PROGRESS REPORT

OF THE

JOINT COMMITTEE ON STANDARD SPECIFICATIONS

FOR

CONCRETE AND REINFORCED CONCRETE

SUBMITTING

TENTATIVE SPECIFICATIONS FOR CONCRETE AND REINFORCED CONCRETE

Affiliated Committees

OF THE

American Society of Civil Engineers
American Society for Testing Materials
American Railway Engineering Association
American Concrete Institute
Portland Cement Association

Submitted to Constituent Organizations

June 4, 1921

PREFACE.

The Joint Committee on Standard Specifications for Concrete and Reinforced Concrete consists of five representatives from each of the following:

American Society of Civil Engineers,
American Society for Testing Materials,
American Railway Engineering Association,
American Concrete Institute,
Portland Cement Association.

This Committee is the successor of the Joint Committee on Concrete and Reinforced Concrete which was organized in Atlantic City, N. J., June 17, 1904, and was formed by the union of special committees appointed in 1903 and 1904 by the above-named organizations, except the American Concrete Institute which was added by invitation of the Joint Committee in 1915. The previous Committee presented progress reports in 1909 and 1912 and adopted a final report to its constituent organizations on July 1, 1916. It was the purpose of that Committee to prepare a Recommended Practice for Concrete and Reinforced Concrete. Its final report stated:

"The report is not a specification but may be used as a basis for specifications."

The present Joint Committee is charged with the preparation of Specifications for Concrete and Reinforced Concrete and in preparing these specifications is using as a basis the report of the former Joint Committee with such modifications as are necessary to make its recommendations agree with current practice, and such new data as mark advances in the art.

The initiative in bringing about the present Joint Committee was taken by the Committee on Reinforced Concrete of the American Society for Testing Materials on June 27, 1917, when the committee voted to request the Executive Committee of the Society to invite the Member-Societies of the previous Joint Committee to cooperate in the formation of a new Joint Committee. The Executive Committee approved this request on April 25, 1919, and an invitation was issued to each of the above-named organizations by the Executive Committee on behalf of the American Society for Testing

Materials, to appoint five members on a Joint Committee on Specifications for Reinforced Concrete. The last of these organizations accepted the invitation on November 22, 1919. On January 21, 1920, a call for an organizing meeting on February 11, 1920, was sent by the Executive Committee of that Society to each of the twenty-five representatives of cooperating organizations, together with a list of members of the Joint Committee, and an outline of organization that had been previously submitted by the American Society for Testing Materials to and approved by the cooperating organizations.

The organizing meeting was held at the Engineers' Club, Philadelphia, Pa., and was called to order by George S. Webster, then Vice-President of the American Society for Testing Materials, who explained that he had been directed by the Executive Committee of that Society to act as Temporary Chairman; he further stated that C. L. Warwick, Secretary-Treasurer of the Society, had been requested to act as Temporary Secretary until a formal organization of the Joint Committee had been effected.

The personnel of the Joint Committee is as follows:

American Society of Civil Engineers.

Rudolph P. Miller, *Chairman*,
Consulting Engineer, New York City.
Resigned March 28, 1921. Succeeded as Chairman by
W. A. Slater, Engineer-Physicist,
Bureau of Standards, Washington, D. C.
William K. Hatt, Professor of Civil Engineering,
Purdue University, Lafayette, Ind.
A. E. Lindau, General Manager of Sales,
Corrugated Bar Company, Buffalo, N. Y.
Sanford E. Thompson, Consulting Engineer,
Boston, Mass.
Appointed to fill vacancy,
Franklin R. McMillan,
628 Metropolitan Bank Building, Minneapolis, Minn.

American Society for Testing Materials.

Richard L. Humphrey, *Chairman*,
Consulting Engineer, Philadelphia, Pa.
Albert T. Goldbeck, Engineer of Tests,
Bureau of Public Roads, Washington, D. C.
Edward E. Hughes, Vice-President,
Franklin Steel Works, Franklin, Pa.
Henry H. Quimby, Chief Engineer,
Department of City Transit, Philadelphia, Pa.
Leon S. Moisseiff, Consulting Engineer,
New York City.

American Railway Engineering Association.

J. J. Yates, *Chairman*,
Bridge Engineer, Central Railroad of New Jersey, Jersey City, N. J.
George E. Boyd, Division Engineer,
Delaware, Lackawanna and Western Railroad Company, Buffalo, N. Y.
Frederick E. Schall, Bridge Engineer,
Lehigh Valley Railroad Company, Bethlehem, Pa.
H. T. Welty, Engineer of Structures,
New York Central Railroad, New York City.
C. C. Westfall, Engineer of Bridges,
Illinois Central Railroad Company, Chicago, Ill.

American Concrete Institute.

S. C. Hollister, *Chairman*,
Consulting Engineer, Philadelphia, Pa.
Robert W. Lesley, Past-President, Association of American Portland Cement Manufacturers,
Philadelphia, Pa.
Arthur R. Lord, President,
Lord Engineering Company, Chicago, Ill.
Egbert J. Moore, Vice-President,
Turner Construction Company, New York City.
Leonard C. Wason, President,
Aberthaw Construction Company, Boston, Mass.
Resigned October 19, 1920. Succeeded by
Angus B. MacMillan, Chief Engineer,
Aberthaw Construction Company, Boston, Mass.

Portland Cement Association.

Frederick W. Kelley, *Chairman*,
President, Helderberg Cement Company, Albany, N. Y.
Duff A. Abrams, Professor in Charge,
Structural Materials Research Laboratory, Lewis Institute, Chicago, Ill.
Ernest Ashton, Chemical Engineer,
Lehigh Portland Cement Company, Allentown, Pa.
Edward D. Boyer, Cement Expert,
Atlas Portland Cement Company, New York City.
J. H. Libberton, Manager Service Bureau,
Universal Portland Cement Company, Chicago, Ill.
Resigned January 1, 1921. Succeeded by
J. E. Freeman, Manager, Structural Bureau,
Portland Cement Association, Chicago, Ill.

The Committee perfected a permanent organization on February 11, 1920, under the title "Joint Committee on Standard Specifications for Concrete and Reinforced Concrete" with the following officers:

Chairman, Richard L. Humphrey, Philadelphia, Pa.,
Vice-Chairman, J. J. Yates, Jersey City, N. J.,
Secretary-Treasurer, Duff A. Abrams, Chicago, Ill.,

and an Executive Committee consisting of these officers, and Rudolph P. Miller,[1] New York City, and S. C. Hollister, Philadelphia.

The Committee adopted Rules of Organization and apportioned the work of preparing a tentative draft of the specifications among sub-committees, the present personnel of which is given below:

1. *Materials (other than Reinforcing).*
   Albert T. Goldbeck, *Chairman*
   Duff A. Abrams
   J. E. Freeman[2]
   Sanford E. Thompson
   J. J. Yates

2. *Metal Reinforcement.*
   J. J. Yates, *Chairman*
   Duff A. Abrams
   William K. Hatt
   Edward E. Hughes
   A. E. Lindau

3. *Proportioning and Mixing.*
   W. A. Slater, *Chairman*
   Duff A. Abrams
   Ernest Ashton
   George E. Boyd
   Henry H. Quimby

4. *Forms and Placing.*
   George E. Boyd, *Chairman*
   Edward D. Boyer
   Angus B. MacMillan[3]
   Egbert J. Moore
   Frederick E. Schall

5. *Design.*
   S. C. Hollister, *Chairman*
   William K. Hatt
   A. E. Lindau
   Arthur R. Lord
   Franklin R. McMillan
   Egbert J. Moore
   W. A. Slater
   H. T. Welty

6. *Details of Construction and Fireproofing.*
   Franklin R. McMillan,[4] *Chairman*
   William K. Hatt
   Arthur R. Lord
   Leon S. Moisseiff
   C. C. Westfall

7. *Waterproofing and Protective Treatment.*
   Frederick W. Kelley, *Chairman*
   Albert T. Goldbeck
   S. C. Hollister
   Robert W. Lesley
   C. C. Westfall

8. *Surface Finish.*
   Henry H. Quimby, *Chairman*
   Edward D. Boyer
   J. E. Freeman[2]
   Angus B. MacMillan[3]
   H. T. Welty

9. *Form of Specification.*
   Richard L. Humphrey, *Chairman*
   Duff A. Abrams, *Secretary*
   George E. Boyd
   Albert T. Goldbeck
   S. C. Hollister
   Frederick W. Kelley
   Franklin R. McMillan[4]
   Henry H. Quimby
   W. A. Slater
   J. J. Yates

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[1] Succeeded by W. A. Slater, May 25, 1921.
[2] Succeeded J. H. Libberton, January 1, 1921.
[3] Succeeded Leonard C. Wason, October 19, 1920.
[4] Succeeded Rudolph P. Miller, May 25, 1921.

The Joint Committee held the following meetings:

Organization meeting, Philadelphia, February 11, 1920.
Second meeting, Asbury Park, N. J., June 23 and 24, 1920.
Third meeting, New York City, October 26, 27 and 28, 1920.
Fourth meeting, New York City, December 15, 16 and 17, 1920.
Fifth meeting, New York City, March 2, 3 and 4, 1921.
Sixth meeting, New York City, April 13, 14 and 15, 1921.

At these meetings the Committee considered the reports of its sub-committees which were edited by the Sub-Committee on Form and incorporated in the Tentative Specifications for Concrete and Reinforced Concrete herewith submitted.

The Rules of Organization of the Joint Committee which were submitted to, and approved by, each of its constituent organizations, provide that,

> "The initial report of the Joint Committee shall be considered by each of the five organizations as a tentative report submitted for criticism and discussion limited to not less than six months nor more than one year. Such discussions shall then be referred to the Joint Committee for consideration in revising its report." (Article IX, Section 2.)

The Joint Committee, in submitting these Tentative Specifications for Concrete and Reinforced Concrete in accordance with the above requirement, wishes it clearly understood that it reserves the right to make such changes as may be found desirable, after a further study of the available data. While not prepared to submit a final report at this time the Committee is of the opinion that the specifications are in such shape as to make it desirable to issue them tentatively for the purpose of facilitating the final submission of Standard Specifications for Concrete and Reinforced Concrete.

The Joint Committee earnestly requests that every facility be provided by its constituent organizations for the fullest consideration of these Tentative Specifications in order that it may be in a position, as a result of their thorough discussion, to reflect in the final specifications the best current practice.

The Joint Committee further calls attention to the fact that it has undertaken to prepare specifications covering the fundamentals to be observed in the general use of concrete and reinforced concrete; no attempt has been made to cover the details involved in the use of these materials in special structures. While the sections relating to design deal primarily with building construction, nevertheless the principles involved are in general applicable to structures of other types. It is expected that in using these specifications the necessary supplemental requirements will be added covering details.

This report has been submitted to letter ballot of the committee which consists of 25 members, representing five societies, all of whom have voted affirmatively.

Respectfully submitted,

RICHARD L. HUMPHREY, *Chairman.*

J. J. YATES, *Vice-Chairman.* DUFF A. ABRAMS, *Secretary-Treasurer.*

ERNEST ASHTON,
GEORGE E. BOYD,
EDWARD D. BOYER,
J. E. FREEMAN,
ALBERT T. GOLDBECK,
WILLIAM K. HATT,
S. C. HOLLISTER,
EDWARD E. HUGHES,
FREDERICK W. KELLEY,
ROBERT W. LESLEY,
A. E. LINDAU,
ARTHUR R. LORD,
ANGUS B. MAC MILLAN,
FRANKLIN R. MCMILLAN,
LEON S. MOISSEIFF,
EGBERT J. MOORE,
HENRY H. QIUMBY,
FREDERICK E. SCHALL,
W. A. SLATER,
SANFORD E. THOMPSON,
H. T. WELTY,
C. C. WESTFALL.

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List of Tables.

List of Appendices.

The specifications and methods of test given in Appendices 3 to 15, inclusive, form a part of the Tentative Specifications for Concrete and Reinforced Concrete.[1]

[1] These specifications and methods of test are those of the American Society for Testing Materials, either in their present form as adopted by the Society or in the form in which the respective committees of the Society will recommend them for action at the annual meeting of the Society, June 21-24, 1921.

[2] American Society for Testing Materials, 1921 Book of A. S. T. M. Standards.

[3] American Society for Testing Materials, *Proceedings*, Vol. XXI, Part I (1921).

TENTATIVE SPECIFICATIONS

FOR

CONCRETE AND REINFORCED CONCRETE.

I. GENERAL INSTRUCTIONS.

1. These specifications are not complete; they cover the general conditions affecting the use of concrete and reinforced concrete. To complete them it will be necessary for the engineer to General Instructions.

(*a*) Provide the detail specifications covering the work in particular in which the concrete and reinforced concrete are to be used;

(*b*) Insert in Section 4 the strengths required for the several classes of concrete specified, based either upon preliminary tests or upon the values given in Table IV;

(*c*) Insert in Section 14 the sizes of aggregates required;

(*d*) Strike out one of the titles of the specifications in Section 20;

(*e*) Strike out one of the titles of the specifications in Section 24;

(*f*) Strike out one of the words "volume" or "weight" in Section 27;

(*g*) Strike out two of the three Sections 28 and fill in the necessary blanks for the proportions;

(*h*) Insert in Section 29 the slumps required;

(*i*) Strike out the method or methods inapplicable to the work, in Section 50;

(*j*) Strike out one of the two Sections 97.

II. DEFINITIONS.

2. The following definitions give the meaning of certain terms as used in these specifications: Definitions.

Acid Proofing.—Treatment of a concrete surface to resist the action of acid solutions.

Aggregate.—Inert material which is mixed with Portland cement and water to produce concrete; in general aggregate consists of sand, pebbles, gravel, crushed stone or gravel, or similar materials. (See *Fine Aggregate, Coarse Aggregate.*)

Approved.—Meeting the approval of, or specifically authorized by, the Engineer.

Buttressed Retaining Wall.—A reinforced concrete wall having a vertical stem and a horizontal base, with brackets on the side opposite the pressure face uniting the vertical section with the toe of the base.

Cantilever Retaining Wall.—A reinforced concrete wall having a vertical stem and a horizontal base, each of which resists by cantilever action the pressure to which it is subjected.

Cellular Retaining Wall.—A reinforced concrete wall with a horizontal base, longitudinal vertical sections, and a series of transverse walls, dividing the space between the longitudinal walls into cells which are filled with earth, or other suitable material. If the top of the cells is covered by a floor slab, the front longitudinal wall and the filling may be omitted.

Coarse Aggregate.—Aggregate retained on a No. 4 sieve and of a maximum size generally not larger than 3 in. (See *Aggregate*, *Fine Aggregate.*)

Column.—A vertical compression member whose length exceeds three times its least horizontal dimension.

Column Capital.—An enlargement of the upper end of a reinforced concrete column built monolithic with the column and flat slab to increase the moment of inertia of the column and the shearing resistance of the slab at sections where high bending moment or high shear may occur.

Column Strip.—A portion of a panel of a flat slab which has a uniform width equal to one-fourth of the panel length on a line perpendicular to the direction of the strip, and whose outer edge lies on the edge of the panel. (See *Middle Strip.*)

Concrete.—A mixture of Portland cement, fine aggregate, coarse aggregate and water. (See *Mortar.*)

Consistency.—A general term used to designate the relative plasticity of freshly mixed mortar and concrete.

Counterforted Retaining Wall.—A reinforced concrete wall having a vertical stem and a horizontal base with brackets on the pressure face uniting the vertical section with the heel of the base.

Crusher-Run Stone.—Unscreened crushed stone. (See *Stone Screenings.*

Cyclopean Concrete.—Concrete in which stones larger than one-man size are individually embedded.

Dead Load.—The weight of the structure plus fixed loads and forces.

Deformed Bar.—Reinforcement bar with shoulders, lugs or projections formed integrally from the body of the bar during rolling.

Diagonal Direction.—A direction parallel or approximately parallel to the diagonal of the panel.

Dropped Panel.—The structural portion of a flat slab which is thickened throughout an area surrounding the column capital.

Effective Area of Concrete.—The area of a section of the concrete which lies between the tension reinforcement and the compression surface of the beam or slab.

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

Engineer.—The engineer in responsible charge of design and construction.

Fine Aggregate.—Aggregate passing through a No. 4 sieve. (See *Aggregate, Coarse Aggregate.*)

Flat Slab.—A flat concrete floor or roof plate having reinforcement bars extending in two or more directions and having no beams or girders to carry the load to the supporting columns.

Footing.—A structural unit used to distribute wall or column loads to the supporting material, either directly or through piles.

Gravel.—Loose material containing particles larger than sand, resulting from natural crushing and erosion of rocks. (See *Sand.*)

Laitance.—The extremely fine particles which separate from freshly deposited mortar or concrete and collect on the top surface.

Live Load.—Loads and forces which are variable.

Membrane Waterproofing.—A coating reinforced by fabric, felt, or similar toughening material applied to structures to prevent contact of moisture.

Middle Strip.—The portion of a panel of a flat slab which extends in a direction parallel to a side of the panel, whose width is one-half the panel length on a line at right angles to the direction of the strip and whose center line lies on the center line of the panel. (See *Column Strip.*)

Mortar.—A mixture of Portland cement, fine aggregate and water. (See *Concrete.*)

Negative Reinforcement.—Reinforcement so placed as to take stress due to negative bending moment.

Oilproofing.—Treatment of a concrete surface to resist the action of mineral, animal, or vegetable oils.

One-Man Stone.—Stone larger than coarse aggregate and not exceeding 100 lb. in weight. (See *Rubble Concrete.*)

Panel Length.—The distance between centers of two columns of a panel, in either rectangular direction.

Pedestal or Pier.—A vertical compression member whose length does not exceed three times its least horizontal dimension.

Pedestal Footing.—A member supporting a column, in which the projection from the face of the column on all sides is less than one-half the depth.

Plain Concrete.—Concrete without metal reinforcement.

Positive Reinforcement.—Reinforcement so placed as to take stress due to positive bending moment.

Portland Cement.—The product obtained by finely pulverizing clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

Principal Design Section.—The vertical sections in a flat slab on which the moments in the rectangular directions are critical. (See Section 146.)

Ratio of Reinforcement.—The ratio of the effective area of the reinforcement cut by a section of a beam or slab to the effective area of the concrete cut by that section.

Rectangular Direction.—A direction parallel to a side of the panel.

Reinforced Concrete.—Concrete in which metal is embedded in such a manner that the two materials act together in resisting stress.

Rubble Aggregate.—Stone or gravel larger than coarse aggregate and not larger than one-man stone (See *One-Man Stone.*)

Rubble Concrete.—Concrete in which pieces of rubble aggregate are individually embedded. (See *Rubble Aggregate.*)

Sand.—Loose material consisting of small grains (commonly quartz) resulting from the natural disintegration of rocks. (See *Gravel.*)

Screen.—A metal plate with closely spaced circular perforations. (See *Sieve.*)

Sieve.—Woven wire cloth with square openings. (See *Screen.*)

Slump.—The shortening of a standard test mass of concrete used as a measure of workability.

Standard Sand.—Natural sand mined at Ottawa, Ill., screened to pass a No. 20 sieve and retained on a No. 30 sieve, used as the fine aggregate in standard strength tests of Portland cement. (See Appendix 3 for Specifications.)

Stone Screenings.—Unscreened crushed stone passing through a No. 4 sieve. (See *Crusher-Run Stone.*)

Tremie.—A water-tight pipe of suitable dimensions, generally used in a vertical position, for depositing concrete under water.

Wall Beam.—A reinforced concrete beam which extends from column to column along the outer edge of a wall panel.

III. QUALITY OF CONCRETE.

Quality.

3. The quality of concrete shall be expressed in terms of workability as determined by the slump test and of the compressive strength at 28 days as determined by concrete tests of the materials to be used as specified in Section 28. The proportions required to produce concrete having the strength specified in Section 4 shall be determined in advance of the mixing of the concrete.

Strength.

4. The concrete shall develop under the conditions specified in Section 3, for the various parts of the work, the following strengths[1]:

.... lb. per sq. in.

.... lb. per sq. in.

.... lb. per sq. in.

.... lb. per sq. in.

Tests of Field Specimens.

5. Field concrete test specimens shall be made, stored and tested in accordance with the Standard Methods of Making and Storing Specimens of Concrete in the Field (Serial Designation: C 31–21) of the American Society for Testing Materials. (Appendix 14.)

IV. MATERIALS.

A. Portland Cement.

Portland Cement.

6. Portland cement shall conform to the Standard Specifications and Tests for Portland Cement (Serial Designation: C 9–21) of the American Society for Testing Materials[2] (Appendix 3) and subsequent revisions thereof.

B. Fine Aggregate.

General Requirements.

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

Grading.

8. Fine aggregate shall range in size from fine to coarse, preferably within the following limits:

Passing through No. 4 sieve	not less than	95 per cent
Passing through No. 50 sieve	not more than	30 "
Weight removed by decantation	" "	3 "

[1] The engineer should insert the strengths required for the several classes of concrete specified, based either upon preliminary tests or upon the values given in Table IV.

[2] These specifications are also a standard of the following organizations: American Engineering Standards Committee, United States Government, American Railway Engineering Association, American Concrete Institute, and the Portland Cement Association.

Sieve Analysis.

9. The sieves and method of making sieve analysis shall conform to the Tentative Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C 41–21 T) of the American Society for Testing Materials. (Appendix 9.)

Decantation Test.

10. The decantation test shall be made in accordance with the Standard Method of Test for Quantity of Clay and Silt in Sand for Highway Construction (Serial Designation: D 74–21) of the American Society for Testing Materials. (Appendix 10.)

Mortar Strength Test.

11. Fine aggregate shall preferably be of such a quality that mortar briquettes, cylinders or prisms, consisting of one part by weight of Portland cement and three parts by weight of fine aggregate,[1] mixed and tested in accordance with the methods described in the Standard Specifications and Tests for Portland Cement (Appendix 3) will show a tensile or compressive strength at ages of 7 and 28 days not less than that of 1 : 3 standard Ottawa sand mortar of the same plasticity made with the same cement. However, fine aggregate which fails to meet this requirement may be used, provided the proportions of cement, fine aggregate, coarse aggregate and water are such as to produce concrete of the strength specified.[2] Concrete tests shall be made in accordance with the Tentative Methods of Making Compression Tests of Concrete (Serial Designation: C 39–21 T) of the American Society for Testing Materials. (Appendix 13.)

Organic Impurities in Sand.

12. Natural sand which shows a color darker than the standard color when tested in accordance with the Tentative Method of Test for Organic Impurities in Sands for Concrete (Serial Designation: C 40–21 T) of the American Society for Testing Materials (Appendix 11) shall not be used, unless the concrete made with the materials and in the proportions to be used on the work is shown by tests to be of the required strength.

C. *Coarse Aggregate.*

General Requirements.

13. Coarse aggregate shall consist of crushed stone, gravel, or other approved inert materials with similar characteristics, or combinations thereof, having clean, hard, strong, durable, uncoated particles free from injurious amounts of soft, friable, thin, elongated or laminated pieces, alkali, organic or other deleterious matter.

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[1] In testing aggregate, care should be exercised to avoid the removal of any coating on the grains which may affect the strength. Natural sand should not be dried before being made into mortar, but should contain natural moisture. The quantity of water contained may be determined on a separate sample and the weight of the sand used in the test corrected for the moisture content.

[2] Table IV furnishes a guide in determining the proportions of materials required to produce a concrete of a given strength, using aggregates of various sizes and concrete of different consistencies.

14. Coarse aggregate shall range in size from fine to coarse within the following limits[1]: **Grading.**

Passing —[a] in. Sieve (maximum size).......not more than 95 per cent
Passing —[a] in. " (intermediate size) .... —[a] to —[a] "
Passing No. 4 " ....not more than 15 "
Passing No. 8 " .... " " " 5 "

15. The test for size and grading of aggregate shall be made in accordance with the Tentative Method of Test for Sieve Analysis of Aggregates for Concrete. (Appendix 9.) **Sieve Sizes.**

D. Rubble and Cyclopean Aggregate.

16. Rubble aggregate shall consist of clean, hard, durable stone larger than coarse aggregate and not larger than one-man stone. **Rubble Aggregate.**

17. Cyclopean aggregate shall consist of clean, hard, durable stone, free from fissures and planes of cleavage and larger than one-man stone. **Cyclopean Aggregate.**

E. Storage of Aggregate.

18. Aggregate shall be so stored on platforms or otherwise as to avoid the inclusion of foreign materials. Before using, frost, ice and lumps of frozen materials shall be removed. **Aggregate Storage.**

F. Water.

19. Water for concrete shall be clean and free from oil, acid, alkali, organic matter, or other deleterious substance. **General Requirements.**

G. Metal Reinforcement.

20. Metal reinforcement shall be of a quality and character meeting the requirements of the Standard Specifications[2] for Billet-Steel Concrete Reinforcement Bars (Serial Designation: A 15–14) of the American Society for Testing Materials (Appendix 4), Standard **Quality.**

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

[a] The engineer should insert in these blanks the sizes of aggregates required. The size and grading to be used will be governed by local conditions. The limitation on size and grading is intended to secure uniformity of aggregate. The following table indicates desirable gradings for coarse aggregate for certain maximum sizes:

Maximum Size of Aggregate, in.	Per Cent by Weight Passing Through Standard Sieves with Square Openings.					Per Cent Passing, not more than	
	3 in.	2 in.	$1\frac{1}{2}$ in.	1 in.	$\frac{3}{4}$ in.	No. 4 Sieve.	No. 8 Sieve.
3............	100	...	40 – 75	...	...	15	5
2............	...	100	...	40 – 75	...	15	5
$1\frac{1}{2}$	...	...	100	...	40 – 75	15	5
1............	...	...	...	100	...	15	5
$\frac{3}{4}$	...	...	...	...	100	15	5

[2] See footnote 1, p. 18.

Specifications[1] for Rail-Steel Concrete Reinforcement Bars (Serial Designation: A 16–14) of the American Society for Testing Materials (Appendix 5), except that the provision for machining deformed bars before testing shall be eliminated.

Wire. 21. Wire for concrete reinforcement shall conform to the requirements of the Tentative Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement (Serial Designation: A 82–21 T) of the American Society for Testing Materials. (Appendix 8.)

Standard Sizes of Bars. 22. Reinforcement bars shall conform to the areas and equivalent sizes shown in Table I.

TABLE I.—SIZES AND AREAS OF REINFORCEMENT BARS.

Size of Bar, in.	Area, sq. in.	
	Round.	Square.
$\frac{3}{8}$	0.110	.....
$\frac{1}{2}$	0.196	0.250
$\frac{5}{8}$	0.307	.....
$\frac{3}{4}$	0.442	.....
$\frac{7}{8}$	0.601	.....
1	0.785	1.000
$1\frac{1}{8}$	.....	1.266
$1\frac{1}{4}$	.....	1.563

The areas of deformed bars shall be determined by the minimum cross-section thereof.

Deformed Bars. 23. An approved deformed bar shall be one that will develop a bond strength at least 25 per cent greater than that of a plain round bar of equivalent cross-sectional area.[2]

Structural Shapes. 24. Structural steel shapes used for reinforcement shall conform to the requirements of the Standard Specifications[3] for Structural Steel for Bridges (Serial Designation: A 7–21) of the American Society for Testing Materials (Appendix 6), Standard Specifications[3] for Structural Steel for Buildings (Serial Designation: A 9–21) of the American Society for Testing Materials. (Appendix 7.)

Cast Iron. 25. The quality of cast iron used in composite columns shall conform to the requirements of the Standard Specifications for Cast-Iron Pipe and Special Castings (Serial Designation: A 44–04) of the American Society for Testing Materials. (Appendix 15.)

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[1] The engineer should strike out one of these titles. The Committee recommends as preferred material for reinforcement that meeting the requirements of the Standard Specifications for Billet-Steel Concrete Reinforcement Bars of intermediate grade (except as noted under Section 20), made by the open-hearth process.

[2] The Committee has under consideration a specification for deformed bars but is not prepared at this time to make more definite recommendations.

[3] The engineer should strike out one of these titles.

V. PROPORTIONING AND MIXING CONCRETE.

A. Proportioning.

26. The unit of measure shall be the cubic foot. Ninety-four pounds (one bag or $\frac{1}{4}$ bbl.) of Portland cement shall be considered as one cubic foot. **Unit of Measure.**

27. Each of the constituent materials shall be measured separately by volume[1] weight.[1] The method of measurement shall be such as to secure the specified proportions in each batch. If volume measurement is used, the fine aggregate and the coarse aggregate shall be measured loose as thrown into the measuring device. The water shall be measured by an automatic device that will insure the same quantity in successive batches. **Method of Measuring.**

28.[2] The proportions of cement, water and aggregate shall be such as to produce concrete of the strength and quality specified in Sections 3 and 4. The proportions shall be 1 part of Portland cement, —[a] parts of fine aggregate, and —[a] parts of coarse aggregate as determined by the engineer from concrete tests of the materials to be used. The tests shall be made in accordance with the Tentative Methods of Making Compression Tests of Concrete. (Appendix 13.) The quantity of water used shall be such as to produce concrete of the consistency required by the particular class of work and shall be as specified in Section 29. In case the grading of the supply of available aggregate varies from that upon which the proportions were based, such aggregate may be used, provided the new proportions, as determined by the engineer, are such as to produce concrete of the required strength and quality. **Proportions.**

28.[2] The contractor shall use materials, so proportioned and mixed, as to produce concrete of the required workability and strength.[3] Frequent compression tests of the concrete used in the work will be made by the engineer, and in case of failure to meet the specified strength, the contractor shall make such changes in the materials, proportions, or mixing, as may be necessary to secure concrete of the required strength. Concrete tests shall be made in accordance with the Standard Methods of Making and Storing Specimens of Concrete in the Field (Appendix 14) and the Tentative Methods of Making Compression Tests of Concrete (Appendix 13). **Proportions.**

28.[2] The proportions shall be 1 part of Portland cement, —[a] parts of fine aggregate, and —[a] parts of coarse aggregate. The pro- **Proportions.**

[1] The engineer should strike out one of these terms.

[2] The engineer should indicate his choice of the method of proportioning to be used by striking out two of the Sections numbered 28.

[3] The use of this method should be accompanied by a clause in the contract which indicates the procedure to be followed in case tests show that concrete of the specified strength has not been obtained.

[a] The engineer should fill in these blanks.

portions of materials shall be selected from Table IV. In case the grading of the supply of available aggregate varies from that upon which the proportions were based, such aggregate may be used, provided the new proportions, as determined by the engineer, are such as to produce concrete of the required strength and quality.

B. Consistency.

Consistency. 29. The engineer shall determine and specify the consistency of the concrete for various portions of the work based on tests of the materials to be used. The consistency of the concrete shall be measured by the slump test in the manner described in the Tentative

TABLE II.—WORKABILITY OF CONCRETE.

Type of Concrete.	Maximum Slump, in.
1. Mass concrete	*a*
2. Reinforced concrete:	
(*a*) Thin vertical sections and columns	*a*
(*b*) Heavy sections	*a*
(*c*) Thin confined horizontal sections	*a*
3. Roads and pavements:	
(*a*) Hand finished	*a*
(*b*) Machine finished	*a*
4. Mortar for floor finish	*a*

Specifications for Workability of Concrete for Concrete Pavements (Serial Designation: D 62–20 T) of the American Society for Testing Materials. (Appendix 12.) The slump for different types of concrete shall not be greater than indicated in Table II.

The consistency shall be checked from time to time during the progress of the work.

a The engineer should insert the slumps required, based on tests called for in this section. The slump test requirement is intended to insure concrete mixed with the minimum quantity of water required to produce a plastic mixture The following table indicates the maximum slump desirable for the various types of concrete, based on average aggregates and proportions:

Type of Concrete.	Maximum Slump, in.
1. Mass concrete	2
2. Reinforced concrete:	
(*a*) Thin vertical sections and columns	6
(*b*) Heavy sections	2
(*c*) Thin confined horizontal sections	8
3. Roads and pavements:	
(*a*) Hand finished	4
(*b*) Machine finished	1
4. Mortar for floor finish	2

C. Mixing.

30. Mixing, unless otherwise authorized by the engineer, shall be done in a batch mixer of approved type, which will insure a uniform distribution of the materials throughout the mass, so that the mixture is uniform in color and homogeneous. The mixer shall be equipped with suitable charging hopper, water storage, and a water-measuring device controlled from a case which can be kept locked and so constructed that the water can be discharged only while the mixer is being charged. It shall also be equipped with an attachment for automatically locking 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 before recharging. The mixer shall be cleaned at frequent intervals while in use. **Machine Mixing.**

31. The mixing of each batch shall continue not less than 1½ minutes after all the materials are in the mixer, during which time the mixer shall rotate at a peripheral speed of about 200 ft. per minute. The volume of the mixed material per batch shall not exceed the manufacturer's rated capacity of the mixer. **Time of Mixing.**

32. When hand mixing is authorized by the engineer it shall be done on a water-tight platform. The materials shall be turned at least six times after the water is added and until the batch is homogeneous in appearance and color. **Hand Mixing.**

33. The retempering of concrete or mortar which has partially hardened, that is, remixing with or without additional cement, aggregate or water, shall not be permitted. **Retempering.**

VI. DEPOSITING CONCRETE.

A. Depositing in Air.

34. Before beginning a run of concrete, hardened concrete and foreign materials shall be removed from the inner surfaces of mixing and conveying equipment. **General.**

35. Before depositing concrete, debris shall be removed from the space to be occupied by the concrete; forms shall be thoroughly wetted (except in freezing weather) or oiled. Reinforcement shall be thoroughly secured in position and approved by the engineer. **Approval.**

36. Concrete shall be handled from the mixer to the place of final deposit as rapidly as practicable by methods which shall prevent the separation or loss of the ingredients. It shall be deposited in the forms as nearly as practicable in its final position to avoid rehandling. **Handling.**

It shall be deposited in approximately uniform horizontal layers; the piling up of the concrete in the forms in such manner as to permit the escape of the mortar from the coarse aggregate will not be permitted. Forms for walls or other thin section of considerable height, shall be provided with openings, or other devices that will permit the concrete to be placed in a manner that will avoid accumulations of hardened concrete on forms or metal reinforcement. Under no circumstances shall concrete that has partially hardened be deposited in the work.

Spouting. 37. When concrete is conveyed by spouting, the plant shall be of such size and design as to insure a practically continuous flow in the spout. The angle of the spout with the horizontal shall be such as to allow the concrete to flow without separation of the ingredients.[1] The spout shall be thoroughly flushed with water before and after each run. The delivery from the spout shall be as close as possible to the point of deposit. When operation must be intermittent, the spout shall discharge into a hopper.

Compacting. 38. Concrete, during and immediately after depositing, shall be thoroughly compacted by means of rods or forks. For thin walls or inaccessible portions of the forms where rodding or forking is impracticable, the concrete shall be assisted into place by tapping or hammering the forms. The concrete shall be thoroughly worked around the reinforcement, and around embedded fixtures, into the corners of the forms.

Removal of Water. 39. Water shall be removed from excavations before concrete is deposited unless otherwise directed by the engineer. A continuous flow of water into the excavation shall be diverted through proper side drains to a sump, or by other approved methods which will avoid washing the freshly deposited concrete.

Protection. 40. Exposed surfaces of concrete subjected to premature drying shall be kept thoroughly wetted for a period of at least 7 days.

Cold Weather. 41. Concrete mixed and deposited during freezing weather shall have a temperature of not less than 50° F. nor more than 100° F. Suitable means shall be provided for maintaining a temperature of at least 50° F. for not less than 72 hours after placing, or until the concrete has thoroughly hardened. The methods of heating the materials and protecting the concrete shall be approved by the engineer. Salt, chemicals or other foreign materials shall not be used to prevent freezing.

[1] An angle of about 27 deg., or one vertical to two horizontal, is good practice. Spouting through a vertical pipe is satisfactory when the flow is continuous; when it is unchecked and discontinuous it is highly objectionable unless the flow is broken by baffles.

42. Concrete shall be deposited continuously and as rapidly as practicable and until the unit of operation, as approved by the engineer, is completed. Construction joints at points not provided for in the plans shall be made in accordance with the provisions in Section 69. **Depositing Continuously.**

43. The surface of the hardened concrete shall be roughened and thoroughly cleaned of foreign matter and laitance, and saturated with water and forms retightened before depositing concrete. An excess of mortar on vertical or inclined surfaces shall be secured by thoroughly rodding or forking the freshly deposited concrete to remove the coarse aggregate from contact with the hardened concrete. **Bonding.**

B. *Rubble and Cyclopean Concrete.*

44. Rubble aggregate shall be thoroughly embedded in the concrete. The individual stones shall not be closer to any surface or adjacent stone than the maximum size of the coarse aggregate plus 1 in. Each successive layer of concrete shall be keyed in accordance with the provision in Section 69. **Rubble Concrete.**

45. Cyclopean aggregate shall be thoroughly embedded in the concrete; no stone shall be closer to a finished surface than 1 ft., nor closer than 6 in. to any adjacent stone. Stratified stone shall be laid on its natural bed. **Cyclopean Concrete.**

C. *Depositing Under Water.*[1]

46. The methods, equipment, and materials to be used shall be submitted to and approved by the engineer before the work is started. Concrete shall be deposited by a method that will prevent the washing of the cement from the mixture, minimize the formation of laitance and avoid flow of water until the concrete has fully hardened. Concrete shall be placed so as to minimize segregation of materials. Hand mixing will not be permitted. Concrete shall not be placed in water at temperatures below 35° F. **General.**

47. Concrete deposited under water shall consist of not less than 1 part of Portland cement to 6 parts of fine and coarse aggregate, measured separately. **Proportions.**

48. Cofferdams shall be sufficiently tight to prevent flow of water through the space in which concrete is to be deposited. Pumping will not be permitted while concrete is being deposited, nor until it has fully hardened. **Cofferdams.**

[1] Concrete should not be deposited under water if practicable to deposit in air. There is always uncertainty as to the results obtained from placing concrete under water; where conditions permit, the additional expense and delay of avoiding this method will be warranted. It is especially important that the aggregate be free from loam and other material which may cause laitance. Washed aggregates are preferable. Coarse aggregate consisting of washed gravel of a somewhat smaller size than used in open-air concrete work will give best results. Concrete should never be deposited under water without experienced supervision. Many failures, especially of structures in sea water, can be traced directly to ignorance of proper methods or lack of expert supervision.

Depositing Continuously. 49. Concrete shall be deposited continuously, keeping the top surface as nearly level as possible, until it is brought above water, or to the required height. The work shall be carried on with sufficient rapidity to insure bonding of the successive layers.

Method. 50. The following method[1] shall be used for depositing concrete under water:

(*a*) *Tremie.*—The tremie shall be water-tight and sufficiently large to permit a free flow of concrete. It shall be kept filled[2] at all times during depositing. The concrete shall be discharged and spread by raising the tremie in such manner as to maintain as nearly as practicable a uniform flow and avoid dropping the concrete through water. If the charge is lost during depositing the tremie shall be withdrawn and refilled.

(*b*) *Drop-Bottom Bucket.*—The bucket shall be of a type that cannot be dumped until it rests on the surface upon which the concrete is to be deposited. The bottom doors when tripped shall open freely downward and outward. The top of the bucket shall be open. The bucket shall be completely filled, and slowly lowered to avoid back-wash. When discharged, the bucket shall be withdrawn slowly until clear of the concrete.

(*c*) *Bags.*—Bags of jute or other coarse cloth shall be filled about two-thirds full of concrete and carefully placed by hand in a header-and-stretcher system so that the whole mass is interlocked.

Laitance. 51. The concrete shall be disturbed as little as possible while it is being deposited, in order to avoid the formation of laitance. Laitance shall be removed.

VII. FORMS.

General. 52. Forms shall conform to the shape, lines and dimensions of the concrete as called for on the plans. Lumber used in forms for exposed surfaces shall be dressed to a uniform thickness, and shall be free from loose knots or other defects. Joints in forms shall be horizontal or vertical. For unexposed surfaces and rough work, undressed lumber may be used. Lumber once used in forms shall have nails withdrawn, and surfaces to be in contact with concrete thoroughly cleaned, before being used again.

Design. 53. Forms shall be substantial and sufficiently tight to prevent

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[1] The engineer should strike out the method or methods inapplicable to the work.

[2] The tremie may be filled by one of the following methods: (1) Place the lower end in a box partly filled with concrete, so as to seal the bottom, then lower into position; (2) plug the tremie with cloth sacks or other material, which will be forced down as the tube is filled with concreteup Ɛgl(;) the end of the tremie with cloth sacks filled with concrete.

leakage of mortar; they shall be properly braced or tied together so as to maintain position and shape. If adequate foundation for shores cannot be secured, trussed supports shall be provided.

Workmanship. 54. Bolts and rods shall preferably be used for internal ties; they shall be so arranged that when the forms are removed no metal shall be within 1 in. of any surface. Wire ties will be permitted only on light and unimportant work; they shall not be used through surfaces where discoloration would be objectionable. Shores supporting successive stories shall be placed diretly over those below, or so designed that the lead will be transmitted directly to them. Forms shall be set to line and grade and so constructed and fastened as to produce true lines. Special care shall be used to prevent bulging.

Moldings. 55. Unless otherwise specified, suitable moldings or bevels shall be placed in the angles of forms to round or bevel the edges of the concrete.

Oiling. 56. The inside of forms shall be coated with non-staining mineral oil, or other approved material, or thoroughly wetted (except in freezing weather). Where oil is used, it shall be applied before the reinforcement is placed.

Inspection of Forms. 57. Temporary openings shall be provided at the base of column and wall forms, and other places where necessary to facilitate cleaning and inspection immediately before depositing concrete.

Removal of Forms. 58. Forms shall not be disturbed until the concrete has adequately hardened, nor shall the permanent shores be removed until the structure has attained its full design strength[1] and all excess construction load has been removed. Wall and column forms shall be left in place until the concrete has hardened sufficiently to sustain its own weight and the construction loads likely to come upon it. Forms other than wall or column forms shall be left in place until the concrete has hardened sufficiently to carry the full load which it must sustain, unless removed in sections and each section of the structure is immediately re-shored.

VIII. DETAILS OF CONSTRUCTION.

A. Metal Reinforcement.

Cleaning. 59. Metal reinforcement, before being positioned, shall be thoroughly cleaned of mill and rust scale, and of coatings of any character that will destroy or reduce the bond. Reinforcement appreciably reduced in section shall be rejected. Reinforcement shall

[1] Many conditions affect the hardening of concrete and the proper time for the removal of the forms should be determined by a competent and responsible person.

be re-inspected and when necessary cleaned, where there is delay in depositing concrete.

Bending. 60. Reinforcement shall be carefully formed to the dimensions indicated on the plans or called for in the specifications. The radius of bends shall be 4 or more times the least diameter of the reinforcement bar.

Straightening. 61. Metal reinforcement shall not be bent or straightened in a manner that will injure the material. Bars with kinks or sharp bends shall not be used.

Placing. 62. Metal reinforcement shall be accurately positioned, and secured against displacement by using annealed iron wire of not less than No. 18 gage or suitable clips at intersections, and shall be supported by concrete or metal chairs, or spacers, or by metal hangers. Parallel bars shall not be placed closer in the clear than $1\frac{1}{2}$ times the diameter of round bars or $1\frac{1}{2}$ times the diagonal of square bars; if the ends of bars are hooked as specified in Section 130 the clear spacing may be made equal to the diameter of round bars or to the diagonal of square bars, but in no case shall the spacing between bars be less than 1 in., nor less than $1\frac{1}{4}$ times the maximum size of the coarse aggregate.

Splicing. 63. Splices of tension reinforcement at points of maximum stress shall be avoided. Splices, where required, shall provide sufficient lap to transfer the stress between bars by bond and shear, or by a mechanical connection such as a screw coupling.

Offsets in Column Reinforcement. 64. Vertical reinforcement shall be offset in a region where lateral support is afforded when changes in column cross-section occur and the vertical reinforcement bars are not sloped for the full length of the column.

Future Bonding. 65. Exposed reinforcement bars intended for bonding with future extensions shall be protected from corrosion.

B. *Concrete Covering over Metal.*

Moisture Protection. 66. Metal reinforcement in wall footings and column footings shall have a minimum covering of 3 in. of concrete.

Fire Protection. 67. Metal reinforcement in fire-resistive construction shall be protected by not less than 1 in. of concrete in slabs and walls, and not less than 2 in. in beams, girders and columns, provided aggregate showing an expansion not materially greater than that of limestone or trap rock is used; when impracticable to obtain aggregate of this grade, the protective covering shall be 1 in. thicker and shall be reinforced with metal mesh not exceeding 3 in. in greatest dimensions, placed 1 in. from the finished surface.

The metal reinforcement in structures containing incombustible materials and in bridges where the fire hazard is limited, shall be protected by not less than $\frac{3}{4}$ in. of concrete in slabs and walls and of not less than $1\frac{1}{2}$ in. in beams, girders and columns.

68. Plaster finish on an exposed concrete surface may be allowed to reduce the thickness of concrete protection required in Section 67 by one-half the thickness of the plaster, but the protection shall not be less than that specified in Sections 66 and 67. **Plaster.**

C. Joints.

69. Construction joints not indicated on the plans nor specified shall be located and formed so as to least impair the strength and appearance of the structure. Horizontal construction joints shall be formed by embedding stones projecting above the surface or by roughening the surface in contact, or by mortises or keys formed in the concrete. Sufficient section shall be provided in horizontal as well as vertical keys to resist shear. **Construction Joints.**

70. Construction joints in columns shall be made at the underside of the floor. Haunches and column capitals shall be considered as part of and built monolithic with the floor construction. **Joints in Columns.**

71. Construction joints in floors shall be located near the center of spans of slabs, beams, and 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. Adequate provision shall be made for shear either by sufficient reinforcement, or by sloping the joint so as to provide an inclined bearing. **Joints in Floors.**

72. Girders and beams designed to be monolithic with walls and columns, shall not be cast until 2 hours after the completion of the walls or columns. **Monolithic Construction.**

73. Construction joints made crosswise of a building 100 ft. or more in length, shall have special reinforcement placed at right angles to the joint and extending a sufficient distance on each side of the joint to develop the strength of the reinforcement by bond. This reinforcement shall be placed near the opposite face of the member from the main tension reinforcement; the amount of such reinforcement shall be not less than 0.5 per cent of the section of the members cut by the joint. **Construction Joints in Long Buildings.**

74. Expansion joints shall be so detailed that the necessary movement may occur with the minimum of resistance at the joint. The structure adjacent to the joint shall preferably be supported on separate columns or walls. Reinforcement shall not extend across an expansion joint. The break between the two sections shall be **Expansion Joints.**

complete, and may be effected by a coating of white lead and oil, asphalt paint or petrolatum, or by building paper, placed over the entire surface of the hardened concrete. Exposed edges of expansion joints in walls or abutments shall be bonded. Exposed expansion joints formed between two distinct concrete members shall be filled with an elastic joint filler of approved quality.

Expansion Joints in Long Buildings. 75. Structures exceeding 200 ft. in length and of width less than about one-half the length, shall be divided by means of expansion joints, located near the middle, but not more than 200 ft. apart, to minimize the destructive effects of temperature changes and shrinkage. Structures in which marked changes in plan section take place abruptly, or within a small distance, shall be provided with expansion joints at the points where such changes in section occur.

Sliding Joints. 76. The seat of sliding joints shall be finished with a smooth troweled surface and shall not have the superimposed concrete placed upon it until it has thoroughly hardened. In order to facilitate sliding, two thicknesses of building paper shall be placed over the seat on which the superimposed concrete is to be deposited.

Water-tight Joints. 77. When it is not possible to finish a section of the structure in one continuous operation and water-tight construction is required, the joints shall be prepared as follows: The surface of the first section of concrete shall be provided with continuous key-ways. All laitance and other foreign substances shall be removed from the surface of the concrete first placed; this surface shall then be thoroughly saturated with water and given a heavy coating of neat cement. The next section of concrete shall be placed in such manner as to insure an excess of mortar over the entire surface of the joint. Where shown on the plans, the joint shall be so constructed as to permit of its being caulked with oakum.

IX. WATERPROOFING AND PROTECTIVE TREATMENT.

A. *Waterproofing.*

General. 78. The requirements for quality of concrete in Section 28 shall be strictly followed. Particular attention shall be given to workmanship.

Integral Compounds. 79. Integral compounds shall not be used.

Membrane Waterproofing. 80. Membrane waterproofing shall be used in basements, pits, shafts, tunnels, bridge floors, retaining walls and similar structures, where an added protection is desired.

Water-tight Joints. 81. See Section 77.

B. Oilproofing.

82. Concrete structures for containing light mineral oils, animal oils, certain vegetable oils and other commercial liquids shall be given a special coating which shall be applied immediately after construction. Floors or other surfaces exposed to heavy concentrations of such oils or liquids shall be similarly protected. The treatment to be applied shall be approved by the engineer. **Oilproofing.**

C. Concrete in Sea Water.

83. Plain concrete in sea water or exposed directly along the sea coast shall contain not less than $1\frac{1}{2}$ bbl. (6 bags) of Portland cement per cubic yard in place; concrete from 2 ft. below low water to 2 ft. above high water, or from a plane below to a plane above wave action, shall be made of a mixture containing not less than $1\frac{3}{4}$ bbl. (7 bags) of Portland cement per cubic yard in place. Slag, broken brick, soft limestone, soft sandstone or other porous or weak aggregates shall not be used. **Proportions.**

84. Concrete shall not be deposited under sea water unless unavoidable, in which case it shall be placed in accordance with the methods described in Sections 48 to 51. Sea water shall not be allowed to come in contact with the concrete until it has hardened for at least 4 days. Concrete shall be placed in such a manner as to avoid horizontal or inclined seams or work planes. The placing of concrete between tides shall be a continuous operation, in accordance with the methods described in Section 42; where it is impossible to avoid seams or joints proceed as in Section 43. **Depositing.**

85. Metal reinforcement shall be placed at least 3 in. from any plane or curved surface, and at corners at least 4 in. from all adjacent surfaces. Metal chairs, supports, or ties shall not extend to the surface of the concrete. Where unusually severe conditions of abrasion are anticipated, the face of the concrete from 2 ft. below low water to 2 ft. above high water, or from a plane below to a plane above wave action, shall be protected by creosoted timber, dense vitrified shale brick, or stone of suitable quality, as designated on the plans. **Protection.**

86. The consistency shall be such as to produce concrete which for mass work shall give a slump of not more than 2 in., and for reinforced concrete a slump of not more than 4 in. **Consistency.**

D. Concrete in Alkali Soils or Water.

87. Concrete below the ground-line shall contain not less than $1\frac{3}{4}$ bbl. (7 bags) of Portland cement per cubic yard in place. **Proportions.**

Consistency. 88. The consistency of the concrete shall be such as to produce a slump of not more than 2 in., and for small members in which aggregates coarser than $\frac{3}{8}$ in. cannot be used, a slump of not more than 6 in.

Placing. 89. Concrete should be placed in such a manner as to avoid horizontal or inclined seams, or work planes; where this is impossible the requirements of Section 69 shall be followed.

Curing. 90. Concrete shall be kept wet with fresh water for not less than 7 days following placing.

Protection. 91. Metal reinforcement or other corrodible metal shall not be placed closer than 2 in. to the faces of members exposed to alkali soil or water.

X. SURFACE FINISH.

General. 92. Concrete to have exposed surfaces with specified finish shall be mixed, placed and worked to secure a uniform distribution of the aggregates, and insure uniform texture of surface.[1] Placing shall be continuous throughout each distinct division of an area. Joint lines shall be located at indicated points. Voids which appear upon removal of the forms shall be drenched with water and be immediately filled with material of the same composition as that used in the surface, and smoothed with a wood spatula or float. Fins or offsets shall be neatly removed. The work shall be finished free from streaks.

Top Surfaces not Subject to Wear. 93. Top surfaces not subject to wear shall be smoothed with a wood float and be kept wet for at least 7 days. Care shall be taken to avoid an excess of water in the concrete, and to drain off or otherwise promptly remove any water that comes to the surface. Dry cement, or a dry mixture of cement and sand, shall not be sprinkled directly on the surface.

A. Wearing Surfaces.

One-Course Work. 94. Aggregates for the wearing surface shall have a high resistance to abrasion. They shall be carefully screened and thoroughly washed. The least quantity of mixing water that will produce a dense concrete shall be used. The mix shall not be leaner than 1 part of Portland cement and $2\frac{1}{2}$ parts of aggregate. The surface shall be screeded even and finished with a wood float. Excess water shall be promptly drained off or otherwise removed. Overtroweling shall be avoided.

[1] This is accomplished by uniform proportioning of ingredients, and thorough mixing with the proper amount of water; after placing, the concrete should be thoroughly rodded or forked to force the aggregate against the face forms and prevent the formation of voids.

95. In two-course work the wearing surface shall be placed within $\frac{1}{2}$ hour after the base course. **Two-Course Work.**

If the wearing surface is required to be applied to a hardened base course, the latter shall be prepared by roughening with a pick or other effective tool, thoroughly drenching with water until saturated and covered with a thin layer of neat cement immediately before the wearing surface is placed.

The finished wearing course in two-course work shall not be thinner than 1 in.

96. Concrete wearing surfaces constructed in accordance with Sections 94 and 95, shall be kept wet[1] for at least 10 days in the case of floors and 21 days in the case of roads and pavements. **Curing.**

97.[2] Terrazzo finish shall be constructed by mixing 1 part of Portland cement, $2\frac{1}{2}$ parts of crushed marble which will pass through a $\frac{1}{2}$-in. screen and is free from dust, and sufficient water to produce a dense concrete, which shall be spread on the base course and worked down to a thickness of 1 in. by patting or rolling and troweling. **Terrazzo Finish.**

The surface shall be kept wet for not less than 10 days and after thoroughly curing shall be rubbed to a plane surface with a stone or a surfacing machine. Hardened concrete to which a terrazzo finish is to be applied shall be prepared as prescribed in Section 95.

97.[2] Terrazzo finish shall be constructed by mixing 1 part of Portland cement, 2 parts of sand and sufficient water to produce a plastic mortar, which shall be spread on the base course to a depth of 1 in. Crushed marble, which will pass through a $\frac{1}{4}$-in. screen and is free from dust, shall be sprinkled over the surface of the fresh mortar and pressed or rolled in. **Terrazzo Finish.**

The surface shall be kept wet for not less than 10 days and after thoroughly curing shall be rubbed to a plane surface with a stone or a surfacing machine. Hardened concrete to which a terrazzo finish is to be applied shall be prepared as prescribed in Section 95.

B. Decorative Finishes.

98. Concrete shall be wetted immediately after the forms are removed and rubbed even and smooth with a carborundum brick, or other abrasive, and to uniform appearance without applying any cement or other coating. **Rubbed Finish.**

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[1] Prevention of premature drying during the early hardening of concrete is essential to the development of high resistance to abrasion. The surface may be covered with a layer of burlap, earth or sand, kept wet, or it may be divided into small areas by dikes and flooded with water to a depth of 2 or 3 in.

[2] The engineer should strike out one of the two Sections numbered 97.

Scrubbed Finish. 99. The face forms shall be removed as soon as the concrete has hardened sufficiently. Voids shall be immediately filled with mortar of the same composition as that used in the face. Fins and other unevennesses shall be rubbed off and the whole surface be scrubbed with fiber or wire brushes, using water freely, as the degree of hardness may require, until the aggregate is uniformly exposed; the surface shall then be rinsed with clean water. The corners shall be sharp and unbroken. If portions of the surface have become too hard to scrub in uniform relief, dilute hydrochloric acid (1 part of acid to 4 parts of water) may be used to facilitate scrubbing of hardened surfaces. The acid shall be thoroughly washed off with clean water.

Sand Blast Finish. 100. Immediately following removal of forms, voids shall be filled with mortar of the same composition as that used in the face and allowed to harden. Unevennesses and form marks shall be removed by chipping or rubbing; the face shall then be cut with an air blast of hard sand with angular grains until the aggregate is in uniform relief.

Tooled Finish. 101. The surface shall be permitted to become hard and dry before tooling. The cutting shall remove the entire skin and produce a uniform surface true to lines.

Sand Floated Finish. 102. The forms shall be removed before the surface has fully hardened; the surface shall be rubbed with a wooden float by a uniform circular motion, using fine sand until the resulting finish is even and uniform.

Colored Aggregate Finish. 103. Colored or other special aggregate used for finish shall be exposed by scrubbing as provided in Section 99. Facing mortar of 1 part of Portland cement, $1\frac{1}{2}$ parts of sand, and 3 parts of screenings or pebbles shall be placed against the face forms to a thickness of about 1 in. sufficiently in advance of the body concrete to prevent the latter coming in contact with the form.

Colored Pigment Finish. 104. Mineral pigment shall be thoroughly mixed dry with the Portland cement and fine aggregate; care shall be taken to secure a uniform tint throughout.

XI. DESIGN.

A. General Assumptions.

General Assumptions. 105. The design of reinforced concrete members under these specifications shall be based on the following assumptions:

(*a*) Calculations are made with reference to working stresses and safe loads rather than with reference to ultimate strength and ultimate loads.

(*b*) A plane section before bending remains plane after bending.

(*c*) The modulus of elasticity of concrete in compression is constant within the limits of working stresses; the distribution of compressive stress in beams is therefore rectilinear.

(*d*) The values for the modulus of elasticity of concrete in computations for the position of the neutral axis, for the resisting moment of beams and for compression of concrete in columns, are as follows:

(1) 1/40 that of steel, when the compressive strength of the concrete at 28 days is below 800 lb. per sq. in.;

(2) 1/15 that of steel, when the compressive strength of the concrete at 28 days lies between 800 and 2200 lb. per sq. in.;

(3) 1/12 that of steel, when the compressive strength of the concrete at 28 days lies between 2200 and 2900 lb. per sq. in.;

(4) 1/10 that of steel, when the compressive strength of the concrete at 28 days is higher than 2900 lb. per sq. in.;

(5) 1/8 that of steel for calculating the deflection of reinforced concrete beams which are free to move longitudinally at the supports, and in which the tensile resistance of the concrete is neglected.

(*e*) In calculating the moment of resistance of reinforced concrete beams and slabs the tensile resistance of the concrete is neglected.

(*f*) The adhesion between the concrete and the metal reinforcement remains unbroken throughout the range of working stresses. Under compression the two materials are therefore stressed in proportion to their moduli of elasticity.

(*g*) Initial stress in the reinforcement due to contraction or expansion of the concrete is neglected, except in the design of reinforced concrete columns.

B. Flexure of Rectangular Reinforced Concrete Beams and Slabs.

106. Computations of flexure in rectangular reinforced concrete beams and slabs shall be based on the following formulas: **Flexure Formulas.**

(*a*) *Reinforced for Tension Only.*

Position of neutral axis.

$$k=\sqrt{2pn+(pn)^2}-pn \quad \cdots\cdots\cdots\cdots (1)$$

Arm[1] of resisting couple,

$$j=1-\frac{k}{3} \qquad (2)$$

Compressive unit stress[1] in extreme fiber of concrete,

$$f_c=\frac{2M}{jkbd^2}=\frac{2pf_s}{k} \qquad (3)$$

Tensile unit stress[1] in longitudinal reinforcement,

$$f_s=\frac{M}{A_s jd}=\frac{M}{pjbd^2} \qquad (4)$$

Steel ratio for balanced reinforcement,

$$p=\tfrac{1}{2}\frac{1}{\frac{f_s}{f_c}\left(\frac{f_s}{nf_c}+1\right)} \qquad (5)$$

For formulas on shear and bond, see Sections 120 and 140.

(*b*) *Reinforced for Both Tension and Compression.*
Position of neutral axis,

$$k=\sqrt{2n\left(p+p'\frac{d'}{d}\right)+n^2(p+p')^2}-n(p+p') \qquad (6)$$

Position of resultant compression,

$$z=\frac{\tfrac{1}{3}k^3d+2p'nd'\left(k-\frac{d'}{d}\right)}{k^2+2p'n\left(k-\frac{d'}{d}\right)} \qquad (7)$$

Arm[1] of resisting couple,

$$jd = d-z \qquad (8)$$

Compressive unit stress[1] in extreme fiber of concrete,

$$f_c=\frac{6M}{bd^2\left[3k-k^2+\frac{6p'n}{k}\left(k-\frac{d'}{d}\right)\left(1-\frac{d'}{d}\right)\right]} \qquad (9)$$

Tensile unit stress[1] in longitudinal reinforcement,

$$f_s = \frac{M}{pjbd^2} = nf_c\frac{1-k}{k} \qquad (10)$$

[1] For f_s=16,000 to 18,000 lb. per sq. in. and f_c=800 to 900 lb. per sq. in., j may be assumed as 0.86. For values of pn varying from 0.04 to 0.24, jk is approximately equal to $0.67\sqrt[3]{pn}$.

Compressive unit stress[1] in longitudinal reinforcement,

$$f'_s = nf_c \frac{k - \frac{d'}{d}}{k} \qquad (11)$$

107. The symbols[2] used in Formulas 1 to 23 are defined as follows: **Notation.**

A_s = effective cross-sectional area of metal reinforcement in tension in beams;

b = width of rectangular beam or width of flange of T–beam;

d = depth from compression surface of beam or slab to center of longitudinal tension reinforcement;

d' = depth from compression surface of beam or slab to center of compression reinforcement;

f_c = compressive unit stress in extreme fiber of concrete;

f_s = tensile unit stress in longitudinal reinforcement;

f'_s = compressive unit stress in longitudinal reinforcement;

h = unsupported length of column;

I = moment of inertia of a section about the neutral axis for bending;

j = ratio of lever arm of resisting couple to depth d;

k = ratio of depth of neutral axis to depth d;

l = span length of beam or slab (generally distance from center to center of supports—see Section 108);

M = bending moment or moment of resistance in general;

n = E_s/E_c = ratio of modulus of elasticity of steel to that of concrete;

p = ratio of effective area of tension reinforcement to effective area of concrete in beams = A_s/bd;

p' = ratio of effective area of compression reinforcement to effective area of concrete in beams;

w = uniformly distributed load per unit of length of beam or slab;

z = depth from compression surface of beam or slab of resultant of compressive stresses.

108. The span length, l, of freely supported beams and slabs, **Span Length.** shall be the distance between centers of the supports, but shall not exceed the clear span plus the depth of beam or slab. The span length for continuous or restrained beams built monolithically with supports shall be the clear distance between faces of supports. Where brackets having a width not less than the width of the beam and making an

[1] See footnote, p. 34.

[2] For illustration of notation as applied to typical beams or slabs, see Figs. 1 and 2.

angle of 45 deg. or more with the axis of a restrained beam are built monolithic with the beam and support, the span shall be measured from the section where the combined depth of the beam and bracket is at least one-third more than the depth of the beam. Maximum negative moments are to be considered as existing at the ends of the span, as above defined. No portion of a bracket shall be considered as adding to the effective depth of the beam.

Moments in Freely Supported Beams of Equal Span.

109. The following moments at critical sections of freely supported beams and slabs of equal spans carrying uniformly distributed loads shall be used:

(*a*) Maximum positive moment in beams and slabs of one span,

$$M = \frac{wl^2}{8} \quad \text{(12)}$$

(*b*) Center of slabs and beams continuous for two spans only,

(1) Positive moment at the center,

$$M = \frac{wl^2}{10} \quad \text{(13)}$$

(2) Maximum negative moment,

$$M = \frac{wl^2}{8} \quad \text{(14)}$$

(*c*) Slabs and beams continuous for more than two spans,

(1) Center and supports of interior spans,

$$M = \frac{wl^2}{12} \quad \text{(15)}$$

(2) Center and interior support of end spans,

$$M = \frac{wl^2}{10} \quad \text{(16)}$$

(*d*) Negative moment at the supports of slab or beam built into brick or masonry walls in a manner that develops partial end restraint,

$$M = \text{not less than } \frac{wl^2}{16} \quad \text{(17)}$$

Moments in Beams Monolithic with Supports.

110. The following moments at the critical sections of beams or slabs of equal spans cast monolithic with columns or similar supports and carrying uniformly distributed loads shall be used:

(*a*) Supports of intermediate spans,

$$M = \frac{wl^2}{12} \text{..........................} (18)$$

(*b*) Center of intermediate spans,

$$M = \frac{wl^2}{16} \text{..........................} (19)$$

(*c*) Beams in which I/l is less than twice the sum of the values of I/h for the exterior columns above and below which are built into the beam,

(1) Center and first interior support,

$$M = \frac{wl^2}{12} \text{..........................} (20)$$

(2) Exterior supports,

$$M = \frac{wl^2}{12} \text{..........................} (21)$$

(*d*) Beams in which I/l is equal to, or greater than, twice the sum of the values of I/h for the exterior columns above and below which are built into the beam,

(1) Center of span and at first interior support of end span,

$$M = \frac{wl^2}{10} \text{..........................} (22)$$

(2) Exterior support,

$$M = \frac{wl^2}{16} \text{..........................} (23)$$

Moment Coefficients of Continuous Beams.

111. Continuous beams with unequal spans, whether freely supported or cast monolithic with columns, shall be analyzed to determine the actual moments under the given conditions of loading and restraint. Provision shall be made for negative moment occurring in short spans adjacent to longer spans when the latter only are loaded.

C. *Flexure of Reinforced Concrete T-Beams.*

Flexure Formulas.

112. Computations of flexure in reinforced concrete T-beams shall be based on the following formulas:

(*a*) *Neutral Axis in the Flange.*

Use formulas for rectangular beams and slabs in Section 106.

(*b*) *Neutral Axis below the Flange.*[1]

Position of neutral axis,

$$kd = \frac{2ndA_s + bt^2}{2nA_s + 2bt} \qquad (24)$$

Position of resultant compression,

$$z = \left(\frac{3kd - 2t}{2kd - t}\right)\frac{t}{3} \qquad (25)$$

Arm of resisting couple,

$$jd = d - z \qquad (26)$$

Compressive unit stress in extreme fiber of concrete,

$$f_c = \frac{Mkd}{bt(kd - \frac{1}{2}t)jd} = \frac{f_s}{n}\left(\frac{k}{1-k}\right) \qquad (27)$$

Tensile unit stress in longitudinal reinforcement,

$$f_s = \frac{M}{A_s jd} \qquad (28)$$

Formulas 24, 25, 26, 27 and 28 neglect compression in the stem.[2]

Notation. 113. The symbols[3] used in Formulas 24 to 28 are defined in Section 107, except as follows:

b' = width of stem of T-beam;
t = thickness of flange of T-beam;

Flange Width. 114. Effective and adequate bond and shear resistance shall be provided in beam-and-slab construction at the junction of the beam and slab; the slab shall be built and considered an integral part of the beam; the effective flange width shall not exceed one-fourth of the span length of the beam, and its overhanging width on either side

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[1] For approximate results the formulas for rectangular beams, Section 106, may be used.

[2] The following formulas take into account the compression in the stem; they are recommended where the flange is small compared with the stem:

Position of neutral axis,

$$kd = \sqrt{\frac{2ndA_s + (b-b')t^2}{b'} + \left(\frac{nA_s + (b-b')t}{b'}\right)^2} - \frac{nA_s + (b-b')t}{b'} \qquad (24a)$$

Position of resultant compression,

$$z = \frac{(kdt^2 - \frac{2}{3}t^3)b + [(kd-t)^2(t + \frac{1}{3}(kd-t))]\,b'}{t(2kd-t)b + (kd-t)^2 b'} \qquad (25a)$$

Arm of resisting couple (see footnote Section 106),

$$jd = d - z \qquad (26a)$$

Compressive unit stress in extreme fiber of concrete,

$$f_c = \frac{2Mkd}{[(2kd-t)bt + (kd-t)^2 b']\,jd} \qquad (27a)$$

Tensile unit stress in longitudinal reinforcement,

$$f_s = \frac{M}{A_s jd} \qquad (28a)$$

[3] For illustration of certain symbols as applied to typical T-beams, see Fig. 3.

of the web shall not exceed 8 times the thickness of the slab nor one-half the clear distance to the next beam.

115. The unsupported length of the compression flange of a T-beam shall not exceed 36 times the least width of the beam. **Flange Length.**

116. Where the principal slab reinforcement is parallel to the beam, transverse reinforcement, not less in amount than 0.3 per cent of the sectional area of the slab, shall be provided in the top of the slab and shall extend over the beam and into the slab not less than two-thirds of the effective flange overhang. The spacing of the bars shall not exceed 18 in. **Transverse Reinforcement.**

117. Provision shall be made for the compressive stress at the support in continuous T-beam construction. **Compressive Stress in Supports.**

118. The flange of the slab shall not be considered as effective in computing the shear and diagonal tension resistance of T-beams. **Shear.**

119. 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 4 times the web thickness. **Isolated Beams.**

D. Diagonal Tension and Shear.

a. Formulas and Notation.

120. Diagonal tension and shear in reinforced concrete beams shall be calculated by the following formulas: **Formulas.**

Shearing unit stress,[1]

$$v = \frac{V}{bjd} \qquad (29)$$

Stress[1] in vertical web reinforcement,

$$f_v = \frac{V's}{A_v jd} \qquad (30)$$

121. The symbols used in Formulas 29 to 36 are defined in Section 107, except as follows: **Notation.**

a = spacing of web reinforcement bars measured perpendicular to their direction;

A_v = total area of web reinforcement in tension within a distance of a (a_1, a_2, a_3, etc.) or the total area of all bars bent up in any one plane;

α = angle between web bars and longitudinal bars;

f_v = tensile unit stress in web reinforcement;

o = perimeter of bar;

Σo = sum of perimeters of bars in one set;

[1] Approximate results may be secured by assuming $j=0.875$.

r = ratio of cross-sectional area of negative reinforcement which crosses entirely over the column capital of a flat slab or over the dropped panel, to the total cross-sectional area of the negative reinforcement in the two column strips;
s = spacing of web members, measured at the neutral axis and in the direction of the longitudinal axis of the beam;
u = bond stress per unit of area of surface of bar;
v = shearing unit stress;
V = total shear;
V' = external shear on any section after deducting that carried by the concrete.

b. Beams Without Web Reinforcement.

Bars Not Anchored.

122. The shearing unit stress in beams in which the longitudinal reinforcement is designed to meet all moment requirements, but without special anchorage, shall not exceed 0.02 f'_c, but in no case shall it exceed 40 lb. per sq. in. Adequate reinforcement shall be provided at all sections where negative moment occurs in beams continuous over supports or built into walls or columns at their ends. (For typical design, see Fig. 4.)

Bars Anchored.

123. The shearing unit stress in beams in which longitudinal reinforcement is anchored by means of hooked ends or otherwise, as specified in Section 130, shall not exceed 0.03 f'_c. Adequate reinforcement for both positive and negative moment shall be provided at all sections where maximum moment exists. (For typical design, see Fig. 5.)

c. Beams With Web Reinforcement.

With Web Reinforcement.

124. When the shearing unit stress calculated by Formula 29 exceeds the values specified in Sections 122 and 123, web reinforcement shall be provided by one or more of the following methods:

(*a*) Series of vertical stirrups or web bars;
(*b*) Series of inclined stirrups or web bars;
(*c*) Series of bent-up longitudinal bars;
(*d*) Longitudinal bars bent up in a single plane.

Provision against bond failure of the web reinforcement shall be as specified in Section 131. (For typical designs, see Figs. 6 and 7. For typical detail of anchorage of longitudinal bars and vertical stirrups, see Fig. 8.)

Web or Bent-up Bars.

125. Where web reinforcement is present and where longitudinal reinforcement is provided to meet all moment requirements, the concrete may be assumed to carry a shearing unit stress not greater than

$0.02 f'_c$ and not greater in any case than 40 lb. per sq. in. In the case where a series of web bars or bent-up longitudinal bars is used, the web reinforcement shall be designed according to the formula:

$$A_v = \frac{V'a}{f_v jd} = \frac{V's \sin \alpha}{f_v jd} \quad \ldots\ldots\ldots\ldots\ldots\ldots (31)$$

(For typical design, see Fig. 9.)

126. Where the web reinforcement consists of bars bent up in a single plane at an angle so as to reinforce all sections of the beam in which the shearing unit stress on the web concrete exceeds $0.02 f'_c$, the concrete may be assumed to take a shearing unit stress not greater than $0.02 f'_c$, and not greater than 40 lb. per sq. in.; the remainder of the shear shall be carried by the bent-up bars designed according to the formula: **Bars Bent Up in Single Plane.**

$$A_v = \frac{V'}{f_v \sin \alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (32)$$

In case the web reinforcement consists solely of bent bars, the first bent bar shall bend downward from the plane of the upper reinforcement at the plane of the edge of the support or between that plane and the center of the support. (For typical design, see Fig. 10.)

127. Where two or more types of web reinforcement are used in conjunction, the total shearing resistance of the beam shall be taken as the sum of the shearing resistance as computed for the various types separately.[1] **Combined Web Reinforcement.**

128. Where there is no special mechanical anchorage of the longitudinal reinforcement, the shearing unit-stress shall not exceed $0.06 f'_c$ irrespective of the web reinforcement used. **Maximum Shearing Unit Stress.**

129. Where special mechanical anchorage of the longitudinal reinforcement as prescribed in Section 130 is provided, the shearing unit stress as computed by Formula 29 may be greater than $0.06 f'_c$, but in no case shall it exceed $0.12 f'_c$.[2] In this case the concrete may be assumed to take a shearing unit stress of not more than $0.025 f'_c$, but not more than 50 lb. per sq. in. **Special Mechanical Anchorage.**

130. Special mechanical anchorage of the longitudinal reinforcement for positive moment may consist of carrying the bars beyond the point of inflection of restrained or continuous members a sufficient distance to develop by bond between the point of inflection and the end of the bar a tensile stress equal to one-third the safe working **Anchorage of Longitudinal Reinforcement.**

[1] In such computation the shearing value of the concrete in the web shall be included once only.

[2] The limit $0.12 f'_c$ is based on the ultimate bearing unit stress of $0.5 f'_c$ at which beams reinforced with vertical stirrups fail due to diagonal compression in the webs. A higher value than $0.12 f'_c$ may be permitted in beams with inclined web reinforcement, but it is not thought necessary to allow such higher limit to meet the needs of design practice.

stress in the reinforcement. If such a bar is straight, it shall extend to within 1 in. of the center of the support, or in the case of wide supports shall extend not less than 12 in. beyond the face of the support. Special mechanical anchorage may also be secured by bending the end of the bar over the support in a full semi-circle to a diameter not less than 8 times the diameter of the bar, the total length of the bend being not less than 16 diameters of the bar. Any other mechanical device that secures the end of the bar over the support against slipping without stressing the concrete in excess of 0.5 f'_c in local compression may be used, provided such device does not tend to split the concrete. Negative reinforcement shall be thoroughly anchored at or across the support or shall extend into the span a sufficient distance to develop by bond the tensile stresses due to negative moment. In the case of freely supported ends of continuous beams, special mechanical anchorage shall be provided, which is capable of developing at the end of the span a tensile stress which is not less than one-third of the safe tensile stress of the bar at the point of maximum moment. (For illustrative design, see Fig. 11.)

Anchorage of Web Reinforcement.

131. Anchorage of the web reinforcement shall be by one of the following methods:

(*a*) Continuity of the web bar with the longitudinal bar;

(*b*) Carrying the web bar around at least two sides of a longitudinal bar at both ends of the web bar; or

(*c*) Carrying the web bar about at least two sides of a longitudinal bar at one end and making a semi-circular hook at the other end which has a diameter equal to that of the web bar.

In all cases the bent ends of web bars shall extend at least 8 diameters below or above the point of extreme height or depth of the web bar. In case the end anchorage of the web member is not in bearing on other reinforcement, the anchorage shall be such as to engage an adequate amount of concrete to prevent the bar from pulling off a portion of the concrete. In all cases the stirrups shall be carried as close to the upper and lower surfaces as fireproofing requirements will permit. (For typical designs, see Figs. 8 and 12.)

Size of Web Bars.

132. The size of web reinforcement bars which are neither a part of the longitudinal bars nor welded thereto, shall be such that not less than two-fifths of the allowable tensile stress in the bar may be developed by bond stresses in a length of bar equal to 0.4 d.[1] The remainder of the tensile stress in the bar shall be provided for by adequate end anchorage as specified in Section 131.

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[1] This condition is satisfied for plain round stirrups when the diameter of the bar does not exceed $d/50$.

133. Shearing unit stress shall be computed on the full width of rectangular beams, on the width of the stem of T-beams, and on the thickness of the web in beams of I-section. **Breadth of Beams in Shear.**

134. The shearing stress in tile-and-concrete-beam construction shall not exceed that in beams or slabs with similar reinforcement. The width of the effective section for shear as governing diagonal tension shall be taken as the thickness of the concrete web plus one-half the thickness of the vertical webs of the tile. (For typical design, see Fig. 13.) **Shear in Beam-and-Tile Construction.**

135. The spacing, a, of web reinforcement bars shall be measured perpendicular to their direction and in a plane parallel to the longitudinal axis of the beam. The spacing shall not exceed $\frac{3}{4}\,d$ in any case where web reinforcement is necessary. Where vertical stirrups are used, or where inclined web bars make an angle more than 60 deg. with the horizontal, the spacing shall not exceed $\frac{1}{2}\,d$. Where the shearing unit stress exceeds $0.06\,f'_c$, the spacing of the web reinforcement shall not exceed $\frac{1}{2}\,d$ in any case, nor $\frac{1}{3}\,d$ for vertical stirrups or web reinforcement making an angle more than 60 deg. with the horizontal. The first shear reinforcement member shall cross the neutral axis of the member at a distance from the face of the support, measured along the axis of the beam, not greater than $\frac{1}{4}\,d$, nor greater than the spacing of web members as determined for a section taken at the edge of the support. Web members may be placed at any angle between 20 and 90 deg. with the longitudinal bars, provided that if inclined they shall be inclined in such a manner as to resist the tensile stress in the web. **Spacing of Web Reinforcement.**

d. Flat Slabs.

136. The shearing unit stress shall not exceed the value of v in the formula, **Shearing Stress.**

$$v = 0.02\,f'_c\,(1 + r) \qquad (33)$$

nor in any case shall it exceed $0.03\,f'_c$.

The unit shearing stress shall be computed on

(*a*) A vertical section which has a depth in inches of $\frac{7}{8}\,(t_1 - 1\frac{1}{2})$ and which lies at a distance in inches of $t_1 - 1\frac{1}{2}$ from the edge of the column capital; and

(*b*) A vertical section which has a depth in inches of $\frac{7}{8}\,(t_2 - 1\frac{1}{2})$ and which lies at a distance in inches of $t_2 - 1\frac{1}{2}$ from the edge of the dropped panel.

In no case shall r be less than 0.25. Where the shearing stress on section (*a*) is being considered, r shall be taken as the proportional amount of reinforcement crossing the column capital; where the shearing stress at section (*b*) is being considered, *r* shall be taken as the proportional amount of reinforcement crossing entirely over the dropped panel. (For typical flat slab and designation of principal design sections, see Figs. 14 and 15.)

e. Footings.

Shear and Diagonal Tension in Footings. 137. The shearing stress shall be computed by Formula 29. When so computed the stress on the critical section defined below, or on sections outside of the critical section, shall not exceed 0.02 f'_c for footings with straight reinforcement bars, nor 0.03 f'_c for footings in which the reinforcement bars are anchored at both ends by adequate hooks or otherwise as specified in Section 130.

Critical Section for Soil Footings. 138. The critical section for diagonal tension in footings bearing directly on the soil shall be taken on a vertical section through the perimeter of the lower base of a frustum of a cone or pyramid which has a base angle of 45 deg. and has for its top the base of the column or pedestal and for its lower base the plane of the center of longitudinal reinforcement.

Critical Section for Pile Footings. 139. The critical section for diagonal tension in footings bearing on piles shall be taken on a vertical section at the inner edge of the first row of piles entirely outside a section midway between the face of the column or pedestal and the section described in Section 138 for soil footings, but in no case outside of the section described in Section 138. The critical section for piles not grouped in rows shall be taken midway between the face of the column and the perimeter of the base of the frustum described in Section 138.

E. Bond.

Formula. 140. Bond between concrete and reinforcement bars in reinforced concrete beams and slabs shall be computed by the formula,

$$u = \frac{V}{\Sigma o\, jd} \qquad \text{(34)}$$

Working Stress. 141. Unless otherwise specified, the reinforcement shall be so proportioned that the bond stress between the metal and the concrete shall not exceed the following:

(*a*) Plain bars,

$$u = 0.04\, f'_c \qquad \text{(35)}$$

(*b*) Deformed bars, meeting the requirements of Section 23,

$$u = 0.05\, f'_c \qquad \text{(36)}$$

Bond in Footings. 142. The bond stress on a section of a footing shall be computed by Formula 34. Only the bars counted as effective in bending shall be considered in computing the number of bars crossing a section. The bond stress computed in this manner on sections at the face of the column or outside the column shall not exceed the value specified in Section 141. Special investigation shall be made of bond stresses in footings with stepped or sloping upper surface; maximum stresses may occur at sections near the edges of the footings.

Reinforcement in Two or More Directions.

143. The permissible bond stress given by Formulas 35 and 36 for footings and similar members where reinforcement is required in more than one direction shall be reduced as follows:

(*a*) For two-way reinforcement, 25 per cent;

(*b*) For each additional direction, 10 per cent.

Anchored Bars.

144. The bond stresses for bars adequately anchored at both ends by hooks or otherwise, as provided in Section 130, may be $1\frac{1}{2}$ times the values specified in Section 141. Hooks in footings shall be effectively positioned to insure that they engage a mass of concrete above the plane of the reinforcement.

F. Flat Slabs.[1]

Moments in Interior Panels.

145. The symbols used in Formulas 37 to 42 are defined in Section 107 except as indicated in Sections 145, 148 and 158. In flat slabs in which the ratio of reinforcement for negative moment in the column strip is not greater than 0.01, the numerical sum of the positive and negative moments in the direction of either side of the panel shall be taken as not less than

$$M_0 = 0.09\ Wl\left(1-\frac{2}{3}\frac{c}{l}\right)^2 \qquad (37)$$

where M_0 = sum of positive and negative bending moments in either rectangular direction at the principal design sections of a panel of a flat slab;

c = base diameter of the largest right circular cone, which lies entirely within the column (including the capital) whose vertex angle is 90 deg. and whose base is $1\frac{1}{2}$ in. below the bottom of the slab or the bottom of the dropped panel (see Fig. 14);

l = span length[2] of flat slab, center to center of columns in

[1] The requirements for flat slabs in Sections 145 to 162, inclusive, apply to two-way and four-way systems of reinforcement. The Committee is not prepared at this time to submit requirements covering other types of flat slabs.

[2] The column strip and the middle strip to be used when considering moments in the direction of the dimension l are located and dimensioned as shown in Fig. 15. The dimension l_1 does not always represent the short length of the panel. When moments in the direction of the shorter panel length are considered, the dimensions l and l_1 are to be interchanged and the strips corresponding to those shown in Fig. 15 but extending in the direction of the shorter panel length are to be considered.

the rectangular direction in which moments are considered; and

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

Principal Design Sections.

146. The principal design sections for critical moments in flat slabs subjected to uniform load shall be taken as follows:

(*a*) Negative moment in middle strip: extending in a rectangular direction from a point on the edge of panel $l_1/4$ from column center a distance $l_1/2$ toward the center of adjacent column on the same panel edge.

(*b*) Negative moment in column strip: extending in a rectangular direction along the edge of the panel from a point $l_1/4$ from the center

TABLE III.—MOMENTS TO BE USED IN DESIGN OF FLAT SLABS.

Strip.	Flat Slabs without Dropped Panels.		Flat Slabs with Dropped Panels.	
	Negative.	Positive.	Negative.	Positive.
SLABS WITH 2-WAY REINFORCEMENT.				
Column strip	$0.23\,M_0$	$0.11\,M_0$	$0.25\,M_0$	$0.10\,M_0$
2 Column strips	$0.46\,M_0$	$0.22\,M_0$	$0.50\,M_0$	$0.20\,M_0$
Middle strip	$0.16\,M_0$	$0.16\,M_0$	$0.15\,M_0$	$0.15\,M_0$
SLABS WITH 4-WAY REINFORCEMENT.				
Column strip	$0.25\,M_0$	$0.10\,M_0$	$0.27\,M_0$	$0.095\,M_0$
2 Column strips	$0.50\,M_0$	$0.20\,M_0$	$0.54\,M_0$	$0.190\,M_0$
Middle strip	$0.10\,M_0$	$0.20\,M_0$	$0.08\,M_0$	$0.190\,M_0$

of a column to a point $c/2$ from the center of the same column and thence one-quarter circumference about the column center to the adjacent edge of the panel.

(*c*) Positive moment in middle strip: extending in a rectangular direction from the center of one edge of a middle strip a distance $l_1/2$ to the center of the other edge of the same strip.

(*d*) Positive moment in column strip: extending in a rectangular direction from the center of one edge of a column strip a distance $l_1/4$ to the center of the other edge of the same strip.

Moments in Principal Design Sections.

147. The moments in the principal design sections shall be those given in Table III, except as follows:

(*a*) The sum of the maximum negative moments in the two column strips may be greater or less than the values given in Table III, by not more than $0.03\,M_0$.

(*b*) The maximum negative moment and the maximum positive moments in the middle strip and the sum of the maximum positive moments in the two column strips may each be greater or less than the values given in Table III, by not more than 0.01 M_0.

148. The total thickness,[1] t_1, of the dropped panel in inches, or of the slab if a dropped panel is not used, shall be not less than: **Thickness of Flat Slabs and Dropped Panels.**

$$t_1 = 0.0382\left(1 - 1.44\frac{c}{l}\right) l \sqrt{Rw'\frac{l_1}{b_1}} + 1\frac{1}{2} \ldots\ldots\ldots\ldots (38)^{2}$$

where R = ratio of negative moment in the two column strips to M_0, and w' = uniformly distributed dead and live load per unit of area of floor.

For slabs with dropped panels the total thickness[1] in inches at points away from the dropped panel shall be not less than:

$$t_2 = 0.02\, l \sqrt{w'} + 1 \ldots\ldots\ldots\ldots\ldots\ldots (39)$$

The slab thickness t_1 or t_2 shall in no case be less than $l/32$ for floor slabs, and not less than $l/40$ for roof slabs. In determining minimum thickness by Formulas 38 and 39, the value of l shall be the panel length center to center of the columns, on long side of panel, l_1 shall be the panel length on the short side of the panel, and b_1 shall be the width or diameter of dropped panel in the direction of l_1 except that in a slab without dropped panel b_1 shall be 0.5 l_1.

149. The dropped panel shall have a length or diameter in each rectangular direction of not less than one-third the panel length in that direction, and a thickness not greater than 1.5 t_2. **Minimum Dimensions of Dropped Panels.**

150. In wall panels and other panels in which the slab is discontinuous at the edge of the panel, the maximum negative moment one panel length away from the discontinuous edge and the maximum positive moment between shall be taken as follows: **Wall and Other Irregular Panels.**

(*a*) Column strip perpendicular to the wall or discontinuous edge, 15 per cent greater than that given in Table III.

(*b*) Middle strip perpendicular to wall or discontinuous edge, 30 per cent greater than that given in Table III.

In these strips the bars used for positive moments perpendicular to the discontinuous edge shall extend to the exterior edge of the panel at which the slab is discontinuous.

151. In panels having a marginal beam on one edge or on each **Panels with Wall Beams.**

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[1] The thickness will be in inches regardless of whether l and w' are in feet and pounds per square foot or in inches and pounds per square inch.

[2] The values of R used in this formula are the coefficients of M_0 for negative moment in the column strip in Table III.

of two adjacent edges, the beam shall be designed to carry the load superimposed directly upon it. If the beam has a depth greater than the thickness of the dropped panel into which it frames, the beam shall be designed to carry, in addition to the load superimposed upon it, at least one-fourth of the distributed load for which the adjacent panel or panels are designed, and each column strip adjacent to and parallel with the beam shall be designed to resist a moment at least one-half as great as that specified in Table III for a column strip.[1] If the beam used has a depth less than the thickness of the dropped panel into which it frames, each column strip adjacent to and parallel with the beam shall be designed to resist the moments specified in Table III for a column strip. Where there are beams on two opposite edges of the panel, the slab and the beam shall be designed as though all the load was carried to the beam.

Discontinuous Panels. 152. The negative moments on sections at and parallel to the wall, or discontinuous edge of an interior panel, shall be determined by the conditions of restraint.[2]

Flat Slabs on Bearing Walls. 153. Where there is a beam or a bearing wall on the center line of columns in the interior portion of a continuous flat slab, the negative moment at the beam or wall line in the middle strip perpendicular to the beam or wall shall be taken as 30 per cent greater than the moment specified in Table III for a column strip. The column strip adjacent to and lying on either side of the beam or wall shall be designed to resist a moment at least one-half of that specified in Table III for a column strip.

Point of Inflection. 154. The point of inflection in any line parallel to a panel edge in interior panels of symmetrical slabs without dropped panels shall be assumed to be at a distance from the center of the span equal to $\frac{3}{16}$ of the distance between the two sections of critical negative moment at opposite ends of the line; for slabs having dropped panels, the coefficient shall be $\frac{1}{4}$.

Reinforcement. 155. The reinforcement bars which cross any section and which fulfill the requirements given in Section 156 may be considered as effective in resisting the moment at the section. The sectional area of a bar multiplied by the cosine of the angle between the direction of the axis of the bar and any other direction may be considered effective as reinforcement in that direction.

Arrangement of Reinforcement. 156. The design shall include adequate provision for securing the reinforcement in place so as to take not only the critical moments but

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[1] In wall columns, brackets are sometimes substituted for capitals or other changes are made in the design of the capital. Attention is directed to the necessity for taking into account the change in the value of *c* in the moment formula for such cases.

[2] The committee is not prepared to make a more definite recommendation at this time.

the moments at intermediate sections. All bars in rectangular or diagonal directions shall extend on each side of a section of critical moment, either positive or negative, to points at least 20 diameters beyond the point of inflection as specified in Section 154. In addition to this provision, bars in diagonal directions used as reinforcement for negative moment shall extend on each side of a line drawn through the column center at right angles to the direction of the band at least a distance of 0.35 of the panel length, and bars in diagonal directions used as reinforcement for positive moment shall extend on each side of a diagonal through the center of the panel at least a distance equal to 0.35 of the panel length; no splice by lapping shall be permitted at or near regions of maximum stress except as just described. At least two-thirds of all bars in each direction shall be of such length and shall be so placed as to provide reinforcement at two sections of critical negative moment and at the intermediate section of critical positive moment. Continuous bars shall not all be bent up at the same point of their length, but the zone in which this bending occurs shall extend on each side of the assumed point of inflection, and shall cover a width of at least $\frac{1}{15}$ of the panel length. Mere sagging of the bars shall not be permitted. In four-way reinforcement the position of the bars in both diagonal and rectangular directions may be considered in determining whether the width of zone of bending is sufficient.

Reinforcement at Construction Joints.

157. See Section 73.

Tensile Stress in Reinforcement.

158. The following formula shall be used in computing the tensile stress f_s in the reinforcement in flat slabs; the stress so computed shall not at any of the principal design sections exceed the values specified in Section 205:

$$f_s = \frac{RM_0}{A_s jd} \quad \text{(40)}$$

where RM_0 = moment specified in Section 147 for two column strips or for one middle strip; and

A_s = effective cross-sectional area of the reinforcement which crosses any of the principal design sections and which meets the requirements of Section 156.

Compressive Stress in Reinforcement.

159. The following formulas shall be used in computing maximum compressive stress in the concrete in flat slabs; and the stress so computed shall not exceed $0.4 f'_c$:

(*a*) Compression due to negative moment, RM_0, in the two column strips,

$$f_c = \frac{3.5\, RM_0}{kjb_1 d^2}\left(1 - 1.2\,\frac{c}{l}\right) \quad \text{(41)}$$

(*b*) Compression due to positive moment, RM_0, in the two column strips or negative or positive moment in the middle strip,

$$f_c = \frac{6\ RM_0}{kjl_1d^2} \quad \text{......................} \quad (42)$$

Shearing Stress.

160. See Section 136.

Unusual Panels.

161. The moment coefficients, moment distribution and slab thicknesses specified herein are for slabs which have three or more rows of panels in each direction, and in which the panels are approximately uniform in size. For structures having a width of one or two panels, and also for slabs having panels of markedly different sizes, an analysis shall be made of the moments developed in both slab and columns, and the values given herein modified accordingly. Slabs with paneled ceiling or with depressed paneling in the floor shall be considered as coming under the requirements herein given.

Bending Moments in Columns.

162. See Section 173.

G. Reinforced Concrete Columns.

Limiting Dimensions.

163. The provisions in the following sections for the carrying capacity of reinforced columns are based on the assumption of a short column. Where the unsupported length is greater than 40 times the least radius of gyration (40 *R*), the carrying capacity of the column shall be determined by Formula 48 for slender columns. Principal columns in buildings shall have a width of not less than 12 in. Posts that are not continuous from story to story shall have a width of not less than 6 in.

Unsupported Length.

164. The unsupported length of a column in flat slab construction shall be taken as the clear distance between the under side of the capital and the top of the floor slab below. For beam-and-slab construction the unsupported length of a column shall be taken as the clear distance between the under side of the shallowest beam framing into it and the top of the floor slab below; where beams run in one direction only the clear distance between floor slabs shall be used. For columns supported laterally by struts or beams only, two struts shall be considered an adequate support, provided the angle between the two planes formed by the axis of the column with the axis of each strut is not less than 75 deg. nor more than 105 deg. The unsupported length for this condition shall be considered the clear distance between struts. When haunches are used at the junction of beams or struts with columns, the clear distance between supports may be considered as reduced by two-thirds of the depth of the haunch.

165. The symbols used in Formulas 43 to 50 are defined in Section 107, except as indicated in Sections 165, 167, 170, 172, 180 and 188. The safe axial load on columns reinforced with longitudinal bars and closely spaced spirals enclosing a circular core shall be determined by the following formula: **Safe Load on Spiral Columns.**

$$P = A_c f_c + n f_c pA \ldots\ldots\ldots\ldots\ldots\ldots (43)$$

where

A = area of the concrete core enclosed within the spiral;
P = total safe axial load on column whose h/R is less than 40;
p = ratio of effective area of longitudinal reinforcement to area of the concrete core; and
$A_c = A(1-p)$ = net area of concrete core.

The allowable value of f_c for use in this type of column shall be determined by the following formula:

$$f_c = 300 + (0.10 + 4p) f'_c \ldots\ldots\ldots\ldots\ldots\ldots (44)$$

The longitudinal reinforcement shall consist of at least six bars of minimum diameter of ½ in., and its effective cross-sectional area shall not be less than 1 per cent nor more than 5 per cent of that of the enclosed core.

166. The spiral reinforcement shall be not less in amount than one-fourth the volume of the longitudinal reinforcement. It shall consist of evenly spaced continuous spirals held firmly in place and true to line by at least three vertical spacer bars. The spacing of the spirals shall be not greater than one-sixth of the diameter of the core and in no case more than 3 in. The lateral reinforcement shall meet the requirements of the Tentative Specifications for Cold-Drawn Steel Wire for Concrete Reinforcement. (Appendix 7.) Reinforcement shall be protected everywhere by a covering of concrete cast monolithic with the core, which shall have a minimum thickness of 1½ in. in square columns and 2 in. in round or octagonal columns. **Spiral Reinforcement.**

167. The safe axial load on columns reinforced with longitudinal bars and separate lateral ties shall be determined by the following formula: **Safe Load on Columns with Lateral Ties.**

$$P = A'_c f_c + A_s n f_c \ldots\ldots\ldots\ldots\ldots\ldots (45)$$

where A'_c = net area of concrete in the column (total column area minus steel area); and
A_s = effective cross-sectional area of longitudinal reinforcement.

The value of f_c for this type of column shall not exceed $0.20 f'_c$. The amount of longitudinal reinforcement considered in the calculations shall be not more than 2 per cent nor less than 0.5 per cent of the total area of the column. The longitudinal reinforcement shall consist of not less than 4 bars of minimum diameter of $\frac{1}{2}$ in., placed with clear distance from the face of the column not less than 2 in.

Lateral Ties. 168. Lateral ties shall be not less than $\frac{1}{4}$ in. in diameter, spaced not farther than 8 in. apart.

Bending Stress in Columns. 169. Reinforced concrete columns subjected to bending stresses shall be treated as follows:

(*a*) *Spiral column.*—The compressive unit stress on the concrete within the core area under combined axial load and bending shall not exceed by more than 20 per cent the value given for axial load by Formula 40.

(*b*) *Columns with Lateral Ties.*—Additional longitudinal reinforcement not to exceed 2 per cent shall be used if required and the compressive unit stress on the concrete under combined axial load and bending may be increased to $0.30 f'_c$.

Tension due to bending in the longitudinal reinforcement shall not exceed 16,000 lb. per sq. in.

Composite Columns. 170. The safe carrying capacity of composite columns in which a structural steel or cast-iron column is thoroughly encased in a spirally reinforced concrete core shall be based on a certain unit stress for the steel or cast-iron core plus a unit stress of $0.25 f'_c$ on the area within the spiral core. The unit compressive stress on the steel section shall be determined by the formula:

$$f_r = 18{,}000 - 70\, h/R \qquad (46)$$

but shall not exceed 16,000 lb. per sq. in. The unit stress on the cast-iron section shall be determined by the formula:

$$f_r = 12{,}000 - 60\, h/R \qquad (47)$$

but shall not exceed 10,000 lb. per sq. in. In Formulas 46 and 47, f_r = compressive unit stress in metal core, and R = least radius of gyration of the steel or cast-iron section.

The diameter of the cast-iron section shall not exceed one-half of the diameter of the core within the spiral. The spiral reinforcement shall be not less than 0.5 per cent of the volume of the core within the spiral and shall conform in quality, spacing and other requirements to the provisions for spirals in reinforced concrete columns. Ample sections of concrete and continuity of reinforcement shall be provided at the junction with beams or girders. The area of the concrete between the spiral and the metal core shall be not less than that required to carry the total floor load of the story above on the basis of a stress in the concrete of $0.35 f'_c$, unless special brackets are arranged on the metal core to receive directly the beam or slab loads.

171. The safe load on a structural steel column of a section which fully encloses or encases an area of concrete, and which is protected by an outside shell of concrete at least 3 in. thick, shall be computed in the same way as in the columns described in Section 170, allowing $0.25\ f'_c$ on the area of the concrete enclosed by the steel section. The outside shell shall be reinforced by wire mesh or hoops weighing not less than 0.2 lb. per sq. ft. of surface of the core and with a maximum spacing of strands or hoops of 6 in. Special brackets shall be used to receive the entire floor load at each story. The working stress in steel columns shall be calculated by Formula 46, but shall not exceed 16,000 lb. per sq. in. **Structural Steel Columns.**

172. The permissible working unit stress on the core in axially loaded columns which have a length greater than 40 times the least radius of gyration of the column core ($40\ R$) shall be determined by the formula: **Long Columns.**

$$\frac{P'}{P} = 1.33 - \frac{h}{120\ R} \qquad \text{(48)}$$

where P' = total safe axial load on long column;
P = total safe axial load on column of the same section whose h/R is less than 40, determined as in Section 167; and
R = least radius of gyration of column core.

173. The bending moments in interior and exterior columns shall be determined on the basis of loading conditions and end restraint, and shall be provided for in the design.[1] The recognized standard methods shall be followed in calculating the stresses due to combined axial load and bending. **Bending Moments in Columns.**

H. Footings.

174. Various types of reinforced concrete footings are in use depending on conditions. The fundamental principles of the design of reinforced concrete will generally apply to footings as to other structural members. The requirements for flexure and shear in Sections 112 to 139, inclusive, shall govern the design of footings, except as hereinafter provided. **Types.**

175. The upward reaction per unit of area on the footing shall be taken as the column load divided by the area of base of the footing. **Distribution of Pressure.**

176. Footings carried on piles shall be treated in the same manner as those bearing directly on the soil, except that the reaction shall **Pile Footing.**

[1] The Committee is not prepared to make more definite recommendations at this time.

be considered as a series of concentrated loads applied at the pile centers.

Sloped Footing.

177. Footings in which the depth has been determined by the requirements for shear as specified in Section 137 may be sloped between the critical section and the edge of the footing, provided that the shear on no section outside the critical section exceeds the value specified, and provided further that the thickness of the footing above the reinforcement at the edge shall not be less than 6 in. for footings on soil nor less than 12 in. for footings on piles.

Stepped Footing.

178. The top of the footing may be stepped instead of sloped, provided that the steps are so placed that the footing will have at all sections a depth at least as great as that required for a sloping top. Stepped footings shall be cast monolithically.

Critical Section for Bending.

179. In a concrete footing which supports a concrete column or pedestal, the critical section for bending shall be taken at the face of the column or pedestal. Where steel or cast-iron bases are used, the moment in the footing shall be calculated at the edge of the base and at the center. In calculating this moment, the column or pedestal load shall be assumed as uniformly distributed over its base.

Square Column on Square Footing.

180. For a square footing supporting a concentric square column, the bending moment at the critical section is that produced by the upward pressure on the trapezoid bounded by one face of the column, the corresponding outside edge of the footing, and the portions of the two diagonals. The center of application of the reaction on the two corner triangles of this trapezoid shall be taken at a distance from the face of the column equal to 0.6 of the projection of the footing. The center of the application of the reaction on the rectangular portion of the trapezoid shall be taken at its center of gravity. This gives a bending moment expressed by the formula:

$$M = \frac{w}{2}\,(a+1.2\,c)c^2 \qquad (49)$$

where M = bending moment at critical section of footing;
a = width of face of column or pedestal;
c = projection of footing from face of column; and
w = upward reaction per unit of area of base of footing.

(For typical footing designs, see Figs. 16 to 18.)

Round Column on Square Footing.

181. Square footings supporting a round or octagonal column shall be treated in the same manner as for a square column, using for the distance a the side of a square having an area equal to the area enclosed within the perimeter of the column.

182. The reinforcement necessary to resist the bending moment in each direction in the footing shall be determined as for a reinforced concrete beam; the effective depth of the footing shall be the depth from the top to the plane of the reinforcement. The required area of reinforcement thus calculated shall be spaced uniformly across the footing, unless the footing width is greater than the side of the column or pedestal plus twice the effective depth of the footing, in which case the width over which the reinforcement is spread, may be increased to include one-half the remaining width of the footing. In order that no considerable area of the footing shall remain unreinforced, additional bars shall be placed outside of the width specified, but such bars shall not be considered as effective in resisting the calculated bending moment. For the extra bars a spacing double that used for the reinforcement within the effective belt may be used. **Reinforcement.**

183. The extreme fiber stress in compression in the concrete shall be kept within the limits specified in Section 198. The extreme fiber stress in sloped or stepped footings shall be based on the exact shape of the section for a width not greater than that assumed effective for reinforcement. **Concrete Stress.**

184. Rectangular or irregular-shaped footings shall be calculated by dividing the footings into rectangles or trapezoids tributary to the sides of the column, using the distance to the actual center of gravity of the area as the moment arm of the upward forces. Outstanding portions of combined footings shall be treated in the same manner. Other portions of combined footings shall be designed as beams or slabs. **Irregular Footings.**

185. See Sections 137 to 139. **Shearing Stresses.**

186. See Sections 142 to 144. **Bond Stresses.**

187. The compressive stress in longitudinal reinforcement in columns or pedestals shall be transferred to the footing by one of the following methods: **Transfer of Stress from Column Reinforcement.**

(*a*) By metal distributing bases having a sufficient area and thickness to transmit safely the load from the longitudinal reinforcement in compression and bending. The bases shall be accurately set and provided with a full bearing on the footing.

(*b*) By dowels, at least one for each bar and of total sectional area not less than the area of the longitudinal column reinforcement. The dowels shall project into the columns or into the pedestal or footing a distance not less than 50 times the diameter of the column bars.

188. The allowable compressive unit stress on the gross area of a concentrically loaded pedestal without reinforcement shall not exceed $0.25\,f'_c$. If the column resting on such a pedestal is provided with **Pedestals without Reinforcement.**

distributing bases for the longitudinal reinforcement, the permissible compressive unit stress under the column core shall be determined by the following formula:

$$r_a = 0.25\, f'_c \sqrt[3]{\frac{A}{A'}} \quad \text{.....................(50)}$$

where r_a = permissible working stress over the loaded area;
A = total net area of the top of pedestal; and
A' = loaded area of pedestal.

Pedestals with Reinforcement.

189. Where the permissible load at the top of a pedestal, determined by Formula 50, is less than the column load to be supported, dowels shall be used as specified in Section 187. If the height of the pedestal is not sufficient to give the required embedment to the dowels, they shall extend into the footing to a point 50 diameters below the top of the pedestal for plain bars and 40 diameters for deformed bars. If the column load divided by the cross-section of the pedestal exceeds $0.25\, f'_c$ the pedestal shall be considered as a section of a column and spiral reinforcement shall be provided accordingly.

Permissible Load at Top of Footings.

190. Where distributing bases are used for transferring the stress from column reinforcement directly to the footing, the permissible compressive unit stress shall be determined by Formula 50. This formula may be applied by using A as the area of the top horizontal surface of the footing or with the following modifications:

(*a*) In footings with sloping or stepped top in which a plane, drawn from the edge of the base of the column so that it makes the greatest possible angle with the vertical but remains entirely within the footing, has a slope with the horizontal not greater than 0.5, the total bearing area of the footing may be used for A.

(*b*) In footings in which the slope of the plane referred to is greater than 0.5 but not greater than 2.0, the permissible compressive unit stress at the top shall be determined by direct proportion, in terms of the slope, between the value found for a slope of 0.5 and the value of $0.25\, f'_c$ for a slope of 2.0. For a slope of 2.0 or greater the compressive unit stress at the top shall not exceed $0.25\, f'_c$.

(For typical footing designs, see Figs. 16 and 18.)

Pedestal Footings.

191. Pedestal footings may be designed as pedestals, that is, without reinforcement other than that required to transmit the column load, except that when supported directly on driven piles, a mat of reinforcing bars consisting of not less than 0.20 sq. in. per foot of width in each direction shall be placed 3 in. above the top of the piles. The height of a pedestal footing shall be not greater than 4 times the average width.

I. Reinforced Concrete Retaining Walls.

Types of Retaining Walls. 192. Reinforced concrete retaining walls may be of the following types:

(*a*) Cantilever;
(*b*) Counterforted;
(*c*) Buttressed;
(*d*) Cellular.

Loads and Unit Stresses. 193. Reinforced concrete retaining walls shall be designed[1] for the loads and reactions, and shall be so proportioned that the permissible unit stresses specified in Sections 196 to 208 are not exceeded. The heels of cantilever, counterforted and buttressed retaining walls shall be proportioned for the maximum resultant vertical loads to which they will be subjected, but the sections shall be such that the normal permissible unit stresses will not be increased by more than 50 per cent when the reaction from the foundation bed is neglected.

Details of Design. 194. The following principles shall be followed in the design of reinforced concrete retaining walls:

(*a*) The unsupported toe and heel of the base slabs shall be considered as cantilever beams fixed at the edge of the support.

(*b*) The vertical section of a cantilever wall shall be considered as a cantilever beam fixed at the top of the base.

(*c*) The vertical sections of counterforted and buttressed walls and parts of base slabs supported by the counterforts or buttresses shall be designed in accordance with the requirements specified herein for the continuous slab.

(*d*) The exposed faces of walls without buttresses shall preferably be given a batter of not less than $\frac{1}{4}$ in. in 12 in.

(*e*) Counterforts shall be designed in accordance with the requirements specified for T-beams. Stirrups shall be provided in the counterforts to take the reaction from these spans when the tension reinforcement of the face walls and heels of bases is designed to span between the counterforts. Stirrups shall be anchored as near the exposed faces of the face walls, and as near the lower face of the bases, as practicable.

(*f*) Buttresses shall be designed in accordance with the requirements specified for rectangular beams.

(*g*) The shearing stress at the junction of the base with counter-

[1] In proportioning retaining walls consideration shall be given to the following:
(*a*) Maximum bearing pressure of soil;
(*b*) Uniformity of distribution of foundation pressure on yielding soils;
(*c*) Stability against sliding;
(*d*) Minor increase of the horizontal forces may seriously affect (*a*) and (*b*).

forts or buttresses shall not exceed the values specified in Sections 120 to 135.

(*h*) Horizontal metal reinforcement shall be well distributed and of such form as to develop a high bond resistance. At least 0.25 sq. in. of horizontal metal reinforcement for each foot of height shall be provided near exposed surfaces not otherwise reinforced, to resist the formation of temperature and shrinkage cracks.

(*i*) Provision for temperature changes shall be made by grooved lock joints spaced not over 60 ft. apart.

(*j*) Counterforts and buttresses, where used, shall be located under all points of concentrated loading, and at intermediate points spaced 8 to 12 ft. apart.

(*k*) The walls shall be cast monolithically between expansion joints, unless construction joints made in accordance with Sections 69 and 73 are provided.

Drains. 195. Drains or "weep holes" not less than 4 in. in diameter and not more than 10 ft. apart, shall be provided. In counterforted walls there shall be at least one drain for each pocket formed by the counterforts.

J. *Floor Slabs Supported on Four Sides.*[1]

K. *Shrinkage and Temperature Stresses.*[1]

L. *Summary of Working Stresses.*

Notation. 196. f'_c = ultimate compressive strength of concrete at age of 28 days, based on tests of 6 by 12-in. or 8 by 16-in. cylinders made and tested in accordance with the Standard Methods of Making and Storing Specimens of Concrete in the Field (Appendix 14) and the Tentative Methods of Making Compression Tests of Concrete (Appendix 13).

a. Maximum Direct Stresses in Concrete.

Direct Compression. 197. (*a*) Columns whose length does not exceed 40 *R*:
- (1) With spirals .... varies with amount of longitudinal reinforcement
- (2) Without spirals .... $0.20 f'_c$

(*b*) Long columns .... see Section 172

(*c*) Piers and Pedestals:
- (1) Without reinforcement .... $0.25 f'_c$
- (2) Special cases .... see Section 188

Compression in Extreme Fiber. 198. (*a*) Extreme fiber stress in flexure .... $0.40 f'_c$

(*b*) Extreme fiber stress adjacent to supports of continuous beams .... $0.45 f'_c$

[1] The Committee is not now ready to report on these subjects.

199. Anchorage of reinforcement . . . . $0.50 f'_c$ Bearing
200. All concrete members . . . . none Compression. Tension.

b. Maximum Shearing Stresses in Concrete.

201. (*a*) Longitudinal bars anchored . . . . $0.03 f'_c$ Beams without Web Reinforcement.
(*b*) Longitudinal bars not anchored . . . . $0.02 f'_c$
202. (*a*) Beams with stirrups . . . . see Sections 125 and 128 Beams with Reinforcement.
(*b*) Beams with bars bent up in several planes . . see Section 125
(*c*) Beams with bars bent up in a single plane:
(1) Longitudinal bars anchored . . . . $0.12 f'_c$
(2) Longitudinal bars not anchored . . . . $0.06 f'_c$
203. (*a*) Shear at distance *d* from capital or dropped panel . . . $0.03 f'_c$ Flat Slabs.
(*b*) Other limiting cases in flat slabs . . . . see Section 136
204. (*a*) Longitudinal bars anchored . . . . $0.03 f'_c$ Footings.
(*b*) Longitudinal bars not anchored . . . . $0.02 f'_c$

c. Maximum Stresses in Reinforcement.

205. (*a*) Billet-steel bars: Tension in Steel.
(1) Structural steel grade . . . . 16,000 lb. per sq. in.
(2) Intermediate grade . . . . 18,000 " "
(3) Hard grade . . . . 18,000 " "
(*b*) Rail-steel bars . . . . 16,000 " "
(*c*) Structural steel . . . . 16,000 " "
(*d*) Cold-drawn steel wire:
(1) Spirals . . . . stress not calculated
(2) Elsewhere . . . . 18,000 lb. per sq. in.
206. (*a*) Bars . . . . same as Section 205 (*a*) and (*b*) Compression in Steel.
(*b*) Structural steel core of composite column . . 18,000 lb. per sq. in., reduced for slenderness ratio
(*c*) Structural steel column . . . . 16,000 lb. per sq. in., reduced for slenderness ratio
207. Composite columns with spirals . . . . 10,000 lb. per sq. in. Compression in Cast Iron.

d. Maximum Bond between Concrete and Steel.

208. (*a*) Beams and slabs, plain bars . . . . $0.04 f'_c$ Bond.
(*b*) Beams and slabs, deformed bars . . . . $0.05 f'_c$
(*c*) Footings, plain bars, one-way . . . . $0.04 f'_c$
(*d*) Footings, deformed bars, one-way . . . . $0.05 f'_c$
(*e*) Footings, two-way reinforcement . . . . . . (*c*) or (*d*) reduced by 25 per cent
(*f*) Footings, each additional direction of reinforcement . . . . (*c*) or (*d*) reduced by 10 per cent.

TABLE IV.—PROPORTIONS[1] FOR CONCRETE OF GIVEN COMPRESSIVE STRENGTH AT 28 DAYS.

The table gives the proportions in which Portland cement and a wide range in sizes of fine and coarse aggregates should be mixed to obtain concrete of compressive strengths ranging from 1500 to 3000 lb. per sq. in. at 28 days. Proportions are given for concrete of four different consistencies.

The purpose of the table is twofold:

(1) To furnish a guide in the selection of mixtures to be used in preliminary investigations of the strength of concrete from given materials.

(2) To indicate proportions which may be expected to produce concrete of a given strength under average conditions where control tests are not made.

If the proportions to be used in the work are selected from the table without preliminary tests of the materials, and control tests are not made during the progress of the work, the mixtures in bold-face type shall be used.

The use of this table as a guide in the selection of concrete mixtures is based on the following:

(1) Concrete shall be plastic;

(2) Aggregates shall be clean and structurally sound;

(3) Aggregates shall be graded between the sizes indicated;

(4) Cement shall conform to the requirements of the Standard Specifications and Tests for Portland Cement (Serial Designation: C 9–21) of the American Society for Testing Materials. (Appendix 3.)

The plasticity of the concrete shall be determined by the slump test carried out in accordance with the Tentative Specifications for Workability of Concrete for Concrete Pavements (Serial Designation: D 62–20 T) of the American Society for Testing Materials. (Appendix 12.)

Apply the following rules in determining the size assigned to a given aggregate:

(1) Not less than 15 per cent shall be retained between the sieve which is considered the maximum size[2] and the next smaller sieve.

(2) Not more than 15 per cent of a coarse aggregate shall be finer than the sieve considered as the minimum size.[2]

(3) Only the sieve sizes given in the table shall be considered in applying rules (1) and (2).

(4) Sieve analysis shall be made in accordance with the Tentative Method of Test for Sieve Analysis of Aggregates for Concrete (Serial Designation: C 41–21 T) of the American Society for Testing Materials. (Appendix 9.)

Proportions may be interpolated for concrete strengths, aggregate sizes and consistencies not covered by the table or determined by test.

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[1] Based on the 28-day compressive strengths of 6 by 12-in. cylinders, made and stored in accordance with the Tentative Methods of Making Compression Tests of Concrete (Serial Designation: C 39-21 T) of the American Society for Testing Materials. (Appendix 13.)

[2] For example: a graded sand with 16 per cent retained on the No. 8 sieve would fall in the 0-No. 4 size; if 14 per cent or less were retained, the sand would fall in the 0-No. 8 size. A coarse aggregate having 16 per cent coarser than 2-in. sieve would be considered as 3-in. aggregate.

TABLE IV. (*Continued*).—PROPORTIONS FOR 1500 LB. PER SQ. IN. CONCRETE.

Proportions are expressed by volume as follows: Portland Cement : Fine Aggregate : Coarse Aggregate.

Thus 1 : 2.6 : 4.6 indicates 1 part by volume of Portland cement, 2.6 parts by volume of fine aggregate and 4.6 parts by volume of coarse aggregate.

Size of Coarse Aggregate.	Slump, in.	Size of Fine Aggregate.				
		0 – No. 28	0 – No. 14	0 – No. 8	0 – No. 4	0 – $\frac{3}{8}$ in.
None	$\frac{1}{2}$ to 1	1 : 2.8	1 : 3.2	1 : 3.8	1 : 4.4	1 : 5.1
	3 " 4	1 : 2.4	1 : 2.8	1 : 3.3	1 : 3.8	1 : 4.5
	6 " 7	**1 : 1.9**	**1 : 2.2**	**1 : 2.6**	**1 : 3.0**	**1 : 3.6**
	8 " 10	1 : 1.4	1 : 1.6	1 : 1.8	1 : 2.1	1 : 2.5
No. 4 to $\frac{3}{4}$ in.	$\frac{1}{2}$ to 1	1 : 2.6 : 4.6	1 : 2.9 : 4.3	1 : 3.4 : 4.1	1 : 3.9 : 3.6	1 : 4.6 : 3.1
	3 " 4	1 : 2.3 : 4.0	1 : 2.6 : 3.8	1 : 2.9 : 3.6	1 : 3.4 : 3.2	1 : 4.1 : 2.8
	6 " 7	**1 : 1.8 : 3.4**	**1 : 2.0 : 3.2**	**1 : 2.3 : 3.1**	**1 : 2.6 : 2.8**	**1 : 3.1 : 2.5**
	8 " 10	1 : 1.1 : 2.5	1 : 1.3 : 2.4	1 : 1.5 : 2.4	1 : 1.7 : 2.2	1 : 2.1 : 2.0
No. 4 to 1 in.	$\frac{1}{2}$ to 1	1 : 2.4 : 5.3	1 : 2.7 : 5.2	1 : 3.1 : 5.0	1 : 3.5 : 4.7	1 : 4.3 : 4.3
	3 " 4	1 : 2.1 : 4.7	1 : 2.4 : 4.5	1 : 2.7 : 4.4	1 : 3.1 : 4.1	1 : 3.7 : 3.7
	6 " 7	**1 : 1.6 : 3.9**	**1 : 1.8 : 3.8**	**1 : 2.1 : 3.7**	**1 : 2.4 : 3.5**	**1 : 2.9 : 3.3**
	8 " 10	1 : 1.1 : 2.9	1 : 1.2 : 2.8	1 : 1.4 : 2.8	1 : 1.6 : 2.7	1 : 1.9 : 2.5
No. 4 to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	1 : 2.4 : 6.0	1 : 2.7 : 5.9	1 : 3.1 : 5.8	1 : 3.5 : 5.4	1 : 4.1 : 5.1
	3 " 4	1 : 2.0 : 5.4	1 : 2.3 : 5.3	1 : 2.7 : 5.2	1 : 3.0 : 5.0	1 : 3.5 : 4.6
	6 " 7	**1 : 1.6 : 4.4**	**1 : 1.8 : 4.3**	**1 : 2.0 : 4.3**	**1 : 2.3 : 4.1**	**1 : 2.7 : 3.9**
	8 " 10	1 : 1.0 : 3.3	1 : 1.1 : 3.2	1 : 1.3 : 3.2	1 : 1.5 : 3.1	1 : 1.8 : 2.9
No. 4 to 2 in.	$\frac{1}{2}$ to 1	1 : 2.2 : 6.9	1 : 2.4 : 6.8	1 : 2.8 : 6.8	1 : 3.1 : 6.6	1 : 3.7 : 6.4
	3 " 4	1 : 1.8 : 6.2	1 : 2.0 : 6.1	1 : 2.4 : 6.1	1 : 2.7 : 6.0	1 : 3.1 : 5.7
	6 " 7	**1 : 1.4 : 5.1**	**1 : 1.6 : 5.0**	**1 : 1.8 : 5.0**	**1 : 2.0 : 5.0**	**1 : 2.4 : 4.8**
	8 " 10	1 : 0.9 : 3.8	1 : 1.0 : 3.8	1 : 1.1 : 3.8	1 : 1.3 : 3.8	1 : 1.5 : 3.7
$\frac{3}{8}$ to 1 in.	$\frac{1}{2}$ to 1	1 : 2.8 : 5.2	1 : 3.1 : 5.1	1 : 3.6 : 4.8	1 : 4.2 : 4.6	1 : 4.8 : 4.1
	3 " 4	1 : 2.4 : 4.5	1 : 2.6 : 4.5	1 : 3.1 : 4.3	1 : 3.6 : 4.0	1 : 4.1 : 3.6
	6 " 7	**1 : 1.9 : 3.9**	**1 : 2.1 : 3.7**	**1 : 2.4 : 3.6**	**1 : 2.8 : 3.4**	**1 : 3.2 : 3.1**
	8 " 10	1 : 1.3 : 2.8	1 : 1.4 : 2.8	1 : 1.6 : 2.7	1 : 1.9 : 2.6	1 : 2.2 : 2.4
$\frac{3}{8}$ to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	1 : 2.8 : 5.8	1 : 3.1 : 5.7	1 : 3.5 : 5.5	1 : 4.1 : 5.3	1 : 4.7 : 4.9
	3 " 4	1 : 2.4 : 5.2	1 : 2.7 : 5.1	1 : 3.1 : 5.0	1 : 3.5 : 4.8	1 : 4.1 : 4.4
	6 " 7	**1 : 1.9 : 4.3**	**1 : 2.1 : 4.2**	**1 : 2.4 : 4.2**	**1 : 2.7 : 4.0**	**1 : 3.1 : 3.7**
	8 " 10	1 : 1.2 : 3.2	1 : 1.4 : 3.2	1 : 1.6 : 3.1	1 : 1.8 : 3.0	1 : 2.1 : 2.9
$\frac{3}{8}$ to 2 in.	$\frac{1}{2}$ to 1	1 : 2.7 : 6.6	1 : 3.0 : 6.6	1 : 3.4 : 6.5	1 : 3.9 : 6.4	1 : 4.4 : 6.0
	3 " 4	1 : 2.3 : 5.9	1 : 2.6 : 5.9	1 : 2.9 : 5.8	1 : 3.3 : 5.6	1 : 3.7 : 5.5
	6 " 7	**1 : 1.8 : 4.9**	**1 : 2.0 : 4.8**	**1 : 2.2 : 4.8**	**1 : 2.6 : 4.8**	**1 : 3.0 : 4.5**
	8 " 10	1 : 1.2 : 3.7	1 : 1.3 : 3.7	1 : 1.5 : 3.7	1 : 1.7 : 3.6	1 : 1.9 : 3.5
$\frac{3}{4}$ to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	1 : 3.2 : 5.4	1 : 3.6 : 5.3	1 : 4.1 : 5.1	1 : 4.7 : 4.8	1 : 5.3 : 4.4
	3 " 4	1 : 2.8 : 4.8	1 : 3.2 : 4.8	1 : 3.6 : 4.6	1 : 4.0 : 4.4	1 : 4.6 : 4.0
	6 " 7	**1 : 2.1 : 4.0**	**1 : 2.5 : 4.0**	**1 : 2.8 : 3.9**	**1 : 3.2 : 3.7**	**1 : 3.5 : 3.4**
	8 " 10	1 : 1.5 : 3.0	1 : 1.7 : 3.0	1 : 1.9 : 2.9	1 : 2.2 : 2.8	1 : 2.5 : 2.7
$\frac{3}{4}$ to 2 in.	$\frac{1}{2}$ to 1	1 : 3.2 : 6.2	1 : 3.6 : 6.1	1 : 4.0 : 6.0	1 : 4.6 : 5.8	1 : 5.2 : 5.4
	3 " 4	1 : 2.8 : 5.5	1 : 3.1 : 5.5	1 : 3.5 : 5.4	1 : 3.9 : 5.2	1 : 4.5 : 4.9
	6 " 7	**1 : 2.1 : 4.5**	**1 : 2.4 : 4.6**	**1 : 2.7 : 4.5**	**1 : 3.1 : 4.4**	**1 : 3.5 : 4.1**
	8 " 10	1 : 1.4 : 3.4	1 : 1.6 : 3.4	1 : 1.8 : 3.4	1 : 2.1 : 3.4	1 : 2.4 : 3.3
$\frac{3}{4}$ to 3 in.	$\frac{1}{2}$ to 1	1 : 3.2 : 7.1	1 : 3.6 : 7.1	1 : 4.0 : 7.0	1 : 4.6 : 6.9	1 : 5.2 : 6.6
	3 " 4	1 : 2.7 : 6.3	1 : 3.0 : 6.3	1 : 3.4 : 6.3	1 : 4.0 : 6.2	1 : 4.5 : 5.9
	6 " 7	**1 : 2.1 : 5.1**	**1 : 2.4 : 5.2**	**1 : 2.7 : 5.2**	**1 : 3.1 : 6.1**	**1 : 3.5 : 4.9**
	8 " 10	1 : 1.4 : 3.8	1 : 1.6 : 3.9	1 : 1.8 : 3.9	1 : 2.1 : 3.9	1 : 2.4 : 3.8

TABLE IV. (*Continued*).—PROPORTIONS FOR 2000 LB. PER SQ. IN. CONCRETE.

Proportions are expressed by volume as follows: Portland Cement : Fine Aggregate : Coarse Aggregate.
Thus 1 : 2.6 : 4.6 indicates 1 part by volume of Portland cement, 2.6 parts by volume of fine aggregate and 4.6 parts by volume of coarse aggregate.

Size of Coarse Aggregate.	Slump, in.	Size of Fine Aggregate. 0 – No. 28	0 – No. 14	0 – No. 8	0 – No. 4	0 – $\frac{3}{8}$ in.
None	$\frac{1}{2}$ to 1	1 : 2.2	1 : 2.6	1 : 3.0	1 : 3.5	1 : 4.1
	3 " 4	1 : 1.9	1 : 2.2	1 : 2.6	1 : 3.0	1 : 3.5
	6 " 7	1 : 1.5	1 : 1.7	1 : 2.0	1 : 2.3	1 : 2.7
	8 " 10	1 : 1.0	1 : 1.1	1 : 1.3	1 : 1.6	1 : 1.8
No. 4 to $\frac{3}{4}$ in.	$\frac{1}{2}$ to 1	1 : 2.1 : 3.8	1 : 2.3 : 3.7	1 : 2.6 : 3.5	1 : 3.0 : 3.1	1 : 3.6 : 2.8
	3 " 4	1 : 1.7 : 3.3	1 : 1.9 : 3.2	1 : 2.2 : 3.1	1 : 2.6 : 2.8	1 : 3.0 : 2.4
	6 " 7	1 : 1.3 : 2.7	1 : 1.4 : 2.6	1 : 1.7 : 2.5	1 : 1.9 : 2.3	1 : 2.3 : 2.1
	8 " 10	1 : 0.8 : 1.9	1 : 0.9 : 1.9	1 : 1.0 : 1.8	1 : 1.2 : 1.7	1 : 1.5 : 1.6
No. 4 to 1 in.	$\frac{1}{2}$ to 1	1 : 1.9 : 4.5	1 : 2.2 : 4.3	1 : 2.5 : 4.2	1 : 2.8 : 3.9	1 : 3.4 : 3.6
	3 " 4	1 : 1.6 : 3.9	1 : 1.8 : 3.8	1 : 2.1 : 3.7	1 : 2.4 : 3.5	1 : 2.8 : 3.2
	6 " 7	1 : 1.2 : 3.1	1 : 1.3 : 3.1	1 : 1.5 : 3.0	1 : 1.8 : 2.9	1 : 2.1 : 2.7
	8 " 10	1 : 0.7 : 2.2	1 : 0.8 : 2.2	1 : 1.0 : 2.3	1 : 1.1 : 2.1	1 : 1.3 : 2.0
No. 4 to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	1 : 1.9 : 5.0	1 : 2.1 : 4.9	1 : 2.4 : 4.9	1 : 2.7 : 4.6	1 : 3.2 : 4.4
	3 " 4	1 : 1.6 : 4.4	1 : 1.7 : 4.3	1 : 2.0 : 4.2	1 : 2.4 : 4.0	1 : 2.7 : 3.8
	6 " 7	1 : 1.1 : 3.5	1 : 1.3 : 3.5	1 : 1.4 : 3.5	1 : 1.7 : 3.4	1 : 2.0 : 3.2
	8 " 10	1 : 0.7 : 2.5	1 : 0.8 : 2.5	1 : 0.9 : 2.5	1 : 1.0 : 2.4	1 : 1.2 : 2.3
No. 4 to 2 in.	$\frac{1}{2}$ to 1	1 : 1.7 : 5.8	1 : 1.9 : 5.7	1 : 2.1 : 5.8	1 : 2.4 : 5.6	1 : 2.8 : 5.5
	3 " 4	1 : 1.4 : 5.0	1 : 1.5 : 5.0	1 : 1.8 : 5.0	1 : 2.0 : 4.9	1 : 2.3 : 4.7
	6 " 7	1 : 1.0 : 4.1	1 : 1.1 : 4.1	1 : 1.2 : 4.1	1 : 1.4 : 4.1	1 : 1.7 : 3.9
	8 " 10	1 : 0.6 : 2.9	1 : 0.7 : 2.9	1 : 0.7 : 3.0	1 : 0.8 : 2.9	1 : 1.0 : 2.9
$\frac{3}{8}$ to 1 in.	$\frac{1}{2}$ to 1	1 : 2.2 : 4.4	1 : 2.5 : 4.2	1 : 2.8 : 4.1	1 : 3.3 : 3.8	1 : 3.8 : 3.4
	3 " 4	1 : 1.9 : 3.8	1 : 2.1 : 3.7	1 : 2.4 : 3.6	1 : 2.8 : 3.4	1 : 3.2 : 3.1
	6 " 7	1 : 1.4 : 3.1	1 : 1.5 : 3.0	1 : 1.8 : 3.0	1 : 2.1 : 2.8	1 : 2.4 : 2.5
	8 " 10	1 : 0.9 : 2.2	1 : 1.0 : 2.2	1 : 1.1 : 2.2	1 : 1.3 : 2.0	1 : 1.5 : 1.9
$\frac{3}{8}$ to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	1 : 2.2 : 4.9	1 : 2.5 : 4.8	1 : 2.8 : 4.7	1 : 3.2 : 4.6	1 : 3.7 : 4.2
	3 " 4	1 : 1.9 : 4.3	1 : 2.1 : 4.2	1 : 2.4 : 4.1	1 : 2.7 : 4.0	1 : 3.1 : 3.7
	6 " 7	1 : 1.4 : 3.5	1 : 1.5 : 3.4	1 : 1.7 : 3.4	1 : 2.0 : 3.3	1 : 2.3 : 3.1
	8 " 10	1 : 0.9 : 2.5	1 : 1.0 : 2.5	1 : 1.1 : 2.4	1 : 1.3 : 2.4	1 : 1.5 : 2.3
$\frac{3}{8}$ to 2 in.	$\frac{1}{2}$ to 1	1 : 2.1 : 5.6	1 : 2.3 : 5.5	1 : 2.6 : 5.5	1 : 3.0 : 5.4	1 : 3.5 : 5.1
	3 " 4	1 : 1.7 : 4.8	1 : 2.0 : 4.8	1 : 2.2 : 4.8	1 : 2.5 : 4.7	1 : 2.9 : 4.4
	6 " 7	1 : 1.3 : 4.0	1 : 1.4 : 3.9	1 : 1.6 : 3.9	1 : 1.8 : 3.9	1 : 2.1 : 3.8
	8 " 10	1 : 0.8 : 2.9	1 : 0.9 : 2.9	1 : 1.0 : 2.9	1 : 1.2 : 2.9	1 : 1.3 : 2.8
$\frac{3}{4}$ to $1\frac{1}{2}$ in.	$\frac{1}{2}$ to 1	1 : 2.6 : 4.5	1 : 2.9 : 4.5	1 : 3.3 : 4.4	1 : 3.8 : 4.2	1 : 4.3 : 3.9
	3 " 4	1 : 2.2 : 3.9	1 : 2.5 : 3.9	1 : 2.8 : 3.8	1 : 3.2 : 3.6	1 : 3.6 : 3.3
	6 " 7	1 : 1.6 : 3.2	1 : 1.8 : 3.2	1 : 2.1 : 3.1	1 : 2.4 : 3.0	1 : 2.7 : 2.8
	8 " 10	1 : 1.0 : 2.3	1 : 1.2 : 2.3	1 : 1.4 : 2.2	1 : 1.6 : 2.2	1 : 1.8 : 2.1
$\frac{3}{4}$ to 2 in.	$\frac{1}{2}$ to 1	1 : 2.5 : 5.2	1 : 2.8 : 5.2	1 : 3.2 : 5.1	1 : 3.6 : 5.0	1 : 4.1 : 4.7
	3 " 4	1 : 2.1 : 4.5	1 : 2.4 : 4.5	1 : 2.7 : 4.4	1 : 3.1 : 4.3	1 : 3.5 : 4.0
	6 " 7	1 : 1.6 : 3.7	1 : 1.8 : 3.7	1 : 2.0 : 3.7	1 : 2.3 : 3.6	1 : 2.6 : 3.5
	8 " 10	1 : 1.0 : 2.6	1 : 1.1 : 2.7	1 : 1.3 : 2.6	1 : 1.5 : 2.7	1 : 1.7 : 2.6
$\frac{3}{4}$ to 3 in.	$\frac{1}{2}$ to 1	1 : 2.5 : 6.0	1 : 2.9 : 5.9	1 : 3.2 : 5.9	1 : 3.6 : 5.8	1 : 4.1 : 5.6
	3 " 4	1 : 2.1 : 5.1	1 : 2.4 : 5.2	1 : 2.7 : 5.2	1 : 3.1 : 5.1	1 : 3.5 : 4.9
	6 " 7	1 : 1.5 : 4.1	1 : 1.7 : 4.2	1 : 2.0 : 4.2	1 : 2.3 : 4.2	1 : 2.5 : 4.0
	8 " 10	1 : 1.0 : 2.9	1 : 1.1 : 3.0	1 : 1.3 : 3.0	1 : 1.5 : 3.0	1 : 1.7 : 3.0

TABLE IV. (*Continued*).—PROPORTIONS FOR 2500 LB. PER SQ. IN. CONCRETE.

Proportions are expressed by volume as follows: Portland Cement : Fine Aggregate : Coarse Aggregate. Thus 1 : 2.6 : 4.6 indicates 1 part by volume of Portland Cement, 2.6 parts by volume of fine aggregate and 4.6 parts by volume of coarse aggregate

Size of Coarse Aggregate.	Slump, in.	Size of Fine Aggregate.				
		0 – No. 28	0 – No. 14	0 – No. 8	0 – No. 4	0 – $\frac{3}{8}$ in.
None..............	$\frac{1}{2}$ to 1	1 : 1.8	1 : 2.1	1 : 2.4	1 : 2.9	1 : 3.3
	3 " 4	1 : 1.5	1 : 1.8	1 : 2.1	1 : 2.4	1 : 2.8
	6 " 7	**1 : 1.1**	**1 : 1.3**	**1 : 1.6**	**1 : 1.8**	**1 : 2.1**
	8 " 10	1 : 0.7	1 : 0.8	1 : 0.9	1 : 1.1	1 : 1.3
No. 4 to $\frac{3}{4}$ in.......	$\frac{1}{2}$ to 1	1 : 1.6 : 3.2	1 : 1.8 : 3.1	1 : 2.1 : 3.0	1 : 2.4 : 2.7	1 : 2.9 : 2.4
	3 " 4	1 : 1.3 : 2.8	1 : 1.5 : 2.7	1 : 1.7 : 2.6	1 : 2.0 : 2.4	1 : 2.4 : 2.2
	6 " 7	**1 : 1.0 : 2.2**	**1 : 1.1 : 2.2**	**1 : 1.3 : 2.1**	**1 : 1.5 : 2.0**	**1 : 1.8 : 1.8**
	8 " 10	1 : 0.5 : 1.4	1 : 0.6 : 1.4	1 : 0.7 : 1.4	1 : 0.8 : 1.4	1 : 1.0 : 1.3
No. 4 to 1 in.......	$\frac{1}{2}$ to 1	1 : 1.5 : 3.7	1 : 1.7 : 3.7	1 : 2.0 : 3.5	1 : 2.2 : 3.4	1 : 2.7 : 3.1
	3 " 4	1 : 1.2 : 3.3	1 : 1.4 : 3.2	1 : 1.6 : 3.1	1 : 1.9 : 3.0	1 : 2.2 : 2.7
	6 " 7	**1 : 0.9 : 2.6**	**1 : 1.0 : 2.5**	**1 : 1.1 : 2.5**	**1 : 1.3 : 2.4**	**1 : 1.6 : 2.3**
	8 " 10	1 : 0.5 : 1.7	1 : 0.6 : 1.7	1 : 0.6 : 1.7	1 : 0.7 : 1.6	1 : 0.9 : 1.5
No. 4 to 1$\frac{1}{2}$ in......	$\frac{1}{2}$ to 1	1 : 1.4 : 4.2	1 : 1.6 : 4.1	1 : 1.9 : 4.1	1 : 2.2 : 4.0	1 : 2.5 : 3.8
	3 " 4	1 : 1.2 : 3.7	1 : 1.3 : 3.6	1 : 1.5 : 3.6	1 : 1.8 : 3.5	1 : 2.1 : 3.3
	6 " 7	**1 : 0.9 : 2.9**	**1 : 0.9 : 2.8**	**1 : 1.1 : 2.8**	**1 : 1.3 : 2.8**	**1 : 1.5 : 2.6**
	8 " 10	1 : 0.5 : 1.9	1 : 0.5 : 1.9	1 : 0.6 : 1.9	1 : 0.7 : 1.8	1 : 0.8 : 1.8
No. 4 to 2 in.......	$\frac{1}{2}$ to 1	1 : 1.3 : 4.9	1 : 1.4 : 4.8	1 : 1.6 : 4.9	1 : 1.9 : 4.8	1 : 2.2 : 4.7
	3 " 4	1 : 1.1 : 4.3	1 : 1.2 : 4.2	1 : 1.3 : 4.3	1 : 1.6 : 4.2	1 : 1.8 : 4.1
	6 " 7	**1 : 0.7 : 3.3**	**1 : 0.8 : 3.3**	**1 : 0.9 : 3.4**	**1 1.1 : 3.3**	**1 : 1.2 : 3.3**
	8 " 10	1 : 0.4 : 2.2	1 : 2.4 : 2.2	1 : 0.5 : 2.2	1 : 0.6 : 2.2	1 : 0.6 : 2.2
$\frac{3}{8}$ to 1 in...........	$\frac{1}{2}$ to 1	1 : 1.8 : 3.7	1 : 2.0 : 3.6	1 : 2.3 : 3.5	1 : 2.6 : 3.3	1 : 3.0 : 2.9
	3 " 4	1 : 1.4 : 3.2	1 : 1.6 : 3.1	1 : 1.9 : 2.9	1 : 2.2 : 2.9	1 : 2.5 : 2.6
	6 " 7	**1 : 1.0 : 2.5**	**1 : 1.2 : 2.5**	**1 : 1.3 : 2.4**	**1 : 1.6 : 2.3**	**1 : 1.8 : 2.2**
	8 " 10	1 : 0.6 : 1.6	1 : 0.7 : 1.6	1 : 0.8 : 1.6	1 : 0.9 : 1.6	1 : 1.0 : 1.5
$\frac{3}{8}$ to 1$\frac{1}{2}$ in	$\frac{1}{2}$ to 1	1 : 1.7 : 4.1	1 : 1.9 : 4.1	1 : 2.2 : 4.0	1 : 2.5 : 3.9	1 : 2.9 : 3.6
	3 " 4	1 : 1.5 : 3.6	1 : 1.6 : 3.6	1 : 1.8 : 3.5	1 : 2.1 : 3.4	1 : 2.3 : 3.2
	6 " 7	**1 : 1.0 : 2.9**	**1 : 1.2 : 2.8**	**1 : 1.3 : 2.8**	**1 : 1.5 : 2.7**	**1 : 1.8 : 2.6**
	8 " 10	1 : 0.6 : 1.9	1 : 0.6 : 1.9	1 : 0.8 : 1.8	1 : 0.9 : 1.8	1 : 1.0 : 1.8
$\frac{3}{8}$ to 2 in...........	$\frac{1}{2}$ to 1	1 : 1.7 : 4.7	1 : 1.8 : 4.7	1 : 2.1 : 4.7	1 : 2.4 : 4.6	1 : 2.7 : 4.4
	3 " 4	1 : 1.4 : 4.1	1 : 1.5 : 4.1	1 : 1.7 : 4.1	1 : 2.0 : 4.0	1 : 2.3 : 3.9
	6 " 7	**1 : 1.0 : 3.2**	**1 : 1.1 : 3.2**	**1 : 1.2 : 3.2**	**1 : 1.4 : 3.2**	**1 : 1.6 : 3.1**
	8 " 10	1 : 0.5 : 2.1	1 : 0.6 : 2.1	1 : 0.7 : 2.2	1 : 0.8 : 2.2	1 : 0.9 : 2.1
$\frac{3}{4}$ to 1$\frac{1}{2}$ in.........	$\frac{1}{2}$ to 1	1 : 2.0 : 3.8	1 : 2.3 : 3.8	1 : 2.6 : 3.7	1 : 3.0 : 3.6	1 : 3.4 : 3.3
	3 " 4	1 : 1.7 : 3.3	1 : 2.0 : 3.3	1 : 2.2 : 3.2	1 : 2.5 : 3.2	1 : 2.9 : 2.9
	6 " 7	**1 : 1.2 : 2.6**	**1 : 1.4 : 2.6**	**1 : 1.6 : 2.6**	**1 : 1.9 : 2.5**	**1 : 2.1 : 2.3**
	8 " 10	1 : 0.7 : 1.7	1 : 0.8 : 1.7	1 : 0.9 : 1.7	1 : 1.1 : 1.7	1 : 1.2 : 1.6
$\frac{3}{4}$ to 2 in..........	$\frac{1}{2}$ to 1	1 : 2.0 : 4.4	1 : 2.2 : 4.4	1 : 2.5 : 4.3	1 : 2.9 : 4.3	1 : 3.3 : 4.1
	3 " 4	1 : 1.7 : 3.8	1 : 1.9 : 3.8	1 : 2.1 : 3.8	1 : 2.5 : 3.7	1 : 2.8 : 3.6
	6 " 7	**1 : 1.2 : 3.0**	**1 : 1.4 : 3.0**	**1 : 1.5 : 3.0**	**1 : 1.8 : 3.0**	**1 : 2.0 : 2.8**
	8 " 10	1 : 0.7 : 2.0	1 : 0.8 : 2.0	1 : 0.9 : 2.0	1 : 1.0 : 2.0	1 : 1.2 : 2.0
$\frac{3}{4}$ to 3 in...........	$\frac{1}{2}$ to 1	1 : 2.0 : 5.0	1 : 2.2 : 5.0	1 : 2.5 : 5.0	1 : 2.7 : 5.0	1 : 3.2 : 4.7
	3 " 4	1 : 1.7 : 4.3	1 : 1.9 : 4.3	1 : 2.1 : 4.3	1 : 2.4 : 4.3	1 : 2.7 : 4.1
	6 " 7	**1 : 1.2 : 3.3**	**1 : 1.4 : 3.4**	**1 : 1.5 : 3.4**	**1 : 1.8 : 3.4**	**1 : 2.0 : 3.3**
	8 " 10	1 : 0.7 : 2.2	1 : 0.8 : 2.2	1 : 0.9 : 2.2	1 : 1.0 : 2.3	1 : 1.2 : 2.3

TABLE IV. (*Continued*).—PROPORTIONS FOR 3000 LB. PER SQ. IN. CONCRETE.

Proportions are expressed by volume as follows: Portland Cement : Fine Aggregate : Coarse Aggregate. Thus 1 : 2.6 : 4.6 indicates 1 part by volume of Portland Cement, 2.6 parts by volume of fine aggregate and 4.6 parts by volume of coarse aggregate.

Size of Coarse Aggregate.	Slump, in.	Size of Fine Aggregate.				
		0 – No. 28	0 – No. 14	0 – No. 8	0 – No. 4	0 – ⅜ in.
None	½ to 1	1 : 1.5	1 : 1.7	1 : 2.0	1 : 2.3	1 : 2.7
	3 " 4	1 : 1.2	1 : 1.4	1 : 1.7	1 : 1.9	1 : 2.3
	6 " 7	1 : 0.9	1 : 1.0	1 : 1.2	1 : 1.4	1 : 1.6
	8 " 10	1 : 0.5	1 : 0.6	1 : 0.7	1 : 0.8	1 : 0.9
No. 4 to ¾ in.	½ to 1	1 : 1.3 : 2.7	1 : 1.5 : 2.6	1 : 1.7 : 2.5	1 : 1.9 : 2.4	1 : 2.3 : 2.1
	3 " 4	1 : 1.0 : 2.3	1 : 1.2 : 2.2	1 : 1.4 : 2.2	1 : 1.6 : 2.0	1 : 1.9 : 1.8
	6 " 7	1 : 0.7 : 1.7	1 : 0.8 : 1.7	1 : 0.9 : 1.7	1 : 1.1 : 1.6	1 : 1.3 : 1.4
	8 " 10	1 : 0.3 : 1.0	1 : 0.4 : 1.0	1 : 0.5 : 1.0	1 : 0.5 : 1.0	1 : 0.6 : 0.9
No. 4 to 1 in.	½ to 1	1 : 1.2 : 3.1	1 : 1.3 : 3.1	1 : 1.5 : 3.0	1 : 1.8 : 2.9	1 : 2.1 : 2.7
	3 " 4	1 : 0.9 : 2.7	1 : 1.1 : 2.6	1 : 1.2 : 2.6	1 : 1.4 : 2.5	1 : 1.7 : 2.3
	6 " 7	1 : 0.6 : 2.0	1 : 0.7 : 2.0	1 : 0.8 : 2.0	1 : 0.9 : 1.9	1 : 1.1 : 1.8
	8 " 10	1 : 0.3 : 1.2	1 : 0.3 : 1.2	1 : 0.4 : 1.2	1 : 0.5 : 1.2	1 : 0.6 : 1.2
No. 4 to 1½ in.	½ to 1	1 : 1.1 : 3.6	1 : 1.2 : 3.5	1 : 1.5 : 3.5	1 : 1.7 : 3.4	1 : 2.0 : 3.2
	3 " 4	1 : 0.9 : 3.0	1 : 1.0 : 2.9	1 : 1.2 : 2.9	1 : 1.4 : 2.9	1 : 1.6 : 2.7
	6 " 7	1 : 0.6 : 2.2	1 : 0.7 : 2.2	1 : 0.8 : 2.2	1 : 0.9 : 2.2	1 : 1.1 : 2.1
	8 " 10	1 : 0.3 : 1.4	1 : 0.3 : 1.3	1 : 0.4 : 1.4	1 : 0.5 : 1.4	1 : 0.5 : 1.3
No. 4 to 2 in.	½ to 1	1 : 1.0 : 4.1	1 : 1.1 : 4.1	1 : 1.2 : 4.1	1 : 1.4 : 4.1	1 : 1.6 : 4.0
	3 " 4	1 : 0.8 : 3.4	1 : 0.9 : 3.4	1 : 1.0 : 3.5	1 : 1.1 : 3.4	1 : 1.3 : 3.4
	6 " 7	1 : 0.5 : 2.6	1 : 0.6 : 2.6	1 : 0.6 : 2.7	1 : 0.7 : 2.6	1 : 0.9 : 2.6
	8 " 10	1 : 0.2 : 1.6	1 : 0.3 : 1.6	1 : 0.3 : 1.7	1 : 0.4 : 1.7	1 : 0.4 : 1.7
⅜ to 1 in.	½ to 1	1 : 1.4 : 3.1	1 : 1.5 : 3.0	1 : 1.8 : 2.9	1 : 2.1 : 2.8	1 : 2.4 : 2.6
	3 " 4	1 : 1.1 : 2.6	1 : 1.3 : 2.6	1 : 1.5 : 2.5	1 : 1.7 : 2.4	1 : 2.0 : 2.2
	6 " 7	1 : 0.8 : 2.0	1 : 0.8 : 2.0	1 : 1.0 : 1.9	1 : 1.1 : 1.9	1 : 1.3 : 1.8
	8 " 10	1 : 0.4 : 1.2	1 : 0.4 : 1.2	1 : 0.5 : 1.2	1 : 0.6 : 1.2	1 : 0.7 : 1.1
⅜ to 1½ in.	½ to 1	1 : 1.4 : 3.5	1 : 1.5 : 3.4	1 : 1.7 : 3.4	1 : 2.0 : 3.3	1 : 2.3 : 3.1
	3 " 4	1 : 1.1 : 3.0	1 : 1.2 : 2.9	1 : 1.4 : 2.9	1 : 1.6 : 2.8	1 : 1.9 : 2.6
	6 " 7	1 : 0.6 : 2.2	1 : 0.8 : 2.2	1 : 1.0 : 2.2	1 : 1.1 : 2.1	1 : 1.3 : 2.0
	8 " 10	1 : 0.4 : 1.4	1 : 0.4 : 1.4	1 : 0.5 : 1.4	1 : 0.6 : 1.3	1 : 0.7 : 1.3
⅜ to 2 in.	½ to 1	1 : 1.3 : 4.0	1 : 1.4 : 4.0	1 : 1.6 : 4.0	1 : 1.9 : 3.9	1 : 2.1 : 3.8
	3 " 4	1 : 1.0 : 3.4	1 : 1.2 : 3.4	1 : 1.3 : 3.3	1 : 1.5 : 3.3	1 : 1.7 : 3.2
	6 " 7	1 : 0.7 : 2.6	1 : 0.8 : 2.5	1 : 0.9 : 2.6	1 : 1.0 : 2.6	1 : 1.1 : 2.5
	8 " 10	1 : 0.4 : 1.6	1 : 0.4 : 1.6	1 : 0.5 : 1.6	1 : 0.5 : 1.6	1 : 0.6 : 1.6
¾ to 1½ in.	½ to 1	1 : 1.6 : 3.2	1 : 1.8 : 3.2	1 : 2.1 : 3.2	1 : 2.4 : 3.1	1 : 2.7 : 2.9
	3 " 4	1 : 1.3 : 2.7	1 : 1.5 : 2.7	1 : 1.7 : 2.7	1 : 2.0 : 2.6	1 : 2.3 : 2.5
	6 " 7	1 : 0.9 : 2.0	1 : 1.0 : 2.1	1 : 1.2 : 2.0	1 : 1.4 : 2.0	1 : 1.5 : 1.8
	8 " 10	1 : 0.5 : 1.2	1 : 0.5 : 1.3	1 : 0.6 : 1.3	1 : 0.7 : 1.3	1 : 0.8 : 1.2
¾ to 2 in.	½ to 1	1 : 1.6 : 3.7	1 : 1.8 : 3.7	1 : 2.0 : 3.7	1 : 2.4 : 3.6	1 : 2.6 : 3.5
	3 " 4	1 : 1.3 : 3.1	1 : 1.5 : 3.1	1 : 1.6 : 3.1	1 : 1.9 : 3.1	1 : 2.2 : 3.0
	6 " 7	1 : 0.9 : 2.4	1 : 1.1 : 2.4	1 : 1.1 : 2.4	1 : 1.3 : 2.4	1 : 1.5 : 2.3
	8 " 10	1 : 0.5 : 1.5	1 : 0.5 : 1.5	1 : 0.6 : 1.5	1 : 0.7 : 1.5	1 : 0.8 : 1.5
¾ to 3 in.	½ to 1	1 : 1.6 : 4.2	1 : 1.8 : 4.2	1 : 2.0 : 4.2	1 : 2.3 : 4.1	1 : 2.6 : 4.0
	3 " 4	1 : 1.3 : 3.5	1 : 1.5 : 3.6	1 : 1.6 : 3.6	1 : 1.9 : 3.6	1 : 2.1 : 3.5
	6 " 7	1 : 0.9 : 2.6	1 : 1.0 : 2.6	1 : 1.1 : 2.6	1 : 1.3 : 2.6	1 : 1.4 : 2.6
	8 " 10	1 : 0.5 : 1.6	1 : 0.5 : 1.6	1 : 0.6 : 1.7	1 : 0.7 : 1.7	1 : 0.8 : 1.7

APPENDIX I.

STANDARD NOTATION.

All symbols used in the Tentative Specifications for Concrete and Reinforced Concrete have been collected here for convenience of reference. The symbols are in general defined in the text near the point where formulas occur. In a few instances the same symbol is used in two distinct senses; however, there is little danger of confusion from this source.

a = spacing of web reinforcement bars measured perpendicular to their direction (see Section 135);

a = width of face of column or pedestal;

α = angle between inclined web bars and longitudinal bars;

A = total net area of column, footing, or pedestal, exclusive of fireproofing;

A' = loaded area of pedestal, pier or footing;

A_c = $A(1-p)$ = net area of concrete core of column;

A'_c = net area of concrete in columns (total column area minus steel area);

A_s = effective cross-sectional area of metal reinforcement in tension in beams or compression in columns; and the effective cross-sectional area of metal ıeinforcement which crosses any of the principal design sections of a flat slab and which meets the requirements of Section 156;

A_v = total area of web reinforcement in tension within a distance of a (a_1, a_2, a_3, etc.) or the total area of all bars bent up in any one plane;

b = width of rectangular beam or width of flange of T-beam;

b' = width of stem of T-beam;

b_1 = dimension of the dropped panel of a flat slab in the direction parallel to l_1;[1]

c = base diameter of the largest right circular cone which lies entirely within the column (including the capital) whose vertex angle is 90 deg. and whose base is $1\frac{1}{2}$ in. below the bottom of the slab or the bottom of the dropped panel (see Fig. 14);

[1] In flat slab design, the column strip and the middle strip to be used when considering moments in the direction of the dimension l are located and dimensioned as shown in Fig. 15. The dimension l_1 does not always represent the short length of the panel. When moments in the direction of the shorter panel length are considered, the dimensions l and l_1 are to be interchanged and strips corresponding to those shown in Fig. 15 but extending in the direction of the shorter panel length are to be considered.

c = projection of footing from face of column;
C = total compressive stress in concrete;
C' = total compressive stress in reinforcement;
d = depth from compression surface of beam or slab to center of longitudinal tension reinforcement;
d' = depth from compression surface of beam or slab to center of compression reinforcement;
E_c = modulus of elasticity of concrete in compression;
E_s = modulus of elasticity of steel in tension = 30,000,000 lb. per sq. in.;
f_c = compressive unit stress in extreme fiber of concrete;
f'_c = ultimate compressive strength of concrete at age of 28 days, based on tests of 6 by 12-in. or 8 by 16-in. cylinders made and tested in accordance with the Standard Methods of Making and Storing Specimens of Concrete in the Field (Appendix 14) and the Tentative Methods of Making Compression Tests of Concrete (Appendix 13);
f_r = compressive unit stress in metal core;
f_s = tensile unit stress in longitudinal reinforcement;
f'_s = compressive unit stress in longitudinal reinforcement;
f_v = tensile unit stress in web reinforcement;
h = unsupported length of column;
I = moment of inertia of a section about the neutral axis for bending;
j = ratio of lever arm of resisting couple to depth d;
jd = $d-z$ = arm of resisting couple;
k = ratio of depth of neutral axis to depth d;
l = span length of beam or slab (generally distance from center to center of supports; for special cases, see Sections 108 and 148);
l = span length of flat slab, center to center of columns, in the rectangular direction in which moments are considered;[1]
l_1 = span length of flat slab, center to center of columns, perpendicular to the rectangular direction in which moments are considered;[1]
M = bending moment or moment of resistance in general;
M_0 = sum of positive and negative bending moments in either rectangular direction, at the principal design sections of a panel of a flat slab;
n = E_s/E_c = ratio of modulus of elasticity of steel to that of concrete;

[1] See footnote, p. 65.

o = perimeter of bar;
Σo = sum of perimeters of bars in one set;
p = ratio of effective area of tension reinforcement to effective area of concrete in beams $= A_s/bd$; and the ratio of effective area of longitudinal reinforcement to the area of the concrete core in columns;
p' = ratio of effective area of compression reinforcement to effective area of concrete in beams;
P = total safe axial load on column whose h/R is less than 40;
P' = total safe axial load on long column;
r = ratio of cross-sectional area of negative reinforcement which crosses entirely over the column capital of a flat slab or over the dropped panel, to the total cross-sectional area of the negative reinforcement in the two column strips;
r_a = permissible working stress in concrete over the loaded area of a pedestal, pier or footing;
R = ratio of positive or negative moment in two column strips or one middle strip of a flat slab, to M_0;
R = least radius of gyration of a section;
s = spacing of web members, measured at the neutral axis and in the direction of the longitudinal axis of the beam;
t = thickness of flange of T-beam;
t_1 = thickness of flat slab without dropped panels or thickness of a dropped panel (see Fig. 14);
t_2 = thickness of flat slab with dropped panels at points away from the dropped panel (see Fig 14);
T = total tensile stress in longitudinal reinforcement;
u = bond stress per unit of area of surface of bar;
v = shearing unit stress;
V = total shear;
V' = external shear on any section after deducting that carried by the concrete;
w = uniformly distributed load per unit of length of beam or slab;
w = upward reaction per unit of area of base of footing;
w' = uniformly distributed dead and live load per unit of area of a floor or roof;
W = total dead and live load uniformly distributed over a single panel area;
z = depth from compression surface of beam or slab to resultant of compressive stresses.

APPENDIX II.

See Appendix I for explanation of symbols used in figures.

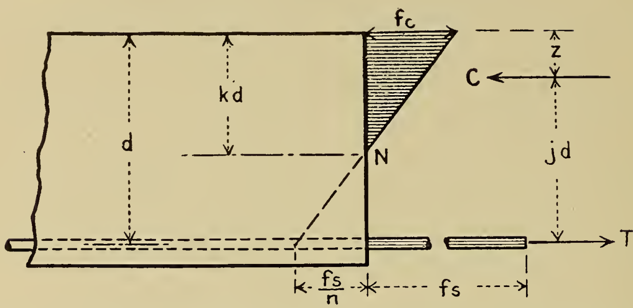

FIG. 1.—Nomenclature for Concrete Beam Reinforced for Tension.

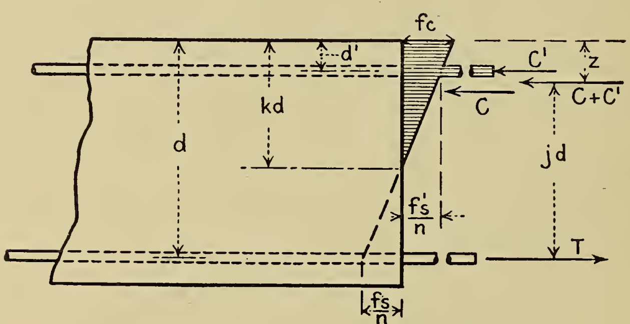

FIG. 2.—Nomenclature for Concrete Beam Reinforced for Tension and Compression.

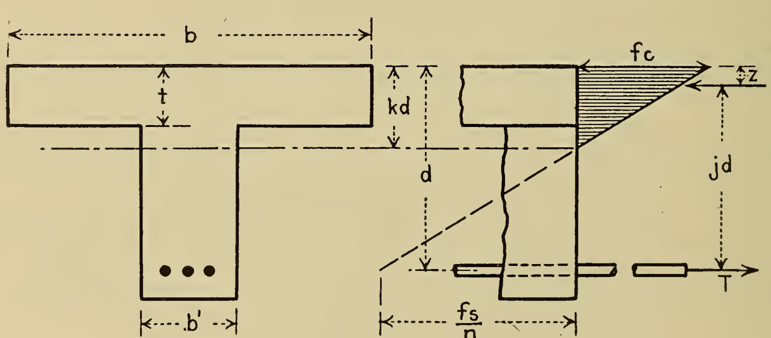

FIG. 3.—Nomenclature for Reinforced Concrete T-Beam.

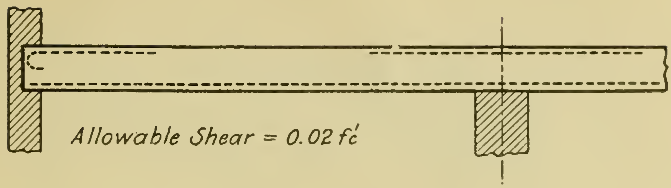

Fig. 4.—Typical Reinforced Concrete Beam; Principal Longitudinal Bars not Anchored.

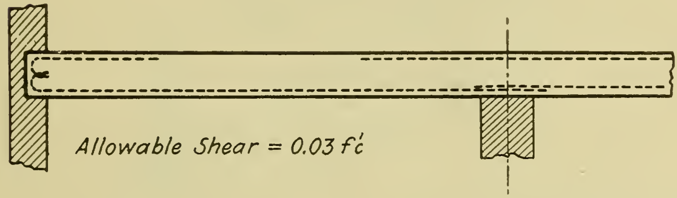

Fig. 5.—Typical Reinforced Concrete Beam; Principal Longitudinal Bars Anchored.

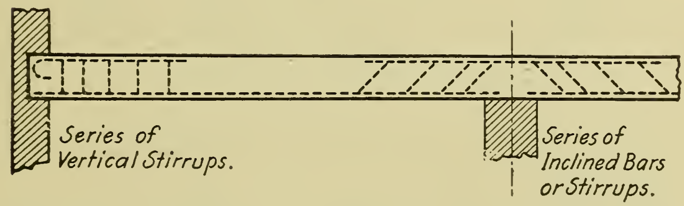

Fig. 6.—Typical Reinforced Concrete Beam; Web Reinforced by Means of Series of Vertical Stirrups or Series of Inclined Bars or Stirrups.

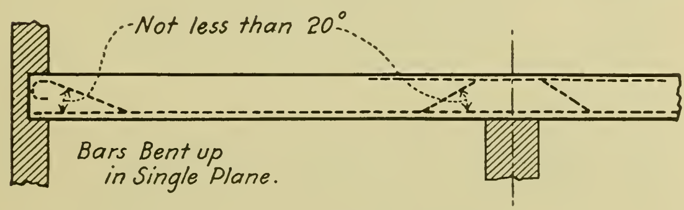

Fig. 7.—Typical Reinforced Concrete Beam; Principal Longitudinal Bars Bent up in Single Plane.

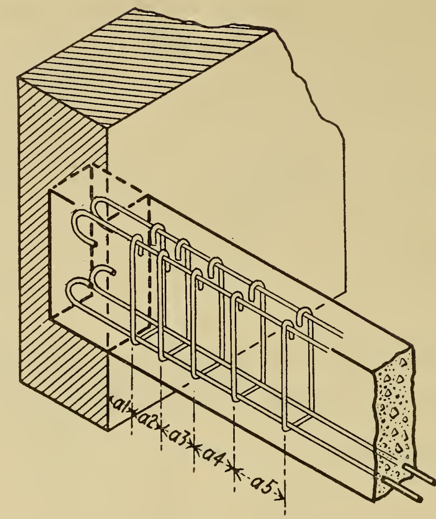

Fig. 8.—Typical Reinforced Concrete Beam with Anchored Longitudinal Bars and Vertical Stirrups.

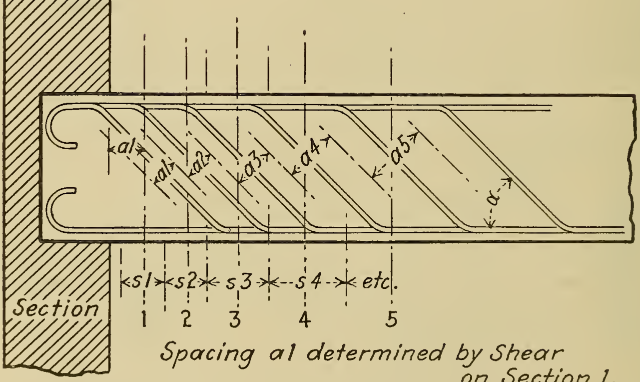

Fig. 9.—Typical Beam with Web Reinforced by Means of Series of Inclined Bars.

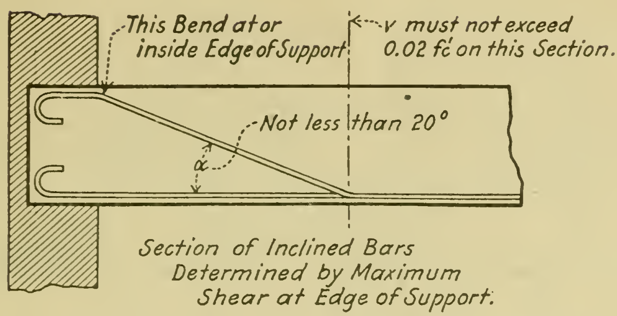

FIG. 10.—Typical Beam with Web Reinforced by Means of Bars Bent up in Single Plane.

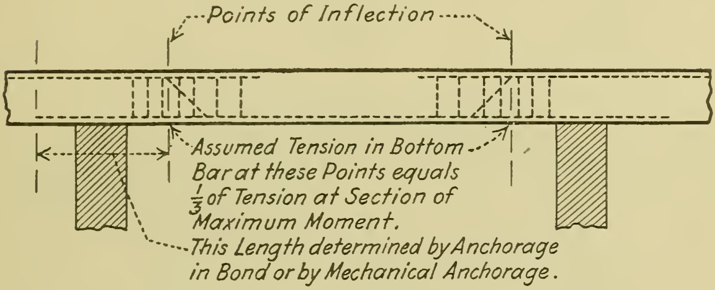

FIG. 11.—Typical Web Reinforcement for Continuous Beams.

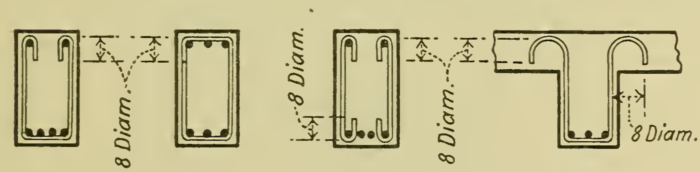

FIG. 12.—Typical Methods of Anchoring Vertical Stirrups.

FIG. 13.—Typical Reinforced Concrete Beam-and-Tile Construction.

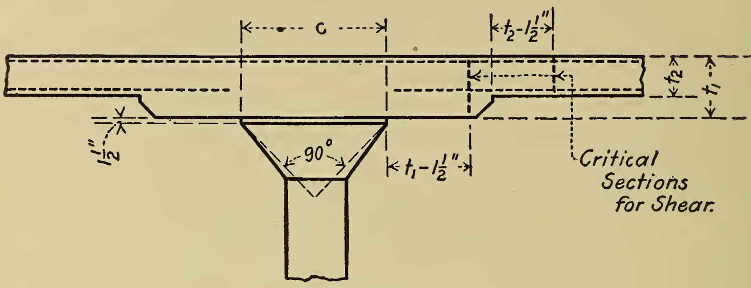

FIG. 14.—Typical Column Capital and Sections of Flat Slab with Dropped Panel.

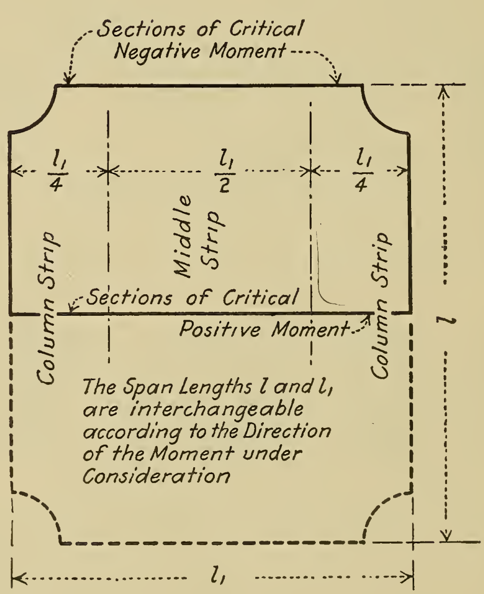

FIG. 15.—Principal Design Sections of a Flat Slab.

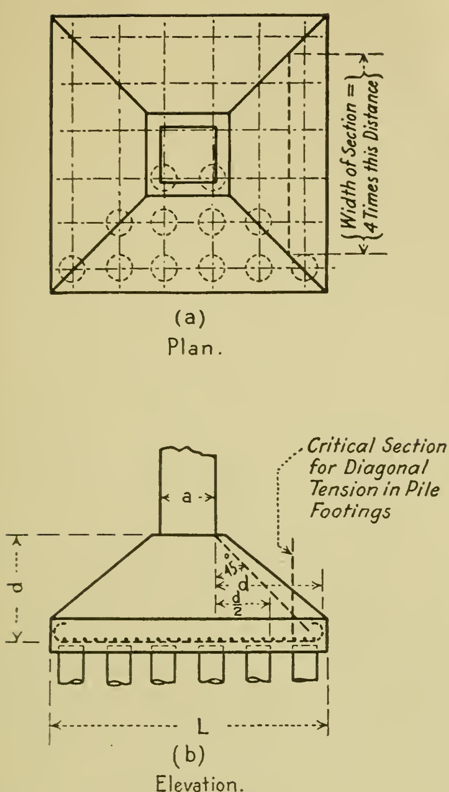

FIG. 16.—Typical Sloped Reinforced Concrete Footing on Piles.

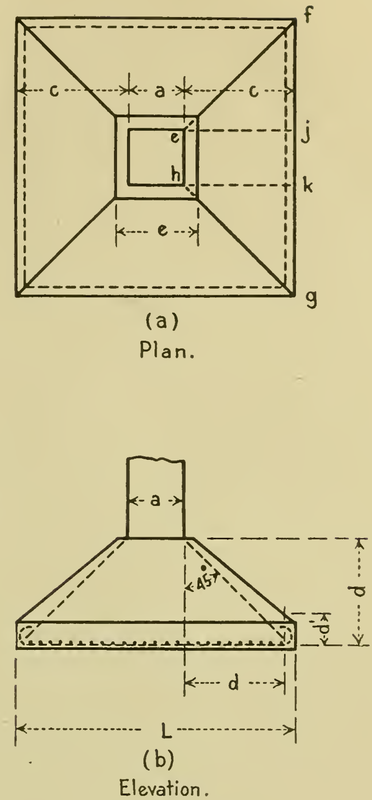

FIG. 17.—Typical Sloped Reinforced Concrete Footing on Soil.

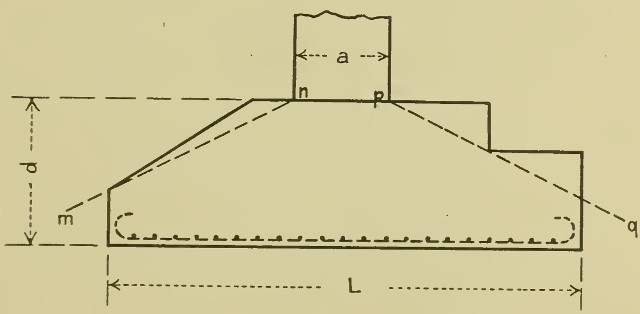

FIG. 18.—Typical Sloped or Stepped Footing.