(C) Expansion Joints

Vertical expansion joints shall be placed in the spandrel walls of arches to provide for movement due to temperature change and arch deflection. These joints shall be placed at the ends of spans and at intermediate points, generally not more than 50 feet apart.

(D) Reinforcement

Arch ribs in reinforced concrete construction shall be reinforced with a complete double line of longitudinal reinforcement consisting of an intradosal system and an extradosal system connected by a series of stirrups or tie-rods.

For barrel arches, a system of transverse reinforcement, thoroughly anchored to the longitudinal reinforcement, shall be used in both intrados and extrados. The transverse reinforcement shall be proportioned to resist the bending stresses due to any overturning action of the spandrel wall.

For rib arches, hoops or tie bars shall be used in connection with the longitudinal rib reinforcement, as in the case of reinforced concrete columns.

(E) Waterproofing

Preferably, the top of the arch ring and the interior faces of the spandrel walls of all filled spandrel arches shall be waterproofed with a membrane waterproofing constructed in accordance with the requirements specified in Division II, Section 17.

(F) Drainage of Spandrel Fill

The fills of filled spandrel arches shall be effectively drained by a system of tile drains or French drains laid along the intersection of the spandrel walls and arch rings and discharging through suitable outlets in the piers and abutments. The location and details of the drainage outlets shall be such as to eliminate, as far as possible, the discoloration by drainage water of the exposed masonry faces.

1.5.11 — VIADUCT BENTS AND TOWERS

When concrete columns are used in viaduct construction, bents and towers shall be effectively braced by means of longitudinal and transverse struts. For height greater than 40 feet, both longitudinal and transverse cross or diagonal bracing, preferably, shall be used and the footings for the columns forming a single bent shall be thoroughly tied together.

1.5.12 — BOX GIRDERS —— depth = $\frac{1}{18}$ span

(A) Effective Compression Flange Width

In girder and flange construction, consisting of a girder stem with top and bottom slab, effective and adequate bond and shear resistance shall be provided at the junction of the girder and slab. The

slab may then be considered an integral part of the girder, but its effective width as a girder flange shall not exceed the following:

(1) One fourth of the span length of the girder.
(2) The distance center to center of girders.
(3) Twelve times the least thickness of the slab plus the width of the girder stem.

For girders having flanges on one side only, the effective overhanging flange width shall not exceed the following:

(1) One-twelfth of the span length of the girder.
(2) One-half of the clear distance to the next girder.
(3) Six times the least thickness of the slab.

(B) Flange Thickness

(1) Top Flange

The minimum flange thickness shall be 1/16 of the clear distance between girders, or 6 inches, whichever is greater.

(2) Bottom Flange

The minimum thickness of the bottom flange shall be determined by maximum allowable unit stresses as specified in (C) and (D) but in no case shall be less than 1/16 of the clear span between girders or 5½ inches, whichever is the greater. Adequate fillets shall be provided at the intersections of all surfaces within the cell of a box girder.

(C) Flexure

(1) Parallel to Girder

The compressive unit stress in extreme fiber of concrete in both girder stem and flange shall not exceed that given in Article 1.5.1(C).

(2) Normal to Girder

The compressive unit stress in extreme fiber of concrete in the girder flange shall not exceed that given in Article 1.5.1(C).

(D) Shear

The flange shall not be considered as effective in computing the shear and diagonal tension resistance of girder stems, except in the determination of the value of j.

The horizontal shearing unit stress at the junction of the flange and the monolithic fillet joining it to the girder stem shall not exceed that given in Article 1.5.1(C), Shear, Beams with web reinforcement.

Changes in girder stem thickness shall be tapered for a minimum distance of 12 times the difference in stem thickness.

(E) Reinforcement

The unit stress in steel for both girder stem and flange shall not exceed that given in Article 1.5.1(D).

(F) Flange Reinforcement

(1) Parallel to Girder *(Longitudinal)*

Minimum reinforcement of 0.6 per cent of the flange section, but in no case less than required by Article 1.3.2(E), shall be placed in both top and bottom flanges, distributed over both surfaces. Where necessary, a single layer of bars may be centered in the bottom slab. Bar spacing shall not exceed 18 inches.

(2) Normal to Girder *(Trans.)*

Minimum reinforcement of 0.5 per cent of the flange section shall be placed in the slab, distributed over both surfaces. Bar spacing shall not exceed 18 inches. These bars shall be bent up into the exterior girder stems at least 10 bar diameters.

Reinforcement in the top flange in a direction transverse to the girders shall extend to the exterior face of all outside girders, and a minimum of ⅓ of such reinforcement shall either be anchored with 90° bends or extended beyond the girder face a sufficient distance to develop the strength of the bar in bond provided the flange projects beyond the girder face a sufficient distance to provide this bond length.

(G) Diaphragms

Diaphragms or spreaders shall be placed between the girders at intervals not to exceed 40 feet.

(H) Flanges Supporting Pipes and Conduits

Flanges supporting both vehicle live load and pipes or conduits shall be designed using unit stresses set forth in Article 1.5.1.

Flanges supporting only dead load of structure and pipes or conduits shall be designed in the direction normal to the girder using unit stresses not exceeding 75 per cent of those set forth in Article 1.5.1.

(I) Position of Negative Moment Reinforcement

When the floor slab of a box girder is placed after the web walls have taken their set, at least 10 per cent of the negative moment reinforcing steel shall be placed in the web walls. This reinforcing steel shall extend a distance of one-fourth the span length each side of the intermediate supports of continuous spans, one-fifth the span length from the restrained ends of continuous spans, and the entire length of cantilever spans. In lieu of the above requirement two number 8 bars full length of the webs may be used.

(J) Reinforcement of Web Wall Sides

The web walls between the top and bottom slabs shall have reinforcing bars placed horizontally in both faces to prevent temperature and shrinkage cracks. The total area of steel shall not be less than ⅛ sq. in. per foot of height of the unreinforced web walls. The spacing of bars shall not exceed 18 inches.

1.5.13 — BEARINGS

Bearing devices for concrete structures shall be designed in accordance with Articles 1.7.50 through 1.7.57.

Section 6—PRESTRESSED CONCRETE

1.6.1 — GENERAL

The design of prestressed concrete members of highway bridges shall conform to the requirements of Section 5, Concrete Design, insofar as the requirements of that section apply and are not specifically modified by requirements set forth herein. The specifications of this section are intended for use in the design of simple-span structures of moderate length. Large or unusual structures require special study and a detailed consideration of effects which, under this section, are neglected or assigned arbitrary values.

1.6.2 — NOTATION

A_b = bearing area of anchor plate of post-tensioning steel.

A_c = maximum area of the portion of the anchorage surface that is geometrically similar to and concentric with the area of the bearing plate of post-tensioning steel.

A_s = area of main prestressing tensile steel.

A'_s = area of conventional steel.

A_{sr} = steel area required to develop the ultimate compressive strength of the web of a flanged section.

A_v = area of web reinforcement.

b = width of flange of flanged member or width of rectangular member.

b' = width of web of a flanged member.

d = distance from extreme compressive fiber to centroid of the prestressing force.

I = moment of inertia about the centroid of the cross section.

I = impact load.

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

$p = A_s/bd$, ratio of prestressing steel.

$p' = A'_s/bd$, ratio of conventional reinforcement.

s = longitudinal spacing of web reinforcement.

t = average thickness of the flange of a flanged member.

Q = statical moment of cross section area, above or below the level being investigated for shear, about the centroid.

D = effect of dead load.

L = effect of design live load including impact, where applicable.

V_c = shear carried by concrete.

V_u = shear due to ultimate load and effect of prestressing.

E_c = flexural modulus of elasticity of concrete.

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1502—General requirements

(a) All provisions of this code, except those of Part IV-A, shall apply to the design of members by ultimate strength method, unless otherwise specifically provided in this Part IV-B.

(b) Bending moments in an axially loaded member shall be taken into account in the calculation of the strength required of the member.

(c) Except as provided in (d), analysis of indeterminate structures, such as continuous beams, frames, and arches, shall be based on the assumption of elastic behavior. For buildings of usual type of construction, spans, and story heights, approximate methods as provided in Chapter 9 are acceptable for determination of moments and shears.

(d) Except where approximate values for bending moments are used, the negative moments calculated by elastic theory, for any assumed loading arrangement, at the supports of continuous flexural members may each be increased or decreased by not more than 10 percent, provided that these modified negative moments are also used for final calculations of the moments at other sections in the spans corresponding to the same loading condition. Such an adjustment shall only be made when the section at which the moment is reduced is so designed that p, $(p - p')$, or $(p_w - p_f)$, which ever is applicable, is equal to or less than 0.50 times the reinforcement ratio p_b, producing balanced conditions at ultimate strength as calculated by Eq. (16-2).

1503—Assumptions

(a) Ultimate strength design of members for bending and axial load shall be based on the assumptions given in this section, and on satisfaction of the applicable conditions of equilibrium and compatibility of strains. The simplified design equations given in Chapters 16 and 19 are satisfactory.

(b) Strain in the concrete shall be assumed directly proportional to the distance from the neutral axis. Except in anchorage regions, strain in reinforcing bars shall be assumed equal to the strain in the concrete at the same position.

(c) The maximum strain at the extreme compression fiber at ultimate strength shall be assumed equal to 0.003.

(d) Stress in reinforcing bars below the yield strength, f_y, for the grade of steel used shall be taken as 29,000,000 psi times the steel strain. For strain greater than that corresponding to the design yield strength, f_y, the reinforcement stress shall be considered independent of strain and equal to the design yield strength, f_y.

(e) Tensile strength of the concrete shall be neglected in flexural calculations.

(f) At ultimate strength, concrete stress is not proportional to strain. The diagram of compressive concrete stress distribution may be assumed to be a rectangle, trapezoid, parabola, or any other shape which results

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in predictions of ultimate strength in reasonable agreement with the results of comprehensive tests.

(g) The requirements of (f) may be considered satisfied by the equivalent rectangular concrete stress distribution which is defined as follows: At ultimate strength, a concrete stress intensity of 0.85 f_c' shall be assumed uniformly distributed over an equivalent compression zone bounded by the edges of the cross section and a straight line located parallel to the neutral axis at a distance $a = k_1c$ from the fiber of maximum compressive strain. The distance c from the fiber of maximum strain to the neutral axis is measured in a direction perpendicular to that axis. The fraction k_1 shall be taken as 0.85 for strengths, f_c', up to 4000 psi and shall be reduced continuously at a rate of 0.05 for each 1000 psi of strength in excess of 4000 psi.

1504—Safety provisions*

(a) Strengths shall be computed in accordance with the provisions of Part IV-B.

(b) The coefficient ϕ shall be 0.90 for flexure; 0.85 for diagonal tension, bond, and anchorage; 0.75 for spirally reinforced compression members; and 0.70 for tied compression members.

(c) The strength capacities of members so computed shall be at least equal to the total effects of the design loads required by Section 1506.

1505—Design strengths for reinforcement

(a) When reinforcement is used that has a yield strength, f_y, in excess of 60,000 psi, the yield strength to be used in design shall be reduced to 0.85 f_y or 60,000 psi, whichever is greater, unless it is shown by tension tests that at a proof stress equal to the specified yield strength, f_y, the strain does not exceed 0.003.

(b) Designs shall not be based on a yield strength, f_y, in excess of 75,000 psi. Design of tension reinforcement shall not be based on a yield strength, f_y, in excess of 60,000 psi unless tests are made in compliance with Section 1508(b).

1506—Design loads†

(a) The design loads shall be computed as follows:

1. For structures in such locations and of such proportions that the effects of wind and earthquake may be neglected the design capacity shall be

$$U = 1.5D + 1.8L \quad \text{(15-1)}$$

The loads D, L, W, and E are the loads specified in the general code of which these requirements form a part.

*The coefficient ϕ provides for the possibility that small adverse variations in material strengths, workmanship, dimensions, control, and degree of supervision, while individually within required tolerances and the limits of good practice, occasionally may combine to result in undercapacity.

†The provisions of Section 1506 provide for such sources of possible excess load effects as load assumptions, assumptions in structural analysis, simplifications in calculations, and effects of construction sequence and methods.