Pins.

For the purpose of rating, the stress in the outer fiber of pins need t be computed unless the lever arm of the couple producing the ment is greater than the diameter of the pin.

. 13. — FIELD INSPECTION.

As a basis for the rating of existing structures, adequate infor- tion as to the dimensions and condition of the members in the ucture shall be provided by competent field inspection. The data ovided shall include line diagrams showing lengths and positions of members, detailed dimensions of all members and connections, pplemented by sketches as necessary; detailed information as to the dition of the material showing reduced sections due to deterioration, ident, or other cause; and any other pertinent information that will l in the intelligent evaluation of the structure. The field inspection all be made under the direction of a thoroughly trained and com- tent engineer who should be familiar with all phases of bridge design d construction.

Section 13 — PRESTRESSED CONCRETE

. 1. — GENERAL.

The design of prestressed concrete members of highway bridges ll conform to the requirements of Section 7, Concrete Design, inso- as the requirements of that section apply and are not specifically dified by requirements set forth herein. The specifications of this tion are intended for use in the design of simple-span structures of derate length. Large or unusual structures require special study l detailed consideration of effects that can be neglected or assigned itary values in the design of structures to which this section is ended to apply.

. 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.
E_s = modulus of elasticity of prestressing steel.
f'_c = compressive strength of concrete at 28 days.
f'_{ci} = compressive strength of concrete at time of initial prestress.
f'_s = ultimate strength of prestressing steel.
f_{se} = effective steel prestress after losses.
f_{su} = average stress in prestressing steel at ultimate load.
f_{sy} = nominal yield point stress of prestressing steel (at 1.0 per cent extension).
f'_y = yield point stress of conventional reinforcing steel.
n = ratio of E_s/E_c.
e = base of Naperian logarithms.
K = friction wobble coefficient per foot of prestressing steel.
T_o = steel stress at jacking end.
T_x = steel stress at any point *x*.
μ = friction curvature coefficient.
α = total angular change of prestressing steel profile in radians from jacking end to point *x*.
l = length of prestressing steel element from jacking end to point *x*.

1. 13. 3. — DESIGN THEORY.

The elastic theory shall be used for the design of prestressed concrete members under design loads at working stresses. The members shall be checked by ultimate strength theory for compliance with specified load factors.

1. 13. 4. — BASIC ASSUMPTIONS.

The following assumptions are made for design purposes:

(a) Strains vary linearly over the depth of the member throughout the entire load range.
(b) Before cracking, stress is linearly proportional to strain.
(c) After cracking, tension in the concrete is neglected.

1. 13. 5.—LOADING STAGES.

The state of stress shall be investigated under each loading condition that is anticipated in the manufacture, handling and service life of the structure. The following are some of the conditions that may exist:

(A) Initial Prestress.

The concrete and steel stresses in the initial stressing of the member before the dead load from other members is effective and before losses due to length changes of the concrete and steel have taken place. The condition of manufacture shall be taken into account, particularly as to whether the dead load of the member itself is effective.

(B) Transportation and Erection.

Precast members that are to be moved from their place of manufacture shall be designed so that handling is practicable.

(C) Design Load.

Stresses in effect after losses and under dead load and the assumed working live load.

(D) Cracking Load.

Complete freedom from cracking may or may not be necessary at any particular loading stage. Type and function of the structure and type, frequency, and magnitude of live loads should be considered.

(E) Ultimate Load.

The ultimate load that a member can withstand without failure shall be the sum of the multiples of live and dead loads specified in the formulas given in Article 1. 13. 6. The ultimate load capacity shall be that producing moments equal to the ultimate moment of the concrete or steel as given in Article 1. 13. 10.

. 13. 6.—LOAD FACTORS.

Load factors are multiples of the design load applied to the structure to insure its safety.

The computed ultimate load capacity shall not be less than

$$1.5\ D + 2.5\ (L+I)$$

These load factors are intended for simple spans of moderate length. For long spans, continuous spans and unusual designs, special investigation is advisable with probable increase in the ultimate load factors.

. 13. 7.—ALLOWABLE STRESSES.

In general the design of prestressed members shall be based on a maximum concrete strength of 5,000 psi. In exceptional cases on individual projects justified by the availability of suitable materials and the assured establishment of rigid control of mixing, placing and curing, this maximum may be increased to 6,000 psi.

(A) Prestressing Steel.

(1) Temporary stress before losses due to creep and shrinkage .... $0.70\ f'_s$
(Overstressing to $0.80\ f'_s$ for short periods of time may be permitted provided the stress, after seating of the anchorage, does not exceed $0.70\ f'_s$.)

(2) Stress at design load (after losses) $0.60\ f'_s$ or $0.80\ f_{sy}$ whichever is smaller.

(B) Concrete.

(1) Temporary stresses before losses due to creep and shrinkage:

Compression

Pretensioned members .... $0.60\ f'_{ci}$

Post-tensioned members .... $0.55\ f'_{ci}$

Tension

Members without nonprestressed reinforcement:

Single element .... $3\ \sqrt{f'_{ci}}$

Segmental element .... zero

Members with nonprestressed reinforcement sufficient to resist tensile force in the concrete without cracking when computed on the basis of an uncracked section :

Single element .... $6\ \sqrt{f'_{ci}}$

Segmental element (within the element itself) .... $3\ \sqrt{f'_{ci}}$

(2) Stress at design load after losses have occurred:

Compression .... $0.40\ f'_c$

Tension (in precompressed tensile zone) .... zero

(3) Cracking stress:

Modulus of rupture from tests or if not available .... $7.5\ \sqrt{f'_c}$

(4) Anchorage bearing stress

Post-tensioned anchorage .... $0.6\ f'_{ci}\ \sqrt[3]{A_c / A_b}$
(but not to exceed f'_{ci})

1. 13. 8.—LOSS OF PRESTRESS.

(A) Friction Losses.

Friction losses in post-tensioned members occur from angle change in draped cables and from wobble of the ducts. These losses can be estimated by the following formula:

$$T_o = T_x\, e^{(Kl + \mu\alpha)}$$

using the following average values of K and μ

Type of Steel	Type of Duct	K	μ
Wire cables	Bright metal sheathing	0.0020	0.30
	Galvanized metal sheathing	0.0015	0.25
	Greased or asphalt-coated and wrapped	0.0020	0.30
	Direct contact with concrete	0.0015	0.45
High-strength bars	Bright metal sheathing	0.0003	0.20
	Galvanized metal sheathing	0.0002	0.15
	Direct contact with concrete	0.0005	0.40
Galvanized strand	Bright metal sheathing	0.0015	0.25
	Galvanized metal sheathing	0.0010	0.20
	Direct contact with concrete	0.0015	0.50

Friction losses occur prior to anchoring but should be estimated for design and checked during stressing operations.

(B) Prestress Losses.

Losses of prestress due to all causes except friction may be assumed to be as follows:

Pretensioned members .... 35,000 psi

Post-tensioned members .... 25,000 psi

(When data are available for losses due to above-cited causes, more exact prestress losses may be estimated. Reference is made to ACI-ASCE Joint Committee Report.)

(C) Lightweight Concrete.

When lightweight aggregates are used, prestress losses should be estimated from tests on concrete made with the aggregates to be used.

13. 9. — FLEXURE.

Prestressed concrete members may be assumed to act as uncracked members subjected to combined axial and bending stresses within specified design loads. The transformed area of bonded reinforcement may be included in pretensioned members and in post-tensioned members after grouting.

13. 10. — ULTIMATE FLEXURAL STRENGTH.

(A) Rectangular Sections.

For rectangular or flanged sections in which the neutral axis lies within the flange, the ultimate flexural strength shall be assumed as

$$M_u = A_s\, f_{su}\, d\ \left(1 - 0.6\frac{pf_{su}}{f'_c}\right).$$

(B) Flanged Sections.

If the neutral axis falls outside the flange (usually if the flange thickness is less than 1.4 dpf_{su}/f'_c), the ultimate flexural strength shall be assumed as

$$M_u = A_{sr} f_{su} d\ \left(1 - 0.6\frac{A_{sr} f_{su}}{b'd\, f'_c}\right) + 0.85\, f'_c\, (b - b')\, t(d - 0.5t)$$

where

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

$A_{sf} = 0.85\, f'_c(b - b')\, t/f_{su}$ = steel area required to develop the ultimate compressive strength of the overhanging portions of the flange.

(C) Steel Stress.

Unless the value of f_{su} can be more accurately known from detailed analysis, the following value may be used:

Bonded members .... $f_{su} = f'_s\ \left(1 - 0.5\frac{p\, f'_s}{f'_c}\right)$

Unbonded members .... $f_{su} = f_{se} + 15{,}000$

provided that

(1) The stress-strain properties of the prestressing steel approximate those specified in Article 2. 4. 43.

(2) The effective prestress after losses is not less than 0.5 f'_s.

1. 13. 11. — MAXIMUM AND MINIMUM STEEL PERCENTAGE.

Prestressed concrete members shall be designed so that failure of the steel rather than of the concrete will occur at ultimate load. In general the percentage of steel shall be such that $p\frac{f_{su}}{f'_c}$ for rectangular sections and $A_{sr}\frac{f_{su}}{b'df'_c}$ for flanged sections does not exceed 0.30. For steel with percentages greater than this, the ultimate flexural strength shall not be assumed as greater than

$M_u = 0.25\, f'_c\, bd^2$ for rectangular sections, or

$M_u = 0.25\, b'd^2\, f'_c + 0.85\, f'_c\, (b - b')\, t(d - 0.5t)$ for flanged sections.

In prestressed concrete members reinforced with tendons of high-tensile-strength steel wire or high-tensile-strength strand in which the anchorage of the tendons is by bond alone, the cross sectional area of the tendons shall be not less than 0.3 per cent of the cross sectional area of the member at the time of the transfer of stress from the prestressing bed to the member.

1. 13. 12. — NONPRESTRESSED REINFORCEMENT.

Nonprestressed reinforcement may be considered as contributing to the tensile strength of the beam at ultimate strength in an amount equal to its area times its yield point, provided that

$$\frac{p\ f_{su}}{f'_c} + \frac{p'\ f'_y}{f'_c} \text{ does not exceed 0.3 for rectangular sections, or}$$

$$A_{sr} \frac{f_{su}}{b'd\ f'_c} + \frac{A'_s\ f'_{sy}}{b'd\ f'_c} \text{ does not exceed 0.3 for flanged sections.}$$

1. 13. 13.—SHEAR.

Prestressed concrete members shall be reinforced for diagonal tension stresses. Shear reinforcement shall be placed perpendicular to the axis of the member. The area of web reinforcement shall be

$$A_v = \frac{(V_u - V_c)}{2\ f'_y\ jd}$$

but shall not be less than

$$A_v = 0.0025\ b's.$$

The spacing of web reinforcement shall not exceed three-fourths the depth of the member and shall provide transverse reinforcement across the bottom flanges.

The critical sections for shear will usually not be near the ends of the span where the shear is a maximum but at some point away from the ends in a region of high moment.

For the design of web reinforcement in simply supported members carrying moving loads, it is recommended that shear be investigated only in the middle half of the span length. The web reinforcement required at the quarter points should be used throughout the outer quarters of the span.

For simply supported beams carrying only uniformly distributed load, the maximum web reinforcement may be taken as that required at a distance from the support equal to the depth of the member. This amount of web reinforcement should be provided from this point to the end of the member. In the middle third of the span length, the amount of web reinforcement provided should not be less than that required at third-points of the span.

1. 13. 14.—COMPOSITE STRUCTURES.

(A) General.

Composite structures in which the deck is assumed to act integrally with the beam shall be interconnected to transfer shear along the contact surfaces and to prevent separation of the elements. Transfer of shear shall be by bond or by shear keys. The elements shall be tied together by extension of the web reinforcement or by dowels.

(B) Shear Capacity.

The shear connection shall be designed for the ultimate load and may be computed by the formula $v = V_u Q/I$.

(C) Bond Capacity.

The following values for ultimate bond resistance at the contact surfaces shall be used in determining the need for shear keys:

When the minimum steel tie requirements of (D) of this article are met .... 75 psi.

When the minimum steel tie requirements of (D) of this article are met and the contact surface of the precast element is artificially roughened .... 150 psi.

When steel ties in excess of the requirements of (D) of this article are provided and the contact surface of the precast element is artificially roughened .... 225 psi.

If bond capacity is less than the computed shear, shear keys shall be provided throughout the length of the member. Keys shall be proportioned according to the concrete strength of each component of the composite member.

(D) Vertical Ties.

All web reinforcement shall extend into cast-in-place decks. The spacing of vertical ties shall not be greater than four times the minimum thickness of either of the composite elements and in any case not greater than 24 inches. The total area of vertical ties shall not be less than the area of two No. 3 bars spaced at 12 inches.

(E) Shrinkage Stresses.

In structures with a cast-in-place slab on precast beams, the differential shrinkage tends to cause tensile stresses in the slab and in the bottom of the beams. Stresses due to differential shrinkage are important only insofar as they affect the cracking load. When cracking load is significant, such stresses should be added to the effect of loads.

1. 13. 15.—END BLOCKS.

End blocks shall have sufficient area to allow the spacing of the prestressing steel as specified in Article 1. 13. 16. Preferably they shall be as wide as the narrower flange of the beam. They shall have a length at least equal to three-fourths of the depth of the beam and in any case 24 inches. In post-tensioned members a closely spaced grid of both vertical and horizontal bars shall be placed near the face of the end block to resist bursting and closely spaced reinforcement shall be placed both vertically and horizontally throughout the length of the block.

1. 13. 16.—COVER AND SPACING OF PRESTRESSING STEEL.

(A) Minimum Cover.

The following minimum concrete cover shall be provided for prestressing and conventional steel:

Prestressing steel and main reinforcement 1½ inches
Slab reinforcement .... 1 inch
Stirrups and ties .... 1 inch

In locations where members are exposed to salt water, salt spray or chemical vapor, additional cover should be provided.

(B) Minimum Spacing.

The minimum clear spacing of prestressing steel at the ends of beams shall be as follows:

Pretensioning steel: three times the diameter of the steel or $1\frac{1}{3}$ the maximum size of the concrete aggregate, whichever is greater.

Post-tensioning ducts: $1\frac{1}{2}$ inches or $1\frac{1}{2}$ times the maximum size of the concrete aggregate, whichever is the greater.

The inside diameter of post-tensioning ducts shall be at least one-fourth inch greater than the diameter of the prestressing steel.

(C) Bundling.

When prestressing steel is draped or deflected, not to exceed three ducts may be bundled in the middle third of the beam length provided that the spacing specified in (B) is maintained in the end three feet of the member.

1. 13. 17.—EMBEDMENT OF PRESTRESSING STRAND.

To insure proper bond in pretensioned members designed to resist flexure, the following minimum length of embedment of seven-wire strand, measured from the free end of the strand to the point of maximum steel stress at ultimate flexural strength, shall be as follows:

1/2-inch strand	135 inches
7/16-inch strand	120 inches
3/8-inch strand	100 inches
1/4-inch strand	65 inches

1. 13. 18.—CONCRETE STRENGTH AT STRESS TRANSFER.

Unless otherwise specified, stress shall not be transferred from strand to concrete in pretensioned members until the compressive strength of the concrete as indicated by test cylinders cured by methods identical with the curing of the members is at least 4,000 psi.

Division II

CONSTRUCTION

Section 1—EXCAVATION AND FILL

2. 1. 1.—GENERAL.

Foundation excavation shall include the removal of all material, of whatever nature, necessary for the construction of foundations and substructures in accordance with the plans or as directed by the engineer. It shall include the furnishing of all necessary equipment and the construction of all cribs, cofferdams, caissons, unwatering, etc., which may be necessary for the execution of the work. It shall also include the subsequent removal of cofferdams and cribs and the placement of all necessary backfill as hereinafter specified. It shall also include the wasting of excavated material, which is not required for backfill, in a manner and in locations so as not to affect the carrying capacity of the channel and not to be unsightly.

Compensation for all clearing and grubbing contained within the area defined by lines connecting the extremities of the substructure units, regardless of whether or not excavation is involved, shall, unless otherwise specified in the contract, be included in the unit price bid for excavation.

All substructures, where practicable, shall be constructed in open excavation and, where necessary, the excavation shall be shored, braced or protected by cofferdams in accordance with approved methods. When footings can be placed in the dry without the use of cribs or cofferdams, backforms may be omitted with the approval of the engineer and the entire excavation filled with concrete to the required elevation of the top of the footing. The additional concrete required shall be placed at the expense of the contractor.

2. 1. 2.—PRESERVATION OF CHANNEL.

Unless otherwise specified, no excavation shall be made outside of caissons, cribs, cofferdams, steel piling or sheeting, and the natural stream bed adjacent to the structure shall not be disturbed without permission from the engineer. If any excavation or dredging is made at the site of the structure before caissons, cribs or cofferdams are sunk or in place, the contractor shall, without extra charge, after the foundation base is in place, backfill all such excavation to the original ground surface or river bed with material satisfactory to the engineer. Material deposited within the stream area from foundation or other excavation or from the filling of cofferdams shall be removed and the stream area freed from obstruction thereby.

2. 1. 3.—DEPTH OF FOOTINGS.

The elevation of the bottoms of footings, as shown on the plans,