This finish coat may be troweled or floated to a smooth or rough surface, as may be desired, or it may be given what is known as a "slap-dash" finish by throwing the mortar on with a brush or twig broom.

Ornamental Construction. Concrete or mortar may be cast by special molds into blocks of any desired size or shape, or molded for ornamental decoration in designs which vie both architecturally and in durability with finely carved sandstone, limestone, and granite. The color may be slightly

FIG. 200. — Pouring Seat Slab of Harvard Stadium. (*See p* 628.)

varied by mixing different kinds of crushed stone. Artificial coloring matter is apt to fade.

Ornaments are run whole in a mold which is made in halves, or are molded in two or three pieces and cemented together. Molds of plaster-of-Paris, shellacked within, are commonly employed.

Another method of molding, similar to that employed for iron castings, is with fine, damp sand, which is sometimes treated by a patented process. A wooden core is made and sand packed around it, then the core is removed, and the mortar is poured in. The surfaces, after setting, may be rubbed down and floated. Fig. 200 illustrates the pouring of a seat slab

at the Harvard Stadium.* The wooden core, which was of the form of an L, for riser and tread, has been removed from the sand, reinforcing wire placed, and thick grout of the consistency of cream is being run in from a box car. The proportions of material were about one part Portland cement to $2\frac{1}{2}$ parts fine crushed trap rock under $\frac{3}{8}$-inch diameter.

Surfacing is treated on page 288.

CONCRETE BUILDING BLOCKS

Numerous machines and patented methods are on the market for forming building blocks of Portland cement, mortar or concrete to compete with brick and stone for house fronts. Some of the machines form the blocks from concrete mixed rather dry and pressed into the mold, while other methods employ a semi-liquid consistency, and the material is merely poured into the molds. The blocks may be hollow so as to extend clear through the wall, or each face of the wall may be laid with separate blocks.

If care is exercised in molding and the sizes and surface appearance of the blocks are varied, a wall of pleasing architectural effect is possible.

The material for building blocks should be first-class Portland cement and fine crushed rock, or fine gravel and sand ranging in size from $\frac{1}{2}$ inch in diameter to dust. Fine sand or fine dust alone makes with Portland cement a very porous stone, and must therefore never be used.

CONCRETE TILE

Concrete hollow tile is being made for the same uses as terra cotta tiling for partitions and floors, and also for dwelling houses in the construction of outside walls as well as of interior partitions. The sizes and shapes of the blocks are varied for the different purposes.

One of the best patented processes for making concrete tile consists in pouring wet concrete of the consistency of grout, into a mold and then, by application of a steam jacket, which forms a part of the mold, evaporating enough of the water from the concrete to permit the withdrawal of the tile from the mold within a few minutes. The product thus has the density and uniformity of wet mixed concrete, and is very true and uniform in shape and size and in thickness of walls. Plastering appears to adhere to it better than to most other forms of concrete.

* Lewis J. Johnson in Journal Association Engineering Societies, June, 1904, p. 305.

REINFORCED CONCRETE CHIMNEYS

High factory chimneys of reinforced concrete are being built in this country and abroad. The cost, especially of those over 100 feet high, is usually much less than brick. If designed and built upon the same principles and by the same methods which have proved essential in other types of reinforced concrete construction, they can be depended upon to give permanent satisfaction.

Reports* from a large number of chimneys have shown that concrete is unaffected by the heat from an ordinary steam boiler plant. The temperature in such chimneys seldom exceeds 700° Fahr. while 400° to 500° Fahr. is more usual. Experimental tests also indicate that concrete is not appreciably injured at temperatures of 600° to 700° Fahr.†

To provide for extremes, it is advisable, however, to build an independent inner shell of concrete or firebrick for at least a portion of the height. Concrete should not be used for a chimney in connection with special high temperature furnaces.

Since concrete and steel have substantially the same coefficient of expansion‡ there is no danger of heat causing a separation of the reinforcement from the concrete.

The expansive effect of heat is a more serious question. Stresses are set up in the shell of any masonry chimney because of the hot interior and cold exterior surfaces. A concrete chimney, however, has thinner walls so that the stress is less than in one of brick or tile and it is also better reinforced. Provision for temperature stresses are discussed in paragraphs on design which follow.

Construction. A reinforced concrete chimney is more difficult to construct than many other kinds of concrete construction because of its height and shape, and it therefore should be handled by experienced builders.

It is essential in chimney construction that the materials be very carefully selected. The sand as well as the cement should be tested by determining the actual tensile strength of mortar made from it. The stone preferably should be of the nature of a hard trap rock ½ inch maximum size. Proportions 1 : 2 : 3 have been found to give good results. A dry mix should not be used, since insufficient water will produce a porous concrete which does not adhere to the steel. The consistency must be wet enough to quake and form jelly-like mass when lightly rammed, so as to properly imbed and

* A special investigation of reinforced concrete chimneys was made by Sanford E. Thompson in 1907 for the Association of American Portland Cement Manufacturers. Many of the points here discussed are summarized from the report, which is printed as Bulletin No. 18 of the Association.

† Tests of Metals, U. S. A.

‡ See page 287.

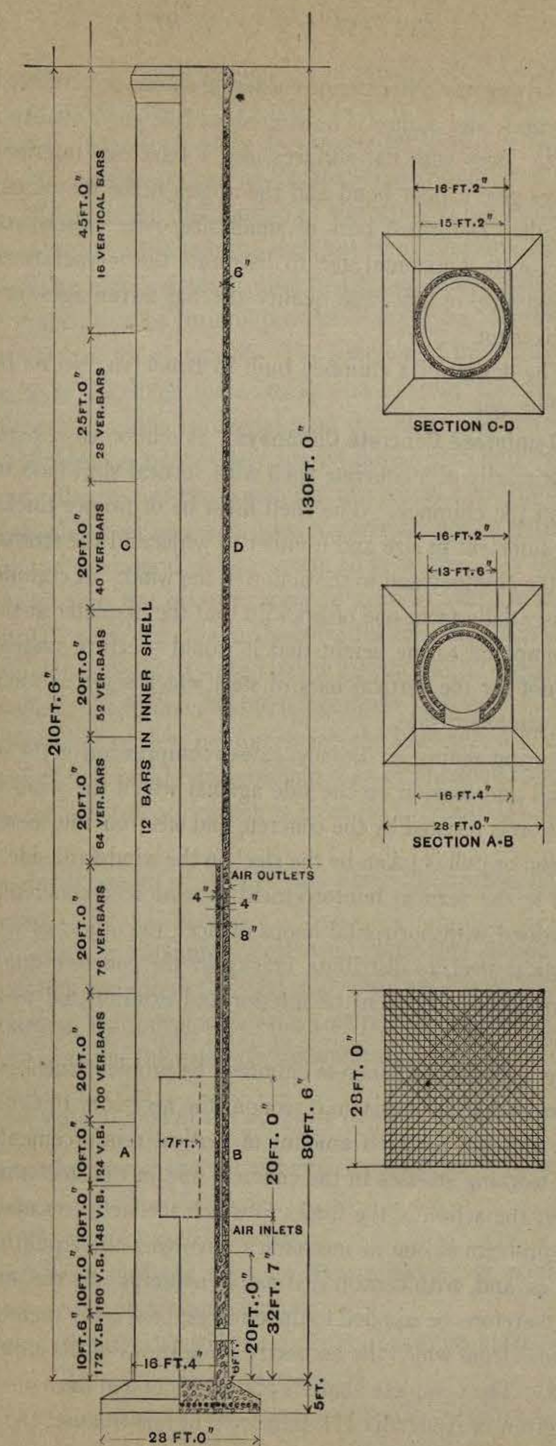

FIG. 201. Design of Chimney of the Edison Electric Illuminating Co., Brooklyn, N. Y. (*See p.* 632.)

bond the reinforcement. No exterior plastering should be permitted because it is liable to check and scale. The steel should be good quality round or deformed bars. Bars with flat surfaces like T-bars are inferior because the flat surfaces give a poor bond and the angles make the placing of the concrete difficult. Deformed bars of small size quite closely spaced are specially good for the horizontal steel to distribute the temperature stresses and high carbon steel of first-class quality also has advantages for the horizontal reinforcement.

Design. The design of a chimney built in Brooklyn, N. Y., in 1907 is illustrated in Fig. 201.

Design of Reinforced Concrete Chimneys. A reinforced concrete chimney consists primarily of a concrete shell with vertical steel bars imbedded in it all around the chimney. The shell must be of proper thickness and the steel bars sufficient in size and number to withstand the stresses due to the weight of the chimney and to the action of the wind. A chimney of this type differs essentially from one of brick in that the diameter at the base is so small as compared to the height that it would overturn under a heavy wind were it not for the vertical bars of steel which serve as anchors and hold it on the windward side.

Wind, in blowing against a chimney, causes compression on the side opposite to the wind and tension on the side against which the wind is acting. This compression is resisted by the concrete and steel on the leeward side, while the tension or pull is taken by the steel on the windward side.

In addition to the vertical reinforcement, a reinforced concrete chimney should be provided with horizontal hoops of steel, the object of which is to stiffen the vertical steel, to distribute cracks in the concrete due to a difference in temperature between the interior and exterior and to resist the diagonal tension.

In designing a reinforced concrete chimney the problem then is primarily to determine at various horizontal sections the necessary thickness of the concrete shell and the required amount of vertical reinforcement, so that the allowable working stresses in the concrete and in the steel shall not be exceeded under the action of the forces to which the structure may be subjected. The problem is one in mechanics, involving the equilibrium of a system of forces, and, with certain reasonable assumptions, the laws of mechanics may therefore be applied to these forces, producing thereby certain rational formulas from which the necessary proportions of the chimney may be determined. The complete analysis and development of the most useful formulas are given in Appendix III, page 765, of this treatise, the formulas themselves being reproduced below.

The problem of the determination of stresses due to the difference in temperature between the interior and the exterior of the shell involves many uncertainties. The heat tends to expand the inner surfaces, producing tension in the outside surface of the shell and compression in the interior surface. Although the distribution of the stress is not clearly known, the variation of the heat through the shell not being uniform, tentative computations indicate high stresses so that it is a question whether vertical temperature cracks can be entirely prevented any more than they can be prevented in brick or tile chimneys. The function of the horizontal steel may therefore be to distribute these cracks and to resist the vertical shear or diagonal tension. This horizontal steel should be distributed therefore by using small diameter bars closely spaced rather than large bars spaced further apart. Because of the possibility of vertical temperature cracks, the concrete should never be relied upon to carry tension or vertical shear, and the amount of horizontal reinforcement to resist this may be obtained in a similar fashion to the determination of vertical stirrups in a beam. In Appendix III, page 772, the analysis for the shearing stresses is indicated, and the final formula is presented below together with suggestions for adapting the horizontal reinforcement to temperature stresses.

The amount of vertical reinforcement, the thickness of the shell, and the percentage of horizontal reinforcement may be obtained from the following formulas, the derivation of which is given in Appendix III, page 765.

Let

W = weight in pounds of the chimney above the section under consideration.

M = moment in inch-pounds of the wind about that section.

f_s = maximum tension in the steel in pounds per square inch.

f_c = maximum compression in the concrete in pounds per square inch (measured at the mean circumference).

$n = \frac{E_s}{E_c}$ = ratio of modulus of elasticity of steel to that of concrete.

D = mean diameter of shell in inches (i. e., diameter of center of ring).

r = mean radius of shell in inches.

t = total thickness of shell in inches.

A_s = total cross-sectional area, in square inches, of reinforcing bars in the section under consideration.

k = ratio of distance of neutral axis, from mean circumference on compression side, to the mean diameter D.

z, C_P, C_T = constants for any given value of k, Tables 1 and 2, pages 635, 636.

p_0 = ratio of area of steel hoop to area of concrete.
h_1 = height in feet of chimney above section under consideration.
F = effective wind pressure against chimney in pounds per square foot.

Then

$$A_s = \frac{8\,(M - W z D)}{C_T f_s D} \qquad (1)$$

$$t = \frac{2\,W + (C_T f_s - C_P f_c n)\,\frac{A_s}{\pi}}{C_P f_c D} + \frac{A_s}{\pi D} \qquad (2)$$

$$p_0 = \frac{h_1 F}{18.8\, f_s\, t} + 0.0025 \qquad (3)$$

Formulas (1), (2), and (3) correspond to formulas (7), (8), and (9) in Appendix III.

In the formula for p_0, the first term gives the ratio of steel to resist vertical shear or diagonal tension, and the second term is an arbitrary ratio designed to distribute the temperature strains. To best distribute the temperature strains, a maximum spacing of the horizontal bars is recommended as 6 inches to 10 inches.

In the formulas the terms z, C_P and C_T are constants, the values of which are fixed for any given position of the neutral axis. By means of tables 1 and 2 (pp. 635-6) these constants may be easily and quickly determined so that the solution of formulas (1) and (2) is rendered quite simple after the selecting of the diameter and height of the chimney and computing the bending moments due to the wind at the various sections considered. The thickness of shell must be assumed in formula (1) in order to determine the average diameter D and to compute the weight W. A new computation may be made to correct this if necessary. For economical distribution of concrete and steel, computation must be made for several sections in the height. It is advisable to make the thickness of exterior shell never less than 5 inches but the number of steel rods may be gradually reduced toward the top.

Summary of Essentials in Design and Construction. In the investigation* referred to, the essential requirements are summarized as follows:

(1) Design the foundations according to the best engineering practice.

(2) Compute the dimensions and reinforcement in the chimney with conservative units of stress, providing a factor of safety in the concrete of not less than 4 or 5.

* See footnote, p. 630.

(3) Provide enough vertical steel to take all of the pull without exceeding 14,000 or at most 16,000 pounds per square inch.

(4) Provide enough horizontal or circular steel to take all the vertical shear and to resist the tendency to expansion due to the interior heat.

(5) Distribute the horizontal steel by numerous small rods in preference to larger rods spaced farther apart.

(6) Specially reinforce sections where the thickness in the wall of the chimney is changed or which are liable to marked changes of temperature.

(7) Select first-class materials and thoroughly test them before and during the progress of the work.

(8) Mix the concrete thoroughly and provide enough water to produce a quaking concrete.

(9) Bond the layers of concrete together.

(10) Accurately place the steel.

(11) Place the concrete around the steel carefully, ramming it so thoroughly that it will slush against the steel and adhere at every point.

(12) Keep the forms rigid.

The fulfillment of these requirements will increase the cost of the structure, but if the recommendations are followed, there should be no difficulty in erecting concrete chimneys which will give thorough satisfaction and will endure.

Table 1. Values of Constants C_P, C_T, z and j for Different Positions of the Neutral Axis, (i. e., for various values of k)

For use with equations (1), (2) and (3), page 634, and (7), (8) and (9), pages 771 to 773. k is ratio of distance of neutral axis from mean circumference on compression side to the mean diameter D. Value of k to suit the condition of the problem is obtained from Table 2, page 636.

k	C_P	C_T	z	j
0.050	0.600	3.008	0.490	0.760
0.100	0.852	2.887	0.480	0.766
0.150	1.049	2.772	0.469	0.771
0.200	1.218	2.661	0.459	0.776
0.250	1.370	2.551	0.448	0.779
0.300	1.510	2.442	0.438	0.781
0.350	1.640	2.333	0.427	0.783
0.400	1.765	2.224	0.416	0.784
0.450	1.884	2.113	0.404	0.785
0.500	2.000	2.000	0.393	0.786
0.550	2.113	1.884	0.381	0.785
0.600	2.224	1.765	0.369	0.784

Table 2. Location of Neutral Axis for various combinations of compressive stress, f_c, tensile stress, f_s and ratio of moduli, n, *(see p. 633.)*

MAXIMUM TENSILE STRESS IN STEEL f_s	k RATIO OF DEPTH OF NEUTRAL AXIS TO DEPTH OF STEEL BELOW MOST COMPRESSED SURFACE OF BEAM														
	$n = 10$ Maximum compressive stress in concrete, f_c					$n = 12$ Maximum compressive stress in concrete, f_c					$n = 15$ Maximum compressive stress in concrete, f_c				
	300	400	500	600	700	300	400	500	600	700	300	400	500	600	700
8000	.272	.334	.384	.428	.466	.310	.375	.428	.474	.512	.360	.428	.484	.530	.568
9000	.250	.308	.357	.400	.438	.285	.348	.400	.444	.483	.334	.400	.454	.500	.538
10000	.231	.286	.334	.375	.412	.264	.324	.375	.418	.456	.310	.375	.428	.474	.512
11000	.214	.266	.312	.353	.389	.246	.304	.353	.395	.433	.290	.353	.405	.450	.488
12000	.200	.250	.294	.334	.368	.231	.285	.334	.375	.412	.272	.334	.384	.428	.466
13000	.188	.236	.278	.316	.350	.217	.270	.316	.356	.392	.257	.316	.366	.409	.447
14000	.176	.222	.263	.300	.334	.204	.255	.300	.340	.375	.243	.300	.349	.391	.428
15000	.166	.210	.250	.285	.318	.198	.242	.286	.324	.360	.231	.286	.334	.375	.412
16000	.158	.200	.238	.272	.304	.184	.231	.272	.310	.344	.220	.272	.319	.360	.396
17000	.150	.190	.228	.261	.291	.175	.220	.261	.298	.330	.210	.261	.306	.346	.382
18000	.143	.182	.218	.250	.280	.166	.210	.250	.285	.318	.200	.250	.294	.334	.368
19000	.136	.174	.208	.240	.270	.160	.201	.240	.275	.306	.192	.240	.283	.322	.356
20000	.130	.166	.200	.231	.260	.152	.194	.231	.264	.296	.184	.231	.272	.310	.344

In connection with reinforced concrete chimneys, the problems which arise are of two general kinds:

(1) A problem in design, involving the determination of the necessary thickness of shell and required amount of reinforcement at the various sections of a chimney of given height and diameter.

(2) A problem in the review or investigation of a chimney of given height and diameter having a certain thickness of shell and a given amount of reinforcement to determine the stresses in the concrete and the steel under the action of certain forces.

The application of the foregoing formulas to such problems and the use of the accompanying tables may best be illustrated by the following numerical examples, although the designer is advised also to refer to Appendix III, pp. 765–773 for a thorough understanding of the subject.

DESIGN OF A CHIMNEY. *Example 1.* Given a chimney with height above section considered, 110 ft.; mean diameter at section considered, 10 ft.; allowable pressure in concrete (f_c), 500 lb. per sq. in.; allowable tension in steel (f_s), 14 000 lb. per sq. in.; ratio of moduli n, 15; wind pressure (on normal plane) 50 lb., per sq. ft., weight of concrete taken as 150 lb. per cu. ft. What is the necessary thickness of shell and amount of reinforcement at the given section?

Solution. As in all chimney designs, it is necessary here to make a trial assumption of the thickness of shell in order to estimate the weight. Suppose

we assume a 6-inch shell for the entire height above the section. Assuming that a wind pressure of 50 lbs. per square foot on a normal plane corresponds to $\frac{6}{10}$ of 50 pounds or 30 pounds per square foot on the projected diameter of a cylindrical surface we have the bending moment due to the wind,

$$M = [10.5 \times 110 \times 30] \times \tfrac{110}{2} \times 12 = 22\ 869\ 000 \text{ in. lb.}$$

and the total weight of the chimney above the section,

$$W = 3.1416 \times 10 \times 0.5 \times 110 \times 150 = 259\ 180 \text{ lb.}$$

For $f_c = 500$, $f_s = 14\ 000$, and $n = 15$, table 1 gives $k = .349$

For $k = .349$ table 2 gives $C_P = 1.637$, $C_T = 2.335$, $z = .427$

Substituting in equation (1),

$$A_s = \frac{8\ (22\ 869\ 000 - 259\ 180 \times .427 \times 120)}{2.335 \times 14\ 000 \times 120} = 19.6$$

Therefore 19.6 square inches of steel are required.

If $\frac{3}{4}$ inch round rods are selected, 45 of them would be required.

Substituting in equation (2), we have

$$t = \frac{2 \times 259180 + [(2.335 \times 14\ 000) - (1.637 \times 500 \times 15)]\ \frac{19.6}{3.1416}}{1.637 \times 500 \times 120} + \frac{19.6}{3.1416 \times 120} = 6.6 \text{ inches}$$

Therefore a 6.6 inch shell would be used.

In general the values of A_s and t as thus obtained should be readjusted by computing W on the basis of the computed thickness of shell. In the case at hand, however, the original assumption of a 6-inch thickness corresponds, for all practical purposes, with the computed thickness of 6.6 inches, so that recomputation is, in this case, unnecessary. If the walls of the chimney taper in thickness the value of W must be altered accordingly.

Having determined the required thickness of shell and amount of vertical reinforcement there remains the question of the necessary horizontal or circular reinforcement. Substituting in formula (3) for f_s say 14000 lb., we have

$$p_0 = \frac{110 \times 30}{18.8 \times 14000 \times 6.6} \times 0.0025 = 0.0044$$

Area of steel, $A_s = 6.6 \times 12 \times 0.0044 = 0.35$ sq. in. Thus $\frac{1}{2}$ inch round rods should be spaced $6\frac{3}{4}$ inches on centers.

In a similar manner any other section of the chimney may be proportioned.

REVIEW OF A CHIMNEY. *Example 2.* Given a chimney with height above section considered, 90 ft; mean diameter at section considered, 8 ft.; thickness of shell at section considered, 6 in.; vertical steel at section condsidered, $60 - \frac{5}{8}$ in. round rods; wind pressure (on normal plane, 50 lb. per sq. ft.); weight of concrete taken as 150 lb. per sq. ft.; ratio of moduli, n, 15.

What are the maximum stresses in the concrete and in the vertical steel at the section under consideration?

Solution. A problem of this kind must necessarily be solved by a method of successive trials, since the position of the neutral axis is not known. The location of the neutral axis is determined by the values of f_c, f_s and n, two of which, in this case, are unknown. The method of procedure, therefore, is to assume outright a trial position of the neutral axis, select the constants accordingly, substitute in equations (1) and (2) and solve them for f_s and f_c.

Then see if the position of the neutral axis, as fixed by these values of f_s and f_c and the given n, is the same as the position assumed at the start. If the two positions agree, then f_s and f_c as found are the actual stresses; if not, a new position of the neutral axis must be assumed, new constants selected, and new values of f_s and f_c computed from equations (1) and (2). Thus a series of trials must be made until the location of the neutral axis as assumed is consistent with the computed values of f_c and f_s together with the given n.

In this problem, assuming 30 pounds pressure on the projected area, we have the bending moment due to the wind,

$$M = [8.5 \times 90 \times 30] \times \frac{90}{2} \times 12 = 12\,393\,000 \text{ in. lb.}$$

and the total weight of the chimney above the section,

$$W = 3.1416 \times 8 \times 0.5 \times 90 \times 150 = 169\,646 \text{ lb.}$$

$$A_s = 60 \times .3068 = 18.41 \text{ sq, in.}$$

Now suppose we assume the neutral axis at, say, $k = .400$

For $k = .400$, table 1 gives $C_P = 1.765$, $C_T = 2.224$, $z = .416$

Substituting in equation (1) we have

$$18.41 = \frac{8\,(12\,393\,000 - 169\,646 \times .416 \times 96)}{2.224 \times f_s \times 96}$$

whence $f_s = 11400$

Substituting in equation (2) we have

$$6 = \frac{2 \times 169646 + (2.224 \times 11400 - 1.765 \cdot f_c\ 15)\dfrac{18.41}{3.1416}}{1.765 \times f_c \times 96} + \frac{18.41}{3.1416 \times 96}$$

whence $f_c = 416$

Now $f_s = 11\,400$, $f_c = 416$, and $r = 15$ gives $k = .354$ which does not correspond with our original assumption of $z = .400$. Evidently the true k must lie somewhere between the assumed and determined values, hence if we now assume, say, $k = .375$ and recompute, we obtain $f_s = 11\,000$ and $f_c = 435$, the values of which together with $n = 15$ gives $k = .371$ which checks fairly well with the assumption of $k = .375$. For all practical purposes we may therefore say that the maximum stress in the steel is 11 000 pounds per square inch, while the maximum stress in the concrete is 435 pounds per square inch. The results indicate that both the thickness of shell and the amount of steel are greater than are necessary for safe stresses.

CHAPTER XXV

FOUNDATIONS AND PIERS

Concrete excels as a material for foundations, and here finds its widest and most important field of usefulness. It is pre-eminently adapted to such construction, because the stresses are chiefly compressive, the forms are easily built, and the surface appearance need not be considered.

Concrete is peculiarly suited to under-water foundations because, although it requires careful handling, it can be placed with great facility. It is now used even in piling. (See p. 650.)

Within recent years concrete has been adopted for foundations above ground, such as bridge piers, and is standing the test of durability even when subjected to excessive wear and impact. (See p. 654.)

Since the design of a foundation or sub-structure is governed almost as much by the character of the underlying rock or soil as by the superstructure, brief reference is made to the standard practice in estimating loads, although the treatment of engineering principles, as such, is not within the province of this treatise.

Reinforced concrete footings are treated in detail (see p. 644).

BEARING POWER OF SOILS AND ROCK

Sound hard ledge will support the weight of any foundation and superstructure, but if the rock is seamy or rotten it may require thorough examination and special treatment. If its surface is weathered, it must be removed. A sloping surface must be stepped or the foundation designed with sufficient toe to prevent sliding.

The sustaining power of earths depends upon their composition, the amount of water which they contain or are likely to receive, and the degree to which they are confined. An approximate idea of the loads which may be safely placed upon uniform strata of considerable thickness is given by Mr. George B. Francis*:

There are several classes of strata that are readily definable, such as ledge rock, hard pan, gravel, clean sand, dry clay, wet clay, and loam, and when these strata are of considerable thickness and uniform for considerable areas, they may be loaded with safety (provided the material

*Journal Association Engineering Societies, June 1903, p. 340.