of a stone which is perpendicular to its quarry bed (see Build).

Retaining Wall or Revetment: A wall built to retain earth deposited behind it (see Breast Wall).

Reveal: The exposed portion of the sides of openings in walls in front of the recesses for doors, window frames, etc.

Slope-Wall Masonry: A slope wall is a thin layer of masonry used to protect the slopes of embankments, excavations, canals, river banks, etc., from rain, waves, weather, etc.

Slips: See Wood Bricks.

Spall: A piece of stone chipped off by the stroke of a hammer.

Sill: The stone, iron, or wood on which the window or door of a building rests. In setting stone sills the mason beds the ends only; the middle is pointed up after the building is enclosed. They should be set perfectly level lengthwise, and have an inclination crosswise, so the water may flow from the frame.

Stone Paving consists of roughly squared or unsquared blocks of stone used for paving the waterway of culverts, etc.; it is laid both dry and in mortar.

Starling: See Cutwater.

Stretcher: A stone or brick whose greatest dimension lies parallel to the face of the wall.

String Course: A horizontal course of brick or stone masonry projecting a little beyond the face of the wall. Usually introduced for ornament.

Two-Men Stone: Stone of such size as to be conveniently lifted by two men.

Toothing: Unfinished brickwork so arranged that every alternate brick projects half its length.

Water-Table: See Plinth.

Wood Bricks, Pallets, Plugs, or Slips are pieces of wood laid in a wall in order the better to secure any woodwork that it may be necessary to fasten to it. Great injury is often done to walls by driving wood plugs into the joints, as they are apt to shake the work. Hollow porous terra-cotta bricks are frequently used instead of wood bricks, etc.

PREPARATION OF THE MATERIALS.

STONE CUTTING.

Dressing the Stones. The stonecutter examines the rough blocks as they come from the quarry in order to determine whether the blocks will work to better advantage as a header, a stretcher, or a cornerstone. Having decided for which purpose the stone is suited, he prepares to dress the bottom bed. The stone is placed with bottom bed up, all the rough projections are removed with the hammer and pitching tool, and approximately straight lines are pitched off around its edges; then a chisel draft is cut on all the edges. These drafts are brought to the same plane as nearly as practicable by the use of two straight edges having parallel sides and equal widths, and the enclosed rough portion is then dressed down with the pitching tool or point to the plane of the drafts. The entire bed is then pointed down to a surface true to the straight edge when applied in any direction—crosswise, lengthwise, and diagonally.

Lines are then marked on this dressed surface parallel and perpendicular to the face of the stone, enclosing as large a rectangle as the stone will admit of being worked to, or of such dimensions as may be directed by the plan.

The faces and sides are pitched off to these lines. A chisel draft is then cut along all four edges of the face, and the face either dressed as required, or left rock faced. The sides are then pointed down to true surfaces at right angles to the bed. The stone is turned over bottom bed down, and the top bed dressed in the same manner as the bottom. It is important that the top bed be exactly parallel to the bottom bed in order that the stone may be of uniform thickness.

Stones having the beds inclined to each other, as skewbacks, or stones having the sides inclined to the beds, are dressed by using a bevelled straight edge set to the required inclination.

Arch stones have two plane surfaces inclined to each other; these are called the beds. The upper surface or extrados is usually left rough; the lower surface or intrados is cut to the curve of the arch. This surface and the beds are cut true by the use of a wooden or metal templet which is made according to the drawings furnished by the engineer or architect.

TOOLS USED IN STONE CUTTING.

The Double-Face Hammer is a heavy tool, weighing from 20 to 30 pounds, used for roughly shaping stones as they come from the quarry and for knocking off projections. This is used for only the roughest work.

The Face Hammer has one blunt and one cutting end, and is used for the same purpose as the double-face hammer where less weight is required. The cutting end is used for roughly squaring stones preparatory to the use of the finer tools.

The Cavil has one blunt and one pyramidal or pointed end, and weighs from 15 to 20 pounds. It is used in quarries for roughly shaping stone for transportation.

The Pick somewhat resembles the pick used in digging, and is used for rough dressing, mostly on limestone and sandstone. Its length varies from 15 to 24 inches, the thickness at the eye being about 2 inches.

The Axe or Pean Hammer has two opposite cutting edges. It is used for making drafts around the arris or edge of stones, and in reducing faces, and sometimes joints, to a level. Its length is about 10 inches and the cutting edge about 4 inches. It is used after the point and before the patent hammer.

The Tooth Axe is like the axe, except that its cutting edges are divided into teeth, the number of which varies with the kind of work required. This tool is not used in cutting granite or gneiss.

The Bush Hammer is a square prism of steel, whose ends are cut into a number of pyramidal points. The length of the hammer is from 4 to 8 inches and the cutting face from 2 to 4 inches square. The points vary in number and in size with the work to be done. One end is sometimes made with a cutting edge like that of the axe.

The Crandall is a malleable-iron bar about 2 feet long slightly flattened at one end. In this end is a slot 3 inches long and $\frac{3}{8}$-inch wide. Through this slot are passed ten double-headed points of $\frac{1}{4}$-inch square steel 9 inches long, which are held in place by a key.

The Patent Hammer is a double-headed tool so formed as to hold at each end a set of wide thin chisels. The tool is in two parts, which are held together by the bolts which hold the chisels. Lateral motion is prevented by four guards on one of the pieces. The tool without the teeth is $5\frac{1}{2} \times 2\frac{3}{4} \times 1\frac{1}{2}$ inches. The teeth are $2\frac{3}{4}$ inches wide; their thickness varies from $\frac{1}{12}$ to $\frac{1}{6}$ of an inch. This tool is used for giving a finish to the surface of stones.

The Hand Hammer, weighing from 2 to 5 pounds, is used in drilling holes and in pointing and chiselling the harder rocks.

The Mallet is used where the softer limestones and sandstones are cut.

The Pitching Chisel is usually of $1\frac{1}{8}$-inch octagonal steel, spread on the cutting edge to a rectangle of $\frac{1}{8} \times 2\frac{1}{2}$ inches. It is used to make a well-defined edge to the face of a stone, a line being marked on the joint surface, to which the chisel is applied and the portion of the stone outside of the line broken off by a blow with the hand hammer on the head of the chisel.

The Point is made of round or octagonal steel from $\frac{1}{4}$ to 1 inch in diameter. It is made about 12 inches long, with one end brought to a point. It is used until its length is reduced to about 5 inches. It is employed for dressing off the irregular surface of stones, either for a permanent finish or preparatory to the use of the axe. According to the hardness of the stone, either the hand hammer or the mallet is used with it.

The Chisel is of round steel of $\frac{1}{4}$ to $\frac{3}{4}$-inch diameter and about 10 inches long, with one end brought to a cutting edge from $\frac{1}{4}$ inch to 2 inches wide; is used for cutting drafts or margins on the face of stones.

The Tooth Chisel is the same as the chisel, except that the cutting edge is divided into teeth. It is used only on marbles and sandstones.

The Splitting Chisel is used chiefly on the softer stratified stones, and sometimes on fine architectural carvings in granite.

The Plug, a truncated wedge of steel, and the *feathers* of half-round malleable iron, are used for splitting unstratified stone. A row of holes is made with the drill on the line on which the fracture is to be made; in each of these two feathers are inserted, and the plugs lightly driven in between them. The plugs are then gradually driven home by light blows of the hand hammer on each in succession until the stone splits.

Machine Tools. In all large stone yards machines are used to prepare the stone. There is a great variety in their form, but since the kind of dressing never takes its name from the machine which forms it, it will be neither necessary nor profitable to attempt a description of individual machines. They include stone saws, stone cutters, stone grinders, stone polishers, etc.

DEFINITION OF TERMS USED IN STONE CUTTING.

Axed : Dressed to a plane surface with an axe.

Boasted or Chiselled : Having face wrought with a chisel or narrow tool.

Broached : Dressed with a "punch" after being droved.

Bush Hammered : Dressed with a bush hammer.

Crandalled : Wrought to a plane with a crandall.

Deadening : The crushing or crumbling of a soft stone under the tools while being dressed.

Dressed Work : That which is wrought on the face; also applied to stones having the joints wrought to a plane surface, but not "squared."

Drafted : Having a narrow chisel draft cut around the face or margin.

Droved, Stroked : Wrought with a broad chisel or hammer in parallel flutings across the stone from end to end.

Hammer Dressed : Worked with the hammer.

Herring Bone : Dressed in angular flutings.

Nigged or Nidged : Picked with a pointed hammer or cavil to the desired form.

Patent Hammered : Dressed with a patent hammer.

Picked : Reduced to an approximate plane with a pick.

Pitched : Dressed to the neat lines or edges with a pitching chisel.

Plain : Rubbed smooth to remove tool marks.

Pointed : Dressed with a point or very narrow tool.

Polished : Rubbed down to a reflecting surface.

Prison: Having surfaces wrought into holes.

Random Tooled or Droved: Cut with a broad tool into irregular flutings.

Rock Faced, Quarry Faced, Rough: Left as it comes from the quarry. It may be drafted or pitched to reduce projecting points on the face to give limits.

Rubbed: See Plain.

Rustic, Rusticated: Having the faces of stones projecting beyond the arrises, which are bevelled or drafted. The face may be dressed in any desired manner.

Scabble: To dress off the angular projections of stones for rubble masonry with a stone axe or hammer.

Smooth: See Plain.

Square Droved: Having the flutings perpendicular to the lower edge of the stone.

Striped: Wrought into parallel grooves with a point or punch.

Stroked: See Droved.

Tooled: Wrought to a plane with an inch tool. See Droved.

Toothed: Dressed with a tooth chisel.

Vermiculated Worm Work: Wrought into veins by cutting away portions of the face.

METHODS OF FINISHING THE FACES OF CUT STONE.

In architecture there are a great many ways in which the faces of cut stone may be dressed, but the following are those that will be usually met in engineering work.

Rough Pointed. When it is necessary to remove an inch or more from the face of a stone it is done by the pick or heavy point until the projections vary from $\frac{1}{2}$ to 1 inch. The stone is said to be rough pointed. In dressing limestone and granite this operation precedes all others.

Fine Pointed. If a smoother finish is desired rough pointing is followed by fine pointing, which is done with a fine point. Fine pointing is used only where the finish made by it is to be final, and never as a preparation for a final finish by another tool.

Crandalled. This is only a speedy method of pointing, the effect being the same as fine pointing, except that the dots on the stone are more regular. The variations of level are about $\frac{1}{8}$ inch and the rows are made parallel. When other rows at right angles to the first are introduced the stone is said to be cross-crandalled.

Axed or Pean Hammered, and Patent Hammered. These two vary only in the degree of smoothness of the surface which is produced. The number of blades in a patent hammer varies from 6 to 12 to the inch; and in precise specifications the number of cuts to the inch must be stated, such as 6-cut, 8-cut, 10-cut, 12-cut. The

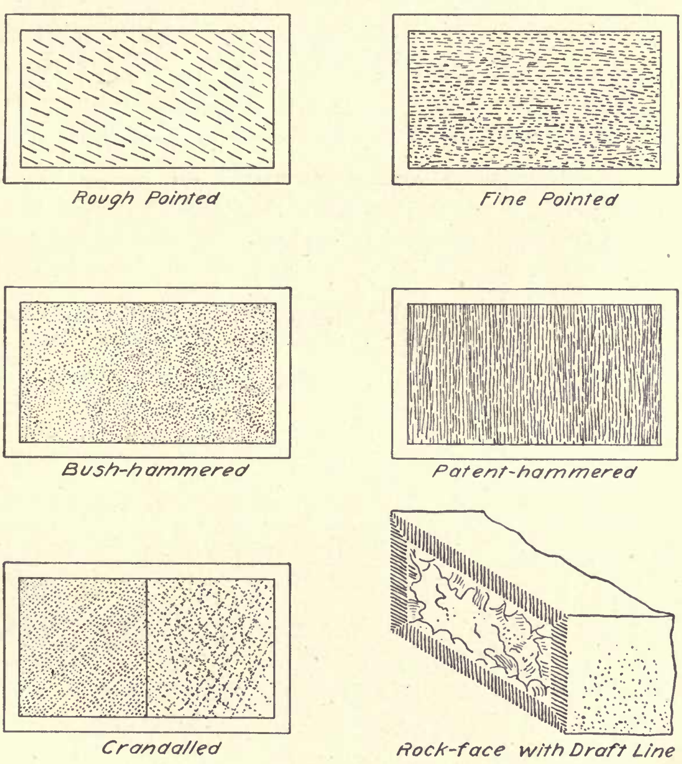


Fig. 19. Methods of Finishing the Faces of Cut Stone.

effect of axing is to cover the surface with chisel marks, which are made parallel as far as practicable. Axing is a final finish.

Tooth Axed. The tooth axe is practically a number of points, and it leaves the surface of a stone in the same condition as fine pointing. It is usually, however, only a preparation for bush hammering, and the work is then done without regard to effect, so long as the surface of the stone is sufficiently levelled.

Bush Hammered. The roughnesses of a stone are pounded off by the bush hammer, and the stone is then said to be "bushed." This kind of finish is dangerous on sandstone, as experience has shown that sandstone thus treated is very apt to scale. In dressing limestone which is to have a bush hammered finish the usual sequence of operation is (1) rough pointing, (2) tooth axing, and (3) bush hammering.

CLASSIFICATION OF THE STONES.

All the stones used in building are divided into three classes according to the finish of the surface, viz.: 1. Rough stones that are used as they come from the quarry. 2. Stones roughly squared and dressed. 3. Stones accurately squared and finely dressed.

Unsquared Stones. This class covers all stones which are used as they come from the quarry without other preparation than the removal of very acute angles and excessive projections from the general figure.

Squared Stones. This class covers all stones that are roughly squared and roughly dressed on beds and joints. The dressing is usually done with the face hammer or axe, or in soft stones with the tooth hammer. In gneiss, hard limestones, etc., it may be necessary to use the point. The distinction between this class and the third lies in the degree of closeness of the joints. Where the dressing on the joints is such that the distance between the general planes of the surfaces of adjoining stones is one-half inch or more, the stones properly belong to this class.

Three subdivisions of this class may be made, depending on the character of the face of the stones.

(*a*) *Quarry-faced* or *Rock-faced* stones are those whose faces are left untouched as they come from the quarry.

(*b*) *Pitched-faced* stones are those on which the arris is clearly defined by a line beyond which the rock is cut away by the pitching chisel, so as to give edges that are approximately true.

(*c*) *Drafted* stones are those on which the face is surrounded by a chisel draft, the space inside the draft being left rough. Ordinarily, however, this is done only on stones in which the cutting of the joints is such as to exclude them from this class.

In ordering stones of this class the specifications should always state the width of the bed and end joints which are expected, and also how far the surface of the face may project beyond the plane of the edge. In practice the projection varies between 1 inch and 6 inches. It should also be specified whether or not the faces are to be drafted.

Cut Stones. This class covers all squared stones with smoothly dressed beds and joints. As a rule, all the edges of cut stones are drafted, and between the drafts the stone is smoothly dressed. The face, however, is often left rough where construction is massive. The stones of this class are frequently termed "dimension" stone or "dimension" work.

ASHLAR MASONRY.

Ashlar masonry consists of blocks of stone cut to regular figures, generally rectangular, and built in courses of uniform height or rise, which is seldom less than a foot.

Size of the Stones. In order that the stones may not be liable to be broken across, no stone of a soft material, such as the weaker kinds of sandstone and granular limestone, should have a length greater than 3 times its depth or rise; in harder materials the length may be 4 to 5 times the depth. The breadth in soft materials, may range from $1\frac{1}{2}$ to double the depth; in hard materials it may be 3 times the depth.

Laying the Stone. The bed on which the stone is to be laid should be thoroughly cleansed from dust and well moistened with water. A thin bed of mortar should then be spread evenly over it, and the stone, the lower bed of which has been cleaned and moistened, raised into position, and lowered first upon one or two strips of wood laid upon the mortar bed; then, by the aid of the pinch bar, moved exactly into its place, truly plumbed, the strips of wood removed, and the stone settled in its place and levelled by striking it with wooden mallets. In using bars and rollers in handling cut stone, the mason must be careful to protect the stone from injury by a piece of old bagging, carpet, etc.

In laying "rock-faced" work, the line should be carried above it, and care must be taken that the work is kept plumb with the cut margins of the corners and angles.

The Thickness of Mortar in the joints of well executed ashlar masonry should be about $\frac{1}{8}$ of an inch, but it is usually about $\frac{3}{8}$.

Amount of Mortar. The amount of mortar required for ashlar masonry varies with the size of the blocks, and also with the closeness of the dressing. With $\frac{3}{8}$ to $\frac{1}{2}$-inch joints and 12 to 20-inch courses will be about 2 cubic feet of mortar per cubic yard; with larger blocks and closer joints, there will be about 1 cubic foot of mortar per yard of masonry. Laid in 1 to 2 mortar, ordinary ashlar will require $\frac{1}{4}$ to $\frac{1}{3}$ of a barrel of cement per cubic yard of masonry.

Bond of Ashlar Masonry. No side joint in any course should be directly above a side joint in the course below; but the stones should overlap or break joint to an extent of from once to once and a half the depth or rise of the course. This is called the bond of the masonry; its effect is to cause each stone to be supported by at least two stones of the course below, and assist in supporting at least two stones of the course above; and its objects are twofold: first, to distribute the pressure, so that inequalities of load on the upper part of the structure, or of resistance at the foundation, may be transmitted to and spread over an increasing area of bed in proceeding downwards or upwards, as the case may be; and second, to tie the structure together, or give it a sort of tenacity, both lengthwise and from face to back, by means of the friction of the stones where they overlap. The strongest bond in ashlar masonry is that in which each course at the face of the wall contains a header and a stretcher alternately, the outer end of each header resting on the middle of a stretcher of the course below, so that rather more than one-third of the area of the face consists of ends of headers. This proportion may be deviated from when circumstances require it; but in every case it is advisable that the ends of headers should not form less than one-fourth of the whole area of the face of the wall.

SQUARED-STONE MASONRY.

The distinction between squared-stone masonry and ashlar lies in the character of the dressing and the closeness of the joints. In this class of masonry the stones are roughly squared and roughly dressed on beds and joints, so that the width of the joints is half an inch or more. The same rules apply to breaking joint, and to the proportions which the lengths and breadths of the stones should bear to their depths, as in ashlar; and as in ashlar, also, at least one-fourth of the face should consist of headers, whose length should be from three to five times the depth of the course.

Amount of Mortar. The amount of mortar required for squared-stone masonry varies with the size of the stones and with the quality of the masonry; as a rough average, one-sixth to one-quarter of the mass is mortar. When laid in 1 to 2 mortar, from $\frac{1}{2}$ to $\frac{3}{4}$ of a barrel of cement will be required per cubic yard of masonry.

BROKEN ASHLAR.

Broken ashlar consists of cut stones of unequal depths, laid in the wall without any attempt at maintaining courses of equal rise, or the stones in the same course of equal depth. The character of the dressing and closeness of the joints may be the same as in ashlar or squared-stone masonry, depending upon the quality desired. The same rules apply to breaking joint, and to the proportions which the lengths and breadths of the stones should bear to their depths, as in ashlar; and as in ashlar, also, at least one-fourth of the face of the wall should consist of headers.

Amount of Mortar. The amount of mortar required when laid in 1 to 2 mortar, will be from $\frac{3}{4}$ to 1 barrel per cubic yard of masonry, depending upon the closeness of the joints.

RUBBLE MASONRY.

Masonry composed of unsquared stones is called rubble. This class of masonry covers a wide range of construction, from the commonest kind of dry-stone work to a class of work composed of large stones laid in mortar. It comprises two classes: (1) uncoursed rubble, in which irregular-shaped stones are laid without any attempt at regular courses, and (2) coursed rubble, in which the blocks of unsquared stones are levelled off at specified heights to an approximately horizontal surface. Coursed rubble is often built in random courses; that is to say, each course rests on a plane bed, but is not necessarily of the same depth or at the same level throughout, so that the beds occasionally rise or fall by steps. Sometimes it is required that the stone shall be roughly shaped with the hammer.

In building rubble masonry of any of the classes above mentioned the stone should be prepared by knocking off all the weak angles of the block. It should be cleansed from dust, etc., and moistened before being placed on its bed. Each stone should be firmly imbedded in the mortar. Care should be taken not only that each stone shall rest on its natural bed, but that the sides parallel to that natural bed shall be the largest, so that the stone may lie flat, and not be set on edge or on end. However small and irregular the stones, care should be taken to break joints. Side joints should not form an angle with the bed joint sharper than 60°. The hollows or interstices between the larger stones must be filled with smaller stones and carefully bedded in mortar.

One-fourth part at least of the face of the wall should consist of bond stones extending into the wall a length of at least 3 to 5 times their depth, as in ashlar.

Amount of Mortar. If rubble masonry is composed of small and irregular stones, about $\frac{1}{3}$ of the mass will consist of mortar; if the stones are larger and more regular $\frac{1}{6}$ to $\frac{1}{4}$ will be mortar. Laid in 1 to 2 mortar, ordinary rubble requires from $\frac{1}{2}$ to 1 barrel of cement per cubic yard of masonry.

ASHLAR BACKED WITH RUBBLE.

In this class of masonry the stones of the ashlar face should have their beds and joints accurately squared and dressed with the hammer or the points, according to the quality desired, for a breadth of from once to twice (or on an average, once and a half), the depth or rise of the course, inwards from the face; but the backs of these stones may be rough. The proportion and length of the headers should be the same as in ashlar, and the "tails" of these headers, or parts which extend into the rubble backing, may be left rough at the back and sides; but their upper and lower beds should be hammer dressed to the general plane of the beds of the course. These tails may taper slightly in breadth, but should not taper in depth.

The rubble backing, built in the manner described under Rubble Masonry, should be carried up at the same time with the face work, and in courses of the same rise, the bed of each course being carefully formed to the same plane with that of the facing.

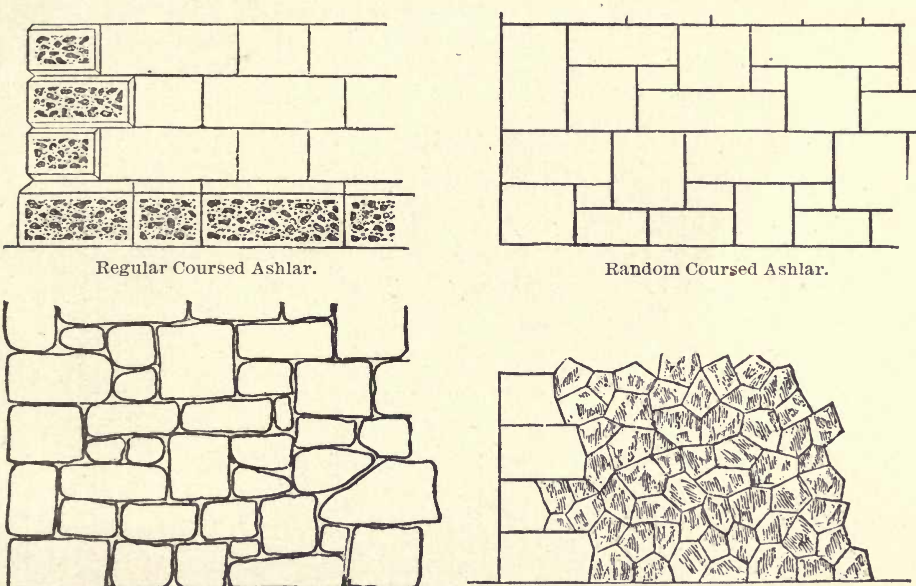
GENERAL RULES FOR LAYING ALL CLASSES OF STONE MASONRY.

1. Build the masonry, as far as possible, in a series of courses, perpendicular, or as nearly so as possible, to the direction of the pressure which they have to bear, and by breaking joints avoid all long continuous joints parallel to that pressure.

2. Use the largest stones for the foundation course.

3. Lay all stones which consist of layers in such a manner that the principal pressure which they have to bear shall act in a direction perpendicular, or as nearly so as possible, to the direction of the layers. This is called laying the stone on its natural bed, and is of primary importance for strength and durability.

4. Moisten the surface of dry and porous stones before bedding them, in order that the mortar may not be dried too fast and reduced



Regular Coursed Ashlar. Random Coursed Ashlar.

A

Rubble, Undressed, Laid at Random. Random Rubble with Hammer-Dressed Joints and no Spalls on Face.

Fig. 20. Types of Masonry.

to powder by the stone absorbing its moisture.

5. Fill every part of every joint and all spaces between the stones with mortar, taking care at the same time that such spaces shall be as small as possible.

6. The rougher the stones, the better the mortar should be. The principal object of the mortar is to equalize the pressure; and the more nearly the stones are dressed to closely fitting surfaces, the less important is the mortar. Not infrequently this rule is exactly reversed; *i.e.*, the finer the dressing the better the quality of the mortar used.

All projecting courses, such as sills, lintels, etc., should be covered with boards, bagging, etc., as the work progresses, to protect them from injury and mortar stains.

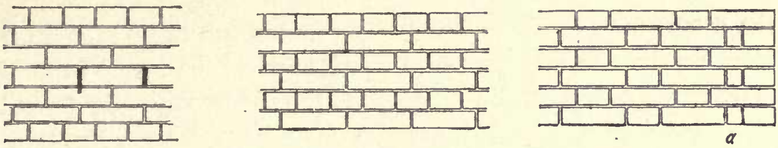
When setting cut stone a pailful of clean water should be kept at hand, and when any fresh mortar comes in contact with the face of the work it should be immediately washed off.

GENERAL RULES FOR BUILDING BRICK MASONRY.

1. Reject all misshapen and unsound bricks.
2. Cleanse the surface of each brick, and wet it thoroughly before laying it, in order that it may not absorb the moisture of the mortar too quickly.
3. Place the beds of the courses perpendicular, or as nearly perpendicular as possible, to the direction of the pressure which they have to bear; and make the bricks in each course break joint with those of the courses above and below by overlapping to the extent of from one-quarter to one-half of the length of a brick. (For the style of bond used in brick masonry, see under Bond in list of definitions.)
4. Fill every joint thoroughly with mortar.

Brick should not be merely laid, but every one should be rubbed and pressed down in such a manner as to force the mortar into the pores of the bricks and produce the maximum adhesion; with quick-setting cement, this is still more important than with lime mortar. For the best work it is specified that the brick shall be laid with a "shove joint," that is, that the brick shall first be laid so as to project over the one below, and be pressed into the mortar, and then be shoved into its final position.

Bricks should be laid in full beds of mortar, filling end and side joints in one operation. This operation is simple and easy with skilful masons—if they will do it—but it requires persistence to get it accomplished. Masons have a habit of laying brick in a bed of mortar, leaving the vertical joints to take care of themselves, throwing a little mortar over the top beds and giving a sweep with the trowel which more or less disguises the open joint below. They also have a way after mortar has been sufficiently applied to the top bed of brick to draw the point of their trowel through it, making an open channel with only a sharp ridge of mortar on each side (and generally throwing some of it overboard), so that if the succeeding brick is taken up it will show a clear hollow, free from mortar through the bed. This enables them to bed the next brick with more facility and avoid pressure upon it to obtain the requisite thickness of joint.



Common Bond. English Bond. Flemish Bond.

Fig. 21. Bond Used in Brick Masonry.

With ordinary interior work a common practice is to lay brick with $\frac{1}{2}$ and $\frac{3}{4}$-inch mortar joints; an inspector whose duty is to keep joints down to $\frac{1}{4}$ or $\frac{3}{8}$ inch will not have an enviable task.

Neglect in wetting the brick before use is the cause of most of the failures of brickwork. Bricks have a great avidity for water, and if the mortar is stiff and the bricks dry, they will absorb the water so rapidly that the mortar will not set properly, and will crumble in the fingers when dry. Mortar is sometimes made so thin that the brick will not absorb all the water. This practice is objectionable; it interferes with the setting of the mortar, and particularly with the adhesion of the mortar to the brick. Watery mortar also contracts excessively in drying (if it ever does dry), which causes undue settlement and, possibly, cracks or distortion.

The bricks should not be wetted to the point of saturation, or they will be incapable of absorbing any of the moisture from the mortar, and the adhesion between the brick and mortar will be weak.

The common method of wetting brick by throwing water from buckets or spraying with a hose over a large pile is deceptive, the water reaches a few brick on one or more sides and escapes many. Immersion of the brick for from 3 to 8 minutes, depending upon its quality, is the only sure method to avert the evil consequences of using dry or partially wetted brick.

Strict attention must be paid to have the starting course level, for the brick being of equal thickness throughout, the slightest irregularity or incorrectness in it will be carried into the superposed courses, and can only be rectified by using a greater or less quantity of mortar in one part or another, a course which is injurious to the work.

A common but improper method of building thick brick walls is to lay up the outer stretcher courses between the header courses, and then to throw mortar into the trough thus formed, making it semi-fluid by the addition of a large dose of water, then throwing in the brick (bats, sand, and rubbish are often substituted for bricks), allowing them to find their own bearing; when the trough is filled it is plastered over with stiff mortar and the header course laid and the operation repeated This practice may have some advantage in celerity in executing work, but none in strength or security.

Amount of Mortar. The thickness of the mortar joints should be about $\frac{1}{4}$ to $\frac{3}{8}$ of an inch. Thicker joints are very common, but should be avoided. If the bricks are even fairly good the mortar is the weaker part of the wall; hence the less mortar the better. Besides, a thin layer of mortar is stronger under compression than a thick one. The joints should be as thin as is consistent with their insuring a uniform bearing and allowing rapid work in spreading the mortar. The joints of outside walls should be thin in order to decrease the disintegration by weathering. The joints of inside walls are usually made from $\frac{3}{8}$ to $\frac{1}{2}$-inch thick.

The proportion of mortar to brick will vary with the size of the brick and with the thickness of the joint. With the standard brick ($8\frac{1}{4} \times 4 \times 2\frac{1}{4}$ inches), the amount of mortar required will be as follows:

Thickness of Joints.	Mortar required. Per Cubic Yard. Cubic Yards.	Per 1,000 Brick. Cubic Yards.
$\frac{1}{2}$ to $\frac{5}{8}$ inch	0.30 to 0.40	0.80 to 0.90
$\frac{1}{4}$ " $\frac{3}{8}$ "	0.20 " 0.30	0.40 " 0.60
$\frac{1}{8}$ " "	0.10 " 0.15	0.15 " 0.20

Face or Pressed Brick Work. This term is applied to the facing of walls with better bricks and thinner joints than the backing. The bricks are pressed, of various colors, and are laid in colored mortar. The bricks are laid in close joints, usually $\frac{1}{8}$-inch thick, and set with an imperceptible batter in themselves, which may not be seen when looking at the work direct, but which makes the joint a prominent feature and gives the work a good appearance. The brick of each course must be gauged with care and exactness, so that the joints may appear all alike. The bond used for the face of the wall is called the "running bond," the bricks are clipped on the back, and a binder placed transversely therein to bond the facing to the backing. The joints in the backing being thicker than those of the face work, it is only in every six or seven courses that they come to the same level, so as to permit headers being put in. This class of work requires careful watching to see that the binders or headers are put in; it frequently happens that the face work is laid up without having any bond with the backing.

In white-joint work the mortar is composed of white sand and fine lime putty. The mason when using this mortar spreads it carefully on the bed of the brick which is to be laid in such a way that when the brick is set the mortar will protrude about an inch from the face of the wall. When there are a number laid, and before the mortar becomes too hard, the mortar that protrudes is cut off flush with the wall, the joint struck downwards, and the upper and lower edges cut with a knife guided by a small straight edge. When the front is built, the whole is cleaned down with a solution of muriatic acid and water, not too strong, and sometimes oiled with linseed oil cut with turpentine, and applied with a flat brush. After the front is thoroughly cleaned with the muriatic acid solution, it should be washed with clean water to remove all remains of the acid.

When colored mortars are required, the lime and sand should be mixed at least 10 days before the colored pigments are added to it, and they should be well soaked in water before being added to the mortar.

BRICK MASONRY IMPERVIOUS TO WATER.

It sometimes becomes necessary to prevent the percolation of water through brick walls. A cheap and effective process has not yet been discovered, and many expensive trials have proved failures. Laying the bricks in asphaltic mortar and coating the walls with asphalt or coal tar are successful. "Sylvester's Process for Repelling Moisture from External Walls," has proved entirely successful. The process consists in using two washes for covering the surface of the walls, one composed of Castile soap and water, and one of alum and water. These solutions are applied alternately until the walls are made impervious to water.

EFFLORESCENCE.

Masonry, particularly in moist climates or damp places, is frequently disfigured by the formation of a white efflorescence on the surface. This deposit generally originates with the mortar. The water which is absorbed by the mortar dissolves the salts of soda, potash, magnesia, etc., contained in the lime or cement, and on evaporating deposits these salts as a white efflorescence on the surface. With lime mortar the deposit is frequently very heavy, and, usually, it is heavier with Rosendale than with Portland cement. The efflorescence sometimes originates in the brick, particularly if the brick was burned with sulphurous coal or was made from clay containing iron pyrites; and when the brick gets wet the water dissolves the sulphates of lime and magnesia, and on evaporating leaves the crystals of these salts on the surface. The crystallization of these salts within the pores of the mortar and of the brick or stone causes disintegration, and acts in many respects like frost.

The efflorescence may be entirely prevented by applying "Sylvester's" washes, composed of the same ingredients and applied in the same manner as for rendering masonry impervious to moisture. If can be much diminished by using impervious mortar for the face of the joints.

REPAIR OF MASONRY.

In effecting repairs in masonry, when new work is to be connected with old, the mortar of the old must be thoroughly cleaned off along the surface where the junction is to be made and the surface thoroughly wet. The bond and other arrangements will depend upon the circumstances of the case. The surfaces connected should be fitted as accurately as practicable, so that by using but little mortar no disunion may take place from settling.

As a rule, it is better that new work should butt against the old, either with a straight joint visible on the face, or let into a chase, sometimes called a "slip-joint," so that the straight joint may not show; but if it is necessary to bond them together the new work should be built in a quick-setting cement mortar and each part of it allowed to set before being loaded.

In pointing old masonry all the decayed mortar must be completely raked out with a hooked iron point and the surfaces well wetted before the fresh mortar is applied.

MASONRY STRUCTURES.

The component parts of masonry structures may be divided into several classes according to the efforts they sustain, their forms and dimensions depending on these efforts.

1. Those which sustain only their own weight, and are not liable to any cross strain upon the blocks of which they are composed, as the walls of enclosures.

2. Those which, besides their own weight, sustain a vertical pressure arising from a weight borne by them, as the walls of edifices, columns, the piers of arches, bridges, etc.

3. Those which sustain lateral pressures and cross strains, arising from the action of earth, water, frames, arches, etc.

4. Those which sustain a vertical upward or downward pressure, and a cross strain, as lintels, etc.

5. Those which transfer the pressure they directly receive to lateral points of support, as arches.

WALLS.

Walls are constructions of stone, brick, or other materials, and serve to retain earth or water, or in buildings to support the roof and floors and to keep out the weather. The following points should be attended to in the construction of walls:

The whole of the walling of a building should be carried up simultaneously; no part should be allowed to rise more than about 3 feet above the rest; otherwise the portion first built will settle down to its bearings before the other is attached to it, and then the settlement which takes place in the newer portion will cause a rupture, and cracks will appear in the structure. If it should be necessary to carry up one part of a wall before the other, the end of that portion first built should be *racked back,* that is, left in steps, each course projecting farther than the one above it.

Work should not be hurried along unless done in cement mortar, but given time to settle to its bearings.

Thickness of Walls. The thickness necessary to be given walls depends upon the height, length, and pressure of the load, wind, etc., and may be determined from that section of applied mechanics termed "Stability of Structures." In practice, however, these calculations are rarely made except for the most important structures, for the reason that if a vertical wall be properly constructed upon a sufficient foundation, the combined mass will retain its position, and bear pressure acting in the direction of gravity, to any extent that the ground on which it stands and the component materials will sustain. But pressure acting laterally has a tendency to overturn the wall, and therefore it must be the aim of the constructor to compel as far as possible, all forces that can act upon an upright wall to act in the direction of gravity.

In determining thickness of walls the following general principles must be recognized:

1. That the center of pressure (a vertical line through the center of gravity of the weight), shall pass through the center of the area of the foundation. If the axis of pressure does not coincide exactly with the axis of the base, the ground will yield most on the side which is pressed most; and as the ground yields, the base assumes an inclined position, and carries the lower part of the structure with it, producing cracks, if nothing more.

2. That the length of a wall is a source of weakness and that the thickness should be increased at least 4 inches for every 25 feet over 100 feet in length.

3. That high stories and clear spans exceeding 25 feet require thick walls.

4. That walls of warehouses and factories require a greater thickness than those used for dwellings or offices.

5. That walls containing openings to the extent of 33 per cent of the area should be increased in thickness.

6. That a wall should never be bonded into another wall either much heavier or lighter than itself.

In nearly all of the larger cities the minimum thickness of walls is prescribed by ordinance.

The accompanying table gives the more usual dimensions:

HEIGHT OF WALLS. Measured from the curb opposite center of building.	FOUNDATIONS. Stone.	FOUNDATIONS. Brick.	OUTSIDE AND BEARING WALLS.	REMARKS.
Not exceeding 35 feet......	20″	16″	12″ in basement, 8″ above	8″ partition walls may be built not exceeding 50 ft. in height
35 feet and not over 50 ft..	20″	16″	12″ above foundation.	
50 feet and not over 60 ft..	24″	20″	16″ in first story if level with ground, 12″ above	The height in all cases to be taken to the nearest tier of floor beams.
60 feet and not over 75 ft..	24″	20″	16″ for 25 ft. and 12″ above	
75 feet and not over 85 ft..	28″	24″	20″ for 20 ft., 16″ to 60 ft., 12″ above.	
85 feet and not over 100 ft..	32″	28″	24″ for 35 ft., 20″ to 75 ft., 16″ above.	Non-bearing walls may be 4″ less in thickness, but not less than 12″.
100 feet and not over 115 ft..	36″	32″	28″ for 25 ft., 24″ to 50 ft., 20″ to 90 ft., 16″ above.	

Walls exceeding 115 feet in height to be increased at the bottom 4″ for every additional 25 ft. in height or part thereof, the upper 115 feet remaining the same as specified for walls of that height.

WALLS FOR WAREHOUSES.

Not exceeding 40 feet......	20″	16″	12 inches.	If there is to be a clear span of over 25 ft. between walls, the bearing walls shall be 4″ more in thickness than here specified for every 12½ ft. or fraction thereof, that said walls are more than 25 ft. apart.
40 feet and not over 60 ft..	24″	20″	16″ for 40 ft., 12″ above.	
60 feet and not over 75 ft..	28″	24″	20″ for 25 ft., 16″ above.	
75 feet and not over 85 ft..	32″	28″	24″ for 25 ft., 20″ to 60 ft., 16″ above.	
85 feet and not over 100 ft..	36″	32″	28″ for 25 ft., 24″ to 50 ft., 20″ to 75 ft., 16″ above.	

Walls exceeding 100 feet in height to be increased at the bottom 4″ for every additional 25 feet in height or part thereof, the upper 100 feet remaining the same as specified for walls of that height.

RETAINING WALLS.

A retaining wall is a wall built for the purpose of "retaining" or holding up earth or water. In engineering practice such walls attain frequently large proportions, being used in the construction of railroads, docks, waterworks, etc.

The form of cross-section varies considerably according to circumstances, and often according to the fancy of the designer. The

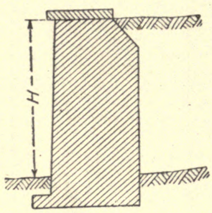


Fig. 22.

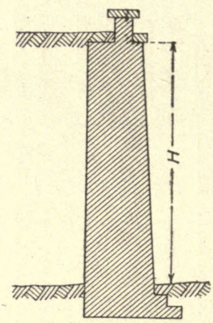


Fig. 23.

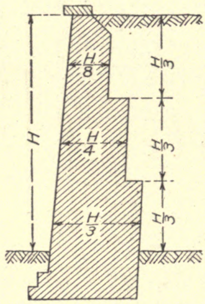


Fig. 24.

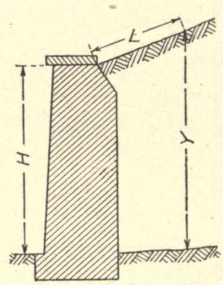


Fig. 25.

more usual forms are shown in Figs. 22 to 25. The triangular section is the one which is theoretically the most economical, and the nearer that practical consideration will allow of its being conformed to the better.

All other tnings being equal, the greater the face batter the greater will be the stability of the wall; but considerations connected with the functions of the wall limit the full application of this condition, and walls are usually constructed with only a moderate batter on the face, the diminution towards the top being obtained by a back batter worked out in a series of offsets. Walls so designed contain no more material and present greater resistance to overturning than walls with vertical backs.

Dry stone retaining walls are best suited for roads on account of their self-draining properties and their cheapness. If these dry walls are properly filled in behind with stones and chips, they are, if well constructed, seldom injured or overthrown by pressure from behind. If the stone is stratified with a flat cleavage, the construction of retaining and parapet walls is much facilitated. If the stone has no natural cleavage, great care is necessary to obtain a proper bond. If walls built of such stone are of coursed rubble, care is required that the masons do not sacrifice the strength of the walls to the face appearance. The practice of building walls with square or rectangular-faced stones, tailing off behind, laid in rows, one course upon the other, the rear portions of the walls being of chips and rough stones, set anyhow, cannot be condemned too strongly. Such a construction, which is very common, has little transverse and no longitudinal strength.

Little or no earth should be used for back filling if stone is available. Where earth filling is used, it should only be thrown in and left to settle itself; on no account should it be wetted and rammed.

Thickness of Walls. Retaining walls require a certain thickness to enable them to resist being overthrown by the thrust of the material which they sustain. The amount of this thrust depends upon the height of the mass to be supported and upon the quality of the material.

Surcharged Walls. A retaining wall is said to be surcharged when the bank it retains slopes backwards to a higher level than the top of the wall; the slope of the bank may be either equal to or less, but cannot be greater, than the angle of repose of the earth of the bank.

Proportions of Retaining Walls. In determining the proportions of retaining walls experience, rather than theory, must be our guide. The proportions will depend upon the character of the material to be retained. If the material be stratified rock with interposed beds of clay, earth, or sand, and if the strata incline toward the wall, it may require to be of far greater thickness than any ordinary retaining wall; because when the thin seams of earth become softened by infiltrating rain, they act as lubricants, like soap or tallow, to facilitate the sliding of the rock strata; and thus bring an enormous pressure against the wall. Or the rock may be set in motion by the action of frost on the clay seams. Even if there be no rock, still if the strata of soil dip toward the wall, there will always be danger of a similar result; and additional precautions must be adopted, especially when the strata reach to a much greater height than the wall.

The foundation of retaining walls should be particularly secure; the majority of failures which have occurred in such walls have been due to defective foundations.

Failure of Retaining Walls. Retaining walls generally fail (1) by overturning or by sliding, or (2) by bulging out of the body of the masonry. Sliding may be prevented by inclining the courses inward. An objection to this inclination of the joints in dry walls is that rainwater, falling on the battered face, is thereby carried inwards to the earth backing, which thus becomes soft and settles. This objection may be overcome by using mortar in the face joints to the depth of a foot, or by making the face of the wall nearly vertical.

Protection of Retaining Walls. The top of the walls should be protected with a coping of large heavy stones laid as headers.

Where springs occur behind or below the wall, they must be carried away by piping or otherwise got rid of.

The back of the wall should be left as rough as possible, so as to increase the friction of the earth against it.

Weep Holes. In masonry walls, weep holes must be left at frequent intervals, in very wet localities as close as 4 feet, so as to permit the free escape of any water which may find its way to the back of the wall. These holes should be about 2 inches wide and should be backed with some permeable material, such as gravel, broken stone, etc.

Formula for Calculating Thickness of Retaining Walls.

E = weight of earthwork per cubic yard.

W = weight of wall per cubic yard.

H = height of wall.

T = thickness of wall at top.

$T = H \times$ tabular number (Table 12).

TABLE 12.

Coefficients for Retaining Walls.

Batter of Wall.	E : W :: 1 : 5		E : W :: 1 : 4	
	Clay.	Sand.	Clay.	Sand.
1 in 4	.083	.029	.115	.054
1 in 5	.122	.065	.155	.092
1 in 6	.149	.092	.183	.118
1 in 8	.184	..125	.218	.153
1 in 12	.221	.160	.256	.189
Vertical	.300	.239	336	.267

Retaining walls of dry stone should not be less than 3 feet thick at top, with a face batter of 1 in 4 and back perpendicular, the courses laid perpendicular to the face batter. Weep holes are unnecessary unless the walls are in very wet situations.

Retaining walls of masonry should be at least 2 feet thick at top, back perpendicular and face battered at the rate of 1 in 6.

Surcharged Walls. In calculating the strength of surcharged walls substitute Y for H, Y being the perpendicular at the end of a line, L = H measured along the slope to be retained (Fig. 26).

$$
\begin{aligned}
Y &= 1.71H \text{ in slopes of } 1 : 1; \\
&= 1.55H \text{ “ “ “ } 1\tfrac{1}{2} : 1; \\
&= 1.35H \text{ “ “ “ } 2 : 1; \\
&= 1.31H \text{ “ “ “ } 3 : 1; \\
&= 1.24H \text{ “ “ “ } 4 : 1.
\end{aligned}
$$

DESCRIPTION OF ARCHES.

Basket-Handle Arch : One in which the intrados resembles a semi-ellipse, but is composed of arcs of circles tangent to each other

Circular Arch : One in which the intrados is a part of a circle.

Discharging Arch : An arch built above a lintel to take the superincumbent pressure therefrom.

Elliptical Arch : One in which the intrados is a part of an ellipse.

Geostatic Arch : An arch in equilibrium under the vertical pressure of an earth embankment.

Hydrostatic Arch : An arch in equilibrium under the vertical pressure of water

Inverted Arches are like ordinary arches, but are built with the crown downwards. They are generally semicircular or segmental in section, and are used chiefly in connection with foundations.

Plain or Rough Arches are those in which none of the bricks are cut to fit the splay. Hence the joints are quite close to each other at the soffit, and wider towards the outer curve of the arch; they are generally used as *relieving and trimer arches*, *for tunnel lining*, and all arches where strength is essential and appearance no particular object. In constructing arches of this kind it is usual to form them of two or more four-inch concentric rings until the required thickness is obtained. Each of the successive rings is built independently, having no connection with the others beyond the adhesion of the mortar in the ring joint. It is necessary that each ring should be finished before the next is commenced; also that each course be bonded throughout the length of the arch, and that the ring joint should be of a regular thickness. For if one ring is built with a thin joint and another with a thick one the one having the most mortar will shrink, causing a fracture and depriving the arch of much of its strength.

Pointed Arch : One in which the intrados consists of two arcs of equal circles intersecting over the middle of the span.

Relieving Arch : See Discharging Arch.

Right Arch : A cylindrical arch either circular or elliptical, terminated by two planes, termed *heads* of the arch, at right angles to the axis of the arch.

Segmental Arch: One whose intrados is less than a semicircle.

Semicircular Arch : One whose intrados is a semicircle; also called a *full-centered* arch.

Skew Arch : One whose heads are oblique to the axis. Skew arches are quite common in Europe, but are rarely employed in the United States; and in the latter when an oblique arch is employed it is usually made, not after the European method with spiral joints, but by building a number of short right arches or ribs in contact with each other, each successive rib being placed a little to one side of its neighbor.

DEFINITIONS OF PARTS OF ARCHES.

Abutment: The outer wall that supports the arch, and which connects it to the adjacent banks.

Arch Sheeting: The voussoirs which do not show at the end of the arch.

Camber is a slight rise of an arch, as $\frac{1}{8}$ to $\frac{1}{4}$ inch per foot of span.

Crown: The highest point of the arch.

Extrados: The upper and outer surface of the arch.

Haunches: The sides of the arch from the springing line half way up to the crown.

Heading Joint: A joint in a plane at right angles to the axis of the arch. It is not continuous.

Intrados or Soffit: The under or lower surface of the arch.

Invert: An inverted arch, one with its intrados below the axis or springing line; *e.g.*, the lower half of a circular sewer.

Keystone: The center voussoir at the crown.

Length: The distance between face stones of the arch.

Pier: The intermediate support for two or more arches.

Ring Course: A course parallel to the face of the arch.

Ring Stones: The voussoirs or arch stones which show at the ends of the arch.

Rise: The height from the springing line to under side of the arch at the keystone.

Skew Back: The upper surface of an abutment or pier from which an arch springs; its face is on a line radiating from the center of the arch.

Span: The horizontal distance from springing to springing of the arch.

Spandrel: The space contained between a horizontal line drawn through the crown of the arch and a vertical line drawn through the upper end of the skew back.

Springing: The point from which the arch begins or springs.

Springer: The lowest voussoir or arch stone.

String Course: A course of voussoirs extending from one end of the arch to the other.

Voussoirs: The blocks forming the arch.

Arches: The arch is a combination of wedge-shaped blocks, termed arch stones, or voussoirs, truncated towards the angle of the wedges by a curved surface which is usually normal to the surfaces of the joints between the blocks. This inferior surface of the arch is termed the soffit. The upper or outer surface of the arch is termed the back.

The extreme blocks of the arch rest against lateral supports, termed abutments, which sustain both the vertical pressure arising from the weight of arch stones, and the weight of whatever lies upon them; also the lateral pressure caused by the action of the arch.

The *forms* of an arch may be the semicircle, the segment, or a compound curve formed of a number of circular curves of different radii. Full center arches, or entire semicircles, offer the advantages of simplicity of form, great strength, and small lateral thrust; but if the span is large they require a correspondingly great rise, which is often objectionable. The flat or segmental arch enables us to reduce the rise, but it throws a great lateral strain upon the abutments. The compound curve gives, when properly proportioned, a strong arch with a moderate lateral action, is easily adjustable to different ratios between the span and the rise, and is unsurpassed in its general appearance. In striking the compound curve, the following conditions are to be observed: The tangents at the springing must be vertical, the tangent at the crown horizontal, and the number of centers must be uneven, curves of 3 and 5 centers will be found to fulfil all requirements.

In designing an arch the first step is to determine the thickness at the crown, *i.e.*, the depth of the keystone. This depth depends upon the form, and rise of the arch, the character of the masonry, and the quality of the stone; and is usually determined by Trautwine's formula, which is as follows for a first-class cut stone arch whether circular or elliptical.

$$D = \frac{\sqrt{R + \frac{1}{2} S}}{4} + 0.2.$$

in which

D = the depth at the crown in feet.
R = the radius of curvature of the intrados in feet.
S = the span in feet.

For second-class work, the depth found by this formula may be increased about one-eighth part; and for *brickwork* or *fair rubble,* about one-third.

Table 13 gives the depth of keystone for semicircular arches, the second column being for hammer-dressed beds, the third for beds roughly dressed with the chisel, and the fourth for brick masonry.

TABLE 13.

Span in feet.	Thickness of Arch in inches.		
	First-class Masonry.	Second-class Masonry	Brick Masonry.
6	12	15	12
8	13	16	16
10	14	17	20
12	15	19	20
14	16	20	24
16	17	21	24
18	18	23	24
20	19	24	24
25	20	25	28
30	21	26	28
35	22	28	28
40	23	29	32
45	24	30	32
50	25	31	32

Thickness of Arch at the Springing. Generally the thickness of the arch at the springing is found by an application of theory.

If the loads are vertical, the horizontal component of the compression on the arch is constant; and hence, to have the mean pressure on the joints uniform, the vertical projection of the joints should be constant. This principle leads to the following formula:

The length measured radially of each joint between the joint of rupture and the crown should be such that its vertical projection is equal to the depth of the keystone.

The length of the joint of rupture, *i.e.*, the thickness of the arch at the practical springing line, can be computed by the formula

$$z = d \sec a$$

in which z is the length of the joint,
d the depth of the crown,
a the angle the joint makes with the vertical.

The following are the values for circular and segmental arches:

$$\text{If } \frac{R}{S} > \frac{1}{4},\ l = 2.00\ d$$

$$\text{“}\ \frac{R}{S} = \frac{1}{6},\ l = 1.40\ d$$

$$\text{“}\ \frac{R}{S} = \frac{1}{8},\ l = 1.24\ d$$

$$\text{“}\ \frac{R}{S} = \frac{1}{10},\ l = 1.18\ d$$

$$\text{“}\ \frac{R}{S} = \frac{1}{12},\ l = 1.10\ d$$

in which R = the rise, in feet
S = the span, in feet.

Thickness of the Abutments. The thickness of the abutment is determined by the following formula:

$$t = 0.2\ p + 0.1\ R + 2.0$$

in which t is the thickness of the abutment at the springing, p the radius, and R the rise—all in feet.

The above formula applies equally to the smallest culvert or the largest bridge—whether circular or elliptical, and whatever the proportions of rise and span—and to any height of abutment.

Table 14 gives the minimum thickness of abutments for arches of 120 degrees where the depth of crown does not exceed 3 feet.

Calculated from the formula

$$T = \sqrt{6R + \left(\frac{3R}{2H}\right)^2} - \frac{3R}{2H},$$

in which D = depth or thickness of crown in feet;
H = height of abutment to springing in feet;
R = radius of arch at crown in feet;
T = thickness of abutment in feet.

Arches fail by the crown falling inward, and thrusting outward the lower portions, presenting five points of rupture, one at the keystone, one on each side of it which limit the portions that fall inward, and one on each side near the springing lines which limit the parts thrust outward. In pointed arches, or those in which the rise is greater than half the span, the tending to yielding is, in some cases, different; and thrust upward and outward the parts near the crown.

TABLE 14.

Minimum Thickness of Abutments for Arches of 120 Degrees Where the Depth of Crown Does Not Exceed 3 Feet.

Span of Arch.	Height of Abutment to Springing, in feet.				
	5	7.5	10	20	30
8 feet	3.7	4.2	4.3	4.6	4.7
9 "	3.9	4.4	4.6	4.9	5.0
10 "	4.2	4.6	4.8	5.1	5.2
12 "	4.5	4.7	5.2	5.6	5.7
14 "	4.7	5.2	5.5	6.0	6.1
16 "	4.9	5.5	5.8	6.4	6.5
18 "	5.1	5.8	6.1	6.7	6.9
20 "	5.3	6.0	6.4	7.1	7.2
22 "	5.5	6.2	6.6	7.3	7.6
24 "	5.6	6.4	6.9	7.6	7.9
30 "	6.0	7.0	7.5	8.4	8.8
40 "	6.5	7.7	8.4	9.6	10.0
50 "	6.9	8.2	9.1	10.5	11.1
60 "	7.2	8.7	9.7	11.4	12.0
70 "	7.4	9.1	10.2	11.8	12.9
80 "	7.6	9.4	10.6	12.8	13.6
90 "	7.8	9.7	11.0	13.4	14.3
100 "	7.9	10.0	11.4	14.0	15.0

NOTE. The thickness of abutment for a semicircular arch may be taken from the above table by considering it as approximately equal to that for an arch of 120 degrees having the same radius of curvature; therefore by dividing the span of the semicircular arch by 1.155 it will give the span of the 120-degree arch requiring the same thickness of abutment.

The angle which a line drawn from the center of the arch to the joint of rupture makes with a vertical line is called the *angle of rupture.* This term is also used when the arch is stable, or where there is no joint of rupture, in which case it refers to that point about which there is the greatest tendency to rotate. It may also be defined as including that portion of the arch near the crown which will cause the greatest *thrust* or horizontal pressure at the crown. This thrust tends to crush the *voussoirs* at the crown, and also to overturn the abutments about some outer joint. In very thick arches rupture may take place from *slipping* of the joints.

In order to avoid any tendency of the joints to open, the arch should be so designed that the actual resistance line shall everywhere be within the middle third of the depth of the arch ring.

In general the design of an arch is reached by a series of approximations. Thus, a form of arch and spandrel must be assumed in advance in order to find their common center of gravity for the purpose of determining the horizontal thrust at the crown, and the reaction at the skewback.

Backing. The backing is masonry of inferior quality or concrete, laid outside and above the arch stones proper, to give additional

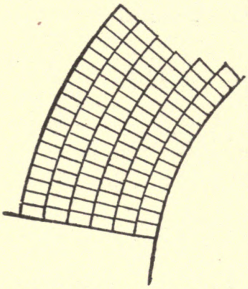


Fig. 26. Rowlock Bond.

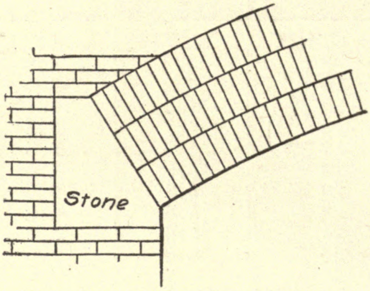


Fig. 27. Rowlock with Skewback.

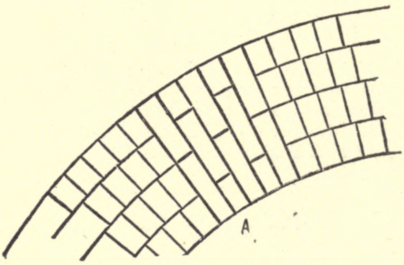


Fig. 28. Block in Course Bond.

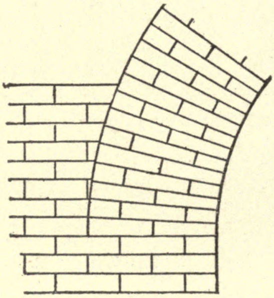


Fig. 29. Header and Stretcher.

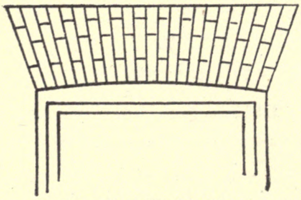


Fig. 30. Flat Arch.

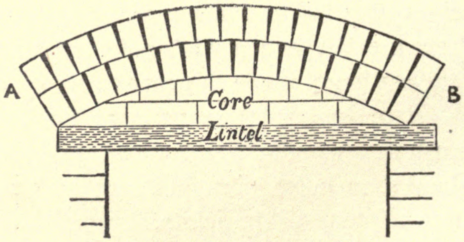


Fig. 31. Relieving Arch.

security. Ordinarily, the backing has a zero thickness at or near the crown, and gradually increases to the upringing line.

Spandrel Filling. Since the surface of the roadway must not deviate from a horizontal line, a considerable quantity of material is required above the backing to bring the roadway level. Ordinarily this space is filled with earth, gravel, broken stone, cinders, etc. Sometimes to save filling small arches are built over the haunches of the main arch.

Drainage. The drainage of arch bridges of more than one span is generally effected by giving the top surface of the backing a slight inclination from each side toward the center of the width of the bridge and also from the center toward the end of the span. The water is thus collected over the piers, from whence it is discharged through pipes laid in the masonry.

To prevent leakage through the backing and through the arch sheeting, the top of the former should be covered with a layer of puddle, or plastered with a coat of cement mortar, or painted with coal tar or asphaltum.

Brick Arches. The only matter requiring special mention in connection with brick arches is the bond to be employed. When the thickness of the arch exceeds a brick and a half, the bond from the soffit outward is a very important matter. There are three principal methods employed in bonding brick arches: (1) The arch may be built in concentric rings; *i.e.*, all the brick may be laid as stretchers, with only the tenacity of the mortar to unite the several rings. This method is called *rowlock bond:* (2) Part of the brick may be laid as stretchers and part as headers, by thickening the outer ends of the joints—either by using more mortar or by driving in thin pieces of slate, so that there shall be the same number of brick in each ring. This form of construction is called *header and stretcher bond:* (3) *Block in course bond* is formed by dividing the arch into sections similar in shape to the voussoirs of stone arches, and laying the brick in each section with any desired bond.

Skewback. In brick arches of large span a stone skewback is used for the arch to spring from. The stone should be cut so as to bond into the abutment, and the springing surface should be cut to a true plane, radiating from the center from which the arch is struck.

Flat Arches are often built over door or window openings; they are always liable to settle and should be supported by an angle bar, the vertical flange of which may be concealed behind the arch.

Relieving Arches. This term is applied to arches turned over openings in walls to support the wall above; beams called lintels are usually used in connection with this type of arch, the lintel should not have a bearing on the wall of more than 4 inches, and the arch should spring from beyond the ends of the lintel as shown in A, Fig. 31, and not as at B.

CONSTRUCTION OF ARCHES.

In constructing ornamental arches of small span the bricks should be cut and rubbed with great care to the proper splay or wedge like form necessary, and according to the gauges or regularly measured dimensions.

This is not always done, the external course only being rubbed, so that the work may have a pleasing appearance to the eye, while the interior, which is hidden from view, is slurred over, and in order to save time many of the interior bricks are apt to be so cut away as to deprive the arch of its strength. This class of work produces cracks and causes the arch to bulge forward, and may cause one of the bricks of a straight arch to drop down lower than the soffit.

In setting arches the mason should be sure that the centers are set *level* and *plumb*, that the arch brick or stone may rest upon them *square*. When the brick or stone are properly cut beforehand the courses can be gauged upon the center from the key downwards. The soffit of each course should fit the center perfectly.

The mortar joints should be as thin as possible and well flushed up.

In setting the face stones it is necessary to have a radius line, and draw it up and test the setting of each stone as it is laid.

The framing, setting up, and striking of the centers are very important parts of the construction of any arch, particularly one of long span. A change in the shape of the center, due to insufficient strength or improper bracing, will be followed by a change in the curve of the intrados, and consequently of the line of resistance, which may endanger the safety of the arch itself.

CENTERING FOR ARCHES.

No arch becomes self-supporting until keyed up, that is, until the crown or keystone course is laid. Until that time the arch ring, which should be built up simultaneously from both abutments, has to be supported by frames called centers. These consist of a series of ribs placed from 3 to 6 or more feet apart, supported from below. The upper surface of these ribs is cut to the form of the arch, and over these a series of planks called *laggings* are placed, upon which the arch stones directly rest. The ribs may be of timber or iron. They should be strong and stiff. Any deformation that occurs in the rib will distort the arch, and may even result in its collapse.

Striking the Center. The ends of the ribs or center frames usually rest upon a timber lying parallel to, and near, the springing line of the arch. This timber is supported by wedges, preferably of hardwood, resting upon a second stick, which is in turn supported by wooden posts, usually one under each end of each rib. The wedges between the two timbers, as above, are used in removing the center after the arch is completed, and are known as *striking wedges*. They consist of a pair of folding wedges, 1 to 2 feet long, 6 inches wide, and having a slope of from 1 to 5 to 1 to 10, placed under each end of each rib. It is necessary to remove the centers slowly, particularly for large arches; and hence the striking wedges should have a very slight taper, the larger the span the smaller the taper.

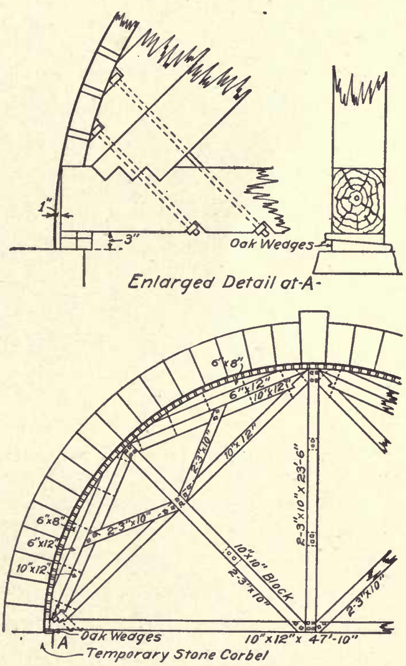


Fig. 32. Arch Center.

The center is lowered by driving back the wedges. To lower the center uniformly the wedges must be driven back uniformly. This is most easily accomplished by making a mark on the side of each pair of wedges before commencing to drive, and then *moving* each the same amount.

The inclined surfaces of the wedges should be lubricated when the center is set up, so as to facilitate the striking.

Screws may be used instead of wedges for lowering centers.

Sand is also employed for the same purpose. The method followed is to support the center frames by wooden pistons or plungers resting on sand confined in plate-iron cylinders. Near the bottom of each cylinder there is a plug which can be withdrawn and replaced at pleasure, thus regulating the outflow of the sand and the descent of the center.

There is great difference of opinion as to the proper time for striking centers. Some hold that the center should be struck as soon as the arch is completed and the spandrel filling is in place; while others contend that the mortar should be given time to harden. It is probably best to slacken the centers as soon as the keystone course is in place, so as to bring all the joints under pressure. The length of time which should elapse before the centers are finally removed should vary with the kind of mortar employed and also with its amount. In brick and rubble arches a large proportion of the arch ring consists of mortar, and if the center is removed too soon the compression of this mortar might cause a serious or even dangerous deformation of the arch. Hence the centers of such arches should remain until the mortar has not only set, but has attained a considerable part of its ultimate strength.

Frequently the centers of bridge arches are not removed for three or four months after the arch is completed, but usually the centers for the arches of tunnels, sewers, and culverts are removed as soon as the arch is turned and, say, half of the spandrel filling is in place.

BRIDGE ABUTMENTS.

Form. There are four forms of abutment in use, they are named according to their form as the *straight* abutment, the *wing* abutment, the U abutment and the T abutment.

The form to be adopted for any particular case will depend upon the location—whether the banks are low and flat, or steep and rocky, whether the current is swift or slow, and also upon the relative cost of earthwork and masonry. Where a river acts dangerously upon a shore, wing walls will be necessary. These wings may be curved or straight. The slope of the wings may be finished with an inclined coping, or offset at each course. Wing walls subjected to

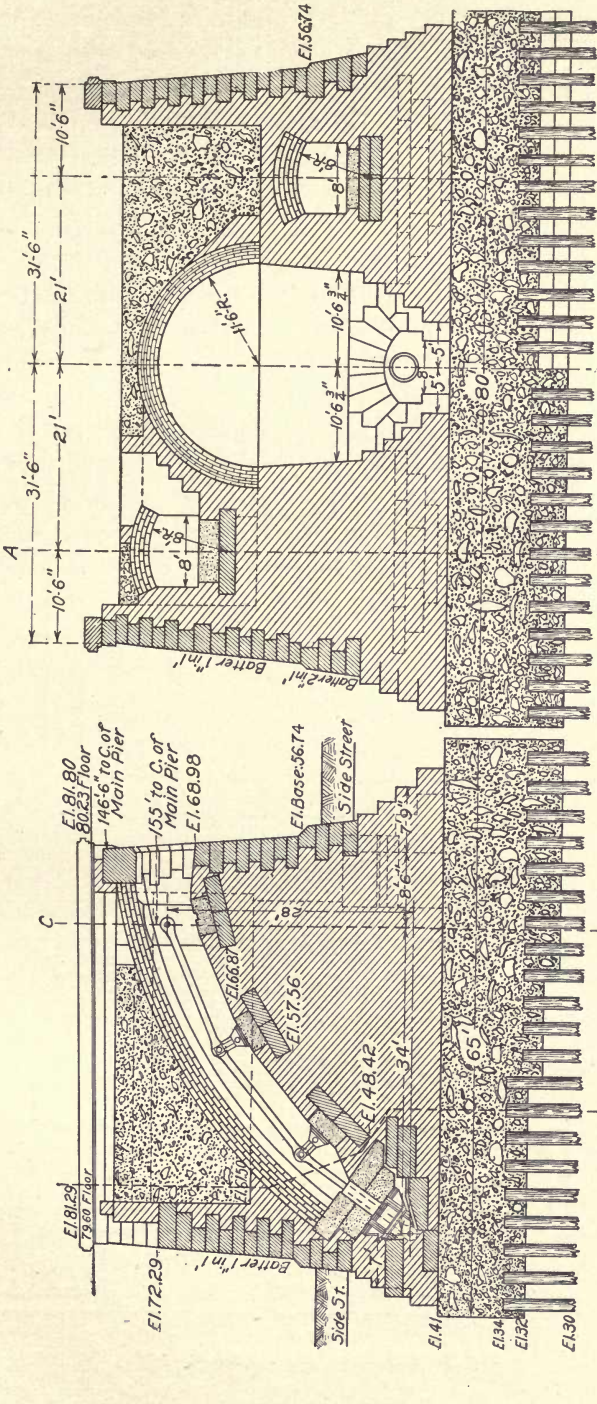


Fig. 33. Bridge Abutment and Anchorage.

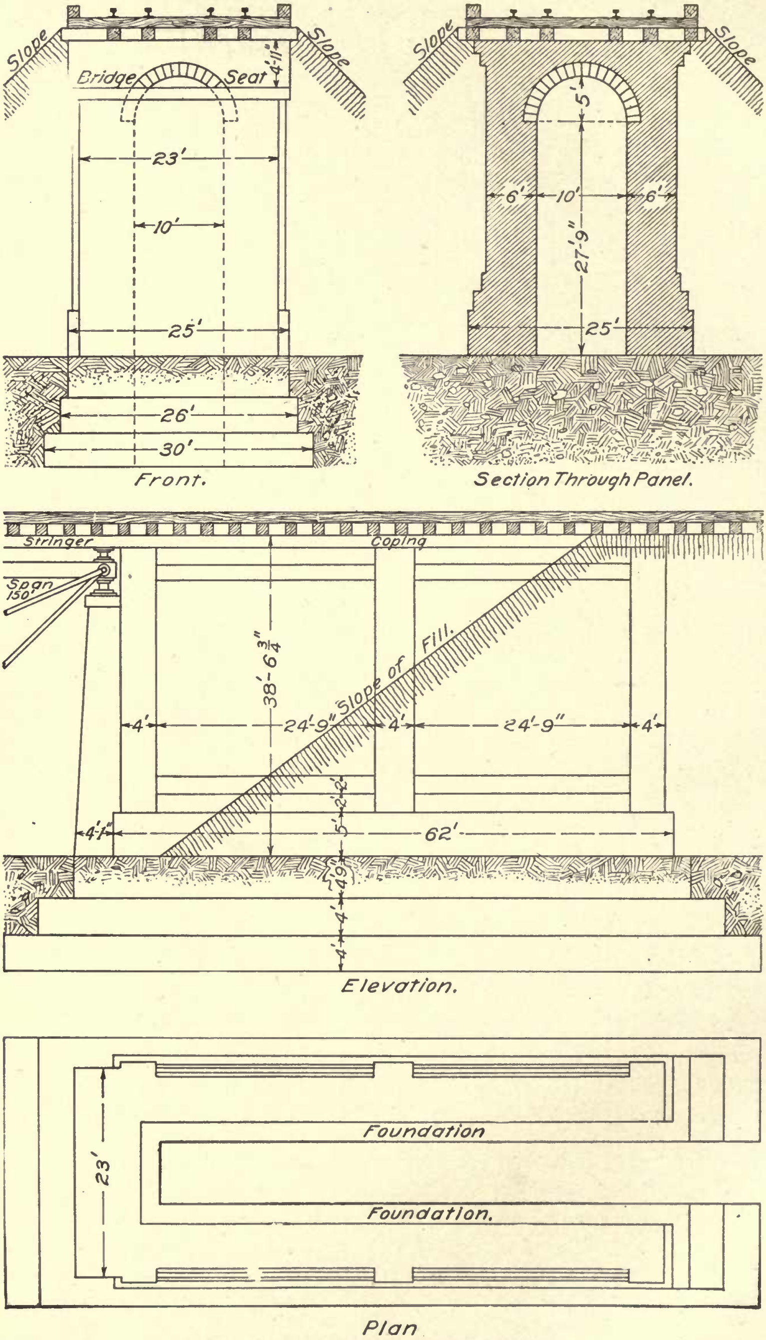


Fig. 34. Abutment for Railroad Bridge.

special strains, or to particular currents of water require positions and forms accordingly.

The abutment of a bridge has two offices to perform; (1) to support one end of the bridge, and (2) to keep the earth embankment from sliding into the water.

The abutment may fail (1) by sliding forward, (2) by bulging, or (3) by crushing.

The dimensions of abutments will vary with each case, with the form and size of the bridge and with the pressure to be sustained; the dimensions may be determined by the same formulas as used for retaining walls.

For railroad bridges the top dimensions are usually 5 feet wide by 20 feet long. The usual batter is 1 in 12, for heights under 20 feet the top dimensions and the batter determine the thickness at the bottom. For greater heights, the uniform rule is to make the thickness four-tenths the height.

Bridge abutments are built of first or second-class masonry or of concrete alone or faced with stone masonry, according to the importance and location of the structure.

BRIDGE PIERS.

The thickness of a pier for simply supporting the weight of the superstructure need be but very little at the top, care being taken to secure a sufficient bearing at the foundation. Piers should be thick enough, however, to resist shocks and lateral strains, not only from a passing load, but from floating ice and ice jams; and in rivers where a sandy bottom is liable to deep scouring, so that the bottom may work out much deeper on one side of a pier than on the other, regard should be paid to the lateral pressure thus thrown on the pier. For mere bearing purposes the following widths are ample for first-class masonry—span 50 feet, width 4 feet, span 200 feet, width 7 feet. Theoretically the dimensions at the bottom are determined by the area necessary for stability; but the top dimensions required for the bridge seat, together with the batter, 1 in 12 or 1 in 24, generally make the dimensions of the base sufficient for stability.

The up-stream end of a pier, and to a considerable extent the down-stream end also, should be rounded or pointed to serve as a cutwater to turn the current aside and to prevent the formation of whirls which act upon the bed of the stream around the foundation, and also to form a fender to protect the pier proper from being damaged by ice, tugs, boats, etc. This rounding or pointing is designated by the name *starling,* the best form appears to be a semi-ellipse. The distance to which they should extend from the pier depends upon local circumstances.

A bridge pier may fail in any one of these ways; (1) by sliding on any section on account of the action of the wind against the ex-

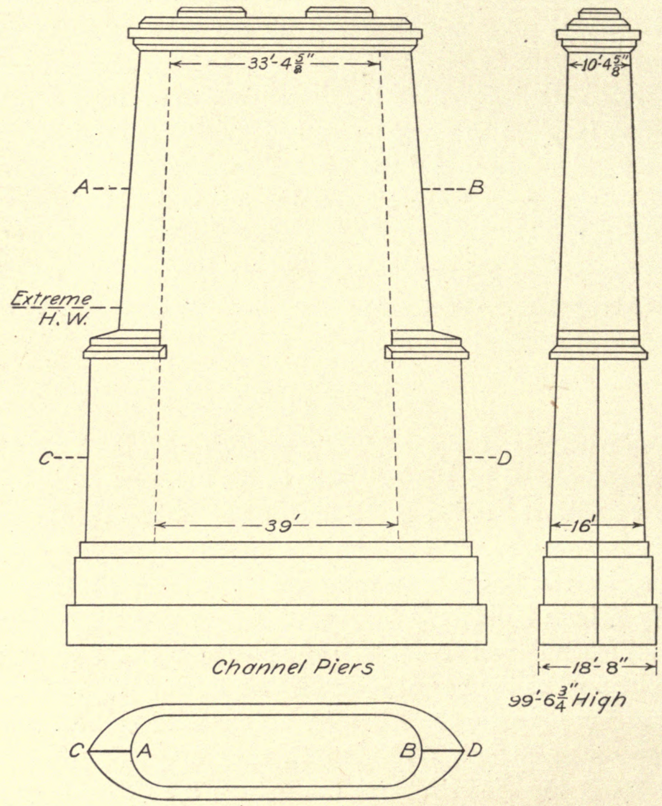


Fig. 35. Type of Bridge Pier.

posed part of the pier; (2) by overturning at any section where the moment of the horizontal forces above the section exceeds the moment of the weight of the section; or (3) by crushing at any section under the combined weight of the pier, the bridge and the load. Bridge piers are usually constructed of quarry-faced ashlar backed with rubble or concrete. Occasionally, for economy, piers, particularly pivot-piers, are built hollow—sometimes with and sometimes without cross walls.

CULVERTS.

Culverts are employed for conveying under a railroad, highway, or canal the small streams crossed. They may be of stone, brick, concrete, earthenware, or iron pipe or any of these in combination. Two general forms of masonry culverts are in use, the *box* and the *arch*.

Box Culverts. The box consists of vertical side walls of masonry with flagstones on top extending from one wall to another. The foundation consists of large stones and the side walls may be laid dry or in mortar.

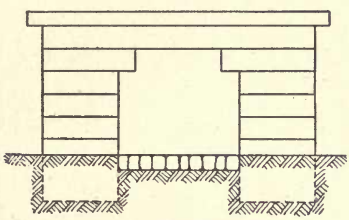


Fig. 36. End Elevation.

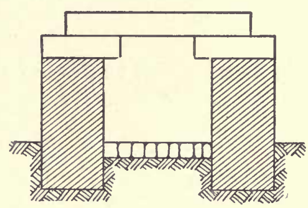


Fig. 37. Section AB.

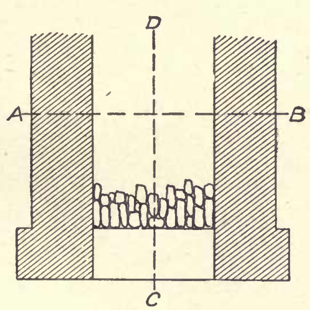


Fig. 38. Plan.

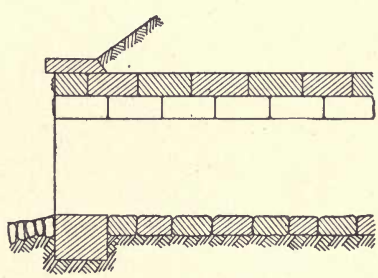


Fig. 39. Section CD.

Types of Box Culverts.

The paving should be laid independent of the walls and should be set in cement mortar. The end walls are finished either with a plain wall perpendicular to the axis of the culvert and may be stepped, or provided with wing walls as the circumstances of each case may require.

The thickness of the cover stone may be determined by considering it as a beam supported at the ends and loaded uniformly.

Figs. 36 to 39 show the form of this class of culverts and the dimensions given in Table 15 will serve as an approximate guide for general use.

TABLE 15.

Dimensions for Box Culverts.

Area.	Opening.	Side Wall.	Depth of Cover.	Length of Cover.
4 feet	2′ × 2′	2′ × 2′	12 inches	5 feet
9 "	3 × 3	3 × 2½	16 "	6 "
16 "	4 × 4	4 × 3	20 "	7 "
25 "	5 × 5	5 × 3½	22 "	8 "
36 "	6 × 6	6 × 4	24 "	9 "

Arch Culverts. The dimensions of arch culverts are determined in the manner described herein under arches, attention, however, being given to the following points:

Wing Walls. There are three common ways of arranging the wing walls at the end of arch culverts: (1) The culvert is finished with straight walls at right angles to the axis of the culvert. (2) The wings are placed at an angle of 30 degrees with the axis of the culvert. (3) The wing walls are built parallel to the axis of the culvert, the back of the wing and the abutment being in a straight line and the only splay being derived from thinning the wings at their outer edge. The most economical and better form for hydraulic considerations is the second form.

Designing Culverts. In the design of culverts care is required to provide an ample way for the water to be passed. If the culvert is too small, it is liable to cause a washout, entailing interruption of traffic and cost of repairs, and possibly may cause accidents that will require the payment of large sums for damages. On the other hand, if the culvert is made unnecessarily large, the cost of construction is needlessly increased.

The area of waterway required, depends (1) upon the rate of rainfall; (2) the kind and condition of the soil; (3) the character and inclination of the surface; (4) the condition and inclination of the bed of the stream; (5) the shape of the area to be drained, and the position of the branches of the stream; (6) the form of the mouth and the inclination of the bed of the culvert; and (7) whether it is permissible to back the water up above the culvert, thereby causing it to discharge under a head.

(1) The maximum rainfall as shown by statistics is about one

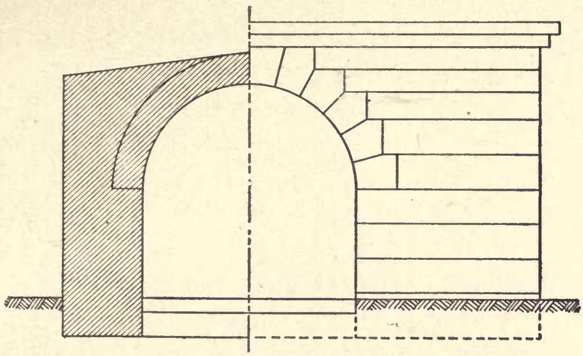


Fig. 40. Sectional Elevation.

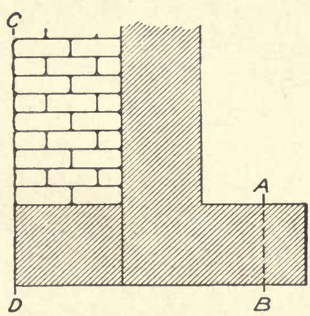


Fig. 41. Plan.

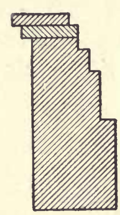


Fig. 42. Section AB.

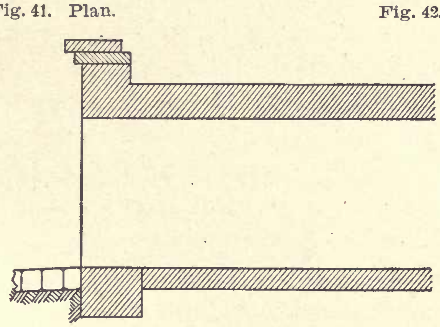


Fig. 43. Section CD.

Type of Arch Culvert.

inch per hour (except during heavy storms), equal to 3,630 cubic feet per acre. Owing to various causes, not more than 50 to 75 per cent of this amount will reach the culvert within the same hour.

Inches of rainfall × 3,630 = cubic feet per acre.

Inches of rainfall × 2,323,200 = cubic feet per square mile.

(2) The amount of water to be drained off will depend upon the permeability of the surface of the ground, which will vary greatly with the kind of soil, the degree of saturation, the condition of the cultivation, the amount of vegetation, etc.

(3) The rapidity with which the water will reach the watercourse depends upon whether the surface is rough or smooth, steep or flat, barren or covered with vegetation, etc.

(4) The rapidity with which the water will reach the culvert depends upon whether there is a well-defined and unobstructed channel, or whether the water finds its way in a broad thin sheet. If the watercourse is unobstructed and has a considerable inclination, the water may arrive at the culvert nearly as rapidly as it falls; but if the channel is obstructed, the water may be much longer in passing the culvert than in falling.

(5) The area of the waterway depends upon the amount of the area to be drained; but in many cases the shape of this area and the position of the branches of the stream are of more importance than the amount of the territory. For example, if the area is long and narrow, the water from the lower portion may pass through the culvert before that from the upper end arrives; or, on the other hand, if the upper end of the area is steeper than the lower, the water from the former may arrive simultaneously with that from the latter. Again, if the lower part of the area is better supplied with branches than the upper portion, the water from the former will be carried past the culvert before the arrival of that from the latter; or, on the other hand, if the upper portion is better supplied with branch watercourses than the lower, the water from the whole area may arrive at the culvert at nearly the same time. In large areas the shape of the area and the position of the watercourses are very important considerations.

(6) The efficiency of a culvert may be materially increased by so arranging the upper end that the water may enter it without being retarded. The discharging capacity of a culvert can also be increased by increasing the inclination of its bed, provided the channel below will allow the water to flow away freely after having passed the culvert.

(7) The discharging capacity of a culvert can be greatly increased by allowing the water to dam up above it. A culvert will

discharge twice as much under a head of four feet as under a head of one foot. This can be done safely only with a well-constructed culvert.

The determination of the values of the different factors entering into the problem is almost wholly a matter of judgment. An estimate for any one of the above factors is liable to be in error from 100 to 200 per cent, or even more, and of course any result deduced from such data must be very uncertain. Fortunately, mathematical exactness is not required by the problem nor warranted by the data. The question is not one of 10 or 20 per cent of increase; for if a 2-foot pipe is insufficient, a 3-foot pipe will probably be the next size, an increase of 225 per cent; and if a 6-foot arch culvert is too small, an 8-foot will be used, an increase of 180 per cent. The real question is whether a 2-foot pipe or an 8-foot arch culvert is needed.

Calculating Area of Waterway. Numerous empirical formulas have been proposed for this and similar problems; but at best they are all only approximate, since no formula can give accurate results with inaccurate data.

The size of waterway may be determined approximately by the following formula:

$$Q = Cr\sqrt[4]{\frac{S}{A}},$$

in which

Q = the number of cubic feet per acre per second reaching the mouth of the culvert or drain.

C = a coefficient ranging from .31 to .75, depending upon the nature of the surface; .62 is recommended for general use.

r = average intensity of rainfall in cubic feet per acre per second.

S = the general grade of the area per thousand feet.

A = the area drained, in acres.

CONCRETE STEEL MASONRY.

Concrete in the form of blocks made at a factory, and concrete formed in place and reinforced by steel rods and bars of differing shapes is being substituted in many situations for stone and brick masonry. For the construction of bridges and floors it is extensively employed. Several systems are in use, each known by the name of the inventor. Fig. 44 shows the different types which are more or less popular.

The Monier type consists of a mesh work of longitudinal and transverse rods of steel, usually placed near the center line of the arch

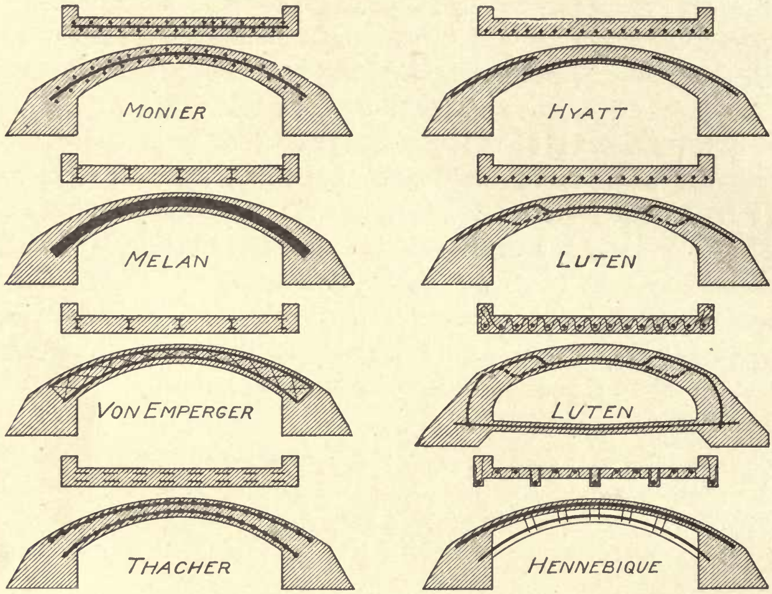


Fig. 44. Types of Concrete Steel Arches.

rib. This type rests on the theory that the steel rods will resist the compressive stresses of the rib, while the concrete acts merely as a stiffener to prevent the steel from buckling,

The Melan type consists of steel ribs embedded in the concrete and extending from abutment to abutment. The ribs are in the form of steel I-beams curved to follow the center line of the arch rib. The steel is assumed to be sufficient to resist the bending moments of the arch, while the concrete is relied upon to resist the thrust and to act as a preservative coating for the steel.

The Von Emperger arch is a modification of the Melan arch, the ribs are built up with angles for the flanges and diagonal lacing replaces the web, on the theory that the metal should be concentrated near the extrados of the arch to more effectually resist the bending moments.

The Thacher type is formed by omitting the web and reinforcing the concrete by steel bars in pairs one above the other, one near the extrados and one near the intrados, the steel being relied upon to resist the bending moments while the concrete is expected to resist the thrust of the arch.

In the Hyatt arch that portion of the steel bars or rods which in the Thacher arch is subjected to the greatest compression is omitted.

In the Luter arch the concrete rib is reinforced by tension members passing from one side of the arch rib to the other.

In the Hennebique system an arch barrel or drum, four to six inches in diameter, is supported by ribs of concrete below, the concrete of the drum being reinforced with steel rods placed near the extrados, and that of the ribs by steel rods near the intrados.

Numerous forms of steel shapes are advocated for the reinforcement of concrete when employed for arches, retaining walls, etc.; twisted bars, corrugated bars, expanded metal and lock woven steel are some of the names applied to the different shapes.

The method employed for constructing concrete walls is in brief as follows: A wooden form is erected, consisting of slotted standards made of 6-inch boards nailed together with spacing blocks between them at their ends, $\frac{5}{8}$-inch bolts are used to join the standards on opposite sides of the wall. The standards are for the purpose of holding molding boards in position while the concrete is being deposited between them. These boards are of dressed pine $1\frac{1}{2}$ inches thick. After the lower portions of the concrete has set the boards are removed and used above. Vertical rods of twisted or corrugated steel are built in the wall spaced about 12 inches apart. In some cases level horizontal bars of steel are also embedded in the walls.

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