

TABLE 3.22.1A Factors for Load Factor Design

Group	Gamma Factor	Beta Factors														
		D	(L+I)H	(L+I)P	CF	E	B	SF	W	WL	LF	PS	R+S+T	EQ	ICE	CT
I _H	1.30	β D	1.67	0	1	β E	1	1	0	0	0	0.77	0	0	0	0
I _{PC}	1.30	β D	0	1	1	β E	1	1	0	0	0	0.77	0	0	0	0
I _{PW}	1.30	β D	1	1.15	1	β E	1	1	0	0	0	0.77	0	0	0	0
I _{P3D}	1.30	β D	1	1.25	1	β E	1	1	0	0	0	0.77	0	0	0	0
II	1.30	β D	0	0	0	β E	1	1	1	0	0	0.77	0	0	0	0
III	1.30	β D	1	0	1	β E	1	1	0.3	1	1	0.77	0	0	0	0
IV	1.30	β D	1	0	1	β E	1	1	0	0	0	0.77	1	0	0	0
V	1.25	β D	0	0	0	β E	1	1	1	0	0	0.80	1	0	0	0
VI	1.25	β D	1	0	1	β E	1	1	0.3	1	1	0.80	1	0	0	0
VII	1.00	1	0	0	0	β E	1	1	0	0	0	1.00	0	1	0	0
VIII	1.30	β D	1	0	1	β E	1	1	0	0	0	0.77	0	0	1	0
IX	1.20	β D	0	0	0	β E	1	1	1	0	0	0.83	0	0	1	0
X*	1.30	β D	1.67	0	0	β E	0	0	0	0	0	0.67	0	0	0	0
XI	1.0	0	0.5	0	0	β E	0	0	0	0	0	1.0	0	0	0	1

H denotes H loads.

PC denotes P loads on closely spaced girders used only for superstructures.

PW denotes P loads on widely spaced girders and substructures.

P3D denotes P loads only on superstructures when three-dimensional analysis is used for load distribution.

β D = 0.75 when checking columns for maximum moment or maximum eccentricities and associated axial load; and when Dead Load effects are of opposite sign to the net effects of other loads in a Group.

β D = 1.00 when checking columns for maximum axial load and associated moment.

β D = 1.00 for flexural and tension members and for culverts.

β E = 0.50 for checking positive moments in rigid frames.

β E = 1.00 for vertical earth pressure and for rigid culverts.

β E = 1.30 for lateral earth pressure. (Not for culverts.)

β E = 1.50 for flexible culverts.

* Group X applies only to culverts. Other Groups do not apply to culverts.



**Part C
Distribution of Loads**

3.23 DISTRIBUTION OF LOADS TO STRINGERS, LONGITUDINAL BEAMS, AND FLOOR BEAMS*

3.23.1 Position of Loads for Shear

3.23.1.1 In calculating end shears and end reactions in transverse floor beams and longitudinal beams and stringers, no longitudinal distribution of the wheel load shall be assumed for the wheel or axle load adjacent to the end at which the stress is being determined.

3.23.1.2 Lateral distribution of the wheel load shall be that produced by assuming the flooring to act as a simple span between stringers or beams. For loads in other positions on the span, the distribution for shear shall be determined by the method prescribed for moment, except that the calculations of horizontal shear in rectangular timber beams shall be in accordance with Article 13.3.

3.23.2 Bending Moments in Stringers and Longitudinal Beams**

3.23.2.1 General

In calculating bending moments in longitudinal beams or stringers, no longitudinal distribution of the wheel loads shall be assumed. The lateral distribution shall be determined as follows.

3.23.2.2 Interior Stringers and Beams

The live load bending moment for each interior stringer shall be determined by applying to the stringer

* Provisions in this Article shall not apply to orthotropic deck bridges.

** In view of the complexity of the theoretical analysis involved in the distribution of wheel loads to stringers, the empirical method herein described is authorized for the design of normal highway bridges.

the fraction of a wheel load (both front and rear) determined in Table 3.23.1.

3.23.2.2.1 The dead load bending moments for each interior stringer shall be determined by applying the panel load to the stringer. Box girders designed as whole-width units shall have the dead load applied uniformly to the whole cross-section.

3.23.2.2.2 Curbs, sidewalks, railings, and wearing surface may be considered equally distributed to all roadway stringers or beams, but shall not be distributed beyond a longitudinal expansion joint in the roadway slab.

3.23.2.2.3 The weight of each utility to be carried on a structure shall be distributed to supporting longitudinal members assuming a simple beam between longitudinal members.

3.23.2.3 Outside Roadway Stringers and Beams

3.23.2.3.1 Steel-Timber-Concrete T-Beams

3.23.2.3.1.1 The dead load supported by the outside roadway stringer or beam shall be that portion of the floor slab carried by the stringer or beam. Curbs, railings, and wearing surface, if placed after the slab has cured, may be distributed equally to all roadway stringers or beams.

3.23.2.3.1.2 The live load bending moment for outside roadway stringers or beams shall be determined by applying to the stringer or beam the fraction of a wheel line determined by multiplying the value of the interior stringers or beams by

$$W_e/S$$

W_e = The top slab width as measured from the outside face of the slab to the midpoint between the exterior and interior stringer or beam. The cantilever dimension of any slab extending beyond the exterior girder shall not exceed $S/2$, measured from the centerline of the exterior beam.

S = average stringer spacing in feet. If S exceeds values given in Table 3.23.1 use footnote f.



TABLE 3.23.1 Distribution of Wheel Loads in Longitudinal Beams

Kind of Floor	Bridge Designed for One Traffic Lane	Bridge Designed for Two or more Traffic Lanes
Timber ^a :		
Plank ^b	S/4.0	S/3.75
Nail laminated ^c 4" thick or multiple layer ^d floors over 5" thick	S/4.5	S/4.0
Nail laminated ^c 6" or more thick	S/5.0 If S exceeds 5' use footnote f.	S/4.25 If S exceeds 6.5' use footnote f.
Glued Laminated ^e Panels on glued Laminated Stringers		
4" thick	S/4.5	S/4.0
6" or more thick	S/6.0 If S exceeds 6' use footnote f.	S/5.0 If S exceeds 7.5' use footnote f.
On Steel Stringers		
4" thick	S/4.5	S/4.0
6" or more thick	S/5.25 If S exceeds 5.5' use footnote f.	S/4.5 If S exceeds 7' use footnote f.
Concrete:		
On Steel I-Beam Stringers ^g and Prestressed Concrete Girders	S/7.0 If S exceeds 10' use footnote f.	S/5.5 If S exceeds 14' use footnote f.
+ On Concrete + T-Beams ^k	S/6.5 If S exceeds 6' use footnote f.	S/6.0 If S exceeds 15' use footnote f.
On Timber Stringers	S/6.0 If S exceeds 6' use footnote f.	S/5.0 If S exceeds 10' use footnote f.
+ Concrete box girders ^{h,j} :		
+ Designed as whole width units.		<u>Overall deck width</u>
+ Do not apply Article 3.12.		7.0
On Steel Box Girders		See Article 10.39.2.
On Prestressed Concrete Spread Box Beams		See Article 3.28.
Steel Grid:		
(Less than 4" thick)	S/4.5	S/4.0
(4" or more)	S/6.0 If S exceeds 6' use footnote f.	S/5.0 If S exceeds 10.5' use footnote f.
Steel Bridge Corrugated Plank ⁱ (2" min. depth)	S/5.5	S/4.5

S = average stringer spacing in feet.

^aTimber dimensions shown are for nominal thickness.

^bPlank floors consist of pieces of lumber laid edge to edge with the wide faces bearing on the supports. (See Article 16.3.11-Division II).

^cNail laminated floors consist of pieces of lumber laid face to face with the narrow edges bearing on the supports, each piece being nailed to the preceding piece. (See Article 16.3.12-Division II).

^dMultiple layer floors consist of two or more layers of planks, each layer being laid at an angle to the other. (See Article 16.3.11-Division II).

^eGlued laminated panel floors consist of vertically glued laminated members with the narrow edges of the laminations bearing on the supports. (See Article 16.3.13-Division II).

^fIn this case the load on each stringer shall be the reaction of the wheel loads, assuming the flooring between the stringers to act as a simple beam.

^g"Design of I-Beam Bridges" by N. M. Newmark-Proceedings, ASCE, March 1948.

^hThe sidewalk live load (see Article 3.14) shall be omitted for interior and exterior box girders designed in accordance with the wheel load distribution indicated herein.

ⁱDistribution factors for Steel Bridge Corrugated Plank set forth above are based substantially on the following reference:

Journal of Washington Academy of Sciences, Vol. 67, No. 2, 1977 "Wheel Load Distribution of Steel Bridge Plank," by Conrad P. Heins, Professor of Civil Engineering, University of Maryland.

These distribution factors were developed based on studies using 6" x 2" steel corrugated plank. The factors should yield safe results for other corrugation configurations provided primary bending stiffness is the same as or greater than the 6" x 2" corrugated plank used in the studies.

^jUnusual plan layouts may be designed as individual girders, using S/7. If S exceeds 16' use footnote f.

^k"Design of Slab and Stringer Highway Bridges", by N.M. Newmark and C.P. Siess - Public Roads, January-February-March 1943. "Distribution of Loads to Girders in Slab-and-Girder Bridges; Theoretical Analyses and Their Relation to Field Tests" by C.P. Siess and A.S. Veletsos - Highway Research Board Report 14-B, 1952.

3.23.2.3.1.3 When the outside roadway beam or stringer supports the sidewalk live load as well as traffic live load and impact and the structure is to be designed by the service load method, the allowable stress in the beam or stringer may be increased by 25 percent for the combination of dead load, sidewalk live load, traffic live load, and impact, providing the beam is of no less carrying capacity than would be required if there were no sidewalks. When the combination of sidewalk live load

and traffic live load plus impact governs the design and the structure is to be designed by the load factor method, 1.25 may be used as the beta factor in place of 1.67.

3.23.2.3.1.4 In no case shall an exterior stringer have less carrying capacity than an interior stringer.

+ 3.23.2.3.1.5 Deleted

3.23.2.3.2 Concrete Box Girders

+ Dead load and live load distribution to exterior girders shall be included in whole-width unit designs as given in Article 3.23.2.2.

3.23.2.3.3 Total Capacity of Stringers and Beams

The combined design load capacity of all the beams and stringers in a span shall not be less than required to support the total live and dead load in the span.

3.23.3 Bending Moments in Floor Beams (Transverse)

3.23.3.1 In calculating bending moments in floor beams, no transverse distribution of the wheel loads shall be assumed.

3.23.3.2 If longitudinal stringers are omitted and the floor is supported directly on floor beams, the beams shall be designed for loads determined in accordance with Table 3.23.3.1.

3.23.4 Precast Concrete Beams Used in Multi-Beam Decks

3.23.4.1 A multi-beam bridge is constructed with precast reinforced or prestressed concrete beams that are placed side by side on the supports. The interaction between the beams is developed by continuous longitudinal shear keys used in combination with transverse tie assemblies which may, or may not, be prestressed, such as bolts, rods, or prestressing strands, or other mechanical means. Full-depth rigid end diaphragms are needed to ensure proper load distribution for channel, single- and multi-stemmed tee beams.

TABLE 3.23.3.1 Distribution of Wheel Loads in Transverse Beams

Kind of Floor	Fraction of Wheel Load to Each Floor Beam
Plank ^{a,b}	$\frac{S}{4}$
Nail laminated ^c or glued laminated ^e , 4 inches in thickness, or multiple layer ^d floors more than 5 inches thick	$\frac{S}{4.5}$
Nail laminated ^c or glued laminated ^e , 6 inches or more in thickness	$\frac{S^f}{5}$
Concrete	$\frac{S^f}{6}$
Steel grid (less than 4 inches thick)	$\frac{S}{4.5}$
Steel grid (4 inches or more)	$\frac{S^f}{6}$
Steel bridge corrugated plank (2 inches minimum depth)	$\frac{S}{5.5}$

Note:

S = spacing of floor beams in feet.

^{a-c}For footnotes a through e, see Table 3.23.1.

^f If S exceeds denominator, the load on the beam shall be the reaction of the wheel loads assuming the flooring between beams to act as a simple beam.

3.23.4.2 In calculating bending moments in multi-beam precast concrete bridges, conventional or prestressed, no longitudinal distribution of wheel load shall be assumed.

3.23.4.3 The live load bending moment for each section shall be determined by applying to the beam the fraction of a wheel load (both front and rear) determined by the following equation:

$$\text{Load Fraction} = \frac{S}{D} \quad (3-11)$$

where,

$$S = \text{width of precast member;} \\ D = (5.75 - 0.5N_L) + 0.7N_L(1 - 0.2C)^2 \\ \text{when } C \leq 5 \quad (3-12)$$

$$D = (5.75 - 0.5N_L) \text{ when } C > 5 \quad (3-13)$$

$$N_L = \text{number of traffic lanes from Article 3.6;} \\ C = K(W/L) \quad (3-14)$$

where,

W = overall width of bridge measured perpendicular to the longitudinal girders in feet;

L = span length measured parallel to longitudinal girders in feet; for girders with cast-in-place and diaphragms, use the length between end diaphragms;

$$K = \{(1 + \mu)I/J\}^{1/2}$$

If the value of $\sqrt{I/J}$ exceeds 5.0, the live load distribution should be determined using a more precise method, such as the Articulate Plate Theory or Grillage Analysis.

where,

I = moment of inertia;
 J = Saint-Venant torsion constant;
 μ = Poisson's ratio for girders.

In lieu of more exact methods, "J" may be estimated using the following equations:

For Non-voided Rectangular Beams, Channels, Tee Beams:

$$J = \sum \left\{ \frac{1}{3} b t^3 (1 - 0.630t/b) \right\}$$

where,

b = the length of each rectangular component within the section.

t = the thickness of each rectangular component within the section.

The flanges and stems of stemmed or channel sections are considered as separate rectangular components whose values are summed together to calculate "J". Note that for "Rectangular Beams with Circular Voids" the value of "J" can usually be approximated by using the equation above for rectangular sections and neglecting the voids.

For Box-Section Beams:

$$J = \frac{2t t_f (b - t)^2 (d - t_f)^2}{b t + d t_f - t^2 - t_f^2}$$

where

b = the overall width of the box,

d = the overall depth of the box,

t = the thickness of either web,

t_f = the thickness of either flange.

The formula assumes that both flanges are the same thickness and uses the thickness of only one flange. The same is true of the webs.

For preliminary design, the following values of K may be used.

Bridge Type	Beam Type	K
Multi-beam	Non-voided rectangular beams	0.7
	Rectangular beams with circular voids	0.8
	Box section beams	1.0
	Channel, single and multi-stemmed tee beams	2.2

3.24 DISTRIBUTION OF LOADS AND DESIGN OF CONCRETE SLABS*

3.24.1 Span Lengths (See Article 8.8)

3.24.1.1 For simple spans the span length shall be the distance center to center of supports but need not exceed clear span plus thickness of slab.

3.24.1.2 The following effective span lengths shall be used in calculating the distribution of loads and bending moments for slabs continuous over more than two supports:

- (a) Slabs monolithic with beams or slabs monolithic with walls without haunches and rigid top flange prestressed beams with top flange width to minimum thickness ratio less than 4.0. "S" shall be the clear span.
- (b) Slabs supported on steel stringers, or slabs supported on thin top flange prestressed beams with top flange width to minimum thickness ratio equal to or greater than 4.0. "S" shall be the distance between edges of top flange plus one-half of stringer top flange width.
- (c) Slabs supported on timber stringers. "S" shall be the clear span plus one-half thickness of stringer.

3.24.2 Edge Distance of Wheel Loads

3.24.2.1 In designing sidewalks, the center line of the wheel load shall be 1 foot from the face of the curbs or sidewalks are not used, the wheel load shall be 1 foot from the face of the rail.

* The slab distribution set forth herein is based substantially on the "Westergaard" theory. The following references are furnished concerning the subject of slab design.

Public Roads, March 1930, "Computation of Stresses in Bridge Slabs Due to Wheel Loads," by H.M. Westergaard.

University of Illinois, Bulletin No. 303, "Solutions for Certain Rectangular Slabs Continuous over Flexible Supports," by Vernon P. Jensen; Bulletin 304, "A Distribution Procedure for the Analysis of Slabs Continuous over Flexible Beams," by Nathan M. Newmark; Bulletin 315, "Moments in Simple Span Bridge Slabs with Stiffened Edges," by Vernon P. Jensen; and Bulletin 346, "Highway Slab Bridges with Curbs; Laboratory Tests and Proposed Design Method."

3.24.2.2 In designing sidewalks, slabs and supporting members, a wheel load located on the sidewalk shall be 1 foot from the face of the rail. In service load design, the combined dead, live, and impact stressing for this loading shall be not greater than 150 percent of the allowable stresses. In load factor design, 1.0 may be used as the beta factor in place of 1.67 for the design of deck slabs. Wheel loads shall not be applied on sidewalks protected by a traffic barrier.

3.24.3 Bending Moment

The bending moment per foot width of slab shall be calculated according to methods given under Cases A and B, unless more exact methods are used considering tire contact area. The tire contact area needed for exact methods is given in Article 3.30.

In Cases A and B:

- S = effective span length, in feet, as defined under "Span Lengths" Articles 3.24.1 and 8.8;
- E = width of slab in feet over which a wheel load is distributed;
- P = load on one rear wheel of truck
- P₂₀ = 16,000 pounds for H 20 loading.

3.24.3.1 Case A-Main Reinforcement Perpendicular to Traffic (Spans 2 to 24 Feet Inclusive)

The live load moment for simple spans shall be determined by the following formula (impact not included):

HS 20 Loading:

$$\left(\frac{S+2}{32}\right)P_{20} = \text{Moments in foot - pounds per foot - width of slab} \quad (3-15)$$

In slabs continuous over three or more supports, a continuity factor of 0.8 shall be applied to the above formulas for both positive and negative moment.



3.24.3.2 Case B-Main Reinforcement Parallel to Traffic

For wheel loads, the distribution width, E, shall be (4+0.06S) but shall not exceed 7.0 feet. Lane loads are distributed over a width of 2E. Longitudinally reinforced slabs shall be designed for the appropriate live loading.

3.24.4 Shear

Slabs designed for bending moment in accordance with Article 3.24.3 shall be considered satisfactory in shear.

3.24.5 Cantilever Slabs

3.24.5.1 Truck Loads

Under the following formulas for distribution of loads on cantilever slabs, the slab is designed to support the load independently of the effects of any edge support along the end of the cantilever. The distribution given includes the effect of wheels on parallel elements.

3.24.5.1.1 Case A-Reinforcement Perpendicular to Traffic

Each wheel on the element perpendicular to traffic shall be distributed over a width according to the following formula:

$$E = 0.8X + 3.75 \quad (3-17)$$

The moment per foot of slab shall be (P/E)X foot-pounds, in which X is the distance in feet from load to point of support.

3.24.5.1.2 Case B-Reinforcement Parallel to Traffic

The distribution width for each wheel load on the element parallel to traffic shall be as follows:

$$E = 0.35X + 3.25, \text{ but shall not exceed 7.0 feet} \quad (3-18)$$

The moment per foot of slab shall be (P/E)X foot-pounds.

3.24.5.2 Railing Loads

A horizontal load of 54K shall be applied to the barrier in the transverse direction at the uppermost point, and in accordance with Article 3.22, Group XI loading. The effective length of slab resisting collision loadings shall be equal to E = 10 feet where a solid parapet is used, and based on yield line theory for all other cases.

3.24.6 Slabs Supported on Four Sides

3.24.6.1 For slabs supported along four edges and reinforced in both directions, the proportion of the load carried by the short span of the slab shall be given by the following equations:

For uniformly, distributed load,

$$p = \frac{b^4}{a^4 + b^4} \quad (3-19)$$

For concentrated load at center,

$$p = \frac{b^3}{a^3 + b^3} \quad (3-20)$$

where,

- p = proportion of load carried by short span;
- a = length of short span of slab;
- b = length of long span of slab.

3.24.6.2 Where the length of the slab exceeds 1¹/₂ times its width, the entire load shall be carried by the transverse reinforcement.

3.24.6.3 The distribution width, E, for the load taken by either span shall be determined as provided for other slabs. The moments obtained shall be used in designing the center half of the short and long slabs. The reinforcement steel in the outer quarters of both short and long spans may be reduced by 50 percent. In the design of the supporting beams, consideration shall be given to the fact that the loads delivered to the supporting beams are not uniformly distributed along the beams.

3.24.7 Median Slabs

Raised median slabs shall be designed in accordance with the provisions of this article with truck loadings so placed as to produce maximum stresses. Combined dead, live, and impact stresses shall not be greater than 150 percent of the allowable stresses. Flush median slabs shall be designed without overstress.

3.24.8 Longitudinal Edge Beams

3.24.8.1 Edge beams shall be provided for all slabs having main reinforcement parallel to traffic. The beam may consist of a slab section additionally reinforced, a beam integral with and deeper than the slab, or an integral reinforced section of slab and curb.

3.24.8.2 The edge beam of a simple span shall be designed to resist a live load moment of 0.10PS, where

- + P = wheel load in pounds;
- S = span length in feet.

3.24.8.3 For continuous spans, the moment may be reduced by 20 percent unless a greater reduction results from a more exact analysis.

3.24.9 Unsupported Transverse Edges

The design assumptions of this article do not provide for the effect of loads near unsupported edges. Therefore, at the ends of the bridge and at intermediate points where the continuity of the slab is broken, the edges shall be supported by diaphragms or other suitable means. The diaphragms shall be designed to resist the full moment and shear produced by the wheel loads which can come on them.

3.24.10 Distribution Reinforcement

3.24.10.1 To provide for the lateral distribution of the concentrated live loads, reinforcement shall be placed transverse to the main steel reinforcement in the bottoms of all slabs except culvert or bridge slabs where the depth of fill over the slab exceeds 2 feet.

3.24.10.2 The amount of distribution reinforcement shall be the percentage of the main reinforcement steel required for positive moment as given by the following formulas:

For main reinforcement parallel to traffic,

$$\text{Percentage} = \frac{100}{\sqrt{S}} \quad \text{Maximum 50\%} \quad (3-21)$$

For main reinforcement perpendicular to traffic,

$$\text{Percentage} = \frac{220}{\sqrt{S}} \quad \text{Maximum 67\%} \quad (3-22)$$

where S = the effective span length in feet.

3.24.10.3 For main reinforcement perpendicular to traffic, the specified amount of distribution reinforcement shall be used in the middle half of the slab span, and not less than 50 percent of the specified amount shall be used in the outer quarters of the slab span.

3.25 DISTRIBUTION OF WHEEL LOADS ON TIMBER FLOORING

For the calculation of bending moments in timber flooring each wheel load shall be distributed as follows.

3.25.1 Transverse Flooring

3.25.1.1 In direction of span, the wheel load shall be distributed over the width of tire as given in Article 3.30.

Normal to direction of span, the wheel load shall be distributed as follows: +

Plank floor:

the width of plank.

Non-interconnected* nail laminated panel floor:

15 inches, but not to exceed panel width.

* The terms interconnected and non-interconnected refer to the joints between the individual nail laminated or glued laminated panels.

Non-interconnected glued laminated panel floor:
15 inches plus thickness of floor, but not to exceed panel width.

Continuous nail laminated floor and interconnected nail laminated panel floor, with adequate shear transfer between panels*:

15 inches plus thickness of floor, but not to exceed panel width.

Interconnected** glued laminated panel floor, with adequate shear transfer between panels*, not less than 6 inches thick:

15 inches plus twice thickness of floor, but not to exceed panel width.

3.25.1.2 For transverse flooring the span shall be taken as the clear distance between stringers plus one-half the width of one stringer, but shall not exceed the clear span plus the floor thickness.

3.25.1.3 One design method for interconnected glued laminated panel floors is as follows: For glued laminated panel decks using vertically laminated lumber with the panel placed in a transverse direction to the stringers and with panel interconnected using steel dowels, the determination of the deck thickness shall be based on the following equations for maximum unit primary moment and shear.† The maximum shear is for a wheel position assumed to be 15 inches or less from the centerline of the support. The maximum moment is for a wheel position assumed to be centered between the supports.

$$M_x = P(.51 \log_{10} s - K) \quad (3-23)$$

$$R_x = .034P \quad (3-24)$$

* This shear transfer may be accomplished using mechanical fasteners, splines, or dowels along the panel joint or other suitable means.

** The terms interconnected and non-interconnected refer to the joints between the individual nail laminated or glued laminated panels.

† The equations are developed for deck panel spans equal to or greater than the width of the tire (as specified in Article 3.30), but not greater than 200 inches.

$$\text{Thus, } t = \sqrt{\frac{6M_x}{F_b}} \quad (3-25)$$

or,

$$t = \frac{3R_x}{2F_v} \text{ whichever is greater} \quad (3-26)$$

where,

M_x = primary bending moment in inch-pounds per inch;

R_x = primary shear in pounds per inch;

x = denotes direction perpendicular to longitudinal stringers;

P = design wheel load in pounds;

s = effective deck span in inches;

t = deck thickness, in inches, based on moment or shear, whichever controls;

K = design constant depending on design load as follows:

$$H 15 \quad K = 0.47$$

$$H 20 \quad K = 0.51$$

F_b = allowable bending stress, in pounds per square inch, based on load applied parallel to the wide face of the laminations, (see Tables 13.2.2A and B);

F_v = allowable shear stress, in pounds per square inch, based on load applied parallel to the wide face of the laminations, (see Tables 13.2.2A and B).

3.25.1.4 The determination of the minimum size and spacing required of the steel dowels required to transfer the load between panels shall be based on the following equation:

$$n = \frac{1,000}{s_{PL}} \times \left[\frac{\overline{R}_y}{R_D} + \frac{\overline{M}_y}{M_D} \right] \quad (3-27)$$

where

n = number of steel dowels required for the given spans;

σ_{PL} = proportional limit stress perpendicular to grain (for Douglas Fir or Southern pine, use 1,000 psi);

\overline{R}_y = total secondary shear transferred, in pounds, determined by the relationship:

$$\overline{R}_y = 6Ps/1,000 \text{ for } s \leq 50 \text{ inches} \quad (3-28)$$

or,

$$\overline{R}_y = \frac{P}{2s}(s-20) \text{ for } s > 50 \text{ inches} \quad (3-29)$$

M_y = total secondary moment transferred, in inch-pound, determined by the relationship

$$\overline{M}_y = \frac{Ps}{1,600}(s-10) \text{ for } s \leq 50 \text{ inches} \quad (3-30)$$

$$\overline{M}_y = \frac{Ps}{20} \frac{(s-30)}{(s-10)} \text{ for } s > 50 \text{ inches} \quad (3-31)$$

R_D and M_D = shear and moment capacities, respectively, as given in the following table:

Diameter of Dowel	Shear Capacity	Moment Capacity	Steel Stress Coefficients		Total Dowel Length Required
	R_D	M_D	C_R	C_M	
in.	lb.	in.-lb.	1/in. ²	1/in. ³	in.
0.5	600	850	36.9	81.5	8.50
.625	800	1,340	22.3	41.7	10.00
.75	1,020	1,960	14.8	24.1	11.50
.875	1,260	2,720	10.5	15.2	13.00
1.0	1,520	3,630	7.75	10.2	14.50
1.125	1,790	4,680	5.94	7.15	15.50
1.25	2,100	5,950	4.69	5.22	17.00
1.375	2,420	7,360	3.78	3.92	18.00
1.5	2,770	8,990	3.11	3.02	19.50

3.25.1.5 In addition, the dowels shall be checked to ensure that the allowable stress of the steel is not exceeded using the following equation:

$$\sigma = \frac{1}{n} (C_R \overline{R}_y + C_M \overline{M}_y) \quad (3-32)$$

where,

- σ = minimum yield point of steel pins in pounds per square inch (see Table 10.32.1A);
- $n, \overline{R}_y, \overline{M}_y$ = as previously defined;
- C_R, C_M = steel stress coefficients as given in preceding table.

3.25.2 Plank and Nail Laminated Longitudinal Flooring

3.25.2.1 In the direction of the span, the wheel load shall be considered a point loading.

3.25.2.2 Normal to the direction of the span the wheel load shall be distributed as follows:

Plank floor:

width of plank.

Non-interconnected nail laminated or glued

laminated panel floor:

width of tire plus thickness of floor, but not to exceed panel width. Continuous nail

laminated floor and interconnected nail

laminated or glued laminated panel floor, with

adequate shear transfer between panels*, not

less than 6 inches thick: width of tire plus twice thickness of floor.

3.25.2.3 For longitudinal flooring the span shall be taken as the clear distance between floor beams plus one-half the width of one beam but shall not exceed the clear span plus the floor thickness.

3.25.3 Longitudinal Glued Laminate Timber Deck

3.25.3.1 Bending Moment

In calculating bending moments in glued laminated timber longitudinal decks, no longitudinal distribution of wheel loads shall be assumed. The lateral distribution shall be determined as follows.

The live load bending moment for each panel shall be determined by applying to the panel the fraction of a wheel load determined from the following equations:

* This shear transfer may be accomplished using mechanical fasteners, splines, or dowels along the panel joint or spreader beams located at intervals along the panels or other suitable means.

TWO OR MORE TRAFFIC LANES

$$\text{Load Fraction} = \frac{W_P}{3.75 + \frac{L}{28}} \text{ or } \frac{W_P}{5.00}, \text{ whichever is greater.}$$

ONE TRAFFIC LANE

$$\text{Load Fraction} = \frac{W_P}{4.25 + \frac{L}{28}} \text{ or } \frac{W_P}{5.50}, \text{ whichever is greater.}$$

where, W_P = Width of Panel; in feet ($3.5 \leq W_P \leq 4.5$)

L = Length of span for simple span bridges and the length of the shortest span for continuous bridges in feet.

3.25.3.2 Shear

When calculating the end shears and end reactions for each panel, no longitudinal distribution of the wheel loads shall be assumed. The lateral distribution of the wheel load at the supports shall be that determined by the equation:

Wheel Load Fraction per Panel

$$= \frac{W_P}{4.00} \text{ but not less than 1.}$$

For wheel loads in other positions on the span, the lateral distribution for shear shall be determined by the method prescribed for moment.

3.25.3.3 Deflections

The maximum deflection may be calculated by applying to the panel the wheel load fraction determined by the method prescribed for moment.

3.25.3.4 Stiffener Arrangement

The transverse stiffeners shall be adequately attached to each panel, at points near the panel edges, with either steel plates, thru-bolts, C-clips or aluminum brackets.

The stiffeners spacing required will depend upon the spacing needed in order to prevent differential panel movement; however, a stiffener shall be placed at midspan with additional stiffeners placed at intervals not to exceed 10 feet. The stiffness factor EI of the stiffener shall not be less than 80,000 kip-in².

3.25.4 Continuous Flooring

If the flooring is continuous over more than two spans, the maximum bending moment shall be assumed as being 80 percent of that obtained for a simple span.

3.26 DISTRIBUTION OF WHEEL LOADS AND DESIGN OF COMPOSITE WOOD-CONCRETE MEMBERS

3.26.1 Distribution of Concentrated Loads for Bending Moment and Shear

3.26.1.1 For freely supported or continuous slab spans of composite wood-concrete construction, as described in Article 20.19.1 Division II, the wheel loads shall be distributed over a transverse width of 5 feet for bending moment and a width of 4 feet for shear.

3.26.1.2 For composite T-beams of wood and concrete, as described in Article 20.19.2-Division II, the effective flange width shall not exceed that given in Article 10.38.3. Shear connectors shall be capable of resisting both vertical and horizontal movement.

3.26.2 Distribution of Bending Moments in Continuous Spans

3.26.2.1 Both positive and negative moments shall be distributed in accordance with the following table:

Maximum Bending Moments-Percent of Simple Span Moment

Span	Maximum Dead Load Moments		Uniform Live Load Moments		Maximum Live Load Moments		Uniform Load	
	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.	Pos.	Neg.
Interior	50	50	55	45	75	25	75	55
End	70	60	70	60	85	30	85	65
2-Span ^a	65	70	60	75	85	30	80	75

^aContinuous beam of 2 equal spans.

3.26.2.2 Impact should be considered in computing stresses for concrete and steel, but neglected for wood.

3.26.3 Design

The analysis and design of composite wood-concrete members shall be based on assumptions that account for the different mechanical properties of the components. A suitable procedure may be based on the elastic properties of the materials as follows:

$$\frac{E_c}{E_w} = 1 \text{ for slab in which the net concrete thickness is less than half the overall depth of the composite section}$$

$$\frac{E_c}{E_w} = 2 \text{ for slab in which the net concrete thickness is at least half the overall depth of the composite section}$$

$$\frac{E_s}{E_w} = 18.75 \text{ (for Douglas fir and Southern pine)}$$

in which

- E_c = modulus of elasticity of concrete;
- E_w = modulus of elasticity of wood;
- E_s = modulus of elasticity of steel.

3.27 DISTRIBUTION OF WHEEL LOADS ON STEEL GRID FLOORS*

3.27.1 General

3.27.1.1 The grid floor shall be designed as continuous, but simple span moments may be used and reduced as provided in Article 3.24.

3.27.1.2 The following rules for distribution of loads assume that the grid floor is composed of main elements that span between girders, stringers, or cross beams, and secondary elements that are capable of transferring load between the main elements.

3.27.1.3 Reinforcement for secondary elements shall consist of bars or shapes welded to the main steel.

3.27.2 Floors Filled with Concrete

3.27.2.1 The distribution and bending moment shall be as specified for concrete slabs, Article 3.24. The following items specified in that article shall also apply to concrete filled steel grid floors:

- Longitudinal edge beams
- Unsupported transverse edges
- Span lengths

3.27.2.2 The strength of the composite steel and concrete slab shall be determined by means of the "transformed area" method. The allowable stresses shall be as set forth in Articles 8.15.2, 8.16.1, and 10.32.

3.27.3 Open Floors

3.27.3.1 A wheel load shall be distributed, normal to the main elements, over a width equal to 1¹/₄ inches per ton of axle load plus twice the distance center to center of main elements. The portion of the load assigned to each main element shall be applied uniformly over a length equal to the rear tire width (20 inches for H 20, 15 inches for H 15).

* Provisions in this article shall not apply to orthotropic bridge superstructures.

3.27.3.2 The strength of the section shall be determined by the moment of inertia method. The allowable stresses shall be as set forth in Article 10.32.

3.27.3.3 Edges of open grid steel floors shall be supported by suitable means as required. These supports may be longitudinal or transverse, or both, as may be required to support all edges properly.

3.27.3.4 When investigating for fatigue, the minimum cycles of maximum stress shall be used.

3.28 DISTRIBUTING OF LOADS FOR BENDING MOMENT IN SPREAD BOX GIRDERS*

3.28.1 Interior Beams

The live load bending moment for each interior beam in a spread box beam superstructure shall be determined by applying to the beam the fraction (D.F.) of the wheel load (both front and rear) determined by the following equation:

$$D.F. = \frac{2N_L}{N_B} + k \frac{S}{L} \quad (3-33)$$

where,

- N_L = number of design traffic lanes (Article 3.6);
 - N_B = number of beams ($4 \leq N_B \leq 10$);
 - S = beam spacing in feet ($6.57 \leq S \leq 11.00$);
 - L = Span length in feet;
 - $k = 0.07W - N_L(0.10N_L - 0.26) - 0.20N_B - 0.12$;
- (3-34)

W = numeric value of the roadway width between curbs expressed in feet ($32 \leq W \leq 66$).

3.28.2 Exterior Beams

The live load bending moment in the exterior beams shall be determined by applying to the beams the reaction of the wheel loads obtained by assuming the flooring to act as a simple span (of length S) between beams, but shall not be less than $2N_L/N_B$.

* The provisions of Article 3.12, Reduction in Load Intensity, were not applied in the development of the provisions presented in 3.28.1 and 3.28.2.

3.29 MOMENTS, SHEARS, AND REACTIONS

Maximum moments, shears, and reactions are given in tables, Appendix A, for H 15, H 20, HS 15, and HS 20 loadings. They are calculated for the standard truck or the lane loading applied to a single lane on freely supported spans. It is indicated in the table whether the standard truck or the lane loadings produces the maximum stress.

3.30 TIRE CONTACT AREA

The tire contact area shall be assumed as a rectangle with an area in square inches of $0.01P$, and a Length in Direction of Traffic/Width of Tire ratio of $1/2.5$, in which P = wheel load in pounds.

Section 3 Commentary - Loads

3.10.4 Centrifugal Forces

This specification has been revised to require a centrifugal force generated by the reaction due to the controlling live load. This will eliminate inconsistency which required a considerable increase in reinforcement and a corresponding increase in the probable yield strength. Single column bents were especially affected in the transverse direction. For example, if one permit load generated the critical moment, a significant centrifugal moment, generated by HS trucks in all lanes, formerly would have been added to it. For this example, the revised specification will require adding only the centrifugal moment generated by one permit truck traveling at a slow speed.