DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

PROPERTIES AND MANUFACTURE OF CONCRETE BUILDING UNITS

CIRCULAR OF THE BUREAU OF STANDARDS, No. 304

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FIG. 1.—*House built of faced concrete building block*

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ABSTRACT

Numerous inquiries have been received at the Bureau of Standards from prospective makers or users of concrete units who were interested in learning more of their properties or the details of the manufacturing methods. This circular endeavors to bring out the essential features concerning concrete brick, block, and building tile, and to give some information on their manufacture.

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[1] Prepared by Frank A. Hitchcock, engineer, and John R. Dwyer, associate engineer, of the cement and concreting materials section of the Bureau of Standards.

I. INTRODUCTION

1. GENERAL

Concrete units of various types have long been used in building construction, some having been produced 60 or 70 years ago. However, it is within the last few years that the manufacture of concrete units has attained a rapid growth. This growth is due largely to the heavy demand for building materials and the efforts of cement and concrete products associations in bringing to the attention of the public the desirable features of the concrete units. Laboratories and technical societies have studied the several factors affecting the quality of the products and have devised methods of test to determine if the necessary properties are present in the finished product.

Numerous inquiries have been received at the Bureau of Standards from prospective users or makers of concrete units who are interested in learning more of their properties or the details of the manufacturing methods. This circular endeavors to bring out the essential features concerning concrete brick, block, and building tile, and to give some information about their manufacture. It is not intended to be a complete treatise on the many elements of the industry, but to serve as a means of answering in a reasonably complete manner the questions which frequently come to this bureau. It is hoped that it will encourage the study of the problems affecting these units and bring out the importance of securing and maintaining quality in their manufacture. A real interest on the part of the producers and promoters of concrete products in learning the results obtained from use, tests, and investigations will not only be of assistance in advancing and maintaining quality, but may give a clearer idea of the useful field for concrete units. Consideration of the reasonable limitations for the use of any material is of importance and often does much toward avoiding costly mistakes and unwarranted claims which would bring the product into disfavor in the minds of the public.

2. PROPERTIES AND ADVANTAGES

Concrete brick, block, and building tile have been successfully used in masonry construction. However, the choice of a material for any particular work should not be decided by appearance or preference alone. The selection of the material for the work at hand must necessarily consider first, the structural requirements of the project. In general, it appears that the comparison of the concrete building units with other materials can be covered by consideration of the structural requirements, architectural aims, and economic features.

In the past many blocks have been made without regard to the appearance of the finished structure, and the surfaces produced were uninteresting and monotonous. Excellent imitations of natural stone have been produced, but imitation is not without its dangers, and some imitative surfaces have been a detriment rather than an asset to the finished appearance of the structure. Extreme monotony appears in some walls of rock face design where the same plate effect is used in every unit. However, in the hands of the experienced operator, and by using proper care in the selection of units, concrete surfaces can be made to render very effective and pleasing results in a large variety of colors, textures, and designs.

The economy of concrete products in any particular case will depend upon the basis used for making the relative cost estimate. Distances and freight rates to the sources of natural stone and clay products often figure very largely in the comparison, since concrete products are usually of local production. The relative costs of laying concrete units have frequently been set forth in advertising and other literature, but such cost data must not be applied to definite cases without an investigation of the local conditions. An important factor is the size of the concrete unit. Because a given size of block or tile may effect a saving over another type of masonry construction, it does not follow necessarily that a larger unit will be proportionately cheaper. There are often serious objections to the handling and laying of the very large and heavy blocks, and this problem may be very materially affected by the attitude of the local labor. In the consideration of economy one should not overlook the appearance, the desired architectural effects, and the structural requirements, and full allowance should be made for the estimated cost of maintenance and fire insurance over a period of years.

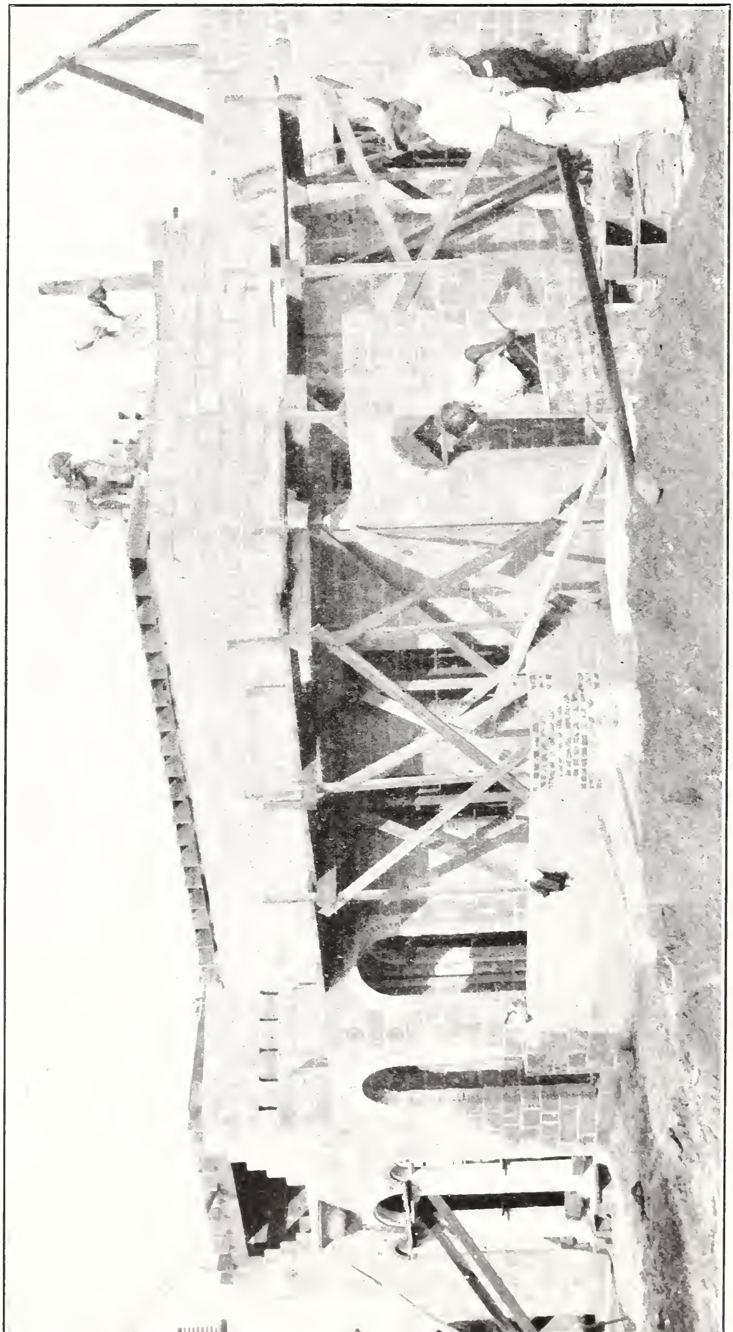

FIG. 2.—*House being constructed of rough-faced concrete block to serve as a base for Portland cement stucco*

3. TYPES OF UNITS

The masonry units included in this circular are concrete brick, block, and building tile. These can be well classified as to size, shape, and relation between concrete and core space area by the following definitions:

(*a*) Concrete Brick.—A concrete brick is a solid concrete building unit, usually rectangular in shape, of the following approximate dimensions: Height, 2¼ inches; width, 3¾ inches; and length, 8 inches.

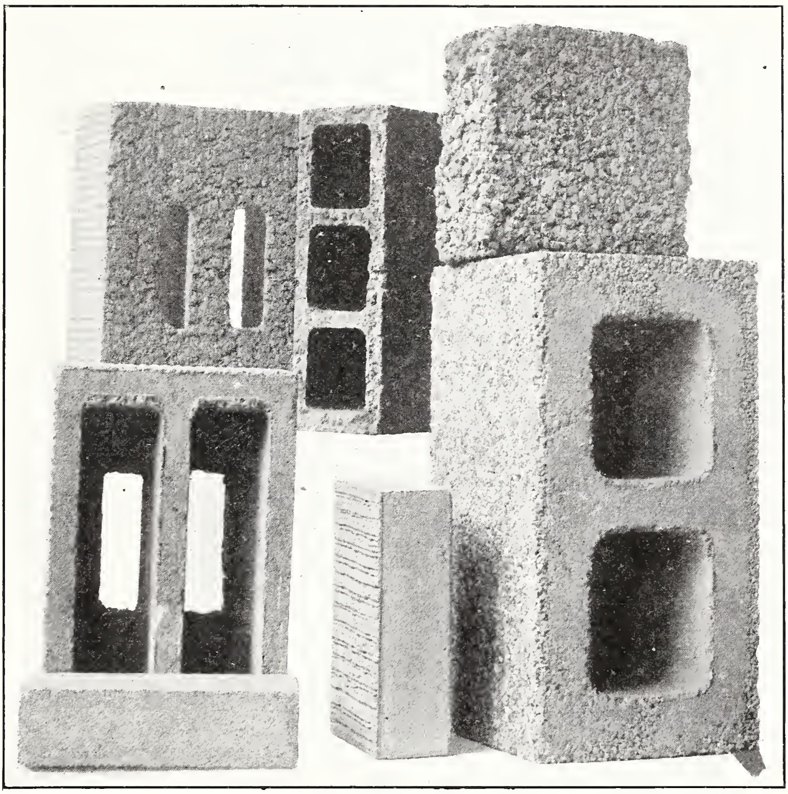

Fig. 3.—*Some commonly used types of concrete building units*

(*b*) Concrete Block.—A concrete building block is a precast rectangular unit of which approximately 60 per cent or more of the cross-sectional area, as laid in the wall, is of concrete material. There are three general types in use—solid blocks, hollow blocks having one, two, or three air cells, and two-piece blocks which are held together in the wall by mechanical means, thus affording an air space and furnishing any desired wall thickness.

At the present time there are some 12 varieties of blocks which vary in height from 1¾ to 11¾ inches, from 1¾ to 24 inches in width, and from 15⅝ to 31¾ inches in length. With the cooperation of interested societies and manufacturers, the division of simplified practice, Department of Commerce, is recommending one uniform height of 7⅝ inches, a length of 15⅝ inches, and three widths of 6, 8, and 12 inches.

(*c*) CONCRETE TILE.—A concrete tile is a smaller and lighter weight unit than the block and is generally of hollow construction. Usually the area of the concrete material as the tile is laid in the wall is less than 60 per cent of the total. There are now some six sizes in use with heights varying from 3 to 8 inches, widths from 3⅞ to 17½ inches, and lengths from 10 to 14 inches. The division of simplified practice is recommending one uniform height of 5 inches, a length of 12 inches, and three widths of 3¾, 8, and 12 inches.

Some interesting descriptions of various types of concrete products will be found in literature dealing with concrete. There have been novel designs and combinations of materials proposed or actually used, but no attempt is made to describe them in this circular.

II. MATERIALS

1. GENERAL

The three important materials used in the manufacture of concrete units are cement, aggregate, and water. Constant care in the proper gradation of the aggregate, the correct proportions of the fine and coarse aggregates to the cement, and the required amount of water to give the necessary consistency is absolutely essential in the economical production of any product of uniformly high quality.

2. CEMENT

Portland cement is generally used in the manufacture of concrete products, and some specifications do not recognize or permit the use of any other cement. Throughout this circular, unless otherwise qualified, the word "cement" means Portland cement. In order to obtain the best quality of concrete products, the cement used should meet the requirements of standard specifications and be of uniform color. The well-known commercial brands of cement on the market generally meet these requirements, but occasional lots, due to some cause or other, sometimes fail to do so. The standard tests of the cement will provide assurance to the block producer that he is using a cement meeting the necessary requirements. All cement purchased by the Government must conform to the requirements of the United States Government specifications for Portland cement as set forth in the Bureau of Standards Circular No. 33, third edition. Both the physical and chemical requirements are given, together with the methods for making the tests and analyses. The cement specifications adopted by most technical societies are the same as those used by the United States Government. The present specifications represent the results of long cooperative work between producers, technical societies, and Government offices. These specifications have been adopted by the American Engineering Standards Committee as the American Standard Specification No. 1.

The ordinary Portland cement is usually of a grayish color but varies from light yellowish gray to slate. The color is largely affected by its composition, particularly by the amount of the iron oxide content, and in some cases by manganese. The color will, therefore, depend largely on the raw materials and the process of manufacture and may not be the same even for one brand if the company producing the cement has mills at several points situated at some distance apart.

The maintenance of a uniformly colored product will, therefore, require attention to the cement, and changes from the product of one mill to that of another should not be made without consideration of this fact. The color of the two dry cements may be roughly compared by placing small quantities of each close together and then smoothing them off to an even surface, or pressing a glass down upon them, so that the cements run together. Slight differences in color of the dry cements are quite noticeable at the line of contact of the two materials.

White Portland cement is one which contains a very small iron oxide content. The same standard cement specifications govern it. It is largely used in concrete products, because its light color permits the attainment of desired color effects, either alone or with added pigment materials. White Portland cement is usually ground more finely than the average gray variety, takes up moisture more rapidly, and must, therefore, be carefully stored.

Special cements appear on the market from time to time, accompanied by various claims as to their valuable properties. Only actual tests and investigations can develop the extent to which the claims are justified, and the concrete products manufacturer should carefully ascertain the facts about new cementing materials before using them. This caution should be particularly borne in mind when considering the assertions that certain cements will produce a concrete absolutely impervious and nonabsorbent with regard to water.

3. AGGREGATES

Concrete aggregate has been defined by the committee on nomenclature of the American Concrete Institute as "the inert material which is mixed with water and cement to produce concrete. In general, aggregate consists of sand, pebbles, crushed rock, or similar materials." Usually aggregates are classified by an arbitrary line of division into fine and coarse. In general practice, the No. 4 screen is taken as the line of demarcation between the coarse and fine materials which are prepared and handled separately up to the point of mixing the concrete. The essential physical requirements for all aggregates are that they shall be clean and durable. If by test they are lacking in cleanness this can be remedied by washing, but the latter quality—durability, by which is meant weather resistance—is an important one and aggregate from a new source should not be used without a thorough investigation of its properties.

The maximum and minimum sizes of the aggregate will be governed by the process of block manufacture, the general requirements for the quality of the concrete, the desired surface effects, and also the type and dimensions of the product manufactured. However, both the fine and coarse aggregate should be graded from fine to coarse within the limiting sizes. It must be borne in mind that the workability of the mix, the amount of water required to obtain a given consistency, the strength and density of the concrete, and the surface effect will be greatly affected by large variations in size and gradations of aggregates. Particularly, the amount of cement required to attain a given strength in the product will be greatly varied by the aggregate used. Actual tests of units prepared from trial mixes will be of great assistance in determining the economical and desirable proportions of the available aggregates. Occasional tests of the aggregates themselves should be made as a check on the quality and uniformity of the supply.

The importance of fineness and gradation makes it obvious that the use of "pit-run" aggregates, or "run-of-crusher" material is undesirable. In the handling of such aggregates containing both coarse and fine material segregation of sizes always occurs. Certainty of obtaining desired proportions of relative sizes necessitates the separation of the fine and coarse aggregates, such as sand and gravel, for example, their individual storage and handling, and their recombining in the proper quantities when preparing the mixer batch. Aggregates should always be stored on clean surfaces and be protected from foreign material.

4. SAND

Natural sand is probably the most widely used fine aggregate for all concrete work. It may be defined as the loose material, smaller than gravel, resulting from the erosion and crushing of rocks. In practice, sand is now quite generally understood to be the material passing the No. 4 sieve which has openings 0.187 inch square. Sharpness, once so prominently stressed in specifications for concrete sand, is no longer considered an essential requirement for good quality. A specification for a good concrete products sand would require clean, hard, durable, uncoated grains, graded from coarse to fine, with the coarse grains predominating. It shall be free from organic matter or other harmful impurities, but may contain a small amount of silt. The proper way to select a sand for use would be to determine its grading by screening, its cleanness by washing and chemical tests, and its concrete-making value by strength tests. After the selection of a supply the shipments should be tested for uniformity of grading and cleanness. The weight per cubic foot of dry sand will necessarily vary with the limiting sizes, the grading and nature of the particles, the specific gravity, and the method used in making the determination. An approximate value for the weight can be taken at 110 pounds per cubic foot. The specific gravity for typical river sands is about 2.65, and the void space is 30 to 40 per cent of the dry packed volume. The amount of moisture contained in sand is important, as sand swells when dampened and weighs less per cubic foot than dry sand. Both the unit weight and the void space are affected by variation in the amount of contained moisture. Up to about 4 to 6 per cent moisture content there is an increase in bulk. Sometimes the bulking of volume will be as much as 20 to 30 per cent. As the amount of water increases, filling the voids, an inundated stage is reached and the sand returns to the same volume it had in the dry condition. In proportioning mixes this has a relatively large effect on the resulting concrete, and the sand should be dry if volume measurements are used, or the amount of moisture determined and corrections made for it in the amount of sand. If this is not considered, a richer mix than necessary may result.

Organic matter in a sand may produce injurious effects particularly by possible action on the setting time and the loss of strength in the resulting concrete. Small amounts of silt, clay, or loam may not be objectionable provided they do not contain any organic matter of either vegetable or animal origin. In rich mixes, where the cement supplies sufficient fine material, silt introduced with the sand will result in a loss in strength. In a lean mixture, deficient in fine material, small amounts of silt will in most cases improve the strength. It is felt that sand which has a quantity of silt not to exceed 10 per cent by weight can be used safely in the manufacture of concrete products. In all sands there should be no coating of grains which will prevent the adhesion of the cement to the grains. Small quantities of mica are usually present in ordinary river sands. It is not advisable to add much mica to a mortar to produce surface effects, since its presence may decrease both strength and weather resistant properties. More than 1 per cent of mica has been reported as being detrimental to concrete mixes. It is especially injurious in sands for surface work and causes the surfaces to dust and peel.

It has been stated previously that aggregates should be graded from fine to coarse, but for concrete products it is important that consideration be given to the minimum size. In general, for equivalent strength more cement will be required for a sand containing a very large amount of fine material than for a coarse sand. Moreover, fine sands are not desirable in the usual concrete products. Some operators endeavor to avoid the use of material passing the No. 50 sieve, and better results are obtained if the sand does not have over 20 to 25 per cent passing this sieve.

5. MISCELLANEOUS FINE AGGREGATES

Among fine aggregates other than the natural sand there may be listed such materials as crushed granite, limestone, trap rock, marble, miscellaneous stones, slag, burned clay, and cinders. A careful study of the general concrete literature bearing on the uses of the various fine aggregates, their preparation and properties, will be of considerable assistance to the manufacturer of products in producing special finishes and in the possible utilization of materials close at hand.

6. GRAVEL

Gravel, on account of its general occurrence, is largely used as coarse aggregate for concrete products. It is composed of fragments of rocks broken away from the natural beds and worn round by the process of erosion. In practice it is generally assumed as the part of such material that is retained on the No. 4 sieve. The practical requirements for its use are that it shall be clean and of a durable mineral quality, free from soft, flat, or elongated pieces. The pebbles should be graded from fine to coarse sizes. The maximum size will be limited by the dimensions of the product. A rule sometimes followed is that the diameter of the largest pebble should not exceed one-half the thickness of the minimum section of the product. Where dimensions permit, sizes up to 1 inch are often used. It is not generally practical to exclude all material finer than the No. 4 sieve and some tolerance is usually permitted. Fifteen per cent passing the No. 4 sieve can be taken as a fair tolerance. The use of the proper amount of gravel will produce a denser mix than mortar alone and give a more economical block for any required strength. The gravel may be made to form a large part of the volume of the product, and the saving in cement thus obtained is obvious. Gravel will probably prove somewhat superior to angular material resulting from crushing in the ease with which the mix can be placed and compacted in the molds.

7. CRUSHED STONE

Such rocks as granites, traps, sandstones, and limestones when crushed are good concrete materials, and they are often used as both fine and coarse aggregates. Slates and shales are not recommended for aggregates, and some forms of the sedimentary rocks may be lacking in durability. Particular care must be exercised in the use of materials from new sources, and soft and easily abraded stone should be avoided. The important physical requirements for the rock, when used as aggregate, are that it shall be of a dense structure and of durable mineral constituents. The crushed material should be of suitable sizes, as fixed by molding conditions, and be well graded from fine to coarse. It must not be expected that the run of the crusher plant with wide variation in sizes and occasional large amounts of dust can be relied upon to give uniform results. It is very important that the stone be free from excessive amounts of crusher dust, and good practice makes it advisable that broken stone aggregate, especially screenings when used as fine aggregate, have the fine dust removed.

8. SLAG

Blast-furnace slag affords an economic source of aggregate in the vicinity of large steel plants, as it is a product of the steel industry. It has been technically defined as the nonmetallic product, consisting essentially of silicate and alumino silicates of lime, which is developed simultaneously with iron in a blast furnace.

There are two general classifications—"air-cooled" and "granulated" slag—which are important in the use of this material for aggregate. The air-cooled slag has been solidified and cooled in the atmosphere while the granulated slag has been poured while molten into water. The air-cooling process forms large masses of a hard and porous material which is crushed and marketed in a variety of sizes from large coarse aggregate to slag sand passing a ¼-inch screen. The water-cooling process forms hard, dense, small grains all of which will usually pass the ¼-inch screen. The slag used in concrete should be of the air-cooled type, uniform in quality, free from metallic iron, dirt, and other objectionable matter.

Slag will vary in weight according to the quality and gradation. Committee C–9 of the American Society for Testing Materials has recommended that slag as used for coarse aggregate in concrete not subject to abrasion should weigh not less than 65 pounds per cubic foot.

As in the other aggregate materials, gradation must be considered, and large amounts of dust are undesirable. Because of its hard and porous nature and the angularity of the pieces, slag produces a harsh working mix, particularly when it is used for both fine and coarse aggregates. This deficiency can be overcome by increasing the proportion of slag sand or by adding some other fine sand or material.

9. CINDERS

Cinders are used on a large scale in some localities for the manufacture of concrete blocks. Not all cinders are equally suitable for this purpose, but, in general, cinders from power plants provide the best raw material. The suitability of cinders from any source should be determined by tests of concrete. Crushing to size is necessary, as is also the elimination of scrap iron prior to crushing and screening. Cinders are very absorbent and do not mix as readily as some other aggregates, and thorough mixing is required whenever they are used.

10. AGGREGATE SPECIFICATIONS AND TESTS

Commercial concerns dealing in most of the described aggregates will furnish them prepared as to maximum and minimum sizes and complying with reasonable screening requirements. The specifications and tests which are in general use for determining the size and quality of aggregates have been largely formulated by the committees of the American Society for Testing Materials. The following standard or tentative standards of the society have been added as appendixes to this circular.

1. Standard method of test for unit weight of aggregate for concrete.
2. Standard method of decantation test for sand and other fine aggregate.
3. Standard method of test for organic impurities in sands for concrete.
4. Standard methods of test for sieve analyses of aggregates for concretes.
5. Tentative specifications for concrete aggregates.

11. QUALITY OF MIXING WATER

Mixing water for concrete should be free from oils, acids, strong alkalies, vegetable matter, or factory wastes. Water is used not only to make a mix plastic and easily molded, but is essential in the hydration of the cement. Impurities may seriously lower the strength of the concrete, particularly the early time strength, and may effect undesirable acceleration or retardation of the setting time of the cement. The effect of temperature must not be neglected, and water should be not colder than 16° C. (60° F.). Water may be warmed by perforated steam pipes in the tanks or by specially designed heaters. Low temperature will tend to retard setting time and the early hardening. Water used for curing and surface treatments must be clean to avoid stains on the concrete. In general, water suitable for drinking purposes is usually satisfactory for concrete.

12. ADMIXTURES AND COATINGS

Various materials in both liquid and powdered form are often added to concrete mixtures to serve one or more of the following purposes: Increasing workability, early strength, water resistant properties, and improving curing conditions. They are generally known as admixtures, accelerators, or waterproofing materials. Some of them probably serve more than one purpose, and there is no sharp line of division between the several classes.

Hydrated lime, diatomaceous earth, kaolin, and fine sand have been widely used as admixtures to increase the workability and density of concrete. The powdered admixtures have been found beneficial in increasing the workability of lean or harsh working mixes. As to the density, they probably act as inert void fillers and make up for a deficiency of fine-sized material. They should not be used as substitutes for cement but as additions, probably being limited to 3 to 10 per cent by weight of the cement, depending upon their own unit weight.

The integral accelerators or hardeners are essentially compounds of calcium chloride of various concentration. It appears that their accelerating effect depends largely upon the calcium-chloride content. Flake calcium chloride is largely used for this purpose and, up to about 3 per cent by weight of the cement, increase in the amount of calcium chloride is accompanied by an increase in the early strength and a decrease in the setting time of the cement. Beyond 3 per cent the beneficial effects are not always evident, and when used in amounts above 5 per cent the calcium chloride becomes harmful, generally causing quick set and a decrease in the strength of the concrete. It is also helpful in retaining the moisture in the specimen and thus aiding the curing. Generally calcium chloride is added to the mixing water in such proportions as to obtain a solution of the desired concentration. It is recommended that all accelerators be used so that the calcium-chloride content will not exceed 3 per cent by weight of the cement used.

There are a number of chemical surface hardeners on the market consisting mainly of solutions of one of the following: Sodium silicate, magnesium fluosilicate, aluminum sulphate, and zinc sulphate. While these have been successfully used as floor treatments, it would appear that the benefits to be derived from their use on the face of the concrete block will not compensate for the added cost.

Materials used in the endeavor to increase the water resistant properties of concrete and mortar may be divided, according to the method of application, into two general classes—integral and superficial.

In the first class are (*a*) materials which are added to the water or cement when preparing the concrete mix, and (*b*) materials added to the special cement in the course of its manufacture. The "integral" compounds include inert fillers, active fillers in both liquid and solid form, and water-repellent substances. In the second class are such materials for external coating as linseed oil paints, varnishes, bitumens, liquid hydrocarbons, soaps, cements, and miscellaneous compounds.

While it is felt that there are conditions which arise when some one of the materials can be used to advantage, they will not compensate for lean mixtures, poor materials, or poor workmanship. Only actual investigation will afford definite knowledge of their merits, and it is necessary to obtain analyses and tests of such a material before it can be decided whether it is economical or even satisfactory for use. In considering the value of integral admixtures it has been found that all materials which increase the workability or early strength are not entirely satisfactory, as the tendency of many of them is to decrease the final strength especially in the richer mixes. The mix can often be improved by regrading the aggregate, adding sand of finer grading, or by the addition of small amounts of cement, and thus avoid the use of an additional ingredient in the concrete.

13. FACING MATERIALS

Various materials and different combinations thereof are used in the preparation of the surfaces described in this circular. This is particularly true when the desired finish necessitates a surface treatment subsequent to molding. Some of these special facing materials and mixtures are described in the following paragraphs.

In some cases the facing consists simply of a richer concrete or mortar, made of the same materials as the body of the block. This provides a more durable and resistant face for exposure to the weather, may assist in securing a more attractive appearance, and effect a saving in cement. In general, mixtures richer than 1 part cement to 3 parts sand have a tendency to craze.

The desired surface texture will place obvious limits on the sizes of the aggregate, particularly the maximum size. This is especially true when the surface film of cement is to be removed. However, the minimum size is of great importance, even if not so apparent at first thought. Very fine material tends to lower the strength of a mix and increases the tendency to craze and, in general, is to be avoided. Comparatively fine white sands are sometimes used for facing, but for the best results, particularly when the aggregate is to be exposed, it is usually considered advantageous to use material retained on the No. 20 sieve. Within the limiting sizes, the variations of gradations of materials are of importance in securing the desired color and texture.

The aggregates are not limited to those as found in nature, but many special materials are prepared for this purpose, such as various colored marbles, crushed granite, mica spar, slag, ceramic materials, glass, and mica. There are firms which specialize in products of this nature, and their names can be secured through some of the trade journals or associations.

For exposed aggregates it is important that their coloring be permanent. The following list illustrates the variety of colors furnished by a limited number of materials:

Granite: Pink, red, yellow, gray, dark green, black.

Marble: Various colors, white, black.

Trap: Black.

Spar: Neutral.

Sandstone: Buff, red.

Gravel: Natural colors.

Sand: White, and natural colors, some very delicate.

Slag: Some copper slag is very glassy and black.

Silica sands will not produce as intense a white as crushed white marble.

The acid solution used to remove the film of cement from the face of the blocks is usually one of muriatic acid and water. Generally the solutions vary from 1:4 to 1:7 parts of acid to water. After using, the solution should be removed from the blocks by thorough rinsing with water. Muriatic acid has a tendency to produce a yellowish tinge on white cement products, and it is suggested that for them a sulphuric acid solution be used instead. In mixing and using acid solutions, every precaution should be taken to protect the operators from serious burns.

The same general requirements apply to these special materials as are outlined under "aggregate" particularly with respect to weather resistant properties. Materials must not be used which disintegrate upon exposure to weather or which cause serious decrease in the durability of the concrete. Mica must be used sparingly, and if used it should be in a finely divided state.

14. COLORING MATERIALS AND PROCESSES

Certain color effects may be obtained or aided by selection from among the various brands of ordinary light to dark gray cements. However, when delicate tints are to be produced white Portland cement is generally required.

Various materials are used for coloring the product through their incorporation into the mix. Most of them are mineral pigments. The use of oil paints for coloring is open to question, and, considering the permanency of the colors, it is wise to adhere to the mineral

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pigments, most of which are oxides. Certain manufacturers specialize in such pigments, and it is advisable to use none but reliable colors. Both quality of product and economy demand that the colors be purchased carefully. They are usually heavy, and consideration of cost as well as freight charges make it necessary to look into the relative coloring powers as well as the lasting quality. Pigments should be finely powdered. Those with strong or powerful coloring effects are preferable, other conditions being satisfactory, for less pigment will then be needed. This is important, for excess of fine coloring materials, in general, is harmful to the concrete. The action of the various pigments on the strength of the concrete is not always similar. Some tests have indicated that certain coloring materials have about the same effect as inert powdered admixtures and cause a slight reduction in strength. One compound was reported to have produced consistent and marked strength increases. Carbon black, on the other hand, even in quantities as small as one-half per cent by weight of the cement, has been reported to have caused large decreases in strength. In general, it is recommended that the mineral color should not exceed 8 per cent by weight of the cement, and it is preferable to use less. Lampblack and carbon-gas black should not be used in anything like such large amount and also should not be depended upon to produce permanent color effects. Manganese dioxide produces a good black.

The variety of available colors is briefly outlined below. The colors of the iron oxides will vary according to their origin.

Natural iron oxides: Red, brown, chocolate.

Iron hydroxide: Yellow.

Manganese dioxide: Black.

Lampblack: Black (grayish).

Carbon-gas black: Black.

Ultramarine: Blue.

Chrome oxide: Green.

Some green pigments have at times given unsatisfactory results. The chrome oxide referred to above should not be confused with chrome greens containing Prussian blue. Some blue colorings likewise have been unsatisfactory. As in preparing paints, some desired effects can be secured through combinations of various pigments, as suggested in the following:

Green: Yellow and blue pigments.

Gray: Black.

Orange: Yellow and red.

Maroon: Red and black.

Purple: Red and black and a little ultramarine.

A variety of colors may be obtained by the selection and combination of white and gray cements and suitably colored fine aggregates.

By a process sometimes known as metallization a solution of metal salts is applied with a brush. The process is reported to have been used in Holland and to have given good weather resistant properties still manifest after three and one-half years of exposure. Sometimes units have been dipped into solutions of iron and copper sulphates and the absorbed matter left on the surface to oxidize in the weather. There are also a number of prepared cement paints and stains on the market. Investigation should be made before they are used to determine whether they are satisfactory for the particular purposes in view.

III. PROPORTIONING

1. MIXTURES

Previous sections have already treated of certain aggregates and general requirements for aggregates, particularly as to their permanent qualities. However, when cement and aggregates are combined to form concrete attention must be paid to the properties of the resultant mixture, and the proportions of the various ingredients must be so regulated as to attain as far as possible the desired results.

Once the general make-up of the mix is selected, it is evident that there must be some means of duplicating it in practice if uniformity and quality are to be maintained and economy effected. This can be done only by actual measurement of the ingredients and by keeping record of the proportions and kinds of materials used. This practically precludes the use of pit-run or crusher-run material.

There must be some systematic method of expressing the quantities used if comparisons are to be made. It is usual in practical work to express the proportions as volumes of dry materials, with cement as a basis, the order of the ingredients being cement, sand, and coarse aggregate. Thus a 1:2:4 mix consists of 1 part cement, 2 parts sand, and 4 parts gravel, all measured by volume. The amount of water is expressed in various ways, one of the convenient methods being gallons of water per bag of cement used in the mix. Sometimes proportions are expressed as parts by weight, and this may be far from the same thing as parts by volume. In the appendixes is set forth the method of determining the volume-weight ratios for aggregates. There is no standard method for determining the weight per cubic foot of Portland cement, but it is the usual custom to consider the contents of one bag, weighing 94 pounds net, as 1 cubic foot.

Aggregates are widely sold and handled on a weight basis, and in proportioning, even when expressed in terms of volumes, the materials are sometimes actually measured by the weight corresponding to the desired volume. One advantage of weight measuring methods is the ease of making proper allowance for the moisture content in fine aggregate. There is an increased consumption of cement for a given quantity of output when no allowance is made for this bulking effect of moisture in the sand. No matter which method is used in handling the aggregate, it is desirable that cement should be handled by weight, which is easy if used in units or bags. If bulk cement is used, it is strongly urged that it be measured only by weight, for attempts to handle bulk cement by volume measurement in small lots will probably give uncertain results.

In any case, whether weight or volume is the basis of proportioning, it is essential that the method used be such as will permit uniform and ready duplication of the proportioning. Consideration of economy alone should make a satisfactory system of measurement desirable.

One of the simplest of the methods for measuring volumes of aggregate is the bottomless box, made of such inside dimensions as will provide the desired cubic contents. Such a box should hold at least 1 cubic foot and is often made to hold considerably more. The box should be made of dressed lumber, well braced, preferably cubical in inside dimensions. In practice the aggregate is shoveled into the box, the surface of the material is struck off flush with the top, and the box is then lifted, leaving the aggregate. Such a box can be used to measure each batch, or else as a means of determining to what point a wheelbarrow or other irregularly shaped receptacle is to be filled. Sometimes screeds are used with wheelbarrows, being so shaped that a load of aggregate can be struck off to the desired point.

When aggregates are stored in overhead bins, and particularly where cars are used to collect the dry materials for a batch, good use can be made of measuring chutes or outlets which can be adjusted to measure the desired volumes. The use of continuous mixers necessitates the use of feeding devices which automatically maintain the desired proportions of materials. Evidently the means of measurement will depend largely on the amount of output and the type of mixer and plant equipment, but, whether simple or elaborate, means of measurement or control should be provided and occasional check made on their operation. Automatic feeding and measuring devices are made by some manufacturers.

The foregoing has set forth the advisability, indeed the necessity, of providing means of measuring and proportioning the materials and of ascertaining the sizes and gradations of the aggregates. As to the actual proportions to be used, only very general comment can be made. Regardless of theories and extensive laboratory work, it is only by actual test of a product that definite information can be secured as to the results obtainable from various combinations of the materials available. Therefore, the following remarks are but for general guidance, and the block maker is strongly urged to investigate the possibilities of his materials, as developed by tests, in order to secure desired quality with all possible economy.

For the manufacture of concrete block, brick, and tile, using no coarse aggregate, some have recommended a mix consisting of 1 part cement to 3 parts of sand by volume, but much leaner mixes are frequently used, some containing 5 and 6 parts sand. The size and gradation of a sand as well as its general characteristics will have a great effect on the workability of the mortar and strength of the product, and the wide range in recommended proportions is ample evidence of the need of tests if cement is to be used economically. In general, the coarser sand will produce the stronger concrete for a given amount of cement and similar workability of mortar. Very fine sands, as a rule, will produce products having low strength.

When coarse aggregate is employed, a mix of 1 part cement, 2½ parts sand, and 3 parts coarse aggregate is sometimes used, but here again tests are needed. The literature on concrete products contains much helpful data as to what some manufacturers have accomplished along these lines. In general, the use of coarse aggregate will tend to improve the quality of the concrete and result in higher strength and density and lower absorption. However, the manufacture of concrete building units, particularly of bricks, differs from the production of ordinary structural concrete very widely with respect to density and absorption. High density and low absorption are usually sought in ordinary concrete construction. However, the use of units, especially brick, requires certain characteristics of behavior during their laying in the wall. A very dense, or very slightly absorptive unit may have so little absorptive effect on the mortar as to make it difficult to lay it properly or speedily. Even large and experienced manufacturers have found this a point for study and test, in addition to considerations of strength and other properties. Unnecessarily high strength may be secured at the sacrifice of other desirable, almost necessary, qualities.

When units are to be faced with a special mixture and the appearance of the body is a minor matter, an economy in cement or aggregate may be effected by using a body having ample strength and yet not possessing the appearance and properties suitable for an exposed wall surface.

For facings where fine aggregate only is used, it has been recommended by some authorities that the mixes be 1 part cement to 3 parts sand. This is probably as rich as should be used, for a facing too rich in cement may have objectionable features in color, appearance, and cracking. When coarse aggregate is used with the sand, the proportions are sometimes 1:1½:3 or 1:2:3. Very fine aggregate tends to produce uniformity of color and smoothness of surface as well as sharpness of detail. However, an excessively fine sand may result in a comparatively weak facing with poor weather-resistant qualities.

2. QUANTITY OF MIXING WATER

The essential points relating to the quality of water to be used have already been discussed; but quantity of mixing water is particularly important in its effect on the properties of concrete. A certain amount of water is required for the proper hydration of the cement, and usually this amount of water is increased in construction work to assist in placing the concrete in the forms. Large increase in water above the amount needed will produce a marked decrease in strength, while the use of a very dry mix may result in a concrete which can not be molded easily or well and which may not develop a very high strength. However, the manufacture of concrete products imposes conditions peculiar to itself. Dry tamp or pressure machines will require a mix much drier than ordinary field concrete, since the blocks must be removed from the molds as soon as compressed. On the other hand, in the poured or wet block process a comparatively wet mix is used in order to secure easy and thorough filling of the molds. It would appear that in the dry tamp and pressure processes there is a tendency to use too little water. The aim in these two processes should be to use as much water as possible without causing the block to lose its shape when removed from the mold. This will not produce too wet a mix in so far as the quality of the concrete is concerned, but, on the contrary, the blocks will need additional moisture during their curing. Slump tests and other means for measuring consistency are used in construction work, but they are not suitable for such dry mixes as are here discussed. It would seem that a good rule for dry-block mixes would be to add water up to the point where the freshly stripped block will barely stand up and where the surfaces will show occasional weblike watermarks, although there may be some objection to these latter when they appear on the face. Another suggestion is that a handful of the concrete tightly squeezed should show some traces of water on the exterior. Some molding machines may permit the use of a slightly wetter mix than others, but probably most of them will handle concrete wet enough so that water will show on the back of the block after the use of a steel trowel thereon. It is said that generally the pressure-type machine will use a slightly wetter mix than the dry-tamp machine.

It is probable that much of the difficulty in the manufacture of the dry-tamp block has been caused by the lack of moisture for either mixing or curing, or probably both. The wetter mixes do not find favor with operators, since they can not always be handled as rapidly as the drier mixes directly after molding.

For the poured or cast block the mix should be just plastic enough to fill the molds readily when they are rammed or agitated. However, even this will usually require more water than desirable for the development of the maximum strength in the concrete, and the endeavor should be to cast the poured block as dry as possible and yet fill molds properly.

Whether using dry or wet processes, it is important to remember that the amount of water required depends, among other things, on the nature and gradation of the aggregate. Undesirable working properties may often be lessened by careful attention to the grading of the aggregate. An excess of fine material may require more water than desirable, while the absence of some of the finer or intermediate sizes may make a harsh working mix, even with a large amount of mixing water. Using the same aggregate, equal workability may be obtained with less water by changes in grading.

Facing mixtures are usually made somewhat drier than the backings, since the drier mixes show better effects in surface texture. However, if too dry, they may be of low strength and highly absorptive with a tendency to become spotted or discolored.

It is helpful, particularly on large-scale production, to have automatic measuring devices for the mixing water. There are a number of such devices on the market. Ordinary flush tanks have been used. However, the amounts to be used can not be definitely set beforehand if the moisture content of the aggregate varies. On this account the measuring device is often set somewhat below the figure ordinarily required and the remaining small amount added by hand during the mixing. It is sometimes found advantageous to add the water to the mix by means of a spray during the mixing operation.

3. AMOUNT OF MATERIALS

The amount of each material required for a given number of units must be known if intelligent estimates and accurate accounts are to be obtained. A careful comparison should be made of estimated and consumed quantities of materials, and stock records should be checked at intervals. The cost of cement makes this question very important. For example, any long-continued error in measuring the sand might result in an unintended increase in the consumption of cement, which is a relatively expensive ingredient. It is not sufficient to know the amount of one material only, as cement, but the quantity of each should be ascertained, for a change in market prices of raw material, or the use of some special aggregate, might make a relatively big change in the proportionate cost of some one ingredient.

Several methods for estimating the number of blocks have been proposed, some of them being based on the weights of the block and the material entering into it and expressed as the number of blocks per bag of cement. One of the approximate formulas gives the number of blocks produced from one bag of cement as the quotient obtained by dividing 400 by the weight of the block for 1:3 mortar and the number obtained for 1:2½:4 concrete as the quotient when dividing 685 by the weight of the block. Another formula estimates that for a 1:4 mortar 8½ blocks 8 by 8 by 16 inches containing 33 per cent core space are obtained from each bag of cement or 10¾ blocks when a 1:2:4 concrete is used. The best manner of determining the number of blocks is to obtain the quantity of mortar or concrete resulting from various mixtures and divide this quantity by the volume of concrete in the type of block being manufactured.

Various claims have been made as to the number of units which can be made from one bag of cement by different machines. However, assuming the mix to be the same, it would appear that the number of units would be governed largely by the dimensions of the block, its percentage of hollow or core space, and the thoroughness of compacting.

IV. MIXING

1. TIME REQUIREMENT FOR MIXING

The dry mixes used in block manufacture require longer mixing than ordinary concrete as used in construction work. Tests have shown the value of the longer mixing period for dry mixes. However, the increased benefits are not proportional to the increase in time, and after the second or third minute the gain becomes relatively smaller. At least two or three minutes mixing is always advisable. Actual study or tests of the results obtained might be of economic value in large production. When the proper time is once determined, it should be adhered to as helpful in maintaining uniformity of quality and workability of the concrete.

The pouring process will require mixes of a comparatively wet nature, and the gain in strength resultant from an increase in mixing time will not be so large as for the drier mixes. However, a mixing period of two minutes is not too long. If subjected to much delay in the process of molding, it is possible the wet mixes may require additional mixing to prevent segregation of materials. It is important that the same amount of water and time of mixing be used when duplicating colored mixes.

2. TYPE OF MIXERS

There are two classifications of mixers, according to continuity of operation—namely, batch type and continuous type. The batch mixer is the type generally used on construction work. A given charge of materials is placed therein, mixed and discharged before the next lot of materials is added. However, for large quantity production, some plants use mixers through which the ingredients pass continuously after having been proportioned by various controlling devices and during the passage the mixing is performed. The user of a continuous mixer must bear in mind that he can obtain a uniform quality of concrete only in so far as he controls the uniformity of the proportions and duration of mixing. The water supply particularly must be watched in order to meet possible variations in the moisture content of the aggregate. The successful use of dry pigments requires very thorough dry mixing of the cement and pigment to obtain uniformity of distribution and color. On that account, it is the custom to have a small mixing mill for the purpose of blending the cement and color in a dry state before adding them to the concrete mix. Likewise important is the necessity of keeping a permanent record of the treatment as well as the materials used in making colored mixes, since ready duplication of results will make such data necessary.

The essential purpose of a concrete-mixing device is to secure a thorough, intimate, and uniform mingling of the materials, and, in so far as the quality of the concrete is concerned, with given proportions of the same materials it is probable that any of the machines on the market will give satisfactory results provided they secure that uniform and intimate mixture.

3. ADAPTABILITY TO VARIOUS PROCESSES

Concrete mixers are made in a great variety of sizes and combinations of mechanical features. Many of the features are largely economic questions of capacity, desired location of mixer with respect to loading and discharging, and initial cost. However, there is one point on which some machines differ—that is, their fitness for handling very dry mixes. The dry mixes for the dry-tamp process are usually handled in machines which are particularly designed for mortars and dry concrete and in which the materials are mixed by the action of revolving blades.

4. CAPACITY AND RATING OF MIXERS

Concrete mixers are designed for certain operating conditions, particularly as it concerns capacity and speed of revolution. The rated capacity should not be exceeded, and the operating speed

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should be maintained as designed. The results of an increase in speed of rotation might fail by far to equal the effects of a corresponding increase in the time of mixing.

Fig. 4.—*A charged concrete mixer of the revolving-blade type which is particularly well adapted for mixing dry concretes and mortars*

5. CARE OF MIXING MACHINES

Regardless of what type is used, the interior of the mixer must be thoroughly cleaned at the end of each operating period, or oftener if necessary, in order to prevent the gradual accumulation of concrete which will greatly detract from the efficiency of the mixer.

V. MOLDING

1. PROCESSES

From the standpoint of molding processes, block machines would be divided into three main types—dry tamp, pressure, and pour machines.

The dry-tamp machine is probably the most widely used. The essential principle is the use of rammers to compact into a mold a mix of such dry nature that the freshly formed block can be immediately removed from the mold without breaking or serious deformation. In its simplest form, the tamping is done by hand. Even in some quite large-scale production, involving special facings, hand tamping is done in connection with comparatively inexpensive machines. Of course, this hand process will reflect the character and the amount of work of the individual. Some machines for brick making have a gang of tamping plates operated by hand.

In the ordinary dry-tamp machine heavy tampers are raised a definite height and allowed to fall freely upon the material in the mold. The number and shape of the tampers are somewhat governed by the type of the block and whether the machine has vertical or horizontal cores. The weights of the tampers vary for different machines. Regardless of the type of machine used, there is one thing to be borne in mind—tampers should compress the concrete and uniformly fill the mold, not merely disturb or separate the materials.

The pressure type of machine effects the compacting of the mortar or concrete by pressure applied by hydraulic means or by power or hand through a system of levers and toggle joints. There will be found some difference of opinion as to the actual relative merits of the dry tamp and the pressure machines. The latter can probably use a slightly wetter mix than the tamp machines.

In the pour process a wet mix is poured into molds and the concrete is worked into place by tamping, vibrating, or jigging. In some cases the jigging is accomplished by means of deformed wheels on the mold cars during the movement of the cars. The molds are usually of the gang pattern, a large number being placed on one car. The cores are generally horizontal, the finished face of the block being placed either down or up, as the process in use determines. This pouring method requires the retention of the concrete in the molds until sufficiently hardened to permit handling.

2. MOLDS

In general, the molds for concrete units are composed of several parts, which provide a form for the retention of the concrete during molding, frequently with a core or cores to produce a hollow space in the unit when molded, and mechanical arrangements which enable the operator to withdraw the cores and remove the unit from the mold. Except for portions of two-piece blocks and for special blocks, the cores are generally used to provide openings which are desired both as air space and a means of effecting economy in materials and weight. Some of the machines involve such features as the turning over of the block from a face-down position to a vertical

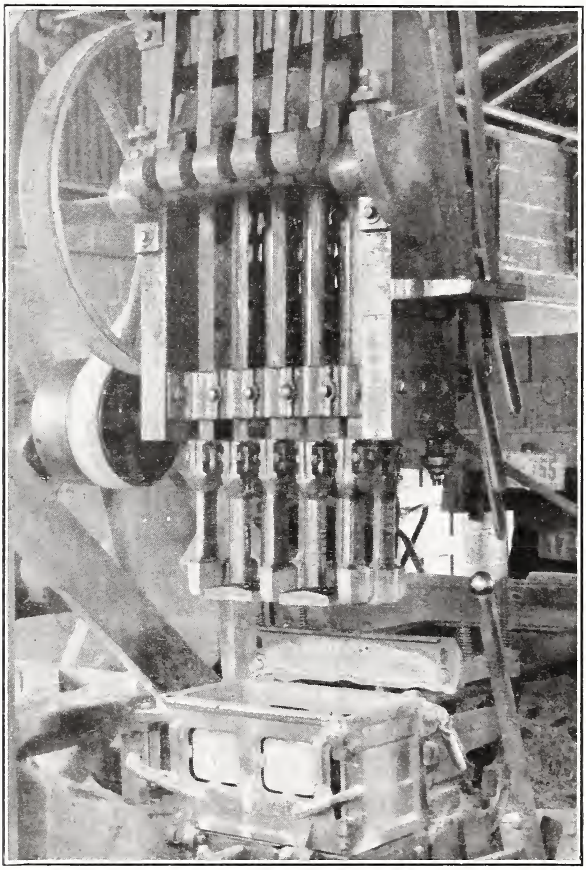

Fig. 5.—*Horizontal face block machine used in connection with power-operated tampers*

position on the pallet. In general, the molds may be divided into three classes, according to the position of the block in the mold (1) face at side, (2) face at top, and (3) face at bottom.

In the first class, with the face at the side of the mold, are many of the machines which are used for making tile for ordinary use, where special exterior finish is neglected or not desired. In this class the stripping of the vertically arranged molds and cores is easily and quickly done. Molds of the same type have been used in the making of specially faced blocks, but this requires a partition plate or other device to keep the facing material in position while the backing is placed, and the uniformity of texture of the face is not so readily maintained.

Molds with the face of the block at the top have been used, particularly in the making of brick, and where it is desired to trowel a

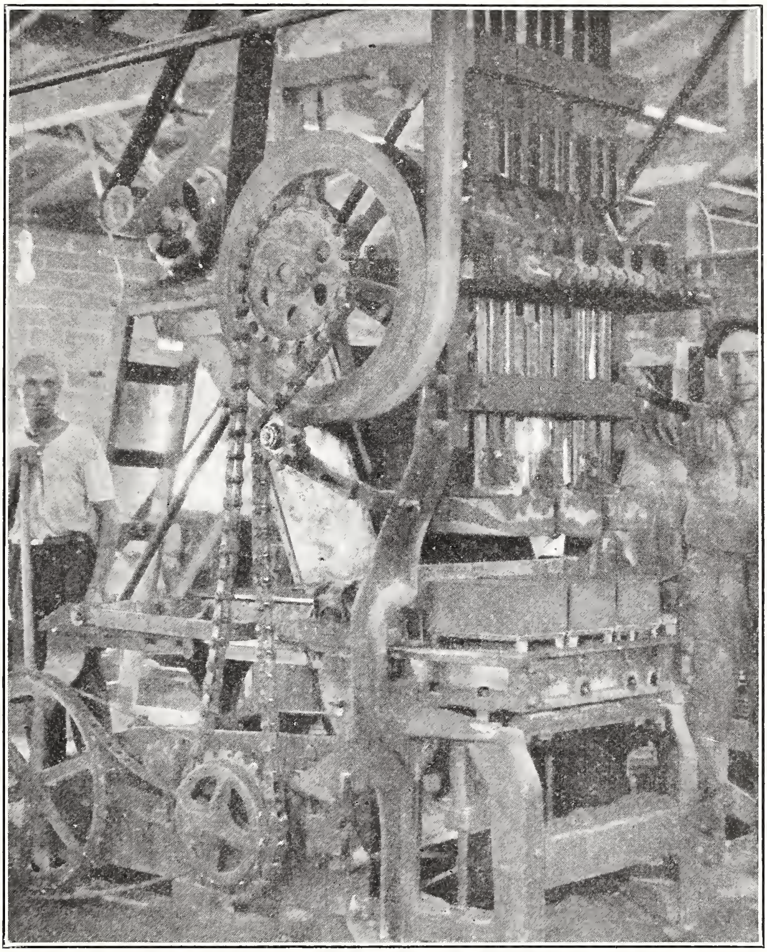

Fig. 6.—*A power-operated concrete tile machine with tile stripped ready for removal*

facing over the body, or apply some surface treatment, such as stippling, combing, or the application of special materials. This type of mold is used sometimes in making the poured blocks.

The face-down mold is probably the most generally used for specially faced concrete blocks. It has some working advantage and avoids the effects of troweling required for some of the face-up blocks. The lower part of the mold can usually be filled with facing and other material before cores are inserted, and this assists in securing uniformly compacted faces. Molds for rough, rock face, and other special design are usually of the face-down type.

The general operation of the dry-tamp, face-down mold is as follows: Add facing, if used, distribute it over faceplate, partly fill mold with backing, tamp, insert cores, fill mold, tamp, strike off and pack top, withdraw core, remove mold, remove completed block on a pallet. The facing must be thoroughly mixed and well distributed to obtain a uniform surface. The facing mix is usually of a drier consistency than that of the body. The body material should be as wet as can be used. It has been claimed that machines which provide for the turning of the mold box, so that the cores can be withdrawn vertically, permit the use of a mix wetter than those in which the cores are withdrawn horizontally.

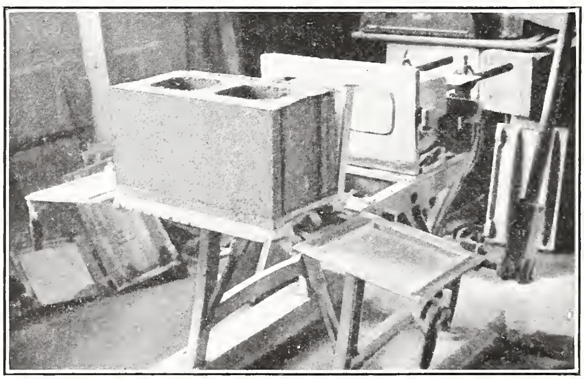

FIG. 7.—*Horizontal face block machine used in the hand-tamping process*

Note the withdrawn cores and the block turned on bottom ready for removal from the machine.

The filling of molds in the pour process sometimes requires the placing of the facing mix in the molds prior to the pouring of the body mix. One process for which patents are claimed involves the sprinkling of special aggregate on the face of the molds, previously coated with glue. When hardened, a coating of neat cement is brushed over the aggregate and the concrete poured upon it. When the concrete has set, the moisture will have softened the glue and the facing aggregate will adhere to the block but will not be hidden by any surface film of cement. Very thorough working into the molds is essential in securing faces uniform and free from air bubbles when using the face-down pour process. On the other hand, excessive tamping of a wet concrete is not desirable, for it may segregate the materials. It may sometimes be found in the pour process that improvement in the grading of the aggregate will improve the workability of the concrete to a very noticeable extent and lessen the difficulty of molding. When the gang molds are portable and can be brought to the mixer the pouring is often done directly from the mixer. However, concrete is sometimes transported from the mixer to the molds, and in such cases care must be taken to prevent segregation of material.

Oil is needed at times for molds and plates, and particularly for the molds used in the pour process. For faceplates it is advisable to use mineral oils, paraffin oil, or soft-soap liquids of such nature as will not discolor the face of the block. This is an important point for white and specially colored faces. For more ordinary faces some of the heavier black lubricating oils, thinned with kerosene, have been used. These lubricating oils will leave a dark stain, but it usually evaporates within a week or two to such an extent that it does not disfigure the ordinary cement-colored surfaces. However, these dark oils will probably leave enough traces to show more or less permanent stains on white or very light colored faces.

3. SURFACE EFFECTS

It is evident from the preceding paragraphs relating to materials, mixtures, and methods of molding that the successful use of some of the special facing methods will require some trials and observations of actual operations and results and a more detailed study than can be herein included. However, there are certain general comments which may be made here as to the effect of molding methods.

Regardless of the method used, the amount of facing material should be sufficient to prevent the body material from penetrating to the surface and to provide good corners and edges, particularly when the units are to be laid with raked joints. The facing material must be well bonded to the body of the block and should be from ½ to 1 inch thick. When the face-up method is used excessive working of the surface is to be avoided, since it may tend to bring water or cement paste to the surface and increase the tendency to craze.

In the wet-pour, face-down process, with or without special facing mixtures, there are often many small bubble holes in the faces of the blocks. These can be minimized in some instances by using as little water as possible, by improving the workability of the mix by careful grading and proportioning the aggregates, and by providing careful and thorough tamping or vibration.

The painting or spreading on of neat cement or rich grouts, sometimes containing special fine material or coloring, has frequently been done, both on ordinary blocks and on concrete bricks and special products. It does, perhaps, aid in securing desired facings or uniformity of color and is sometimes an improvement over the unfinished or untreated surface of the concrete. However, neat cement washes and thin rich coatings applied to bodies with relatively different expansive properties, even if they adhere, will often craze badly. Their use should be carefully tried out before any large number of blocks are so treated. Special cement paints should also be observed for their permanency in body and color when exposed to the weather and for any tendency to rub or "dust."

Special patterns and effects, with or without other treatments, are obtained by the use of specially shaped molds. They are sometimes used to good effect in producing bevels or margins similar to those on cut stone. The use of such molds requires care in the proper filling of details and the handling of the product during hardening.

The "rock-faced" type of block has been used very widely and yet has been greatly criticized. It is suggested that the prospective maker or buyer consider carefully the suitability of this type. Local preference or special work may make it a desirable and profitable line. However, there is also much sentiment against it. Perhaps one of the chief objections may be the extreme sameness or monotony resulting from the use of only one or at the most a very limited number of faceplate designs. The constant repetition of the same pattern in a wall, particularly when the sun is in position to cast deep shadows across the faces of the blocks, emphasizes the fact that the material is not only imitative, but is a poor imitation.

One of the very widely practiced methods of obtaining relief from the monotony of the cement color, or in securing desired surface effects, has been the exposure of the aggregate just beneath the surface by removing the overlying film of cement. Perhaps the simplest method has been the washing off of the film by means of a fine spray while the block is in the mold or just after it has been removed. This process frequently involves the use of no special quality of aggregate, although the grading may be varied from that in the back of the block. The spraying may be assisted by the use of a brush. The time at which spraying may be done will vary greatly, according to the methods used, the richness of the mix, and the rate of hardening of the cement. The water spray should be used before the cement has become appreciably hard. A second spraying may be found of value in clearing up the surface of the aggregate. Some consider it advisable to have the blocks face up during the spraying to avoid the streaking or accumulation of film on the surface of the aggregate or injury to lower edge due to the running off of the spraying water. Care must be taken to prevent the dripping of water from one block upon the surface of another freshly made unit. Often the concrete is allowed to attain a slight degree of hardness, and then it is scrubbed with water and a fiber brush, with possibly a muriatic-acid solution. When still harder, wire brushes or wire cloth are used, together with a solution of muriatic acid.

Carborundum stone is sometimes used on hard concrete. The sand blast also has been utilized to remove the cement coating from the aggregate after the concrete has attained an age of about a month.

In the manufacture of monumental cast stone and special pieces the concrete is sometimes finished by stoneworking machinery, involving surfacing, grinding, and polishing. However, this is usually done on products other than building blocks.

There is on the market a special preparation to be applied as a coating to the interior faces of the mold to prevent the hardening of cement to a slight depth below the surface of the concrete. After approximately 24 hours the film of cement may be readily brushed from the aggregate. This material is prepared as a paste and also as a coated paper. With the cement film removed, there is a great variety of effects obtainable through the use of special aggregates. The great number of colors and surface characteristics of the aggregate, the effects of varying gradations, sizes, and combinations of materials, and the contrast or harmony resulting from the judicious use of color in the binding medium afford the concrete-products maker a means of developing the architectural possibilities as to color and texture.

4. CRAZING

Small check marks or cracks, usually of a weblike nature, sometimes seen on concrete products, are known as "crazing." When the surfaces are moist, crazing is particularly noticeable. It is the result of volume changes incident to variations in moisture and temperature and the setting of the concrete. With very thin, rich coatings on relatively lean bodies crazing generally appears. How to prevent crazing on concrete products is a question which is now engaging the attention of many investigators. However, much can be done by the concrete-products manufacturer to lessen the tendency to craze by using lean facing mixtures, providing thorough curing, avoiding excessive troweling of surfaces, not using too much water, using coarse surfacing materials, and removing the surface film of cement in which the cracks are often so pronounced. In some cases the use of a different body mix might be helpful. Exposure of fresh concrete to sun or wind should be avoided.

VI. CURING

1. NECESSITY

Characteristic of all concrete work is the need for proper and adequate curing of the freshly molded product. This need of proper curing treatment has been neglected not only in the past by some producers, but is even now sometimes wholly neglected. Some advertising literature pictures freshly made products exposed to the weather. The total neglect of curing is not general, but even the occasional small cases where curing has been neglected have not helped the reputation of concrete products. There has been a great deal written on this subject and many trade publications, technical books, and committee reports contain details of curing processes. Valuable information as to details of construction, general layout, and capacity of curing chambers can be found in the proceedings of the American Concrete Institute and publications of some of the cement manufacturers. Only some general statements will be made in this paper.

2. STEAM CURING

Curing as generally practiced consists in providing moisture and heat. Since moisture is so important, steam is preferable to dry heat. Generally, steam-curing chambers consist of long tunnel-like rooms of masonry or concrete construction, provided with doors at each end, one to the molding room and the other to the storage yard. Usually the steam is admitted through outlets submerged in water-filled troughs or wells in the floor. Steam radiation coils are also provided on the walls where increased heat is needed. After molding the product is stored in the curing chambers, often being carried on steel cars along tracks in floor or on rubber-tired lift trucks. Curing is usually continued for 24 to 48 hours, depending on the material and weather, the longer period being preferable and even three or four days of curing being desirable in cold weather.

The time within the steam chamber should, perhaps, vary according to the outside temperature. If the temperature is warm or moderate, water can be sprinkled on the blocks for the first few days after removal to outdoor storage and curing thus extended. However, when temperature approaches freezing, it may not be advisable to wet down the blocks in yard storage, and the chamber curing will be more effective in obtaining strength. The products need moisture while curing, and dry steam must not be used without sufficient water.

The following suggestions are offered for the consideration of prospective investors in steam-curing equipment:

Examine detailed descriptions and layouts of other plants which appear in various trade and technical literature. The report of committee P–6, American Concrete Institute, contains considerable data on the subject of "Details of estimating steam curing equipment." The construction should be substantial and the capacity should be sufficient to care for the output for the desired period of curing. Good tight-fitting doors are essential to maintain uniform conditions and conserve fuel. Concrete floors are advisable with a slope to the steam troughs or drains. The ceilings of chambers should be sloped so that condensation will not drop on the faces of freshly made blocks but will be carried to the side walls.

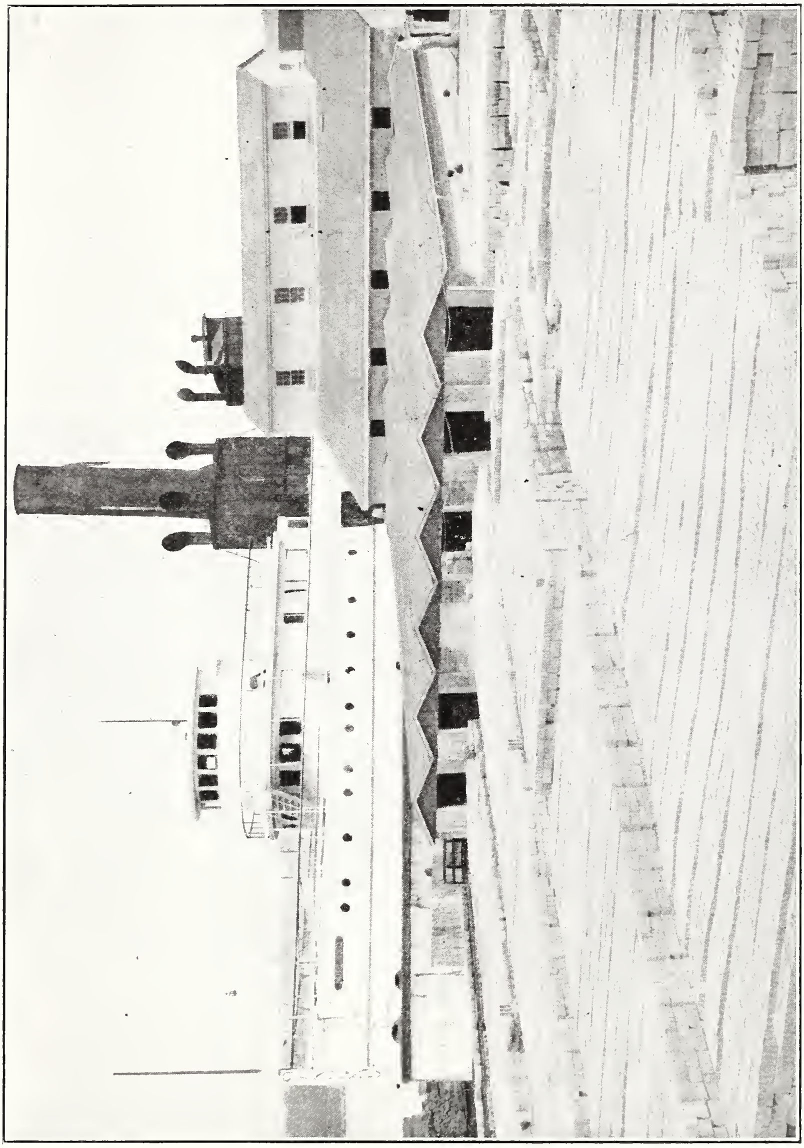

Fig. 8.—*A well-designed concrete products plant showing the location of the six steam curing chambers between the plant proper and the storage yard*

If the faces of blocks are kept from drying out prior to commencement of curing this may assist in avoiding undesired surface effects. It is preferable that there be no period of drying between molding and completion of steam curing. Drafts of air are to be avoided, but free access of moist air in the curing chambers should be provided by arranging the blocks so that they do not rest on each other.

The temperature of the storage chamber will vary but should be at least 38° C. (100° F.). In cold weather it will be of material assistance in maintaining curing temperature if the aggregates and mixing water are heated to 16° C. (60° F.), and it is advisable to maintain the working rooms at this temperature as a minimum. The temperature of the green concrete when first placed in the curing chamber must not be too low, or vapor will condense too rapidly and cause possible marking and injury on surfaces and edges. It has been recommended by some that the difference in temperatures of the product and the chamber should not exceed 20° C. (35° F.). The temperature of the chamber should not be raised very much until the products have been in it long enough to become warm (probably five or six hours), and thus avoid condensation. The steam assists in securing uniform curing conditions in chamber, but live steam must not strike fresh concrete products.

3. MOIST CURING

Although often lacking the benefits derived from the warmth of steam curing, moisture alone is of great assistance in securing better curing than would be derived from immediate open-air storage. Of course, as protection and inclosure are decreased so are the benefits of curing lessened or, perhaps, made uncertain.

Moist-chamber storage is sometimes used without steam. The essentials are a room maintained at temperatures between 16° C. (60° F.) and 38° C. (100° F.) and free from drafts. Evaporation must be prevented. When the specimens have become sufficiently hardened, they are sprinkled and maintained in a moist condition for the number of days desired (10 or more usually specified). Moist-air storage is usually supplemented by yard storage.

4. AIR CURING

In some plants blocks are "air cured" by sprinkling several times daily. When out of doors or under a roof and exposed to drafts, clean straw or boards are often used to cover the blocks, layers of straw or hay being placed between the several courses. Water must not be applied to the product until the initial hardening has occurred and danger of washing material away is past. Even then the water should not be directed in strong streams against freshly molded material. It is customary to equip chambers with special spray nozzles for distributing the water.

5. IMMERSION

Total immersion has been used for curing, but it is not recommended for all products, particularly for those with special surface effects which would probably become somewhat obscured or injured by such treatment.

6. ACCELERATORS

"Accelerators" have been used to aid in the curing of concrete. Combined with the possible benefits to the curing derived from the use of calcium chloride there is an increased rate of hardening during the first several days. It is recommended that the use of an accelerator for curing be preceded by some investigation of its merit and economy. In no case should accelerators be relied upon to take the place of heat or proper protection in cold weather. Investigation should also be made as to the possible effects any compound may have on the surface of specially prepared blocks. Accelerators may increase the output of the plant by decreasing the length of time in curing chambers, lessening the number of forms in use, and decreasing the breakage in handling newly made units.

7. GENERAL

The proper curing of concrete blocks requires that newly molded or incompletely cured products be protected from the sun, evaporation, strong air currents, excessive dry heat, or freezing temperatures. In determining by trial specimens the quantities of materials required for certain color effects, it should be remembered that the average block when cured and dry will be lighter colored than when moist. Accelerated drying may also produce effects in colors different from that obtained in the usual curing process. Experimental pieces should be subjected to conditions actually to be used in the manufacture of the blocks, at least for the first few days. As a rule, colored concrete products are not cured by the steam-curing process because of the possibility of spotting and efflorescence.

VII. REQUIREMENTS FOR CONCRETE PRODUCTS

1. GENERAL

There are certain requirements which concrete products must meet if their use is to be generally satisfactory. Some of these requirements are obviously imposed by the conditions of use. Others, such as architectural and structural, are not so evident and are imposed either by local ordinances or commonly used standards. The specifications of the American Concrete Institute are frequently used for determining the quality of concrete units and cover requirements for unit weight, strength, absorption and quality of cement. As a matter of information they are printed as an appendix to this paper. There are also in frequent use the American Society for Testing Materials tentative specifications covering the testing of brick. These have been recently adopted, and amendments may be expected from time to time. As the methods of testing are somewhat different under these two specifications, all reports on concrete products should clearly indicate the procedure by which the tests were made.

2. STRUCTURAL REQUIREMENTS

Municipal codes are chiefly matters of local interest, and the block manufacturer should familiarize himself with the requirements relative to properties and uses of concrete units, such as strength, absorption, use in exterior, party, fire, and foundation walls, chimneys, and for the support of floor joists. In any case the block maker should consider the practical limitations on the use of his product.

Occasional tests, even if not imposed by the regulations, are desirable as indications of quality and as sources of data for study of possible economy. There are other points worthy of study, and the producer is urged to familiarize himself with data from investigations of weight, weather-resistant properties, insulating value against heat and cold, and moisture penetration.

3. ARCHITECTURAL REQUIREMENTS

Architectural requirements vary widely. It is probable that the block manufacturer in some localities will find it worth while to study the various means of improving the appearance of his product and increasing the variety of finishes from which the architect may choose. The concrete-block industry has not benefited by the use of products which were carelessly finished, of monotonous color and surface, and poorly imitative of natural stone. Indeed, one of the faults may have been the frequent effort to imitate not only the material but the workmanship on the natural stone. The prominence of craze cracks on much of the smooth surface material has detracted from the general appearance of many jobs.

Concrete-block construction furnishes one of the best surfaces obtainable for the application of Portland cement stucco. The blocks, the mortar used in setting them and the stucco coatings, being made of similar materials, will have approximately the same rate of expansion and contraction, and the danger of any unsightly cracking of the stucco is greatly minimized. Concrete block for stucco walls should be rough and of a coarse texture in order to secure a uniform and effective adhesion between the block face and the scratch coat of the stucco.

4. FIRE-RESISTANT PROPERTIES

From the viewpoint of economy and structural reliability particular attention is paid by many to the fire-resistant properties of the concrete units. Much has been written in the line of general discussion of this matter. A large amount of test data have been collected over a number of years by various laboratories, indicating the behavior in fire of concrete aggregate and reinforced concrete construction. However, all of the results are not directly applicable to the behavior of the hollow concrete unit. The Underwriters Laboratories, of Chicago, have made a series of fire tests on concrete blocks involving a number of different concretes. These tests were made for the American Concrete Institute, Concrete Products Association, and the Portland Cement Association.

Fire tests require special equipment. The brief and improvised fire tests of concrete units are not without meaning, but definite statements of the fire-resistant properties of the concrete units must have as a basis the results of thorough tests. Tests to be of value must be carried out on typical wall sections and require special laboratory equipment for the application of fire, the measurement of temperature, and the maintenance of the desired superimposed loads on the wall panel during test.

5. CONSIDERATION OF TEST DATA

The discussion of tests and properties should not only consider the conditions governing the tests but also the terms descriptive of the results. Particularly, the terms permeability and absorption should not be confused. A concrete under a given condition may be practically impermeable and yet show high absorptive properties. Dense concrete, or the apparent water-repellant nature of a surface, should not be taken to mean absence of water-absorbent properties. Absorption tests are easily made. However, absorption does not appear to be definitely related to strength, durability, or permeability of a concrete. The relative absorptive properties may not be indicative of the relative durability of concrete products, although low absorption is usually associated with dense, strong concrete.

VIII. SPECIAL CONCRETE PRODUCTS

There are a number of special lines of endeavor open to the concrete products maker. Among them are the manufacture of special shapes, porch block and rails, ornamental trim, precast steps, garden furniture, silo blocks, posts, drain tile, tubs, troughs, light standards, floor tile, and roofing tile. Before engaging in the production of any of them a study should be made of the particular problems involved. The successful production of certain specials requires not only a considerable outlay of capital but the employment of experienced operators in such work as carving, glue molds, surface treatments, and stoneworking. Some localities will prove more favorable to a certain product than others. Certain lines will require comparatively large investment in special pallets and molds.

IX. ECONOMIC CONSIDERATIONS FOR PROSPECTIVE INVESTORS

The profitable manufacture of concrete building products in one locality does not necessarily justify the investment in a similar enterprise in another place or even an additional project in the same locality. The possible market should be studied, with attention not only to local building restriction, but to competition from other concrete unit makers and particularly the competition from the producers of building units of other materials, such as clay, sand-lime brick, and stone. The source of raw materials is important, and local or near-by aggregates should be investigated. Some large plants have been located near the source of raw materials, even though the finished product had to be hauled a considerable distance to market. In conjunction with freight rates and hauling, consideration should be given to the cost or rental of the land and the possibility for enlargement of the plant. In connection with the selection of materials, design, unit, and process of manufacture the question of patent claims should not be overlooked. Litigation has resulted from a number of disputes over patent claims.

The choice of the type and size of block is not altogether separated from the choice of the materials and processes. However, certain points of interest bear on the subject. Large blocks displace more brick or other small units than do the smaller blocks, but in some localities it is possible that the smaller, lighter unit will meet with more favor, particularly with the mechanic. Progress is being made in standardization of sizes, and those selected should meet the recommendations of the division of simplified practice.

The number and size of core spaces is governed by the dimensions of the block, thickness of walls, type of material used, whether faced block or unfinished tile, and whether tamped or poured. When much cutting of blocks is to be done it appears that there is an advantage in having one or more intermediate webs across the interior. Also regulations, specifications, or structural demands may limit the area of core spaces. Local demands alone may largely govern the type of block to be made. The decision as to rough, rock-face plates should involve consideration not only of the probable demand for them, but the necessity of having a variety of mold plates to avoid monotony of product and to care for special sizes and shapes.

The choice of a machine will be affected by many factors, among them type of block desired, cost and rate of production, and process to be employed. The first cost of the machine is not sufficient basis for decision. The rate of production claimed for any machine must take into account the conditions under which that production was attained, the number of men, amount of power employed, and particularly the estimated maximum output and curing capacity of the proposed plant. Hand-tamped block machines have in some cases been considered economical, even with considerable output. The method of operating the tamper of power machines is also one which should be considered as well as the weights and drops of the tampers and the materials used in the parts subject to greatest wear.

The quantity of molds or pallets required will be controlled largely by the desired output. In the pour process the concrete must remain in the molds until it has hardened sufficiently to handle, which is generally about 24 hours. The number of pallets for tamped or pressed units will be controlled by the daily output, together with the length of time they are to remain in curing chambers. Consideration should also be given to the merits and relative economy of metal pallets and wood pallets.

Mixers involve not only the question of capacity and general type which will be largely settled by the desired rate of production and choice as to wet or dry process, but there are also factors that depend somewhat on the layout of the plant. Some conditions may make it advisable to purchase mixers with power-operated loading devices to lift the charge. In other layouts the materials may be conveniently transported above the mixers by means of barrows, trolleys, chutes, or conveyers. Likewise, plant layout and method will affect the choice as to the discharging operations and the facilities for cleaning.

The kind and amount of power required in the operation of a plant will be governed largely by individual layouts and processes and the cost of labor. Where electricity is used for a considerable number of machines, it would appear advisable to use individual direct-motor drive. This not only eliminates much shafting and belting but provides a more flexible unit when repairs or partial shutdowns are necessitated. If steam power is used, it should be remembered that the steam curing of a large output not only demands a constant supply of steam, but that steam under high pressure is not desirable for curing. It will probably be found advisable to provide a separate steam source for the curing.

Estimates of cost of production must include the first cost of plant and equipment, depreciation, overhead, and cost of raw material, labor, freight, and drayage. The successful operation of a concrete products plant, large or small, requires consideration of the relative merits of various methods, machines, and materials prior to their selection and thereafter a careful accounting of the actual cost of production.

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XI. APPENDIX

Standard Specifications for Concrete Building Block and Concrete Building Tile

[Submitted by Committee P–1, on Standard Building Units. American Concrete Institute. (Serial Designation P–1A–25)]

1. GENERAL

1. The purpose of these specifications is to define the requirements for concrete building block and concrete building tile to be used in construction.

2. The word "concrete" shall be understood to mean Portland cement concrete.

Strength Requirements.—3. According to the strength in compression 28 days after being manufactured or when shipped, concrete block and concrete tile shall be classified as heavy load bearing, load bearing, and nonload bearing on the basis of the following requirements:

Name of classification	Compressive strength in pounds per square inch of gross cross-sectional area as laid in the wall	
	Average of three or more units	Minimum for individual unit
Heavy load-bearing block or tile	1,200	1,000
Medium load-bearing block or tile	700	600
Nonload-bearing block or tile	250	200

4. The gross cross-sectional area of a one-piece concrete block or tile shall be considered as the product of the length times the width of the unit as laid in the wall. No allowance shall be made for air spaces in hollow units. The gross cross-sectional area of each unit of a two-piece block or tile shall be considered the product of the length of the unit times one-half the thickness of the wall for which the two-piece block or tile is intended.

5. The compressive strength of the concrete in units of all classifications except "nonload-bearing block" shall be at least 1,000 lbs./in.^{2} when calculated on the minimum cross-sectional area in bearing.

Absorption Requirements.—6. Concrete building block and tile to be exposed to soil or weather in the finished work (without stucco, plaster, or other suitable protective covering) shall meet the requirements of the absorption test.

7. All concrete building block and tile not covered by paragraph 6 need not meet an absorption requirement.

8. Concrete block and tile shall not absorb more than 10 per cent of the dry weight of the unit when tested as hereinafter specified, except when it is made of concrete weighing less than 140 lbs./ft.^{3}. For block or tile made with concrete weighing less than 140 lbs./ft.^{3} the absorption in per cent by weight shall not be

more than 10 multiplied by 140 and divided by the unit weight in pounds per cubic foot of the concrete under consideration.

Sampling.—9. Specimens for tests shall be representative of the commercial product of the plant.

10. Not less than three and preferably five specimens shall be required for each test.

11. The specimens used in the absorption test may be used for the strength test.

2. METHODS OF TESTING

Absorption Test.—12. The specimens shall be immersed in clean water at approximately 70° F. for a period of 24 hours. They shall then be removed, the surface water wiped off, and the specimens weighed. Specimens shall be dried to a constant weight at a temperature of from 212 to 250° F. and reweighed. Absorption is the difference in weight divided by the weight of the dry specimens and multiplied by 100.

Weight of Concrete.—13. The weight per cubic foot of the concrete in a block or tile is the weight of the unit in pounds divided by its volume in cubic feet. To obtain the volume of the unit fill a vessel with enough water to immerse the specimen. The greatest accuracy will be obtained with the smallest vessel in which the specimen can be immersed with its length vertical. Mark the level of the water, then immerse the saturated specimen and weigh the vessel. Draw the water down to its original level and weigh the vessel again. The difference between the two weights divided by 62.5 equals the volume of the specimen in cubic feet.

Strength Test.—14. Specimens for the strength test shall be dried to constant weight at a temperature of from 212 to 250° F.

15. The specimens to be tested shall be carefully measured for over-all dimensions of length, width, and height.

16. Bearing surfaces shall be made plane by capping with plaster of Paris or a mixture of Portland cement and plaster which shall be allowed to thoroughly harden before the test.

17. Specimens shall be accurately centered in the testing machine.

18. The load shall be applied through a spherical bearing block placed on top of the specimen.

19. When testing other than rectangular block or tile, care must be taken to see that the load is applied through the center of gravity of the specimen.

20. Metal plates of sufficient thickness to prevent appreciable bending shall be placed between the spherical bearing block and the specimen.

21. The specimen shall be loaded to failure.

22. The compressive strength in pounds per square inch of gross cross-sectional area is the total applied load in pounds divided by the gross cross-sectional area in square inches.

Standard Specifications for Concrete Brick

[Submitted by Committee P-1 on Standard Building Units American Concrete Institute. (Serial Designation P-1B-25)]

1. GENERAL

1. The purpose of these specifications is to define the requirements for concrete brick to be used in construction.

2. The word "concrete" shall be understood to mean Portland-cement concrete.

3. The average compressive strength of concrete brick 28 days after being manufactured or when shipped shall be not less than 1,500 lbs./in.^{2} of gross cross-

sectional area as laid in the wall, and the compressive strength of any individual brick shall be not less than 1,000 lbs./in.^{2} of gross cross-sectional area as laid in the wall.

4. The gross cross-sectional area of a brick shall be considered as the product of the length times the width of the unit as laid in the wall.

5. Concrete brick shall not absorb more than 12 per cent of the dry weight of the brick when tested as hereinafter specified except when they are made of concrete weighing less than 125 lbs./ft.^{3} For brick made of concrete weighing less than 125 lbs./ft.^{3} the average absorption in per cent by weight shall be not more than 12 multiplied by 125 and divided by the unit weight in pounds per cubic foot of the concrete under consideration.

6. Specimens for tests shall be representative of the commercial product of the plant.

7. Five specimens shall be required for each test.

8. The specimens used in the absorption test may be used for the strength test.

2. METHOD OF TESTING

Absorption Test.—9. The specimens shall be immersed in clean water at approximately 70° F. for a period of 24 hours. They shall then be removed, the surface water wiped off, and the specimens weighed. Specimens shall be dried to a constant weight at a temperature of from 212 to 250° F. and reweighed. Absorption is the difference in weight divided by the weight of the dry specimens and multiplied by 100.

Strength Test.—10. Specimens for the strength test shall be dried to constant weight at a temperature of from 212 to 250° F.

11. The specimens to be tested shall be carefully measured for over-all dimensions of length, width, and thickness.

12. Bearing surfaces shall be made plane by capping with plaster of Paris or a mixture of Portland cement and plaster which shall be allowed to thoroughly harden before the test.

13. Specimens shall be accurately centered in the testing machine.

14. The load shall be applied through a spherical bearing block placed on top of the specimen.

15. Metal plates of sufficient thickness to prevent appreciable bending shall be placed between the spherical bearing block and the specimen.

16. The specimen shall be loaded to failure.

17. The compressive strength in pounds per square inch of gross cross-sectional area is the total applied load in pounds divided by the gross cross-sectional area in square inches.

Standard Method of Test for Unit Weight of Aggregate for Concrete

[Serial Designation: C 29–21]

[Proposed as tentative, 1920; adopted, 1921]

[This method is issued under the fixed designation C 29; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision. This method was approved May 29, 1923, as "Tentative American Standard" by the American Engineering Standards Committee]

1. The unit weight of fine, coarse, or mixed aggregates for concrete shall be determined by the following method:

2. (*a*) The apparatus required consists of a cylindrical metal measure, a tamping rod, and a scale or balance, sensitive to 0.5 per cent of the weight of the sample to be weighed.

(*b*) *Measures.*—The measure shall be of metal, preferably machined to accurate dimensions on the inside, cylindrical in form, water-tight, and of sufficient rigidity to retain its form under rough usage, with top and bottom true and even, and preferably provided with handles.

The measure shall be of $\frac{1}{10}$, ½, or 1 cubic foot capacity, depending on the maximum diameter of the coarsest particles in the aggregate, and shall be of the following dimensions:

Capacity in cubic feet	Inside diameter	Inside height	Minimum thickness of metal, U. S. gauge	Diameter of largest particles of aggregate
	Inches	*Inches*	*No.*	*Inches*
$\frac{1}{10}$	6.00	6.10	11	Under ½
½	10.00	11.00	8	Under 1½
1	14.00	11.23	5	Over 1½

(*c*) *Tamping Rod.*—The tamping rod shall be a straight metal rod ¾ inch in diameter and 18 inches long, with one end tapered for a distance of 1 inch to a blunt bullet-shape point.

3. The measure shall be calibrated by accurately determining the weight of water at 16.7° C. (62° F.) required to fill it. The factor for any unit shall be obtained by dividing the unit weight of water at 16.7° C. (62° F.)[1a] by the weight of water at 16.7° C. (62° F.) required to fill the measure.

4. The sample of aggregate shall be room dry and thoroughly mixed.

5. (*a*) The measure shall be filled one-third full and the top leveled off with the fingers. The mass shall be tamped with the pointed end of the tamping rod 25 times, evenly distributed over the surface. The measure shall be filled two-thirds full and again tamped 25 times as before. The measure shall then be filled to overflowing, tamped 25 times, and the surplus aggregate struck off, using the tamping rod as a straightedge.

In tamping the first layer the rod should not be permitted to forcibly strike the bottom of the measure. In tamping the second and final layers only enough force to cause the tamping rod to penetrate the last layer of aggregate placed in the measure should be used. No effort should be made to fill holes left by the rod when the aggregate is damp.

(*b*) The net weight of the aggregate in the measure shall be determined. The unit weight of the aggregate shall then be obtained by multiplying the net weight of the aggregate by the factor found as described in section 3.

6. Results with the same sample should check within 1 per cent.

Tentative Method of Decantation Test for Sand and Other Fine Aggregates

[Serial Designation: D 136–22 T]

[Issued, 1922]

[This is a tentative standard only, published for the purpose of eliciting criticism and suggestions. It is not a standard of the society and until its adoption as standard it is subject to revision]

1. This method of test covers the determination of the total quantity of silt, loam, clay, etc., in sand and other fine aggregates.[2]

2. The pan or vessel to be used in the determination shall be approximately 9 inches (230 mm) in diameter and not less than 4 inches (102 mm) in depth.

3. The sample must contain sufficient moisture to prevent segregation and shall be thoroughly mixed. A representative portion of the sample sufficient

[1a] The unit weight of water at 16.7° C. (62° F.) is 62.355 lbs./ft.^{3}

[2] This determination of the percentage of silt, clay, loam, etc., will include all water-soluble material present, the percentage of which may be determined separately if desired.

to yield approximately 500 g of dried material shall then be dried to a constant weight at a temperature not exceeding 110° C. (230° F.).

4. The dried material shall be placed in the pan and sufficient water added to cover the sample (about 225 cc). The contents of the pan shall be agitated vigorously for 15 seconds and then be allowed to settle for 15 seconds, after which the water shall be poured off, care being taken not to pour off any sand. This operation shall be repeated until the wash water is clear. As a precaution the wash water shall be poured through a 200-mesh sieve and any material retained thereon returned to the washed sample. The washed sand shall be dried to a constant weight at a temperature not exceeding 110° C. (230° F.) and weighed.

5. The results shall be calculated from the formula:

$$\text{Percentage of silt, clay, loam, etc.} = \frac{\text{Original dry weight} - \text{weight after washing}}{\text{Original dry weight}} \times 100$$

6. When check determinations are desired, the wash water shall be evaporated to dryness, the residue weighed, and the percentage calculated from the formula:

$$\text{Percentage of silt, loam, clay, etc.} = \frac{\text{Weight of residue}}{\text{Original dry weight}} \times 100$$

Standard Method of Test for Organic Impurities in Sands for Concrete

[Serial Designation: C 40–22]

[Proposed as tentative, 1921; adopted, 1922]

[This method is issued under the fixed designation C 40; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision. This method was approved May 29, 1923, as "Tentative American Standard" by the American Engineering Standards Committee]

1. The test herein specified is an approximate test for the presence of injurious organic compounds in natural sands for cement mortar or concrete. The principal value of the test is in furnishing a warning that further tests of the sand are necessary before they be used in concrete. Sands which produce a color in the sodium hydroxide solution darker than the standard color should be subjected to strength tests in mortar or concrete before use.

2. (*a*) A representative test sample of sand of about 1 pound shall be obtained by quartering or by the use of a sampler.

(*b*) A 12-ounce graduated glass prescription bottle shall be filled to the 4½-ounce mark with the sand to be tested.

(*c*) A 3 per cent solution of sodium hydroxide ($NaOH$) in water shall be added until the volume of sand and liquid after shaking gives a total value of 7 liquid ounces.

(*d*) The bottle shall be stoppered and shaken thoroughly and then allowed to stand for 24 hours.

(*e*) A standard color solution shall be prepared by adding 2.5 cc of a 2 per cent solution of tannic acid in 10 per cent alcohol to 22.5 cc of a 3 per cent sodium hydroxide solution. This shall be placed in a 12-ounce prescription bottle, stoppered and allowed to stand for 24 hours, then 25 cc of water added.

(*f*) The color of the clear liquid above the sand shall be compared with the standard color solution prepared as in paragraph (*e*) or with a glass of color similar to the standard solution.

3. Solutions darker in color than the standard color have a "color value" higher than 250 parts per million in terms of tannic acid.

Standard Method of Test for Sieve Analysis of Aggregates for Concrete

[Serial Designation: C 41–24]

[Issued as tentative, 1921; adopted, 1922; revised, 1924]

[This method is issued under the fixed designation C 41; the final number indicates the year of original adoption as standard or, in the case of revision, the year of last revision]

1. A representative test sample of the aggregate shall be selected by quartering or by use of a sampler, which after drying will give not less than the following:

(*a*) Fine aggregate, 500 g.

(*b*) Coarse aggregate or a mixture of fine and coarse aggregates, weight in grams, 3,000 times size of largest sieve required, measured in inches.

Table 1

Sieve number or size in inches [1]	Sieve opening		Wire diameter		Tolerance			
					Average opening	Wire diameter		Maximum opening
						Under	Over	
	mm	*Inch*	*mm*	*Inch*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
No. 100	0. 149	0. 0059	0. 102	0. 0040	6	15	35	40
No. 50	. 297	. 0117	. 188	. 0074	6	15	35	40
No. 30	. 59	. 0232	. 33	. 0130	5	15	30	25
No. 16	1. 19	. 0469	. 54	. 0213	3	15	30	10
No. 8	2. 38	. 0937	. 84	. 0331	3	15	30	10
No. 4	4. 76	. 187	1. 27	. 050	3	15	30	10
⅜-inch	9. 5	. 375	2. 33	. 092	3	10	10	10
¾-inch	19. 0	. 75	3. 42	. 135	3	10	10	10
1-inch	25. 4	1. 00	4. 12	. 162	3	10	10	10
1½-inch	38. 0	1. 50	4. 50	. 177	3	10	10	10
2-inch	50. 8	2. 00	4. 88	. 192	3	10	10	10
3-inch	76. 0	3. 00	6. 3	. 25	3	10	10	10

[1] The requirements for sieves No. 100 to No. 4 conform to the requirements of the United States Standard Sieve Series as given in U. S. Bureau of Standards Letter Circular No. 74. The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the numbers given in table.

2. The sample shall be dried at not over 110° C. (230° F.) to constant weight.

3. (*a*) The sieves shall be of square-mesh wire cloth and shall be mounted on substantial frames constructed in a manner that will prevent loss of material during sifting.

(*b*) The size of wire and sieve openings shall be as given in Table 1.

4. (*a*) The sample shall be separated into a series of sizes by means of the sieves specified in section 3. Sifting shall be continued until not more than 1 per cent by weight of the sample passes any sieve during one minute.

(*b*) Each size shall be weighed on a balance or scale which is sensitive to $\frac{1}{1000}$ of the weight of the test sample.

(*c*) The percentage by weight of the total sample which is finer *than each* of the sieves shall be computed.

5. (*a*) The percentages in sieve analysis shall be reported to the nearest whole number.

(*b*) If more than 15 per cent of a fine aggregate is coarser than the No. 4 sieve, or more than 15 per cent of a coarse aggregate is finer than the No. 4 sieve, the sieve analysis of the portions finer and coarser than this sieve shall be reported separately.

Tentative Specifications for Concrete Aggregates

[Serial Designation: C 33–23 T]

[Issued 1921; revised, 1923]

[This is a tentative standard only, published for the purpose of eliciting criticism and suggestions. It is not a standard of the society and is subject to revision]

FINE AGGREGATE

1. Fine aggregate shall consist of sand, stone screenings, or other inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated grains, free from injurious amounts of dust, lumps, soft or flaky particles, shale, alkali, organic matter, loam, or other deleterious substances.

2. Fine aggregate shall preferably be graded from fine to coarse, with the coarser particles predominating, within the following limits:

	Per cent
Passing ⅜-inch sieve	100
Passing No. 4 sieve	85
Passing No. 50 sieve not more than	30
Weight removed by decantation test do	3

The sieves shall conform to the requirements specified in the Standard Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C 41) of the American Society for Testing Materials.[3]

3. The fine aggregate shall be tested in combination with the coarse aggregate and the cement with which it is to be used and in the proportions, including water, in which they are to be used on the work, in accordance with the requirements specified in section 6. In case the test provided in section 6 shows the strengths specified therein, the fine aggregate shall be considered acceptable.

4. With the approval and consent of the engineer, the following requirements may be substituted:

(*a*) Mortar briquettes, cylinders or prisms, consisting of one part by weight of Portland cement and three parts by weight [4] of fine aggregate, mixed and tested in accordance with the methods described in the Standard Specifications and Tests for Portland Cement (Serial Designation: C 9) of the American Society for Testing Materials [5] for tension tests and in accordance with the Tentative Specifications and Tests for Compressive Strength of Portland-Cement Mortars (Serial Designation: C 9–16 T) of the American Society for Testing Materials [6] for compression tests shall show a tensile or compressive strength at the age of 7 and 28 days not less than that of 1: 3 standard Ottawa sand mortar of the same consistency made with the same cement.

NOTE.—In testing aggregates care should be exercised to avoid the removal of any coating on the grains which may affect the strength; bank sand should not be dried before being made into mortar but should contain natural moisture. The percentage of moisture may be determined upon a separate sample and the weight of the sand used in the test corrected for the moisture content.

(*b*) Upon failure to meet this requirement the proportion of cement in the concrete mixture shall be increased or the proportions of cement, fine aggregate, coarse aggregate, and water changed in such a way as to produce the strength specified in section 6.

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[3] See p. 47.

[4] When approved by the engineer, these proportions may be by volume, assuming 1 cubic foot of cement to weigh 94 pounds.

[5] 1924 Book of A. S. T. M. Standards, or Publication T-9 of the Portland Cement Association.

[6] Proceedings, Am. Soc. Testing Mats., Vol. XX, Part I, p. 599; 1920.

5. No fine aggregate showing a color darker than the standard color when tested in accordance with the Standard Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C 40) of the American Society for Testing Materials [7] shall be used unless the strength requirement of sections 4 or 6 is fulfilled.

6. The grade of concrete required with its compressive strength in pounds per square inch shall be specified by the engineer. The concrete materials, including cement, fine aggregate, coarse aggregate, and water, mixed in the proportions in which they are to be used in the work and tested in accordance with the standard methods of test, shall at 28 days develop a strength of not less than that specified for the grade of concrete required. Upon failure to meet this requirement the proportion of cement in the concrete mix shall be increased or the proportions of cement, fine aggregate, coarse aggregate, and water shall be changed in such a way as to produce the specified strength.

COARSE AGGREGATE

7. Coarse aggregate shall consist of crushed stone, gravel, air-cooled blast-furnace slag, or other approved inert materials with similar characteristics, or a combination thereof, having clean, hard, strong, durable, uncoated pieces free from injurious amounts of soft, friable, thin, elongated, or laminated pieces, alkali, organic, or other deleterious matter.

8. In the case of blast-furnace slag, the weight per cubic foot shall not be less than 65 lbs./ft.^{3} for use in concrete structures not subject to abrasion and not less than 70 lbs./ft.^{3} for use in concrete floor or road construction.

9. (*a*) Coarse aggregate shall be well graded from fine to coarse within the following limits: [8]

	Per cent
Passing —-inch sieve (maximum size)	95
Passing —-inch sieve (intermediate size)	— to —

Not more than 15 per cent shall pass the No. 4 sieve; not more than 5 per cent shall pass the No. 8 sieve.

(*b*) The maximum size of coarse aggregate shall be either designated by the engineer or indicated on the plans.

NOTE.—The grading as above specified is intended to secure uniformity of aggregate but will be governed by local conditions. The following table indicates desirable gradings, in percentages, for coarse aggregate for certain maximum sizes:

Maximum size of aggregate, in inches	Square openings, in inches							Per cent passing No. 4 sieve, not more than—	Per cent passing No. 8 sieve, not more than—
	3	2½	2	1½	1	¾	½		
3	95			40–75				15	5
2½		95						15	5
2			95		40–75			15	5
1½				95		40–75		15	5
1					95		40–75	15	5
¾						95		15	5

[7] See p. 46.

[8] When there are several suitable aggregates available a thorough investigation of the relative economy of each for producing concrete of the desired strength is advisable, especially for work of considerable magnitude.

WASHINGTON, September, 1925.