Bureau of Yards and Docks,
Navy Department,
Washington, D. C., January 1, 1918.

STANDARDS OF DESIGN, REINFORCED CONCRETE.

Details of construction.

1. *Materials, methods of mixing, placing and finishing, character of forms, inspection, etc.*, shall be in strict accordance with the requirements of Navy Standard Specification, concrete and mortar, 59C2c.

2. *Protective covering.*—The minimum thickness of concrete or mortar for protection of metal against corrosion shall be 1 inch.

The minimum thickness of concrete or mortar for protection of metal against fire shall be as follows:

	Inches.
Columns and girders	2
Floor beams	1 1/2
Slabs	1

The above dimensions are from face of rod to face of concrete. To determine distance from face of concrete to center of steel add half the diameter of the rods to the above dimensions.

All corners and edges of columns, girders, and beams shall be either beveled or rounded.

3. *Splicing reinforcing material and joints in reinforced concrete construction.*—Where *tension or compression reinforcement* is spliced it shall be lapped on the basis of the bond stress and the stress in the bar at the point of splice, or a connection shall be made between the bars of sufficient strength to carry the stress.

In columns, small rods (3/4 inch and under) shall be lapped as specified above, and structural shapes or heavy bars shall be properly spliced and provided with bearing plates at foundations; rods above 3/4 inch shall be squared and butted in sleeves, and in foundations, or the bars shall be carried into the footing a sufficient distance to transmit the stress of the steel to the concrete by means of the bond resistance.

4. *Stopping points.*—Whenever it is found impossible, owing to the magnitude of the work, to cast the entire structure in one operation, the following locations shall govern for stopping points for the respective parts: Joints in columns shall be flush with bottom surface of girders, and in flat slab construction at the bottom of the flare of the column head; joints in girders shall be at center of span, unless a floor beam intersects the girder at this point, in which case the joint shall be offset a distance equal to at least twice the width of the beam; joints in floor beams and slabs shall be at the center of the span. All joints shall be perpendicular to the axis or surface of the member jointed. In every case planes of cleavage caused by stoppage of work shall be provided with offsets and extra reinforcement, if necessary, to develop the full designed strength.

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5. *General assumptions.*—Slabs and floor beams shall be designed to support the total dead and live loads; girders shall be designed to support the total dead load and 80 per cent of the live load and columns shall be designed for the total dead load and 75 per cent of the live load, except as noted below. For roof loads the full live load shall be used. In storehouses 80 per cent of the live load shall be used on columns only; beams and girders shall carry full live load. Proper provision shall be made for the dynamic effect of live load, where same justifies consideration, by the addition of a percentage. In special cases, where conditions justify, girders and columns shall be designed for 100 per cent of the live load in addition to the total dead load.

6. *Span lengths of slabs, beams, and girders, and column lengths.*—The span length for slabs, beams, and girders, simply supported, shall be taken as the distance from center to center of supports with a maximum span length of the clear distance between supports plus the depth of girder or slab. For continuous or restrained beams the span length shall be taken as the clear distance between faces of supports exclusive of brackets. The length of column shall be taken as the maximum unsupported length.

7. *Spacing of rods.*—The lateral spacing of parallel bars shall not be less than 3 diameters from center to center and not less than 2 diameters from side of beam to center of rod. The clear space between 2 layers of bars shall not be less than 1 inch. The use of more than 2 layers will not be allowed unless special reasons make same imperative, in which case special provisions shall be made for tying together.

8. *Columns.*—For columns reinforced longitudinally and with or without spiral hooping, the ratio of unsupported length of column to its least over-all diameter shall not exceed 15. For columns reinforced with spiral hooping only, this ratio shall not exceed 10. In no case shall the least over-all diameter be less than 12 inches. The protective covering over the steel shall be 2 inches. The effective area of hooped columns shall be taken as the area within the perimeter inclosing the spiral. Longitudinal reinforcement shall not exceed 4 per cent nor be less than 1 per cent of the effective area. The total amount of spiral or hooping reinforcement shall not be less than 1 per cent of the volume of the column, inclosed. The clear spacing between hoops shall not exceed 1/6 of the diameter of the inclosed column, and shall in no case be greater than 2 1/2 inches.

Where structural steel shapes are used for reinforcing columns, they shall be provided with lattice bars or plates to tie them together, no dependence being placed on the concrete for this purpose. All splices, connections, etc., shall be designed in strict accordance with structural steel practice.

9. *Reinforcement for shrinkage and temperature stresses.*—Reinforcement should be equal to about 1/3 of 1 per cent and should be of a form to develop high bond resistance. It shall be placed near exposed surface and shall be well distributed.

10. T-*beams.*—Where a floor slab and beam are built as a monolithic structure, the total width of that portion which is used as the flange of the T beam, shall not exceed the width of the stem plus

eight times the thickness of the slab; also it shall not exceed four times the width of the stem. For isolated beams the width of the flange shall not exceed three times the width of the stem. In all cases the total width of flange shall not exceed one-fourth of the length of the span.

11. *Maximum allowable unit stresses and ratio of moduli of elasticity.*—The allowable unit stresses shall be the percentages given herein of the ultimate strength of the particular concrete which is to be used, as shown in the following:

Table of ultimate compressive strengths of different mixtures of concrete.

[In pounds per square inch.]

Aggregate.	1:1:2	1:1½:3	1:2:4	1:2½:5	1:3:6
Granite, trap rock gravel, hard limestone, and hard sandstone	3,000	2,500	2,000	1,600	1,300
Soft limestone and sandstone	2,200	1,800	1,500	1,200	1,000
Cinders	800	700	600	500	400

ALLOWABLE UNIT STRESSES FOR PIERS AND FOUNDATIONS.

(*a*) Plain bearing on a concrete surface of at least twice the loaded area, **35** per cent of compressive strength.

(*b*) Plain bearing on other surfaces, **25** per cent of compressive strength.

(*c*) Axial compression in a plain concrete pier, the length of which does not exceed four diameters, **22.5** per cent of compressive strength.

ALLOWABLE UNIT STRESSES FOR SLABS, BEAMS, AND GIRDERS.

(*d*) Compression in extreme fibers of concrete, **32.5** per cent of compressive strength.

(*e*) Compression in extreme fibers of concrete at supports of continuous beams, **37.5** per cent of compressive strength.

(*f*) Vertical shearing stress, horizontal bars only and without web reinforcement, **2** per cent of compressive strength.

(*g*) Vertical shearing stress, bent-up bars only and without vertical stirrups, **3** per cent of compressive strength.

(*h*) Vertical shearing stress, combination of bent-up bars and vertical stirrups fastened securely to the bars and spaced horizontally not more than one-half of the depth of the beam, **5** per cent of compressive strength.

(*i*) Punching shear with diagonal tension provided for, **6** per cent of compressive strength.

The unit shearing stress shall be computed by formula 22, given in the appendix.

In providing for diagonal tension the web reinforcement shall be designed to take two-thirds of the total vertical shear.

ALLOWABLE UNIT BOND STRESS.

(*j*) Bond between concrete and plain bars, 4 per cent of compressive strength.

(*k*) Bond between concrete and deformed bars, 5 per cent of compressive strength.

(*l*) Bond between concrete and drawn wire, 2 per cent of compressive strength.

ALLOWABLE UNIT STRESSES IN COLUMNS.

(*m*) Columns with longitudinal bars held by bands, the bars being not less than 1 per cent nor more than 4 per cent of the area of the column core, the bands being not less than 1/4 inch in diameter and approximately 12 inches on centers, shall have a unit stress on the concrete core not to exceed 25 per cent of the compressive strength.

(*n*) Columns with close hoops or spirals only, of not less than 1 per cent of the column core and spaced not more than one-sixth of the diameter of the column core nor more than 2 1/2 inches on centers, shall have a unit stress on the concrete core not to exceed 27 per cent of the compressive strength.

(*o*) Columns with close hoops or spirals and with longitudinal bars all within the limits specified above, shall have a unit stress on the concrete core not to exceed 33 1/3 per cent of the compressive strength, and in no case to exceed 800 pounds per square inch.

ALLOWABLE UNIT STRESS IN STEEL REINFORCEMENT.

(*p*) The tensile or compressive stress in steel shall not exceed 16,000 pounds per square inch. Steel in compression shall be considered to be stressed "n" times the stress in the adjacent concrete, where "n" represents the ratio of the modulus of elasticity of steel to that of concrete, as given below.

MODULI OF ELASTICITY.

In designing reinforced concrete, the ratio of the modulus of elasticity of steel to the modulus of elasticity of concrete shall be taken as—

(*q*) Forty, when the compressive strength of the concrete does not exceed 800 pounds per square inch.

(*r*) Fifteen, when the compressive strength of the concrete is greater than 800 pounds per square inch and less than 2,200 pounds per square inch.

(*s*) Twelve, when the compressive strength of the concrete is greater than 2,200 pounds per square inch and less than 2,900 pounds per square inch.

(*t*) Ten, when the compressive strength of the concrete is greater than 2,900 pounds per square inch.

12. STANDARD NOTATION.

RECTANGULAR BEAMS.

The following notation shall be used:

f_s=tensile unit stress in steel.
f_c=compressive unit stress in concrete.
E_s=modulus of elasticity of steel.
E_c=modulus of elasticity of concrete.
$n=\frac{E_s}{E_c}$
M=moment of resistance, or bending moment in general, in inch-pounds.
A=steel area in square inches.
b=breadth of beam in inches.
d=depth of beam, to center of steel, in inches.
k=ratio of depth of neutral axis to effective depth d.
z=depth of resultant compression below top.
j=ratio of lever arm of resisting couple to depth d.
$jd=d-z$=arm of resisting couple.
p=steel ratio (not percentage).
w=load per lineal foot of slab or beam.
l=length of span in feet.

T-BEAMS.

b=width of flange.
b'=width of stem.
t=thickness of flange.

BEAMS REINFORCED FOR COMPRESSION.

A=area of compressive steel.
p'=steel ratio for compressive steel.
f'_s=compressive unit stress in steel.
C=total compressive stress in concrete.
C'=total compressive stress in steel.
d'=depth to center of compressive steel.
z=depth of resultant of C and C'.

SHEAR AND BOND.

V=total shear.
v=shearing unit stress.
u=bond stress per unit superficial area of bar.
o=circumference or perimeter of bar.
Σ_o=sum of the perimeters of all bars.

COLUMNS.

A=total net area.
A_s=area of longitudinal steel.
A_c=area of concrete.
P=total safe load.

DESIGN.

13. Beams and slabs.

(*a*) *Continuous spans.*

Slabs $\frac{1}{12}wl^2$ at center and over supports.

Beams $\frac{1}{12}wl^2$ at center and over supports for interior spans.

$\frac{1}{10}wl^2$ at center and over support for end span of a series.

Beams and slabs $\frac{1}{8}wl^2$ over center support for 2 spans only.

$\frac{1}{10}wl^2$ at center of spans for 2 spans only.

At ends of continuous beams the amount of negative moment depends on the form of construction.

No smaller moments than the above shall be allowed over supports even if more reinforcement is put in at the center of the span.

Steel on compression side may be considered as acting.

(*b*) *Ends free and simply supported.*

Beams and slabs $\frac{1}{8}wl^2$ *at center.*

14. Slabs supported along four sides and reinforced in two directions.

(*a*) *Square slabs.*—One-half the load shall be considered as carried by each system of reinforcement.

(*b*) *Rectangular slabs.*—If w is the total load per square foot, l and l_1 are the length and breadth of panel, respectively, in feet and $r=\frac{l}{l_1}$, then the load per square foot carried by the transverse system of reinforcement shall be taken as—

$$\frac{wl^4}{l^4+l_1^4} \text{ or } \frac{wr^4}{1+r^4}$$

and the load per square foot carried by the longitudinal system shall be taken as—

$$\frac{wl_1^4}{l^4+l_1^4} \text{ or } \frac{w}{1+r^4}$$

Assuming these unit loads as determined above for (*a*) and (*b*), two-thirds of the calculated moments shall be assumed as carried by the center half and one-third by the outside quarters of each system of reinforcement.

15. *Stirrups* should be spaced by the formula:

$$s=\frac{16000a}{(v-40)b}$$

for 1:2:4 concrete where—

v=unit shearing stress, see formula (22) of the Appendix.

b=breadth of beam in inches.

s=distance between stirrups in inches.

a=cross-sectional area of 1 stirrup in square inches.

Note.—The unit shear on cross section should never exceed **120** pounds per square inch.

If main reinforcing rods are bent up for web reinforcement, the points of bending shall be calculated. For this purpose the method used for designing cover plates of built-up steel girders is applicable, the formula for uniform load on a simply supported beam being:

$$\frac{L'}{L}=\sqrt{\frac{a'}{A}}$$

where L'=length of horizontal part of bent rods.
L =span length.
a' =area of bent rods.
A =total area of reinforcement.

For continuous beams, bending up at the 1/4 points will be satisfactory, but sufficient steel must be placed top and bottom, on each side of the quarter points, to take care of the stresses resulting from irregular loads.

16. In girders and beams use 1:2:4 concrete and the following maximum unit stresses:

Tension in steel..................................pounds..	16,000
Compression in concrete............................do....	650

This gives—

$$kd=\ 0.3786\ d$$
$$jd=\ 0.8738\ d$$
$$M=107.5\ bd^2$$
$$A=\ 0.0077\ bd$$

17. *Outside work*, such as piers, wharves, sea walls, etc., shall not exceed the following unit stresses used in their design:

Tension in steel..................................pounds..	12,500
Compression in concrete............................do....	600

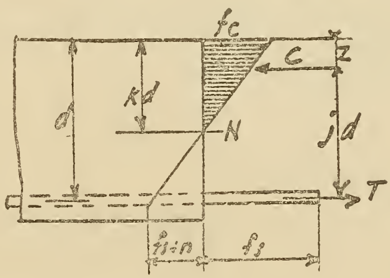
This gives—

$$M=\ 108.0\ bd^2$$
$$A=\ 0.01\ bd$$
$$kd=\ 0.418\ d$$
$$jd=\ 0.861\ d$$

APPENDIX.

The formulæ given in the above standards are based on the following general formulæ, which were compiled by the committee on concrete and reinforced concrete, appointed by the American Society of Civil Engineers:

1. Rectangular Beams.



Position of neutral axis,

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

Arm of resisting couple,

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

(For f_s=15,000 to 16,000, and f_c=600 to 650, k may be taken at $\frac{3}{8}$.)
Fiber stresses,

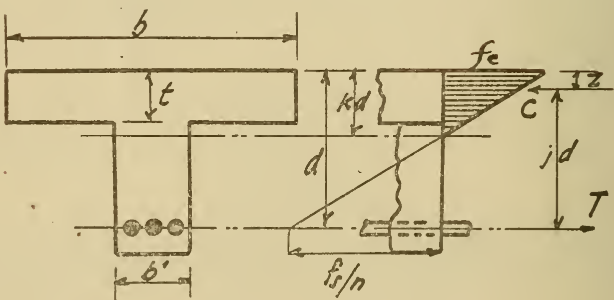
$$f_s=\frac{M}{Ajd}=\frac{M}{pjbd^2} \qquad (3)$$

$$f_c=\frac{2M}{jkbd^2}=\frac{2pf_s}{k} \qquad (4)$$

Steel ratio, for balanced reinforcement,

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

2. T-Beams.



Case I. When the neutral axis lies in the flange, use the formulas for rectangular beams.

Case II. When the neutral axis lies in the stem, the following formulas neglect the compression in the stem:

Position of neutral axis,

$$kd=\frac{2ndA+bt^2}{2nA+2bt} \qquad (6)$$

Position of resultant compression,

$$z=\frac{3kd-2t}{2kd-t}\cdot\frac{t}{3} \qquad (7)$$

Arm of resisting couple,

$$jd = d - z \tag{8}$$

Fiber stresses,

$$f_s = \frac{M}{Ajd} \tag{9}$$

$$f_c = \frac{Mkd}{bt(kd - \frac{1}{2}t)jd} = \frac{f_s}{n} \cdot \frac{k}{1-k} \tag{10}$$

(For approximate results the formulas for rectangular beams may be used.)

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,

$$kd = \sqrt{\frac{2ndA + (b-b')t^2}{b'} + \left(\frac{nA + (b-b')t}{b'}\right)^2} - \frac{nA + (b-b')t}{b'} \tag{11}$$

Position of resultant compression,

$$z = \frac{\left(kdt^2 - \frac{2}{3}t^3\right)b + \left[(kd-t)^2\left(t + \frac{1}{3}(kd-t)\right)\right]b'}{t(2kd-t)b + (kd-t)^2b'} \tag{12}$$

Arm of resisting couple,

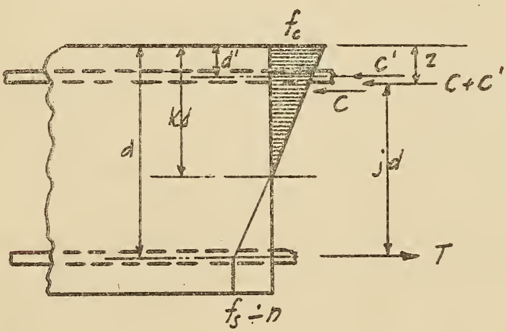
$$jd = d - z \tag{13}$$

Fiber stresses,

$$f_s = \frac{M}{Ajd} \tag{14}$$

$$f_c = \frac{2\ Mkd}{[(2kd-t)bt + (kd-t)^2b']jd} \tag{15}$$

3. Beams Reinforced for Compression.



Position of neutral axis,

$$k=\sqrt{2n\left(p+p'\frac{d'}{d}\right)+n^2(p+p')^2}-n(p+p') \qquad (16)$$

Position of resultant compression,

$$z=\frac{\frac{1}{3}k^3d+2p'nd'\left(k-\frac{d'}{d}\right)}{k^2+2p'n\left(k-\frac{d'}{d}\right)} \qquad (17)$$

Arm of resisting couple,

$$jd=d-z \qquad (18)$$

Fiber stresses,

$$f_c=\frac{6M}{bd^2\left[3k-k^2+\frac{6p'n}{k}\left(k-\frac{d'}{d}\right)\left(1-\frac{d'}{d}\right)\right]} \qquad (19)$$

$$f_s=\frac{M}{pjbd^2}=nf_c\frac{1-k}{k} \qquad (20)$$

$$f'_s=nf_c\frac{k-\frac{d'}{d}}{k} \qquad (21)$$

4. Shear, Bond, and Web Reinforcement.

In the following formulas Σ_0 refers only to the bars constituting the tension reinforcement at the section in question, and jd is the lever arm of the resisting couple at the section.

For rectangular beams.

$$v=\frac{V}{bjd} \qquad (22)$$

$$u=\frac{V}{jd\Sigma_0} \qquad (23)$$

(For approximate results j may be taken as $\frac{7}{8}$.)

The stresses in web reinforcement may be estimated by the following formulas:

Vertical web reinforcement.

$$P=\frac{Vs}{jd} \qquad (24)$$

Web reinforcement inclined at 45° (not bent-up bars),

$$P=0.7\frac{Vs}{jd} \qquad (25)$$

in which P=stress in single reinforcing member, V=amount of total shear assumed as carried by the reinforcement, and s=horizontal spacing of the reinforcing members.

The same formulas apply to beams reinforced for compression as regards shear and bond stress for tensile steel.

For T beams,

$$v=\frac{V}{b'jd} \qquad (26)$$

$$u=\frac{V}{jd\Sigma_0} \qquad (27)$$

(For approximate results j may be taken at $\frac{7}{8}$.)

5. Columns.

Total safe load,

$$P=f_c(A_c+nA_s)=f_cA[1+(n-1)p] \qquad (28)$$

Unit stresses,

$$f_c=\frac{P}{A[1+(n-1)p]} \qquad (29)$$

$$f_s=nf_c \qquad (30)$$

THE FLAT SLAB FLOOR WITHOUT BEAMS.

1. Symbols for Square Panels.

l=distance center to center of columns in feet measured along the side of a square panel.
C=diameter of column capital in feet measured on the bottom surface of the slab or dropped panel.
S=side of square dropped panel in feet.
B=width of any band of rods in feet.
W=sum of live and dead loads in pounds per square foot.
M=bending moment in foot-pounds.
d=effective depth of slab in inches.
D=effective depth of dropped panel in inches.
t=total thickness of slab in inches.
T=total thickness of dropped panel in inches. Other symbols are those used in the Standard Notation.

2. Four-Way System With Dropped Panel.

The following formulas shall be used in design:

$S=0.42l$
$C=0.225l$
$B=0.42l$

$d=l\frac{\sqrt{w}}{61}$, on basis of moment, for w not greater than 440 pounds and $p=0.77$ per cent.

$d=\frac{wl}{1,278}$, on basis of sheer, for w greater than 440 pounds.

$D=1.5d$.
$t=d+1.5$ inches.
$T=D+2$ inches.

Total negative M at column (in any direction) $=0.032wl^3$.
Positive M at middle of bands $=0.012wl^3$.
Negative M over middle of side bands $=0.009wl^3$.

NOTE.—The above proportions for S, C, B, and D make it necessary to solve only two of the other formulas. Assume a total thickness, t, to determine a tentative value of w. Solve for d and determine the correct value of w. D then becomes $1.5d$. Find the positive moment at the middle of the bands from the formula positive $M=0.012wl^3$. From the moment thus found find the amount of positive steel required at the middle of each band. Carry this same amount of steel over the column in each band, which will take care of the total negative moment at the column. Finally, take three-fourths of this positive steel and distribute it in the top of the slab over the side bands and over the central half of the panel to take care of the negative moment at the middle of the side bands.

3. Two-Way System With Dropped Panel.

The following formulas shall be used in design:

$S=0.4l$.

$C=0.225l$.

$B=0.4l$.

$d=l\frac{\sqrt{w}}{50}$, on basis of moment, for w not greater than 576 pounds and $p=0.77$ per cent.

$d=\frac{wl}{1,200}$, on basis of shear, for w greater than 576 pounds.

$D=1.25d$, for $p=1$ per cent.

$t=d+1.5$ inches.

$T=D+2$ inches.

Negative M at column for each band $=0.032wl^3$.
Positive M at middle of side band $=0.017wl^3$.
Negative M over middle of side band $=0.015wl^3$.
Positive M at middle of center band $=0.008wl^3$.

4. Details of Construction.

The above formulas apply to square panels and uniformly distributed live loads. For heavy concentrated loads special provision will have to be made by the use of beams or girders.

The diameter of the column capital shall be considered to be measured where its vertical thickness is at least 1 1/2 inches, provided the slope of the capital below this point nowhere makes an angle with the vertical of more than 45 degrees.

Points of inflection on any line joining two column centers may be taken as one-fifth of the clear distance on that line between the perimeters of the column capitals and measured from the perimeters.

If the length of end panels is made equal to 0.85 of the length of interior panels, it will not be necessary to compute the moments for end panels, and the same distribution of steel may be used in both end and interior panels.

Punching shear at the face of the column shall not exceed 120 pounds per square inch.

The total thickness of the slab shall never be less than 6 inches.

5. Rectangular Panels With Unequal Sides.

The following applies to both the four-way and the two-way systems:

In determining the thickness of slabs and dropped panels the factor l, occurring in the formulas for thickness, shall be the longest side distance center to center of columns.

In determining moments in side bands and center bands the factor l, occurring in the formulas for moments, shall be the distance center to center of columns parallel to the band in question.

In determining moments in diagonal bands the factor l, occurring in the formulas for moments, shall be the average of the two side distances center to center of columns.

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