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(ACI PROCEEDINGS Vol. 41)

(Contents on Back Cover)

Vol. 16 | June 1945 | No. 6

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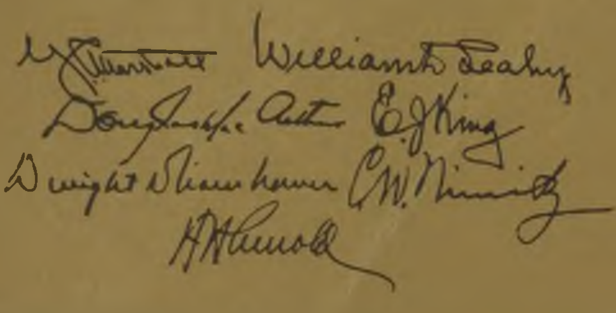

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1 This Journal issue contains all ACI Standards adopted since the inauguration standards procedure under the Standards Committee in 1937. They have been and will continue to be available singly in separate prints but will shortly be available also in one "ACI Book of Standards"—$1.50 ($1.00 to ACI Members).

2 Many readers (in spite of repeated announcements apparently are unaware of the availability of separate prints of each paper and report. Many who are aware of their availability have not been aware that the Institute, organized and financed as it is, is not in a position to make free distribution of its literature. See the new announcement which tops the first page of each paper and report—separate prints are usually available at 25 or 50 cents. In quantities the prices are lower—for large quantities much lower.

3 Many papers and discussions are submitted for consideration of the Publications Committee in a single copy of the manuscript. Three copies are required. In fact all prospective contributors should have q copy of "American Concrete Institute Publications Policy" (an 8-page reprint from the September 1941 Journal). It will be sent without charge, on request.

To facilitate selective distribution, **separate prints** of this title (41-22) are currently available from ACI at 25 cents each—quantity quotations on request. **Discussion** of this paper (copies in triplicate) should reach the Institute not later than Aug. 15, 1945

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Vol. 16 No. 6 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN **June 1945**

Slabs Supported on Four Sides*

Suggested Changes in ACI Building Regulations

By R. L. BERTIN, JOSEPH DI STASIO, and M. P. VAN BUREN†
Members American Concrete Institute

SYNOPSIS

The ACI Building Regulations for Reinforced Concrete provide, with respect to slabs supported on four sides, a method of analysis which reflects a clear picture of the elastic action of the structure, and, through the use of equivalent uniform load factors, permits the direct solution for bending moments and shears in the slabs and beams with the same coefficients as prescribed for one-way construction. To clarify the manner of presentation, the authors have prepared a suggested change of the entire Chapter 7 of the Code. While retaining all the original basic features, notation has been simplified, non-essential formulas and extraneous theory eliminated, and the regulations condensed to the fundamentals requisite for direct design. Final results are unchanged from those obtained through the use of the present 1941 regulations.

In this paper, the proposed changes are stated and reasons for them given. Suggested regulations are presented in new form. Comparisons are shown to indicate conformity with theory. Finally, an analysis of a typical series of floor panels is given to illustrate the facility with which computations could be made under suggested changes. It is believed that engineers would find the suggested modification of this section of the Code simple and easy to apply.

INTRODUCTION

The development of empirical methods of design for inclusion in building codes is generally motivated by two basic concepts stated in the order of their importance to the designers:

*Received by the Institute Jan. 25, 1945.

†R. L. Bertin, Chief Engr. White Construction Co., Joseph Di Stasio, and M. P. Van Buren, J. Di Stasio & Co., Consulting Engrs., N. Y. City.

(a) Simplicity of application,

(b) Adherence to theoretical correctness.

This is particularly true of two-way slab design because of the complexity of the theoretical analysis.

It is believed that the ACI regulations yield results throughout the range of two-way slabs conforming more nearly than any other to the theoretical analysis, and in the new suggested form it is not only simple of application, but compatible with the frame analysis of continuous structures in which two-way slabs occur.

It is the purpose of this paper to present comparative data from which these beliefs are deduced. Sub-divisions of the present paper are: Part 1—Suggested modified regulations; Part 2—Comparative analysis: Part 3—General application.

PART 1

Suggested changes

The regulations first developed for the New York City Building Code were recommended to the ACI by Committee 501 in its Proposed Building Regulations in 1935, and the basic theory explained by a paper in 1936*.

The original 1935 transcript was re-arranged and amplified by tables in the ACI Building Regulations for Reinforced Concrete, adopted in 1941. The re-editing of this section as suggested by the authors, includes the following proposed modifications:

1—Elimination of tables and formulas involving determination of lines of inflection. Elastic analysis is a definitely established theory and requires no special exposition under this heading. Limitations are retained within which prescribed values of the distance between inflection lines may be used.

2—Elimination of special treatment of unusual cases by definitely specifying that all slabs be securely attached to supports. Structures in which panel edges are free to uplift are of limited practical value and should be considered as individual problems.

3—Simplification of formulas for moment and shear. Terms involving width of slab strip and tributary width carried by beam, are eliminated by expressing the load in terms of W, the total slab load on either slab strip or beam. All factors, by which moment and shear at any section in one-way construction in either direction are obtained, are presented in two short tables. Corresponding charts are also shown as graphic illustrations of the tables.

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*"Slabs Supported on Four Sides," by Di Stasio and Van Buren, ACI Journal Jan.-Feb. 1936; *Proceedings* V. 32, p. 350.

4—Simplification of notation. Special symbols are eliminated and replaced with a condensed and more familiar nomenclature. Of these, some, such as L and W may be used without change in definition for other sections of the Code.

5—Elimination of all footnote formulas. These are no longer required as all information for the design of slabs may be obtained from the tables in their suggested form. For general information, the formulas on which the tables are based are given here as derived from the 1941 regulations by direct substitution in the new notation.

$$r > .5 . C = \left(\frac{1}{1+r^3}\right)\left(\frac{2r.}{4r-1}\right) \quad (1)$$

$$r < .5 . C = \frac{1}{1+r^3} \quad (2)$$

$$C_s = (.5 - X)\left(\frac{1-6X}{1+r^3} + 6XC\right) \quad (3)$$

$$C_b = .5 - X - C_s \quad (4)$$

Suggested regulations

700—Notation (For Slabs Supported On Four Sides)

L = Span length

L_1 = Span length in the direction normal to L in floors supported on four sides.

m = Ratio of span between lines of inflection to L in the direction of span L, when span L only is loaded.

m_1 = Ratio of span between lines of inflection to L_1 in the direction of span L_1, when span L_1 only is loaded.

r = Degree of rectangularity between lines of inflection of a panel supported on four sides $= \frac{mL}{m_1L_1}$

w = Uniformly distributed total load per unit area of slab.

W = Total uniform load for one way construction between opposite supports on slab strip of any width or on beam in the direction of L.

X = Ratio of distance from support to any section of slab or beam, to span L or L_1.

C = Factor modifying bending moments prescribed for one-way construction for use in proportioning the slabs and beams in the direction of L of slabs supported on four sides.

C_s = Ratio of the shear at any section of a slab strip distant xL from the support to the total load W on the strip in direction of L.

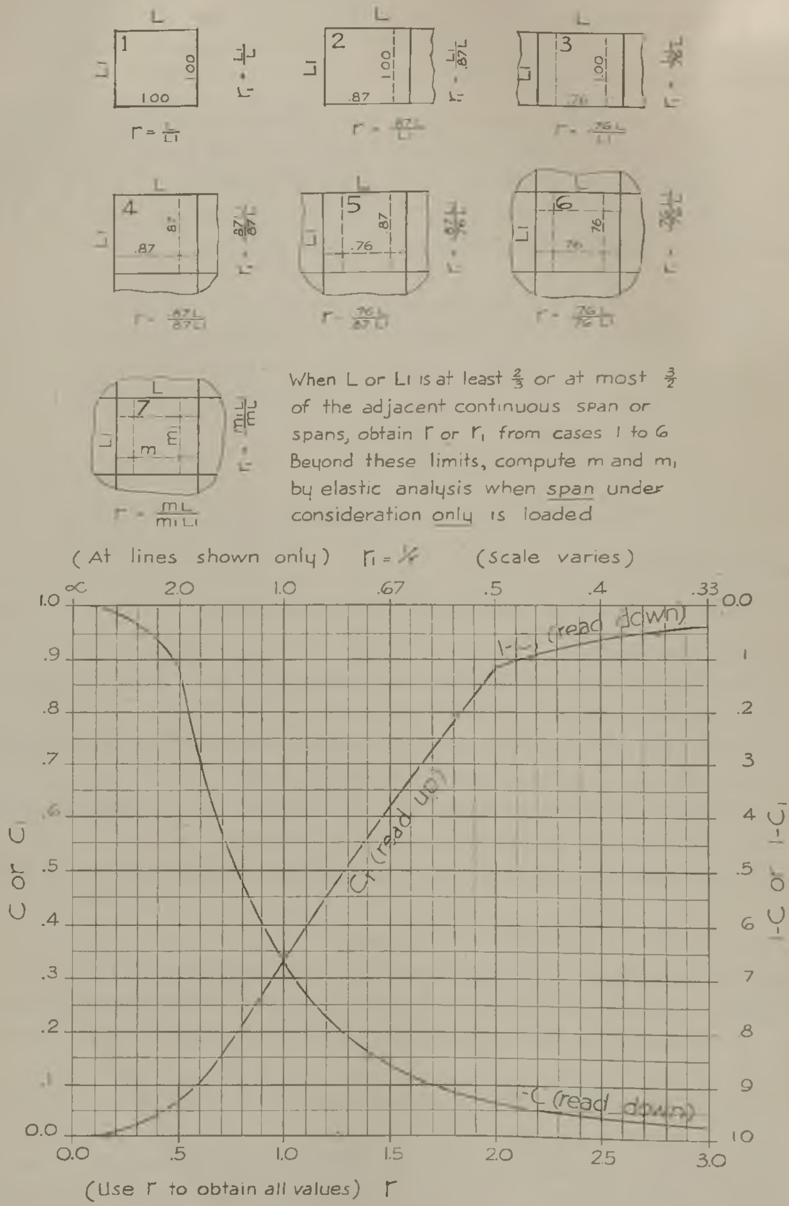


Fig. 1 (at top) and 2

C_b = Ratio of the Shear at any section of a Beam distant xL from the support to the total load W on the Beam in direction of L.

$B.M.C.$ = Bending Moment Coefficient.

W_1, C_1, C_{s1}, C_{b1}, are corresponding values of W, C, C_s, C_b, for slab strip or beam in direction of L_1.

709—Floors supported on four sides

(a) This construction, consisting of floors reinforced in two directions and supported on four sides, includes solid reinforced concrete slabs; concrete joists with burnt clay or concrete tile fillers, with or without concrete top slabs; and concrete joists with top slabs placed monolithically with the joists. The slab shall be supported around its periphery along the spans L and L_1, and shall be securely attached to said supports by monolithic construction or other adequate means.

(b) *Minimum slab thickness*

The slab thickness shall satisfy prescribed working stresses and shall not be less than 4″ nor less than the sum of the clear length of all supports at which the slab is continuous with the adjacent panels divided by 180 plus the clear length of all other supports divided by 144.

(c) *Lines of inflection for determination of r*

The lines of inflection shall be determined by elastic analysis of the continuous structure in each direction, when the span under consideration *only* is loaded.

When the span L or L_1 is at least 2/3 and at most 3/2 of the adjacent continuous span or spans, the values of m or m_1 may be taken as 0.87 for exterior spans and 0.76 for interior spans. (See Fig. 1).

For freely supported spans m or m_1 shall be taken as unity.

(d) *Bending moments and shear*

Bending moments shall be determined in each direction with the coefficients prescribed for one-way construction in section 701 and 702 and modified by factor C or C_1 from Tables 1 or 2 or from chart. (See Fig. 2).

	In L Direction	*In L_1 Direction*
$B.\ M.$ for slab strip	$= M = CWL\ (B.M.C.)$	$M_1 = C_1W_1L_1\ (B.M.C.)$
$B.\ M.$ for beam	$= M = (1-C)\ WL\ (B.M.C.)$	$M_1 = (1-C_1)\ W_1L_1\ (B.M.C.)$

When the coefficients prescribed in 701(c) are used, the average value of Cw or C_1w for the two spans adjacent to a support shall be used in determining the negative bending moment at the face of the support.

The shear at any section distance xL or xL_1 from supports shall be determined by modifying the total load on the slab strip or beam by the factors C_s, C_{s1}, C_b *or* C_{b1} taken from Table 1 or 2 or from charts. (See Fig. 3 or 4).

TABLE 1—SLABS

Upper Figure / Lower Figure			C_s / C_{s1}					C / C_1
r	$\frac{1}{r}$	X	0.0	.1	.2	.3	.4	
0.00	∞		.50 / .00	.40 / .00	.30 / .00	.20 / .00	.10 / .00	1.00 / .00
.50	2.00		.44 / .06	.36 / .03	.27 / .02	.18 / .00	.09 / .00	.89 / .06
.55	1.82		.43 / .07	.33 / .04	.23 / .02	.15 / .01	.07 / .00	.79 / .08
.60	1.67		.41 / .09	.30 / .05	.20 / .03	.12 / .01	.05 / .00	.70 / .10
.65	1.54		.39 / .11	.28 / .06	.18 / .03	.10 / .01	.04 / .00	.64 / .13
.70	1.43		.37 / .13	.26 / .08	.16 / .04	.09 / .01	.03 / .00	.58 / .15
.80	1.25		.33 / .17	.22 / .10	.13 / .06	.07 / .02	.02 / .00	.48 / .21
.90	1.11		.29 / .21	.19 / .13	.11 / .07	.05 / .03	.01 / .01	.40 / .27
1.00	1.00		.25 / .25	.16 / .16	.09 / .09	.04 / .04	.01 / .01	.33 / .33
1.10	.91		.21 / .29	.13 / .19	.07 / .11	.03 / .05	.01 / .01	.28 / .39
1.20	.83		.18 / .32	.11 / .21	.06 / .13	.02 / .06	.00 / .02	.23 / .45
1.30	.77		.16 / .34	.10 / .23	.05 / .14	.02 / .07	.00 / .03	.19 / .51
1.40	.71		.13 / .37	.08 / .25	.04 / .16	.02 / .09	.00 / .03	.16 / .57
1.50	.67		.11 / .39	.07 / .27	.04 / .17	.01 / .10	.00 / .04	.14 / .61
1.60	.63		.10 / .40	.06 / .29	.03 / .19	.01 / .11	.00 / .05	.12 / .66
1.80	.55		.07 / .43	.04 / .33	.02 / .23	.01 / .15	.00 / .07	.08 / .79
2.00	.50		.06 / .44	.03 / .36	.02 / .27	.00 / .18	.00 / .09	.06 / .89
∞	0.00		.00 / .50	.00 / .40	.00 / .30	.00 / .20	.00 / .10	.00 / 1.00

TABLE 2—BEAMS

Upper Figure Lower Figure			C_b C_{b1}					1-C 1-C_1
r	$\frac{1}{r}$	X	0.0	.1	.2	.3	.4	
0.00	∝		.00 .50	.00 .40	.00 .30	.00 .20	.00 .10	.00 1.00
.50	2.00		.06 .44	.04 .37	.03 .28	.02 .20	.01 .10	.11 .94
.55	1.82		.07 .43	.07 .36	.07 .28	.05 .19	.03 .10	.21 .92
.60	1.67		.09 .41	.10 .35	.10 .27	.08 .19	.05 .10	.30 .90
.65	1.54		.11 .39	.12 .34	.12 .27	.10 .19	.06 .10	.36 .87
.70	1.43		.13 .37	.14 .32	.14 .26	.11 .19	.07 .10	.42 .85
.80	1.25		.17 .33	.18 .30	.17 .24	.13 .18	.08 .10	.52 .79
.90	1.11		.21 .29	.21 .27	.19 .23	.15 .17	.09 .09	.60 .73
1.00	1.00		.25 .25	.24 .24	.21 .21	.16 .16	.09 .09	.67 .67
1.10	.91		.29 .21	.27 .21	.23 .19	.17 .15	.09 .09	.72 .61
1.20	.83		.32 .18	.29 .19	.24 .17	.18 .14	.10 .08	.77 .55
1.30	.77		.34 .16	.30 .17	.25 .16	.18 .13	.10 .07	.81 .49
1.40	.71		.37 .13	.32 .15	.26 .14	.18 .11	.10 .07	.84 .43
1.50	.67		.39 .11	.33 .13	.26 .13	.19 .10	.10 .06	.86 .39
1.60	.63		.40 .10	.34 .11	.27 .11	.19 .09	.10 .05	.88 .34
1.80	.55		.43 .07	.36 .07	.28 .07	.19 .05	.10 .03	.92 .21
2.00	.50		.44 .06	.37 .04	.28 .03	.20 .02	.10 .01	.94 .11
∝	0.00		.50 .00	.40 .00	.30 .00	.20 .00	.10 .00	1.00 .00

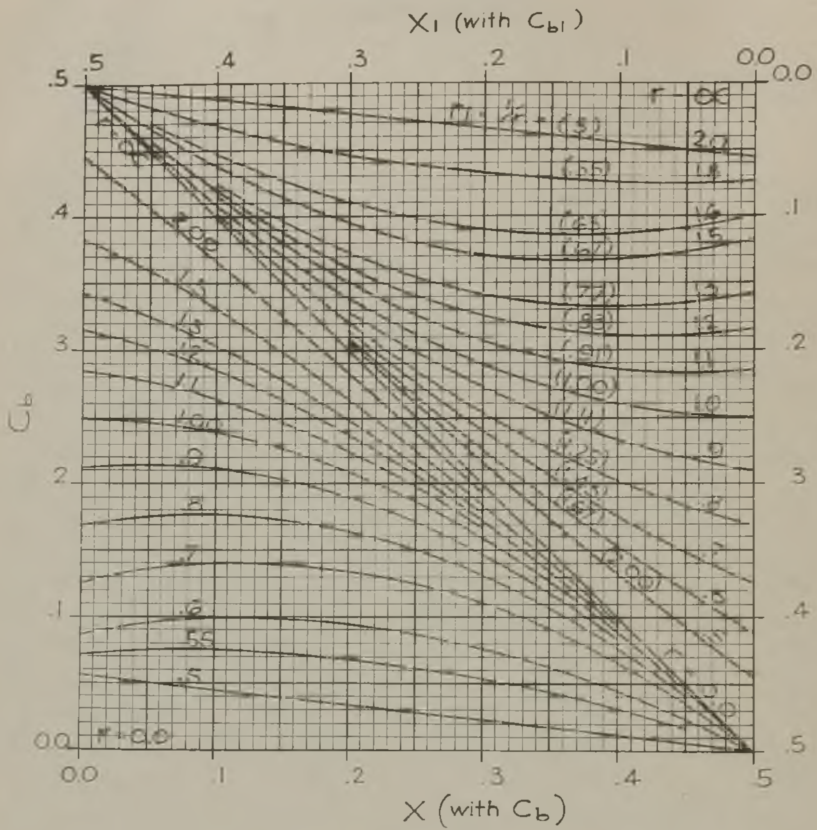


Fig. 3

	In L Direction	*In L_1 Direction*
Shear for Slab Strip. . . .	$V = C_sW$	$V_1 = C_{s1}W_1$
Shear for Beam.	$V = C_bW$	$V_1 = C_{b1}W_1$

For spans where the end moments are unbalanced, shear values at any section shall be adjusted in accordance with Sections 701 and 702.

(e) *Arrangement of reinforcement*

1. In any panel, the area of reinforcement per unit width in the long direction shall be at least one-third that provided in the short direction.

2. The area of positive moment reinforcement adjacent to a continuous edge only and for a width not exceeding one-fourth of the shorter dimension of the panel may be reduced 25 per cent.

3. At a non-continuous edge the area of negative moment reinforcement per unit width shall be at least-one-half of that required for maxi-

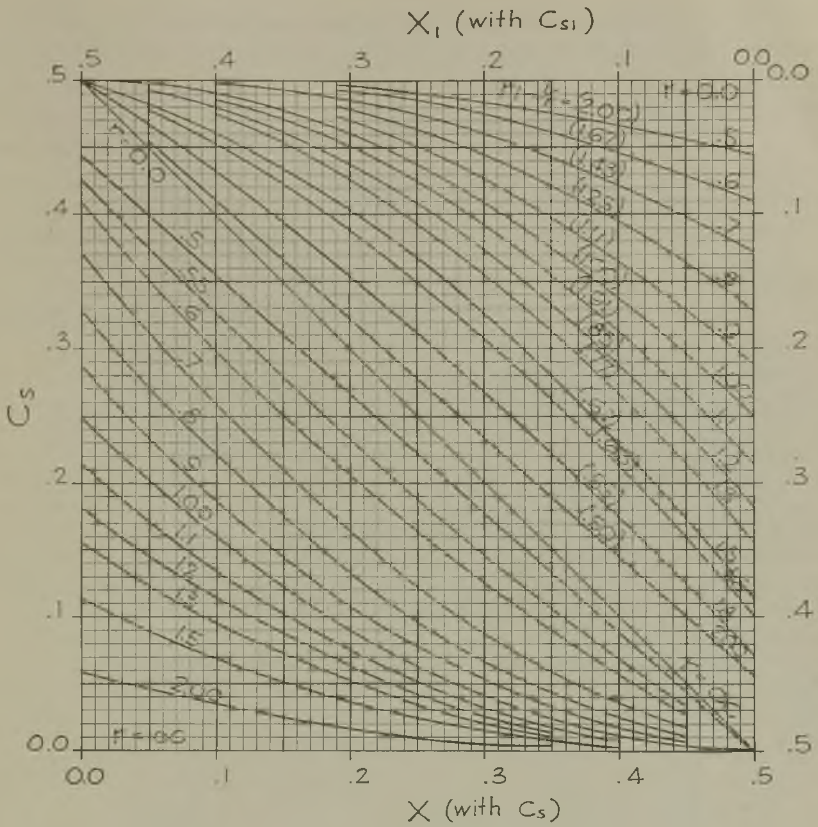


Fig. 4

mum positive moment for the center one-half of the panel and shall be provided across the entire width of the exterior support.

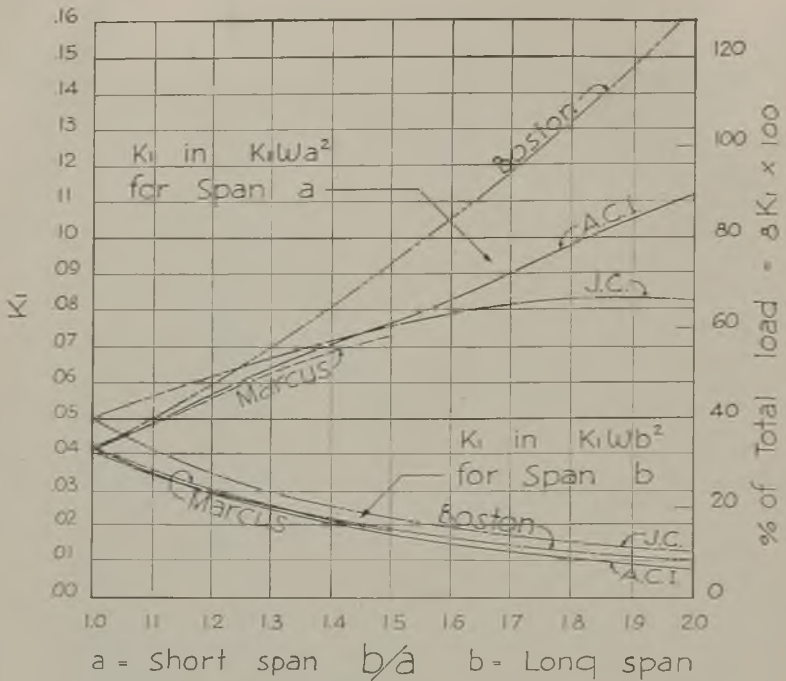
4. The spacing of the bars shall be at most three times the slab thickness and the ratio of reinforcement at least 0.0025.

PART 2

Conformity with theory

This section is devoted to a comparison of these regulations with the results of other authoritative investigations and codes, namely, the formulas of Dr. Marcus*, Dr. Westergaard†, the 1940 Joint Committee, and the Boston Code. In order to eliminate any difference in primary assumptions as to proportion or arrangement of the live load, panels

*"Design of Reinforced Concrete Slabs," Joseph A. Wise, ACI *Proceedings*, V. 25, 1929.
†"Formulas for the Design of Rectangular Floor Slabs and the Supporting Girders," H. M. Westergaard, ACI *Proceedings* V. 22, 1926.



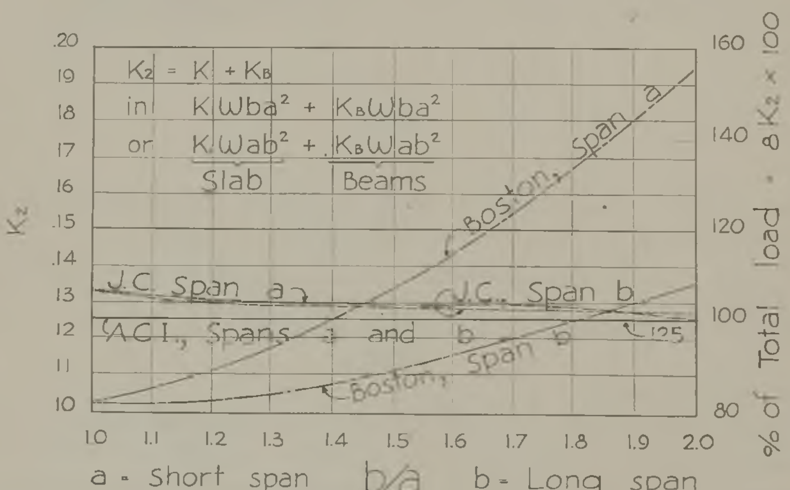


Fig. 5 (top)—Slab moment coefficients in simple panel

Fig. 6—Sum of moment coefficients for parallel beam and slab in simple panel

with various combinations of free and fully fixed edges have been selected as representing the extreme range of continuity for one definite loading condition. As indicated on the graphs of Fig. 5 to 8, the ACI Code more nearly conforms to the theoretical analyses of two-way slabs than any other code, as follows:

(a) Load Distribution. The equivalent uniform load causing slab bending ($8K_1w$) in either direction of a simply supported panel agrees closely with the results of Dr. Marcus, which, in the opinion of the authors, present the most direct theoretical approach to this problem. (See Fig. 5).

(b) Total Panel Moment. The sum of the beam and slab moments in either direction (K_2WL) equal the statical moments (1/8WL). (See Fig. 6).

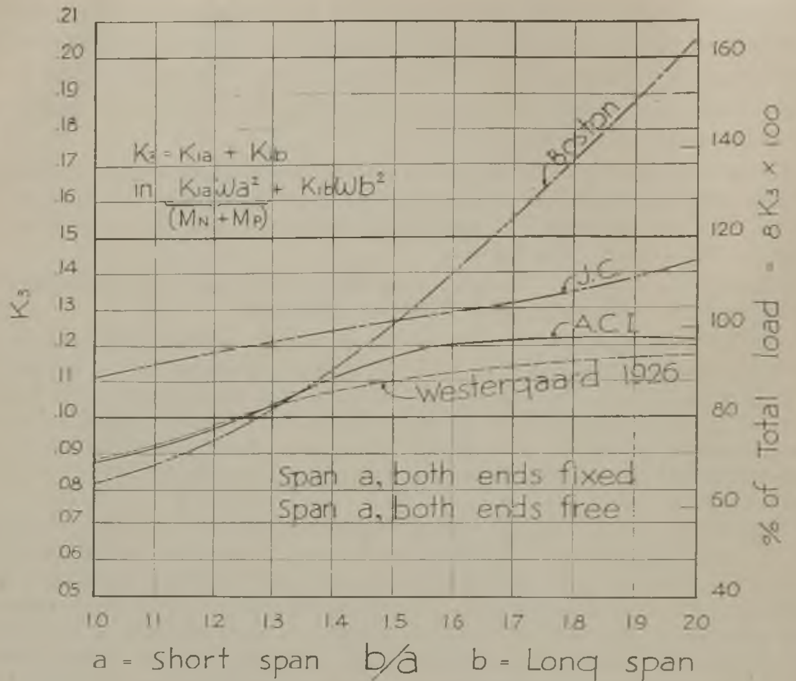
(c) Total Slab Bending. The sum of the equivalent uniform loads causing slab bending in *both* directions ($8K_3w$ or $8K_4w$) for extreme variations in edge restraint are in close agreement with Dr. Westergaard's 1926 formulas. In determining Dr. Westergaard's total slab moment for one direction, the method of averaging simple and continuous panels was followed as described in his paper. For the Joint Committee, this moment was taken as 1½ times the negative moment in accordance with Section (812(b) of that Code.

These criteria are presented as typical illustrations of the consistency by which the ACI regulations properly distribute and provide for the effect of the total load, both on the slab and on the supporting beams. Similar consistency prevails for other conditions of loading and continuity. Comparison of Fig. 7 and 8 demonstrates the wide variation in slab bending caused by changes in edge restraint, and establishes the ACI method of using lines of inflection as a satisfactory measure of true rectangularity. In consequence, it follows that the panel will be affected by the loading and stiffness of adjacent panels in a continuous structure, as prescribed in the Code. Thus, fundamentally, the ACI formulas and method are in substantial accord with accepted theory.

PART 3

General Application

A unique feature of the ACI formula is its flexibility and general applicability to a wide range of different conditions. Through the simple process of modifying the load by the tabulated factors, there results an equivalent uniform load to be used as in one-way construction. Any combination of live and dead load can be treated in this manner with resultant economy of design. Where warranted, accepted methods of adjustment for the transverse torsional resistance of the girders can be included in the determination of the one-way coefficients, as such restraint is in no way peculiar to two-way slabs. In the treatment of unequal panels, the ACI Code surpasses all others in directness and facility, and, through the use of equivalent uniform loads, permits an accurate and easy solution of the complete structure as a rigid frame. Alternately, in simple structures, where arbitrary coefficients are permissible, these may be used as prescribed for one-way spans. Therefore, consistent factors of safety are maintained throughout with other types of floor.



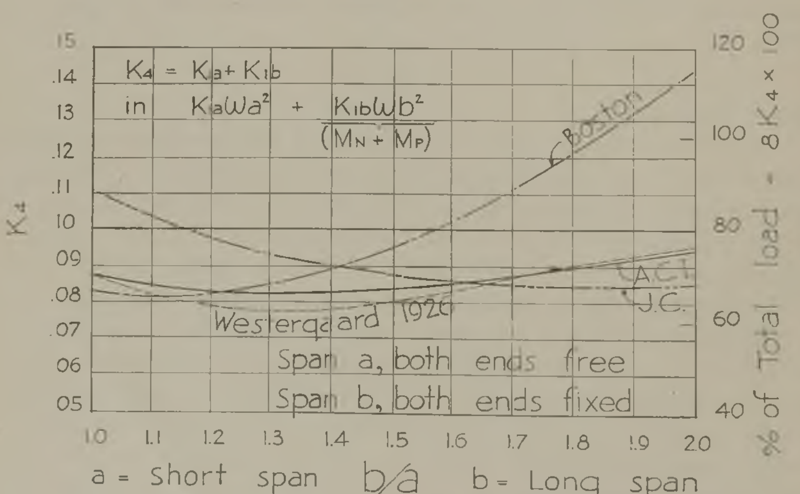


Fig. 7 (top) and 8—Sum of total moment coefficients of slab for two directions

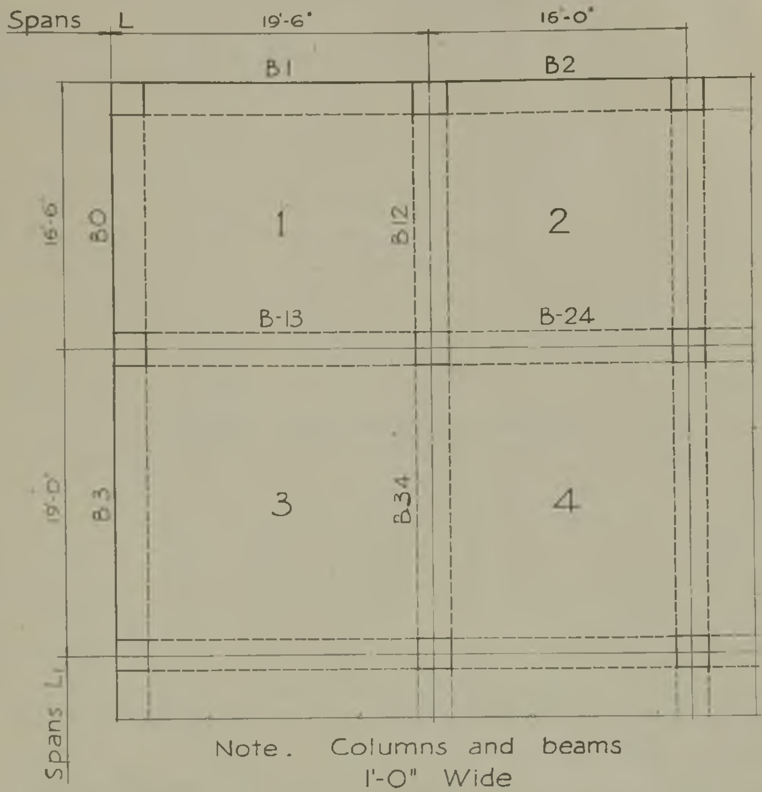


Fig. 9—Typical example

Thus, the ACI Code provides a method of analyzing slabs supported on four sides which is accurate, flexible, and also as now proposed, very simple to apply. An example will be instructive in illustrating the design procedure in a typical building.

Typical example

Let Fig. 9 represent four floor panels at the corner of a building in which the slabs and beams are numbered as shown. First, determine the minimum permissible slab thicknesses in accordance with Sec. 709(b). Using the clear spans, the minimum thickness for Panel 1 becomes

$$\left(\frac{18 + 15}{144}\right) 12 \quad + \quad \left(\frac{18 + 15}{180}\right) 12 \quad = \quad 4.95 \text{ in.}$$

Similarly, in panels 2, 3 and 4, the results are 4.65 in., 4.70 in. and 4.40 in., respectively. A 5-in. slab could therefore be used throughout, provided

TABLE 3—RECTANGULARITY

Panel	r in L Direction $= \frac{mL}{m_1L_1}$
1	$\frac{.87 \times 18}{.87 \times 15} = 1.20$
2	$\frac{.76 \times 15}{.87 \times 15} = .87$
3	$\frac{.87 \times 18}{.76 \times 18} = 1.15$
4	$\frac{.76 \times 15}{.76 \times 18} = .83$

TABLE 4—TWO-WAY SLAB FACTORS

Panel	r	$X = 0$		C	C_1	1—C	$1—C_1$
		$C_s = C_{b1}$	$C_b = C_{s1}$				
1	1.20	.18	.32	.23	.45	.77	.55
2	.87	.30	.20	.42	.26	.58	.74
3	1.15	.20	.30	.26	.42	.74	.58
4	.83	.32	.18	.45	.23	.55	.77

"C" values taken from Tables 1, 2 or graph Fig .2.

working stresses determined from moments and shears fall within the prescribed values.

As all spans are "at least 2/3 and at most 3/2 of the adjacent continuous span or spans", lines of inflection, when the span under consideration only is loaded, may be determined without recourse to elastic analysis from the ratios m or m_1 = .87 for exterior spans and .76 for interior spans. The degree of rectangularity r of the various panels follows directly from Fig. 1, and are given in Table 3. It is only necessary to compute r for one direction in each panel, as with these values factors for determining all moments and shears may be selected from the tables. Generally, only the values of C, $1 - C$. and C_s and C_b for $x = 0$, are required as listed in Table 4. Identical results can be obtained by using $1/r$ with L and L_1 reversed. It is to be noted that for reciprocal values of r with X equal to zero, C_s and C_b are interchanged in amount, and that C_s plus C_b is a constant, in this case .50. This must be true to account for the total panel load. The apparent conformity of panels 3 and 4 with 1 and 2 is coincidental to the shape of the structure.

Given a uniformly distributed total dead and live slab load, w, 100 lb. per sq. ft., an additional interior beam load of 100 lb. per lin. ft., and an exterior wall load of 1000 lb. per lin. ft., shears and bending moments may be determined as in one-way construction modified by the appropriate factors. As, in the example chosen, the larger of two adjacent spans does not exceed the shorter by more than 20 per cent, the one-way coefficients, prescribed under Section 701(c), may be used in the formulas of 709 (d):

$$V = C_s W \text{ (coefficient)},\ M = CWL\ (B.M.C.)$$

The results for slabs may be tabulated as indicated in Table 5: With these moments, minimum slab thicknesses should be checked for structural requirements and reinforcement determined in the usual way. Due regard should be given to the difference in effective depth in the two directions. It will usually be found best practice to place the steel in the direction of the heavier bending moment closest to the surface, The regulations provide that positive reinforcement adjacent to a continuous edge, and for a width not exceeding one-fourth of the shorter dimension of the panel, may be reduced 25 per cent. Accordingly, in this case, bar spacing within a width of 3 ft. 9 in. from B12, B13, B24 and B34, may be increased one third. Negative reinforcement not less than half that required for the unreduced positive moment should be provided across BO, B1, B2 nd B3. The amount of steel at any section is also limited by minimum percentage, maximum bar spacing, and general details as in one-way construction.

Beams may be analyzed in a similar manner with the addition of the effects of special loads. Beam B1 is selected as typical of the method, and shears at intermediate points distance XL from the support will be investigated. From Table 2 the factors listed in Table 6 are found. Using the coefficients prescribed in Section 701(c), the resultant shears and bending moments are as given in Tables 7 and 8 respectively. Where necessary, shear at intermediate sections of the slab may be investigated in a similar manner, using the factors C_s or C_{s1}.

In the design of structures, it is often sufficient to determine the end shears and maximum moments only, as shears at other sections can be estimated with satisfactory accuracy for the spacing of the stirrups. In this instance, it may be convenient to work with equivalent uniformly distributed loads. The factors to be used are (1—C) for bending, and twice the value of C_b when $X = O$, for shear. The equivalent loads required in the design of all beams of the example are given in Table 9.

With these loads, end shears and bending moments may be calculated in exactly the same manner as in one-way construction. This is of particular advantage in the analysis of rigid frames. Where theoretical refinement is desired, the equivalent loads may be adjusted for the elastic reactions of the slab span normal to the beam by the algebraic addition of the difference in slab end moments divided by its span.

TABLE 5—SLAB SHEARS AND MOMENTS

Panel	Span in Ft. L or L_s	Maximum End Shear in Lbs. per Ft. V or V_l					Maxiumm Positive Moment in Ft. Lbs. per Ft. M or M_l					Maximum Negative Moment in Ft. Lbs. per Ft. M or M_l				
		C_s ×	w ×	L ×	Coef. =	V	C ×	w ×	L^2 ×	B.M.C. =	M	C*av. ×	w ×	L^2av.* ×	B.M.C. =	M
1	$L = 18$	.18	100	18	1.15	372	.23	100	18^2	1/14	530	.325	100	16.5^2	1/10	885
	$L_l = 15$	.32	100	15	1.15	554	.45	100	15^2	1/14	723	.435	100	16.5^2	1/10	1184
2	$L = 15$	.30	100	15		450	.42	100	15^2	1/16	590	See Panel 1				885
	$L_l = 15$	.20	100	15	1.15	345	.26	100	15^2	1/14	419	.245	100	16.5^2	1/10	667
3	$L = 18$	.20	100	18	1.15	415	.26	100	18^2	1/14	601	.355	100	16.5^2	1/10	965
	$L_l = 18$	.30	100	18		540	.42	100	18^2	1/16	851	See Panel 1				1198
4	$L = 15$	.32	100	15		480	.45	100	15^2	1/16	633	See Panel 3				980
	$L_l = 18$	.18	100	18		324	.23	100	18	1/16	465	See Panel 2				667

*Average values of spans either side of support.

TABLE 6—FACTORS FOR BEAM B1

r \ x	C_b 0.00	.1	.2	.3	.4	1—C
1.20	.32	.29	.24	.18	.10	.77

TABLE 7—SHEARS IN BEAM 1

at X	$\left[\left(C_b\right.\right.$	$\times\ w$	$\times\ \frac{L_1}{2}\Big)$	+ Beam Load	$\times\left(\frac{1}{2}-X\right)\Big]$	$\times\ L$	$\times$ Coeff. =	Shear V
.0	.32	100	7.5	1000	.5	18′	1.15	15350
.1	.29	"	"	"	.4	"	"	12790
.2	.24	"	"	"	.3	"	"	9900
.3	.18	"	"	"	.2	"	"	6930
.4	.10	"	"	"	.1	"	"	3620

TABLE 8—MOMENTS IN BEAM 1

Max. Moment M	$\Big\{\Big[$(1-C) $\times$	w $\times$	$\frac{L_1}{2}\Big]$	+ Beam Load $\Big\}$	$\times\ L^2$	$\times$ B.M.C. =	Moment Ft. Lbs
Max. Pos. Moment..	.77	100	7.5	1000	18^2	1/14	36400
Max. Neg. Moment..	.77	"	"	"	18^2	1/10	51000

For interior beams in Table 9 under Beam load, the first column gives the floor load directly over the beam, and the second column the weight of the beam itself. If preferred, these two terms could be omitted without material error, provided the beam weights are distributed in the unit floor load, and calculations are based on center to center dimensions.

A comparison of the equivalent loads carried by the various spans in this problem illustrates the tendency of the load to be distributed in direct proportion to the stiffness of the respective slab spans. Interior spans are relatively more rigid than end spans, and in wall panels particularly, a greater proportion of the load is attracted to the span in the direction of the smaller moment coefficient. A natural economy of materials is the result.

CONCLUSION

The suggested changes of the 1941 regulations for Slabs Supported on Four Sides are believed to present this subject in the simplest form so far

TABLE 9—BEAM LOADS

Equivalent Uniform Load in Lbs. per Lin. Foot

	For End Shear							For Bending Moment					
Beam	(2 ×	C_b ×	w ×	$\frac{L_1}{2}$) +	(Beam (1)	Load (2)) =	End Shear	((1-C) ×	w ×	$\frac{L_1}{2}$) +	(Beam (1)	Load (2)) =	Load for B.M.
B.1	2	.32	100	7.5	1	1000	1480	.77	100	7.5		1000	1578
B.2	2	.20	100	7.5		1000	1300	.58	100	7.5		1000	1435
B13	2 2	.32 .30	100 100	7.5 9.0	100×1	100	1220	.77 .74	100 100	7.5 9.0	100×1	100	1443
B24	2 2	.20 .18	100 100	7.5 9.0	100×1	100	824	.58 .55	100 100	7.5 9.0	100=1	100	1130
BO	2	.18	100	9.0		1000	1324	.55	100	9.0		1000	1495
B.3	2	.20	100	9.0		1000	1360	.58	100	9.0		1000	1522
B12	2 2	.18 .30	100 100	9.0 7.5	100×1	100	974	.55 .74	100 100	9.0 7.5	100×1	100	1250
B34	2 2	.20 .32	100 100	9.0 7.5	100×1	100	1040	.58 .77	100 100	9.0 7.5	100×1	100	1263

(1) Floor load directly over Beam.
(2) Weight of Beam, walls, etc.

devised. Without change in resultant values, notation has been clarified and re-stated with a few familiar symbols. Nonessential formulas and extreneous theory have been eliminated. With these revisions, the Code is properly limited to the statement of the fundamentals requisite for design.

Analysis by this method compares favorably with theoretical standards. By one and the same formula, any variations of live load, rectangularity of panel or inequality of adjacent spans, are handled with equal facility. Computations are short and direct, and provide a clear picture of the equilibrium and elastic actions involved. The many advantages of proportioning two-way slabs from equivalent uniform loads with one-way coefficients are apparent, and the method is made available for convenient use in the suggested new arrangements of this section of the Code.

Current ACI Standards

Standards of the American Concrete Institute adopted since the inauguration of the current procedures for their consideration and promulgation under the supervision of the Standards Committee (see ACI Directory, 1944, p. 131) are published in the pages which follow—559-704, collected in one publication. Each Standard will also be available in separate prints as heretofore. New editions of the collected ACI Standards will be issued as rapidly as is justified by the completion of technical committee work. Some of the present Standards have had some few editorial revisions. They include changes in the substance of the texts as approved by the ACI Conventions which adopted them and as subsequently ratified by letter ballot of the ACI Membership. Not included here are "proposed standards" presented in recent years, nor proposed or ratified Standards prior to 1937. Some of the latter will have thorough review and eventually come before the Institute for consideration.

ACI STANDARDS—1945

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ACI Standard

Building Regulations for Reinforced Concrete (ACI 318-41)*

Reported by ACI Committee 318

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CHAPTER I—GENERAL

101—Scope

(*a*) These regulations cover the use of reinforced concrete and plain concrete in any structure to be erected under the provisions of the building code of which they form a part. They are intended to supplement the general provisions of the code in order to provide for the proper design and construction of structures of these materials. In all matters pertaining to design and construction where these specific regulations are in conflict with other provisions of the code, these regulations shall govern.

102—Permits and drawings

(*a*) Drawings and typical details of all reinforced concrete construction showing the size and position of all structural members, metal reinforcement, design strength of concrete, and the live load used in the design shall be filed with the building department as a permanent record before a permit to construct such work will be

*Adopted as a Standard of the American Concrete Institute at its 37th Annual Convention, February 20, 1941 as reported by Committee 318; Ratified by Letter Ballot July 21, 1941 (with editorial corrections from previous printings, in accordance with "Errata" leaflet issued 1943.) The Committee acknowledges the active cooperation of the Committee on Engineering Practice of the Concrete Reinforcing Steel Institute.

†Deceased (succeeded 1944 by Arthur J. Boase as chairman). Names are those representing committee personnel when report was presented.

issued. All plans submitted for approval or use on the work shall clearly show the strength of concrete at a specified age for which all parts of the structure were designed. Calculations pertaining to the design shall be filed with the drawings when required by the Commissioner of Buildings.

103—Special systems of reinforced concrete

(*a*) The sponsors of any system of reinforced concrete which has been in successful use, or the adequacy of which has been shown by test, and the design of which is either in conflict with, or not covered by these regulations shall have the right to present the data on which their design is based to a "Board of Examiners for Special Construction" appointed by the Commissioner of Buildings. This Board shall be composed of competent engineers, architects and builders, and shall have the authority to investigate the data so submitted and to formulate rules governing the design and construction of such systems. These rules when approved by the Commissioner of Buildings shall be of the same force and effect as the provisions of this code.

104—Definitions

(*a*) The following terms are defined for use in this code:

Aggregate—Inert material which is mixed with portland cement and water to produce concrete.

Column—An upright compression member the length of which exceeds three times its least lateral dimension.

Column Capital—An enlargement of the upper end of a reinforced concrete column designed and built to act as a unit with the column and flat slab.

Column Strip—A portion of a flat slab panel one-half panel in width consisting of the two adjacent quarter-panels on either side of the column center lines and extending through the panel in the direction of the span considered for bending.

Combination Column—A column in which a structural steel section, designed to carry the principal part of the load, is wrapped with wire and encased in concrete of such quality that some additional load may be allowed.

Composite Column—A column in which a steel or cast-iron section is completely encased in concrete containing spiral and longitudinal reinforcement.

Concrete—A mixture of portland cement, fine aggregate, coarse aggregate and water.

Deformed Bar—Reinforcing bars with closely spaced shoulders, lugs or projections formed integrally with the bar during rolling. Wire mesh with welded intersections not farther apart than twelve inches in the direction of the principal reinforcement and with cross wires not smaller than No. 10 W. & M. gage may be rated as a deformed bar.

Diagonal Band—A group of reinforcing bars covering a width approximately 0.4 the average span, placed symmetrically with respect to the diagonal running from corner to corner of the panel of a flat slab.

Direct Band—A group of reinforcing bars, covering a width approximately 0.4 of l_1, placed symmetrically with respect to the center lines of the supporting columns of a flat slab.

Drop Panel—The structural portion of a flat slab which is thickened in the area surrounding the column capital.

Effective Area of Concrete—The area of a section which lies between the centroid of the tensile reinforcement and the compression face of the flexural member.

Effective Area of Reinforcement—The area obtained by multiplying the right cross-sectional area of the reinforcement by the cosine of the angle between its direction and the direction for which the effectiveness is to be determined.

Flat Slab—A concrete slab reinforced in two or more directions, generally without beams or girders to transfer the loads to supporting columns.

Middle Strip—A portion of a flat slab panel one-half panel in width, symmetrical about the panel center line and extending through the panel in the direction of the span considered for bending.

Paneled Ceiling—A flat slab in which approximately that portion of the area enclosed within the intersection of the two middle strips is reduced in thickness.

Panel Length—The distance along a panel side from center to center of columns of a flat slab.

Pedestal—An upright compression member whose height does not exceed three times its least lateral dimension.

Plain Concrete—Concrete without reinforcement, or reinforced only for shrinkage or temperature changes.

Ratio of Reinforcement—The ratio of the effective area of the reinforcement to the effective area of the concrete at any section of a flexural member.

Reinforced Concrete—Concrete in which reinforcement other than that provided for shrinkage or temperature changes is embedded in such a manner that the two materials act together in resisting forces.

Surface Water—The water carried by the aggregate except that held by absorption within the aggregate particles themselves.

CHAPTER 2—MATERIALS AND TESTS

200—Notation

D = Deflection of a floor member under load test.
L = Span of member under load test.
t = The total thickness or depth of a member under load test.

201—Tests

(*a*) The Commissioner of Buildings, or his authorized representative, shall have the right to order the test of any material entering into concrete or reinforced concrete when there is reasonable doubt as to its suitability for the purpose; to order reasonable tests of the concrete from time to time to determine whether the materials and methods in use are such as to produce concrete of the necessary quality; and to order the test under load of any portion of a completed structure, when the conditions have been such as to leave reasonable doubt as to the adequacy of the structure to serve the purpose for which it is intended.

(*b*) Tests of materials and of concrete shall be made in accordance with the requirements of the American Society for Testing Materials as noted elsewhere in this chapter. The complete records of such tests shall be available for inspection by the Commissioner of Buildings at all times during the progress of the work, and shall be preserved by the engineer or architect for two years after the completion of the structure.

202—Load tests

(*a*) When a load test is required, the member or portion of the structure under consideration shall be subject to a superimposed load equal to one and one-half times the live load plus one-half of the dead load. This load shall be left in position for a period of twenty-four hours before removal. If, during the test, or upon removal of the load, the member or portion of the structure shows evident failure, such changes or modifications as are necessary to make the structure adequate for the rated capacity shall be made; or, where lawful, a lower rating shall be established. The structure shall be considered to have passed the test if the maximum deflection at the end of the twenty-four hour period does not exceed the value of D as given in the following:

$$D = \frac{.001\,L^2}{12\,t} \qquad \text{(1)}$$

all terms expressed in the same units.

If the deflection exceeds the value of D as given in formula (1), the construction shall be considered to have passed the test if within twenty-four hours after the removal of the load the member or portion of the structure shows a recovery of at least seventy-five per cent of the observed deflection.

203—Supervision

(*a*) All concrete work shall be supervised by the architect or engineer responsible for its design, or by a competent representative responsible to the architect or engineer. A record shall be kept of such supervision, which record shall cover the quality and quantity of concrete materials, the mixing and placing of the concrete, and the placing of the reinforcing steel. A complete record shall also be kept of the progress of the work and of the temperatures, when these fall below 40 degrees F., and of the protection given to the concrete while curing. This record shall be available for inspection by the Commissioner of Buildings at all times during the progress of the work and shall be preserved by the architect or engineer for two years after the completion of the work.

204—Portland cement

(*a*) Portland cement shall conform to the "Standard Specifications for Portland Cement" (A.S.T.M. Serial Designation: C9-38) or the "Standard Specifications for High-Early-Strength Portland Cement" (A.S.T.M. Serial Designation: C74-39).

205—Concrete aggregates

(*a*) Concrete aggregates shall conform to the "Standard Specifications for Concrete Aggregates" (A. S. T. M. Serial Designation: C33-40), provided however, that aggregates which have been shown by test or actual service to produce concrete of the required strength, durability, water-tightness, fire-resistance, and wearing qualities may be used under Section 302(a) Method 2, where authorized by the Commissioner of Buildings.

(*b*) The maximum size of the aggregate shall be not larger than one-fifth of the narrowest dimension between sides of the forms of the member for which the concrete is to be used nor larger than three-fourths of the minimum clear spacing between reinforcing bars.

206—Water

(*a*) Water used in mixing concrete shall be clean, and free from injurious amounts of oils, acids, alkalis, organic materials, or other deleterious substances.

207—Metal reinforcement

(*a*) Metal reinforcement shall conform to the requirements of the "Standard Specifications for Billet-Steel Bars for Concrete Reinforcement" (A. S. T. M. Serial Designation: A15-39), or for "Rail-Steel Bars for Concrete Reinforcement" (A. S. T. M. Serial Designation: A16-35), or for "Axle-Steel Bars for Concrete Reinforcement" (A. S. T. M. Serial Designation: A160-39).

(*b*) Cold-drawn wire or welded wire fabric for concrete reinforcement shall conform to the requirements of the "Standard Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement" (A. S. T. M. Serial Designation: A82-34), or "Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement" (A. S. T. M. Serial Designation: A185-37).

(*c*) Structural steel shall conform to the requirements of the "Standard Specifications for Structural Steel for Bridges and Buildings" (A. S. T. M. Serial Designation: A7-39).

(*d*) Cast-iron sections for composite columns shall conform to the "Tentative Specifications for Cast Iron Pit-cast Pipe for Water and Other Liquids" (A.S.T.M. Serial Designation: A44-39T).

208—Storage of materials

(*a*) Cement and aggregates shall be stored in such a manner as to prevent deterioration or intrusion of foreign matter. Any material which has deteriorated or which has been damaged shall not be used for concrete.

CHAPTER 3—CONCRETE QUALITY AND WORKING STRESSES

300—Notation

f_c = Compressive unit stress in extreme fiber of concrete in flexure.

f'_c = Ultimate compressive strength of concrete at age of 28 days unless otherwise specified.

f_r = Allowable unit stress in the metal core of a composite column.

f_s = Tensile unit stress in longitudinal reinforcement; nominal working stress in vertical column reinforcement.

f_v = Tensile unit stress in web reinforcement.

n = Ratio of modulus of elasticity of steel to that of concrete.

u = Bond stress per unit of surface area of bar.

v = Shearing unit stress.

v_c = Shearing unit stress permitted on the concrete.

301—Concrete quality

(*a*) For the design of reinforced concrete structures, the value of f'_c used for determining the working stresses as stipulated in Section 305 shall be based on the specified minimum ultimate 28-day compressive strength of the concrete, or on the specified minimum ultimate compressive strength at the earlier age at which the concrete may be expected to receive its full load. All plans, submitted for approval or used on the job, shall clearly show the assumed strength of concrete at a specified age for which all parts of the structure were designed.

(*b*) All concrete exposed to the action of the weather shall have a water-content of not to exceed six gallons per sack of cement.*

302—Determination of strength-quality of materials

(*a*) The determination of the proportions of cement, aggregate and water to attain the required strengths shall be made by one of the following methods:

Method 1—Concrete made from average materials:

When no preliminary tests of the materials to be used are made, the water-content per sack of cement shall not exceed the values in Table 302(*a*). Method 2 shall be employed when artificial aggregates or admixtures are used.

*In climates where frost action is not severe this section should be omitted.

TABLE 302(a)—ASSUMED STRENGTH OF CONCRETE MIXTURES

Water-Content U. S. Gallons Per 94-lb. Sack of Cement	Assumed Compressive Strength at 28 Days—p.s.i.
7½	2000
6¾	2500
6	3000
5	3750

Note—In interpreting this table, surface water carried by the aggregate must be included as part of the mixing water in computing the water-content.

Method 2—Controlled Concrete:

Water-content other than shown in Table 302(*a*) may be used provided that the strength-quality of the concrete proposed for use in the structure shall be established by tests which shall be made in advance of the beginning of operations, using the consistencies suitable for the work and in accordance with the "Standard Method of Making Compression Tests of Concrete" (A.S.T.M. Serial Designation: C39-39). A curve representing the relation between the water-content and the average 28-day compressive strength or earlier strength at which the concrete is to receive its full working load, shall be established for a range of values including all the compressive strengths called for on the plans.

The curve shall be established by at least three points, each point representing average values from at least four test specimens. The maximum allowable water-content for the concrete for the structure shall be as determined from this curve and shall correspond to a strength which is fifteen per cent greater than that called for on the plans. No substitutions shall be made in the materials used on the work without additional tests in accordance herewith to show that the quality of the concrete is satisfactory.

303—Tests on concrete

(*a*) The Commissioner of Buildings shall require a reasonable number of compression tests to be made during the progress of the work. Such tests shall be made in accordance with the "Standard Method of Making and Storing Compression Test Specimens of Concrete in the Field" (A. S. T. M. Serial Designation C31-39), and cured in accordance with the requirements for laboratory control tests.

(*b*) Not less than three specimens shall be made for each test; nor less than one test for each 250 cu. yd. of concrete.

(*c*) The standard age of test shall be 28 days, but 7-day tests may be used provided that the relation between the 7- and 28-day strengths of the concrete is established by test for the materials and proportions used.

(*d*) Where the average strength of the laboratory control cylinders for any portion of the structure falls below the minimum ultimate compressive strengths called for on the plans, the Commissioner of Buildings shall have the right to order a change in the mixture or in the water-content for the remaining portion of the structure. In cases where the average strength of the cylinders cured on the job falls below the required strength, the Commissioner of Buildings shall have the right to require conditions of temperature and moisture necessary to secure the required strength. If the average strength of either the laboratory control cylinders or the cylinders cured on the job falls below the required strength, load tests as specified in Section 202 may be required on the portion of the structure so affected.

304—Concrete proportions and consistency

(*a*) The proportions of aggregate to cement for any concrete shall be such as to produce a mixture which will work readily into the corners and angles of the forms and around reinforcement with the method of placing employed on the work, but without permitting the materials to segregate or excess free water to collect on the surface. The combined aggregates shall be of such composition of sizes that when separated on the No. 4 standard sieve, the weight passing the sieve (fine aggregate) shall not be less than thirty per cent nor greater than fifty per cent of the total, except that these proportions do not necessarily apply to light-weight aggregates.

(*b*) The methods of measuring concrete materials shall be such that the proportions can be accurately controlled and easily checked at any time during the work.* Measurement of materials for ready mixed concrete shall conform to the "Standard Specifications for Ready-Mixed Concrete" (A. S. T. M. Serial Designation: C94-38).

305—Allowable unit stresses in concrete

(*a*) The unit stresses in pounds per square inch on concrete to be used in the design shall not exceed the values of Table 305(a) where f'_c equals the minimum specified ultimate compressive strength at 28 days, or at the earlier age at which the concrete may be expected to receive its full load.

306—Allowable unit stresses in reinforcement

Unless otherwise provided in these Regulations, steel for concrete reinforcement shall not be stressed in excess of the following limits:

(*a*) *Tension*

(f_s = Tensile unit stress in longitudinal reinforcement)

and (f_v = Tensile unit stress in web reinforcement)

20,000 p.s.i. for Rail-Steel Concrete Reinforcement Bars, Billet-Steel Concrete Reinforcement Bars (of intermediate and hard grades), Axle-Steel Concrete Reinforcement Bars (of intermediate and hard grades), and Cold-Drawn Steel Wire for Concrete Reinforcement.

*Wherever practicable such measurement shall be by weight rather than by volume.

TABLE 305(a)—ALLOWABLE UNIT STRESSES IN CONCRETE

Description		Allowable Unit Stresses				
		For Any Strength of Concrete as Fixed by Test in Accordance with Section 302 $n = \frac{30000}{f'_c}$	When Strength of Concrete is Fixed by the Water-Content in Accordance with Section 302			
			$f'_c =$ 2000 p.s.i. $n = 15$	$f'_c =$ 2500 p.s.i. $n = 12$	$f'_c =$ 3000 p.s.i. $n = 10$	$f'_c =$ 3750 p.s.i. $n = 8$
Flexure: f_c						
Extreme fiber stress in compression	f_c	$0.45f'_c$	900	1125	1350	1688
Shear: v						
Beams with no web reinforcement and without special anchorage of longitudinal steel	v_c	$0.02f'_c$	40	50	60	75
Beams with no web reinforcement but with special anchorage of longitudinal steel	v_c	$0.03f'_c$	60	75	90	113
Beams with properly designed web reinforcement but without special anchorage of longitudinal steel	v	$0.06f'_c$	120	150	180	225
Beams with properly designed web reinforcement and with special anchorage of longitudinal steel	v	$0.12f'_c$	240	300	360	450
*Flat slabs at distance d from edge of column capital or drop panel	v_c	$0.03f'_c$	60	75	90	113
**Footings	v_c	$0.03f'_c$ but not to exceed 75 p.s.i.	60	75	75	75
‡Bond: u						
In beams and slabs and one-way footings:						
Plain bars	u	$0.04f'_c$ but not to exceed 160 p.s.i.	80	100	120	150
Deformed bars	u	$0.05f'_c$ but not to exceed 200 p.s.i.	100	125	150	188
In two-way footings:						
Plain bars (hooked)	u	$0.045f'_c$ but not to exceed 160 p.s.i.	90	113	135	160
Deformed bars (hooked)	u	$0.056f'_c$ but not to exceed 200 p.s.i.	112	140	168	200
Bearing: f_c						
On full area	f_c	$0.25f'_c$	500	625	750	938
On one-third area or less†	f_c	$0.375f'_c$	750	938	1125	1405

*See Section 807. **See Section 905(a) and 808(a).

†The allowable bearing stress on an area greater than one-third but less than the full area shall be interpolated between the values given.

‡Where special anchorage is provided (see Section 903(a)), one and one-half times these values in bond may be used in beams, slabs and one-way footings, but in no case to exceed 200 p.s.i. for plain bars and 250 p.s.i. for deformed bars. The values given for two-way footings include an allowance for special anchorage.

18,000 p.s.i. for Billet-Steel Concrete Reinforcement Bars (of structural grade), and Axle-Steel Concrete Reinforcement Bars (of structural grade).

(b) *Tension in One-Way Slabs of Not More Than 12 Feet Span*

(f_s = Tensile unit stress in main reinforcement).

For the main reinforcement, ⅜ inch or less in diameter, in one-way slabs, 50 per cent of the minimum yield point specified in the Standard Specifications of the American Society for Testing Materials for the particular kind and grade of reinforcement used, but in no case to exceed 30,000 p.s.i.

(c) *Compression, Vertical Column Reinforcement*

(f_s = Nominal working stress in vertical column reinforcement).

Forty per cent of the minimum yield point specified in the Standard Specifications of the American Society for Testing Materials for the particular kind and grade of reinforcement used, but in no case to exceed 30,000 p.s.i.

(f_r = Allowable unit stress in the metal core of composite and combination columns):

Structural steel sections . . . . 16,000 p.s.i.
Cast iron sections . . . . 10,000 p.s.i.
Steel pipe . . . . See limitations of Section 1106(b)

(d) *Compression, Flexural Members*

For compression reinforcement in flexural members see Section 706(b).

CHAPTER 4—MIXING AND PLACING CONCRETE

401—Preparation of equipment and place of deposit

(*a*) Before placing concrete, all equipment for mixing and transporting the concrete shall be cleaned, all debris and ice shall be removed from the spaces to be occupied by the concrete, forms shall be thoroughly wetted (except in freezing weather) or oiled, and masonry filler units that will be in contact with concrete shall be well drenched (except in freezing weather), and the reinforcement shall be thoroughly cleaned of ice or other coatings.

(*b*) Water shall be removed from place of deposit before concrete is placed unless otherwise permitted by the Commissioner of Buildings.

402—Mixing of concrete

(*a*) Unless otherwise authorized by the Commissioner of Buildings, the mixing of concrete shall be done in a batch mixer of approved type.

(*b*) The concrete shall be mixed until there is a uniform distribution of the materials and shall be discharged completely before the mixer is recharged.

(*c*) For job mixed concrete, the mixer shall be rotated at a speed recommended by the manufacturers and mixing shall be continued for at least one minute after all materials are in the mixer. A longer mixing period may be required for mixers larger than one cubic yard capacity.

(*d*) Ready-mixed concrete shall be mixed and delivered in accordance with the requirements set forth in the "Standard Specifications for Ready-Mixed Concrete" (A. S. T. M. Serial Designation C94-38).

403—Conveying

(*a*) Concrete shall be conveyed from the mixer to the place of final deposit by methods which will prevent the separation or loss of the materials.

(*b*) Equipment for chuting, pumping and pneumatically conveying concrete shall be of such size and design as to insure a practically continuous flow of concrete at the delivery end without separation of the materials.

404—Depositing

(*a*) Concrete shall be deposited as nearly as practicable in its final position to avoid segregation due to rehandling or flowing. The concreting shall be carried on at such a rate that the concrete is at all times plastic and flows readily into the spaces between the bars. No concrete that has partially hardened or been contaminated by foreign materials shall be deposited on the work, nor shall retempered concrete be used.

(*b*) When concreting is once started, it shall be carried on as a continuous operation until the placing of the panel or section is completed. The top surface shall be generally level. When construction joints are necessary, they shall be made in accordance with Section 508.

(*c*) All concrete shall be thoroughly compacted by suitable means during the operation of placing, and shall be thoroughly worked around the reinforcement and embedded fixtures and into the corners of the forms. Vibrators may be used to aid in the placement of the concrete provided they are used under experienced supervision, and the forms are designed to withstand their action.

(*d*) Where conditions make compacting difficult, or where the reinforcement is congested, batches of mortar containing the same proportions of cement to sand as used in the concrete, shall first be deposited in the forms to a depth of at least one inch.

405—Curing

(*a*) In all concrete structures, concrete made with normal portland cement shall be maintained in a moist condition for at least the first seven days after placing and high-early-strength concrete shall be so maintained for at least the first three days.

406—Cold weather requirements

(*a*) Adequate equipment shall be provided for heating the concrete materials and protecting the concrete during freezing or near-freezing weather. No frozen materials or materials containing ice shall be used.

(*b*) All concrete materials and all reinforcement, forms, fillers and ground with which the concrete is to come in contact, shall be free from frost. Whenever the temperature of the surrounding air is below 40 degrees Fahrenheit, all concrete when placed in the forms shall have a temperature of between 60 and 90 degrees Fahrenheit and shall be maintained at a temperature of not less than 50 degrees Fahrenheit for at least 72 hours for normal concrete or 24 hours for high-early-strength concrete, or for as much more time as is necessary to insure proper rate of curing of the concrete. The housing, covering or other protection used in connection with curing shall remain in place and intact at least twenty-four hours after the artificial heating is discontinued. No dependence shall be placed on salt or other chemicals for the prevention of freezing. Manure, when used for protection, shall not be allowed to come into contact with the concrete.

CHAPTER 5—FORMS AND DETAILS OF CONSTRUCTION

501—Design of forms

(*a*) Forms shall conform to the shape, lines, and dimensions of the members as called for on the plans, and shall be substantial and sufficiently tight to prevent leakage of mortar. They shall be properly braced or tied together so as to maintain position and shape.

502—Removal of forms

(*a*) Forms shall be removed in such manner as to insure the complete safety of the structure. Where the structure as a whole is supported on shores, the removable floor forms, beam and girder sides, column and similar vertical forms may be removed after twenty-four hours, providing the concrete is sufficiently hard not to be injured thereby. In no case shall the supporting forms or shoring be removed until the members have acquired sufficient strength to support safely their weight and the load thereon. The results of suitable control tests may be used as evidence that the concrete has attained such sufficient strength.

503—Pipes, conduits, etc., embedded in concrete

(*a*) Pipes which will contain liquid, gas or vapor at other than room temperature shall not be embedded in concrete necessary for structural stability or fire protection. Drain pipes and pipes whose contents will be under pressure greater than atmospheric pressure by more than one pound per square inch shall not be embedded in structural concrete except in passing through from one side to the other of a floor, wall or beam. Electric conduits and other pipes whose embedment is allowed shall not, with their fittings, displace that concrete of a column on which stress is calculated or which is required for fire protection, to greater extent than four per cent of the area of the cross section. Sleeves or other pipes passing through floors, walls or beams shall not be of such size or in such location as unduly to impair the strength of the construction; such sleeves or pipes may be considered as replacing structurally the displaced concrete, provided they are not exposed to rusting or other deterioration, are of uncoated iron or steel not thinner than standard wrought-iron pipe, have a nominal inside diameter not over two inches, and are spaced not less than three diameters on centers. Embedded pipes or conduits other than those merely passing through, shall not be larger in outside diameter than one-third the thickness of the slab, wall or beam in which they are embedded; shall not be spaced closer than three diameters on centers, nor so located as unduly to impair the strength of the construction. Circular uncoated or galvanized electric conduit of iron or steel may be considered as replacing the displaced concrete.

504—Cleaning and bending reinforcement

(*a*) Metal reinforcement, at the time concrete is placed, shall be free from rust scale or other coatings that will destroy or reduce the bond. Bends for stirrups and ties shall be made around a pin having a diameter not less than two times the minimum thickness of the bar. Bends for other bars shall be made around a pin having a diameter not less than six times the minimum thickness of the bar, except that for bars larger than one inch, the pin shall be not less than eight times the minimum thickness of the bar. All bars shall be bent cold.

505—Placing reinforcement

(*a*) Metal reinforcement shall be accurately placed and adequately secured in position by concrete or metal chairs and spacers. The minimum clear distance between parallel bars shall be one and one-half times the diameter for round bars and twice the side dimension for square bars. If special anchorage as required in Section 903 is provided, the minimum clear distance between parallel bars shall be equal to the diameter for round bars and one and one-half times the side dimension for square bars. In no case shall the clear distance between bars be less than one in., nor less than one and one-third times the maximum size of the coarse aggregate.

(*b*) When wire or other reinforcement, not exceeding one-fourth inch in diameter is used as reinforcement for slabs not exceeding ten feet in span, the reinforcement may be curved from a point near the top of the slab over the support to a point near the bottom of the slab at mid-span; provided such reinforcement is either continuous over, or securely anchored to the support.

506—Splices and offsets in reinforcement

(*a*) In slabs, beams and girders, splices of reinforcement at points of maximum stress shall generally be avoided. Splices shall provide sufficient lap to transfer the stress between bars by bond and shear. In such splices the minimum spacing of bars shall be as specified in Section 505.

(*b*) Where changes in the cross section of a column occur, the longitudinal bars shall be offset in a region where lateral support is afforded. Where offset, the slope of the inclined portion shall not be more than 1 in 6, and in the case of tied columns the ties shall be spaced not over three inches on centers for a distance of one foot below the actual point of offset.

507—Concrete protection for reinforcement

(*a*) The reinforcement of footings and other principal structural members in which the concrete is deposited against the ground shall have not less than three inches of concrete between it and the ground contact surface. If concrete surfaces after removal of the forms are to be exposed to the weather or be in contact with the ground, the reinforcement shall be protected with not less than two inches of concrete for bars more than $\frac{5}{8}$ inch in diameter and one and one-half inches for bars $\frac{5}{8}$ inch or less in diameter.

(*b*) The concrete protective covering for reinforcement at surfaces not exposed directly to the ground or weather shall be not less than three-fourths inch for slabs and walls; and not less than one and one-half inches for beams, girders and columns. In concrete joist floors in which the clear distance between joists is not more than thirty inches, the protection of metal reinforcement shall be at least three-fourths inch.

(*c*) If the code of which these regulations form a part specifies, as fire-protective covering of the reinforcement, thicknesses of concrete greater than those given in this section, then such greater thicknesses shall be used.

(*d*) Concrete protection for reinforcement shall in all cases be at least equal to the diameter of round bars, and one and one-half times the side dimension of square bars.

(*e*) Exposed reinforcement bars intended for bonding with future extensions shall be protected from corrosion by concrete or other adequate covering.

508—Construction joints

(*a*) Joints not indicated on the plans shall be so made and located as to least impair the strength of the structure. Where a joint is to be made, the surface of the concrete shall be thoroughly cleaned and all laitance removed. In addition to the foregoing, vertical joints shall be thoroughly wetted but not saturated, and slushed with a coat of neat cement grout immediately before placing of new concrete.

(*b*) At least two hours must elapse after depositing concrete in the columns or walls before depositing in beams, girders, or slabs supported thereon. Beams, girders, brackets, column capitals, and haunches shall be considered as part of the floor system and shall be placed monolithically therewith.

(*c*) Construction joints in floors shall be located near the middle of the spans of slabs, beams, or girders, unless a beam intersects a girder at this point, in which case the joints in the girders shall be offset a distance equal to twice the width of the beam. In this last case provision shall be made for shear by use of inclined reinforcement

CHAPTER 6—DESIGN—GENERAL CONSIDERATIONS

600—Notation

f'_c = Ultimate compressive strength of concrete at age of 28 days, unless otherwise specified.

n = Ratio of modulus of elasticity of steel to that of concrete $= \frac{E_s}{E_c}$; assumed as equal to $\frac{30{,}000}{f'_c}$.

601—Assumptions

(*a*) The design of reinforced concrete members shall be made with reference to working stresses and safe loads. The accepted theory of flexure as applied to reinforced concrete shall be applied to all members resisting bending. The following assumptions shall be made:

1. The steel takes all the tensile stress.

2. In determining the ratio n for design purposes, the modulus of elasticity for the concrete shall be assumed as 1000 f'_c, and that for steel as 30,000,000 p.s.i.

602—Design loads

(*a*) The provisions for design herein specified are based on the assumption that all structures shall be designed for all dead- and live-loads coming upon them, the live-loads to be in accordance with the general requirements of the building code of which this forms a part, with such reductions for girders and lower story columns as are permitted therein.

603—Resistance to wind forces

(*a*) The resisting elements in structures required to resist wind forces shall be limited to the integral structural parts.

(*b*) The moments, shears, and direct stresses resulting from wind forces determined in accordance with recognized methods shall be added to the maximum stresses which obtain at any section for dead- and live-loads.

(*c*) In proportioning the component parts of the structure for the maximum combined stresses, including wind stresses, the unit stresses shall not exceed the allowable stresses for combined live- and dead-loads provided in Sections 305, 306 and 1110 by more than one-third. The structural members and their connections shall be so proportioned as to provide suitable rigidity of structure.

CHAPTER 7—FLEXURAL COMPUTATIONS

700—Notation

A = Span length between opposite supports in one direction.

B = Span length at right angles to A.

b = Width of rectangular beam or width of flange of T-beam.

b' = Width of web in beams of I or T sections.

d = Depth from compression face of beam or slab to center of longitudinal tensile reinforcement; the diameter of a round bar or side of a square bar.

e_A = Factor modifying r_A, used in obtaining an equivalent uniform load for bending moments on span A.

e_B = Factor modifying r_B, used in obtaining an equivalent uniform load for bending moments on span B.

E = The modulus of elasticity of concrete in compression.

$F_A A$ = The distance between lines of inflection in span A, considering span A only to be loaded.

$F_B B$ = The distance between lines of inflection in span B, considering span B only to be loaded.

F_A = Ratio of the distance between assumed inflection points of the span A to span A in an isolated strip extending the entire width of the structure when a uniformly distributed load is applied to span A only.

F_B = Ratio as defined above, but applying to span B.

h = Unsupported length of a column.

I = Moment of inertia of a section about the neutral axis for bending.

K = The stiffness factor, that is, the moment of inertia divided by the span.

K_A = Stiffness factor $\frac{I}{A}$ for span A of panel AB.

K_B = Stiffness factor $\frac{I}{B}$ for span B of panel AB.

K_{AR} = Stiffness factors for any span adjacent to and continuous with span A.

K_{BR} = Stiffness factors for any span adjacent to and continuous with span B.

l = Span length of slab or beam.

l' = Clear span for positive moment and the average of the two adjacent clear spans for negative moment (See Section 701).

N = The sum of the lengths of those edges of panel AB which are also edges of adjacent panels continuous with AB.

$q_A = 6r_A (1 - e_A)$.

$q_B = 6r_B (1 - e_B)$.

r_A = Proportion of the total load carried by span A of slab.

r_B = Proportion of the total load carried by span B of slab.

t_1 = Minimum total thickness of slab.

w = Uniformly distributed load per unit of length of beam or per unit area of slab.

x = Distance from face of support to point in span.

701—General requirements

(*a*) All members of frames or continuous construction shall be designed to resist at all sections the maximum moments and shears produced by dead load, live load and wind load, as determined by the theory of elastic frames in which the simplified assumptions of Section 702 may be used.

(*b*) Approximate methods of frame analysis are satisfactory for buildings of usual types of construction, spans and story heights.

(*c*) In the case of two or more approximately equal spans (the larger of two adjacent spans not exceeding the shorter by more than 20 per cent) with loads uniformly distributed, where the unit live load does not exceed three times the unit dead load, design for the following moments and shears is satisfactory:

Positive moment at center of span

End spans. . . . . $\frac{1}{14} wl'^2$

Interior spans. . . . . $\frac{1}{16} wl'^2$

Negative moment at exterior face of first interior support

Two spans. . . . . $\frac{1}{9} wl'^2$

More than two spans. . . . . $\frac{1}{10} wl'^2$

Negative moment at other faces of interior supports $\frac{1}{11}wl'^2$

Negative moment at face of all supports for, (a) slabs with spans not exceeding ten feet, and (b) beams and girders where ratio of sum of column stiffnesses to beam stiffness exceeds eight $\frac{1}{12}wl'^2$

Shear in end members at first interior support $1.15\frac{wl'}{2}$

Shear at other supports $\frac{wl'}{2}$

702—Conditions of design*

(a) *Arrangement of Live Load*

1. The live load may be considered to be applied only to the floor under consideration, and the far ends of the columns may be assumed as fixed.

2. Consideration may be limited to combinations of dead load on all spans with full live load on two adjacent spans and with full live load on alternate spans.

(b) *Span length*

1. The span length, l, of members that are not built integrally with their supports shall be the clear span plus the depth of the slab or beam but shall not exceed the distance between centers of supports.

2. In analysis of continuous frames, center to center distances, l and h, may be used in the determination of moments. Moments at faces of supports may be used for design of beams and girders.

3. Solid or ribbed slabs with clear spans of not more than ten feet that are built integrally with their supports may be designed as continuous slabs on knife edge supports with spans equal to the clear spans of the slab and the width of beams otherwise neglected.

(c) *Stiffness*

1. The stiffness, K, of a member is defined as EI divided by l or h.

2. In computing the value of I of slabs, beams, girders, and columns, the reinforcement may be neglected. In T-shaped sections allowance shall be made for the effect of flange.

*Chapter 7 deals with floor members only. For moments in columns see Section 1108.

3. Any reasonable assumption may be adopted as to relative stiffness of columns and of floor system. The assumption made shall be consistent throughout the analysis.

(*d*) *Haunched Floor Members*

1. When members are widened near the supports, the additional width may be neglected in computing moments, but may be considered as resisting the resulting moments and shears.

2. When members are deepened near the supports, they may be analyzed as members of constant depth provided the minimum depth only is considered as resisting the resulting moments; otherwise an analysis taking into account the variation in depth is required. In any case, the actual depth may be considered as resisting shear.

(*e*) *Limitations*

1. Wherever at any section positive reinforcement is indicated by analysis, the amount provided shall be not less than .005 $b'd$ except in slabs of uniform thickness.

2. Not less than 0.005 $b'd$ of negative reinforcement shall be provided at the outer end of all members built integrally with their supports.

3. Where analysis indicates negative reinforcement along the full length of a span, the reinforcement need not be extended beyond the point where the required amount is 0.0025 $b'd$ or less.

4. In slabs of uniform thickness the minimum amount of reinforcement in the direction of the span shall be:

For structural, intermediate and hard grades and rail steel.......................................0.0025 bd

For steel having a minimum yield point of 56,000 p. s. i.......................................0.002 bd

703—Depth of beam or slab

(*a*) The depth of the beam or slab shall be taken as the distance from the centroid of the tensile reinforcement to the compression face of the structural members. Any floor finish not placed monolithically with the floor slab shall not be included as a part of the structural member. When the finish is placed monolithically with the structural slab in buildings of the warehouse or industrial class, there shall be placed an additional depth of one-half inch over that required by the design of the member.

704—Distance between lateral supports

(*a*) The clear distance between lateral supports of a beam shall not exceed thirty-two times the least width of compression flange.

705—Requirements for T-beams

(*a*) In T-beam construction the slab and beam shall be built integrally or otherwise effectively bonded together. The effective flange width to be used in the design of symmetrical T-beams shall not exceed one-fourth of the span length of the beam, and its overhanging width on either side of the web shall not exceed eight times the thickness of the slab nor one-half the clear distance to the next beam.

(*b*) For beams having a flange on one side only, the effective overhanging flange width shall not exceed one-twelfth of the span length of the beam, nor six times the thickness of the slab, nor one-half the clear distance to the next beam.

(*c*) Where the principal reinforcement in a slab which is considered as the flange of a T-beam (not a joist in concrete joist floors) is parallel to the beam, transverse reinforcement shall be provided in the top of the slab. This reinforcement shall be designed to carry the load on the portion of the slab assumed as the flange of the T-beam. The spacing of the bars shall not exceed five times the thickness of the flange, nor in any case eighteen inches.

(*d*) Provision shall be made for the compressive stress at the support in continuous T-beam construction, care being taken that the provisions of Section 505 relating to the spacing of bars, and 404(d), relating to the placing of concrete shall be fully met.

(*e*) The overhanging portion of the flange of the beam shall not be considered as effective in computing the shear and diagonal tension resistance of T-beams.

(*f*) Isolated beams in which the T-form is used only for the purpose of providing additional compression area, shall have a flange thickness not less than one-half the width of the web and a total flange width not more than four times the web thickness.

706—Compression steel in flexural members

(*a*) Compression steel in beams, girders, or slabs shall be anchored by ties or stirrups not less than ¼ inch in diameter spaced not farther apart than 16 bar diameters, or 48 tie diameters. Such stirrups or ties shall be used throughout the distance where the compression steel is required.

(*b*) The effectiveness of compression reinforcement in resisting bending may be taken at twice the value indicated from the calculations assuming a straight-line relation between stress and strain and the modular ratio given in Section 601, but not of greater value than the allowable stress in tension.

707—Shrinkage and temperature reinforcement

(*a*) Reinforcement for shrinkage and temperature stresses normal to the principal reinforcement shall be provided in floor and roof slabs where the principal reinforcement extends in one direction only. Such reinforcement shall provide for the following minimum ratios of reinforcement area to concrete area *bd*, but in no case shall such reinforcing bars be placed farther apart than five times the slab thickness nor more than eighteen inches:

Floor slabs where plain bars are used	0.0025
Floor slabs where deformed bars are used	0.002
Floor slabs where wire fabric is used, having welded intersections not farther apart in the direction of stress than twelve inches	0.0018
Roof slabs where plain bars are used	0.003
Roof slabs where deformed bars are used	0.0025
Roof slabs where wire fabric is used, having welded intersections not farther apart in the direction of stress than twelve inches	0.0022

708—Concrete joist floor construction

(*a*) Concrete joist floor construction consists of concrete joists and slabs placed monolithically with or without burned clay or concrete tile fillers. The joists shall not be farther apart than thirty inches face to face. The ribs shall be straight, not less than four inches wide, nor of a depth more than three times the width.

(*b*) When burned clay or concrete tile fillers, of material having a unit compressive strength at least equal to that of the designed strength of the concrete in the joists are used, and the fillers are so placed that the joints in alternate rows are staggered, the vertical shells of the fillers in contact with the joists may be included in the calculations involving shear or negative bending moment. No other portion of the fillers may be included in the design calculations.

(*c*) The concrete slab over the fillers shall be not less than one and one-half inches in thickness, nor less in thickness than one-twelfth of the clear distance between joists. Shrinkage reinforcement in the slab shall be provided as required in Section 707.

(*d*) Where removable forms or fillers not complying with (*b*) are used, the thickness of the concrete slab shall not be less than one-twelfth of the clear distance between joists and in no case less than two inches. Such slab shall be reinforced at right angles to the joists with a minimum of .049 sq. in. of reinforcing steel per foot of width, and in slabs on which the prescribed live load does not exceed fifty lb. per sq. ft., no additional reinforcement shall be required.

(*e*) When the finish used as a wearing surface is placed monolithically with the structural slab in buildings of the warehouse or industrial class, the thickness of the concrete over the fillers shall be one-half inch greater than the thickness used for design purposes.

(*f*) Where the slab contains conduits or pipes, the thickness shall not be less than one inch plus the total over-all depth of such conduits or pipes at any point. Such conduits or pipes shall be so located as not to impair the strength of the construction.

709—Floors with supports on four sides (1) (2)

(*a*) This construction, consisting of floors reinforced in two directions and supported on four sides, includes solid reinforced concrete slabs; concrete joists with burned clay or concrete tile fillers, with or without concrete top slabs; and concrete joists with top slabs placed monolithically with the joists. The supports for the floor slabs may be walls, reinforced concrete beams, or steel beams fully encased in concrete.

Footnotes:

(1) For comparative use the moment of inertia of a slab shall be taken as that of the total plain concrete section.

(2) Formulas for F_A, F_B, e_A, e_B, r_A, r_B. (See "Slabs Supported on Four Sides" by J. DiStasio and M. P. van Buren, JOURNAL of the A. C. I., January-February, 1936).

End Span, continuous at one end only

$$F_A = 1 - \frac{0.25}{1 + \frac{7K_A}{8K_{AR}}} \qquad (7)$$

Interior continuous span with K_{AR} the same for both adjacent spans continuous with A

$$F_A = \sqrt{1 - \frac{1}{1.5 + \frac{7K_A}{8K_{AR}}}} \qquad (8)$$

For interior spans where the spans adjacent to and in continuation of the span A under consideration differ in stiffness, for F_A use the average of the two values, one obtained using K_{AR} for the span in continuation on one end of the span A, and the other obtained by using the value of K_{AR} for the span at the other end.

To obtain F_B replace K_A with K_B and K_{AR} with K_{BR}.

$$r_A = \frac{1}{1 + \left(\frac{F_A A}{F_B B}\right)^3} = 1 - r_B \qquad (9)$$

$$e_A = \frac{2}{4 - \frac{F_B B}{F_A A}} \qquad (10a) \qquad\qquad e_B = \frac{2}{4 - \frac{F_A A}{F_B B}} \qquad (10b)$$

$$e_A = 1.0 \text{ for } \frac{F_B B}{F_A A} = 2 \qquad\qquad e_B = 0.5, \text{ as } \frac{F_A A}{F_B B} = 0$$

The total load carried by a strip of slab of unit width, span A ,equals $r_A wA$ and is considered to vary in intensity from $r_A w$ $(3e_A - 2)$ at the center of the span, to $r_A w$ $(4 - 3\,e_A)$ at the supports.

The total load carried by a beam of span A, one-half panel tributary width, equals

$$(1 - r_A)\frac{wBA}{2} \qquad (11)$$

and varies uniformly in intensity from $(1 + 2r_A - 3e_A r_A)\ \frac{wB}{2}$ at the center of the span to

$(1 - 4r_A + 3e_A r_A)\ \frac{wB}{2}$ at the supports.

When considering the B spans use the above expressions, replacing A with B, B with A, r_A with r_B, and e_A with e_B.

(Footnote (2) continued next page)

(*b*) *Minimum Slab Thickness*

The slab thickness shall satisfy prescribed working stresses and shall be not less than 4 inches nor less than

$$t_1 = \frac{A + B - 0.10N}{72} \quad \ldots\ldots (2)$$

(*c*) *Bending Moments and Shears*

The bending moment at any section shall be determined with coefficients derived as prescribed for one-way construction (Sections 701 and 702), using the following equivalent uniform load per unit length of span considered:

Slab: Strip of unit width, span A, ... $(e_A r_A)w$ .... (3)

Beam: Span A, carrying one half of load from panel width B,

(*Footnote (2) continued from previous page.*)

TABLE 1—F_A AND F_B

The values given in the table are for F_A directly. They are also the values for F_B when the designation K_A/K_{AR} is replaced by K_B/K_{BR}.

Span A	$\frac{K_A}{K_{AR}}$ =	0.00	0.25	0.50	0.67	0.80	1.00	1.25	1.50	2.00	4.00	0. ∞
Interior*.	F_A =	0.58	0.65	0.69	0.72	0.74	0.76	0.78	0.80	0.83	0.89	1.00
End.....	F_A =	0.75	0.80	0.83	0.84	0.85	0.87	0.88	0.89	0.91	0.95	1.00
Simple...	F_A =	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*For interior spans where the spans adjacent to and in continuation of the span A under consideration differ in stiffness, for F_A use the average of the two values, one obtained using K_{AR} for the span in continuation on one end of the span A, and the other obtained by using the value of K_{AR} for the span at the other end.

For values of K_A/K_{AR} between 2/3 and 3/2 the values of F_A may be taken as 0.76 for interior spans and 0.87 for end spans.

TABLE 2

The value of e_A or e_B shall be taken as unity for the computation of shear and bending moment in slabs and beams where the span in direction under consideration is not rigidly attached to the supports at one or both ends of the span.

$\frac{F_A A}{F_B B}$	r_A or $1 - r_B$	e_A	$e_A r_A$	$1 - e_A r_A$	$q_A = 6r_A(1 - e_A)$
0.00	1.00	1.00	1.00	0.00	0.00
0.50	0.89	1.00	0.89	0.11	0.00
0.55	0.86	0.92	0.79	0.21	0.41
0.60	0.82	0.86	0.71	0.29	0.69
0.65	0.78	0.81	0.63	0.37	0.89
0.70	0.74	0.78	0.58	0.42	0.98
0.80	0.66	0.73	0.48	0.52	1.07
0.90	0.58	0.69	0.40	0.60	1.08
1.00	0.50	0.67	0.33	0.67	1.00
1.10	0.43	0.65	0.28	0.72	0.90
1.20	0.37	0.63	0.23	0.77	0.82
1.30	0.31	0.62	0.19	0.81	0.71
1.40	0.27	0.61	0.16	0.84	0.63
1.50	0.23	0.60	0.14	0.86	0.55
1.60	0.20	0.59	0.12	0.88	0.49
1.80	0.15	0.58	0.09	0.91	0.38
2.00	0.11	0.57	0.06	0.94	0.28
3.00	0.04	0.55	0.02	0.98	0.11
$\frac{F_B B}{F_A A}$	r_B or $1 - r_A$	e_B	$e_B r_B$	$1 - e_B r_B$	$6r_B(1 - e_B) = q_B$

$$\frac{B}{2}(1 - e_A r_A)w \qquad (4)$$

The shear at any section at a distance x from the face of the support shall be taken as:

Slab: Strip of unit width, span A,

$$\left(\frac{A}{2} - x\right)\left(r_A - \frac{q_A x}{A}\right)w \qquad (5)$$

Beam: Span A, carrying one half of load from panel, width B,

$$\frac{B}{2}\left(\frac{A}{2} - x\right)\left(1 - r_A + \frac{q_A x}{A}\right)w \qquad (6)$$

For span B, use the above expressions substituting A for B, B for A, e_B for e_A, r_A for r_B, and q_B for q_A.

The factors e_A, r_A, etc., may be taken from Table 2, footnote (2) below after the ratio $F_A A/F_B B$ or $F_B B/F_A A$ on which they depend has been determined by the aid of Table 1, footnote (2); or the several factors may be computed from the formulas which appear in the footnote (2).

(*d*) *Arrangement of Reinforcement*

1. In any panel, the reinforcement per unit width in the long direction shall be at least one-third of that provided in the short direction.

2. The positive moment reinforcement adjacent to a continuous edge only and for a width not exceeding one-fourth of the shorter dimension of the panel may be reduced twenty-five per cent.

3. At a non-continuous edge negative moment reinforcement per unit width in amount at least as great as one-half of that required for maximum positive moment for the center one-half of the panel shall be provided across the entire width of the exterior support.

4. The spacing of the reinforcement shall be not more than three times the slab thickness and the ratio of reinforcement shall be at least 0.0025.

710—Maximum spacing of principal slab reinforcement

(*a*) In slabs other than concrete joist floor construction or flat slabs, the principal reinforcement shall not be spaced farther apart than three times the slab thickness, nor shall the ratio of reinforcement be less than specified in Section 707(a).

CHAPTER 8—SHEAR AND DIAGONAL TENSION

800—Notation

A_v = Total area of web reinforcement in tension within a distance of s (measured in a direction parallel to that of the main reinforcement), or the total area of all bars bent up in any one plane.

α = Angle between inclined web bars and axis of beam.

b = Width of rectangular beam or width of flange of T-beam.

b' = Width of web in beams of I or T sections.

d = Depth from compression face of beam or slab to center of longitudinal tensile reinforcement.

f'_c = Ultimate compressive strength of concrete at age of 28 days unless otherwise specified.

f_v = Tensile unit stress in web reinforcement.

j = Ratio of distance between centroid of compression and centroid of tension to the depth d.

s = Spacing of stirrups or of bent bars in a direction parallel to that of the main reinforcement.

t_2 = Thickness of flat slab without drop panels, or the thickness of flat slab through the drop panels where such are used.

t_3 = Thickness of flat slab (with drop panels) at points outside the drop panel.

v = Shearing unit stress.

V = Total shear.

V' = Excess of the total shear over that permitted on the concrete.

801—Shearing unit stress

(*a*) The shearing unit stress v, as a measure of diagonal tension, in reinforced concrete flexural members shall be computed by formula (12):

$$v = \frac{V}{bjd} \qquad \text{(12)}$$

(*b*) For beams of I or T section, b' shall be substituted for b in formula (12).

(*c*) In concrete joist floor construction, where burned clay or concrete tile are used, b' may be taken as a width equal to the thickness of the concrete web plus the thicknesses of the vertical shells of the concrete or burned clay tile in contact with the joist as in Section 708(b).

(*d*) When the value of the shearing unit stress computed by formula (12) exceeds the shearing unit stress v_c permitted on the concrete of an unreinforced web (see Section 305), web reinforcement shall be provided to carry the excess.

802—Types of web reinforcement

(*a*) Web reinforcement may consist of:

1. Stirrups or web reinforcement bars perpendicular to the longitudinal steel.

2. Stirrups or web reinforcement bars welded or otherwise rigidly attached to the longitudinal steel and making an angle of 30 degrees or more thereto.

3. Longitudinal bars bent so that the axis of the inclined portion of the bar makes an angle of 15 degrees or more with the axis of the longitudinal portion of the bar.

4. Special arrangements of bars with adequate provisions to prevent slip of bars or splitting of the concrete by the reinforcement (See Section 804(f)).

(*b*) Stirrups or other bars to be considered effective as web reinforcement shall be anchored at both ends, according to the provisions of Section 904.

803—Stirrups

(*a*) The area of steel required in stirrups placed perpendicular to the longitudinal reinforcement shall be computed by formula (13).

$$A_v = \frac{V's}{f_v\,jd} \qquad (13)$$

(*b*) Inclined stirrups shall be proportioned by formula (15) (Section 804(d).)

(*c*) Stirrups placed perpendicular to the longitudinal reinforcement shall not be used alone as web reinforcement when the shearing unit stress (v) exceeds $0.08f'_c$.

804—Bent bars

(*a*) When the web reinforcement consists of a single bent bar or of a single group of bent bars the required area of such bars shall be computed by formula (14).

$$A_v = \frac{V'}{f_v \sin \alpha} \qquad (14)$$

(*b*) In formula (14) V' shall not exceed $0.040\,f'_c\,bjd$.

(*c*) Only the center three-fourths of the inclined portion of such bar, or group of bars, shall be considered effective as web reinforcement.

(*d*) Where there is a series of parallel bent bars, the required area shall be determined by formula (15).

$$A_v = \frac{V's}{f_v jd\ (\sin \alpha + \cos \alpha)} \qquad (15)$$

(*e*) When bent bars, having a radius of bend of not more than two times the diameter of the bar are used alone as web reinforcement, the allowable shearing unit stress shall not exceed 0.060 f'_c. This shearing unit stress may be increased at the rate of 0.01 f'_c for each increase of four bar diameters in the radius of bend until the maximum allowable shearing unit stress is reached. (See Section 305(a).)

(*f*) The shearing unit stress permitted when special arrangements of bars are employed shall be that determined by making comparative tests, to destruction, of specimens of the proposed system and of similar specimens reinforced in conformity with the provisions of this code, the same factor of safety being applied in both cases.

805—Combined web reinforcement

(*a*) Where more than one type of reinforcement is used to reinforce the same portion of the web, the total shearing resistance of this portion of the web shall be assumed as the sum of the shearing resistances computed for the various types separately. In such computations the shearing resistance of the concrete shall be included only once, and no one type of reinforcement shall be assumed to resist more than $\frac{2\ V'}{3}$.

806—Spacing of web reinforcement

(*a*) Where web reinforcement is required it shall be so spaced that every 45 degree line (representing a potential crack) extending from the mid-depth of the beam to the longitudinal tension bars shall be crossed by at least one line of web reinforcement. If a shearing unit stress in excess of 0.06 f'_c is used, every such line shall be crossed by at least two such lines of web reinforcement.

807—Shearing stress in flat slabs

(*a*) In flat slabs, the shearing unit stress on a vertical section which lies at a distance $t_2 - 1\frac{1}{2}$ in. beyond the edge of the column capital and parallel or concentric with it, shall not exceed the following values when computed by formula (12) (in which d shall be taken as $t_2 - 1\frac{1}{2}$ in.):

1. 0.03 f'_c, when at least 50 per cent of the total negative reinforcement in the column strip passes directly over the column capital.

2. 0.025 f'_c, when 25 per cent or less of the total negative reinforcement in the column strip passes directly over the column capital.

3. For intermediate percentages, intermediate values of the shearing unit stress shall be used.

(*b*) In flat slabs, the shearing unit stress on a vertical section which lies at a distance of $t_3 - 1\frac{1}{2}$ in. beyond the edge of the drop panel and parallel with it shall not exceed 0.03 f'_c when computed by formula (12) (in which d shall be taken as $t_3 - 1\frac{1}{2}$ in.). At least 50 per cent of the cross-sectional area of the negative reinforcement in the column strip must be within the width of strip directly above the drop panel.

808—Shear and diagonal tension in footings

(*a*) In isolated footings the shearing unit stress computed by formula (12) on the critical section (see 1205(a)), shall not exceed 0.03 f'_c, nor in any case shall it exceed 75 p.s.i.

CHAPTER 9—BOND AND ANCHORAGE

900—Notation

d = Depth from compression face of beam or slab to center of longitudinal tensile reinforcement.

f'_c = Ultimate compressive strength of concrete at age of 28 days unless otherwise specified.

j = Ratio of distance between centroid of compression and centroid of tension to the depth d.

Σo = Sum of perimeters of bars in one set.

u = Bond stress per unit of surface area of bar.

V = Total shear.

901—Computation of bond stress in beams

(*a*) In flexural members in which the tensile reinforcement is parallel to the compression face, the bond stress at any cross section shall be computed by formula (16).

$$u = \frac{V}{\Sigma o \, jd} \quad \text{(16)}$$

in which V is the shear at that section.

(*b*) Adequate end anchorage shall be provided for the tensile reinforcement in all flexural members to which formula (16) does not apply, such as footings, brackets and other tapered or stepped beams in which the tensile reinforcement is not parallel to the compression face.

902—Ordinary anchorage requirements

(*a*) Tensile negative reinforcement in any span of a continuous, restrained, or cantilever beam, or in any member of a rigid frame shall be adequately anchored by bond, hooks or mechanical anchors in or through the supporting member. Within any such span every reinforcing bar shall be extended at least twelve diameters beyond the point at which it is no longer needed to resist stress. In cases where the length from the point of maximum tensile stress in the bar to the end of the bar is not sufficient to develop this maximum stress by bond, the bar shall extend into a region of compression and be anchored by means of a standard hook or it shall be bent across the web at an angle of not less than 15 degrees with the longitudinal portion of the bar and either made continuous with the positive reinforcement or anchored in a region of compression.

(*b*) Of the positive reinforcement in continuous beams not less than one-fourth the area shall extend along the same face of the beam into the support a distance of ten or more bar diameters, or shall be extended as far as possible into the support and terminated in standard hooks, or other adequate anchorage.

(*c*) In simple beams, or at the outer or freely supported ends of end spans of continuous beams, at least one-half the positive reinforcement shall extend along the same face of the beam into the support a distance of twelve or more bar diameters, or shall be extended as far as possible into the support and terminated in standard hooks.

903—Special anchorage requirements

(*a*) Where increased shearing or bond stresses are permitted because of the use of special anchorage (See Section 305), every bar shall be terminated in a standard hook in a region of compression, or it shall be bent across the web at an angle of not less than 15 degrees with the longitudinal portion of the bar and made continuous with the negative or positive reinforcement.

904—Anchorage of web reinforcement

(*a*) Single separate bars used as web reinforcement shall be anchored at each end by one of the following methods:

1. Welding to longitudinal reinforcement.

2. Hooking tightly around the longitudinal reinforcement through 180 degrees.

3. Embedment above or below the mid-depth of the beam on the compression side, a distance sufficient to develop the stress to which the bar will be subjected at a bond stress of not to exceed .04 f'_c on plain bars nor .05 f'_c on deformed bars.

4. Standard hook (see Section 906(a)), considered as developing 10,000 p.s.i., plus embedment sufficient to develop by bond the remainder of the stress to which the bar is subjected. The unit bond stress shall not exceed that specified in Table 305(a). The effective embedded length shall not be assumed to exceed the distance between the mid-depth of the beam and the tangent of the hook.

(*b*) The extreme ends of bars forming simple U or multiple stirrups shall be anchored by one of the methods of Section 904(a) or shall be bent through an angle of at least 90 degrees tightly around a longitudinal reinforcing bar not less in diameter than the stirrup bar, and shall project beyond the bend at least twelve diameters of the stirrup bar.

(*c*) The loops or closed ends of such stirrups shall be anchored by bending around the longitudinal reinforcement through an angle of at least 90 degrees, or by being welded or otherwise rigidly attached thereto.

(*d*) Hooking or bending stirrups or separate web reinforcement bars around the longitudinal reinforcement shall be considered effective only when these bars are perpendicular to the longitudinal reinforcement.

(*e*) Longitudinal bars bent to act as web reinforcement shall, in a region of tension, be continuous with the longitudinal reinforcement. The tensile stress in each bar shall be fully developed in both the upper and the lower half of the beam by one of the following methods:

1. As specified in Section 904(a), (3).

2. As specified in Section 904(a), (4).

3. By bond, at a unit bond stress not exceeding .04 f'_c on plain bars nor .05 f'_c on deformed bars, plus a bend of radius not less than two times the diameter of the bar, parallel to the upper or lower surface of the beam, plus an extension of the bar of not less than twelve diameters of the bar terminating in a standard hook. This short radius bend extension and hook shall together not be counted upon to develop a tensile unit stress in the bar of more than 10,000 p.s.i.

4. By bond, at a unit bond stress not exceeding .04 f'_c on plain bars nor .05 f'_c on deformed bars, plus a bend of radius not less than two times the diameter of the bar, parallel to the upper or lower surface of the beam and continuous with the longitudinal reinforcement. The short radius bend and continuity shall together not be counted upon to develop a tensile unit stress in the bar of more than 10,000 p.s.i.

5. The tensile unit stress at the beginning of a bend may be increased from 10,000 p.s.i. when the radius of bend is two bar diameters, at the rate of 1,000 p.s.i. tension for each increase of 1½ bar diameters in the radius of bend, provided that the length of the bar in the bend and extension is sufficient to develop this increased tensile stress by bond at the unit stresses given in Section 904(e), (3).

(*f*) In all cases web reinforcement shall be carried as close to the compression surface of the beam as fireproofing regulations and the proximity of other steel will permit.

905—Anchorage of bars in footing slabs

(*a*) All bars in footing slabs shall be anchored by means of standard hooks. The outer faces of these hooks shall be not less than three inches nor more than six inches from the face of the footing.

906—Hooks

(*a*) The terms "hook" or "standard hook" as used herein shall mean either

1. A complete semicircular turn with a radius of bend on the axis of the bar of not less than three and not more than six bar diameters, plus an extension of at least four bar diameters at the free end of the bar, or

2. A 90° bend having a radius of not less than four bar diameters plus an extension of twelve bar diameters.

Hooks having a radius of bend of more than six bar diameters shall be considered merely as extensions to the bars, and shall be treated as in Section 904(e), (5).

(*b*) In general, hooks shall not be permitted in the tension portion of any beam except at the ends of simple or cantilever beams or at the freely supported ends of continuous or restrained beams.

(*c*) No hook shall be assumed to carry a load which would produce a tensile stress in the bar greater than 10,000 p.s.i.

(*d*) Hooks shall not be considered effective in adding to the compressive resistance of bars.

(*e*) Any mechanical device capable of developing the strength of the bar without damage to the concrete may be used in lieu of a hook. Tests must be presented to show the adequacy of such devices.

CHAPTER 10—FLAT SLABS—WITH SQUARE OR RECTANGULAR PANELS

1000—Notation

A = The distance from the center line of the column, in the direction of any span, to the intersection of a 45-degree diagonal line from the center of the column to the bottom of the flat slab or drop panel, where such line lies wholly within the column, capital, or bracket, provided such capital or bracket is structurally capable of resisting shears and moments without excessive unit stress. In no case shall A be greater than one-eighth the span in the direction considered.

A_{av} = Average of the two values of A for the two columns at the ends of a column strip, in the direction of the spans considered.

c = Diameter or width of column capital at the under side of the slab or drop panel. No portion of the column capital shall be considered for structural purposes which lies outside the largest right circular cone, with 90 degrees vertex angle, that can be included within the outlines of the column capital.

L = Span length of slab center to center of columns in the direction of which bending is considered.

M_o = Sum of the positive and the average negative bending moments at the critical design sections of a flat slab panel. See Section 1003(b).

W = Total dead and live load uniformly distributed over a single panel area.

W_{av} = The average of the total load on two adjacent panels.

x = Coefficient of span L which gives the distance from the center of column to the critical section for negative bending in design according to Section 1002(a).

1001—Scope

(*a*) The term flat slab shall mean a reinforced concrete slab supported by columns with or without flaring heads or column capitals, with or without depressed or drop panels and generally without beams or girders.

(*b*) Recesses or pockets in flat slab ceilings, located between reinforcing bars and forming cellular or two-way ribbed ceilings, whether left open or filled with permanent fillers, shall not prevent a slab from being considered a flat slab; but allowable unit stresses shall not be exceeded.

(*c*) This chapter provides for two methods of design of flat slab structures.

1. Any type of flat slab construction may be designed by application of the principles of continuity, using the method outlined in Section 1002, or using other recognized methods of elastic analysis. In either case, the design must be subject to the provisions of Sections 1005(a) and (c), 1006, 1008 and 1009.

2. The common cases of flat slab construction described in Section 1003 may be designed by the use of moment coefficients, given in Sections 1003 and 1004, and subject to the provisions of Sections 1005, 1006, 1007, 1008 and 1009.

1002—Design of flat slabs as continuous frames

(*a*) Except in the cases of flat slab construction where specified coefficients for bending may be used, as provided in Section 1003, bending and shear in flat slabs and their supports shall be determined by an analysis of the structure as a continuous frame, and all sections shall be proportioned to resist the moments and shears thus obtained. In the analysis, the following assumptions may be made:

1. The structure may be considered divided into a number of bents, each consisting of a row of columns and strips of supported slabs, each strip bounded laterally by the center line of the panel on either side of the row of columns. The bents shall be taken longitudinally and transversely of the building.

2. Each such bent may be analyzed in its entirety; or each floor thereof and the roof may be analyzed separately with its adjacent columns above and below, the columns being assumed fixed at their remote ends. Where slabs are thus analyzed separately, in bents more than four panels long, it may be assumed in determining the bending at a given support that the slab is fixed at any support two panels distant therefrom beyond which the slab continues.

3. The joints between columns and slabs may be considered rigid and this rigidity may be assumed to extend in the slabs a distance A from the center of the columns, and in the column to the intersection of the sides of the column and the 45 degree line defining A. The change in length of columns and slabs due to direct stress, and deflections due to shear, may be neglected.

Where metal column capitals are used, account may be taken of their contributions to stiffness and resistance to bending and shear.

4. The supporting columns may be assumed free from settlement or lateral movement unless the amount thereof can be reasonably determined.

5. The moment of inertia of slab or column at any cross-section may be assumed to be that of the gross section of the concrete. Variation in the moments of inertia of the slabs and columns along their axes shall be taken into account.

6. Where the load to be supported is definitely known, the structure shall be analyzed for that load. Where the live load is variable but does not exceed three-quarters of the dead load, or the nature of the live load is such that all panels will be loaded simultaneously, the maximum bending may be assumed to obtain at all sections under full live load. Elsewhere, maximum positive bending near mid-span of a panel may be assumed to obtain under full live load in the panel and in alternate panels; and maximum negative bending at a support may be assumed to obtain under full live load in the adjacent panels only.

7. Where neither beams nor girders help to transfer the slab load to the supporting column, the critical section for negative bending may be assumed as not more than the distance xL from the column center, where

$$x = 0.073 + 0.57 \frac{A}{L} \quad \text{(17)}$$

In slabs supported by beams, girders, or walls, the critical section for negative bending shall be assumed at the face of such support.

8. The numerical sum of the maximum positive and the average maximum negative bending moments for which provision is made in the design in the direction of either side of a rectangular panel shall be assumed as not less than

$$\frac{1}{10} W_{av} L \left(1 - \frac{4A_{cs}}{3L}\right)^2 \quad \text{(18)}$$

9. The bending at critical sections across the slabs of each bent may be apportioned between the column strip and middle strip, as defined in Section 1005, in the ratio of the specified coefficients which affect such apportionment in the special cases of flat slabs provided for in Section 1003.

10. The maximum bending in columns may be assumed to obtain under full live load in alternate panels. Columns shall be proportioned to resist the maximum bending combined with the maximum direct load consistent therewith; and for maximum direct load combined with the bending under full load, the direct load subject to allowable reductions, in the manner provided in Chapter 11. In computing moments in columns at any floor, the far ends of the columns may be considered fixed.

(*b*) The foregoing provisions outline the method to be followed in analyzing and designing flat slabs in the general case. In all instances the design must conform to the requirements for panel strips and critical design sections, slab thickness and drop panels, capitals and brackets, arrangement of reinforcement and openings in flat slabs, as provided in Sections 1005(a) and (c), 1006, 1008 and 1009.

1003—Design of flat slabs by moment coefficients

(*a*) In those cases of flat slab construction which fall within the following limitations as to continuity and dimensions, the bending moments at critical sections may be determined by the use of specified coefficients as provided in Section 1004.

1. The ratio of length to width of panel does not exceed 1.33.
2. The slab is continuous for at least three panels in each direction.
3. The successive span lengths in each direction differ by not more than twenty per cent of the shorter span.

(*b*) In such slabs, the numerical sum of the positive and negative bending moments in the direction of either side of an interior rectangular panel shall be assumed as not less than

$$M_o = 0.09\ WL\left(1 - \frac{2c}{3L}\right)^2 \qquad (19)$$

(*c*) Three-fourths of the width of the strip shall be taken as the width of the section in computing compression due to bending, except that, on a section through a drop panel, three-fourths of the width of the drop panel shall be taken. Account shall be taken of any recesses which reduce the compressive area. Tension reinforcement distributed over the entire strip shall be included in the computations.

(*d*) The design of slabs under the procedure given in this section is subject to the provisions of all subsequent sections of this chapter (Sections 1004 to 1009).

1004—Bending moment coefficients

(*a*) The bending moments at the critical sections of the middle and column strips of an interior panel shall be assumed as given in Table 1004(a).

TABLE 1004(a)—BENDING MOMENTS IN INTERIOR FLAT SLAB PANEL

With drop panel		
Column strip....................	Negative moment	$0.50M_o$
	Positive moment	$0.20M_o$
Middle strip....................	Negative moment	$0.15M_o$
	Positive momtnt	$0.15M_o$
Without drop panel		
Column strip....................	Negative moment	$0.46M_o$
	Positive moment	$0.22M_o$
Middle strip....................	Negative moment	$0.16M_o$
	Positive moment	$0.16M_o$

TABLE 1004(b)—BENDING MOMENTS IN EXTERIOR FLAT SLAB PANEL

With drop panel		
Column strip....................	Exterior negative	$0.45M_o$
	Positive moment	$0.25M_o$
	Interior negative	$0.55M_o$
Middle strip....................	Exterior negative	$0.10M_o$
	Positive moment	$0.19M_o$
	Interior negative	$0.165M_o$
Without drop panel		
Column strip....................	Exterior negative	$0.41M_o$
	Positive moment	$0.28M_o$
	Interior negative	$0.50M_o$
Middle strip....................	Exterior negative	$0.10M_o$
	Positive moment	$0.20M_o$
	Interior negative	$0.176M_o$

TABLE 1004(c)—BENDING MOMENTS IN PANELS WITH MARGINAL BEAMS OR WALLS

		Marginal Beams with Depth greater than 1½ times the Slab Thickness; or Bearing Wall.		Marginal Beams with depth 1½ times the Slab Thickness or less.	
(a) Load to be carried by Marginal Beam or Wall		Loads directly superimposed upon it plus a uniform load equal to one-quarter of the total live and dead panel load.		Loads directly superimposed upon it exclusive of any panel load.	
		With Drop	Without Drop	With Drop	Without Drop
(b) Moment to be used in the design of Half Column Strip adjacent and parallel to Marginal Beam or Wall.	Neg.	$0.125M_o$	$0.115M_o$	$0.25M_o$	$0.23M_o$
	Pos.	$0.05M_o$	$0.055M_o$	$0.10M_o$	$0.11M_o$
(c) Negative Moment to be used in Design of Middle Strip continuous across a Beam or Wall	Neg.	$0.195M_o$	$0.208M_o$	$0.15M_o$	$0.16M_o$

(*b*) The bending moments at critical sections of strips, in an exterior panel, at right angles to the discontinuous edge, where the exterior supports consist of reinforced concrete columns or reinforced concrete bearing walls integral with the slab, the ratio of stiffness of the support to that of the slab being at least as great as the ratio of the live load to the dead load and not less than one, shall be assumed as given in Table 1004(b). Where a flat slab is so supported by a wall providing restraint at the discontinuous edge, the coefficient for negative bending at the edge shall be assumed more nearly equal in the column and middle strips, the sum remaining as given in Table 1004(b), but that for the column strip shall not be less than 0.30 M_o. Bending in middle strips parallel to a discontinuous edge, except in a corner panel, shall be assumed the same as in an interior panel. M_o shall be determined as provided in Section 1003(b) for an interior panel.

(*c*) The bending moments at critical sections of strips, in an exterior panel, at right angles to the discontinuous edge, where the exterior supports are masonry bearing walls or other construction which provide only negligible restraint to the slab, shall be assumed as given in Table 1004(b) with the following modifications.

1. On critical sections at the face of the exterior support, negative bending in each strip shall be assumed as 0.05 M_o.

2. The coefficients for positive bending shall be increased by forty per cent.

3. The coefficients for negative bending at the first interior columns shall be increased thirty per cent.

(*d*) The bending moments in panels with marginal beams or walls, in the strips parallel and close thereto, and in the beams, shall be determined upon the basis of assumptions presented in Table 1004(c).

(*e*) For design purposes any of the moment coefficients of Tables 1004(a), 1004(b), and 1004(c) may be varied by not more than six per cent, but the numerical sum of the positive and negative moments in a panel shall not be taken as less than the amount specified.

(*f*) Panels supported by marginal beams on opposite edges shall be designed as solid one or two-way slabs to carry the entire panel load.

(*g*) The ratio of reinforcement in any strip shall not be less than 0.0025.

1005—Panel strips and critical design sections

(*a*) A flat slab panel shall be considered as consisting of strips in each direction as follows:

A middle strip one half panel in width, symmetrical about panel center line and extending through the panel in the direction of the span for bending.

A column strip consisting of the two adjacent quarter-panels either side of the column center lines.

(*b*) The critical sections for bending are located as follows:

Sections for negative bending shall be taken along the edges of the panel, on column center lines between capitals and around the perimeters of column capitals.

Sections for positive bending shall be taken at mid-span of the strips.

(*c*) Only the reinforcement which crosses a critical section within a strip may be considered effective to resist bending in the strip at that section. Reinforcement which crosses such section at an angle with the center-line of the strip shall be assumed to contribute to the resistance of bending only its effective area in the direction of the strip, as defined in Chapter 1.

1006—Slab thickness and drop panels

(*a*) The thickness of a flat slab and the size and thickness of the drop panel, where used, shall be such that the compressive stress due to bending at the critical sections of any strip and the shear about the column capital and the drop panel shall not exceed the unit stresses allowed in concrete of the quality used.

(*b*) The shearing stresses in the slab outside the capital or drop panel shall be computed as provided in Section 807.

(*c*) Slab thickness shall not, however, be less than

$$\frac{L}{40} \text{ with drop panels}$$

or

$$\frac{L}{36} \text{ without drop panels}$$

(*d*) The thickness of the drop panel below the slab shall not be more than one-fourth the distance from the edge of the column capital to the edge of the drop panel.

1007—Capitals and brackets

(*a*) Where a column is without a flaring concrete capital the distance c shall be taken as the diameter of the column. Structural metal embedded in the slab or drop panel may be regarded as contributing to resistance in bending and shear.

(*b*) Where a reinforced concrete beam frames into a column without capital or bracket on the same side with the beam, the value of c may be taken as the width of the column plus twice the projection of the beam above or below the slab or drop panel for computing bending in strips parallel to the beam.

(*c*) Brackets capable of transmitting the negative bending and the shear in the column strips to the columns without excessive unit stress may be substituted for column capitals at exterior columns. The value of c where brackets are used shall be taken as twice the distance from the center of the column to a point where the bracket is $1\frac{1}{2}$ inches thick, but not more than the thickness of the column plus twice the depth of the bracket.

(*d*) The average of the diameters c of the column capitals at the four corners of a panel shall be used in determining the bending in the middle strips of the panel. The average of the diameters c of the two column capitals at the ends of a column strip shall be used in determining bending in the strip.

1008—Arrangement of reinforcement

(*a*) Slab reinforcement shall be provided to resist the bending and bond stresses not only at critical sections, but also at intermediate sections.

(*b*) Bars shall be spaced evenly across strips or bands and the spacing shall not exceed three times the slab thickness.

(*c*) In exterior panels the reinforcement perpendicular to the discontinuous edge for positive bending, shall extend to the edge and have embedment of at least six inches in spandrel beams, walls or columns. All such reinforcement for negative bending shall be bent, hooked or otherwise anchored in spandrel beams, walls or columns.

1009—Openings in flat slabs

Openings of any size may be cut through a flat slab if provision is made for the total positive and negative resisting moments, as required in Sections 1002 or 1003, without exceeding the allowable stresses as given in Sections 305 and 306.

CHAPTER 11—REINFORCED CONCRETE COLUMNS AND WALLS

1100—Notation

A_c = Area of core of a spirally reinforced column measured to the outside diameter of the spiral; net area of concrete section of a composite column.

A_g = The overall or gross area of spirally reinforced or tied columns; the total area of the concrete encasement of combination columns.

A_r = Area of the steel or cast-iron core of a composite column; the area of the steel core in a combination column.

A_s = Effective cross-sectional area of reinforcement in compression in columns.

C = Ratio of allowable concrete stress, f_a, in axially loaded column to allowable fiber stress for concrete in flexure.

$D = \frac{t^2}{2R^2}$ = a factor, usually varying from 3 to 9. (The term R as used here is the radius of gyration of the entire column section.)

d = The least lateral dimension of a concrete column.

e = Eccentricity of the resultant load on a column, measured from the gravity axis.

$F = \frac{\text{Yield point of pipe}}{45{,}000}$ (See Section 1106(b)).

f_a = Average allowable stress in the concrete of an axially loaded reinforced concrete column.

f_c = Computed concrete fiber stress in an eccentrically loaded column.

f'_c = Ultimate compressive strength of concrete at age of 28 days, unless otherwise specified.

f_p = Maximum allowable concrete fiber stress in an eccentrically loaded column.

f_r = Allowable unit stress in the metal core of a composite column.

f'_r = Allowable unit stress on unencased steel columns and pipe columns.

f_s = Nominal working stress in vertical column reinforcement.

f'_s = Useful limit stress of spiral reinforcement.

h = Unsupported length of column.

K = Least radius of gyration of a metal pipe section (in pipe columns).

$$n = \frac{30,000}{f'_c}$$

N = Axial load applied to reinforced concrete column.

p' = Ratio of volume of spiral reinforcement to the volume of the concrete core (out to out of spirals) of a spirally reinforced concrete column.

p_g = Ratio of the effective cross-sectional area of vertical reinforcement to the gross area A_g.

P = Total allowable axial load on a column whose length does not exceed ten times its least cross-sectional dimension.

P' = Total allowable axial load on a long column.

R = Least radius of gyration of a section.

t = Overall depth of column section.

1101—Limiting dimensions

(*a*) The following sections on reinforced concrete and composite columns, except Section 1107(a), apply to a short column for which the unsupported length is not greater than ten times the least dimension. When the unsupported length exceeds this value, the design shall be modified as shown in Section 1107 (a). Principal columns in buildings shall have a minimum diameter of twelve inches, or in the case of rectangular columns, a minimum thickness of ten inches, and a minimum gross area of 120 sq. in. Posts that are not continuous from story to story shall have a minimum diameter or thickness of six inches.

1102—Unsupported length of columns

(*a*) For purposes of determining the limiting dimensions of columns, the unsupported length of reinforced concrete columns shall be taken as the clear distance between floor slabs, except that

1. In flat slab construction, it shall be the clear distance between the floor and the lower extremity of the capital.

2. In beam and slab construction, it shall be the clear distance between the floor and the under side of the deeper beam framing into the column in each direction at the next higher floor level.

3. In columns restrained laterally by struts, it shall be the clear distance between consecutive struts in each vertical plane; provided that to be an adequate support, two such struts shall meet the column at approximately the same level, and the angle

between vertical planes through the struts shall not vary more than 15 degrees from a right angle. Such struts shall be of adequate dimensions and anchorage to restrain the column against lateral deflection.

4. In columns restrained laterally by struts or beams, with brackets used at the junction, it shall be the clear distance between the floor and the lower edge of the bracket, provided that the bracket width equals that of the beam or strut and is at least half that of the column.

(*b*) For rectangular columns, that length shall be considered which produces the greatest ratio of length to depth of section.

1103—Spirally reinforced columns

(*a*) *Allowable Load*—The maximum allowable axial load, P, on columns with closely spaced spirals enclosing a circular concrete core reinforced with longitudinal bars shall be that given by Formula (20).

$$P = A_g\,(0.225\,f'_c + f_s p_g) \qquad (20)$$

Wherein A_g = the gross area of the column

f'_c = compressive strength of the concrete

f_s = nominal working stress in vertical column reinforcement, to be taken at forty per cent of the minimum specification value of the yield point; viz., 16,000 p.s.i. for intermediate grade steel and 20,000 p.s.i. for rail or hard grade steel.*

p_g = ratio of the effective cross-sectional area of vertical reinforcement to the gross area, A_g.

(*b*) *Vertical Reinforcement*—The ratio p_g shall not be less than 0.01 nor more than 0.08. The minimum number of bars shall be six, and the minimum diameter shall be ⅝ in. The center to center spacing of bars within the periphery of the column core shall not be less than 2½ times the diameter for round bars or three times the side dimension for square bars. The clear spacing between bars shall not be less than 1½ inches or 1½ times the maximum size of the coarse aggregate used. These spacing rules also apply to adjacent pairs of bars at a lapped splice; each pair of lapped bars forming a splice may be in contact, but the minimum clear spacing between one splice and the adjacent splice should be that specified for adjacent single bars.

(*c*) *Splices in Vertical Reinforcement*—Where lapped splices in the column verticals are used, the minimum amount of lap shall be as follows:

*Nominal working stresses for reinforcement of higher yield point may be established at forty per cent of the yield point stress, but not more than 30,000 p.s.i., when the properties of such reinforcing steels have been definitely specified by standards of A.S.T.M. designation. If this is done, the lengths of splice required by Section 1103(c) shall be increased accordingly.

1. For deformed bars—with concrete having a strength of 3000 p.s.i. or above, twenty-four diameters of bar of intermediate grade steel and thirty diameters of bar of hard grade steel. For bars of higher yield point, the amount of lap shall be increased in proportion to the nominal working stress. When the concrete strengths are less than 3000 p.s.i., the amount of lap shall be one-third greater than the values given above.

2. For plain bars—the minimum amount of lap shall be twenty-five per cent greater than that specified for deformed bars.

3. Welded splices or other positive connections may be used instead of lapped splices. Welded splices shall preferably be used in cases where the bar diameter exceeds 1¼ in. An approved welded splice shall be defined as one in which the bars are butted and welded and that will develop in tension at least the yield point stress of the reinforcing steel used.

4. Where changes in the cross section of a column occur, the longitudinal bars shall be offset in a region where lateral support is afforded by a concrete capital, floor slab or by metal ties or reinforcing spirals. Where bars are offset, the slope of the inclined portion from the axis of the column shall not exceed 1 in 6 and the bars above and below the offset shall be parallel to the axis of the column.

(*d*) *Spiral Reinforcement*—The ratio of spiral reinforcement, p', shall not be less than the value given by Formula (21).

$$p' = 0.45\left(\frac{A_g}{A_c} - 1\right)\frac{f'_c}{f'_s} \qquad (21)$$

Wherein p' = ratio of volume of spiral reinforcement to the volume of the concrete core (out to out of spirals).

f'_s = useful limit stress of spiral reinforcement, to be taken as 40,000 p.s.i. for hot rolled rods of intermediate grade, 50,000 p.s.i. for rods of hard grade, and 60,000 p.s.i. for cold drawn wire.

The spiral reinforcement shall consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. The spirals shall be of such size and so assembled as to permit handling and placing without being distorted from the designed dimensions. The material used in spirals shall have a minimum diameter of ¼ in. for rolled bars or No. 4 W. & M. gage for drawn wire. Anchorage of spiral reinforcement shall be provided by 1½ extra turns of spiral rod or wire at each end of the spiral unit. Splices, when necessary shall be made in spiral rod or wire by welding or by a lap of 1½ turns. The center to center spacing of the spirals shall not exceed one-sixth of the core diameter. The clear spacing between spirals shall not exceed 3 in. nor be less than 1⅜ in. or 1½ times the maximum size of coarse aggregate used. The reinforcing spiral shall extend from the floor level in any story or from the top of the footing in the basement, to the level of the lowest horizontal reinforcement in the slab, drop panel or beam above. In a column with a capital, it shall extend to a plane at which the diameter or width of the capital is twice that of the column.

(*e*) *Protection of Reinforcement*—The column reinforcement shall be protected everywhere by a covering of concrete cast monolithically with the core, for which the thickness shall not be less than 1½ in. nor less than 1½ times the maximum size of the coarse aggregate, nor shall it be less than required by the fire protection and weathering provisions of Section 507.

(*f*) *Isolated Column with Multiple Spirals*—In case two or more interlocking spirals are used in a column, the outer boundary of the column shall be taken as a rectangle of which the sides are outside the extreme limits of the spiral at a distance equal to the requirements of Section 1103(*e*).

(*g*) *Limits of Section of Column Built Monolithically with Wall*—For a spiral column built monolithically with a concrete wall or pier, the outer boundary of the column section shall be taken either as a circle at least 1½ in. outside the column spiral or as a square or rectangle of which the sides are at least 1½ in. outside the spiral or spirals.

(*h*) *Equivalent Circular Columns*—As an exception to the general procedure of utilizing the full gross area of the column section, it shall be permissible to design a circular column and to build it with a square, octagonal, or other shaped section of the same least lateral dimension. In such case, the allowable load, the gross area considered, and the required percentages of reinforcement shall be taken as those of the circular column.

1104—Tied columns

(*a*) *Allowable Load*—The maximum allowable axial load on columns reinforced with longitudinal bars and separate lateral ties shall be 80 per cent of that given by Formula (20). The ratio, p_g, to be considered in tied columns shall not be less than 0.01 nor more than 0.04. The longitudinal reinforcement shall consist of at least four bars, of minimum diameter of ⅝ inch. Splices in reinforcing bars shall be made as described in Section 1103 (c).

(*b*) *Lateral Ties*—Lateral ties shall be at least ¼ in. in diameter and shall be spaced apart not over 16 bar diameters, 48 tie diameters or the least dimension of the column. When there are more than four vertical bars, additional ties shall be provided so that every longitudinal bar is held firmly in its designed position and has lateral support equivalent to that provided by a 90-degree corner of a tie.

(*c*) *Limits of Column Section*—In a tied column which for architectural reasons has a larger cross section than required by considerations of loading, a reduced effective area, A_g, not less than one-half of the total area may be used in applying the provisions of Section 1104 (a).

1105—Composite columns

(*a*) *Allowable Load*—The allowable load on a composite column, consisting of a structural steel or cast-iron column thoroughly encased in concrete reinforced with both longitudinal and spiral reinforcement, shall not exceed that given by Formula (22).

$$P = 0.225\, A_c f'_c + f_s A_s + f_r A_r \qquad (22)$$

Wherein A_c = net area of concrete section
$= A_g - A_s - A_r$
A_s = cross-sectional area of longitudinal bar reinforcement.
A_r = cross-sectional area of the steel or cast-iron core.
f_r = allowable unit stress in metal core, not to exceed 16,000 p.s.i. for a steel core; or 10,000 p.s.i. for a cast-iron core.

The remaining notation is that of Section 1103.

(*b*) *Details of Metal Core and Reinforcement*—The cross-sectional area of the metal core shall not exceed 20 per cent of the gross area of the column. If a hollow metal core is used it shall be filled with concrete. The amounts of longitudinal and spiral reinforcement and the requirements as to spacing of bars, details of splices and thickness of protective shell outside the spiral shall conform to the limiting values specified in Section 1103 (b), (c) and (d). A clearance of at least three inches shall be maintained between the spiral and the metal core at all points except that when the core consists of a structural steel H-column, the minimum clearance may be reduced to two inches.

(*c*) *Splices and Connections of Metal Cores*—Metal cores in composite columns shall be accurately milled at splices and positive provision shall be made for alignment of one core above another. At the column base, provision shall be made to transfer the load to the footing at safe unit stresses in accordance with Section 305 (a). The base of the metal section shall be designed to transfer the load from the entire composite column to the footing, or it may be designed to transfer the load from the metal section only, provided it is so placed in the pier or pedestal as to leave ample section of concrete above the base for the transfer of load from the reinforced concrete section of the column by means of bond on the vertical reinforcement and by direct compression on the concrete. Transfer of loads to the metal core shall be provided for by the use of bearing members such as billets, brackets or other positive connections; these shall be provided at the top of the metal core and at intermediate floor levels where required. The column as a whole shall satisfy the requirements of Formula (22) at any point; in addition to this, the reinforced concrete portion shall be designed to carry, in accordance with Formula (20), all floor loads brought onto the column at levels between the metal brackets or connections. In applying Formula (20), the value of A_g shall be interpreted as the area of the concrete section outside the metal core, and the allowable load on the reinforced concrete section shall be further limited to 0.35 $f'_c A_g$. Ample section of concrete and continuity of reinforcement shall be provided at the junction with beams or girders.

(*d*) *Allowable Load on Metal Core Only*—The metal cores of composite columns shall be designed to carry safely any construction or other loads to be placed upon them prior to their encasement in concrete.

1106—Combination columns

(*a*) *Steel Columns Encased in Concrete*—The allowable load on a structural steel column which is encased in concrete at least 2½ inches thick over all metal (except rivet heads) reinforced as hereinafter specified, shall be computed by Formula (23).

$$P = A_r f'_r \left[1 + \frac{A_g}{100\,A_r}\right] \quad \text{(23)}$$

Wherein A_r = cross-sectional area of steel column.
f'_r = allowable stress for unencased steel column.
A_g = total area of concrete section.

The concrete used shall develop a compressive strength, f'_c, of at least 2000 p.s.i. at 28 days. The concrete shall be reinforced by the equivalent of welded wire mesh having wires of No. 10 W. and M. gage, the wires encircling the column being spaced not more than four inches apart and those parallel to the column axis not more than eight inches apart. This mesh shall extend entirely around the column at a distance of one inch inside the outer concrete surface and shall be lap-spliced at least forty wire diameters and wired at the splice. Special brackets shall be used to receive the entire floor load at each floor level. The steel column shall be designed to carry safely any construction or other loads to be placed upon it prior to its encasement in concrete.

(*b*) *Pipe Columns*—The allowable load on columns consisting of steel pipe filled with concrete shall be determined by Formula (24).

$$P = 0.225\, f'_c A_c + f'_r A_r \quad \ldots\ldots (24)$$

The value of f'_r shall be given by Formula (25).

$$f'_r = \left[18{,}000 - 70\,\frac{h}{K}\right] F \quad \ldots\ldots (25)$$

Wherein f'_r = allowable unit stress in metal pipe.

h = unsupported length of column.

K = least radius of gyration of metal pipe section.

$$F = \frac{\text{yield point of pipe.}}{45{,}000}$$

If the yield point of the pipe is not known, the factor F shall be taken as 0.5.

1107—Long columns

(*a*) The maximum allowable load, P', on axially loaded reinforced concrete or composite columns having a length, h, greater than ten times the least lateral dimension, d, shall be given by Formula (26).

$$P' = P\left[1.3 - .03\,\frac{h}{d}\right] \quad \ldots\ldots (26)$$

where P is the allowable axial load on a short column as given by Formulas (20) and (22).

The maximum allowable load, P', on eccentrically loaded columns in which $\frac{h}{d}$ exceeds ten shall also be given by Formula (26), in which P is the allowable eccentrically applied load on a short column as determined by the provisions of Sections 1109 and 1110. In long columns subjected to definite bending stresses, as determined in Section 1108, the ratio $\frac{h}{d}$ shall not exceed twenty.

1108—Bending moments in columns

(*a*) The bending moments in the columns of all reinforced concrete structures shall be determined on the basis of loading conditions and restraint and shall be provided for in the design. When the stiffness and strength of the columns are utilized to reduce moments in beams, girders, or slabs, as in the case of rigid frames, or in other forms of continuous construction wherein column moments are unavoidable, they shall be provided for in the design. In building frames, particular attention shall be given to the effect of unbalanced floor loads on both exterior and interior columns and of eccentric loading due to other causes. Wall columns shall be designed to resist moments produced by

1. Loads on all floors of the building
2. Loads on a single exterior bay at two adjacent floor levels, or
3. Loads on a single exterior bay at one floor level

Resistance to bending moments at any floor level shall be provided by distributing the moment between the columns immediately above and below the given floor in proportion to their relative stiffnesses and conditions of restraint.

1109—Determination of combined axial and bending stresses

(*a*) In a reinforced concrete column, designed by the methods of this Chapter, which is (1) symmetrical about two perpendicular planes through its axis and (2) subject to an axial load, N, combined with bending in one or both of the planes of symmetry (but with the ratio of eccentricity to depth, e/t, no greater than 1.0 in either plane), the combined fiber stress in compression may be computed on the basis of recognized theory applying to uncracked sections, using Formula 27.

$$f_c = \frac{N}{A_g}\left[\frac{1 + \frac{De}{t}}{1 + (n-1)p_g}\right] \qquad (27)$$

Equating this calculated stress, f_c, to the allowable stress, f_p, in Formula 29, it follows that the column can be designed for an equivalent axial load, P, as given by Formula 28.*

$$P = N\left[1 + \frac{CDe}{t}\right] \qquad (28)$$

When bending exists on both axes of symmetry, the quantity $\frac{De}{t}$ is to be computed as the numerical sum of the $\frac{De}{t}$ quantities in the two directions.

(*b*) For columns in which the load, N, has an eccentricity, e, greater than the column depth, t, or for beams subject to small axial loads, the determination of the fiber stress f_c shall be made by use of recognized theory for cracked sections, based on the assumption that no tension exists in the concrete. For such cases the tensile steel stress shall also be investigated.

*For approximate or trial computations, D may be taken as eight for a circular spiral column and as five for a rectangular tied or spiral column.

1110—Allowable combined axial and bending stress

(*a*) For spiral and tied columns, eccentrically loaded or otherwise subjected to combined axial compression and flexural stress, the maximum allowable compressive stress, f_p, is given by Formula (29).

$$f_p = f_a \left[\frac{1 + \frac{De}{t}}{1 + \frac{CDe}{t}} \right] = f_a \left[\frac{t + De}{t + CDe} \right] \quad \ldots\ldots\ldots\ldots (29)$$

Wherein the notation is that of Section 1103 and 1109, and, in addition f_a is the average allowable stress in the concrete of an axially loaded reinforced concrete column, and C is the ratio of f_a to the allowable fiber stress for members in flexure. Thus $f_a = \frac{0.225 f'_c + f_s p_g}{1 + (n - 1) p}$ for spiral columns and 0.8 of this value for tied columns, and $C = \frac{f_a}{0.45 f'_c}$.

1111—Wind stresses

(*a*) When the allowable stress in columns is modified to provide for combined axial load and bending, and the stress due to wind loads is also added, the total shall still come within the allowable values specified for wind loads in Section 603 (c).

1112—Reinforced concrete walls

(*a*) The allowable working stresses in reinforced concrete bearing walls with minimum reinforcement as required by Section 1112(i), shall be $0.25f'_c$ for walls having a ratio of height to thickness of ten or less, and shall be reduced proportionally to $0.15f'_c$ for walls having a ratio of height to thickness of twenty-five. When the reinforcement in bearing walls is designed, placed and anchored in position as for tied columns, the allowable working stresses shall be on the basis of Section 1104, as for columns. In the case of concentrated loads, the length of the wall to be considered as effective for each shall not exceed the center to center distance between loads, nor shall it exceed the width of the bearing plus four times the wall thickness. The ratio p_g shall not exceed 0.04.

(*b*) Walls shall be designed for any lateral or other pressure to which they are subjected. Proper provision shall be made for eccentric loads and wind stresses. In such designs the allowable stresses shall be as given in Section 305(a) and 603(c).

(*c*) Panel and enclosure walls of reinforced concrete shall have a thickness of not less than five inches and not less than one thirtieth the distance between the supporting or enclosing members.

(*d*) Bearing walls of reinforced concrete in building of fire-resistive construction shall be not less than six inches in thickness for the uppermost fifteen feet of their height; and for each successive twenty-five feet downward, or fraction thereof, the minimum thickness shall be increased one inch. In two story dwellings the walls may be six inches in thickness throughout.

(*e*) In buildings of non-fire resistive construction bearing walls of reinforced concrete shall not be less than one and one-third times the thickness required for buildings of fire-resistive construction, except that for dwellings of two stories or less in height the thickness of walls may be the same as specified for buildings of fire-resistive construction.

(*f*) Exterior basement walls, foundation walls, fire walls and party walls shall not be less than eight inches thick whether reinforced or not.

(*g*) Reinforced concrete bearing walls shall have a thickness of at least one twenty-fifth of the unsupported height or width, whichever is the shorter; provided however, that approved buttresses, built-in columns, or piers designed to carry all the vertical loads, may be used in lieu of increased thickness.

(*h*) Reinforced concrete walls shall be anchored to the floors, columns, pilasters, buttresses and intersecting walls with reinforcement at least equivalent to three-eighths inch round bars twelve inches on centers, for each layer of wall reinforcement.

(*i*) Reinforced concrete walls shall be reinforced with an area of steel in each direction, both vertical and horizontal, at least equal to 0.0025 times the cross-sectional area of the wall, if of bars, and 0.0018 times the area if of electrically welded wire fabric.* The wire of the welded fabric shall be of not less than No. 10 W. & M. gage. Walls more than ten inches in thickness shall have the reinforcement for each direction placed in two layers parallel with the faces of the wall. One layer consisting of not less than one-half and not more than two-thirds the total required shall be placed not less than two inches nor more than one-third the thickness of the wall from the exterior surface. The other layer, comprising the balance of the required reinforcement, shall be placed not less than three-fourths inches and not more than one-third the thickness of the wall from the interior surface. Bars, if used, shall not be less than the equivalent of three-eighths inch round

*Expanded metal has been omitted until a specification can be formulated.

bars, nor shall they be spaced more than eighteen inches on centers. Welded wire* reinforcement for walls shall be in flat sheet form.

(*j*) In addition to the minimum as prescribed in 1112(i) there shall be not less than two five-eighths inch diameter bars around all window or door openings. Such bars shall extend at least twenty-four inches beyond the corner of the openings.

(*k*) Where reinforced concrete bearing walls consist of studs or ribs tied together by reinforced concrete members at each floor level, the studs may be considered as columns, but the restrictions as to minimum diameter or thickness of columns shall not apply.

*See footnote previous page.

CHAPTER 12—FOOTINGS

1201—Scope

(*a*) The requirements prescribed in Sections 1202 to 1209 apply only to isolated footings.*

1202—Loads and reactions

(*a*) Footings shall be proportioned to sustain the applied loads and induced reactions without exceeding the allowable stresses as prescribed in Sections 305 and 306, and as further provided in Sections 1205, 1206 and 1207.

(*b*) In cases where the footing is concentrically loaded and the member being supported does not transmit any moment to the footing, computations for moments and shears shall be based on an upward reaction assumed to be uniformly distributed per unit area or per pile and a downward applied load assumed to be uniformly distributed over the area of the footing covered by the column, pedestal, wall, or metallic column base.

(*c*) In cases where the footing is eccentrically loaded and/or the member being supported transmits a moment to the footing, proper allowance shall be made for any variation that may exist in the intensities of reaction and applied load consistent with the magnitude of the applied load and the amount of its actual or virtual eccentricity.

(*d*) In the case of footings on piles, computations for moments and shears may be based on the assumption that the reaction from any pile is concentrated at the center of the pile.

1203—Sloped or stepped footings

(*a*) In sloped or stepped footings, the angle of slope or depth and location of steps shall be such that the allowable stresses are not exceeded at any section.

(*b*) In sloped or stepped footings, the effective cross-section in compression shall be limited by the area above the neutral plane.

(*c*) Sloped or stepped footings shall be cast as a unit.

1204—Bending moment

(*a*) The external moment on any section shall be determined by passing through the section a vertical plane which extends completely

*The committee is not prepared at this time to make recommendations for combined footings—those supporting more than one column or wall.

across the footing, and computing the moment of the forces acting over the entire area of the footing on one side of said plane.

(*b*) The greatest bending moment to be used in the design of an isolated footing shall be the moment computed in the manner prescribed in Section 1204 (a) at sections located as follows:

1. At the face of the column, pedestal or wall, for footings supporting a concrete column, pedestal or wall.
2. Halfway between the middle and the edge of the wall, for footings under masonry walls.
3. Halfway between the face of the column or pedestal and the edge of the metallic base, for footings under metallic bases.

(*c*) The width resisting compression at any section shall be assumed as the entire width of the top of the footing at the section under consideration.

(*d*) In one-way reinforced footings, the total tensile reinforcement at any section shall provide a moment of resistance at least equal to the moment computed in the manner prescribed in Section 1204(a); and the reinforcement thus determined shall be distributed uniformly across the full width of the section.

(*e*) In two-way reinforced footings, the total tensile reinforcement at any section shall provide a moment of resistance at least equal to eighty-five per cent of the moment computed in the manner prescribed in Section 1204(a); and the total reinforcement thus determined shall be distributed across the corresponding resisting section in the manner prescribed for square footings in Section 1204(f), and for rectangular footings in Sec. 1204(g).

(*f*) In two-way square footings, the reinforcement extending in each direction shall be distributed uniformly across the full width of the footing.

(*g*) In two-way rectangular footings, the reinforcement in the long direction shall be distributed uniformly across the full width of the footing. In the case of the reinforcement in the short direction, that portion determined by formula (30) shall be uniformly distributed across a band-width (B) centered with respect to the center line of the column or pedestal and having a width equal to the length of the short side of the footing. The remainder of the reinforcement shall be uniformly distributed in the outer portions of the footing.

$$\frac{\textit{Reinforcement in band-width } (B)}{\textit{Total reinforcement in short direction}} = \frac{2}{(S + 1)} \quad \text{(30)}$$

In formula (30), "S" is the ratio of the long side to the short side of the footing.

1205—Shear and bond

(*a*) The critical section for shear to be used as a measure of diagonal tension shall be assumed as a vertical section obtained by passing a series of vertical planes through the footing, each of which is parallel to a corresponding face of the column, pedestal, or wall and located a distance therefrom equal to the depth d for footings on soil, and one-half the depth d for footings on piles.

(*b*) Each face of the critical section as defined in Section 1205(a) shall be considered as resisting an external shear equal to the load on an area bounded by said face of the critical section for shear, two diagonal lines drawn from the column or pedestal corners and making 45° angles with the principal axes of the footing, and that portion of the corresponding edge or edges of the footing intercepted between the two diagonals.

(*c*) Critical sections for bond shall be assumed at the same planes as those prescribed for bending moment in Section 1204(b); also at all other vertical planes where changes of section or of reinforcement occur.

(*d*) Computations for shear to be used as a measure of bond shall be based on the same section and loading as prescribed for bending moment in Section 1204(a).

(*e*) The total tensile reinforcement at any section shall provide a bond resistance at least equal to the bond requirement as computed from the following percentages of the external shear at the section:

1. In one-way reinforced footings, 100 per cent.
2. In two-way reinforced footings, 85 per cent.

(*f*) In computing the external shear on any section through a footing supported on piles, the entire reaction from any pile whose center is located six inches or more outside the section shall be assumed as producing shear on the section; the reaction from any pile whose center is located six inches or more inside the section shall be assumed as producing no shear on the section. For intermediate positions of the pile center, the portion of the pile reaction to be assumed as producing shear on the section shall be based on straight-line interpolation between full value at six inches outside the section and zero value at six inches inside the section.

(*g*) For allowable shearing stresses, see Section 305 and 808.

(*h*) For allowable bond stresses, see Section 305 and 901 to 905.

1206—Transfer of stress at base of column

(*a*) The stress in the longitudinal reinforcement of a column or pedestal shall be transferred to its supporting pedestal or footing either by extending the longitudinal bars into the supporting member, or by dowels.

(*b*) In case the transfer of stress in the reinforcement is accomplished by extension of the longitudinal bars, they shall extend into the supporting member the distance required to transfer to the concrete, by allowable bond stress, their full working value.

(*c*) In cases where dowels are used, their total sectional area shall be not less than the sectional area of the longitudinal reinforcement in the member from which the stress is being transferred. In no case shall the number of dowels per member be less than four and the diameter of the dowels shall not exceed the diameter of the column bars by more than one-eighth inch.

(*d*) Dowels shall extend up into the column or pedestal a distance at least equal to that required for lap of longitudinal column bars (see Section 1103) and down into the supporting pedestal or footing the distance required to transfer to the concrete, by allowable bond stress, the full working value of the dowel.

(*e*) The compressive stress in the concrete at the base of a column or pedestal shall be considered as being transferred by bearing to the top of the supporting pedestal or footing. The unit compressive stress on the loaded area shall not exceed the bearing stress allowable for the quality of concrete in the supporting member as limited by the ratio of the loaded area to the supporting area.

(*f*) For allowable bearing stresses see Table 305(a), Section 305.

(*g*) In sloped or stepped footings, the supporting area for bearing may be taken as the top horizontal surface of the footing, or assumed as the area of the lower base of the largest frustum of a pyramid or cone contained wholly within the footing and having for its upper base the area actually loaded, and having side slopes of one vertical to two horizontal.

1207—Pedestals and footings (plain concrete)

(*a*) The allowable compressive unit stress on the gross area of a concentrically loaded pedestal shall not exceed $0.25f'_c$. Where this stress is exceeded, reinforcement shall be provided and the member designed as a reinforced concrete column.

(*b*) The depth and width of a pedestal or footing of plain concrete shall be such that the tension in the concrete shall not exceed $.03f'_c$, and the average shearing stress shall not exceed $.02f'_c$ taken on sections as prescribed in Section 1204 and 1205 for reinforced concrete footings.

1208—Footings supporting round columns

(*a*) In computing the stresses in footings which support a round or octagonal concrete column or pedestal, the "face" of the column or pedestal shall be taken as the side of a square having an area equal to the area enclosed within the perimeter of the column or pedestal.

1209—Minimum edge-thickness

(*a*) In reinforced concrete footings, the thickness above the reinforcement at the edge shall be not less than six in. for footings on soil, nor less than twelve in. for footings on piles.

(*b*) In plain concrete footings, the thickness at the edge shall be not less than eight in. for footings on soil, nor less than fourteen in. above the tops of the piles for footings on piles.

[To facilitate selective distribution, **separate prints** of this ACI Standard (title 41-24) are currently available from ACI at 25 cents each—quantity quotations on request.]

Title 41-24 —a part of PROCEEDINGS, AMERICAN CONCRETE INSTITUTE Vol. 41

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ACI Standard

Recommended Practice for use of Metal Supports for Reinforcement—(ACI 319-42)*

Reported by ACI Committee 319

WILLIAM F. ZABRISKIE
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1. General

All reinforcing steel shall be accurately located in the forms and held firmly in place before and during the placing of concrete, by means of metallic supports, spacer bars or wires.

2. Supports

Bar supports shall be sufficiently strong and stable to sustain construction loads without permanent distortion or displacement. (see "Types of Devices") These shall be designed to permit full embedment in the concrete without the formation of voids and with a minimum exposure of metal on finished surfaces. They shall, in combination with tie wires or clips, provide positive means for establishing and maintaining operative association with the reinforcing steel.

3. Number and location of supports

Minimum requirements for number and location of supports and spacers under various usual conditions shall be as set forth in Tables 1 to 4.

4. Responsibility

The number, type, and location of supporting and spacing devices shall be clearly indicated on the drawings which show placing of reinforcement.

It shall be the responsibility of the seller of such devices to furnish the quantities, types, and capacities as indicated on the drawings, with the necessary identification marks.

It shall be the responsibility of the builder to install all of such devices, and to maintain them accurately in place until the concrete is placed.

*Adopted as a Standard of the American Concrete Institute at its 38th Annual Convention; ratified by letter ballot May 24, 1942.

Any and all disturbances of reinforcement from any cause whatsoever shall be fully corrected prior to the placing of concrete, and all damaged bar supports and spacers shall be repaired, or removed and replaced by the builder.

TABLE 1.—ONE-WAY SLAB CONSTRUCTION

Span	Rows of Slabs Bar Spacers for Panel	High Chairs and ⅝″ Support Bars in Slabs 4″ and Thicker*	
		Support Bars	High Chairs
0′ to 6′ Steel Continuous	1	1 Row at Beam	4′-0 o.c.
0′ to 14′ Steel Not Continuous	2	2 Rows at Beam	4′-0 o.c.
14′ to 20′ Steel Not Continuous	3	2 Rows at Beam	4′-0 o.c.
20′ to 26′ Steel Not Continuous	4	2 Rows at Beam	4′-0 o.c.

*Continuous high chairs may be substituted for individual high chairs and support bars.

Table 2.—ORDINARY BEAM AND JOIST CONSTRUCTION

(Bars 1 in. square and smaller)

Clear spans, beam (or joist)	Number of beam (joist) chairs					
	Single layer of bars	Two Layers		Three Layers		
		Lower	Top	Lower	Middle	Top
Over 0 ft. to 14 ft.......	2	2	2	2	2	2
Over 14 ft. to 23 ft.......	3	3	2	3	2	2
Over 23 ft. to 30 ft.......	4	4	3	4	3	2
Over 30 ft...............	(*)	(*)	(*)	(*)	(*)	(*)

*See Table 3.

TABLE 3.—HEAVY BEAM AND GIRDER CONSTRUCTION

(Beams or girders with large number of 1⅛- or 1¼-inch bars)

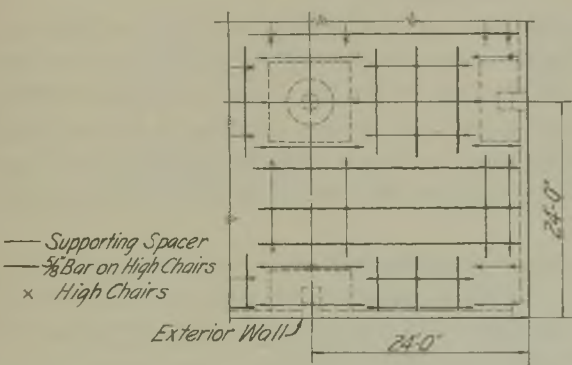
Clear Spans	Number of beam chairs					
	Single layer of Bars	Two Layers		Three Layers		
		Lower	Top	Lower	Middle	Top
Over 0 ft. to 14 ft.......	2	3	2	3	2	2
Over 14 ft. to 23 ft.......	3	5	2	6	2	2
Over 23 ft. to 30 ft.......	4	6	3	7	3	2
Over 30 ft. to 40 ft.......	6	7	4	8	4	3
Over 40 ft. to 50 ft.......	7	8	4	9	5	4
Spacing of beam chairs in spans other than above: All spans...........	7′0″	6′0″	10′0″	5′0″	8′0″	10′0″

TABLE 4.—FLAT SLABS

(Two and four way flat slabs—See Fig. 1 and 2)

Spans (center to center of Columns)	Supporting Spacers		High Chairs and ⅝″ Support Bars under Ends of Bent Bars*			
	Column Strip or Direct Band	Middle Strip or Diagonal Band Bottom Layer	Support for Column Head Reinforcement		Support for Negative Reinforcement, Middle Strip	
			Support Bars	High Chairs	Support Bars	High Chairs
Over 0 ft. to 18 ft.	3	2	....	....	....	....
Over 18 ft. to 26 ft.	3	3	....	....	....	....
Over 26 ft. to 36 ft.	4	4	....	....	....	....
Around interior columns	....	....	2	8	....	....
Around exterior columns	....	....	2	5	....	....
Around corner columns	....	....	2	4	....	....
In interior panels	....	....	....	....	4	12
In exterior panels	....	....	....	....	5	15
In corner panels	....	....	....	....	6	18

*Continuous high chairs may be substituted for individual high chairs and support bars.



In roof slabs use one (1) more supporting spacer under column strips, or diagonal bands, and bottom layers of middle strips or diagonal bands, and one (1) more ⅝in. support bar at interior column heads, than the number shown in Table 3.

Fig. 1—Two-way system

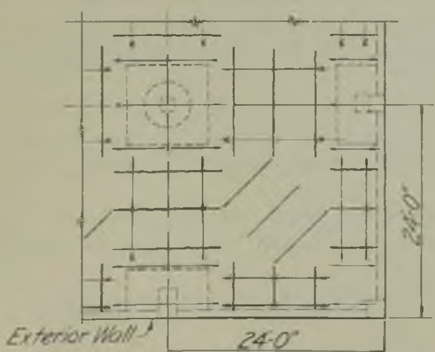


Fig. 2—Four-way system

TYPES OF DEVICES

Since various satisfactory types of supporting devices are on the market, this report makes no attempt to specify exact details and sizes. However, the following indicates the Committee's opinion as to a specification covering the most common types, which should produce devices meeting the requirements of paragraph 2, "Supports."

For supporting devices for slab steel in which the spanning member is a round section, either of cold drawn wire or of hot rolled steel having a yield point not less than 45,000 psi., the spacing of legs shall not exceed the following:

For continuous high chairs $s = 400\ d^3$

For continuous slab spacers, where the spanning member is not over 1½ in. above the forms $s = 550\ d^3$

in which

s — spacing of legs in inches

d — diameter of round wire or rod in inches

The above rules shall apply to spacers having legs at a spacing not to exceed 30 in.

Supporting legs for continuous high chairs shall be so formed that the effective width of the support where it rests on the form shall not be less than ¾ of the height from the form to the top of the spanning member.

Supporting legs for continuous slab spacers shall be so formed that the effective width of the support, where it rests on the form, shall not be less than two times the height from the form to the top of the spanning member.

Legs of continuous high chairs made of wire or round rods shall be of such size that the ratio of height to radius of gyration shall not exceed 120 in the case of wires having a diameter less than ¼ in. or in case of all chairs which are supported upon metal forms.

In the case of continuous high chairs which are supported upon wood forms and in which the material of the legs is of a diameter of ¼ in. or larger the ratio of height to radius of gyration shall not exceed 156.

[To facilitate selective distribution, **separate prints** of this ACI Standard (title 41-25) are currently available in covers from ACI at 50 cents each—quantity quotations on request.]

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ACI Standard

Recommended Practice for Measuring, Mixing and Placing Concrete (ACI 614-42)*

Reported by ACI Committee 614

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I. INTRODUCTION

1. This report has been prepared in response to an expressed need for an outline of good practices for measuring and mixing the ingredients for concrete and for placing the finished product.

2. At the outset the Committee faced the question whether it should describe "common practices" or "best practices." Since this report is a recommendation, and not a specification, it is believed that the interests of progress in the development of concrete construction will be better served if the best methods known are outlined.

3. On small jobs, or in the more competitive uses of concrete such as building construction, practices somewhat more relaxed than those

*Adopted as a Standard of the American Concrete Institute at its 38th Annual Convention, 1942, as reported by Committee 614; ratified by Letter Ballot May 24, 1942.

here recommended may be economically justified. The profitable degree of such deviation must be determined by those in charge of each job, in view of the conditions which obtain. In general, the Committee has no evidence that good concrete operations cannot be performed as economically as poor ones or that the methods here recommended, where applicable, will result in higher ultimate costs than other methods. The refinements recommended are intended primarily to improve uniformity and to eliminate segregation in aggregates and concrete. Where properly executed, the methods described have resulted in smoother operation and any additional costs resulting from them have been offset by consequent higher production rates.

4. It has been assumed that whoever will give serious consideration to these recommendations will have a reasonable knowledge of the ordinary practices and preparations required in concrete work. For that reason, many routine instructions for measuring, mixing, and placing concrete are omitted. Since the specific objective of these recommendations is maximum uniformity, homogeneity and quality of concrete in place, special consideration is given practices designed to accomplish that end. In order to portray more clearly certain of the principles involved and their application to concreting operations, four figures are included as a part of these recommendations, illustrative of some examples of good and bad practice.

5. For further discussions of the standard aspects of measurement, mixing, and placing, the reader is referred to the 1940 Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete and to the particularly excellent and specific document of recommended practice adopted by the American Association of State Highway Officials relating to Measuring, Mixing, and Placing of Concrete for Use in Concrete Pavements. With the recommendations of those reports, ACI Committee 614 is, in general in accord, although a few exceptions in details or in emphasis may be noted.

II. MEASUREMENT

Essential requirement

1. Equipment should be used which is capable of performing accurate measurement. Materials should be handled, and measuring operations performed in such a manner that satisfactory reproducibility of the selected batch assembly and aggregate grading is obtained batch after batch. The objective is ultimate uniformity and homogeneity of the concrete.

Aggregates

2. The number of separate sizes of coarse aggregate which should be used, to reduce segregation in handling to a practical minimum and

to permit reasonably close control of the grading from batch to batch, is dependent upon the maximum size of the material. For particles larger than 1 inch, the ratio of the maximum to the minimum designated sizes should not exceed 2; for coarse aggregate particles finer than 1 inch, this ratio should not exceed 3. The permissible tolerance of undersize or oversize material in each designated size of aggregate should not exceed 10 per cent, and handling operations should be such that variation in these portions of such material is held to a practical minimum.

3. The maximum size of sand should not exceed that which will pass a screen having 1/8-in. openings if it is screened and handled dry. The standard No. 4 sieve (3/16-in. openings) represents a suitable maximum size for wet screened sand which is to remain damp throughout all handling and batching operations, except when the use of the smaller size is desirable to control the percentage of pea gravel (about No. 8 to 3/8-in.) in the mix. When two sizes of sand are used to obtain proper grading, no attempt should be made to blend them by placing alternate amounts in stock piles or in cars and trucks as loaded or by other equally crude procedures. With adequate equipment and ample supervision and inspection, good results are obtainable, when the fine aggregate is produced, by blending the different sizes of sand as they flow into a common stream from regulating gates or feeders. Such methods can, however, produce very irregular results. For the majority of work, separate batching of the fine and coarse sand is preferable since it will produce consistently uniform results under the wide range of common plant and job conditions.

4. The production or purchase of sand should be controlled insofar as possible to minimize variations in grading, particularly in the finer sizes. In plants where sand is washed, care should be exercised to avoid removal of fines essential to good grading and to plastic, workable concrete. For sand passing a 1/8-in. screen, 20 per cent finer than 50 mesh is considered close to an ideal percentage of fines for average concrete work. Lean mixes are benefited by ample percentages of such fines while rich mixes are improved with a smaller percentage of these sizes.

5. Varying amounts of water in aggregates commonly contribute to lack of uniformity. Effort should be made to maintain a uniform moisture content in the aggregate supplied for batching. For this reason aggregates from dry deposits, if not high in absorption, may preferably be prepared and handled dry when washing is not essential. Before placing the material in batcher bins, wet aggregates should be drained until, by actual test, there is little difference in the moisture content of the wettest and driest portions of the materials. Adequate drainage

will require at least 8 hours and additional time may be necessary, depending on the grading of the material and the efficiency of the drainage system provided. On large jobs when thorough drainage is difficult, an electric moisture indicator in the sand batcher and a consistency meter on the mixer will permit rather close control of consistency, even when there are wide fluctuations in aggregate moisture.*

6. Aggregates should be handled in stockpiles and bins in a manner producing minimum segregation of sizes. Stockpiles should be permitted only when built up in layers no thicker than those resulting from truck loads dumped on the same plane. When stockpiling sand and pea gravel, segregation may be further avoided if moisture contents of at least 5 and 2 per cent, respectively, are maintained. Coarse aggregate should be removed from stockpiles, by clamshell bucket or other means, in horizontal layers of such width that aggregate is not permitted to run down the slopes at the edge of the pile. Storage bins should have the smallest practicable equal horizontal dimensions. Round bins are preferable. Bins should have only one outlet located at the center of a bottom sloping to it from all directions at not less than 50 degrees from the horizontal. They should be charged by material falling vertically directly over the outlet. They should be kept as full as possible at all times to avoid breakage and grading changes as the bins are emptied.

7. Reference is made to the sketches, a part of these recommendations, for illustrations of preferred practice in the handling of aggregates. Unless precautions are exercised in the selection and handling of aggregates, refinements in measuring, mixing and placing are nullified.

Batching aggregates

8. *For jobs of from 2,000 to 5,000 cu. yd.*, the cost of hand batching soon justifies a simple weigh batcher installation, into whose bins aggregates may be delivered directly. As the size of the job increases, the saving in materials and the prevention of contamination by dirt or by other sizes adds considerably to the balance in favor of bins as opposed to dumping materials on the ground. As the size of the work increases still greater refinement should be required.

9. *From 2,500 to 10,000 cu. yd. jobs*, cumulative manual weigh batching and from *10,000 to 25,000 cu. yd.*, cumulative automatic weigh batching are recommended. For jobs of over *25,000 cu. yd.*, requirement of individual automatic weighing of the aggregate is justified by the improved perfection of uniformity of measurement. (See favored sketch.) If good inspection and dependable plant men are available,

**Engineering News-Record*, Page 52, July 11, 1935.

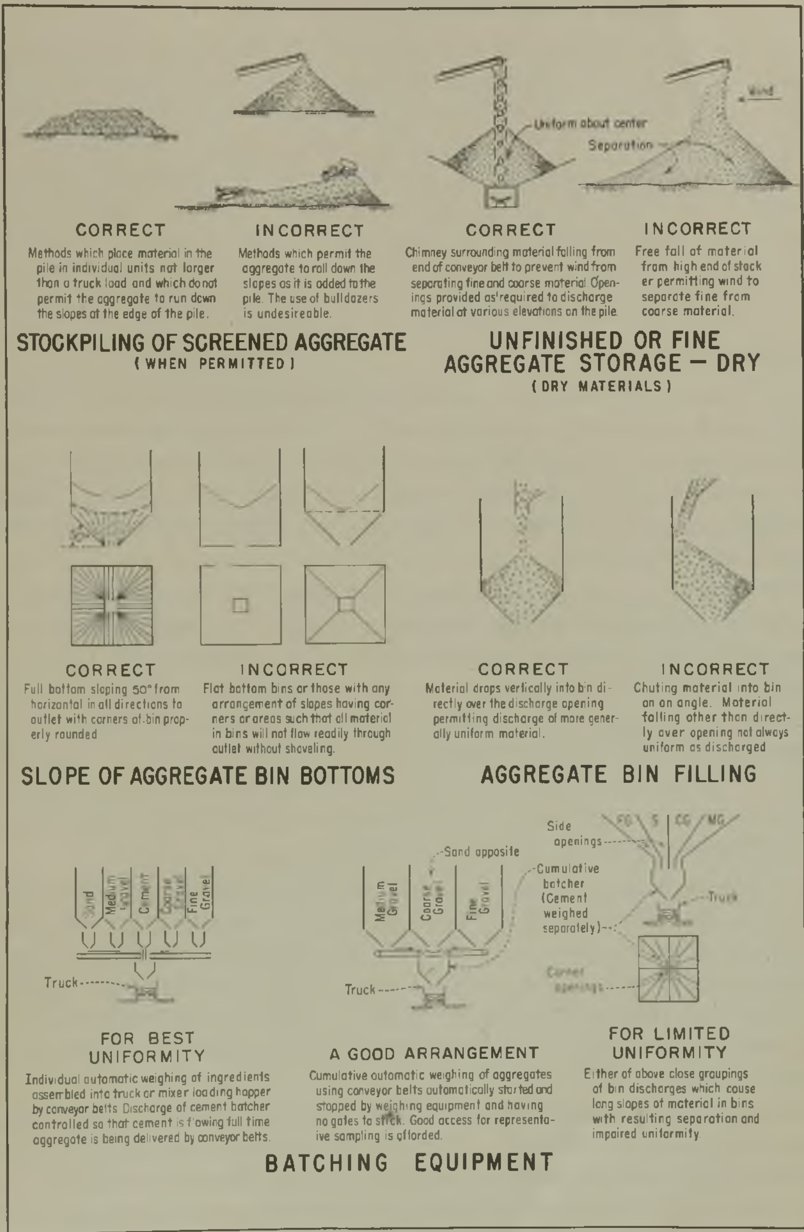

Fig. 1—Correct and incorrect handling of aggregates in storing and batching

it may not be economically justifiable to require new equipment, especially for the smaller jobs in the foregoing brackets.

10. Individual automatic and cumulative manual aggregate batchers should be charged through easy operating clamshell or undercut radial type gates. Power-operated gates are used with the automatic batchers and may be used with the manual batchers. Where necessary for the required degree of accuracy, the gate charging the automatic equipment should be arranged to operate with a suitable "dribble" after there is nearly the desired quantity of material in the batcher. Automatic cumulative batchers should preferably be supplied from short conveyor belts operating between the center of the bin bottom and the batcher.

Batching cement

11. Cement for large jobs should be handled in bulk and weighed for each batch, preferably automatically. New equipment for this purpose probably is not justified except on jobs of well over 10,000 cu. yd. Cement should never be weighed with the aggregate. Sacked cement should be measured in units of not less than one sack unless the fractional bags are weighed.

12. Bulk cement batchers should be charged by means of controlled screw conveyors or equally effective devices. Moisture should be thoroughly removed from the air used in jets to loosen the cement in storage. Cement hoppers and batchers should have smooth metal or metal covered sides with rounded corners. Silos, bins, and hoppers for cement should be governed by principles outlined above for aggregate bins. Control should be available on the batcher discharge gate so that, in event of over-run, the excess cement may be withheld unless it is removed before the batch is discharged.

13. Modern specifications issued by government and highway agencies contain excellently detailed specifications for manual and automatic weigh batching equipment for cement and aggregate. Ordinarily, the present equipment on the market, when in good mechanical condition, will have approved tolerances in weighing ability. Operation should be required within a degree of accuracy of 1 per cent for cement and 2 per cent for aggregate.

14. Bulk cement is often lost or scattered indescriminately in dropping from the batcher to trucks or batch cars below. Free fall of cement should never be permitted. A typical good method of preventing this is to enclose the discharging cement in a narrow canvas boot long enough so that its outlet may be buried in the cement when loading portable batch compartments. Such compartments should contain a separate section for the cement, attached to and operating with the individual

batch release gate. The boot may be used as a tremie or the cement may be eased into the compartment by controlling the amount of kinking or doubling back of the canvas at the lower end of the boot. The canvas may then be lifted, shaken, and dropped into the next compartment. A telescopic rubber hose drop-chute from the cement batcher is also available for this purpose. If a separate section is not provided for the cement in each batch compartment, or the cement is not enclosed in the aggregate, tarpaulin covers should be required during transportation. For placing bulk cement into a batch hopper for a stationary mixer, a pipe of suitable size to hold the cement should extend from the batcher discharge to a level near the bottom of the hopper. After covering the end of this with the aggregate, the cement may be discharged. It will then enter the mixer without loss of dust, and it will be well distributed through the entering aggregate.

Water measurement

15. Water measurement on the larger jobs justifies the recommendation that for pavers and other portable mixers, there be used only automatic meters of proved mechanical dependability, or automatic measuring tanks of the vertical cylinder center-siphon discharge type, capable of routine measurement within an accuracy of 1 per cent under all operating conditions. For central mixing or batching plants, either of these devices or automatic weigh batchers of proved dependability and accuracy within 1 per cent should be required. Tanks should be permitted only as an auxiliary part of the automatic meter or weigh batcher, but not as a means of measurement, except in the form of a vertical cylinder with center-siphon discharge.

The small jobs

16. For the small job, usually less than two to five thousand cubic yards, concreting operations are likely to be so irregular that many of the foregoing preludes to uniformity in the concrete, as far as aggregate preparation and handling are concerned, are often next to impossible of attainment. It is well to keep them in mind, however, as standards to be used wherever possible. Cement should be handled and measured in sacks. Mixers should be of sufficient capacity and batches of such a size that no fractional bags of cement are required unless they are weighed for each batch. Water measuring equipment of expensive refinement may not be economical for the small job, but the use of simple equipment that is accurate, positive and dependable is justified and should be required. A manually operated standard disc water meter, of capacity according to the size of the mixer, equipped with a vertical-face, set-back register is not expensive and is recommended where water temperatures do not exceed 100°F. A vertical cylinder tank with center-

siphon discharge is equally satisfactory, and should be used if water temperatures are greater than 100°F. Aggregates should be weighed. In a metropolitan area where weigh batched aggregates or plant controlled ready mixed concrete is available, one of these should be used, even at a reasonable premium, in preference to handling and measuring the materials on the job. Where such services are not available, the quantities for each batch should be weighed in wheelbarrows or buggies on platform scales now generally available for this purpose on small jobs.

General

17. If standards of uniformity, such as are readily obtainable with modern batching equipment, are to be maintained uniformly throughout an operation, there is greater need for emphasis of correct procedure in incidental operations than on the actual weighing of ingredients. Care should be exercised that batches accurately assembled arrive as uniform batches in the mixer. These sources of error should be avoided: (1) Over-lap of batches in loading and discharging multiple batch trucks and cars. (2) Loss of material in transferring batches to the skips of portable mixers. (3) Loss or "hang up" of a portion of one batch, or its inclusion with another, when dry batches are transferred by means of belts and hoppers. All such damage to the correctness of the quantities in each assembled batch should be strictly avoided and methods should be approved or discarded accordingly.

III. MIXING

Essential requirements

1. Thorough mixing is, of course, a first essential. Equipment and methods used shall be such as to insure uniformity of strength, and uniformity of consistency, cement and water content, and aggregate grading from beginning to end of each batch *as discharged*. For concrete work of the highest general quality, mixing equipment should be used which is capable of handling concrete suited to the particular work, from the standpoint of its placeability and workability *in the forms* (preferably by means of vibration where this is applicable). Mixing equipment requiring, for efficient operation, mixes containing larger proportions of sand, cement, or water than indicated for best results on the basis mentioned is not recommended.

The mixer

2. The mixer should preferably have a combination of blade arrangement and drum shape such as to insure an end to end exchange of the materials parallel to the axis of rotation as well as a rolling, folding, or spreading movement of the mix over on itself as the batch is mixed. Otherwise the action should be such that comparable mixing efficiency

and uniformity of the batch is obtained within a reasonable mixing period. The mixer should be operated at the speed designated by the manufacturer, unless a reasonable change of speed definitely shows better results.

3. Any mixer leaking mortar or causing waste of materials due to faulty size, shape, or operation of charging equipment should be taken out of service immediately until satisfactory repairs and improvements have been made to eliminate such waste. Hardened concrete or mortar should not be permitted to accumulate on the inner surfaces of mixing equipment. Worn blades should not be continued in service when they materially decrease mixing efficiency.

Size of batch

4. The size of the batch in job mixers should not exceed the manufacturer's guaranteed capacity of 10 per cent more than the rated capacity of the mixer. The rated capacity should be exceeded only when: (1) it results in no loss of mortar during mixing, and (2) tests show the larger batch to be properly mixed. When, to shorten time of discharge or to reduce segregation due to retention of coarse aggregate, it is desired to retain a portion of the batch in excess of the normal "hold back," the amount of material held back should be taken into account in fixing the size of the batch in relation to the capacity of the mixer.

The charging operation

5. All ingredients of the mix should enter the mixer promptly and as uniformly as possible at the same time. It is particularly important in charging stationary mixers that the solid materials be arranged in the charging hopper in such a manner that no one of them enters separately but that proportional amounts of each (particularly of cement and sand) will be in all parts of the stream of material as it flows into the mixer. To avoid "gumming" and for greater uniformity, cement should never be charged separately, especially ahead of the aggregates but should be enclosed within the other materials. Water for the batch should be released first and continue to flow while the solids are entering the mixer, and should have completed flowing shortly after the last of the batch has entered the drum. This flow should not continue for more than the first 25 per cent of the mixing time, and should be stopped as much short of this as the apparent requirements of good operation of the particular mixer will permit. Where meters are used, and particularly if water pressure is low, auxiliary tanks, into which the quantity of water for the batch may be measured in advance, equipped with a discharge pipe to the mixer of such a size as to insure the foregoing rate of delivery, may be necessary.

Mixing time

6. The net mixing time for a one-yard or smaller mixer when mixing gravel concrete of medium consistency containing 1.5 bbl. or more of cement per cu. yd. should not be less than 1 minute under the best conditions. For concretes containing less cement, mixed to drier consistencies, or containing an unusually harsh mixing aggregate, time should be increased 25 per cent to 50 per cent according to the degree of departure from concretes of the most readily mixed type.

7. For job mixers larger than one cu. yd. capacity, particularly when mixing mass concrete, a nominal minimum net mixing time of 1 minute plus ¼ minute for each additional cubic yard of capacity should be required. The use of mixers unable to pass subsequently prescribed tests for mixing efficiency after twice this period of mixing and when charged indescriminately, should be prohibited. The total net mixing time for mixers meeting this test should be the foregoing minimum (determined by the size of the mixer) plus such additional time as necessary to bring the batch within the requirements of the mixer efficiency test when the mixer is charged and operated in accordance with practice which may be established as routine for the job.

8. The mixing period should be measured from the time when all the solid materials are in the mixer drum provided that all the mixing water shall be introduced before 25 per cent of the mixing time has elapsed. Over-mixing of more than three times the above required periods should not be permitted and for that reason all mixing equipment should be so arranged that it can be stopped and started under full load.

9. A batch timer and counter, including an automatic lock which will release the discharge lever only at the end of the proper mixing period, and an audible indicator, should be installed and maintained in operation on each concrete mixer. On truck mixers the audible indicator is unnecessary. For jobs requiring 2 cu. yd. or larger stationary mixers a recording watt meter or consistency meter has definite advantages and should be required on each mixer because it is more reliable as a batch counter, and because it provides a permanent record of number of batches, type of batch, mixing time, retempering, and the uniformity of consistency. Failure of any of this equipment should be sufficient cause for discontinuance of the use of the mixer until the device is repaired or a new one is installed.

Retempering

10. Retempering or indiscriminate addition of water to delayed batches which have become stiffer than the usual consistency should be

prohibited. Under careful supervision an increment of water may sometimes be added with results beneficial to essential workability, provided the maximum allowable water-cement ratio is not exceeded. Concrete delayed in placing should not be wasted unless the amount of additional water, necessary to restore sufficient workability to permit it to be placed, would exceed the allowable water-cement ratio. Batches considerably wetter than the specified consistency, or batches in which there has been some obvious error in the measurement of solid ingredients, particularly a shortage of cement, should be wasted unless proper corrections can be made at once and the corrected batch thoroughly mixed.

Ready mixed concrete

11. The use of ready mixed concrete is an important development in connection with general concrete construction—particularly in metropolitan areas. A ready mixed concrete operation, adequately equipped and supervised, affords excellent opportunities for the control of concrete quality. Thus, ready mixed concrete may be made to offer the small job the control facilities ordinarily available only to large jobs.

12. Ready mixed concrete may be centrally mixed, truck mixed (mixed in transit), or partially centrally mixed and partially truck mixed (often referred to as "shrink-mixing"). The use of ready mixed concrete introduces certain new problems of control to which, while not fundamentally different from those encountered in other forms of concreting operations, attention should be directed.

13. Centrally mixed concrete presents about the same problems as job-mixed concrete which must be transported for considerable distances from the plant to the place of deposit. The possibilities of loss in consistency, resulting from lapse of time between mixing and placing, should be given consideration. For normal periods and temperature, and when agitator trucks are used for transportation, this factor is generally negligible. Nevertheless, precautions should be taken to minimize loss of slump by expediting delivery, eliminating delays and, in warm weather, keeping the concrete as cool as practicable by using cold mixing water, avoiding hot cement, and by shading and sprinkling aggregate. Under conditions where loss of workability cannot be otherwise controlled and is likely to be a serious matter, mixing at the forms or adequately controlled truck mixing as hereinafter outlined, will eliminate the difficulty.

14. In the case of truck mixing operations it is necessary to exercise more than usual control of all factors governing consistency because of the difficulty of judging consistency until the concrete is delivered and discharge is started. Variations in consistency may be minimized by:

(a) Handling aggregates in such a manner as to reduce variations in grading and moisture content to the greatest practical extent.

(b) Exercising accurate control over the quantity of mixing water which may be admitted to the truck mixers.

(c) Telephone communication between the point of placing and the batching plant to keep minimum the quantity of concrete arriving before a change order goes into effect.

(d) Responsible technical supervision of the entire operation.

15. In some cases satisfactory control may be readily obtained only by withholding the final increment of the mixing water until the mixer arrives at the form and then doing the additional mixing as necessary to incorporate thoroughly the added water. As pointed out earlier, complete truck mixing en route will produce consistencies of satisfactory uniformity, with minimum water content, only when special care is exercised in the control of grading and moisture content; in the absence of such control resort should be made to mixing at the forms or to completing the mixing at the forms. While every effort should be made to have concrete batches arrive at the job at a suitable consistency, it is possible to make adjustments after arrival if proper provisions are made in specifications and on the job. If the batch arrives too dry, but contains less water than the maximum allowed, additional mixing water, within specification limits, may be added and additional mixing done at the job site. In general, batches which arrive too dry, and already contain the maximum allowable mixing water, or batches which arrive too wet, should be rejected. However, adjustments may be made where conditions permit, although they are to be avoided since they interfere with orderly routine. Every care should be exercised to see that concrete arrives at the job with the desired consistency.

16. Truck mixers should be operated at a mixing speed in accordance with the recommendations of their manufacturer and should also be capable of operating at a suitable lower agitating speed of not less than 2 nor more than 6 r.p.m. of the drum. The time of mixing in truck mixers should be not less than 50 revolutions of the drum or blades at the rate of rotation specified by the manufacturer as mixing speed. The volume of the batch should not exceed the manufacturer's rating of the truck mixer's capacity and, in any event, should not be greater than fifty-seven and one-half (57.5) per cent of the gross volume of the drum or container. If, from any cause, this amount of mixing is insufficient, as determined by the subsequent tests for mixer efficiency or by other means, additional mixing should be required until satisfactory results are obtained. In truck mixing and shrink mixing, not more than 150

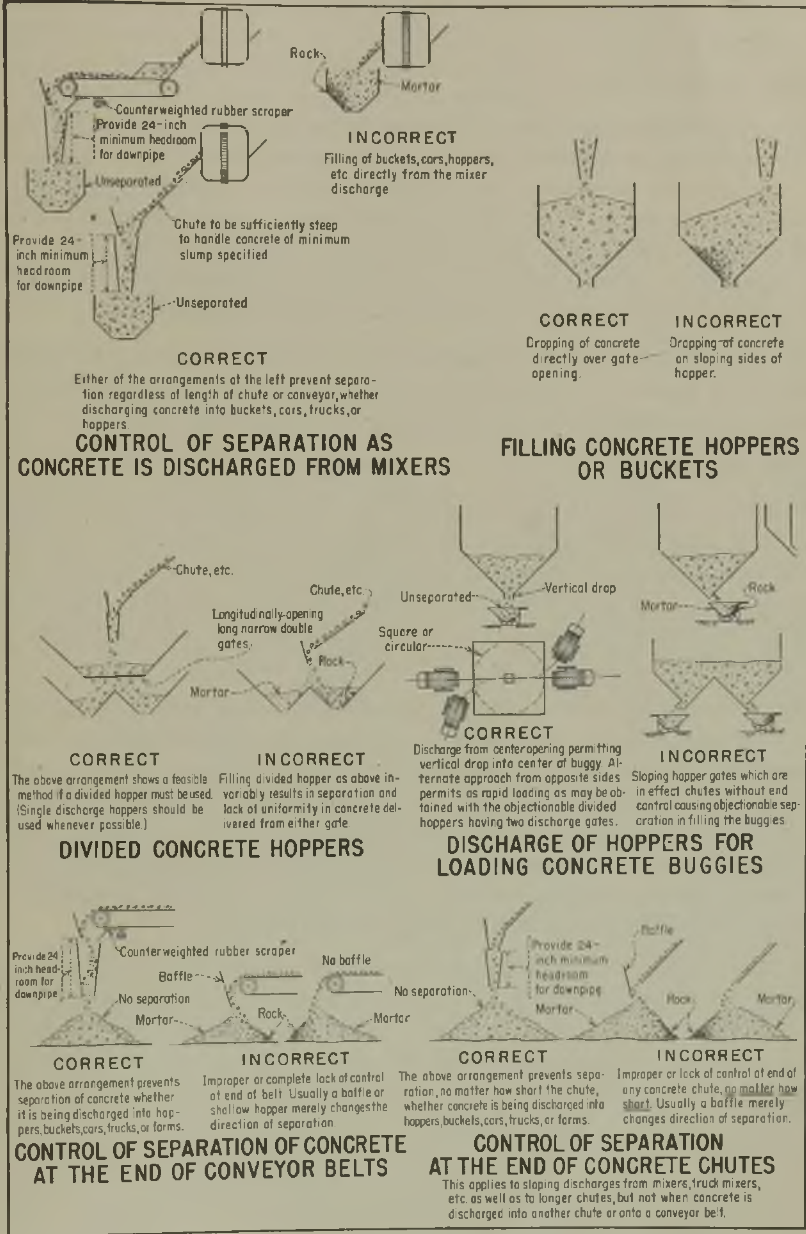

Fig. 2—Correct and incorrect methods of handling mixed concrete

revolutions of the drum should be at a peripheral speed in excess of that designated as agitator speed. Additional mixing, if necessary, should be at agitator speed.

Measure of mixing efficiency

17. The efficiency of the mixing operation in intermingling the constituents of the concrete in all types of mixers should be such that at the end of the prescribed or permitted mixing period spread in the water-to-fines ratios, W/F, of three 1500-gram samples of mortar from well separated localities in the mixer, should be within ten per cent of the average of the three samples; W being the mixing water and F being the cement and other fine material passing the No. 100 screen.*

18. The ratio of coarse aggregate to mortar should appear to be uniform in all parts of the mixer on visual inspection and this should be borne out by subsequent observation of the workability of the concrete.

The discharge operation

19. No portion of the time required for discharging any type of mixer should be considered a part of the required net mixing time. The discharge facilities of all types of mixers should be capable of ready discharge of concrete of the stiffest consistency which should be placed by means of vibration. To meet this requirement, all mixers should be capable of ready discharge of concrete of 1 inch slump.

20. To preserve the uniformity of distribution of materials and the usual homogeneity of the concrete in the mixer immediately prior to discharge, all types of mixers discharging into hoppers, buckets, cars, etc., should be so equipped that the concrete will drop vertically, not diagonally, into such containers in accordance with the principles shown in the sketches which constitute a part of these recommendations. Separation of coarse aggregate from the mortar, commonly resulting as concrete is discharged from the mixer, is thus avoided.

21. The blade arrangement and discharge mechanism of all types of mixers, including agitating, shrink, and truck mixers, should be such that the amount of aggregate larger than ¾ inch in any portion of the batch will not differ by more than 20 per cent from the amount of such aggregate in any other portion of the batch. This may be determined readily by comparing the weights of coarse aggregate retained when at least 200 lb.† of concrete from each portion of the batch in question is washed over a ¾-in. screen. Until or unless equipment is available which will meet this requirement, and is operated in this manner, when

*For one method of test see "Mortar Test for Mixer Efficiency," Method B, U. S. Bureau of Reclamation Concrete Manual, third edition, January 1941, p. 419.

†A 500-lb. sample is preferable if it does not contain portions of the batch other than those supposedly represented.

the fraction of the batch containing excessive amounts of coarse aggregate is ordinarily the last portion discharged, that fraction should be withheld from discharge and mixed with the succeeding batch. As heretofore recommended in this case, the size of batches charged into the mixer should be reduced by this amount. In some truck mixers this type of separation may be avoided by reversing the direction of rotation for one or two revolutions prior to the final discharge.

General

22. In general, all of the foregoing recommendations should be considered where applicable in connection with the mixers of proper capacity for the job regardless of the size of the job or its classification.

IV. PLACING

Essential requirements

1. Only those methods and arrangements of equipment should be used which will reduce to a minimum the separation of coarse aggregate from the mortar at all points from the mixer to the forms. For highest quality of concrete *in place*, the placing equipment should be considered for its ability to handle mixes ideal for the particular work, from the standpoint of the concrete placeability and workability *in the forms* (preferably by means of vibration where this is applicable). Equipment should be capable of expeditious placing of concrete of the proper consistency, grading and maximum size of aggregate, at the rate most advantageous to good workmanship. Selection or approval of any part of placing equipment requiring, for efficient operation, mixes containing larger proportions of sand, cement, or water, or smaller coarse aggregates, than indicated for best results on the above basis, is not recommended.

Avoidance of separation

2. The most important consideration in handling and placing concrete is the avoidance of separation of coarse aggregate from the concrete. Particular attention must be paid to that tendency at ends of chutes and conveyor belts, at hopper gates and at all other points of discharge, if uniformity and homogeneity of concrete in place and good workmanship are to be assured. No consideration should be given to the common fallacy that separation occurring in handling will be eliminated in the course of other operations. Separation should be prevented—not corrected after its occurrence.

3. Important in arranging equipment to prevent separation is the provision that the concrete shall *drop vertically* into the center of whatever container receives it. The importance of this increases very greatly with increases in slumps, maximum size, amounts of coarse aggregate,

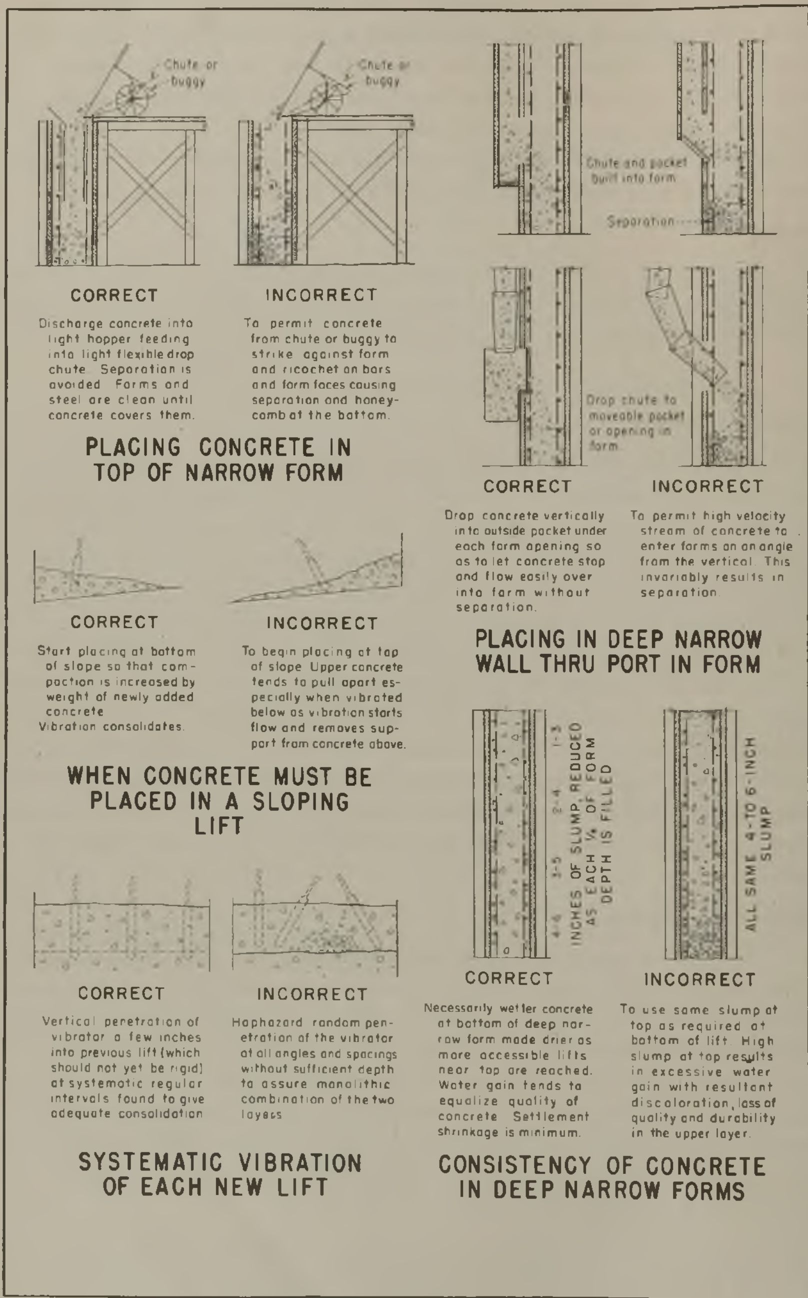

Fig. 3—Correct and incorrect methods of placing concrete

and with reductions in cement content. Falling concrete should be closely confined in a down pipe of the proper size to within a few feet of the place of deposit in the forms or other container *and the final drop must be vertical* if separation is to be prevented. Application of this principle to various common details of concrete handling equipment is shown in the accompanying sketches.

4. Where applicable, the use of bottom discharge buckets is a superior method of handling and placing mass concrete, provided: (1) they are of a size, and may be discharged in a manner and with such frequency, that the concrete may be placed in approximately horizontal layers while the previous layer is still soft; (2) they are capable of discharging concrete of the stiffest consistency specified; (3) successive batches are so placed as to afford opportunity for thoroughly working the concrete by means of internal vibrators; (4) only complete mixer batches are placed in the bucket; and (5) separation is avoided in filling the buckets (see sketch).

5. Concrete should not be dropped through reinforcement steel, or into any deep form whether reinforcement is present or not, so as to cause separation of the coarse aggregate from the mortar by repeatedly hitting rods or the sides of the form as it falls. For placing under such conditions, hoppers and, if possible, vertical ducts should be used in the forms, or other means employed so that the concrete may reach the place of final deposit without separation or coating the steel and forms with mortar that will dry out long before it can be covered with concrete. In difficult cases of deposit of this kind in deep, narrow, reinforced walls, where even narrow rectangular ducts can not be inserted, good results may be obtained by closing each third space between studs on one side of the wall for a duct through which to drop the concrete which then enters the form through holes cut in the sheathing at vertical intervals not greater than 4 ft. as the concrete rises to each opening. A pocket should be provided at the bottom of each duct successively, below each opening, so that the concrete will stop and flow easily over into the forms with minimum scattering and separation. A good internal vibrator should be in operation on each side of an opening while concrete is entering the forms.

Vibration

6. Except for a few special sections, such as thin slabs, no method of compaction and consolidation of concrete in place is superior to effective internal vibration. Vibration contributes general improvement to concrete work in the fact that superior workmanship may be obtained at lower cost, and because it permits successful routine use of a concrete

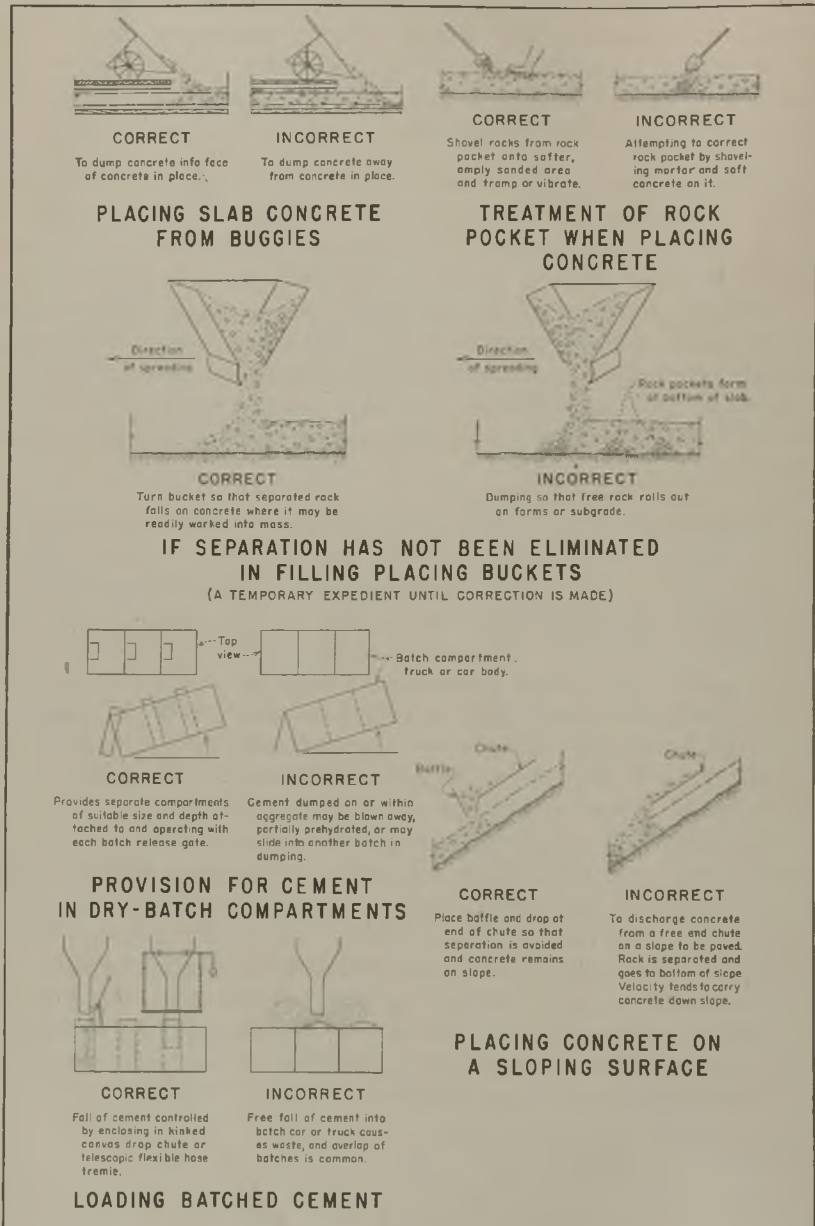

Fig. 4—Correct and incorrect methods in handling materials and placing concrete

less wet than the usual "medium" consistency, resulting in more durable, higher quality concrete. The advantages and importance of vibration where applicable are now so well established that it is worthy of serious favorable consideration for small jobs of a few hundred yards, and its requirement is recommended for all larger concrete work.

7. Detailed recommendations are omitted here and the reader is referred to "Recommendations for Placing Concrete by Vibration" reported by ACI Committee 609, ACI JOURNAL, Mar.-Apr. 1936; *Proceedings* V. 32, p. 445. Sufficient to say that the name of vibration is not enough. Equipment should be powerful, of high frequency, efficient, and rugged. Operators should be experienced, competent, dependable and energetic. Ample standby units and parts should be provided. Care should be exercised that concrete is not over-vibrated, particularly if it exceeds 4 in. in slump. Vibrators should not be used improperly to "transport" concrete in the forms. Vibrators should be inserted and withdrawn at many points, from 18 in. to 30 in. apart, for short periods, (usually from 5 to 15 seconds is sufficient) in preference to insertion for longer periods at wider intervals. Systematic spacing of insertions of the vibrator should be established to insure that no concrete remains unvibrated.

8. Inadvertent or intended revibration of concrete or steel embedded in it, any time before the concrete becomes so far set that it will not again become plastic by continued vibration, is not detrimental but may actually increase the strength of the concrete and its bond with the steel. As far as the ordinary job is concerned there is little likelihood of damage from revibration of lower lifts or from vibration transmitted by the steel, provided there is avoidance of actual rupture of newly hardened concrete that will not again become plastic by the vibration. This condition can be determined by an experienced operator from the action and sound of the vibrator.

9. In some cases, vibration may be advantageously supplemented by spading at the face of the forms. The use of flattened spading tools or rods (together with concrete placed in shallow lifts) is helpful in liberating air bubbles which often deface vertical walls and invariably are found on surfaces molded by forms which slope toward the concrete. Under sloping forms vibration without spading tends to aggravate the characteristic imperfections usually found on such surfaces and overvibration is particularly undesirable. (It is in the improvement of such surfaces that absorptive form lining is finding a very valuable application.) At corners, obstructions, and other points where perfect placing may be in question, supplementary hand rodding of the concrete is desirable.

Provision for handling concrete of the proper consistency

10. Objection is frequently made on the job to a relative stiff consistency which will not flow down a certain chute, drop out of a certain hopper or discharge through certain gates, although it is freely admitted that it is readily workable in the forms, particularly when properly vibrated. Such an objection is not valid and should not be sustained if the drier consistency has been determined in advance to be of practicable workability in the forms and has been made a requirement of the specifications. It is the function of concrete handling and placing equipment to handle and place concrete of proportions and consistencies that can be properly worked in the forms and selected for the results required in the forms. Limitations on consistencies and proportions should not be imposed by inadequate chutes, hoppers or gates.

11. Thus it is important, in the design and approval of concrete handling equipment that chutes, where necessary, be amply steep, metal or metal lined, round bottomed, of large size, rigid, and protected from overflow. Discharge gates and hoppers should be large enough to pass quickly and freely concrete of the stiffest consistency likely to be found practicable for placing in the forms by means of vibration. In many cases chutes steeper than 2 to 1 should be used, and double or triple the usual area of hopper outlets and gates would not be excessive.

12. Except where loss of slump due to delayed placing is unimportant and no increase in the original amount of mixing water is made because of it, or when remixing without additional water after a period of delay is desirable and practicable for reduction of shrinkage due to setting, every effort should be made to keep as short as possible the time elapsed from the moment water and cement come together, and the arrival of the concrete in the forms. This facilitates control of uniformity of consistency of the concrete in the forms, and reduces to a minimum the water content of the concrete, and the variable loss of slump between the mixer and the forms. For this same reason concrete should not be exposed in thin streams in long chutes or on long conveyor belts in which condition it is subject to the variable effects of all kinds of weather. It should not be necessary to mix the concrete any wetter than it may be worked in the forms by means of vibration.

V. GENERAL CONSIDERATIONS

1. In mixing and placing concrete, all concerned should remain aware that shrinkage cracks and lack of durability are primarily proportional to the volume of mixing water per unit volume of concrete within the range of practical and suitable mixes for most work. Though in many

cases they are, they *may* not be correlative to the water-cement ratio except for mixes otherwise identical in aggregate and cement content, or for mixes identical only in water content and consistency. An example is the case in which both cement and water are added without changing the water-cement ratio but with an increase in slump. Another, when increases in cement and water are accompanied by use of finer grading of aggregate resulting in little change in consistency. Such variations in unit water content proportionately affect the ultimate quality of the concrete without relation to the water-cement ratio. The more a form is filled with the right combination of solids, and the less it is filled with water, the better will be the resulting concrete. Thus to this end, moderation in the use of water, cement, and fine aggregate, together with the use of aggregate graded to the largest practical maximum size, all in conformity with the elemental needs of the work, should be consistently practiced. Only as much cement should be used as is required to obtain adequate strength and other essential properties; and only sufficient water and fine aggregate should be used as is required to obtain concrete with no more than a degree of workability which may be properly worked in the forms by means of vibration or by more appropriate methods where vibration is not applicable.

2. Sufficient mixing and placing capacity (with judgment in planning the progress of the work) should be provided so that the work may be kept alive and free from "cold joints." In all formed structures, including tunnel linings, concrete should be placed in horizontal layers of not greater depth than 2 feet, particularly avoiding inclined layers and inclined construction joints. It is very important that each layer be placed while the previous layer is still soft. Concrete should not be allowed or caused to flow horizontally or on slopes in the forms. Where concrete must be placed on a slight slope, placing should begin at the lower end of the slope and progress upward thereby increasing the compaction of the concrete. Pneumatic means of placing concrete should, in general, be avoided wherever an alternative method may be used.

Construction joints

3. For the sake of appearance, irregular construction joints should not be permitted. Each lift of concrete should be filled up to a temporary grade strip, or preferably a "V" or a slightly beveled rectangular strip should be left on the forms at the line of the joint where such grooves can be located so as not to detract from the appearance of the work and so as to be less unsightly than the usual construction joint. Particular precautions should be taken to secure the forms tightly against the concrete at the joint, since, otherwise, an unsightly offset will occur

and mortar from the subsequently placed concrete will disfigure the surface of the concrete in place.

4. The surface of the construction joint should be prepared in a manner that will insure bonding with the concrete later placed on it, and if the joint must be watertight the preparation of the joint must be particularly thorough. It is not difficult to obtain a good joint where good quality low-slump concrete has been used at the top of the lift and has not been overworked. Where wet consistencies have been used, or where excessive vibrating or working has brought water or mortar to the surface, the concrete at the surface of the lift is usually so inferior that it is not easy to obtain a good joint.

5. In the latter case the so-called initial jet cleanup is a good expedient for such an inferior joint condition, which on good work would not be encountered. The first step should be the removal of all laitance and inferior surface concrete and the washing of mortar from protruding aggregate by means of a strong jet of air and water, at approximately 100 psi pressure, after the concrete has hardened sufficiently to prevent the jet from raveling the surface below the desired depth and from forming cloudy pools of water that will leave a film on the surface when they dry. The surface of joints so treated should be especially well moist-cured, preferably by a 1-inch layer of saturated sand, and, if possible the surfaces should never be permitted to dry out during the interval before concrete is placed on it. Before placing the new concrete the surface should be restored to the bright clean condition existing immediately following the initial jetting by means of vigorous brushing with fine wire hand brushes or by sandblasting as necessary. If the surface has been properly wet sand cured, very little final scrubbing or sandblasting will be necessary.

6. Initial jetting, followed by a thorough final cleanup can also be used with good results where quality of concrete at the joint surface is good. It produces no better results, however, than can be readily obtained, on surfaces which have been properly placed at the right consistency, by omitting any initial treatment and removing the surface film and dirt to a bright new surface by sandblasting and washing immediately prior to placing the new concrete. The initial jetting method including a comparable final cleanup is usually found to be more expensive than the final sandblasting method and is not as foolproof. Final sandblasting without initial cleanup has been found to produce excellent results economically on horizontal joint surfaces of mass concrete that has been placed at dry consistencies with the aid [illegible]brators, if the surface is protected from excess working due to

keyway construction, the endeavor to embed all coarse aggregate, and the general job traffic until the concrete has hardened.

7. In all cases the new concrete should be preceded by about one-half inch of soft mortar of the same proportions as that in the concrete. When accessible, this should be scrubbed into the surface of the joint with wire brooms. In column forms and deep narrow forms where one-half inch of mortar may seem inadequate, it is preferable to follow the mortar with several inches of concrete containing mortar in excess of that in the usual mix and possibly containing coarse aggregate somewhat reduced in maximum size rather than use large quantities of straight mortar.

Finishing of unformed surfaces

8. For the most durable results in any type of finished, unformed concrete surfaces, the following general requirements should be made. Concrete should be used of the stiffest consistency that can be properly placed and worked or vibrated in accordance with the finishing process adopted. In the initial operations of screeding, floating, and first troweling, the surface of the concrete should be worked *as little as possible* in obtaining the desired result. Each step in the finishing operation from the secondary floating to the final operation should be delayed *as long as possible* and yet permit the desired result to be obtained. The use of any finishing tool in any area where water has accumulated should be prohibited. Dry topping and mortar topping should be avoided. The surface of the concrete should be directly finished to the texture desired.

Cold weather concreting

9. For concrete in sections thinner than would be called mass concrete, when the weather is such that freezing of the concrete may occur, arrangements should be made to heat the mixing water and the aggregate so that the temperature of the fresh concrete in place is approximately 70F. At this temperature setting commences at once and, due to the heat liberated by hydration, will progress at a normal rate, provided the work is protected for several days from dissipation of heat more rapidly than additional heat is generated. This procedure is eminently preferable to that of placing the concrete cold at any temperature above freezing and then endeavoring to heat it in place by salamanders or other means; however, under severe conditions it may be necessary to surround the work with some form of heating protection in addition to protection by insulation. Steam released under a tarpaulin enclosure is an excellent protection since a moist atmosphere favorable to curing as well as protection from freezing is afforded. Corners, edges and surfaces of concrete are particularly vulnerable to

freezing and the need for their adequate protection cannot be too strongly emphasized. In fact they may be frosted when the dry bulb temperature is above 32 F. if the wet bulb temperature reaches 32 F. In connection with cold weather protection, such precautions should be taken that the curing of the concrete will not be impaired and that no portions of the work will become overheated. It is important that there should be a curing period of sufficient length at temperatures above freezing so that when it is exposed to temperatures below freezing at the end of the curing period the concrete will not be injured.

10. With adequate protection of the surfaces from freezing, the minimum temperature of freshly mixed mass concrete may be permitted to be as low as 40F. when placed, because the heat of hydration is lost much more slowly from this type of concrete.

Hot weather concreting

11. For best ultimate quality, concrete should be placed at the lowest practicable temperature during hot weather. Effective results can usually be accomplished by concreting only at night, sprinkling or cooling the aggregate, avoiding hot cement, and using very cold mixing water. Any combination or degree of these practices that may be feasible for the particular work are important and should be required. Curing should preferably be obtained by sprinkling or covering with moist burlap for its additional cooling value. If curing must be done by means of black bituminous sealing compounds, they should be given a coat of whitewash promptly so as not to expose the heat absorbing black surface to the sun.

Forms

12. Provisions as to certain types of forms are necessary because, when they are not followed, concrete containing excessive amounts of sand, cement, or water is usually necessary in order to obtain acceptable workmanship. Horizontally moving slip forms should not be used on slab work on which standard types of paving and finishing machines can be used. Preferably such machines should be equipped with an effective form of vibration or mechanical device for working and compacting the concrete. A continually moving slip form, however, should be used in preference to fixed forms whenever possible on slope paving slabs or steeply curved inverts.

13. Workmanship in placing concrete is largely judged by the appearance of the work on removal of the forms, and appearance in itself is an important quality which must usually be obtained when the concrete is placed. It is therefore necessary in these recommendations to mention other requirements for satisfactory results.

14. With the general adoption of vibration of concrete, forms must not only be built substantially, but they must be tight, since, otherwise, unsightly sand streaks and gravel pockets will be caused by loss of mortar made unusually liquid during vibration. Exceptional care should be exercised to insure that all form panel joints, corners, and connections and all seams between all types of sheathing are completely tight immediately prior to placing the concrete. Because of their superior tightness where they penetrate the forms, tie rods are recommended in preference to tie wires. Where wires must be used holes for them should be as small as possible to keep mortar leakage at a minimum.

15. Forms should be protected from deterioration, weather and shrinkage prior to concreting by proper oiling or by effective wetting. Form surfaces should be clean and of uniform texture. Where they are permissible, re-used forms should be carefully cleaned and oiled. Steel forms should be thoroughly cleaned but never sand blasted nor abraded to bright metal. Where "peeling" is encountered with steel forms, leaving the cleaned, oiled, forms in the sun for a day, or vigorously rubbing the affected areas with liquid paraffin will usually improve the condition. It is generally less expensive and more satisfactory to obtain the desired surface effect by proper treatment and preparation of the forms than it is to obtain it by working over the concrete after the forms are removed.

VI. CLOSURE

1. In general, all of the foregoing features should be considered, insofar as applicable, in connection with each job classification, regardless of type or capacity of equipment.

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ACI Standard

Recommended Practice for the Design of Concrete Mixes (ACI 613-44)*

Reported by ACI Committee 613

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INTRODUCTION

1. General comments

The design of concrete mixes is the determination of the most economical and practicable combination of available aggregates, cement, water, and, in some cases, admixture, that will produce a mixture, having the required degree of workability, and which will develop required qualities on hardening.

The most practical procedure for determining the final proportions of concrete for a given purpose is actual trial and adjustment on the job. The problem thus becomes a matter of selecting a trial mix, for starting concrete operations, that will require the least adjustment on the job.

The design of trial mixes can be accomplished most effectively by laboratory investigation of the concrete-making properties of the particular materials to be used. For work of considerable magnitude, for unusual conditions or materials, or where strength (especially flexural

*Adopted as a Standard of the American Concrete Institute at its 40th Annual Convention March 1, 1944 (as revised and corrected by Committee 613 from Report published ACI JOURNAL, November 1943—*Proceedings* V. 40, p. 93) and ratified by Letter Ballot July 28, 1944.

strength) is a controlling factor, such laboratory tests are particularly desirable. The minimum laboratory determinations that will permit effective trial mix design are tests of the grading, specific gravity, absorption, and total moisture content of the aggregates. The specific gravity of the cement may be taken as 3.15, without appreciable sacrifice in accuracy. Methods for determining these properties are prescribed in 1 of the appendix.

Important factors which should be determined by tests of concrete mixes in the laboratory include:

(a) Relation between water-cement ratio and strength (compressive or flexural).

(b) Variations in workability characteristics for various combinations of the ingredient materials.

(c) Unit water contents and cement requirements for various aggregate gradings.

In addition to supplying data for more precise design of trial mixes, the laboratory tests provide information that is useful in adjusting concrete mixes in the field and for determining the relative costs of concretes made with different combinations of materials. The recommended procedure for making laboratory mix tests is outlined in 1 of the appendix.

When it is impracticable to conduct laboratory concrete tests, trial mixes for starting concrete operations can be selected by judicious application of known basic concepts and established empirical relationships.

RECOMMENDED PROCEDURE

2. Outline of procedure

The six steps involved in the determination of a trial mix for initial field use are:

(a) Select the water-cement ratio from test data, experience, or established relationships, to meet the specified requirements for durability and strength (compressive or flexural).

(b) Select the limits of slump that will permit proper handling and consolidation of the concrete under the job conditions involved.

(c) Determine the largest size of available aggregate suitable for use under job conditions.

(d) Estimate, from test data, experience, or established relationships, the minimum percentage of sand that will provide the proper degree of workability.

(e) Estimate the amount of water per cubic yard of concrete that will be required to fulfill the conditions of steps (b), (c), and (d).

(f) Compute the trial mix proportions that conform with the factors determined in steps (a) to (e). Make such adjustments in the trial mix, on the job, as may be necessary.

TABLE 1—NET WATER-CEMENT RATIOS FOR VARIOUS TYPES OF CONSTRUCTION AND EXPOSURE CONDITIONS**

Type or Location of Structure	Severe or Moderate Climate, Wide Range of Temperature, Rain, and Long Freezing Spells or Frequent Freezing and Thawing										Mild Climate, Rain or Semiarid Rarely Snow or Frost									
	Thin Sections				Moderate Sections				Heavy and Mass Sections		Thin Sections				Moderate Sections				Heavy and Mass Sections	
	Reinf.		Plain		Reinf.		Plain				Reinf.		Plain		Reinf.		Plain			
	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack
A. At the water line in hydraulic or water-front structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged:																				
In sea water	0.44	5	0.49	5½	0.49	5½	0.53	6	0.53	6	0.44	5	0.49	5½	0.49	5½	0.53	6	0.53	6
In fresh water	0.49	5½	0.53	6	0.53	6	0.58	6½	0.58	6½	0.49	5½	0.53	6	0.53	6	0.58	6½	0.58	6½
B. Portions of hydraulic or water-front structures some distance from the water line, but subject to frequent wetting:																				
By sea water	0.49	5½	0.53	6	0.53	6	0.53	6	0.53	6	0.49	5½	0.58	6½	0.58	6½	0.62	7	0.62	7
By fresh water	0.53	6	0.58	6½	0.58	6½	0.58	6½	0.58	6½	0.53	6	0.62	7	0.62	7	0.67	7½	0.67	7½
C. Ordinary exposed structures, buildings and portions of bridges not coming under above groups	0.53	6	0.58	6½	0.58	6½	0.62	7	0.62	7	0.53	6	0.62	7	0.62	7	0.67	7½	0.67	7½
D. Complete continuous submergence:																				
In sea water	0.53	6	0.58	6½	0.58	6½	0.62	7	0.62	7	0.53	6	0.58	6½	0.58	6½	0.62	7	0.62	7
In fresh water	0.58	6½	0.62	7	0.62	7	0.67	7½	0.67	7½	0.58	6½	0.62	7	0.62	7	0.67	7½	0.67	7½
E. Concrete deposited through water	*	*	*	*	0.49	5½	0.49	5½	0.49	5½	*	*	*	*	0.49	5½	0.49	5½	0.49	5½
F. Pavement slabs directly on ground:																				
Wearing slabs	0.49	5½	0.53	6	*	*	*	*	*	*	0.53	6	0.58	6½	*	*	*	*	*	*
Base slabs	0.58	6½	0.62	7	*	*	*	*	*	*	0.62	7	0.67	7½	*	*	*	*	*	*

G. Special case: (a) For concrete not exposed to the weather, such as interiors of buildings and portions of structures entirely below ground, no exposure hazard is involved, and the water-cement ratio should be selected on the basis of the strength and workability requirements.

*These sections not practicable for the purpose indicated.
**Adapted from Table 1 of the 1940 Joint Committee Report on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete

3. Selection of water-cement ratio

The water-cement ratio should be chosen on the basis of (a) the required durability, and (b) the strength specified.

The maximum water-cement ratio for the type of construction and exposure conditions involved should be selected from Table 1. The water-cement ratio for the specified strength should be determined by laboratory tests, as described in 1 of the appendix. When it is not practicable to make such tests, the water-cement ratio required for the specified *compressive* strength may be taken directly from Table 2, which gives a series of conservative values derived from a large number of tests with typical materials.

TABLE 2—COMPRESSIVE STRENGTH FOR VARIOUS WATER-CEMENT RATIOS*

Net Water-Cement Ratio		Probable Strength at 28 Days (Pounds per Square Inch)
By Weight	Gallons per Sack of Cement	
0.44	5	5,000
0.49	5½	4,500
0.53	6	4,000
0.58	6½	3,600
0.62	7	3,200
0.67	7½	2,800
0.71	8	2,500
0.75	8½	2,000

*Adapted from Table 2 of the 1940 Joint Committee Report on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete. The strengths listed are based on the use of normal portland cement.

A corresponding table of values for flexural strength is not given because of the wider range in flexural strength which may be obtained with a given water-cement ratio for different materials. Where flexural strength is specified, the required water-cement ratio should be determined by laboratory tests, as previously stated.

The lower of the two water-cement ratios, (a) that required for durability as shown in Table 1, or (b) that required for the specified strength as determined by test or from Table 2, should always be used.

4. Selection of limiting slump and maximum size of aggregate

It is advisable to use the lowest slump compatible with proper placing. Table 3 gives the limiting values recommended for various types of construction.

For economic and other reasons, the maximum size of aggregate should be as large as practicable and available, but should not exceed two-thirds of the minimum clear distance between reinforcement. Recommended limits are given in Table 4.

TABLE 3—RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION*

Type of Construction	Slump in Inches**	
	Maximum	Minimum
Reinforced foundation walls and footings	5	2
Plain footings, caissons, and substructure walls	4	1
Slabs, beams, and reinforced walls	6	3
Building columns	6	3
Pavements	3	2
Heavy mass construction	3	1

*Adapted from Table 4 of the 1940 Joint Committee Report on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete.
**When high-frequency vibrators are used, the values given should be reduced about one-third.

TABLE 4—MAXIMUM SIZE OF AGGREGATE RECOMMENDED FOR VARIOUS TYPES OF CONSTRUCTION

Minimum Dimension of Section (Inches)	Maximum Size of Aggregate*, in Inches, for:			
	Reinforced Walls, Beams, and Columns	Unreinforced Walls	Heavily Reinforced Slabs	Lightly Reinforced or Unreinforced Slabs
2½ - 5	½ - ¾	¾	¾ - 1	¾ - 1½
6 - 11	¾ - 1½	1½	1½	1½ - 3
12 - 29	1½ - 3	3	1½ - 3	3
30 or more	1½ - 3	6	1½ - 3	3 - 6

*Based on square openings.

5. Estimating the percentage of sand and unit water content

For a given set of materials and water-cement ratio, the unit water content (water required per cubic yard of concrete) is the most important basic factor affecting the quality of concrete. The optimum percentage of sand for a concrete mix is that quantity which will result in the lowest unit water content and also provide the required degree of workability, with an adequate margin to prevent difficulties from variations in working conditions and materials. Obviously, for a given water-cement ratio, the mix requiring the lowest water content will also require the least cement.

The optimum percentage of sand can be determined to best advantage on the job, under working conditions. However, laboratory mix tests with the materials to be used in the work will provide information permitting a close approximation to the proper proportion. The committee recognizes that there are several satisfactory methods for proportioning sand and coarse aggregate for trial concrete mixes. Where conditions or personal preference dictates, use may be made of any of the basically sound methods described in the current literature (see bibliography).

It is recommended that the proportions for trial concrete mixes be determined on the basis of the estimated unit water requirements. When laboratory tests cannot be made, Table 5 may be employed. The values given in Table 5, which are average values for aggregate gradings within acceptable limits were derived from a composite of data, information, and experience from many sources.

TABLE 5—APPROXIMATE SAND AND WATER CONTENTS PER CUBIC YARD OF CONCRETE

Based on aggregates of average grading and physical characteristics in mixes having a W/C of about 0.57 by weight or 6½ gallons per sack of cement; 3-in. slump, and natural sand having an F.M. of about 2.75.

Maximum Size of Coarse Aggregate	Rounded Coarse Aggregate			Angular Coarse Aggregate		
	Sand Per Cent of Total Aggregate by Absolute Volume	Net Water Content Per Cubic Yard		Sand Per Cent of Total Aggregate by Absolute Volume	Net Water Content Per Cubic Yard	
Inches		Pounds	Gallons		Pounds	Gallons
½	51	335	41	56	360	44
¾	46	310	37	51	335	40
1	41	300	36	46	325	39
1½	37	280	34	42	305	37
2	34	265	32	39	290	35
3	31	250	30	36	275	33
6	26	220	26	31	245	29

Adjustment of Values in Table 5 for Other Conditions

Changes in Conditions Stipulated in Table 5	Effect on Values in Table 5	
	Per Cent Sand*	Unit Water Content*
Each 0.05 increase or decrease in water-cement ratio	±1	0
Each 0.1 increase or decrease in F. M. of sand	±½	0
Each 1 in. increase or decrease in slump	—	±3%
Manufactured sand (sharp and angular)	+3	+15 lb.
For less workable concrete, as in pavements	−3	− 8 lb.

*(+) indicates an increase and (−) a decrease corresponding to the conditions stated in the first column.

6. Computation of trial mix

Assume a project which involves an ordinary heavily reinforced retaining wall having a minimum thickness of 8 in., and also a pavement slab. The concrete will be subjected to severe climatic exposure. The wall and slab have been designed on the basis of compressive and flexural strengths at 28 days of 4,000 and 600 psi, respectively. A trial concrete mix is required, either to start a series of laboratory mix tests or, if laboratory tests cannot be made, to start concrete construction in the field. The concrete in the retaining wall will be consolidated by vibration, and the following information regarding the materials to be used in the work is available:

Cement—Type I, average characteristics.
Specific gravity—3.15 (assumed).

Sand—River sand, damp.
Medium fineness and grading.
Specific gravity—2.65 (saturated, surface dry).
Free moisture content—5 per cent by weight.

Coarse aggregate—Crushed stone (saturated surface-dry.)
Reasonably well graded, angular.
Specific gravity—2.55 (saturated, surface dry.)

From Table 1 it is found that a water-cement ratio of 0.53 is the maximum which should be used for the type of structures and service conditions involved. Table 2 indicates that a water-cement ratio of 0.53 will provide the required compressive strength of 4,000 psi. The water-cement ratio required for the specified flexural strength of 600 psi can be established only by laboratory tests such as outlined in 1-c of the appendix. From Tables 3 and 4 it is concluded that for the concrete in the retaining wall a three-in. slump and 1½-in. maximum aggregate will be satisfactory.

On the basis of information given in Table 5 it is estimated that the percentage of sand for the trial mix should be 42 per cent, by absolute volume of the total aggregate, and that 305 pounds (about 37 gallons) of water will be required per cubic yard of concrete. (Actually the water content may be more or less than the estimated amount as determined by the amount of water required for a three-in. slump when a trial batch is mixed in the laboratory or on the job.)

$$\text{Cement content} = \frac{\text{Net water content}}{\text{water-cement ratio}}$$

$$= \frac{305}{0.53} = 575 \text{ lb. per cu. yd.}$$

$$= \frac{575}{94} = 6.12 \text{ sacks per cu. yd.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{water + cement}\end{pmatrix} = \frac{\text{Water content}}{62.4} + \frac{\text{Cement content}}{\text{specific gravity} \times 62.4} =$$

$$\frac{305}{62.4} + \frac{575}{3.15 \times 62.4} = 7.81 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{total aggregate}\end{pmatrix} = 27 - \begin{pmatrix}\text{absolute volume,}\\ \text{water + cement}\end{pmatrix}^{*}$$
$$= 27 - 7.81 = 19.19 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{sand}\end{pmatrix} = \text{percent sand} \times \begin{pmatrix}\text{absolute volume,}\\ \text{total aggregate}\end{pmatrix}$$
$$= 0.42 \times 19.19 = 8.06 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{coarse aggregate}\end{pmatrix} = \begin{pmatrix}\text{absolute volume,}\\ \text{total aggregate}\end{pmatrix} - \begin{pmatrix}\text{absolute volume,}\\ \text{sand}\end{pmatrix}$$
$$= 19.19 - 8.06 = 11.13 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{sand}\\ \text{content}\end{pmatrix} = \text{absolute volume} \times \text{specific gravity} \times 62.4$$
$$= 8.06 \times 2.65 \times 62.4 = 1{,}333 \text{ lb. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Coarse aggregate}\\ \text{content}\end{pmatrix} = 11.13 \times 2.55 \times 62.4 = 1{,}771 \text{ lb. per cu. yd. of concrete.}$$

$$\text{Trial-mix proportions} = \frac{575}{575} : \frac{1{,}333}{575} : \frac{1{,}771}{575}$$
$$= 1 : 2.32 : 3.08, \text{ say } 1{:}2.3{:}3.1$$

This mix provides a starting point for a series of laboratory tests, such as described in 1-c of the appendix, or for field operations in constructing the retaining wall.

The equipment available on the job includes a three-sack batch mixer equipped with a water tank calibrated in gallons and also a water meter graduated in pounds, and batching scales for weighing the separated sizes of sand and coarse aggregate.

Cement is to be batched on the basis of integral sacks and the batch will contain three sacks, or 3 x 94 = 282 lb. of cement, which is a fixed quantity. The batch weights of sand and coarse aggregate for the trial mix will be:

Sand $= 1{,}333 \times \frac{282}{575} = 654$ lb. (net), to which must be added the weight of the free moisture in the sand: $654 + (0.05 \times 654) = 687$ lb. damp sand.

Coarse aggregate $= 1{,}771 \times \frac{282}{575} = 869$ lb.

7. Adjustment of trial mix

A few batches of concrete are mixed on the job, and the average quantity of water added per batch for the desired three-in. slump is 13.1 gal. or 13.1 x 8.34 = 109 lb.

The free water in the sand is: $0.05 \times 654 = 33$ lb.
The net water in the mix is: $109 + 33 = 142$ lb.

The net water-cement ratio is: $\frac{142}{282} = 0.50$ by weight.

*Air voids assumed to be negligible. When the air content is appreciable, as when air entraining agents are used, a suitable allowance should be made, considering the air as replacing an equal volume of sand.

Since a water-cement ratio of 0.53 is desired (water content of $0.53 \times 282 = 150$ lb. for a three-sack batch), the batch requires less water than was estimated.

The absolute volume of the field batch = volume of water + absolute volumes of cement + sand + coarse aggregate =

$$\frac{142}{62.4} + \frac{282}{3.15 \times 62.4} + \frac{654}{2.65 \times 62.4} + \frac{869}{2.55 \times 62.4} = 13.13 \text{ cu. ft.}$$

The correct unit water content is: $142 \times \frac{27}{13.13} = 292$ lb. per cu. yd.

Using the corrected value for unit water content, as determined by the trial batches, the batch quantities for the adjusted mix having a water-cement ratio of 0.53, may be computed in the same manner as for the trial mix. This procedure should result in concrete having the desired three-in. slump because it is a recognized fact that for a given slump and aggregate grading, substantially the same unit water content is required for any water-cement ratio.*

The adjusted mix for 292 lb. of water per cubic yard and a 0.53 water-cement ratio is 1:2.46:3.27; say 1:2.5:3.3.

After the initial adjustment for water-cement ratio has been made and after stabilized operating conditions have been established, the optimum percentage of sand should be determined. This may be done by trial, noting the water requirement for each percentage of sand tried, until the lowest percentage compatible with proper workability, with a safe working margin, is established. The mix is again adjusted to maintain the correct water-cement ratio.

Rich mixes normally require less sand than lean mixes. After the optimum percentage of sand has been determined for a given mix, cement and sand may be interchanged by absolute volumes (keeping the sum of their absolute volumes the same) without affecting the water content or slump. For practical purposes a change in cement content of one sack per cubic yard of concrete will permit a change in sand percentage of about two.

Changes in consistency may be made by simply increasing or decreasing the amount of water to provide the desired slump, with appropriate adjustment to maintain the specified water-cement ratio.

The job mix should not be adjusted for minor fluctuations in water-cement ratio. A variation of ± 0.02 (by weight) to maintain a constant slump is considered normal.

*A short-cut method for adjusting a mix for change in water-cement ratio is illustrated in 3 of the appendix.

APPENDIX

1. Laboratory tests

As stated in the introduction, the design of trial mixes can be accomplished most effectively by laboratory investigations: *First*, to determine the basic physical properties of the materials to be used; and *second*, to establish certain fundamental relationships, including: (1) Relation between water-cement ratio and strength; (2) variations in workability characteristics for various combinations of the ingredient materials; and (3) unit water contents and cement requirements for various aggregate gradings.

The extent of the investigations desirable for any given job will depend on the size, importance, and service conditions of the structures involved. Details of the laboratory program will also vary depending on the facilities available and individual preferences.

(a) *Physical properties of cement*—The fineness and chemical composition of cement influence the workability and strength development of concrete; however, the only property of cement directly required in computations for the design of concrete mixes and batch quantities is specific gravity. The specific gravity of cement may be assumed to be 3.15 without introducing appreciable error in the mix computations, or it may be determined by test. A sack of cement weighs 94 pounds. It is, of course, desirable to assemble complete information concerning the cement to be used, including both chemical and physical properties.

The sample of cement should be obtained from the mill which will supply the job or preferably from the job itself, if time permits. The sample should contain ample quantity for the tests contemplated with a liberal margin of excess for additional tests that might be desirable. The test cement should be shipped and stored in air-tight containers or at least in moisture-proof packages.

(b) *Physical properties of aggregate*—Specific gravity, absorption, and moisture content are the essential physical properties of aggregates required in mix design computations. The weight per cubic foot and void content of the aggregate will be useful in analyzing concrete mixes.

For large or special types of work, various additional tests of aggregate materials, including petrographic analyses, chemical reactivity tests, soundness tests, abrasion tests, and tests for various deleterious substances, may be justified in connection with mix design studies, because all such tests yield information of value in judging the ultimate quality of the concrete and in selecting appropriate mix design factors.

Aggregate gradation, or particle size distribution, is a major factor controlling the unit water requirement, percentage of sand and cement content of concrete mixes for a given degree of workability. Some standard for comparing different aggregate gradings in concrete mix tests is needed to properly evaluate such factors as workability, cement and water requirements, benefits to be derived from processing or the use of admixtures, and the relative economy of alternative aggregate sources. Numerous "ideal" aggregate grading curves have been proposed but a universally accepted standard has not been developed. Experience and individual conditions and judgment must continue to play important roles in determining "acceptable aggregate gradings."

Variations in sand grading may be accomplished by (1) separation of the sand into two or more size fractions and recombination in suitable proportions, (2) adding or removing materials to balance the grading, or (3) reducing excess coarse material by grinding. Variations in coarse aggregate grading may be accomplished by (1) crushing excess material from coarser fractions or oversize material, (2) wasting excess materials from other fractions, or (3) a combination of these methods. Insofar as grading limitations and consideration of cement economy permit, the relative proportions of the various sizes of coarse aggregate used in the trial mixes should be governed by the natural grading of the materials. Whatever processing is done in the laboratory for the purpose of comparing mixes should be practical from the standpoint of economy and job operation.

Samples of aggregates for concrete mix tests should be representative of the aggregate selected for use in the work. The coarse aggregate should be cleanly separated into the required size fractions to provide uniform control of mix proportions.

(c) *Concrete mix tests*—The example used in section 6 of the recommended procedure requires flexural and compressive strengths at 28 days of 600 and 4,000 psi, respectively. A minimum series of concrete mix tests to establish the relationships needed for the selection of appropriate mix design factors is illustrated in Tables 6 and 7.

The trial mix, as calculated in section 6, provides a starting point for the laboratory test series. Five additional mixes are then made with the water-cement ratio varying over a total range of 0.20 to establish water-cement-ratio-strength relationships. For this set of mixes the percentage of sand is varied according to the water-cement ratio, or richness of mix, as indicated in the recommended procedure.

The strength data obtained from the concrete mix tests are given in Table 7. With such information, for the specific materials to be used on the job, it is unnecessary to use the empirical values and relationships for average conditions as given in Tables 2 and 5 of the recommended procedure. The test data show that a water-cement ratio of

TABLE 6—TYPICAL MINIMUM PROGRAM OF CONCRETE MIX TESTS

Maximum size aggregate—1½ in. Required slump approximately 3 in.

Mix No.	Actual Net W/C by Wt.	Sand % of Total Aggregate (by Abs. Volume)	Mix by Weight Based on Saturated Surface-Dry Aggregates	Unit Weight Lbs. per Cu. Ft.	Slump, In.	Unit Water Content Lbs. per Cu. Yd.	Cement Content Lbs. per Cu. Yd.	Workability			
								Rod-ability	Finish	Segre-gation	Remarks
1	.50	42	1:2.32:3.08	148.2	3	292	584	Good	Very good	None	Very workable, could use less sand.
2	.43	38	1:1.79:2.81	149.0	2¾	287	667	Good	Excellent	None	Excellent mix, slightly sticky.
3	.48	39	1:2.09:3.15	148.6	3¼	287	598	Good	Excellent	None	Excellent mix
4	.53	40	1:2.40:3.47	148.2	3	287	541	Good	Very good	None	Excellent mix.
5	.58	41	1:2.72:3.77	148.0	2¾	287	495	Good	Good	None	Good mix.
6	.63	42	1:3.06:4.07	147.9	3¼	287	456	Good	Fair	None	Good mix, lacks cohesiveness

0.50 is required to provide the specified flexural strength of 600 psi. A maximum water-cement ratio of 0.53, required for durability, will result in workable concrete that will develop more than the 4,000 psi compressive strength specified for the retaining wall. The trial field mixes may now be calculated as before or taken directly from Tables 6 and 7 by interpolation.

TABLE 7—STRENGTH DATA FROM CONCRETE MIX TESTS SHOWN IN TABLE 6

Average Unit Strengths at 28 Days

Mix No.	Compression psi of 3 6x12-in. Cylinders	Flexural psi of 5 6x6x21-in. Beams	Compression psi of 2 6x6x6-in. Modified Cubes
1	4,390	610	5,000
2	5,060	680	5,730
3	4,630	625	5,260
4	4,080	570	4,800
5	3,800	525	4,390
6	3,440	490	3,950

In conducting laboratory mix tests, it will seldom be found, even with experienced operators, that the desired conditions are obtained so precisely for every mix as indicated in Table 6. Some trial and error and rerun of mixes may be anticipated. Furthermore, it should not be expected that field materials, conditions, and equipment will permit an exact check of laboratory results, and adjustment of the selected trial mix on the job will probably be desirable. Closer agreement between laboratory and field results will be assured if machine mixing is employed in the laboratory, and this procedure is recommended. If laboratory mixer equipment is not available, hand mixing can be used. Similarly, any processing of materials in the laboratory should simulate as closely as practicable the corresponding treatment in the field.

The minimum series of tests illustrated in Tables 6 and 7 may be expanded as the size, cost, and special requirements of the work might warrant. Alternative aggregate sources, different sand and coarse aggregate gradings, different percentages of sand, different types or brands of cement, admixtures, mixes for various maximum sizes of aggregate, and concrete performance in durability, volume change, and thermal property tests, are some of the variable factors that may require consideration in more extensive programs.

(d) *Test methods*—In conducting laboratory tests, it is recommended that the latest issue of the following listed standards be used.

Cement

Sampling and physical testing of portland cement—ASTM Designation: C77.
Chemical analysis of portland cement—ASTM Designation: C114.
Fineness of portland cement by means of the turbidimeter—ASTM Designation: C115
Compressive strength of portland cement mortars—ASTM Designation: C109.
Autoclave expansion of portland cement—ASTM Designation: C151.

Water

Quality of water to be used in concrete—AASHO Designation: T26.

Aggregate

Abrasion of coarse aggregate—Los Angeles machine—ASTM Designation: C131.
Abrasion of rock by use of the Deval machine—ASTM Designation: D2.
Abrasion of stone and slag by use of the Deval machine—AASHO Designation: T3.
Abrasion of gravel by use of the Deval machine—ASTM Designation: D289.
Toughness of rock—ASTM Designation: D3.
Clay lumps in aggregates—ASTM Designation: C142.
Coal and lignite in sand—ASTM Designation: C123.
Percentage of shale in aggregate—AASHO Designation: T10
Organic impurities in sand—ASTM Designation: C40.
Material finer than No. 200 sieve—ASTM Designation: C117.
Sieve analysis of fine and coarse aggregate—ASTM Designation: C136.
Soundness—Sodium and magnesium sulfate method—ASTM Designation: C88.
Soundness—Freezing and thawing method—ASTM Designation: C137.
Specific gravity and absorption—Coarse aggregate—ASTM Designation: C127.
Specific gravity and absorption—Fine aggregate—ASTM Designation: C128.
Surface moisture in fine aggregate—ASTM Designation: C70.
Unit weight of aggregate—ASTM Designation: C29.
Voids in aggregate for concrete—ASTM Designation: C30.
Structural strength of fine aggregate using constant water-cement ratio mortar—ASTM Designation: C87.

Concrete

Machine mixing of concrete in laboratory—Bureau of Reclamation Concrete Manual—Designation: 28.
Sampling of fresh concrete—ASTM Designation: C172.
Consistency by slump—ASTM Designation: C143.
Consistency by flow table—ASTM Designation: C124.
Yield of concrete (includes unit weight test)—ASTM Designation: C138.
Air content of freshly mixed concrete—ASTM Designation: C173.
Making and storing compression test specimens in the field—ASTM Designation: C31.
Compressive strength—ASTM Designation: C39.
Compressive strength—Modified cube method—ASTM Designation: C116.
Flexural strength—ASTM Designation: C78.
Volume change—ASTM Designation: C157.
Absorption of concrete—AASHO Designation: T25.
Securing and testing specimens of hardened concrete from the structure—ASTM Designation: C42.
Cement content of hardened concrete—ASTM Designation: C85.

2. Other methods for computation of trial mixes

Many charts, rules, and tables have been devised for use in concrete mix computations. These devices, which are largely timesavers, range in accuracy from that of the method described in the recommended procedure to rough tables from which a mix may be chosen that may be safely used, in small work, without adjustment.

Nomographic chart—The nomograph illustrated in Fig. 1 is based on the same principles as the recommended procedure, being merely a graphic solution of these fundamentals. An explanation of the use of the chart follows—the illustration is the same as the one employed in section 6:

Water-cement ratio = 0.53 by weight.
Unit water content = 305 lb. per cu. yd.
Proportion of sand = 42 per cent.
Specific gravity: Sand = 2.65, coarse aggregate = 2.55.

Place a transparent straightedge across the nomograph—see line (1) on chart—to connect scale points for water-cement ratio of 0.53 and water content of 305.

Read off chart: Parts of aggregate by weight = 5.5 (for 2.65 sp. gr.)
Cement content = 1.53 bbl. per cu. yd. (6.12 sacks per cu. yd.)

Parts of sand by weight = 42 per cent of 5.5 = 2.3.

Parts of coarse aggregate by weight = 5.5 — 2.3 = 3.2 (for 2.65 sp. gr.) or $\frac{2.55}{2.65} \times 3.2 = 3.1$ (for 2.55 sp. gr.)

Trial mix = 1:2.3:3.1 by weight.

3. Other methods for adjustment of trial mixes

Short-cut methods for adjusting concrete mixes can be used with sufficient accuracy for most practical purposes.

(a) *The nomographic chart*—The nomographic chart illustrated in Fig. 1 can be used, either as shown or in any preferred variation. In the example which follows, the mix and required adjustment are the same as those employed in the recommended procedure.

Connect scale points on nomograph—line (2) on chart—for water-cement ratio of 0.50 and parts of aggregate of 5.5 (2.65 sp. gr.).

Read off chart: Water content = 292 lb. per cu. yd.

Connect scale points on nomograph—line (3) on chart—for water content of 292 and water-cement ratio of 0.53.

Read off chart: Parts of aggregate = 5.9 (for 2.65 sp. gr.)
Cement content = 1.46 bbl. per cu. yd. (5.84 sacks per cu. yd.)

Parts of sand = 42 per cent of 5.9 = 2.5.

Parts of coarse aggregate = 5.9 — 2.5 = 3.4 (for 2.65 sp. gr.) = $\frac{2.55}{2.65} \times 3.4 = 3.3$ (for 2.55 sp. gr.)

Adjusted mix: 1:2.5:3.3 by weight.

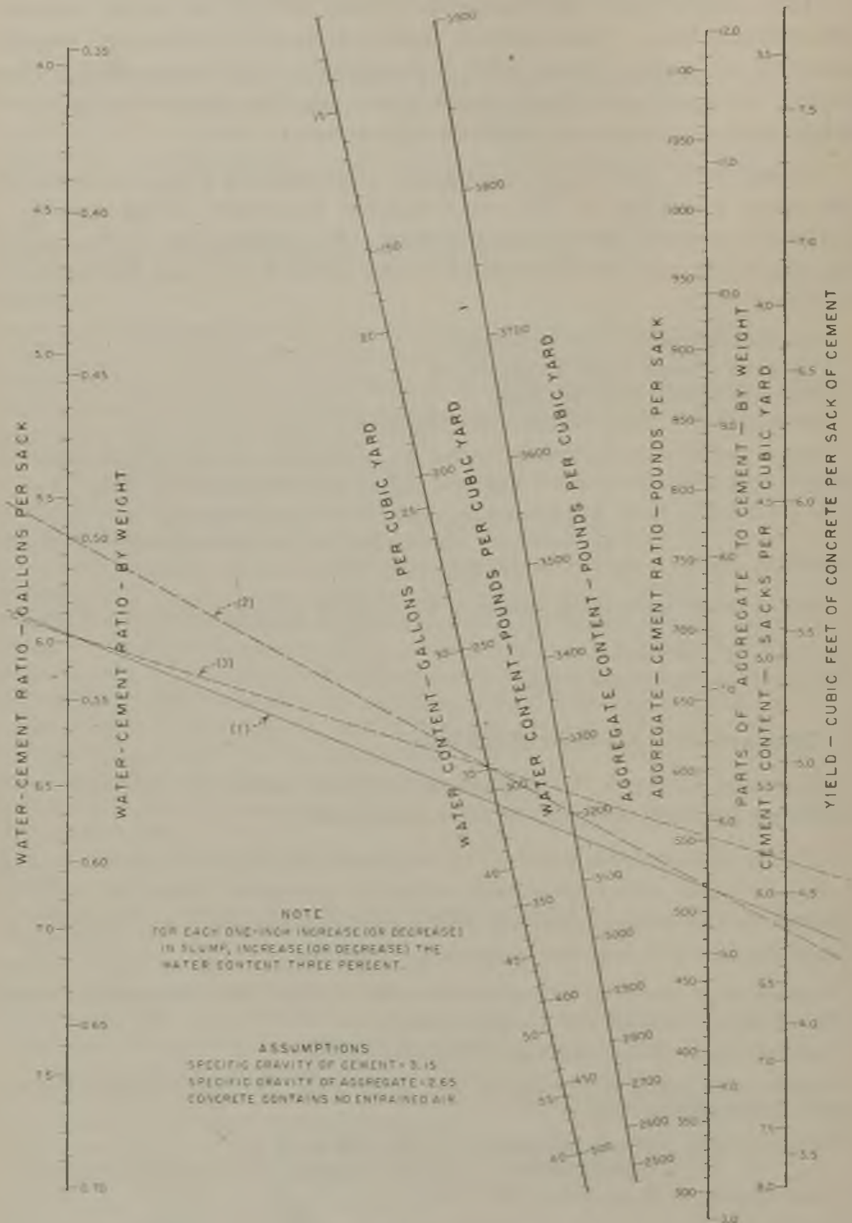

Fig. 1—Chart for design and adjustment of concrete mixes

(b) *Rules for adjustment of mixes*—For those who prefer a procedure for adjusting mixes that is not dependent on charts, absolute volume computations or detail tabulations, the rules in Table 8 may be found useful.

TABLE 8—RULES AND INCREMENTS FOR MIX ADJUSTMENTS
(Constant Aggregate Grading and Specific Gravity)

To Change	To Hold	Corresponding Adjustments				
		Slump	W/C By Weight	Unit Water Content	Total (1) Mix Parts By Weight	Cement (2) Content Bbl. per Cu. Yd.
CASE I						
W/C	Slump	Constant	Variable	Constant	*Directly proportional to W/C	Inversely proportional to W/C
This adjustment amounts to replacing aggregate with cement (or vice versa) in a unit volume of concrete						
CASE II						
Slump	W/C	1-in. increase 1-in. decrease	Constant Constant	+3% −3%	−0.25 +0.25	+0.04 −0.04
This adjustment amounts to replacing aggregate with cement-and-water paste (or vice versa) in a unit volume of concrete						
CASE III						
W/C	Mix Parts	1-in. increase 1-in. decrease	+0.02 −0.02	+3% −3%	Constant Constant	−0.01 +0.01
This adjustment amounts to replacing cement and aggregate with water (or vice versa) in a unit volume of concrete						
CASE IV						
% of sand by Weight	Slump and W/C	Constant	Constant	For each change of 1 in % of sand change water content 2.5 lbs. in same direction	Variable (4)	For each change of 1 in % of sand change cement content 0.01 bbl. in same direction

*For all practical purposes.

(1) Total mix parts equals total parts of aggregate and cement.

(2) Approximate cement content for unit weights shown in footnote (3.)

$$\text{Bbl. per cu. yd.} = \frac{(\text{wt. of concrete per cu. ft.})\ 27^{(3)}}{(\text{Total mix parts} + w/c)\ 376}$$

(3) The unit weight of concrete containing aggregate of 2.65 average specific gravity is approximately 148 lb. per cu. ft. for ¾-in. max. aggregate; 150 lb. for 1½-in. max; 152 lb. for 3-in. max.

If the specific gravity of the combined aggregate differs materially from the average value of 2.65, the computed cement content may be corrected by adding or subtracting 0.02 for each 0.05 increase or decrease, respectively in specific gravity.

(4) For each change of 3 in the percentage of sand, change the parts of sand 0.1, and the total parts of aggregate, in the opposite direction, 0.15, 0.20, 0.25, and 0.30 for ¾, 1½, 3, and 6-in. maximum aggregate sizes, respectively.

Application of these rules to the mix adjustment illustrated in section 7, is as follows:

Mix 1:2.3:3.1 by weight; W/C = 0.50.

To adjust the W/C to 0.53, without changing the slump or percentage of sand by weight, Case I, Table 8, would apply.

The new total mix parts $= 6.4 \times \frac{0.53}{0.50} = 6.8$, or 1 part cement to 5.8 parts of aggregate.

Parts of sand $= 5.8 \times \frac{2.3}{2.3 + 3.1} = 2.5$

Parts of coarse aggregate $= 5.8 - 2.5 = 3.3$.

Adjusted mix = 1:2.5:3.3.

Other practical uses for the relationships given in Table 8 will be readily apparent to the concrete technician or engineer.

4. Mixes for small jobs

For very small jobs, involving only a few batches of concrete, where time or personnel are not available to determine mixes in accordance with

TABLE 9—MIXES FOR SMALL JOBS

Maximum Size of Aggregate	Mix Designation	Approx. Sacks Cement per Cu. Yd. of Concrete	Pounds of Aggregate per 1-Sack Batch	
			Sand*	Coarse Aggregate
½-in.	A	7.0	245	170
	B	6.9	235	190
	C	6.8	235	205
¾-in.	A	6.6	235	225
	B	6.4	235	245
	C	6.3	225	265
1-in.	A	6.4	235	245
	B	6.2	225	275
	C	6.1	215	290
1½-in.	A	6.0	235	290
	B	5.8	225	320
	C	5.7	215	345
2-in.	A	5.7	235	330
	B	5.6	225	360
	C	5.4	215	380

*Weights are for dry sand. If sand is damp, increase weight of sand 10 pounds for one-sack batch, and if very wet, add 20 pounds for one-sack batch. For slag, use 85 per cent of coarse aggregate weights shown.

These mixes do not apply for lightweight aggregate.

Procedure: Select the proper maximum size of aggregate and then, using mix B, add just enough water to produce a sufficiently workable consistency. If the concrete appears to be undersanded use mix A, and if it appears to be oversanded use mix C.

the recommended procedure, the mixes in Table 9 will provide concrete that is amply strong, dense, and durable if the amount of water added at the mixer is never so large as to make the concrete sloppy. These mixes have been predetermined in conformity with the recommended procedure by assuming conditions applicable for the average small job using aggregate of average specific gravity.

Three mixes are given for each maximum size of coarse aggregate. (Table 4 may be used as a guide in selecting an appropriate maximum size of aggregate). Mix B, for each size of coarse aggregate is intended for use as a starting mix. If this mix happens to be oversanded, change to mix C; if it is undersanded, change to mix A.

It should be noted that the mixes listed in the table apply where the sand is dry, or appears to be dry. If the sand is moist, or very wet, make the corrections in batch weights described in the note at the foot of the table.

The approximate cement contents in sacks per cubic yard of concrete will be helpful in estimating cement requirements for the job. These are based on concrete that has just enough water in it to permit ready working in the forms without objectionable separation. The concrete should slide off a shovel—not run off.

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ACI Standard
Specifications for Concrete Pavements and Bases (ACI 617-44)*

Reported by ACI Committee 617

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SCOPE

1. Concrete pavement and base

These specifications apply to the construction of portland cement concrete pavement and base under normal conditions, including the preparation of the subgrade, and shall govern unless modified by special provisions to take into account unusual conditions of traffic, subgrade, drainage, exposure and other factors.

MATERIALS

2. Approval of sources of material supply

Portland cement, aggregates and water shall be furnished only from sources of supply approved by the engineer before shipments are started. The basis of approval of such sources shall be the ability to produce materials of the quality and in the quantity required.

3. Portland cement

(*a*) Cement shall conform to the requirements of the current American Society for Testing Materials Standard Specifications for Portland Cement (Designation C 150). Type I cement shall be supplied unless Type II (Moderate Heat of Hydration) or Type III (High Early Strength) is required by the special provisions.

(*b*) Cement shall be protected from the weather and against loss in handling or in transit. Either package or bulk cement may be used.

*Adopted as a Standard of the American Concrete Institute at its 40th Annual Convention, March 2, 1944 as reported by Committee 613; ratified by Letter Ballot July 28, 1944. (With editorial revisions from report as published ACI JOURNAL, Nov. 1943).

4. Aggregates

(*a*) Aggregates shall conform to the requirements of the current ASTM Standard Specifications for Concrete Aggregates (Designation C 33).

Note: It will be necessary to include limits in these specifications to meet local conditions.

Coarse aggregate shall be furnished in two separate sizes with the separation at the ¾-in. sieve when combined material graded from No. 4 to 1½ in. is required, and at the 1-in. sieve when combined material graded from No. 4 to 2 in. is required.

(*b*) In arranging for storage of aggregates, positive means shall be used to prevent the inclusion of foreign material. Aggregates shall not be placed upon the finished subgrade. Aggregates of different kinds and sizes shall be placed in different stock piles. Stock piles of coarse aggregates shall be built up in successive horizontal layers not more than 3 ft. thick. Each layer shall be completed before the next is started. Should segregation occur, the aggregates shall be remixed to conform to the grading requirements.

(*c*) Frozen aggregates or aggregates containing frozen lumps shall be thawed before use. Washed aggregates and aggregates produced or manipulated by hydraulic methods shall be allowed to drain for at least twelve hours before use. Stock piles or cars and barges equipped with weep holes are considered to offer suitable opportunity for drainiage.

5. Water

Water used in mixing or curing concrete shall be clean and free from injurious amounts of oil, salt, acid, vegetable or other substances harmful to the finished product. Sources of water shall be maintained at such a depth, and the water shall be withdrawn in such a manner (by enclosing pump intake, etc.), as to exclude silt, mud, grass or other foreign materials.

6. Reinforcement steel and accessories

(*a*) *Steel wire fabric.* Steel wire fabric reinforcement shall conform to the requirements of the current ASTM Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement (Designation: A 185).

(*b*) *Bar mats.* The steel in bar mats shall conform to the requirement of the current ASTM Standard Specifications for Bar or Rod Mats for Concrete Reinforcement (Designation: A 184). Members shall be of the size and spacing shown on the plans. All intersections of longitudinal and transverse bars shall be securely wired, clipped or welded together.

(*c*) *Dimensions of wire fabric and bar mats.* The width of fabric sheets or bar mats shall be such that, when properly placed in the work, the extreme longitudinal members of the sheet or mat will be located not less than 3 in. nor more than 6 in. from the edges of the slab. The length of fabric sheets or bar mats shall be such that, when properly placed in the work, the reinforcement will clear all transverse joints by not less than 2 in. nor more than 4 in. as measured from the center of the joint to the tip ends of the longitudinal members of the sheet or mat.

(*d*) *Bars.* Reinforcement bars shall conform to the requirements of the current ASTM Standard Specifications for Billet-Steel Bars for Concrete Reinforcement (Designation: A 15) or for Rail-Steel Bars for Concrete Reinforcement (Designation: A 16). Bars depending upon bond for their effectiveness shall be free from excessive rust, scale, or other substances which prevent the bonding of the concrete to the reinforcement.

(*e*) *Tie bars.* Tie bars shall be deformed steel bars conforming to the requirements of the specifications for reinforcement bars except that rail steel bars shall not be used where they are to be bent and restraightened.

(*f*) *Dowels and sleeves.* Dowels shall be plain round bars conforming to the requirements of the specifications for reinforcement bars.

When metal sleeves are used they shall cover the ends of the dowels for not less than 2 in. nor more than 3 in. The sleeve shall be closed at one end. It shall have a suitable stop to hold the end of the bar at least 1 in. from the closed end of the sleeve. It shall be of such rigid design that the closed end will not collapse during construction.

(*g*) *Chairs.* Chairs for holding tie rods in correct position while the concrete is being placed shall be of metal, slightly rounded and tapered at one end. The minimum dimensions shall be: Thickness 16 gauge (U. S. Standard Gauge 1893), length 12 in., width 1¾ in. measured along the metal.

(*h*) *Stakes.* Stakes used to support expansion joint fillers shall be channel- or U-shaped, at least ¾ in. wide and ⅜ in. deep and of metal not thinner than 16 gauge (U. S. Standard Gauge 1893). They shall be 15 in. long or longer if required to provide proper bearing support.

7. Subgrade paper

Subgrade paper shall conform to the requirements of the current American Association of State Highway Officials Standard Specification for Subgrade Paper, M 74.

8. Expansion joint filler

Expansion Joint Filler shall conform to the requirements of the current ASTM or AASHO Standard Specifications for Preformed Expansion Joint Fillers for Concrete.

9. Metal joint plate and pins

Plates for tongue and groove joints shall be steel or iron not thinner than 16 gauge, (U. S. Standard Gauge, 1893). Each section shall be a continuous strip of metal not more than 15 ft. long having a width ½ in. less than the depth of the pavement; it shall be provided with an end connection which will hold the ends of strips firmly together. Each section shall be of the specified cross section, and shall be punched for dowels or tie bars, and pins, as shown on the plans.

Pins shall be channel shaped, pressed out of sheet steel of not less than 12 gauge (U. S. Standard Gauge, 1893) and not less than 15 in. long.

10. Cover materials for curing

(*a*) *Burlap*. Burlap shall be made from jute or hemp and, at time of using shall be in good condition, free from holes, dirt, clay, or any other substance which interferes with its absorptive quality. It shall not contain any substance which would have a deleterious effect on the concrete. Burlap shall be of such quality that it will absorb water readily when dipped or sprayed and shall weigh not less than 7 oz. per square yard when clean and dry. Burlap made into mats may be used if care in handling is exercised to avoid marring the finished surface of the concrete.

(*b*) *Cotton mats*. Cotton mats for curing concrete shall conform to the requirements of the current AASHO Standard Specifications for Cotton Mats for Curing Concrete Pavements. (Designation M 73).

11. Testing materials

Materials shall be tested in accordance with methods referred to in the appropriate specifications, except as otherwise specified.

12. Flexural strength tests of concrete as basis of design

Flexural strength tests to be used as the basis for the design of concrete mixtures shall be carried out in accordance with the current ASTM Standard Method of Test for Flexural Strength of Concrete. (Laboratory Method Using Simple Beam with Third Point Loading, Designation C 78).

13. Flexural strength tests of concrete for field control

(*a*) Flexural tests of concrete specimens molded and cured in the field shall be made, whenever feasible, using the testing machine described in ASTM Method C 78. Field Cured Specimens should not be used as a basis for design of mixtures. If another type of testing machine is used, results obtained with it should be correlated with those obtained from the standard apparatus. Apparatus for making flexure tests of concrete shall be so designed as to incorporate the following principles:

(1) The distance between supports and points of load application shall remain constant for a given apparatus.

(2) The load shall be applied normal to the loaded surface of the beam and in such a manner as to avoid eccentricity of loading.

(3) The direction of the reactions shall, at all times during a test, be parallel to the direction of the applied load.

(4) The load shall be applied at a uniform rate and in such a manner as to avoid shock.

(5) The ratio of distance between point of load application and nearest reaction to the depth of the beam shall not be less than one.

Note: The directions of loads and reactions may be maintained parallel by judicious use of linkages, rocker bearings and flexure plates. Eccentricity of loading can be avoided by use of spherical bearings.

(*b*) *Molding, curing and marking.* Concrete for the field test specimens shall be secured in accordance with the current ASTM Method of Sampling Fresh Concrete (Designation: C 172) from the concrete deposited on the subgrade. The specimens shall be molded and finished as described in the current ASTM Method of Test for Flexural Strength of Concrete (Designation C 78). They shall be cured, as nearly as practicable, in the same manner as the pavement concrete. They shall be properly identified as to date of molding and location of pavement represented; weather conditions prevailing at the time of molding shall be noted.

(*c*) *Number of specimens.* At least two beams shall be made for each one thousand square yards of pavement.

14. Specific gravity and absorption of aggregates

(*a*) *Fine aggregate.* The bulk specific gravity and absorption of fine aggregate shall be determined in accordance with the current ASTM Standard Method of Test for Specific Gravity and Absorption of Fine Aggregates. (Designation C 128).

(*b*) *Coarse Aggregate.* The bulk specific gravity and absorption of coarse aggregate shall be determined in accordance with the current ASTM Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate. (Designation C 127).

15. Consistency

Consistency shall be determined in accordance with the current ASTM Standard Slump Test for consistency of concrete. (Designation C 143).

PROPORTIONS OF MATERIALS

16. Basis of proportions

The proportions of water, cement and aggregates shall be in accordance with *Proportions based on design for minimum strength* (Section 17) or in accordance with *Proportions based on uniform cement factor* (Section 18) as specified in the special provisions.

17. Proportions based on design for minimum strength

(*a*) The proportions of cement, fine aggregate, coarse aggregate and water to be used in the mix shall be determined by the Engineer, within the limits of Sections 17(b) and 17(c), by means of laboratory tests of the flexural strength of concrete made with aggregates from the same sources and of the same gradings as will be employed in the work and that portland cement which is found to produce the lowest strength concrete of any acceptable cement available for the work.

(*b*) The mixture determined upon shall produce workable concrete having a slump of 2 in. to 3 in. for unvibrated concrete, or ½ in. to 1½ in. for vibrated concrete, and a modulus of rupture at 14 days of not less than 550 psi as determined from specimens made, cured and tested in accordance with the current ASTM Method C 78.

(*c*) The resulting proportions shall be such that the mixing water, including free surface moisture on the aggregates but exclusive of moisture absorbed by the aggregates, shall not exceed 6 gal. per sack of cement for any individual batch in localities where the concrete will be subjected to severe freezing and thawing conditions. In no case shall the mixing water exceed 6½ gal. per sack of cement for any individual batch. The cement content shall be not less than 5 sacks per cubic yard.

(*d*) Unless otherwise specified in the special provisions the following requirements shall govern the contractural relations concerning proportions based on design for minimum strength:

(1) Upon request, the Engineer will furnish prospective bidders with information as to the proportions by weight required for aggregates from established sources available for use on the project. This information will also include the grading of the aggregates used in determining these proportions.

(2) Promptly after receipt of notice of award of the contract, the Contractor shall furnish the Engineer with the location, or locations of the source or sources of aggregates which he proposes to use. The proportions will be designated by the Engineer. Except as hereinafter provided the designated proportions shall govern as long as materials are furnished from the sources designated and as long as they continue to meet the requirements specified.

(3) If, during the progress of the work, the contractor proposes to use aggregates from approved sources other than those originally designed, the Engineer will designate the new proportions to be used.

(4) If satisfactory plasticity and workability are not secured using the proportions and aggregates originally designated, the engineer may alter such proportions. If such alterations change the designated cement factor originally fixed by 2 per cent or less, no adjustment in the amount paid the contractor shall be made. If such alterations change the designated cement factor by more than 2 per cent, the source and quality of the aggregates remaining the same, payment shall be adjusted for or against the contractor in whatever amount the total cost of materials, f.o.b. contractor's material yard, has been increased or decreased by more than 2 per cent. The calculation of the amount of such increase or decrease shall be based upon the designated cement factor and not on count of bags of cement used or of the batches where bulk cement is used.

18. Proportions based on uniform cement content

(*a*) The proportions herein specified have been shown by experience to give satisfactory results for materials meeting the requirements of these specifications. They are so fixed as to produce concrete of constant yield for all types of materials meeting the requirements of these specifications. The proportions of water, cement and saturated surface dry aggregates for the mixture shall be selected from Table 1, unless otherwise specified in the special provisions. To determine the pounds of saturated surface dry aggregate per bag of cement, multiply the factors given under Sand, Gravel, Crushed Stone, or slag by the bulk specific gravities of the aggregates to be used. Batch weights thus determined, shall be corrected to take into account the moisture condition of the aggregates as delivered to the measuring bin. If the aggregates contain more water than required for saturation the weight shall be increased accordingly; if they contain less water than required for saturation the weights shall be decreased accordingly.

(*b*) Mixture A shall be used when the concrete is to be compacted and finished with a standard finishing machine without vibration. Mixture B shall be used when the concrete is to be compacted and finished by vibration and it is desired to maintain the same water-cement ratio as when the standard finishing machine without vibration is used. Mixture C shall be used when the concrete is to be compacted and finished by vibration and where it is desired to maintain the same cement content as when the standard finishing machine is used.

(*c*) The ratio of fine to coarse aggregate may be adjusted, for different gradations within the limits of these specifications, to secure concrete of satisfactory plasticity and workability. During the progress of the work, the total weight of aggregate per bag of cement shall not be changed, except as necessary to compensate for differences in specific gravity, and except when concrete of satisfactory plasticity and workability cannot be made without exceeding the maximum net water content specified; under these latter circumstances the Engineer shall reduce the total weight of aggregate as computed from Table 1, by an amount sufficient to insure that the maximum net water content will not be exceeded. The Contractor shall not receive additional compensation for any extra cement which may be required by such adjustment.

MEASUREMENT AND HANDLING OF MATERIALS

19. Cement, aggregates, water

(*a*) Standard size sacks of cement as packed by the manufacturer shall be considered to weigh 94 lb. net. Bulk cement and cement from fractional sacks shall be weighed.

(*b*) When package cement is used, the cement shall be emptied from the sacks into the batch immediately prior to mixing. When bulk cement is used, satisfactory methods of handling and weighing shall be employed. A separate hopper shall always be so designed and operated that the

TABLE 1—PROPORTIONS BASED ON UNIFORM CEMENT CONTENT

Factors Used for Determining Weights of Saturated Surface-Dry Fine and Coarse Aggregate Per Bag (94 lb.) of Cement

Mixture	Cement Bags per Cubic Yard	Maximum Net Water Content Per Bag of Cement	Slump in Inches	Factor (F) x bulk specific gravity = lbs. of saturated surface dry aggregate per Bag of Cement								
				When Gravel Is Used as Coarse Aggregate			When Crushed Stone Is Used as Coarse Aggregate			When Slag Is Used as Coarse Aggregate		
				Sand	Gravel		Sand	Crushed Stone		Sand	Slag	
		Gal.			Fine Size	Coarse Size		Fine Size	Coarse Size		Fine Size	Coarse Size
				F	F	F	F	F	F	F	F	F
A	6.0	6.0	2–3	66	53	81	75	49	76	79	48	73
B	5.5	6.0	1–1½	66	64	96	75	60	91	79	59	88
C	6.0	5.5	1–1½	60	59	87	68	55	83	71	54	81

NOTE: Using the maximum allowable water content, the weights of Aggregates as determined by the above factors (when multiplied by the appropriate number of bags of cement per cubic yard plus the water and cement will produce a cubic yard of concrete. (If an amount of water less than the maximum is used the weights of aggregates will be adjusted to maintain the same minimum cement content as indicated.

quantity of cement for each batch will be maintained in a separate container so as not to come in direct contact with the aggregates.

(*c*) Aggregates shall be weighed. Each size of aggregate shall be weighed separately.

(*d*) The scales for weighing cement and aggregates shall be accurate within one-half of one per cent throughout the range of use. Operation shall be within a maximum allowable error of one per cent for cement and two per cent for aggregates.

(*e*) Mixing water may be measured by weight or by volume. The water measuring device shall be accurate to ½ of 1 per cent. Operation shall be required to be within a maximum allowable error of 1 per cent. When wash water is used as a portion of the mixing water for succeeding batches it shall be measured according to this requirement.

MIXING

20. Mixing at site or at central mixing plant

(*a*) The concrete shall be mixed in a batch mixer. When a drum mixer is used it shall conform to the requirements of the concrete mixer standards of the Mixer Manufacturers Bureau of the Associated General Contractors of America. If another type of mixer is used it shall be of a type satisfactory to the Engineer. The mixer shall be capable of combining the aggregates, cement and water into a thoroughly mixed and uniform mass within the specified time, and of discharging the mixture without segregation. Each batch of concrete shall be mixed for one minute or more after all materials, exclusive of the mixing water, are in the mixer drum. The batch shall be so charged into the mixer that some water will enter in advance of the cement and aggregate, and will continue to flow for a period which may extend to the end of the first one-third of the specified mixing time. The mixer shall rotate at the rate recommended by its manufacturer. Concrete shall be mixed only in quantities required for current use; any concrete which has set so that it cannot be placed properly shall not be used. Retempering of concrete which has partially set, by mixing with additional water, will not be permitted.

(*b*) The mixer shall be equipped with a suitable charging hopper, water storage, and a water-measuring device controlled from a case which can be kept locked. Controls shall be so arranged that the water can be started only while the mixer is being charged and so as to lock automatically the discharge lever until the batch has been mixed the required time after all materials are in the mixer. The entire contents of the drum shall be discharged after each charge has been mixed the required time. In case of mixing at the site suitable equipment for discharging and spreading the concrete on the subgrade will be provided. The mixer shall be cleaned at suitable intervals. The pick-up and throw-over blades in the drum shall be replaced when they have lost ten (10) per cent of their depth. The volume of the mixed material per batch shall not exceed the manufacturer's normal rated capacity of the mixer, exclusive of the overload. The manufacturer shall install a plate upon the mixer stating the rated capacity and the recommended revolutions per minute.

21. Ready mixed concrete

Ready mixed concrete shall be mixed and transported in accordance with the current ASTM Specifications for Ready Mixed Concrete (Designation C 94).

HIGH EARLY STRENGTH CONCRETE

22. Methods of production

High early strength concrete shall be produced by one of the following methods, or any combination thereof, as specified in the special provisions.

(*a*) By the use of high-early strength portland cement Type III in lieu of normal portland cement (Type I or Type II).

(*b*) By the use of additional normal portland cement (Type I or Type II) in which case the total amount of cement shall not exceed seven bags of cement per cubic yard of concrete.

(*c*) By the use of calcium chloride as one of the ingredients of the concrete in an amount between one and two pounds of calcium chloride per sack of cement. Calcium chloride may be added either dry or in solution. When used in solution, it is convenient so to proportion the solution that one quart contains one pound of calcium chloride.

High early strength concrete shall meet the requirements of these specifications for portland cement concrete.

SUBGRADE PREPARATION

23. Grading stakes

Grading stakes shall be protected by the Contractor. Stakes which become disturbed shall be reset at the Contractor's expense.

24. Disposal of excavated material

Material removed in excavation shall be used in fills on the job, or otherwise disposed of as provided on the plans or in the special provisions. If excavation is in excess of fill, the excess material shall be disposed of by the Contractor at his expense.

25. Excavation below the subgrade

Where the work is in cut, if the Contractor excavates below the surface of the subgrade shown on the plans, he shall refill with approved material compacted as provided for filling and compaction at his expense.

26. Borrowed material

If filling is in excess of excavation, the contractor shall secure the necessary material from borrow pits indicated on the plans. If no such location is indicated or if the amount in the indicated location is insufficient he shall furnish material satisfactory to the Engineer. Payment shall be made for such material at an agreed-upon price per cubic yard.

27. Removal of sod

Any sod within the limits of the fill shall be completely removed to a depth of at least six inches.

28. Filling and compacting

All fills shall be made in layers not more than 9-in. thick which shall be thoroughly compacted by means of a smooth roller, pneumatic tired roller, or a tamping, or sheepsfoot roller. Smooth rollers shall be self-propelled and weigh not less than six tons nor less than 250 lb. per in. width of tread.

Pneumatic tired rollers shall be towed by mechanical equipment sufficiently powered to maintain an even rolling speed. The roller shall be capable of delivering at least 200 lb. per in. of tire tread, and an internal pressure of 4.5 psi shall be maintained.

Tamping or sheepsfoot rollers shall consist of metal rollers, drums or shells surmounted by metal studs with tamping feet projecting not less than 6 in. from the surface of the roller, drum or shell. The rollers shall be of such weight that the load upon each tooth, when any one row of teeth is supporting the whole weight of the roller, shall not be less than 1,250 lb. Each tamping roller shall consist of two sections and the length of each section shall not be less than four feet.

Inaccessible places, and places where rolling is not practicable on account of possible damage to subsurface structures, shall be thoroughly compacted with mechanical tampers capable of striking a blow equivalent to at least 250 lb. per sq. ft. The dead weight of any mechanical tamper shall be in excess of 40 lb. per sq. ft. of bearing surface. Payment for compacting layers in fills by rolling or tamping shall be included in the contract price per cu. yd. for "Grading."

29. Removal of unsuitable material

Fill material shall not contain trash, brick, broken concrete, tree roots, sod or cinders, and all unsuitable material shall be removed to a depth of at least 18 in. below the finished surface of the subgrade. The Contractor will be paid for this work at the prices bid for grading. and materials used. When unsuitable material is removed from the subgrade the surface shall be brought to the correct elevation with approved material placed and compacted as specified herein. Payment for this work will be made at the contract prices for grading and materials.

30. Removing and grubbing for stumps

Where fills higher than 10 ft. are to be made the ground shall be cleared of all underbrush and trees. Where fills are less than 10 ft. high, all underbrush, trees, tree stumps and saplings shall be grubbed and entirely removed.

31. Solid rock

Solid rock (boulders of one cubic yard or more in content, or ledges in their original bed) shall be removed six inches below grade and shall be paid for at the contract price per cubic yard of solid rock.

32. Sidewalk grading

Sidewalk grading included in the contract shall be done at the same time the roadway is rough graded.

33. Payment for grading

The contract prices for grading shall include the cost of excavating and filling, clearing and grubbing, excavating and removing unsuitable materials as required, shaping the subgrade to the prescribed lines and grades, sloping cuts, intersections and approaches, and rolling or tamping below the subgrade in the case of fills; and in connection with street construction, sloping and filling between the curb and sidewalk pavement, and grading and shaping of sidewalk spaces where shown on the plans. The work shall be estimated to the grades and slopes shown on the plans.

34. Rolling the subgrade

The subgrade shall be prepared by compacting with a self-propelled roller weighing not less than 6 tons. Places inaccessible to the roller shall be compacted with mechanical tampers capable of striking a blow equivalent to at least 250 lb. per sq. ft. The dead weight of any mechanical tamper shall be more than 40 lb. per sq. ft. of bearing surface. If the sub-grade is disturbed after acceptance it shall be reshaped and compacted without additional compensation. Payment for compacting subgrade shall be included in the contract prices for grading.

35. Wetting the subgrade

Concrete shall be placed on a moist subgrade except where subgrade paper is required by the special provisions. The subgrade shall be thoroughly wetted a sufficient time in advance of the placing of the concrete to insure that there will be no puddles or pockets of mud when the concrete is placed. The degree of saturation shall depend upon the characters of materials in the subgrade. The subgrade shall not be allowed to dry out before the concrete is placed.

36. Placing subgrade paper

When specified in the special provisions the subgrade after it has been shaped and compacted, shall be covered with subgrade paper. Adjacent strips of paper shall lap 4 in. and ends shall lap 12 in. After being placed on the subgrade, the paper shall be kept reasonably intact and shall not be hauled over nor have unnesessary holes punched through it.

37. Testing and correcting subgrade

Immediately prior to placing concrete, the subgrade shall be tested for conformity with the cross section shown on the plans by means of an approved template riding on the side forms. If necessary, material shall be removed or added, as required, to bring all portions of the subgrade to the correct elevation. It shall then be thoroughly compacted and again tested with the template. Concrete shall not be placed on any portion of the subgrade which has not been tested for correct elevation.

FORMS

38. Material, dimensions, setting

Side forms shall be of metal of a cross section approved by the Engineer. The height of the forms shall be equal to the specified edge thickness of the concrete. Building up of forms shall not be permitted. Flexible or curved forms of proper radius shall be used for curves of 100 ft. radius or less. Forms shall be of ample strength, not less than $\frac{7}{32}$ in. thick. They shall be provided with adequate devices for secure setting so that when in place they shall withstand, without visible springing or settlement, the weight, impact and vibration of the finishing machine. In no case shall base width be less than 8 in. for forms 8 in. or more in height. The flange braces must extend outward on the base not less than two-thirds ($\frac{2}{3}$) the height of the form. The forms shall be free from warp, bends, or kinks. Any variation of the top of a form from its true plane when tested with a 10 ft. straight edge shall not be greater than $\frac{1}{8}$ in. in 10 ft. and any variation laterally when tested with a 10 ft. straight edge shall not be greater than $\frac{1}{4}$ in. in 10 ft.

39. Grade and alignment

The alignment and grade elevations of the forms shall be checked and the necessary corrections made by the contractor immediately before placing the concrete. When any form has been disturbed or any subgrade thereunder has become unstable, the form shall be reset and rechecked.

40. Base support

The subgrade under the forms shall be compacted and cut to grade so that the form when set shall be uniformly supported for its entire length and at the specified elevations. Subgrade found to be below established grade at the form line shall be filled to grade in lifts of $\frac{1}{2}$ in. or less for 18 in. on each side of the base of the form and thoroughly re-rolled or tamped. Imperfections and variations above grade shall be corrected by tamping or by cutting as necessary. In exceptional cases the Engineer may require suitable stakes to be driven to the grade of the bottom of the forms to afford additional firmness.

41. Staking forms

Forms shall be staked with three or more pins for each 10 ft. section. A pin shall be placed adjacent to each side of every joint if required. Form sections shall be tightly joined by a locked joint free from play or movement in any direction.

42. Advanced setting

Where practicable forms shall be set for at least 300 ft. in advance of the point where concrete is being placed. Forms shall remain in place at least 12 hours after the concrete has been placed and shall be cleaned and oiled each time they are used.

INSTALLATION OF JOINTS AND REINFORCEMENT

43. General

(*a*) Longitudinal and transverse joints shall be constructed as shown on the plans.

(*b*) Transverse joints shall be expansion joints, contraction joints, or construction joints. Unless other locations are shown on the plans longitudinal joints shall be along or parallel to the center line of the pavement. Transverse joints shall be at right angles to the center line and shall extend the full width of the pavement. All joints shall be per pendicular to the finished grade of the pavement and, when tested with a 10 ft. metal straight-edge placed at right angles to the joint, the surfaces of adjacent slabs shall not vary from each other by more than ⅛ in. Joints shall be finished as shown on the plans or as indicated in the special provisions.

(*c*) Especial care shall be taken to finish the subgrade accurately to the required cross-section, at the locations where transverse joints are to be installed. If, for any reason, the subgrade is trimmed too low, or if there are any open spaces beneath the joint, the joint material shall be removed, the subgrade backfilled and firmly tamped, and the joint reset.

(*d*) The edges of the pavement at joints shall be rounded to the radius shown on the plans. The joints shall be continuous from form to form, from joint to joint, or from form to edge of slab, as the case may require. The final horizontal position of transverse joints shall be at right angles to the center-line of the pavement on tangents and radially on curves. Longitudinal joints and reinforcement, except dowels, shall not extend through any transverse joints.

44. Longitudinal joints

(*a*) Tie bars shall be placed across longitudinal joints as shown on the plans. They shall be held in position, by chairs or other supports.

(*b*) Longitudinal "metal strip" joints shall be formed by installing a metal parting strip of the gage, shape and dimensions shown on the plans, to be left permanently in place. The metal strip shall be held securely in place, true to line and grade by suitable steel pins, which may be either channel shaped or round bars, spaced at intervals that average not less than 3 ft. and in no case more than 4 ft. The minimum length of metal strips shall be 10 ft. and adjoining sections shall be securely fastened by lapping and pinning, by means of a slip joint, or other approved method. The Contractor shall furnish an approved gage to ride on the side forms for checking the position of the parting strip before concrete is placed against it.

(*c*) Longitudinal "dummy" joints shall be formed by a groove or cleft in the top of the slab of the dimensions shown on the plans. The groove made in the soft concrete by a suitable tooling device, shall extend vertically downward from the surface to at least one third the depth of slab and shall be true to line. When the joint is of the poured type, the groove, as soon as possible after its completion, shall be cleaned and poured full of approved sealing material. When the joint is of the premolded type, strips of premolded filler shall be inserted in the groove immediately after it is formed.

(*d*) Longitudinal construction joints (i.e. joints between slabs placed separately) shall be formed as shown on the plans or as indicated in the special provisions. In forming these joints the contact edge (or edges) of the previously completed slab (or slabs) shall be painted with a heavy coat of bituminous material before the concrete of the adjacent slab is placed, unless a premolded joint filler is required and used between the slabs. In such cases the joint shall be trimmed and sealed as required for transverse expansion joints.

45. Expansion joints at structures

Expansion joints shall be formed about all structures and features projecting through, into, or against the pavement. Unless otherwise indicated on the plans, such joints shall be not less than ¼ in. thick and shall be of the premolded type.

46. Transverse premolded expansion joints

(*a*) Transverse joints using premolded expansion material shall be formed during the placing of the concrete. The methods of construction shall be such that the joints will extend to the full depth and width of a slab. The finished joint shall be true to the transverse line prescribed with an allowable variation of ¼ in. in the width of one traffic lane.

(*b*) Transverse premolded expansion joints shall be formed by securely staking an approved "installing bar" or installing device perpendicular to the proposed surface of the pavement. The installing bar shall be of substantial metal plate and shall have a length one-half inch less than the required width of the slab and shall be cut to the required depth and crown of the slab. It shall be securely staked in position so that the top edge, unless otherwise provided on the plans, will be uniformly ¼ in. below the pavement surface. The lower edge shall be cut to conform to the prescribed cross-section of the subgrade. The installing bar shall be slotted from the bottom as necessary to permit the installation of the required dowels. Suitable means shall be provided on the bar for facilitating its removal. Header boards, sheet metal holders or other devices used in lieu of the installing bar shall be subject to approval by the Engineer. The joints shall be protected against damage until they are installed in the work. Joints damaged during transportation, or by careless handling, or while in storage shall be replaced or repaired by the Contractor. Repaired joints shall not be used until they have been approved by the Engineer.

(*c*) The designated premolded joint filler shall be appropriately punched to the exact diameter and at the locations of the dowels. It shall be furnished in lengths equal to one-half the designated width of the slab. Where more than one section is used in a joint, they shall be securely laced or clipped together. The premolded joint filler shall be placed on the side of the "installing bar" nearest the mixer. The bottom edge of the filler shall extend downward to or slightly below the bottom of the slab, and the top edge, unless otherwise prescribed, shall be held about one-half inch below the surface of the pavement in order to allow the finishing operations to proceed continuously. The top edge of the filler shall be protected while the concrete is being placed, by a metal channel cap of at least ten gage material, having flanges not less than 1½ in. deep. The installing device may be designed with this cap self-contained.

47. Transverse metal strip joints

Transverse "metal strip" contraction joints shall be formed during the placing of the concrete by installing a metal parting strip to be left in place. This strip shall conform to the requirements for type, gage, shape, and dimensions shown on the plans or indicated in the special provisions and shall be securely staked in place. This strip shall be temporarily capped with a metal channel cap. The dowel assembly and the method of placing it shall be as indicated for transverse expansion joints, except that sleeves or caps on dowels will not be required. Concrete shall be deposited as for transverse expansion joints. After the longitudinal floating has been completed but before the surface is finished the metal cap shall be removed and the concrete edged, and the joint sealed as required for expansion joints.

48. Transverse weakened plane joints

Transverse joints of the weakened plane or "dummy" type shall be constructed in a manner similar to that provided for dummy joints for longitudinal joints, except that such joints shall be provided with slip dowels or other load transfer devices of the type, size, and arrangement shown on the plans.

49. Transverse construction joints

Unless other prescribed joints occur at the same points, transverse "construction" joints shall be made at the end of each day's run or where interruption of more than 30 min. occurs in the concreting operations and the length of pavement laid from the last joint is more than 10 ft. Tie bars ½ in. in diameter and 3 ft. in length shall be placed at intervals of 2½ ft. across all transverse construction joints.

50. Transverse weakened plane contraction joints in pavement base

Concrete bases shall be provided with expansion and contraction joints as shown on the plans. Unless otherwise shown on the plans contraction joints in bases may be made by forming a cleft or groove in the upper portion of the slab either by installation of subgrade paper, or other approved water-proof material, or by means of an installing bar or device used to form the cleft or groove. The installing bar shall be designed to remain straight and true during operation. The groove shall extend across the full width of the slab in a straight line and shall extend vertically downward from the surface for at least one-half the depth of the slab. The groove shall be formed before the concrete has taken an initial set and in such a manner that the finished concrete base shall not be unduly disturbed. Reinforcement shall not extend across weakened plane joints.

Note: For bases other than those laid monolithicly (such as brick vibrated into fresh concrete) with the surfacing material, it is especially important to reduce the interval between joints by means of closely spaced contraction joints so as to control the amount of joint opening (which may extend through the surface course) due to shrinkage and contraction. Experience indicates that the best results are obtained when the spacing of such joints does not exceed 20 ft. Preferably the spacing should not exceed 15 ft.

51. Load transfer devices

(*a*) Dowel bars or some other approved type of load transfer device shall be placed across all transverse joints in the manner shown on the plans. They shall be placed at the approximate center of the slab depth. Dowel bars shall be held rigidly in horizontal and vertical alignment either by suitable holders to be left permanently in place, or they shall be installed as preassembled units wherein the dowels are held in proper alignment by spacer bars welded or otherwise firmly secured to the fixed ends of the dowels. A tolerance of one in 36 from correct alignment for each dowel, and one in 48 from any adjacent dowel, will be permitted.

(*b*) Supporting stakes, when used, shall be located near the ends of the dowel bars. They shall not be attached to the spacer bars, nor shall they be placed to support the dowel bars between the spacer bar and the expansion joints. They shall be left permanently in place.

(*c*) The free end of each dowel bar shall be painted with one coat of red lead or basic sulphate blue lead paint at the site of the work. When the paint has dried, the free end of each bar shall be thoroughly coated with heavy oil immediately before it is placed in position. The free end of each bar for expansion joints shall be provided with a close fitting dowel sleeve.

(*d*) When a load transfer device other than a dowel bar is used it shall be of the type, size, and spacing shown on the plans, and shall be installed in a manner meeting the approval of the engineer.

52. Installation of joints

(*a*) If the paving mixer is operated from the shoulder, the joints shall be set immediately after the final testing of the subgrade. If the paving mixer is operated from the subgrade, the joints shall be set immediately after it moves forward, so as to permit as much time as possible for proper installation.

(*b*) The assembled joint shall be put in place on the prepared subgrade. It shall be placed at right angles to the centerline of the pavement. The top of the joint shall be set at the proper distance below the pavement surface and the elevation checked by a properly designed templet. On widened curves, the longitudinal center joint shall be placed so that it will be, as nearly as possible, equidistant from the edges of the slab. The joint shall be set to the required line and grade and shall be securely held in the required position by stakes or an approved installing device or both during the placing and finishing of the concrete. Joints shall be installed so that the concrete pressure will not disturb their alignment. The joints shall be vertical and no joint shall deviate more than one-fourth inch in horizontal alignment either way from a straight line. If joints are constructed in sections, there shall be no offsets between adjacent units. Dowel bars shall be checked for exact position and alignment as soon as the joint is staked in place on the subgrade and the joint shall be tested to determine whether it is firmly supported. Any joint not firmly supported shall be reset.

53. Placing reinforcement

(*a*) Reinforcing steel, when placed in the work, shall be free from dust, dirt, scale, or other foreign matter, and rust of such degree of development as to impair bond of the steel with the concrete.

(*b*) When bar assemblies are shown on the plans, the reinforcement bars shall be firmly fastened together at all intersections. Adjacent ends shall lap not less than 30 diameters.

(*c*) Where bars are fabricated into mat form by positive welding at all intersections, the lap may be of such length as will permit cross bars to overlap each other by at least 2 in. The same requirements apply to end laps and side laps.

(*d*) Steel fabric sheets shall be lapped and shall clear all edges of the slab, as shown on the plans. Where steel fabric is used, the concrete shall be struck off by means of a template at the indicated depth of the reinforcing below the finished surface of the slab. The fabric reinforcement shall then be placed directly upon the concrete after which the balance of the required concrete shall be placed above it.

(*e*) Where sheets of wire mesh or bar mats are required to be lapped, adjacent sheets or mats shall be tied so as to maintain the required lap during placement of the concrete.

(*f*) If shown on the plans, marginal bars shall be placed on chairs or supports, to insure that the bars will be in correct position after the concrete is placed. They shall be given one coat of red lead or of basic sulphate blue lead paint. At the time the marginal bars are placed, the paint shall be dry and hard. After being placed in position, the marginal bars shall be coated with heavy oil.

(*g*) Displacement of reinforcement during concreting operations shall be prevented.

PLACING AND FINISHING CONCRETE

54. General

(*a*) Concrete shall be distributed to such depth, above grade, that when consolidated and finished, the specified slab thickness will be obtained at all points and the surface will not be below the grade specified for the finished surface at any point.

(*b*) The concrete shall be deposited on the subgrade in such manner as to require as little rehandling as possible. It shall be thoroughly consolidated against and along the faces of the forms. Necessary hand spreading shall be done with shovels, not with rakes. Workmen shall not be allowed to walk in the concrete with boots or shoes covered with earth or other foreign substances.

(*c*) Concrete shall be placed only on subgrade which has been prepared as specified and approved. At all times during operations, at least 300 ft. of subgrade shall have been prepared ahead of the mixer. Concrete shall not be placed on a frozen subgrade. No concrete shall be placed around manholes or other structures until they have been brought to the required grade and alignment.

(*d*) Pavement less than 30 ft. wide may be constructed either to its full width in a single construction operation or in lanes, unless one or the other method is expressly stipulated on the plans. Pavement more than 30 ft. wide shall not be constructed in a single operation. When pavement is constructed in separate lanes, the junction line shall not deviate from the true line shown on the plans by more than ½ in. at any point.

(*e*) Retempering concrete by adding water or by other means will not be permitted.

55. Placing and finishing concrete at joints

(*a*) Concrete shall be deposited on the subgrade as near to the expansion and contraction joints as possible without touching them. It shall then be shoveled against both sides of the joint simultaneously, maintaining equal pressure on both sides. It shall be deposited to a height of approximately two inches more than the depth of the joint, care being taken that it is worked under the load transfer devices. The concrete shall not be dumped from the discharge bucket of the mixer directly upon or against the joints, nor shall it be shoveled or dropped directly on top of the load transfer devices. In placing the concrete, against expansion and contraction joints and in operating a vibrator adjacent to them, workmen shall avoid stepping upon or disturbing in any way the joints or load transfer devices, either before or after they are covered with concrete.

(*b*) The concrete adjacent to the joint shall be compacted with a vibrator inserted in the concrete and worked along the entire length and on both sides of the joint. The vibrator shall not come in contact with the joint, the load transfer devices, or the subgrade. If any of the dowel bars are displaced, they shall be realigned before the finishing machine passes over them.

(*c*) After the concrete has been vibrated, the finishing machine shall be moved forward until the front screed is approximately eight inches from the joint. Segregated coarse aggregate shall be removed from both sides of and off of the joint. The screed shall be lifted and brought directly above the joint, set upon it, and the forward motion of the finishing machine shall be resumed. When the second screed is close enough to permit the excess mortar in front of it to flow over the joint, it shall be lifted and carried over the joint. Thereafter, the finishing machine may be run over the joint without lifting the screeds, provided there is no segregated coarse aggregate immediately between the joint and the screed or on top of the joint.

(*d*) After the concrete has been placed on both sides of the joint and struck off, the installing bar or channel cap shall be slowly and carefully withdrawn leaving the premolded filler in place. After the installing bar or channel cap is completely withdrawn the concrete shall be carefully spaded and additional freshly mixed concrete worked into any depressions left by the removal of the installing bar. The installing bar shall be cleaned and reoiled prior to each installation of a joint.

Immediately after all finishing operations, including brooming, have been completed and before the concrete has taken its initial set, it shall be edged adjacent to all expansion and contraction joints. Care shall be used to remove any concrete which may be over the premolded joint material. The edging tool shall be so manipulated that a well-defined, continuous radius is produced and a smooth, dense mortar finish obtained. The edging tool shall not be tilted while being manipulated.

After the removal of the side forms, the ends of premolded transverse joints at the edges of the pavement shall be carefully opened for the entire depth of the slab, and in the case of air cushion joints any concrete that has been deposited over the end closure shall be removed, care being taken not to injure the ends of the joint. After the curing period and before the pavement is opened to traffic, premolded joints shall be sealed or topped out, leaving a neat uniform strip of an approved filler material.

56. Finishing methods

(*a*) *Machine finishing.* The concrete as soon as placed shall be struck off and screeded by an approved finishing machine to the crown and cross-section shown on the plans and to an elevation slightly above grade so that when properly consolidated and finished the surface of the pavement will be at the exact grade elevation indicated on the plans and free from porous places.

The finishing machine shall be of the screeding and troweling type, equipped with two independently operated screeds, designed and operated both to strike off and to consolidate. The machine shall go over each area of pavement as many times and at such intervals as is necessary to give the proper compaction and to leave a surface of uniform texture, true to grade and crown. Excessive operation over a given area shall be avoided. The last trip for a given area shall be a continuous run of at least 40 ft. The tops of the forms shall be kept clean by an effective device attached to the machine and the travel of the machine on the forms shall be maintained true without lift, wobbling, or other variation tending to affect the precision of finish. The finishing machine shall be of ample strength to withstand severe use and shall be fully and accurately adjustable for loss of crown or other derangement due to wear.

During the first pass of the finishing machine a uniform ridge of concrete at least 3 in. deep shall be maintained ahead of the front screed for its entire length. Except when making a construction joint, the finishing machine shall not be operated beyond that point where the above described surplus can be maintained ahead of the front screed.

(*b*) *Hand finishing.* Where hand finishing is permitted the concrete shall be struck off and consolidated by means of a metal shod screed to the crown and cross-section shown on the plane and to such an elevation above grade that when consolidated and finished, the surface of the pavement will be at the required elevation. The screed shall be moved forward with a combined longitudinal and transverse motion, moving always in the direction in which the work is progressing and so manipulated that neither end is raised from the side forms during the strike-off process.

(*c*) *Vibrated finishing.* When vibrated finishing is required, by the special provisions, the finishing machine shall be equipped for applying high frequency vibration to the upper surface of the concrete in accordance with the requirements for either of the following types. The particular type selected by the contractor shall be subject to approval of the Engineer. The vibratory units shall be synchronized and shall operate at a frequency of not less than 3,500 cycles per minute.

1. Vibrating units mounted directly on the screeds. This type shall consist of two independently operated screeds. The front screed shall be equipped with not less than one vibrating unit for each 7½ ft. length or portion thereof of vibratory screed. The front screed shall be not less than 15 in. wide and shall be equipped with a bull-nose front edge having a radius of not less than 2 in.

2. Vibrating pan mounted independently of the screeds. This type shall consist of two independently operated screeds together with an independently operated vibratory pan (or pans). The pan shall be mounted in such a manner as not to come in contact with the forms. It shall rest directly on the concrete and shall be so adjusted as to produce uniform vibration over the entire width of pavement surface. The pan shall be equipped with not less than one unit for each 7½ feet of length or portion thereof of vibrating pan. The screeds shall be capable of operating in a position that will strike off the concrete at a sufficient height above the top of the forms to allow for proper compaction with the vibratory pan.

3. Internal vibrators. Internal vibrators may be approved for use with the standard finishing machines if specified in the special provisions.

(*d*) *Floating.* As soon as possible, after the concrete has been struck off and consolidated, it shall be further smoothed and consolidated by means of a longitudinal float of a suitable design approved by the Engineer. In this operation the longitudinal float shall be worked with a sawing motion, while held in a floating position parallel to the road centerline and passed gradually from one side of the pavement to the other. Movements ahead along the centerline of the road shall be in successive advances of not more than one-half the length of the float.

(*e*) *Straightedging.* After the longitudinal floating has been completed and the excess water removed, but while the concrete is still plastic, the slab surface shall be tested for trueness with a 10 ft. straightedge swung from handles 3 ft. longer than one-half the width of the slab. The straightedge shall be held in successive positions parallel to the road centerline in contact with the surface and the whole area gone over from one side of the slab to the other. Advance along the road shall be in successive stages of not more than one-half length of the straightedge. Any depressions found shall be filled immediately with freshly mixed concrete, struck off, consolidated and refinished. High areas shall be cut down and refinished. The straightedge testing and refloating shall continue until the entire surface is found to be free from observable departures from the straightedge and the slab has the required grade and crown.

(*f*) *Belting.* After straightedging when most of the water sheen has disappeared and just before the concrete becomes non-plastic, the surface shall be belted with a two-ply canvas belt not less than 8 in. wide and at least 3 ft. longer than the width of the slab, or with an approved wooden belt. Hand belts shall have suitable handles to permit controlled uniform manipulation. The belt shall be operated with short strokes transverse to the road centerline and with a rapid advance parallel to the centerline.

(*g*) *Brooming.* As soon after belting and after the surplus water has risen to the surface, the pavement shall be given a broom finish with an approved steel or fiber broom, not less than 18 in. wide. The broom shall be pulled gently over the surface of the pavement from edge to edge. Adjacent strokes shall be slightly overlapped. Brooming shall be perpendicular to the center line of the pavement and so executed that the corrugations thus produced will be uniform in character and width, and not more than ⅛ in. deep. The broomed surface shall be free from porous spots, irregularities, depressions and small pockets or rough spots such as may be caused by accidentally disturbing particles of coarse aggregate, embodied near the surface. Brooming will not be required for concrete bases.

(*h*) *Edging.* After belting and brooming have been completed, but before the concrete has taken its initial set, the edges of the slab shall be carefully finished with an edger of the radius required by the plans.

(*i*) *Final surface test.* The contractor will be held responsible for the correct alignment, grade, and contour specified. Any spots higher than ⅛ in. and not higher than ¼ in. for concrete pavements and higher than ¼ in. for concrete bases but not higher than ⅜ in. above the correct surface as shown by the 10 ft. straightedge, shall be ground to the required surface by the contractor at his own expense. Where deviation exceeds the foregoing limits the pavement slab shall be removed and replaced by the contractor at his own expense, as directed by the engineer.

57. Cold weather concreting

(*a*) Except by specific written authorization, concrete placing shall cease when the descending air temperature in the shade and away from artificial heat falls below 40 F. It shall not be resumed until the ascending air temperature in the shade and away from artificial heat rises to 35 F.

(*b*) When concreting is permitted during cold weather the temperature of the mixed concrete shall be not less than 60 F. nor more than 100 F. at the time of placing in the forms. The aggregates or water or both may be heated. The aggregates may be heated by steam or dry heat prior to being placed in the mixer. The water shall not be hotter than 175 F.; aggregates shall not be used which are hotter than 150 F.

(*c*) When concrete is being placed during cold weather and the air temperature may be expected to drop below 35 F., a supply of straw, hay grass or other suitable blanketing material shall be provided along the line of the work. At any time when the air temperature may be expected to reach the freezing point during the day or night the material so provided shall be spread over the concrete to a sufficient depth to prevent freezing of the concrete. Such protection shall be maintained for at least five days. If required by the Engineer, concrete less than 24 hours old shall also be covered by approved canvas or similar enclosures and devices capable of maintaining the temperature within the concrete at 50 F. or higher. Concrete injured by frost action shall be removed and replaced at the Contractor's expense.

58. Lighting conditions

When the natural light is insufficient for proper work, operations shall cease unless approved artificial lighting is provided.

CURING

59. Preliminary curing period

The concrete shall be covered with two thicknesses of wet burlap weighing not less than 7 oz. per sq. yd., cotton mats, or other approved material of highly absorptive quality, immediately after final finishing of the pavement surface. The material shall be kept saturated by spraying and shall remain in place for at least 12 hours.

60. Final curing

(*a*) For completion of the curing the burlap. cotton or other mats may be left in place and kept saturated for 72 hours, or they may be removed at the end of the preliminary curing period and the concrete surface protected by keeping the surface covered with water (ponding) for three days after placing of the concrete; or by a one-inch layer of thoroughly wet earth, or sand, or a six inch layer of thoroughly wet straw, hay or similar material maintained on the surface of the concrete and kept thoroughly wet for three days after placing of the concrete. Other methods of final curing may be used if approved by the Engineer. The sides of concrete slabs exposed by the removal of forms shall be protected immediately after the removal of the forms in such a manner as to provide these surfaces with a curing treatment equivalent to that provided by the method prescribed for the surface.

(*b*) Forms shall not be removed from freshly placed concrete until it has set for at least 12 hours.

MISCELLANEOUS

61. Pavement thickness

(*a*) The thickness of the pavement shall be determined by measuring the lengths of drilled concrete cores according to the procedure of the current ASTM Tentative Method C-174-42T. At such points as the Engineer may select, in each 1,000 lin. ft. of pavement, two or more cores shall be taken and measured. The average thickness of each mile of slab, or fractional mile, will be determined from these measurements.

(*b*) Pavement of which the average thickness is within ⅛ in. of the thickness required by the typical cross-section shown on the plans, will be accepted and paid for at the contract price.

(*c*) For pavement, the average thickness of which is less than the thickness shown on the plans by more than ⅛ in. but by less than ½ in., an adjusted unit price shall be used in payment. This price shall bear the same ratio to the contract unit price as the square of the average thickness of the slab bears to the square of the thickness specified on the plans.

(*d*) Payment will not be made for pavement which is found deficient in thickness by ½ in. or more. Such pavement shall be removed and replaced by the contractor with pavement of the specified thickness at his expense. When the measurement of any core indicates that the slab is deficient in thickness by ½ in. or more, determination shall be made of the thickness of transverse sections of the slab at 25 ft. intervals set off along the center line of the road in each direction from the affected location until a transverse section of the slab is found which is not deficient in thickness by as much as ½ in. The area of pavement for which no payment will be made shall be the product of the width of pavement multiplied by the distance along the centerline of the road between the transverse sections found not deficient in thickness by as much as ½ in. If the Contractor is not satisfied he may request additional cores and measurements. Such measurement shall be made at intervals of not less than 200 ft. The cost of additional cores and measurements shall be deducted from any sums due the Contractor unless the measurements indicate that the slab within the area in question is of specified thickness.

(*e*) No additional payment over the unit contract price bid will be made for pavement found to be thicker than the specified amount.

62. Protection of finished pavement

(*a*) The Contractor shall erect and maintain suitable barricades and, when required in the special provisions, shall employ watchmen to exclude traffic from the newly constructed pavement until open for use. These barriers shall be so arranged as not to interfere with public traffic on any lane intended to be kept open, and necessary signs and lights shall be maintained by the Contractor clearly indicating any lanes open to the public. Where, as shown on the plans or indicated in the special provisions, it is necessary to provide for traffic across the pavement, the Contractor shall at his expense construct suitable and substantial crossings to bridge over the concrete.

(*b*) Any part of the pavement damaged by traffic or other causes prior to its final acceptance shall be repaired or replaced by and at the expense of the contractor in a manner satisfactory to the Engineer. The Contractor shall protect the pavement against both public traffic and traffic of his employees and agents.

63. Public use of thoroughfare

(*a*) Normal, unimpeded use of the thoroughfare of which the proposed pavement is to be a unit, is of value to the public. It is, therefore, mutually understood, that for the sections of the thoroughfare identified on the plans as requiring special traffic handling and for the distances stated thereon, surfaced road lanes as indicated shall be made available by the Contractor for unimpeded public traffic at all times, and maintained in proper condition throughout the construction period. These lanes shall be of the clear widths stated on the plans, and shall be kept entirely free from encroachment by equipment of the Contractor, by workmen or employees of the Contractor or by storage or transportation of materials intended for the work.

(*b*) The scheme and sequence of construction of the several lanes, slabs and sections of pavement, including the sequence of the shifting of public lanes during progress of construction, shall be as given on the plans or as described in the special provisions.

(*c*) Where the edge of any stipulated public traffic lane is contiguous to an edge of the slab or lane being placed, the Contractor shall provide, erect and subsequently remove, a substantial temporary guard fence, as shown on the plans along the prescribed dividing line, which shall be maintained there until the slab is opened to traffic. The Contractor's plan of operation shall be such as to obviate any need for encroachment on the public traffic lane or lanes. Where so shown on the plans special lanes for the Contractor's trucks and similar vehicles shall be provided, separate from and not interfering with the prescribed traffic lanes. Where the clearance between public traffic lanes and the Contractor's operating equipment is restricted, special delivering equipment may be necessary, designed to deliver and depart within the width of the slab actually being placed without encroaching any public lane.

(*d*) Except where a special bid price for "traffic handling" is required in the proposal and in the special provisions, all cost of handling and protecting traffic, of special equipment, of temporary road surfacing and its maintenance, of temporary guard fences and of other things to be provided or to be done under this paragraph, shall be at the expense of the Contractor.

64. Opening to traffic

Traffic will ordinarily be excluded from the newly constructed pavement for 14 days after the concrete is placed and may be excluded for a longer period if cross-bending tests indicate its advisability. Cross-bending test specimens, prepared at regular intervals from the concrete as it comes from the mixer and cured under the same temperature, moisture and climatic conditions as the corresponding slabs of pavement, shall be employed as a means of fixing the time of opening the pavement to traffic. These beams shall be made and tested in accordance with Section 13. When tests of these specimens indicate that the corresponding pavement has attained a modulus of rupture of at least 450 psi. the pavement shall be cleaned, the joints filled and trimmed and the pavement opened to traffic. If this strength is not attained within 14 days, the Engineer may open the pavement to traffic at his discretion. The joint or line of separation between adjacent strips or slabs of concrete, when the pavement is constructed in strips or slabs shall be cleaned and filled with an approved sealing material.

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ACI Standard

Specification for Cast Stone (ACI 704-44)*

Reported by ACI Committee 704

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JOHN TUCKER, JR.

The following proposed specification for cast stone is intended to supercede the specification tentatively adopted by the American Concrete Institute in February, 1929 (P3-A-29T) and which has since been generally recognized and used commercially as a standard for the physical quality of cast stone. The principal changes which have been made are an increase in compressive strength requirements from 5,000 psi. to 6,500 psi. and a reduction in permissible absorption for 7 per cent to 6 per cent. The absorption period has been increased from 24 to 48 hours, and the lower limit of 3 per cent on absorption has been eliminated.

I. GENERAL

1. The term "cast stone" shall be understood to mean a building stone manufactured from portland cement concrete, precast and set in place as trim or facing on or in buildings and other structures.

2. The minimum compressive strength of cast stone when delivered to the building site shall be 6,500 psi. when tested as 2 by 2-in. cylinders or 2 by 2-in. cubes in the manner hereinafter specified.

3. The average water absorption of cast stone when delivered to the building site shall be not more than 6 per cent by dry weight of the specimens when tested as 2 by 2-in. cylinders or 2 by 2-in. cubes in the manner hereinafter specified.

*Adopted as a Standard of the American Concrete Institute at its 40th Annual Convention March 2, 1944; ratified by Letter Ballot of the ACI Membership July 28, 1944.

4. All aggregate used in the manufacture of cast stone shall be of known durable quality.

II. SELECTION OF SPECIMENS FOR TESTING

5. Specimens for both compression and absorption tests shall be cut from stone as delivered to the job or from regular stock in the yard. Samples from which specimens will be cut shall be selected by the purchaser or his representative.

6. Specimens of faced cast stone for compression tests shall be cut in such a manner that the specimens are composed of approximately one-half of facing and one-half of backing material. Specimens shall be tested in the position in which the cast stone is laid in the wall.

III. METHODS OF TESTING

7. Not less than 3 and preferably 5 specimens shall be required for each test.

8. Specimens for absorption test shall be dried at a temperature between 215 and 225 F. until the loss in weight is not more than 0.1 per cent in 24 hours of drying. They shall be allowed to cool to room temperature, weighted and then submerged in water at a temperature between 60 and 80 F. for 48 hours. The specimens shall then be removed from the water, the surface water wiped off with a damp cloth and the specimens weighed. The percentage of absorption is the difference in weight divided by the dry weight of the specimen and multiplied by 100.

9. Specimens for strength test shall be dried at a temperature between 215 and 225 F. until the loss in weight is not more than 0.1 per cent in 24 hours of drying.

10. If bearing surfaces of specimens for strength tests are not smooth, they shall be made so by grinding. If they cannot be ground to a smooth surface they shall be capped with a mixture of ½ part portland cement and ½ part plaster of paris, which shall be allowed to harden at least 5 hours before the test. The cap shall be formed by spreading the capping material upon a plate glass and pressing the specimen firmly on it making the cap as thin as possible. On specimens that are to be capped, all surfaces which are likely to come into contact with the capping material shall be shellacked and then allowed to dry before the capping is applied.

11. Load shall be applied through a spherical bearing block placed on top of the specimen in a vertical testing machine. The dimensions of the bearing block shall be the same, or slightly larger, than those of the test specimen.

12. Load shall be applied uniformly and without shock. The speed of the moving head of the machine shall be not more than .05 in. per min. when the machine is running idle.

13. Specimens shall be loaded to failure and the unit compressive strength calculated in pounds per square inch. The type of failure and appearance of specimen shall be noted.

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Vol. 16 No. 6 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN June 1945

Job Problems and Practice

Five cash awards—$50.00, $25.00 and 3 of $10.00 each are to be made for the best contributions to this department in the current volume year—Sept. 1944 to June 1945.

In JPP many Members may participate in few pages. So, if you have a question, ask it. If an answer is of likely general interest, it will be briefed here (with authorship credit unless the contributor prefers not). But don't wait for a question. If you know of a concrete problem solved —in field, laboratory, factory, or office—or if you are moved to constructive comment or criticism, obey the impulse; jot it down for JPP. Remember these pages are for informal and sometimes tentative fragments—not the "copper-riveted" conclusiveness of formal treatises. "Answers" to questions do not carry ACI authority; they represent the efforts of Members to add their bits to the sum of ACI Member knowledge of concrete "know-how."

Precast Concrete Irrigation Pipe Jacked under Railroad Trucks (41-167)

By PAUL A. JONES*

The Buffalo Rapids Project of the Bureau of Reclamation was confronted with the problem of constructing ten canal laterals across a railroad right-of-way which divided an irrigable area. The conduits ranged from 18 in. to 42 in. in diameter. Inasmuch as the estimated cost of approximately $1,000 per structure for track false work and placing monolithic structures or precast pipe in open trenches was much in excess of the funds available it was necessary to devise some other type of construction.

Of the types of construction investigated the jacking method of installing precast pipe offered a practical and economical solution if difficulties in providing an adequate seal for the joints could be overcome. This problem was solved by the adoption of a manufactured rubber gasket with projecting lips which permitted movement at the joint without losing the effectiveness of the seal.

*Construction Engineer, Bureau of Reclamation, Buffalo Rapids Project, Montana.

Fig. 1—Jacking 36-in. diameter precast concrete pipe under railroad tracks

The concrete pipe used was extra-strength pipe purchased under ASTM Specifications C76-37, the required concrete strength being 4,500 psi. The specifications stipulated that the tongued and grooved joints have an annualar clearance between abutting ends of not more than 3/16-in. and a variation between the actual and specified internal and external diameter of not more than ½ of one percent.

Fig. 1 shows a 36-in. diameter pipe being jacked under the roadbed. The installation of this and the other crossings was accomplished using the following procedure. A minimum working area of 10 + 12 ft. was excavated as close to the tracks as safety permitted. This hole was shored in loose ground. Screeds for supporting and alining the pipe were then laid to line and grade on a thoroughly compacted subgrade and securely anchored to the sides of the excavated working area. A length of pipe was placed on the screeds and forced against the excavated face of the roadbed with a 50-ton jack. When available, a ⅜-cu.-yd. dragline was used to handle the pipe but for most of the crossings the pipe was placed in jacking position by the use of a winch, block and tackle, and snubbing posts. Equipment used in excavating from the inside of 18-in. diameter pipe consisted of a 10-inch post hole digger, a specially designed scoop shaped to fit the inside of the pipe, and a wide flat steel plate mounted on roller skate wheels on which a man moved in and out of the pipe. After the excavation reached a distance of

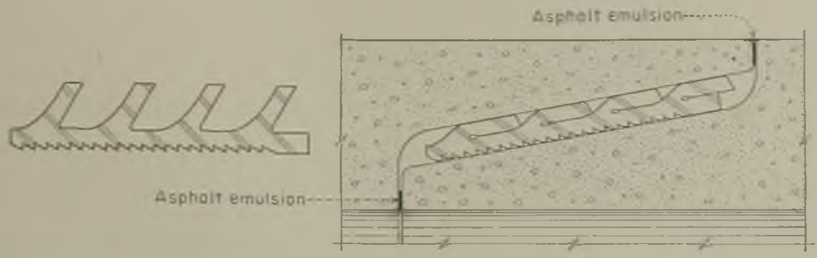

Fig. 2—Pipe joint detail: at left, section through rubber gasket; at right, section through joint of 36-in. diameter pipe.

about 16 feet a hole was augered completely through for ventilation. At this point a flat pan mounted on roller skate wheels was used to transport the scoop into the pipe and after two scoopfuls of excavation were placed in the pan it was removed and unloaded. Excavation for pipe larger than 18 in. was performed by a man working within the pipe, using a short-handled shovel. A box mounted on three small steel wheels was used to facilitate removal of the material thus excavated. To maintain accurate alinement and grade of the larger crossings, the bottom 90 degrees of the excavation was carefully trimmed, and checked with a sheet-iron template, to fit the outside of the pipe. A clearance of approximately one inch was left for the remaining circumference. The pipe was jacked at intervals of about one foot and when jacking had proceeded to the end of a pipe section, a rubber seal and another length of pipe was added. A construction crew consisting of one subforeman and four laborers carried on this work efficiently.

When installing a rubber gasket on the tongued end of the pipe, rubber cement was applied to the inner side of the gasket and a special lubricant was applied to the outer side, in accordance with the recommendations of the manufacturer. To provide protection for the rubber seal, asphalt emulsion was applied to the pipe shoulders where abutting ends come in contact. Care was exercised to prevent the emulsion from contacting the rubber seal. A section of the rubber seal and of a completed joint is shown in Fig. 2.

The length of pipe jacked for the various crossings varied from 20 feet to 52 ft. The longest installation was 30 in. in diameter and was under the main line and two side tracks. No difficulty was experienced in jacking this length with a single 50-ton jack. However, indications were that any additional length would have strained the jack.

One of the difficulties encountered was excavating in the cramped space within a 24-in. pipe. The smallest man available had to work the material back with his feet. This work was not excessive for the 20 ft. of 24-in. pipe installed. However, longer crossings would entail considerable effort and reduce progress materially. It is probable that the procedure later developed for 18-in. diameter pipe would have been satisfactory in excavating for 24-in. pipe.

Two crossings using 36-in.-diameter pipe were excavated through gravel. In this loose material the pipe had a tendency to "dig in" as jacking progressed. To combat this situation a "sled" bent to fit the outside curvature of the pipe and curved upward at the forward end was installed on the front end of the pipe. The arrangement worked satisfactorily. In excavating loose material, use was made of a protective shield, fastened to the upper part of the pipe. This protected the worker from falling rocks and maintained a sloping face the toe of which was beyond the end of the pipe. Between working shifts, a removable bulkhead was fitted into the forward end of the pipe or into the excavation to reduce the likelihood of caving.

Frequent passage of trains caused considerable vibration and tended to enlarge the excavated openings. Such caving, if excessive, resulted in settlement of the tracks. This settlement was particularly noticeable where the clearance between the pipe and rails was small. Plans drawn for the railroad crossings originally required 3-ft. clearance between top of pipe and base of rail. No trouble was experienced in jacking 24-in. pipe under these conditions. However, one 30-in. crossing was attempted with 3-ft. clearance and under heavy freight traffic the excavation could not be held in place. When work on the crossing was interrupted and left for a few days, it was difficult to jack the pipe farther. It was decided that the arching effect of 3 ft. of cover was insufficient for pipe 30 in. or larger. When clearance between top of pipe and base of rail was increased to 5 ft., the vibration from train passage had little or no effect.

Following is an estimate of the cost of installing 30-in. pipe crossings. This cost, except for the difference in cost of the pipe itself, is a close approximation for the 24-in. and 36-in. sizes as increased handling and excavation costs for the larger size are very nearly offset by the more difficult excavation for the smaller size.

	Cost per foot of pipe jacked
Work preliminary to jacking	$ 1.21
Excavation and jacking pipe	4.82
Pipe and joint materials	4.76
Engineering and supervision	1.08
	$11.87

Relatively large savings were effected by jacking the pipe under the tracks and the quality of the completed work is equal to that obtained by installation of pipe in an open trench. It is believed that the life of the rubber joints as installed will compare favorably with that of grouted joints, and that more flexibility under load and settlement is provided.

Setting Heavy Machinery on Concrete Bases (41-164)*

The question and discussion under this heading in February seem to have prompted further discussion of the subject of machinery bases and further inquiry on special problems. For instance a construction engineer with a large industrial corporation writes:

Q—In connection with a large compressor installation, which we made, the unbalanced load of the compressors caused considerable vibration to the entire concrete mat under the foundations. Some time after the original foundations were installed an additional compressor was added, and the concrete mat was joined to the existing mat with the reinforcing dowel bars extending through from the original concrete structure into the new. The question has now arisen whether there is enough movement in the concrete to prevent proper bond between the reinforcing rods and the concrete, during the period of the initial set.

From an ACI Member to whom this inquiry was referred we have this:

A—The amount of bond secured around an embedded bar, vibrated while the concrete is setting, depends on the character of the vibration of the bar. We have some unpublished tests of the results of vibrating smooth ¾-in. bars in 6- by 12-in. concrete cylinders for 30 seconds at 15-minute intervals for periods of 1, 3, 5, and 7 hours. Some bars were vibrated in a vertical position, some horizontal. At 5 and 7 hours the mortar was still plastic around the bars although surrounding concrete had hardened. Conclusions were that such vibration materially increased the bond over that obtained under ordinary conditions and the beneficial results of the vibration were obtained whether the bars were vibrated in a vertical or horizontal position. Presumably this test does not quite represent the case reported because vibration did not continue until the mortar did not again become plastic around the bar when vibrated. Also this was intermittent, not continuous, vibration.

The quality of bond secured around a vibrating bar will depend also on the distance from the source of vibration and the depth of embedment. Also it seems to be a matter of amplitude. Although vibrating concrete will harden, if there is appreciable amplitude in a vibrating

ACI Journal, Feb. 1945, p. 360 (JPP 41-164) bar in the concrete, it is conceivable that, as the concrete passes from the plastic state, the vibrating bar could have sufficient amplitude to press the weak concrete away from its normal position and prevent contact and bond. This may well be the case close to the edge of the new foundation where the dowels enter. Depending on the length of the dowels, surrounding concrete will dampen the vibration to the point where bond will be secured without question, particularly if the unvibrated end is fixed. There is some discussion of this point in the ACI JOURNAL for January 1945, pages 163-5.

Probably under horizontal bars, especially if of square section laid flat, vibration will at first aggravate and then tend to dissipate the accumulation of bleeding water under the bar that would tend to impair bond on the underside of the bar.

As we understand the case, the compressor on one foundation continued running with resultant vibration of protruding dowel bars during the setting of concrete in an adjacent foundation in which the dowels were also embedded. It would be of interest to know if the question now raised is the result of some adverse structural evidence or merely academic. Either way it is a good question and not an uncommon one. Would it be practicable to answer this question positively with some drill cores?

By DOUGLAS S. LAIDLOW†

I must get into the discussion, with a different slant from that of Messrs. Tyler and Lewis, for the practice of placing grout under machinery and column bases has long seemed to me to be one of the hoary blunders of our profession.

See what happens: The manufacturer of a machine builds up an expensive base, either by casting or welding, and then takes the trouble to machine the under side of it truly parallel to the horizontal axis of the machine. Then we prop it up on little stacks of shims and pack in some grout, generally very wet grout around these shims. Unless I am very much mistaken, the grout either crumbles or shrinks away from the machine and leaves it sitting on the shims to be wracked out of shape as soon as the machine is put to work. We take care to get a good true bearing surface at all joints except that essential one at the top of the foundation.

About fifteen years ago, I found that such practice, which had been carried over from machinery to structural frames, was being abandoned. The Dominion Bridge Co., in Montreal, started about that time to have column bases poured a little high and dressed down by hand to exact

*"Concrete Operations in the Concrete Ship Program, *Proceedings*, V. 41.
†Port Arthur, Ontario.

elevation and the true level condition. Then they set their columns up, on small jobs right on the concrete, on important work using a sheet of lead under the steel to take up any minor variations. This method so appealed to me that I wrote it into a specification for a structural steel frame to be built in another city about five years later. What was my horror to find the steel subcontractor coming to me and begging to be allowed to use shims and grout. This was more remarkable as I had given the job of dressing the concrete to the general contractor. What he was afraid of, other than the unknown, is a mystery to me to this day, for I did not consider the point important enough to fight about and let him have his way.

In the years that followed, I have become more and more convinced that the method of dressing the top of the foundation is the proper method to follow, for it is similar to the method used at all other mating surfaces. It is just as easy, perhaps easier, to dress concrete as steel, and I'm all for the practice.

What holds us back? I think the answer is "fear". Men are afraid that, if some novelty in setting a machine is used, and that machine subsequently gives trouble for any reason at all, the manufacturer will blame the method of installation, for all the trouble. Well, he might try, but that doesn't say he would necessarily get away with it. Suppliers of materials and equipment will try it on with anybody they think it profitable to fool until the end of the world; it's only a part of the game and its possibility need never worry anyone who knows his business.

By CHARLES MACKLIN*

To my knowledge the only manufacturers who consistently recognize the necessity of incorporating in their designs a positive means of adjusting objects placed on concrete are the manufacturers of electrical floor junction boxes.

Setting base plates can be done by any of the five schemes shown in Fig. 1 and each may serve a particular need. However schemes 3, 4 and 5 are more accurate and economical. They do however require foresight and planning. When base plates are inaccurately set erection of structural steel is complicated and unnecessary stresses are introduced.

Schemes 1 and 2 require the use of four supports, one near each corner of the base plate. Schemes 3, 4 and 5 are better using only three points of support but four may be used.

The shrinkage of grout may be assumed to be about 1/100 of the thickness of the grout when the grout sets under no pressure and no packing is done after filling. This value may be appreciably reduced by

*Springfield, Ill.

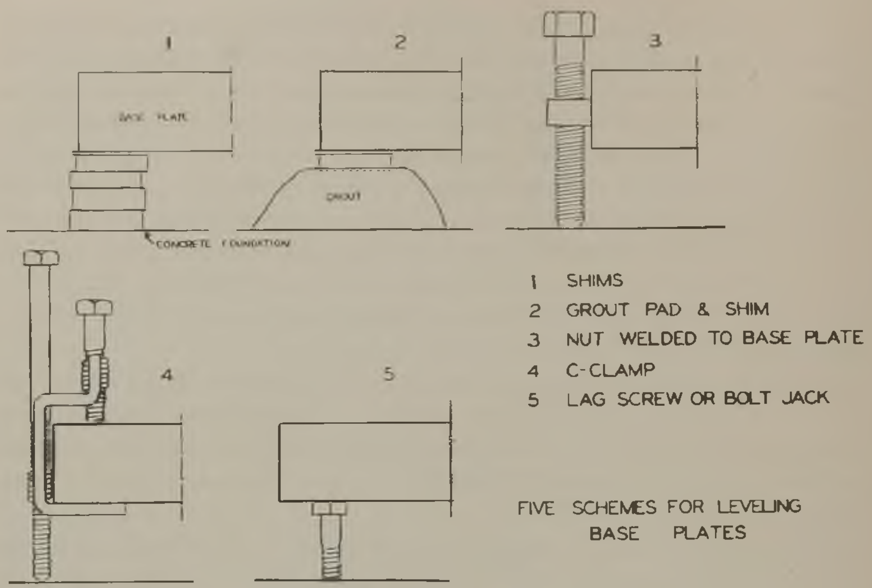

Fig. 1—Five schemes for leveling base plates

filling the grout higher than the bottom of the base plate and allowing settlement to take place for a half hour and then by exerting pressure on the forms and applying some hammer blows the excess water rises and spills over the form. This process may be repeated until the grout no longer responds to pressure. In applying pressure to the forms two methods can be used. One is by using a clamp and the other is by building a rectangle of wood around the form and applying pressure with jacks or wedges. In either case the form should be limber enough to bulge noticeably from the pressure of the grout and after the settling period this deflection can be reduced or eliminated.

Mr. Tyler recommends the procedure of introducing the grout through a pipe which of course does no harm. It is of little advantage unless the form is sealed to maintain a pressure over any appreciable area. The pressure gradient in grout may be very steep and any openings between the form and the plate make it possible to lose this pressure in a very few inches. When the grout completely fills the space between the foundation and the base plate, pressure exerted from any outside source does help to settle the grout, provided there is some place to which the excess will escape. The settlement can be speeded up by vibration. However, since this time element is present, unless pressure is exerted after some settlement has taken place, not much reduction in shrinkage will result from high initial pressures.

The article "Concrete Operations in the Concrete Ship Program" ACI JOURNAL, Jan. 1945 by Lewis H. Tuthill describes the procedure for patching ship hulls which is essentially the operation of patching between the foundation and the base plate.

When they receive the column loads base plates deflect and, coming in contact with the hardened grout, relieve the local pressures on any type of edge support. The possibility of a few thousandths of an inch settlement to make contact with the grout is of slight practical importance.

Since bearing pressures rarely exceed 1000 psi and 2 or 3 times this strength is readily obtained from wet mortars, the object of using a grout of any drier consistency which makes placing difficult seems to this writer absurd because the greater settlement shrinkage of the wetter concrete can be taken care of with pressure. The research of Giesecke (Proceedings ASTM part 2, 1920 page 219) indicates that rodded concrete increases in strength in spite of the water used. The grout is compacted and increased in strength whether worked by pressure on the forms after a time interval, or rodded.

Q—Now the further related problem: Shall the pipe sleeves that encase long holding-down bolts of a heavy machine be filled with grout when, after shimming up the machine in proper alignment, grout is forced between the machine base and the concrete foundation?

By W. ROWLAND*

A—The purpose of the sleeves is to allow enough movement of the top of the bolt to correct inaccuracies in setting the bolts.

After the machine base is set with the bolts fitting properly, the sleeves should be filled with grout for two reasons: 1) no more adjustment of the bolt location is required; 2) By resisting in sheer (as they should in conjunction with friction between base and foundation) bolts can prevent any horizontal movement of the machine only when they are grouted in right up to the underside of the machine base.

By L. C. HANSON*

A—On a five-stage horizontal, steam-driven compressor of which the pipe sleeves had been filled with grout, some of the anchor bolts broke off near the top of the grout. When in operation the machine (moving 0.005 in. back and forth) bent the projecting part of the bolts once back and forth with each revolution. Because the projection measured only 6 in. the bending moment was so great that the bolts broke from fatigue. Had the pipe sleeves not been filled with grout

*The Solvay Process Co., Hopewell, Va.

the projecting part would have been approximately sixteen times as long and consequently for the same deflection the stress would have been 1/256th as great (sixteen to the second power) and therefore safe. My conclusion is that sleeves should not be filled with grout.

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Current Reviews

of Significant Contributions in Foreign and Domestic Publications, prepared by the Institute's Reviewers

Concrete overlays for airfield runways

Engineering News-Record, V. 133, No. 24 (Dec. 14, 1944), pp. 80-82 Reviewed by S. J. Chamberlin

Concrete runways were strengthened to carry a 37,000-lb. wheel load by a 6-in. overlay of reinforced concrete. The old concrete was brushed clean, primed with hot tar and coated with a one-half inch layer of asphaltic concrete to act as a cushion and to prevent bonding with the new concrete. Portable pierced-plank steel runways served as emergency extensions during the remodeling to provide continuous operation of the field. New concrete runways have a thickness of 10:7:7:10 in. on a 4-in., dry-bound macadam base.

Prestressing bands on a concrete tank

John J. Crowley, *Engineering News-Record*, V. 134, No. 18 (May 3, 1945), pp. 116-118
Reviewed by S. J. Chamberlin

In building a 300,000-gal. prestressed concrete water tank, well known methods were used until the time came to get the right tension in the steel bands. After field and laboratory studies were made the extensometer method was abandoned and a shear wrench method developed. The shear wrench method consisted in tightening the nuts on the ends of the bands until the wrench handle sheared a pin of predetermined strength. Nuts and washers were coated with flake graphite mixed with oil. Laboratory calibration of the shear pins indicated 1/16-in. bronze Oxweld brazing rod suitable for the preliminary prestressing of 16000 psi in the ¾-in. square bars and 1/16-in. steel Oxweld welding rod for the final stress of 31,500 psi. It was concluded that refinement in stress control (within 10 per cent) should not be expected.

Rigid-frame concrete span requires no falsework

Jacob Feld, *Engineering News-Record*, V. 134, No. 18 (May 3, 1945), pp. 105-106
Reviewed by S. J. Chamberlin

Structural steel frames are first designed as rigid frames to sustain the weight of forms and fresh concrete. When the concrete has hardened the structure becomes a reinforced frame, the structural angles acting as reinforcement in both faces. Three costly items can be eliminated: 1) supporting arch forms on falsework; 2) bending and placing long and heavy bars; and 3) separating and holding in proper position the intrados and extrados reinforcement layers. Structural steel ribs are spaced 24 in. on centers and are formed of double 4 x 4-in. angles in each chord. Diagonals are single angles and the struts are Z bars. The proposed structure will have a clear span of 80 ft. 6 in. and a width of 100 ft.

Prestressed concrete design overseas

Henri Marcus, *Engineering News-Record*, V. 134, No. 14 (Apr. 5, 1945), pp. 97-100

Reviewed by S. J. Chamberlin

European engineers have made considerable progress in the application to concrete of artifically induced stress. Short descriptions of several examples of prestressing are given (particularly the work of Edouard Freyssinet) including long span beams, slender bridges, increasing the heights of dams and precast caissons. Successful application involves adjusting the prestressing forces to the strain produced by natural forces, the use of adequate tubes for easy manipulation of the reinforcing cables and special grouts for their protection, and specially built hydraulic jacks for rapid and intensive stressing and anchoring of the wires.

Railroad tunnel roof rebuilt from shaft

Engineering News-Record, V. 134, No. 8 (Feb. 22, 1945), pp. 70-74

Reviewed by S. J. Chamberlin

Faced with the problem of replacing an old brick roof with a concrete arch without interrupting traffic, the contractor attacked the job from the top by sinking a vertical shaft and driving a crown drift above the damaged section. The area was then enlarged and shored to the old lining for a length of 10 to 15 ft. Haunch concrete was then placed and 7-segment timbering placed to which the roof supports were transferred. Center sections of the brick arch were removed and all areas above the lagging were back packed with old brick. Forms for the concrete arch were supported by the old timbering that had previously held the damaged brick section. The concrete was then pumped into place for the arch followed by concreting above the arch. Arch forms and the old timber support system will remain in place until the work is completed.

Engineering for dams

William P. Creager, Joel D. Justin and Julian Hinds. 3 vols. John Wiley & Sons, New York; Chapman & Hill, London, 1945. 929 pp., illus., diagrams, tables, charts, cloth, 9¼ x 6 in., $16.50.

Reviewed by R. F. Blanks

A very useful compilation of data and information on the investigation, design and construction of all types of dams, and also on related hydraulic problems, skillfully condensed to usable form. Volume I covers general investigation and design problems including geology, foundations, selection of type, model studies and hydrology. Concrete engineers will find particular interest in Volume II, which deals, in detail, with the design of non-overflow and spillway types of solid gravity dams, arch dams and buttressed, multiple arch and other types of concrete dams. Chapter 15 is devoted exclusively to concrete and concrete materials for concrete dams. Volume III treats the investigation, design and construction of earth, rockfill, steel and timber dams. Soils tests, construction control and related subjects are given particularly prominent emphasis. The authors were assisted by several eminent authorities on dam and hydraulic engineering.

Use of all-in aggregates in concrete

A. R. Collins, *Concrete and Constructional Engineering*, V. 40, (Jan. 1945), pp. 15-19.

Reviewed by Glenn Murphy

The author describes expedient measures for producing concrete of reasonable quality in emergency construction where the available aggregate cannot be washed or graded. Studies indicate that the principal cause of deterioration is silt, clay, or other fine material which increases the water requirement. The resultant high water-cement ratio decreases the strength and durability of the concrete. The need for holding the water-cement ratio constant by increasing the cement content at the same time the water content is increased to maintain workability is pointed out. It is also noted that the resultant rich concretes may have a tendency to shrink and crack. Standard field techniques for making sieve analysis and for detecting the presence of silt and organic impurities are described. The author outlines a trial batch method for field design of the satisfactory mixture. The paper includes a table of gradings for assistance in combining aggregates to improve the grading.

Reconditioning concrete floors to carry heavy warehouse traffic

Engineering News-Record, V. 134, No. 4 (Jan. 25, 1945), pp. 86-89 Reviewed by S. J. CHAMBERLIN

The article is extracted from "Toppings and treatments for the correction of concrete floor deficiencies" compiled by the Repairs and Utilities Branch of the Office of the Chief of Engineers of the Army. The first step in resurfacing with concrete is to cut out the defective surface to a minimum depth of 2 in. with vertical and straight edges. After vigorous cleaning it is recommended that the prepared surface be thoroughly saturated with water, later removed with a mop so the top will be in a surface-dry condition. A cement-paste slush coat should then be brushed in and the excess removed. Recommended proportions for the inlay concrete are 1:1 1/3:2 with a water-cement ratio of 4 to 4½ gal. per bag. Careful finishing and curing are essential. Asphalt mastic for use as an overlay in resurfacing should be a combination of portland cement, asphalt emulsion, water and sand, with a ½-in. minimum thickness and feathered at the free edges. Sodium silicate solution and magnesium fluosilicate solution are recommended to retard "dusting" of floors.

Cement-treated road base built in Arizona

BERNARD TOUHEY, *Engineering News-Record*, V. 134, No. 2 (Jan. 11, 1945), pp. 108-110
Reviewed by S. J. CHAMBERLIN

The first step in the construction of the mixed-in-place base was spreading of the sand and gravel aggregate the full width of the roadway to a depth sufficient to assure a compacted thickness of 6 in. Cement was spotted on top for an approximate mixture of three sacks per cubic yard of compacted material. After motor patrols windrowed the material the dry aggregate and cement were mixed by one of the traveling plants. Water was then added by the second traveling plant and the third plant completed the wet mixing. The traveling mixing plants were pugmills swung under grader frames. Material was picked up in the pugmill and then forced back into the revolving spools to which the mixing paddles were welded. Mixed material was forced out the rear of the mixing box in a uniform flat-topped windrow. A blade grader followed immediately behind the third traveling plant. The mixture was rolled with both steel and pneumatic rollers and then sprayed with emulsified asphalt for a curing seal. Subsequently, a 2-in. plant-mix bituminous seal coat was added. Twenty-eight-day compressive strengths of the material averaged 2,037 psi.

Concrete construction in cold weather and during frost

Revision of paragraph 30 of obligatory specification for mortar and concrete (AMB) of the German State Railways (Deutsche Reichsbahn): *Asph. u. Teer*, 1944, 44 (¾), 27-8. Road Abstracts, Vol. XII, No. 1, January 2, 1945. HIGHWAY RESEARCH ABSTRACTS

The requirements for concrete construction in winter are given in greater detail than in the published account of the earlier revision of paragraph 30 of the specification for mortar and concrete. The following additional points may be mentioned: Rapid-setting cements and strongly exothermic cements are most suitable for winter construction; German aluminous cements are almost unaffected by low temperatures. In frosty weather the proportion of cement may be increased. The proportion of mixing water shall be kept as low as possible by choosing a suitable grading for the aggregates. The concrete should ordinarily be "earth damp" (a somewhat wetter mix is necessary if aluminous cement is used) and should preferably be vibrated. Before being charged, the mixer shall be washed out with hot water. If the aggregate and water are preheated the cement shall not be added until it has been ascertained that the temperature of the mixture does not exceed 40 C. (122 F). The temperature of the concrete in the mixer shall not be below 20 C. (68 F.). The only admixture permitted is calcium chloride (90 to 93 per cent pure), to be used in aqueous solution, and then only at temperatures down to -15 C. (+5 F.). For earth-damp concrete the proportion of calcium chloride should be 1 per cent of the cement used; 2 per cent may be used in wetter mixes.

Expansion joints unnecessary in pavements

Engineering News-Record, V. 134, No. 12 (Mar. 22, 1945), pp. 100-103 Reviewed by S. J. Chamberlin

After three years of observations on two experimental paving projects the Oregon State Highway Department has decided that expansion joints are not needed in Western Oregon provided dummy (contraction) joints are properly spaced. On one project expansion joints of several types were spaced from a minimum of 30 ft. to a maximum of 495 ft., with dummy joints placed every 15 ft. The other test section was placed in two 1,320-ft. sections without expansion joints, but with dummy joints again spaced at 15 ft. The opening and closing of both types of joints were determined with a strain gage, and longitudinal displacements were measured from a transit line across the pavement. The indications were that a relatively rapid closure of expansion joints may be expected during the first season after construction, since most of the expansion between joints must be taken up by the slabs sliding along the subgrade. During the following winter contraction of the concrete opens the dummy joints, with expansion during the second and subsequent summers taken up by closing of the dummy joints. Although only about half of the dummy joints opened during the first winter all opened during the second winter. Vertical displacement of adjacent pavement sections under a 20,000-lb. axle load were measured with a displacement meter to determine the load-transfer property of the expansion joints. Results indicated that a joint with a concrete sill could be substituted for the usual doweled joint with an increase in rigidity.

Observations reveal deformations of steel reinforcement

S. Sergev, *Civil Engineering*, V. 15, No. 2 (Feb., 1945), p. 92. Reviewed by J. R. Shank

Strain readings have been taken from time to time on the steel of reinforced concrete columns and beams of Biology Hall of the University of Washington. The basement columns, $A = 325$ sq. in., $A_s = 6.17$ sq. in., of a 1:1:2 mix under a load of 160,000 lb. showed an average unit stress on the steel at 10 years to be 30,000 psi. First story columns, same cross-section of 1:2:4 concrete showed 22,000 psi under a load of 136,000 lb. Readings on opposite faces in both cases showed deviations from the average of 20 per cent in the basement columns and about 10 percent in the first story columns showing the effects of deformation stresses. Though the author speaks of this increase in unit stress as being due to shrinkage it is obvious that it is due to a combination of shrinkage and plastic flow. Previous data on plastic flow for similar concretes show an increase to 23,000 psi may be expected for the basement columns, leaving 7,000 psi of the increase due to shrinkage, which may be expected.

Strain readings on the tension steel at mid-span points of beams showed a maximum tension of about 10,000 psi to have occurred at 30 to 40 days, after which a slow reduction was had, leaving an observed stress of only 2,500 psi at 10 years. This is one-fourth what calculations would indicate for simple beam action.

Bonneville Dam concrete after six years

C. C. GALBRAITH and R. R. CLARK, *Engineering News-Record*, V. 134, No. 10 (Mar. 8, 1945), pp. 121-124
Reviewed by S. J. CHAMBERLIN

Considering the behavior of the mass concrete to be fully as important as that of the surfaces exposed to erosive action of water, the selection of a modified portland cement ground with 25 per cent pozzolanic material was based on the decision to build the blocks rapidly without vertical joints parallel to the axis. The present condition of the concrete surfaces of the superstructure is approximately the same as at the end of construction. The spillway dam discharges large flows for long periods and severe erosion has occured at local zones at the bases of all piers just downstream from the gate slots and on the curved overflow sections adjacent to the piers. It has been concluded after seasonal repairs with different brands of cements and admixtures that concrete is not suitable for surfacing these localized areas, and they have therefore been covered with ½-in. steel plate. Some of the steel plates have been torn away, but from the experience gained to date it will be possible to maintain these surfaces satisfactorily without excessive cost. Another localized zone of erosion is the downstream baffle deck. The erosion is localized on the vertical face of the triangular baffles and on the horizontal deck at the downstream corners of the upstream row of baffles. At one spot the deck has eroded to a depth of 32 in., with depth ranges to 18 in. in spots at all bays. Repairs with standard cement and a richer mixture seem to withstand the action of the high velocity water somewhat better than the concrete made with pozzolanic cement. The deck is about 20 ft. thick and it is thought that it will not require anything more than the renewal of the surface at intervals of 15 to 20 years (a more favorable condition than was anticipated at time of construction). The interior of the mass concrete appears to be in a satisfactory condition.

High-strength reinforced concrete column developed

GEORGE A. MANEY, *Civil Engineering*, V. 14, No. 12, (Dec., 1944), pp. 496-498.
Reviewed by J. R. SHANK

Reinforced concrete column specimens have been developed at the Northwestern Technological Institute capable of withstanding as much as 57,000 psi in compression. A number of important properties of concrete and steel and combinations of these were employed in this development among which were the high strength that may be developed in portland cement products when vibration cast under high pressure using very low water contents and the high value of spiral column reinforcement when under tension. Water contents as low as 1 gal. per sack of cement and pressures up to 18,200 psi were used.

High strength steel wire was wrapped on a tubular steel section into which very dry concrete was placed and vibrated strenuously under high pressure for a minute, after which the vibration was stopped and the pressure was removed. It was found that the concrete was strong enough to maintain the spiral steel in initial tension. A neat cement specimen, 1 gal. of water per sack of cement, 11 percent of high-strength spiral wire and 3.3 per cent of tubular liner by volume, under a forming pressure of 11,8000 psi developed 47,000 psi strength. The stress-strain curve was straight up to 12,000 psi indicating a modulus of elasticity of 9,400,000 psi. Another specimen 8.3 in diameter, 1:0.5:0.715 mix by weight, 2½ gal. of water per sack, 19 percent spiral wire and 12 percent liner by volume, formed under a pressure of 13,500 psi reached 55,000 psi and showed an initial E value of 8,500,000 psi.

Further research is necessary to find the best types and proportion ranges for spiral wire and tubular steel, as well as forming pressures and concrete mixtures. It is apparent now that units can be manufactured which will have weights comparable to structural aluminum and have higher moduli of elasticities at costs as low as one-third that of structural steel.

Deteriaration of concrete dams due to alkali-aggregate reaction

R. F. Blanks and H. S. Meissner. *Am. Soc. C. E. Proc.* V. 71, No. 1 (Jan. 1945) p. 3-18
Reviewed by H. J. Gilkey

Constitutes a progress report based on close continued observation of concrete dams and other structures and on continuing laboratory studies. Some structures develop signs of surface damage rapidly (within two or three years) and the rate of damage may soon decrease greatly. Other structures may develop initial evidence of damage much more slowly but the progress of deterioration may be continued over a long period. The characteristic large surface cracks do not extend far inward but are the result of interior swelling as demonstrated by decreased core strengths and greatly decreased concrete stiffness (lowered modulus of elasticity) of material from the interior. The swelling has been further demonstrated by chord measurements on arch dams and by measured up-stream movement of the arch crown, misalignment of machinery and by the rising of top surfaces in amounts proportional to depth of concrete. The laboratory mortar bar accelerated tests give valuable indications but the correlation with different actual structures is far from perfect. Most "good" aggregates are probably reactive to the alkalies of the cement in some degree but thus far no trouble has been encountered with cement for which the $Na_2O + K_2O$ is less than 0.60 percent. One of the difficulties in studying any but the most recent of structures is the absence of knowledge regarding the alkali contents of the cements that were used, since such determinations were not a part of normal tests. Representative samples of the aggregates can usually be secured, however. In spite of the many things not yet known regarding the problem the evidence thus far indicates that the use of a low alkali cement (under 0.60 per cent) is a desirable, and to date the only reliable, precaution against possible damage. This may add anything from nothing to $0.20 per barrel to the cost of the cement but the absence of the alkali produces other beneficial effects in the concrete such as reducing the C_3A (tri calcium aluminate) and the C_4AF (tetracalcium alumino-ferrite) with corresponding increases in the desirable constituents C_3S (tricalcium silicate) and C_2S (dicalcium silicate). There is some evidence that pozzolanic cements may safely be used with reactive aggregates and that the addition of pumicite to the cement is helpful. A list of eight selected references ties this paper to the preceding published observations on this vital subject.

South American building codes

Arthur J. Boase, *Engineering News-Record*, V. 134, No. 16 (Apr. 19, 1945), pp. 68-77
Reviewed by S. J. Chamberlin

The author points out the main similarities and great dissimilarities between the building code of Brazil and the American codes (especially ACI 318-41). The engineers of Brazil have organized the Brazilian Association of Engineering Codes and this group has issued the six codes that refer to the calculation and erection of structures. Unit stresses and most other details as set up in one code apply to all reinforced concrete construction and these codes are used by everyone engaged in engineering work. The Brazilian code is direct and simple leaving much to the engineer. Specified minimum live loads are tabulated in the article and compared with those used in New York City. Provision is made in the framing of tall buildings for less than 100 per cent loading on lower floors. Wind pressure is assumed as a function of the height and is designated as q, while the pressure as a function of the type and form of construction is designated as c. Values of q and c are listed. The strength of concrete used is much lower than that used in this country. Reinforcing steel for the most part is plain and corresponds to our structural or intermediate grade. Permissible unit stresses are tabulated and compared with the ACI code as well as the German and French codes. Steel stresses in flexure of 21,300 psi and 25,000 psi in structural grade and intermediate grade respectively are permitted. Steel is about 10 cents a pound. One provision on bond stresses states that where bars or bundles of bars with a diameter of less than one inch are used in flexural member the bond stress need not be calculated, but all bars over ¼-in. in diameter must be hooked. Another provision states that where there are bent bars calculated to resist all diagonal tension stresses, twice the perimeter of the unbent bars may be assumed in bond calculations. Steel protection thicknesses are listed and compared; the protection being much thinner in Brazil. The minimum width of beams and girders is set at 3.2 in. and the designers very often stay very close to this minimum. Beams and girders, one-way slab design, joist floor construction, two-way slab construction, mushroom flat slab design and column design procedures are discussed and compared, with one of the basic differences between the Brazilian code and the ACI code being the handling of continuity. The Brazilian code permits design on an ultimate design basis, that is, it is permitted to design flexural members as a function of the rupture load.

Extend the life of concrete pavements—hints to maintenance men on patching with portland cement

A. A. ANDERSON, *Civil Engineering*, V. 15, No. 3, (Mar. 1945), pp. 131-134. Reviewed by J. R. SHANK

The determination of areas to be patched involves consideration of the condition of the existing pavement and the shape and dimensions of the patch. Patches are divided into five classifications:

1) full width patch; 2) half-width or single-lane patch; 3) exterior edge patch; 4) interior edge patch; 5) interior or plug patch.

The minimum length of a patch on one side of an expansion joint is 6 ft. and at a contraction crack, 8 ft. The expansion joint may be moved to the end of the patch where the area to be patched lies on both sides of an expansion joint if the patch is full-width on both sides. Except for full-width patches, expansion joints should be reproduced in their original positions. Rectangular, or diamond-shaped interior or plug patches, should be not less than 4 ft. nor more than 6 ft. laterally from the center line and not less than 4 ft. long. For diamond-shaped patches at some distance from joints, the angle between the sides of the patch and the center joint should not be less than 30 or more than 60 degrees. At transverse expansion joints this angle should not be less than 30 or more than 45 degrees.

It is recommended that patches be of uniform thickness and that dowels and tie-bars be eliminated. The thickness of the patch should be of the same thickness as the existing slab for uniform thickness slabs, except at unprotected corners where it should be 10 per cent thicker, to 1.3 times the center thickness at unprotected corners for thickened-edge slabs, or, at other places, 1.2 times the center thickness.

Edges of patches should be straight and vertical. The sides of rectangular patches are usually parallel to and at right angles to the center line. Edges may be the original crack where the angle is not less than 30 degrees with the center line.

Concretes should be equal in specifications to, or better than the original concrete and high early strength materials and methods are usually advisable. A modulus of rupture of 500 psi is recommended as the strength at which to open patches to traffic. The concrete should be proportioned and mixed according to best practice and tamped into place against dampened edges of old concrete. After delaying as long as possible, while still permitting the surface to be finished, the concrete should be tamped a second time. Best appearance results if patches are finished with a surface texture as nearly as possible like that of the original pavement.

Sawdust-cement

BUILDING RESEARCH STATION: R.I.B.A.J., 1943, 50 (11), 259-63.

BUILDING SCIENCE ABSTRACTS

Data obtained and conclusions drawn from recent investigations on sawdust-cement conducted at the BUILDING RESEARCH STATION, Garston, are here summarized for the benefit of manufacturers and users. The shrinkage and expansion of sawdust-cement products are discussed and measures for reducing these movements as much as possible are detailed. For precast units the cement/sawdust ratio should be as high as possible, i.e., 1: 2 or 1 : 3 mixes, and the products carefully matured for 4 to 6 weeks, the last stages being done under cover in the open. Residual movements when the products have been built into a structure, i.e., shelving, flooring, etc., may be further reduced by waterproofing with a paint or by a tar or bitumen. Another alternative is to design the method of fixing so as to permit some freedom of movement (1) by using tongued and grooved plank-shaped units with dry joints, (2) by holding roofing units to rafters with simple spring clips and covering these specially shaped units with clay or concrete tiles which can be nailed down, (3) by nailing or bolting flat slabs on roofs leaving the holes sufficiently large for movement and then covering the top surface with roofing felt. Uniformity in weight, strength and setting of sawdust cement may be ensured by (*a*) addition of hydrated lime to the cement-sawdust mix in the proportion of ⅙ to ⅓ volume per 1 volume of cement used; this method, which improves setting and strength development, is applicable to batches of the normal mixed wood sawdusts containing a minimum of larch, or (*b*) pre-treatment: a method equally effective with all sawdusts is outlined. Some points to be observed in the manufacture of pre-cast sawdust-cement products are briefly noted. The use for floors of small pre-cast blocks having a sawdust-cement base has proved satisfactory and it is suggested that a jointless flooring composition of the sawdust-cement type might be an efficient substitute for timber flooring or jointless surfacings which are now unavailable or in very short supply. Plain sawdust-cement mixtures, however, tend to lift or crack, so that to minimize this defect it is advisable to lay the mix immediately on fresh concrete or to use cement-sand-sawdust mixes ranging from 1 : 1½ : 1½ to 1 : 1 : 2 whereby drying shrinkage is considerably reduced. Such mixes, too, may also be laid on old concrete if suitable precautions, here outlined, are taken. Some of the existing and possible uses of sawdust-cement are summarized and finally consideration is given to the question of appropriate performance tests for sawdust-cement products to meet specification requirements. Quantitative data regarding the physical properties and strengths of various cement-sawdust mixes are presented in four tables.

Actual and estimated impact resistance of some reinforced-concrete units failing in bending

L. G. SIMMS. *Journal of the Institution of Civil Engineers* (London).

HIGHWAY RESEARCH ABSTRACTS

What little attention has been given to the behavior of reinforced concrete units under impact has normally been confined to analytical considerations applicable to the point where either the yield of the steel or the crushing of the concrete is reached. While the best way to determine the resistance to impact of reinforced concrete is, and probably always will be, practical trial, there is some evidence that an approximate analysis of transference of energy may, in certain simple cases, lead to the order of resistance to be expected.

It is known that the criterion of resistance for loads acting over a short period is capacity to absorb energy; but since it has been usual practice to discontinue static tests on reinforced-concrete units when the maximum load is reached, few data are available as to energy-absorpton even under static loading.

In this report the beams tested were 7 ft. long, 4 in. wide, and 8 in. deep and the corresponding dimensions of the slabs were 6 ft., 20 in., and 6 in. respectively. In the beams, stirrups were provided to ensure that the failure was in bending without earlier shear failure. In general the longitudinal reinforcement consisted of mild steel bar, the quantity of steel ranging from 0.1 per cent to 3 per cent. In a few tests a high-strength steel was employed. The reinforcement in the slabs consisted of three types of cold-worked steel, ribbed mesh sheet steel, and three steels sold as mild steel.

The average crushing (cube) strength of the concrete employed in the beams was 3,000 psi, and of that in the slabs 3,800 psi.

Under load all specimens were simply supported, with restraint to the ends reduced to the minimum. The load, either static or impact, was transmitted to the concrete through a steel bearing-plate located at the center of spans of 6 ft. and 5 ft. for the beams and slabs respectively.

In the impact tests the deflections were obtained by a stylus fixed to the specimen and travelling with slight pressure over waxed paper fixed to a plate. The stylus, in removing a line of wax coating, revealed the red surface of the paper behind.

The impact testing apparatus was simply a frame with guides for a weight dropped from various heights. It is realized that with this type of apparatus some of the available energy is lost before impact, owing to friction between the weight and the guides, but it is considered that the efficiency of the machine was well above 90 per cent. In all cases it was arranged that the weight of the falling mass was equal to that of the unit under test. The height of the frame was such that the limiting velocity of the falling mass on impact was 30 ft. per sec.

It is important to note that in these experiments the conditions of test were as follows: 1) all specimens were designed to fail in bending; 2) the impact was characterized by local deformation; 3) the weight of the falling mass was equal to that of the specimen; 4) the striking velocity of the falling mass varied over a range from 8 ft. per sec. to 28 ft. per sec.

The tests showed that, in general, the form of damage to some simply-reinforced concrete units was of the same type under impact as under static loading. In such cases reasonable estimations of damage due to impact were obtained from an equation in which a reduction factor had been derived from considerations of an elastic material.

The tests have shown the limits of deformation in bending of some simple reinforced-concrete beams and slabs occurring after the steel had yielded or after the concrete had crushed.

In general, the form of damage to these units was roughly the same under either static loading or impact, and in such cases, the damage to beams and slabs due to impact was reasonably predicted from considerations of the energy absorbed under static loading, used in conjunction with a simple energy-equation.

Where the impact strength of a reinforced-concrete slab was considerably over-estimated, the poor strength was shown to be associated with the low impact strength of the steel employed as mild-steel reinforcement. The very poor performance of this steel under impact was not indicated by the usual routine mechanical acceptance tests, and it is considered that when the tension decides the capacity of reinforced-concrete units to absorb energy, the impact strength of the steel should be tested specially.

Destruction of concrete by frost

Arthur Richard Collins. *Journal of the Institution of Civil Engineers*, No. 1 (Nov. 1944), (London)
Highway Research Abstracts

Under wartime conditions, with the necessity for speed of construction and shortages of suitable labor and materials, it has not always been found possible to apply normal peacetime standards, and concrete of very low quality has sometimes been produced.

In view of the serious nature of the failures, an investigation was begun at the Road Research Laboratory on the general subject of the frost-resistance of concrete and a study was made of the mechanism by which damage is caused.

By means of a dilatometer the total volume of the water and the material in which it was absorbed was measured over a range of temperatures. With a reduction in temperature the normal contraction in volume occurred, but when any part of the water froze the volume-temperature relationship was interrupted by the increase in volume of the water. By plotting the volume against temperature the freezing-point of the water in the voids was determined. This technique has been applied to concrete and in an illustrated case the period of ice-formation extended from about − 3 to − 4 C. in the case illustrated.

An important factor in the formation of ice in porous materials is that ice crystals in contact with water grow parallel to the direction in which the heat is flowing, and not necessarily in the direction of least resistance. The crystals will continue to grow so long as a supply of water is available or until the pressure attains a point at which freezing is inhibited. This pressure which increases as the temperature falls, reaches a maximum of about 30,000 psi at — 22 C. and is exerted in a direction parallel to the axes of the ice crystals; that is, normal to the cold surface.

The mechanism of the failure of concrete during freezing can be vizualized as follows: Cooling begins at the exposed surface and extends slowly inwards. When any layer below the surface reaches a sufficiently low temperature, the water in the largest pores begins to freeze and the latent heat given up by it tends to maintain constant temperature at the point of ice-formation. The ice crystals so formed are in contact with unfrozen water in the surrounding smaller pores and, by drawing water from them, the crystals continue to grow.

As already stated, the force exerted by the ice will be perpendicular to the cold surface, and, if the concrete is of low strength, a plane of weakness parallel to the cold surface will tend to form at the level at which the ice is forming. The water drawn in by the growing crystals of ice will come first from the largest of the unfrozen pores. As these become emptied the supply will be restricted and the rate of growth of the ice will be checked. The evolution of latent heat will not then be sufficient to maintain the temperature constant at the point of ice-formation and the temperature will begin to fall once more. As there is then little or no water in the largest pores in the concrete immediately below the first ice layer, freezing will not begin again until the cold front has penetrated some distance, that is, until either the temperature has dropped sufficiently to freeze the pores that do contain water or a level is reached where the larger pores are not affected by the ice forming above them. The result of this process is that the concrete will contain a series of planes of weakness parallel to the surface of cooling. During subsequent cycles of freezing the ice will again tend to form at the same levels as before, because the pores there have been distended by the previous ice, and the freezing-point of the water in them will be higher than in the surrounding concrete.

The damage to the concrete is considered to be caused, not so much by the actual initial increase of volume of the water in the pores on freezing, as by the growth of the crystals afterwards and the consequent segregation and concentration of the ice into the layers.

Laboratory evidence demonstrating the difference between wet and dry freezing is given in Table 1, which shows the steady reduction in crushing strength of concrete frozen wet while that frozen dry continued to increase in strength though naturally at a lower rate than when cured at normal temperature.

TABLE 1—EFFECT OF WET AND DRY FREEZING ON THE CRUSHING STRENGTH OF CONCRETES

Number of cycles of freezing and thawing	Crushing strenth expressed as a percentage of the strength at 7 days		
	Frozen wet	Frozen dry	Cured at normal temperatures for same period
0	100	100	100
10	141	165	189
20	137	189	240
30	119	201	263
40	99	211	304
50	63	220	332
60	0	228	354

All specimens were cured at normal temperature for 7 days before freezing.

Conclusions. The main points raised in this paper may be summarized as follows: From the evidence available it appears that frost damage in concrete and other porous materials is due to the segregation of ice into layers rather than to the simple expansion of the frozen water in the pores. The mechanism is, in fact, similar to that occurring in soils during frost heaving.

The conditions favoring severe frost damage are concrete of high porosity and low strength, the presence of water within or in contact with the concrete, and cooling to a temperature several degrees below freezing-point over an appreciably long period.

The frost-resistance of concrete, like many of its other properties, is determined largely by the water/cement ratio, and the best way of obtaining good durability is by exercising proper control over the mixing operations. A nominal water/cement ratio of 0.70 by weight is suggested as a maximum for exposed concrete in emergency construction, but lower values than this would normally be required in peacetime.

An improvement in frost-resistance can be obtained, at the expense of a possible reduction in crushing strength, by the use of certain admixtures as tallow, resins and organic foaming agents.

Once concrete of low quality has been placed, little can be done to protect it from damage except by restricting access to moisture and protecting it from extremes of temperature.

ACI NEWS LETTER

Vol. 16 No. 6 JOURNAL of the AMERICAN CONCRETE INSTITUTE June 1945

ACI Book of Standards

In conformity with a decision of the Institute's Board of Direction, to republish ACI Standards in their adopted form (including convention revisions and editorial corrections), the *Proceedings* pages of this JOURNAL are chiefly devoted to the Institute's Standards adopted since the inauguration of the procedures under the Standards Committee in 1937. They have all been and will be available in separate prints and as soon as possible after the appearance of this June number they will become available for sale also in a single book publication. There will be re-publication of such books of Standards as rapidly as the appearance of new standards justifies.

It is well to call special attention to the fact that Standards adopted by convention action subject to revision and editorial correction, and subsequently ratified as revised by letter ballot of the Institute membership appear now in their corrected form.

New Members

The Board of Direction approved 39 applications for Membership (34 Individual, 4 Corporation, 1 Student) received in March and April as follows:

Bross, W. A., U. S. Engineer's Laboratory, University of Wash. Campus, Seattle 5, Wash.

Burns, Bennett W., P. O. Box 591, Baytown, Texas

Coff, Leo, 198 Broadway, New York 7, N. Y.

Colegio Nacional de Ingenieros Civiles de Cuba, Manzana de Gomez, Havana, Cuba

Foss, Frederic D., 256 Whaley St., Freeport L. I., N. Y.

Gilbert, J. R., 6503 Florida St., Chevy Chase, Md.

Hawley, A. J., 236 Harborview, Bridgeport, Conn.

Kavanagh, Thomas C., 2005 Coyle St., Brooklyn 29, N. Y.

Keil, J. P. G., American Viscose Corp., Marcus Hook, Penna.

Kensley, Phillip R., U. S. Engineer Laboratory, University of Washington Campus, Seattle 5, Wash.

Kuszewski, Zygmunt, 281 O'Connor St. Apt. No. 6, Ottawa, Ont., Canada.

Lashbrook, C. A., Okla. Testing Laboratories, P. O. Box 1982, Oklahoma City, Okla.

Lemke, Kenneth F., Box 183, Shawano, Wis.

Lyttle, James B., 635 East 211th St., Bronx 67, N. Y.

McCammon, G. A., Division Chief Engineer, Creole Petroleum Corp., Apartado 172, Maracaibo, Venezuela

McCoy, H. W., 303 Gary Ave., Wheaton, Ill.

McMillen, Dale S., 1621 Oakview Ave., Berkeley, Calif.

Maloney, Charles P., 3112 - K St., N. W., Washington 7, D. C.

Paulmier, C. M., c/o Oregon Shipbldg Corp., Adm. Bldg., Portland, Ore.

Pelarz, Enrique A., Ministerio de Agricultura, Havana, Cuba

Pritchard, E. O., Inversnaid Upton Wirral, Cheshire, England

Prokop, Charles J., 133-36 Dennis Ave., Springfield Gardens, Long Island, N. Y.

Quraishy, Saleh, Head, Dept. of Civil Engr., Muslim University, Aligarh, India

Robertson, C. R., 627 Arsan Ave., Baltimore 25, Md.

Rydland, Anton N., 515 Union Bldg., c/o T. V. A., Knoxville, Tenn.

Simmons Allen, P. O. Box 185, Bethany, West Va.

Societe Egyptienne de Tuyaux, Poteaux et Produits en Ciment Arme, 15 Rue Madabegh, B. P No. 111, Cairo, Egypt (Henry Barcilon)

Sorhegui, Agustin, Metropolitana 238, Havana, Cuba

Sproule, F. R., Wyandotte Chemicals Corp., Wyandotte, Mich.

Stearns, Edward W., 117 Meadowbrook Pl., South Orange, N. J.

Stephenson, Henson K., Texas Engineering Experiment Station, A & M College of Texas, College Station, Texas

Sundt, M. Eugene, 343 North Hermosa, Albuquerque, New Mexico

Tinkler, J. W., 16 Gould Street, Toronto, Ontario

Vaughan, Albert P., 5023 West End Ave., Chicago 44, Ill.

Vilaret, Manuel, c/o Sinclair Oil Co. of Cuba, Banco Canada, Aguiar No. 367, Havana, Cuba

Wilson, Merle D., 1066 Berwin St., Akron 10, Ohio

Wellington Harbour Board, P. O. Box 938, Wellington, New Zealand

Warzyn, W. W., 7318 Church Ave., Ben Avon, Pittsburgh 2, Pa.

Wayne County Road Comm., Board of. 3800 Barlum Tower, Detroit 26, Mich, (Paul Holland)

Who's Who

R. L. Bertin, Joseph DiStasio and Maurice P. VanBuren

are all members of the Institute; are all pretty well known to the readers of this JOURNAL as their present paper, the only paper presented in this issue of the JOURNAL, is not their first contribution.

Mr. Bertin, Chief Engineer of White Construction Company since 1917, has been a member of the Institute since 1921 and a record of some of his major activities in the Institute will be found in the 1944 Directory under his name, page 38. He has served as a member of the Board of Direction; has been active in committee work; written several papers.

Mr. Di Stasio, member of the Institute since 1920, Joseph Di Stasio and Co., Consulting Engineers, New York, has served as a member of the Institute's Advisory Committee and has twice contributed papers to these *Proceedings;* once before on the subject of the present contribution.

Mr. Van Buren has been a member of the Institute since 1926; collaborated with Joseph Di Stasio in presenting "Slabs Supported on Four Sides" to Volume 32, p. 350, ACI *Proceedings*, Jan.-Feb. 1936 Journal.

Patents for License

The United States Patent office has put into operation a new service to industry and inventors, to bring to the attention of the public, patented inventions under which the owners are willing to grant licenses on reasonable terms. To accomplish the results desired by the new service, a "Register of Patents" is now being established and will be maintained in the United States Patent Office. It will be available to the public for inspection in Washington. Lists of patents will be published in the *Official Gazette* of the patent office.

Honor Roll

February 1 to May 31, 1945

Rene Morales, in Havana, Cuba heads the list with 11 new Members since Feb. 1.

Rene Morales	**11**
A. Amirikian	**3**
J. H. Spilkin	**3**
Charles S. Whitney	**3**
Ernst Gruenwald	**2½**
Charles E. Wuerpel	**2½**
C. Blaschitz	**2**
Francis MacLeay	**2**
J. M. Wells	**2**
J. W. Kelly	**1½**
H. W. Cormack	1
Harry B. Dickens	1
R. F. Dierking	1
Harrison F. Gonnerman	1
G. H. Hodgson	1
William G. McFarland	1
Denis Matthews	1
D. E. Parsons	1
A. F. Penny	1
Byram Steel	1
G. W. Stokes	1
M. A. Timlin	1
Maxwell Upson	1
Stanton Walker	1
Roy Zipprodt	1

The following credits are, in each instance, "50-50" with another Member:

Birger Arneberg	Adolph Meyer
E. W. Bauman	M. D. Olver
Harmer E. Davis	Kanwar Sain
L. I. Johnstone	J. L. Savage
H. J. McGillivray	Oskar Schreier
R. E. McLaughlin	Wm. T. Summers

W. F. Way Only Colonel in Navy

Col. W. F. Way (ACI Member since 1921) wrote us not long ago from England. He ventures that he has at least one distinction in being "the only Colonel in U. S. Navy." His address is Colonel W. F. Way, U. S. Navy, 949, c/o Fleet Post Office, New York City. In 27 months he says he's had eight addresses. His letter was written before V-E day and doesn't say too much, but he does report that he has been getting the ACI JOURNAL lately and has read it in spite of the fact that destruction and not construction is his business. He says "I laugh at 'concrete for permanence' as an old fashioned idea, and if we are to continue to have wars, it's better to build with bricks because they can be used over again, while destroyed concrete structures don't seem to make even good fill".

Further he says, "really I'm in the Navy and assigned to ship salvage. The work has been very interesting; even if not too constructive at times." He reports having been through the Mediterranian and Normandy campaigns and recently in England to prepare for another duty.

Norman F. Stineman

one time editor of *Concrete*, Chicago, member of the Institute since 1930; twice a contributor to the Institute *Proceedings*, who has been connected with various federal war agencies in the engineering field for some time, is now in the Veterans Administration, identified with a big program of hospital construction.

Wallace L. Caldwell

ACI member since 1938, died April 22 in a Birmingham (Ala.) hospital from injuries received March 21 when his automobile rolled against him after he had parked it. He had been a resident of Birmingham since 1912 but was absent for some time in the twenties because of various executive responsibilities.

He first went to Birmingham as manager of the Pittsburgh Testing Laboratory, and at the time of his death, age 56, was president of the Alabama Asphaltic Limestone Co., president Southern Vacuum Concrete, Inc., president of the Aerocrete Western Corp., Chicago, and Vice Chairman of the Southern Research Institute.

He had been active in the field of lightweight concrete and lightweight concrete aggregates; was the inventor of the Caldwell slag machine. He had been active in civic and church affairs in Birmingham; was a past president of the Associated Industries of Alabama and the Rotary Club of Birmingham. At the time of his death he was a Director of the National Association of Manufacturers and of the Associated Industries of Alabama. He was also a member of the American Society of Civil Engineers, American Chemical Society, American Society for Testing Materials, American Society of Municipal Engineers, Association of Asphalt Paving Technologists, Alabama Engineers and Birmingham Engineer Club. He was a deacon of the Independent Presbyterian Church.

Journal Volume 16—*Proceedings* Vol. 41

This June issue of the ACI Journal concludes Journal V. 16, Proceedings V. 41 EXCEPT for the Supplement to the November 1945 Journal which will contain Title page, "Contents", closing discussion and Indexes—this Supplement to be mailed with the November Journal. Librarians watch for it. The Volume is then complete, ready to go to the binders.

SYNOPSES of RECENT ACI PAPERS and REPORTS are available for the asking - - - - below is a small sampling only from JOURNAL issues of the current volume year

A pamphlet including synopses for all of the current volume, Sept. 1944 to June 1945, will soon be available. The following and many others may be had in separate prints at 25 cents each except as otherwise noted; starred titles are 50 cents each.

THE EFFECTIVENESS OF VARIOUS TREATMENTS AND COATINGS FOR CONCRETE IN REDUCING THE PENETRATION OF KEROSENE 41-2

F. B. HORNIBROOK—Sept. 1944, p. 13-20 (V. 41)

Measurements were made of the penetration of kerosene under a 12 foot pressure head into discs of concrete which had received various treatments or coatings. The tests were classified into 7 groups as follows: (1) reference concrete, (2) integral admixtures, (3) sodium silicate and magnesium fluosilicate treatments, (4) plaster coats, plain and with admixtures, (5) magnesium oxychloride type coatings, (6) linseed oil and spar varnish coatings, and (7) synthetic plastic and latex coatings. Comparisons of the relative rates of penetration of kerosene into the specimens of each group are given, together with a discussion of various other properties of each group.

ADMIXTURES FOR CONCRETE 41-5

A REPORT BY ACI COMMITTEE 212—Nov. 1944, pp.73-88 (V. 41)

With the aim of providing a perspective of the field of admixtures for the use of the engineer confronted with a need of modifying concrete to meet special requirements of a given job, Committee 212 has classified admixtures into 9 broad groups. Discussions are given of the factors which might indicate the usefulness of admixtures of each group, and of the important effects which may ordinarily be expected from the use of materials of each group. The 9 groups are as follows: (1) accelerators, (2) air-entraining agents, (3) gas-forming agents, (4) natural cementing materials, (5) pozzolanic materials, (6) retarders, (7) water-repelling agents, (8) workability agents, and (9) miscellaneous.

THE EFFECT OF CURING CONDITIONS ON COMPRESSIVE, TENSILE AND FLEXURAL STRENGTH OF CONCRETE CONTAINING HAYDITE AGGREGATE 41-7

E. B. HANSON, JR. and W. T. NEELANDS—Nov. 1944, pp. 105-116 (V. 41)

Lightweight concrete has been given a severe test in the U. S. Maritime Commission's present concrete ship construction program. In its use, problems arose that could not be solved by the application of sand-gravel concrete data. This paper describes some of the strength characteristics of this type of concrete. Data herein are consistent in showing that rapid moisture loss from Haydite concrete produces a serious retrogression in the tensile and flexural strengths, regardless of the length of moist curing. This decline in strength, caused by drying shrinkage stresses developing in the outer fibers as the moisture content becomes unbalanced, is of a temporary nature and apparently can be curbed by the application of paint or membrane seal following the moist curing period. The drying shrinkage may well contribute to serious cracking in some types of structures if control is not maintained.

CONCRETE OPERATIONS IN THE CONCRETE SHIP PROGRAM★ 41-9

LEWIS H. TUTHILL—Jan. 1945, pp. 137-180 (V. 41)

This paper describes only briefly the hulls constructed in the concrete ship program of the U. S. Maritime Commission but goes into more detail in connection with problems encountered and their solution in the course of these concrete operations. Construction joint procedure, lightweight aggregate concrete and mix control, handling, placing and vibration practice, curing, testing and repair problems are described in the belief that much of this information is applicable to any concrete work of high standard. Design of hulls is not discussed except as construction is affected. The ships have not been in service sufficiently long to justify much discussion of their performance or durability.

AN INSTRUMENT AND A TECHNIC FOR FIELD DETERMINATION OF THE MODULUS OF ELASTICITY, AND FLEXURAL STRENGTH, OF CONCRETE (PAVEMENTS).........41-11

BARTLETT G. LONG, HENRY J. KURTZ, and THOMAS A. SANDENAW—Jan. 1945, pp. 217-232 (V. 41)

An instrument for determination of the dynamic modulus of elasticity of concrete, in situ, is described. Test results are presented which show (a) the comparison of test values of E, obtained by various older methods, with that obtained with the new instrument; and (b) the relationship of such values to the flexural strength of concrete. It is concluded that adoption of the new method and technic is justified; and that widespread use of the new instrument would eliminate the necessity for casting field specimens during construction (except perhaps for day-to-day control purposes) or of removing costly "samples" from completed works. A method for determining the thickness of concrete pavements is briefly discussed. A rather extensive bibliography is included.

synopses pamphlets, providing a survey of recent ACI work, are cheerfully sent on request - - - address

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Sources of Equipment, Materials and Services

A reference list of advertisers who participated in the Fourth Annual Technical Progress Issue of the ACI JOURNAL—the pages indicated will be found in the February 1945 issue and (when it is completed) in V. 41, ACI Proceedings. **Watch for the 5th Annual Technical Progress Section in the February 1946 JOURNAL.**

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Testing Equipment

ACI JOURNAL—June 1945

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