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Final Report—Part III

Design Manual for Strengthening Single-Span Composite Bridges by Post-tensioning

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ERRATA

- Add to Fig. 3, p. 14

  i = unit, average longitudinal flexural stiffness

  = total I for all composite, coverplated beams ÷ deck width

  j = unit, average transverse flexural stiffness, including interior diaphragms

  $$AR = \text{aspect ratio} = \frac{\text{deck width}}{\text{SPANB}}$$

  $$IET = \frac{\text{I for exterior composite, coverplated beams}}{\text{I for all composite, coverplated beams}}$$

  $$THETA = \frac{\text{deck width}/2}{L} \sqrt[4]{i/j}$$

  Note that all section properties computed for the longitudinal direction are with respect to the bridge neutral axis.

- Add to end of first paragraph, Section 5.1, p. 31

  All steel shapes in the bridge superstructure are of A7 steel, and all deck and curb concrete has a 28-day strength of 3000 psi.

- Revise Fig. 10, p. 66

  Interchange key descriptions for solid line and dashed line stresses.

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1. INTRODUCTION

1.1. Background

During the period 1930 to 1960 the State of Iowa constructed a considerable number of single-span, composite steel beam and concrete deck bridges. The AASHO bridge design standards in use during that time period permitted exterior beams to be designed for a wheel-load fraction considerably smaller than the fraction for interior beams. As a consequence, Iowa designed and constructed many one- and two-lane composite bridges with exterior steel beams having depths 2 or 3 in. less than the interior steel beams.

The Seventh Edition of Standard Specifications for Highway Bridges [3], issued by AASHO in 1957, increased the wheel-load-distribution fraction for exterior beams for this bridge type. The increase was substantial--as much as 40% for a typical 50-ft span, two-lane, four-beam bridge. As a result, when these typical Iowa composite bridges were rated, they were found to be no longer adequate for their design loads.

In 1980, the Iowa State Legislature passed legislation which significantly increased legal loads in the state. The legal load increase widened the gap between the rated strength of the older composite bridges with small exterior beams and current rating standards.

1.2. Bridge Strengthening

Although shear connectors and other bridge parts may be inadequate, most of the composite bridges designed prior to 1957 are understrength because of excessive flexural stresses in exterior beams. For bridges with this bending stress deficiency, it is logical to strengthen the exterior beams in order to avoid embargoes or costly, early replacement of the bridges.

One method of strengthening exterior beams is post-tensioning. Post-tensioning is already an accepted strengthening method for composite bridges in California [15]. The authors have post-tensioned and monitored two Iowa bridges as described in Refs. [13 and 7] and have field tested the post-tensioning of a composite bridge in Florida [5]. Other applications of post-tensioning as a strengthening method exist also, as noted in Ref. 14.

In most cases, post-tensioning is less costly than the addition of coverplates or alternative methods for increasing flexural capacity. If the brackets for application of post-tensioning are bolted to bridge beams, no special construction skills are required, and, if properly designed, there is no uncertainty as to adequacy of connections--as there might be if the bridge's steel welding characteristics were unknown.

The major drawback to post-tensioning of Iowa bridges has been the unknown distribution of post-tensioning to the various beams of a composite bridge. If all beams are post-tensioned equally, the usual but somewhat inaccurate design assumption is that all forces and moments remain with each strengthened beam. When all composite, post-tensioned beams are of equal or almost equal stiffness, the design assumption is valid; however, when the beam stiffnesses vary significantly, the assumption is not valid.

If only the exterior beams are post-tensioned, one cannot assume that the resulting forces and moments remain only on the exterior beams. A composite bridge behaves as a single structure. The shear connection between steel beams and concrete deck and the transverse stiffness of the bridge deck and diaphragms provide a path through which the post-tensioning on any one beam is distributed to the remainder of the bridge.

The typical composite bridge in need of strengthening (see Fig. 1) is complex in terms of structural variables. The bridge is a variably stiffened orthotropic plate. Variations in longitudinal stiffness occur because of the wide spacing of beams, differences in beam size, differences in coverplate size, differences in location of coverplate cutoff, and the use of curbs integral with the deck. Variations in transverse stiffness are caused by use and placement of diaphragms.

For actual bridges, end conditions can neither be classified as hinged nor as fixed ends. Also, the end conditions may vary depending on whether a load causes positive or negative bending. Although many of the composite bridges are right-angle bridges, others have skews of as much as 45°. Due to the use of the smaller exterior beams and the need for drainage, most of the composite bridges have a deck crown of approximately 3 in.

In order to provide the practical post-tensioning distribution factors given in this manual, the authors developed a finite element

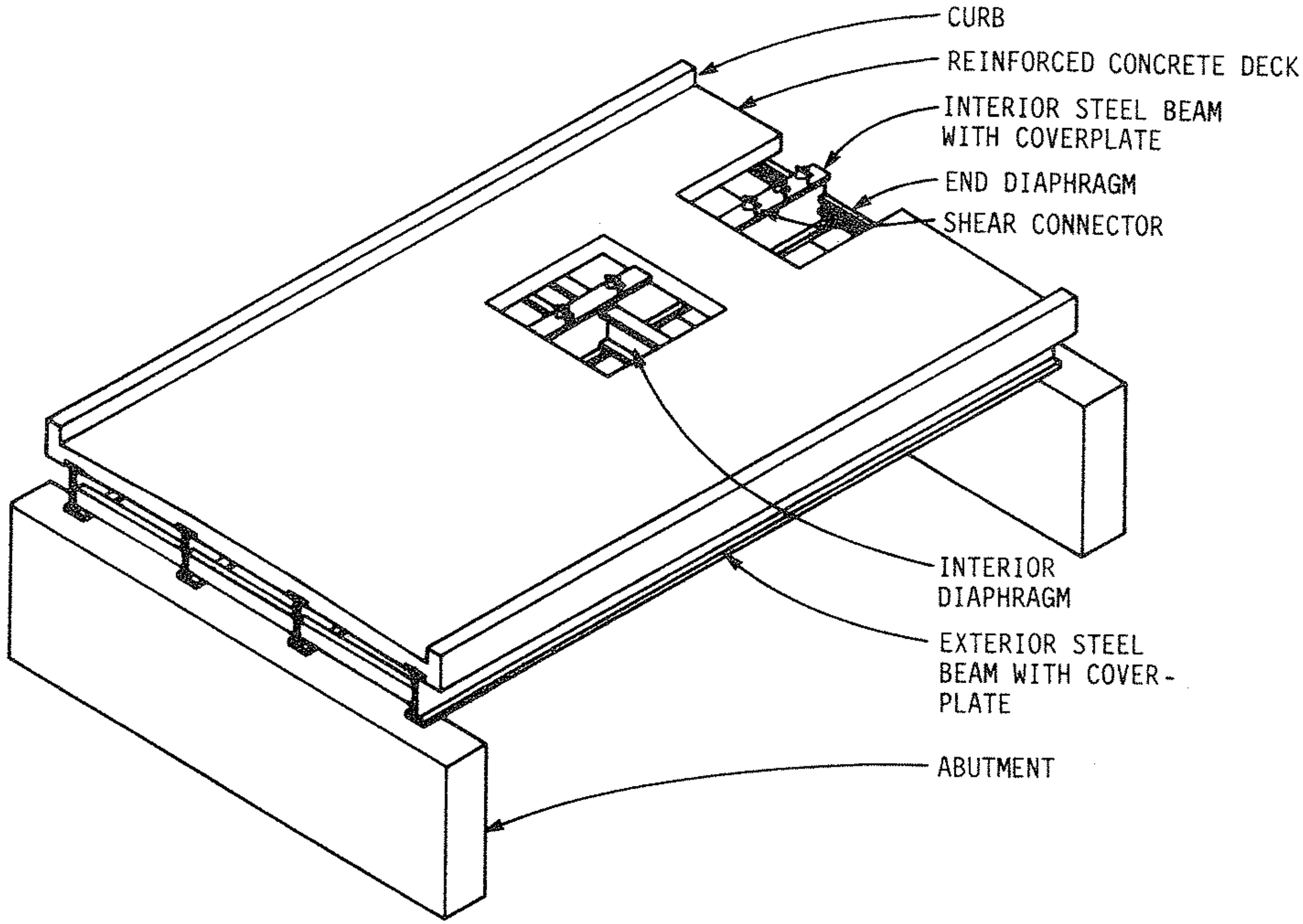


Fig. 1. Typical composite bridge.

model of a composite bridge and checked the model against a one-half scale laboratory bridge and two actual composite bridges, one of which had a 45° skew. Details of the finite element model and verification of the model are given in Chapter 5 of Ref. [7].

The finite element model was applied to standard Iowa DOT bridge designs, specifically the V9 Series [16] for single-lane, three-beam bridges; and the V11, V13, and V15 Series [17,18,19] for two-lane, four-beam bridges. The model also was applied to several Iowa DOT, individually designed, composite bridges. From the finite element model results, the authors developed multiple regression formulas for the post-tensioning distribution fractions. Depending on the elevation of the tendons, the post-tensioning force will create varying amounts of force and moment. Thus, to provide flexibility for the designer, distribution factors were determined separately for force and moment. For additional design flexibility, the distribution factors were determined for a variable bracket location on the span. All of the distribution factors were determined for exterior beams post-tensioned symmetrically.

Within the limits of the three- and four-beam bridges included in the regression analysis, the formulas give quick and accurate results. However, the formulas are not applicable in several cases: bridges with more than four beams, continuous composite bridges, and composite bridges with other significant, differing characteristics. Those bridges must be analyzed individually using finite element analysis or other analysis methods.

Post-tensioning can easily modify the elastic stresses within a bridge and, in so doing, satisfy rating criteria for service loads. However, post-tensioning also will create a certain amount of camber or tension stress, which may cause cracking of curbs and concrete deck. Because the post-tensioning tendons are attached to the beams near the supports but not at any other locations, they do not increase the moment of inertia of the cross section. The tendons do increase the resistance to deflection of the post-tensioned beams but through a mechanism other than ordinary bending stiffness. Post-tensioning will increase the strength of the bridge; however, the increase in strength will be less in percentage terms than the increase in allowable load-carrying capacity computed by the service load design method. Thus, post-tensioning is a more attractive strengthening method for the service load design method.

The sections which follow in this manual explain the use of elastic, composite beam and bridge section properties, the distribution fractions for symmetrically post-tensioned exterior beams, and a method for computing the strength of a post-tensioned beam. Also included is a design example for a typical, 51.25-ft-span, four-beam composite bridge. Moments for Iowa DOT rating trucks, H 20 and HS 20 trucks, have been tabulated for design convenience; these are included in the Appendix.

2. SECTION PROPERTIES

2.1. Service Load Design

Current bridge design and rating practice is to isolate each bridge beam from the total structure and to base dead and live load stresses on the cross-sectional properties for the individual beams, using the rules for computing the properties given in the AASHTO Standard Specifications for Highway Bridges [2]. Because the Iowa composite bridges were constructed without shoring, the dead load stresses are computed for the steel beam, concrete deck, and curb and rail weights as applied to the bare steel beams or beams with coverplates. In addition to the properties of the bare beams and beams with coverplates, the properties of the isolated composite beams are required for the live load plus impact stress computations. The composite moment of inertia method (specified in Ref. 2, Sec. 10.38) assumes that the concrete deck width is limited and that the concrete material areas are reduced by the factor n, the ratio of modulus of elasticity of steel to that of concrete.

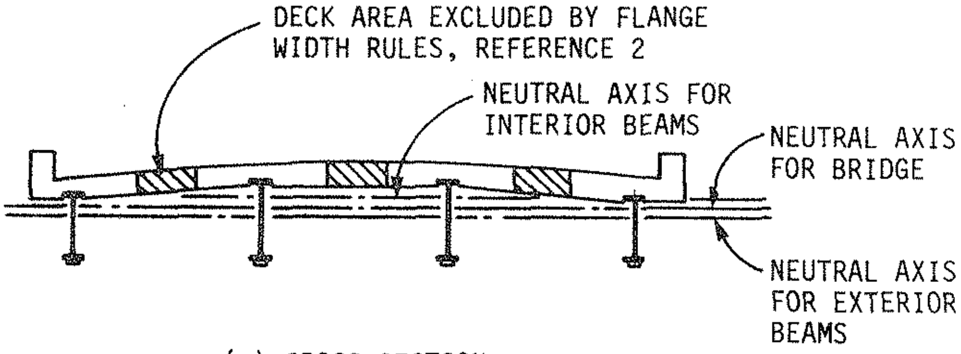
Long-term dead loads due to the weight of a future wearing surface and any other dead loads applied after the concrete deck has cured cause creep in the concrete deck as it is subjected to long-term compression stresses. Reference 2 specifies that the factor n be increased by a factor of three to account for creep due to long-term dead load, thereby reducing the effective moment of inertia of the composite beam cross section. Overall, then, computation of the service load stresses for a composite bridge requires three sets of section properties for a location where stresses are to be checked: properties for the steel beam, properties for a composite beam, and properties for a composite beam with a reduced deck section. Because each exterior beam and interior beam typically have both bare beam and coverplated regions, twelve sets of section properties are usually required for a bridge.

2.2. Post-tensioning

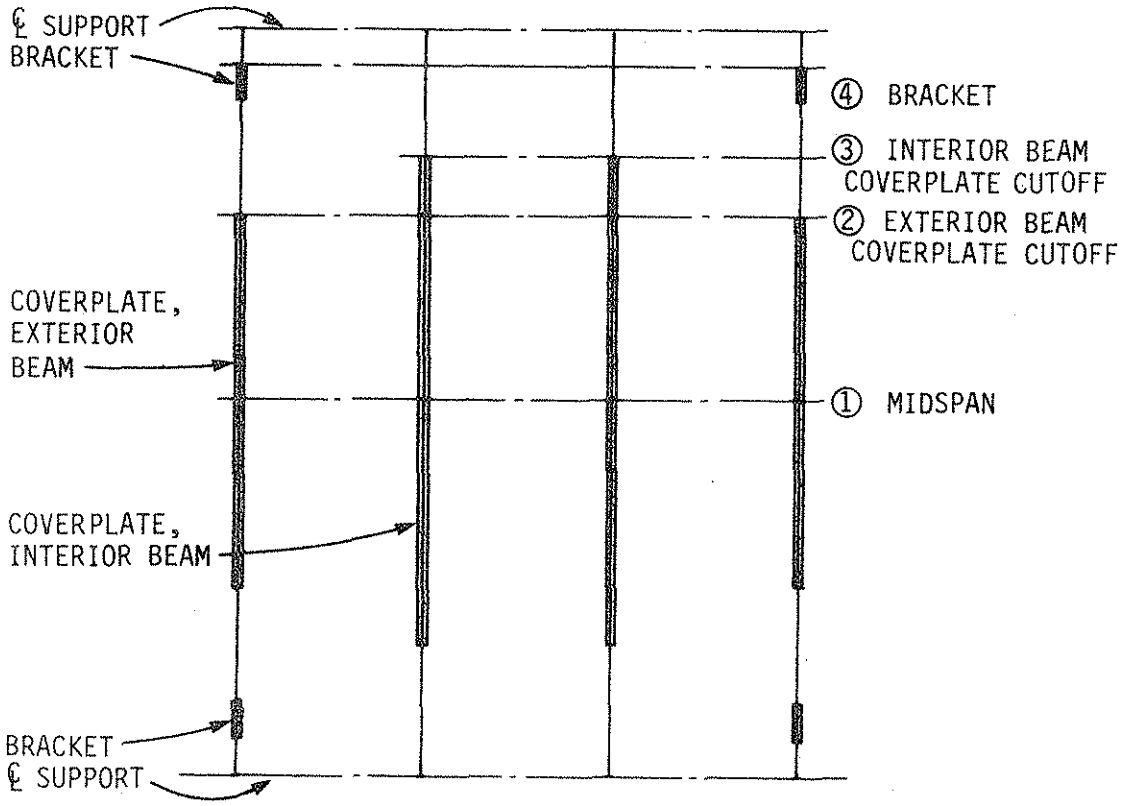
Application of eccentric post-tensioning to a bridge beam causes both axial force and moment. Because the moment is computed as the product of the force in the tendons and the distance between the tendons and the neutral axis, the location of the neutral axis is significant.

As Fig. 2(a) indicates, the elevation of the neutral axis for the exterior beam is not the same as the elevation of the neutral axis for the bridge. Furthermore, the neutral axis elevations will change depending on whether the exterior and/or interior beams are coverplated. How much difference in neutral axis elevations exists is dependent on the size or absence of integral curbs, the relative depths and elevations of the steel beams, and the magnitude or absence of deck crown.

On the basis of trials with several bridges and correlation with field data, it appears that greater accuracy can be achieved if the bridge's neutral axis is considered the elevation about which the post-tensioning force causes moment. For simplicity in computing the additional sets of section properties, the excluded deck areas may be neglected in locating the bridge's neutral axis. Although post-tensioning



(a) CROSS SECTION



(b) STEEL BEAM, COVERPLATE AND POST-TENSIONING BRACKET PLAN

Fig. 2. Typical composite bridge.

is a long-term load, it causes a negative bending moment that induces tension in the concrete deck and curbs. For that reason, the creep condition considered for long-term dead loads is not likely to occur for post-tensioning, and it is reasonable to use the initial, unmagnified n factor for computation of bridge section properties. It is also conservative to use the initial n factor. Use of the magnified n factor decreases the required post-tensioning force in the typical condition considered in this manual.

In developing the post-tensioning distribution fractions from the finite element model, the authors computed the bridge section properties as outlined above, using an initial n factor and disregarding the portions of the bridge deck excluded by the width limitations for the beam flange given in Ref. 2. The distribution fractions also are based on the bridge properties at midspan with all beams coverplated (location (1) in Fig. 2(b)), since this is the most usual condition within the post-tensioned region of the bridge. Thus, in order to use the distribution fractions given in this manual most accurately, stresses induced by post-tensioning forces and moments should be computed on the basis of section properties for composite beams with respect to a composite bridge.

The four locations identified in Fig. 2(b) are all locations at which stresses must be checked for a complete post-tensioning design. Three different sets of properties are required in order to check those locations: properties for the bridge with all beams coverplated, properties for the bridge with only the interior beams coverplated, and properties for the bridge with no beams coverplated.

Since there is need for a considerable number of different sets of section properties in rating a composite bridge as well as in designing the post-tensioning, the designer must be careful in organizing hand computations or in using calculator- or computer-programmed computations. As a guide to setting up the section property computations, the design example given in Sec. 5 should be helpful.

3. SERVICE LOAD DESIGN METHOD

3.1. Force and Moment Distribution Fractions at Midspan

Although the SAP IV finite element model described in Chapter 5 of Ref. 7 is a general, theoretical model adaptable to a wide variety of composite bridges, the model requires access to SAP IV, preprocessing and postprocessing programs, and a large computer. In order to simplify the design process for the typical Iowa composite bridges, the authors have used the model to compute the data and develop simple regression formulas for the force and moment distribution fractions.

The range of bridges included in the data for the distribution fractions is given in Table 1. For three-beam bridges, spans range from 23.75 ft to 80 ft, beam spacing is set at 9.5 ft, deck thickness (less wearing surface) is set at 6.94 in., and the integral curbs and coverplates are as specified in the Iowa DOT V9 Series [16]. To give the designer flexibility in locating the post-tensioning brackets, separate data were generated for brackets at 5% and 20% of the span lengths.

Table 1. Bridges included in regression analysis for distribution fractions.

IDOT Series Date (Earliest Use of Series)	Number of Beams/ No. of Lanes	Smaller Exterior Beams	Beam Spacing, ft	Cover-plate Length	Deck Thickness (less wearing surface), in.	Integral curbs	Spans, L, ft	Design Live Load	No. of SAP IV Runs (bracket at 0.05L & 0.20L)
V9 1964 (1950)	3/1	yes	7.67	partial	6.94	yes	23.75,30, 42.5,55, 67.5,80	H 15-44	12
V11 1964 (1957)	4/2	yes	7.67	partial	6.25	yes	23.75,30, 42.5,55, 67.5,80	H 15-44	12
V13 1964 (1960)	4/2	yes	9.00	partial	6.78	yes	23.75,30, 42.5,55, 67.5,80	H 20-44	12
V15 1975	4/2	no	9.33	no plate or partial	8.00	yes	23.75,30, 42.5,55, 67.5,80	H 20-44	12
Individual Designs 1946-48	4/2	yes	9.69	partial	8.00	yes	41.25, 51.25, 71.25, 79.04	H 20-44	8

For the four-beam bridges, there is considerably more range in the data used to develop the distribution fraction formulas. The data include spans of 23.75 ft to 80 ft, beam spacings of 7.67 ft to 9.69 ft, deck thicknesses of 6.25 in. to 8 in., steel bridge beams of equal or unequal size and partially or completely coverplated beams as given in the Iowa DOT V11, V13, and V15 Series [17,18,19]. All bridges have curbs integral with the deck. The 5% and 20% of the span locations for brackets were also used for all bridges to give design flexibility.

Because the regression formulas given later in this section were developed for the ranges of data outlined above, the distribution fraction formulas should not be applied to bridges which have characteristics beyond those data ranges. The formulas also were developed for midspan distribution factors. For distribution factors at locations other than at midspan, the guidelines given in Sec. 3.2 should be followed.

The finite element experiments reviewed in Chapter 5 of Ref. 7 provided the basis for choosing potential regression variables. After analyzing the potential variables by means of SAS (Statistical Analysis System) and experimenting with various forms of regression equations as described in Chapter 5, the authors chose the regression variables given in Fig. 3.

The most significant variable proved to be the length of the post-tensioned region or the distance between tendon anchorages (SPANB), alone or in an aspect ratio (AR), as computed from the deck width and SPANB. The transverse stiffness of the deck also is significant and was included as a ratio of DECKT (deck thickness) to DECKS (deck span).

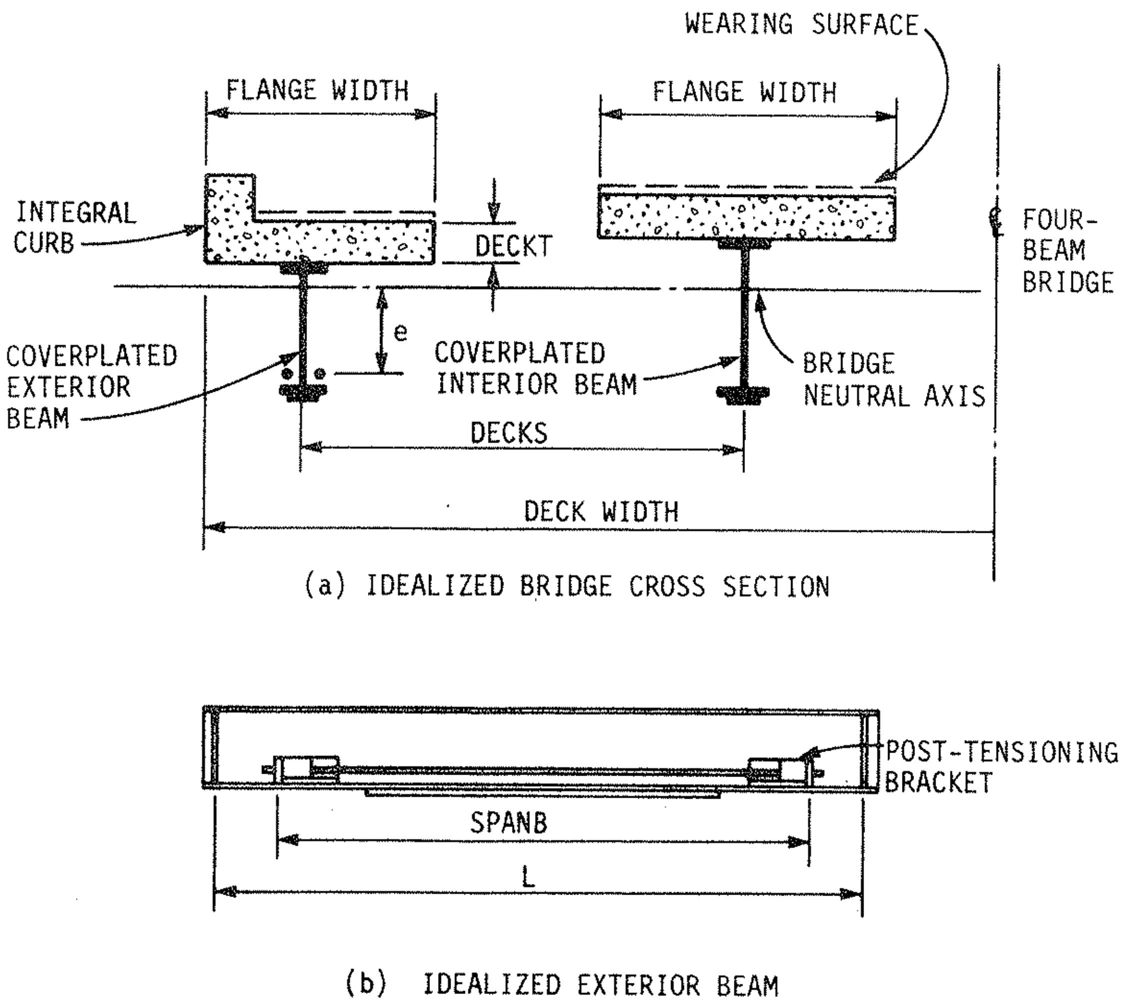


Fig. 3. Regression formula variables.

For moment fractions, the relative stiffness of the exterior beams (IET), computed as the ratio of the total, exterior beam stiffness to the total bridge stiffness was significant. For force fractions (THETA), the orthotropic plate flexural parameter was significant. Further definitions of the variables are given in Fig. 3. Skew, if 45° or less, need not be considered and is not listed among the variables in the figure.

The multiple linear regression formulas given for the force fractions for exterior beams, FF, and the moment fractions for exterior beams, MF (Fig. 4), all have coefficients of determination of 0.95 or greater. According to the coefficients of determination, the moment fraction formulas are more accurate, a desirable situation since a larger portion of the post-tensioning stress is usually caused by moment.

Should the designer want to apply a safety factor to the distribution fraction computed from one of the formulas given in Fig. 4, the error range values are helpful. Since the negative error percentage indicates that the finite element distribution fraction could be that much less than the formula-predicted fraction, the formula-predicted value can simply be reduced by that percentage. As an example, the moment fraction, MF, computed from the four-beam bridge formula can be multiplied by (1 - 0.07) or 0.93.

FF = force fraction
MF = moment fraction

Three-Beam Bridges

$$FF = 0.741 - 0.175 \frac{1}{\sqrt{THETA}} - 0.0624 \frac{1}{\sqrt{AR}}$$

$R^2 = 0.986$, error range +2%, -3%

$$MF = 0.816 - 0.245 \frac{1}{\sqrt{IET}} - 0.0755 \frac{1}{\sqrt{AR}}$$

$R^2 = 0.991$, error range +2%, -2%

Ranges of Regression Variables:

$$0.417 \leq THETA \leq 0.893$$
$$0.456 \leq IET \leq 0.571$$
$$0.306 \leq AR \leq 1.544$$

Four-Beam Bridges

$$FF = 0.605 - 0.323 \frac{1}{\sqrt{THETA}} - 0.0720 \frac{1}{\sqrt{AR}} + 3.87 \frac{DECKT}{DECKS}$$

$R^2 = 0.954$, error range +9%, -6%

$$MF = 0.963 - 0.221 \frac{1}{\sqrt{IET}} - 0.145 \frac{1}{\sqrt{AR}} - 2.18 \frac{DECKT}{DECKS}$$

$R^2 = 0.983$, error range +4%, -7%

Ranges of Regression Variables:

$$0.516 \leq THETA < 1.329$$
$$0.379 \leq IET \leq 0.600$$
$$0.361 \leq AR \leq 2.246$$
$$6.25 \leq DECKT \leq 8.00$$
$$92.00 \leq DECKS \leq 116.25$$

Note that negative error range indicates that SAP IV result is less than regression formula-predicted result.

Figure 4. Regression formulas for force and moment fractions, post-tensioned exterior beams--bridge skew 0° to 45°.

3.2. Force and Moment Distribution Fractions at Locations Other than Midspan

Post-tensioning distribution does not remain constant over the entire bridge span. At the bracket location, where the post-tensioning is applied, most of the post-tensioning remains on the beam to which the brackets are attached. Toward midspan, however, much of the post-tensioning is distributed to the interior of the bridge.

Figure 5 illustrates moments on the spans of three post-tensioned beams. In Fig. 5(a), the moment diagram for an isolated beam of constant cross section is given. In Fig. 5(b), the same beam has been coverplated, and the downward shift in neutral axis elevation reduces the post-tensioning moment over the coverplated region of the span. The beam in Fig. 5(c) is part of a bridge. The restraining effect of the bridge causes small positive moments between brackets and supports and causes reduction in negative moment near midspan. The moment diagram illustrated in Fig. 5(c) is typical for a post-tensioned exterior beam in a composite bridge.

Although for exterior beams it would be conservative to use the midspan moment fraction over all portions of the post-tensioned length, that procedure will not give accurate results. A recommended interpolation procedure is given in Fig. 6. The linear interpolation neglects locations of the brackets, which is convenient for design and also gives more accurate results. Using the support for the second known distribution point accounts partially for the small positive moments between brackets and supports shown in Fig. 5(c).

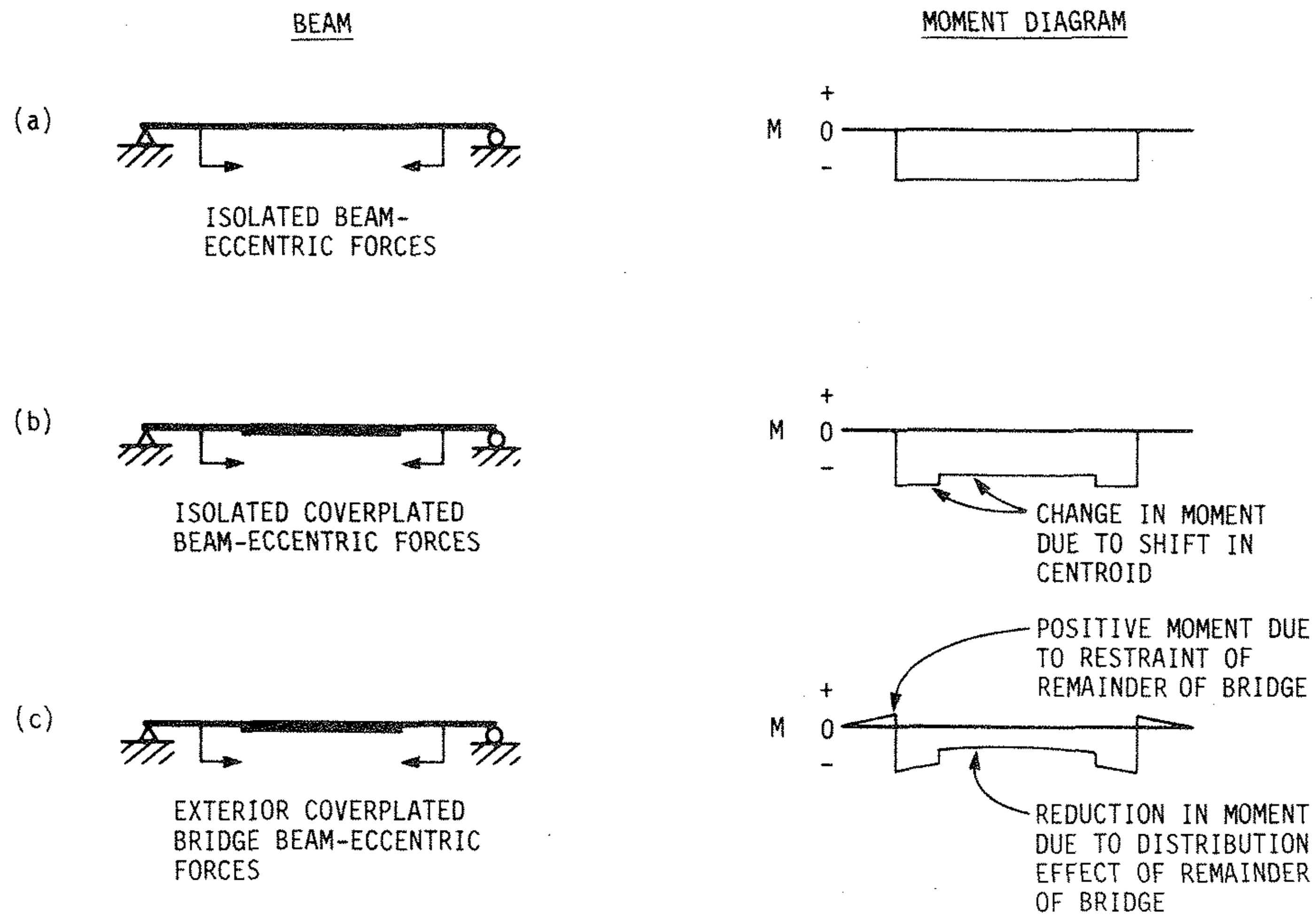
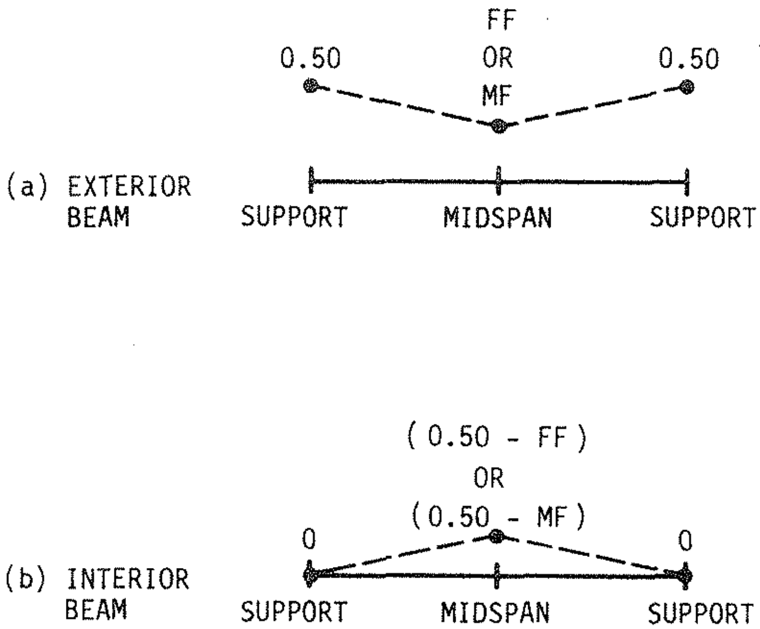


Fig. 5. Post-tensioned beams and moment diagrams.



FF = FORCE FRACTION FROM REGRESSION FORMULA
MF = MOMENT FRACTION FROM REGRESSION FORMULA

Fig. 6. Recommended interpolation for distribution factors at locations other than midspan.

The comparison between the finite element beam stresses and interpolated stresses given in Chapter 5 of Ref. 7 shows agreement generally within 10%. Thus, the interpolation procedure described above gives accurate results.

3.3. Bracket Design and Tendon Selection

In the original design of the Iowa composite bridges, the designers checked two locations on the beams for flexural stresses: midspan and coverplate cutoff. When strengthening a bridge by post-tensioning, a third location must be checked, the bracket location. For the two bridges strengthened by the authors [13], the brackets were located at a distance from the supports--approximately 7% of the span in most cases. The locations of the brackets were determined by trial and error to find the points at which the average beam, bottom flange stress did not exceed an allowable stress of 18 ksi tension, after the bracket bolt holes were cut into the flanges. The 7%-of-the-span bracket location also gave adequate clearance for the jacking operation during the actual post-tensioning.

For a skewed bridge, the authors moved the brackets closer to the supports at the two obtuse corners of the bridge. This placement had the advantage of applying post-tensioning to counteract load from the adjacent interior parts of the bridge (not accounted for in the usual beam stress computations), but the disadvantage of increasing the post-tensioned length and thus causing less of the post-tensioning to remain on the exterior beams at midspan. From the finite element analysis of skewed bridges, it appeared that moving the brackets did not significantly improve the post-tensioned performance of the bridge [6]. For skewed bridges, then, brackets can be located as for right-angle bridges.

Fatigue design is based on stress range. For the two bridges strengthened by the authors, the change in tendon force due to an eccentric truck was on the order of 5% to 7% of the total weight of the truck. If the AASHTO wheel load distribution fraction [2, Section 3.23], rather than the actual fraction, were used in a computation for the tendon force increase, the force increase would be somewhat larger. The stress range for the brackets and welded connections in the brackets still would be quite small and should not pose a major design problem.

Tendon elevation is highly significant for the economical use of post-tensioning. The lower the tendons are placed, the greater the moment effect for a given post-tensioning force. The greater moment effect will relieve tension stress in bridge beams more efficiently, but it also will cause more tension in deck and curbs. The elevation of the brackets to which the tendons are anchored often is limited by clearances. If the brackets and tendons are placed below the bridge beams, they are in a very vulnerable position and will reduce the clearance for any traffic under the bridge. Even when the tendons and brackets are placed above the bottom flanges of the beams, the tendon paths must be considered since bridge diaphragms may cause obstructions.

If brackets are located at the juncture of the beam's bottom flange and the web, it is possible to bolt the bracket to both flange and web.

This thereby reduces the length over which the bracket must be bolted to the beam and provides resistance against the lateral bending which will occur if accident, human error, or temperature differential caused the tendon forces to be unequal on either side of the beam web.

The choice of bracket location and elevation rests with the designer. If the brackets are correctly located, there is no loss of capacity for the bridge if the post-tensioning were to be removed at some future date. The actual design of the brackets is dependent on the number, placement, and type of tendons, as well as other factors particular to a given bridge. Examples of brackets designed by the authors are given in Ref. 13.

Although the authors have used threaded bars for the tendons [8,13], it is possible to use cables for the tendons, as is done by the California DOT [15]. Choice of tendon type, size, and number depends not only on the required post-tensioning force, but also on the means of corrosion protection and tendon-path obstructions. The authors have found it convenient to use epoxy-coated threaded bars rather than cables grouted in conduit. However, the epoxy coating should be omitted at the anchorages, or nuts will not turn readily on the tendon.

With the threaded tendons, the authors have found little reason for post-tensioning loss due to the usual loss factors. If care is taken during the post-tensioning process, the elastic shortening and seating losses are very small or essentially nonexistent if all tendons are stressed at the same time. Mancarti confirms this finding for post-tensioning with cables [15]. There will be some loss of post-tensioning due to relaxation of the tendon steel, and the estimate for that loss should be obtained from the tendon manufacturer. It is possible that there will be some temporary loss (or gain) of post-tensioning force due to temperature differential between the tendons and the bridge. The designer may need to estimate the maximum loss. (See Chapter 4 of Ref. 7 for temperature data for a north-south bridge.)

One loss which can be substantial and is usually not considered in design is the loss that occurs when the bridge deck or integral curbs are replaced or modified. Because the deck and curbs restrain the effects of the post-tensioning and contribute to the composite cross section of the bridge, removal of any part of the cross section will affect the post-tensioning stresses. Deck and curb repairs, therefore, should be coordinated with the post-tensioning and, preferably, not be performed after the bridge has been post-tensioned. If the bridge has been post-tensioned, the authors recommend temporarily removing the post-tensioning until deck and curb repairs are completed.

Partially offsetting some of the losses noted above is the gain in post-tensioning that occurs when a truck loads the bridge. The truck will cause tension in the bottom of a post-tensioned beam, as well as in the tendons anchored to the beam. The theory for computation of the tendon force gain for an isolated beam is given in Ref. 14.

In general, the post-tensioning losses can be expected to be smaller than those for a post-tensioned concrete bridge. There are advantages to post-tensioning with threaded tendons or cables, and the designer should consider those advantages carefully in choosing the type of tendon.

3.4. Recommended Design Procedure

To develop the tendon forces and design the post-tensioning system, the following procedure is suggested.

(1) Determine all loads and load fractions for

- dead load
- long-term dead load
- impact load and
- live load

for both exterior and interior beams.

(2) Compute moments for

- dead load
- long-term dead load and
- live load and impact (Appendix)

at

- midspan
- coverplate cutoffs and
- approximate bracket location (only for exterior beams)

for exterior and interior beams.

(3) Compute section properties for

- steel beam
- steel beam with coverplate
- composite beam
- composite beam with coverplate
- composite beam with concrete creep and
- composite beam with coverplate and concrete creep

for exterior and interior beams. Also compute section properties for

- composite beam and
- composite beam with coverplate

for beams with respect to bridge at several locations, as required by the coverplate configuration.

(4) Compute stress to be removed by post-tensioning at midspan of exterior beam

- Determine approximate tendon elevation
- Compute force and moment factors (see Figs. 3 and 4)
- Compute required total post-tensioning force for the bridge using

$$f = FF\,\frac{P}{A} + MF\,\frac{Pec}{I}$$

- Select tendons and account for losses in determining tendon forces to be specified.

(5) Check stresses at

- top of curb
- top of deck
- top of beam and
- bottom of beam or coverplate

at

- midspan
- coverplate cutoff and
- bracket

for exterior beam and interior beam (omit bracket location for interior beam).

(6) Design brackets and anchorages.

(7) Check other design factors such as
- beam shear
- shear connectors
- deflection
- fatigue and
- beam strength.

4. ULTIMATE STRENGTH

4.1. Analytical Strength Model

The problem of developing a flexural strength model for a post-tensioned composite beam includes the following types of behavior:

- steel-concrete composite action
- partial shear connection
- partial prestressing
- unbonded tendon.

Some empirical formulas are given in codes and standards for prestressed beams, but those formulas generally do not give accurate results for the composite post-tensioned beams under consideration.

The analytical model proposed by the authors is based on the following principles and assumptions:

(1) The post-tensioned beam can be assumed to behave as a steel beam with a plastic hinge at midspan.

(2) The deflection of the plastic hinge at midspan can be taken to be the span length divided by 80.

(3) The effective beam flange width can be determined according to the AASHTO rules for load factor design [2, Sec. 10.38].

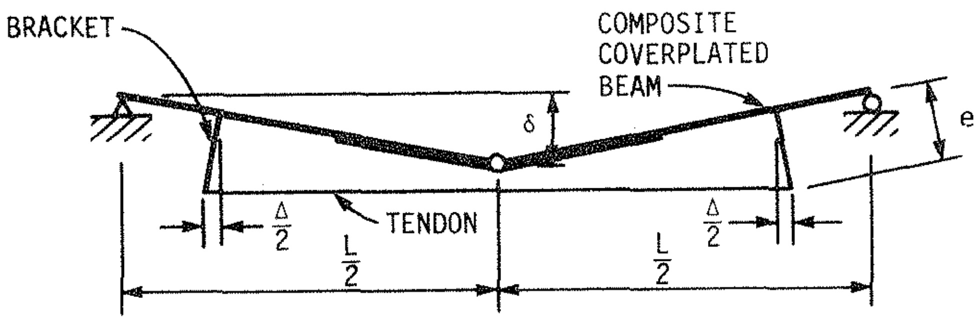
(4) The compressive force in the slab can be determined according to AASHTO rules, which account for slab reinforcing (unlike service load design), relative capacity of concrete slab vs steel beam, and partial or full shear connection [2, Sec. 10.50].

(5) Tendon strain can be determined from an idealized beam configuration as illustrated in Fig. 7. In the idealized beam, the tendon is permitted to rise, and the change in elevation is accounted for in the computations. If the tendons are in any way restrained from rising, the configuration in Fig. 7 must be modified to correctly represent the actual condition.

(6) Tendon force can be computed from an idealized stress-strain curve for the tendon steel.

(7) Shear connector capacities can be computed from the formulas given in Ref. 2, Sec. 10.38. For angle-plus-bar shear connectors, the capacity can be based on a modified channel formula as noted in Ref. 13.

The recommended procedure for computation of the flexural strength of a post-tensioned composite beam is as follows:



δ = L/80

e = DISTANCE BETWEEN NEUTRAL AXIS OF COMPOSITE BEAM AT ULTIMATE LOAD AND CENTER OF TENDON AT ANCHORAGE.

Δ = CHANGE IN TENDON LENGTH AFTER POST-TENSIONING (TOTAL TENDON FORCE MUST BE BASED ON SUM OF INITIAL STRETCH PLUS Δ.)

Fig. 7. Idealized composite, post-tensioned beam failure mechanism.

(1) Assume a plastic hinge at midspan with a deflection of L/80.

(2) Compute the maximum compressive force according to AASHTO rules based on slab and reinforcing; beam, coverplate and tendon at yield; and shear connectors.

(3) Compute the tendon force at ultimate load using strain based on the idealized, plastic beam-tendon configuration, initial strain due to post-tensioning, and a stress strain curve for the tendon. Correct the compressive force computed in (2), if necessary.

(4) Determine the elevations of compressive and tensile force resultants, accounting for the rise in the tendon, if the tendon is unrestrained.

(5) Compute the flexural strength as the product of the maximum compressive force and the distance between compressive and tensile force resultants.

In Chapter 5 of Ref. 7 the procedure given above was applied to composite beams tested to failure and beams analyzed by more complex methods. The computed tendon force fell within 12%, and the flexural strength fell within 7% of the actual test results or otherwise computed values.

A comparison of the flexural strength of composite beams with or without post-tensioning, also given in Chapter 5, indicated that the increase in strength with post-tensioning varied from 8% to 34%. For exterior beams similar to those to be post-tensioned on the Iowa composite bridges, the increase in strength averaged 10%. This increase is less than the capacity increase based on service load design, yet still is significant.

4.2. Flexural Strength of Bridge Beams

The simple analytical model covered in the previous section accurately predicts the strength of individual, post-tensioned composite beams. At this time, however, the authors have no specific experimental or analytical distribution factors by which to extend the individual beam model to an entire bridge with only the exterior beams post-tensioned.

Heins and Kuo [10] have shown that, for truck live loads, distribution factors at ultimate loads are less than the corresponding factors at service loads. This is generally explained by the fact that there are load transfer mechanisms which shift load away from yielded regions. This concept, if applied to post-tensioning, would imply that more post-tensioning is shifted away from the post-tensioned exterior beams at ultimate load than at service load. The service load distribution factors given in Sec. 3.1 would thus be unconservative for exterior beams at ultimate load.

The current AASHTO bridge specifications [2], however, make no distinction between service load and ultimate load distribution factors. If service load distribution factors are to be used for live loads at ultimate load, it would be consistent to use the factors given in Sec. 3.1 also at ultimate load. Without experimental or analytical data for post-tensioning distribution at ultimate load, the distribution must be left to the judgment of the designer.

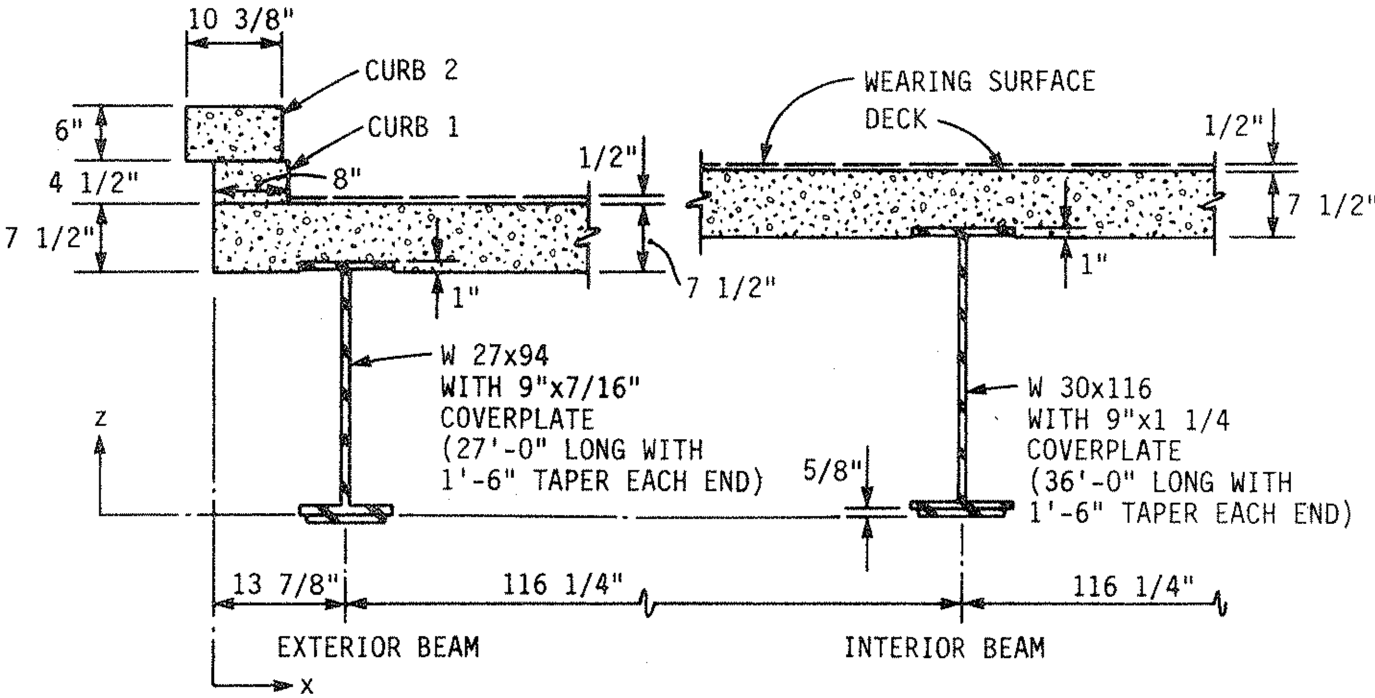
5. DESIGN EXAMPLE

5.1. Bridge Description

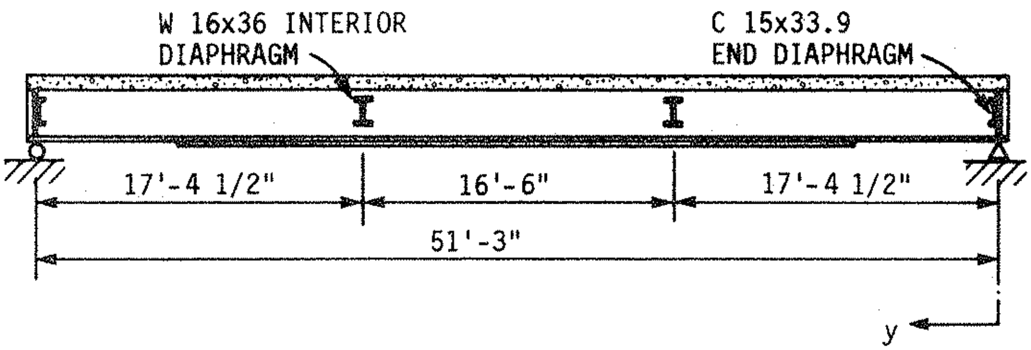
The bridge to be strengthened is a two-lane, four-beam bridge with a 51 ft, 3 in. simple span (see Bridge 1, Figs. 14, 15, and 17 in Ref. 13). The transverse and longitudinal sections of the bridge have been idealized and are shown in Fig. 8. The curb cross section has been idealized as two rectangles. The deck has been assumed level with respect to each of the steel beams, and the 1/2-in. wearing surface has been removed. The steel beams and coverplates are as given on the Bridge 1 plans. Properties will be taken from Ref. 4.

The bridge is to be strengthened to meet the current legal load standards for Iowa. Live load moments will be taken from the Appendix tables for the maximum of the 1980 DOT rating trucks. Dead loads and dead load moments will be computed in accordance with the AASHTO rules [2]. Load distribution and impact load fractions will also be in accordance with Ref. 2.

For the post-tensioning, threadbars with an ultimate strength of 150 ksi will be selected for the tendons [8]. Experience has shown that the tendon anchorage will be at about 7% of the span and that brackets will be about 2 ft in length. One-in.-diameter high strength bolts will be used for attachment of the brackets to exterior beams.



(a) IDEALIZED TRANSVERSE SECTION



(b) IDEALIZED LONGITUDINAL SECTION

Fig. 8. Two-lane, four-beam composite bridge.

5.2. Loads and Load Distribution Fractions

Dead and long-term dead load computations are in accordance with Ref. 2, Sec. 3.3. Dead loads are those loads applied to the steel bridge beams, as given in Table 2, whereas long-term dead loads are those loads applied to the composite bridge, as given in Table 3.

Long-term dead loads are taken to be distributed equally to each beam, as permitted in Ref. 2, Sec. 3.23. Live loads are to be increased by the impact fraction given in Ref. 2, Sec. 3.8.

$$I = \frac{50}{L + 125} \leq 0.30$$

$$I = \frac{50}{51.25 + 125} = 0.284$$

Because the bridge is required to be strengthened to meet Iowa legal load criteria, the 1980 Iowa DOT rating trucks given in Fig. A-1 of the Appendix will be the live loads applied to the bridge. The truck loads are to be distributed according to Ref. 2, Sec. 3.23, as follows:

beam spacing in feet is

$$S = 116.25/12 = 9.69 \text{ ft}$$

For the exterior beam, taking a simple span condition with an eccentric truck 2 ft from the curb, the load fraction can be computed by taking moments about the interior beam

$$(1)(2.16) + (1)(8.16) - D_e(9.69) = 0$$

$$D_e = 1.07$$

Table 2. Dead loads.

Bridge Part	Exterior Beam Dead Load	Exterior Beam plf	Interior Beam Dead Load	Interior Beam plf
Steel beam	W27 × 94	94	W30 × 116	116
Steel coverplate (assumed full length)	$\frac{(9)(0.4375)}{144}$ (490)	13	$\frac{(9)(1.25)}{144}$ (490)	38
Steel shear connectors (average)	$\frac{(16)(6.68)}{51.25}$	2	$\frac{(25)(6.68)}{51.25}$	3
Reinforced concrete deck	$\frac{(72)(8)}{144}$ (150)	600	$\frac{(116.25)(8)}{144}$ (150)	969
Reinforced concrete curb	$\frac{(10.38)(6) + (8)(4)}{144}$ (150)	98	--	
Steel interior diaphragms (average for central portion of span)	$\frac{(36)\left(\frac{9.69}{2}\right)(2)}{33.88}$	10	$\frac{(36)(9.69)(2)}{33.88}$	21
Steel rail (average)		48		--
Total		865		1147

Table 3. Long-term dead loads.

Bridge Part	Exterior Beam Long-term Dead Load, plf		Interior Beam Long-term Dead Load, plf	
Steel tendons and brackets (estimated average)		8		8
Future wearing surface (19 psf)	$\frac{(19)(15)}{2}$	143	$\frac{(19)(15)}{2}$	143
Total		151		151

However, the usual wheel load fraction is larger

$$\frac{S}{4.0 + 0.25S} = \frac{9.69}{4.0 + (0.25)(9.69)} = 1.51$$

Therefore, use 1.51 for the exterior beam. For the interior beam, the load fraction may be computed as

$$\frac{S}{5.5} = \frac{9.69}{5.5} = 1.76$$

(Reference 2, Sec. 3.23, also states "In no case shall an exterior stringer have less carrying capacity than an interior stringer." It is the authors' interpretation that this rule refers to future widening rather than to strengthening of a bridge.)

5.3. Moments

The post-tensioning design stress and stress checks at critical locations require moments at midspan and coverplate, cutoff points for exterior and interior beams, and at post-tensioning anchorages for exterior beams. Dead load and long-term dead load moments are computed from standard formulas, and live load moments are interpolated from Table A-1 in the Appendix. Maximum truck load moments are assumed to act at midspan. Moments at the various critical locations are given in Table 4. Previous experience indicates that the anchorage for the post-tensioning tendons, assuming brackets bolted with 1-in.-diameter bolts, will be located at approximately 7% of the span, as follows:

$$0.07L = (0.07)(51.25) = 3.59 \text{ ft}$$

Table 4: Dead, long-term dead, and live load moments.

(a) Midspan--Exterior Beam: y = 25.625 ft

Dead load moment $$M = \frac{wL^2}{8} = \frac{(0.865)(51.25)^2}{8} = 284.00 \text{ ft k}$$

Long-term dead load moment $$M = \frac{wL^2}{8} = \frac{(0.151)(51.25)^2}{8} = 49.58 \text{ ft k}$$

1980 Iowa DOT rating truck load moment (from Table A-1)

Span	Location	Maximum Moment
50 ft	23 ft	267.32
52 ft	24 ft	280.89
51.25 ft		275.80 ft k per wheel line

Live plus impact load moment $$M = (1.51)(1.284)(275.80) = 534.73 \text{ ft k}$$

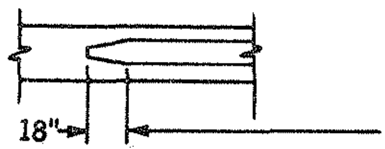
(b) Midspan--Interior Beam: y = 25.625 ft

Dead load moment $$M = \frac{wL^2}{8} = \frac{(1.147)(51.25)^2}{8} = 376.58 \text{ ft k}$$

Long-term dead load moment $M = 49.58$ ft k

Live plus impact load moment $$M = (1.76)(1.284)(275.80) = 623.26 \text{ ft k}$$

(c) Coverplate Cutoff--Exterior Beam: y = 13.625 ft



coverplate cutoff is taken to be at the end of the full width plate.

Dead load moment $$M = \frac{wy}{2}(L - y)$$

$$= \frac{(0.865)(13.63)(51.25 - 13.63)}{2}$$

$$= 221.77 \text{ ft k}$$

Table 4. Continued.

Long-term dead load moment	$M = \frac{wy}{2} (L - y)$
	$= \frac{(0.151)(13.63)(51.25 - 13.63)}{2}$
	$= 38.71$ ft k

1980 Iowa DOT rating truck load moment

Span	Location	Maximum Moment
50 ft	13.63 ft	217.02
52 ft	13.63 ft	225.22
51.25 ft	13.63 ft	222.15 ft k per wheel line

Live plus impact load moment: $M = (1.51)(1.284)(222.15) = 430.71$ ft k

(d) Coverplate Cutoff--Interior Beam: $y = 9.125$ ft

Dead load moment	$M = \frac{wy}{2} (L - y)$
	$= \frac{(1.147)(9.13)(51.25 - 9.13)}{2}$
	$= 220.54$ ft k
Long-term dead load moment	$M = \frac{wy}{2} (L - y)$
	$= \frac{(0.151)(9.13)(51.25 - 9.13)}{2}$
	$= 29.03$ ft k

1980 Iowa DOT rating truck load moment

Span	Location	Maximum Moment
50 ft	9.13 ft	167.17
52 ft	9.13 ft	172.84
51.25 ft	9.13 ft	170.71 ft k per wheel line

Live plus impact load moment: $M = (1.76)(1.284)(170.71) = 385.78$ ft k

Table 4. Continued.

(e) Anchorage--Exterior Beam: $y = 2$ ft

Dead load moment

$$M = \frac{wy}{2}(L - y)$$

$$= \frac{(0.865)(2)(51.25 - 2)}{2}$$

$$= 42.60 \text{ ft k}$$

Long-term dead load moment

$$M = \frac{wy}{2}(L - y)$$

$$= \frac{(0.151)(2)(51.25 - 2)}{2}$$

$$= 7.44 \text{ ft k}$$

1980 Iowa DOT rating truck load moment

Span	Location	Maximum Moment
50 ft	2 ft	47.52
52 ft	2 ft	48.77
51.25 ft	2 ft	48.30 ft k per wheel line

Live plus impact load moment

$$M = (1.51)(1.284)(48.30) = 93.65 \text{ ft k}$$

(f) Anchorage--Exterior Beam: $y = 6$ ft

Dead load moment

$$M = \frac{wy}{2}(L - y)$$

$$= \frac{(0.865)(6)(51.25 - 6)}{2}$$

$$= 117.42 \text{ ft k}$$

Long-term dead load moment

$$M = \frac{wy}{2}(L - y)$$

$$= \frac{(0.151)(6)(51.25 - 6)}{2}$$

$$= 20.50 \text{ ft k}$$

Table 4. Continued.

1980 Iowa DOT rating truck load moment	Span	Location	Maximum Moment
	50 ft	6 ft	123.36
	52 ft	6 ft	127.85
	51.25 ft	6 ft	126.17 ft k per wheel line
Live plus impact load moment	M = (1.51)(1.284)(126.17) = 244.62 ft k		

In order to have some range in possible location, compute moments at $y = 2$ ft and $y = 6$ ft and interpolate later.

Because no material is being removed from the interior beam for bolt-holes, and since the amount of post-tensioning distributed to the interior beam near the support is very small, no stress check and thus no moments for a stress check need be computed.

5.4. Section Properties

For the centroids and moments of inertia, the general formulas are

$$\bar{z} = \text{centroid elevation} = \frac{\Sigma Az}{\Sigma A}$$

$$I_{\bar{z}} = \text{moment of inertia} = \Sigma Az^2 + \Sigma I_o - (\Sigma A)(\bar{z})^2$$ with respect to the axis through the centroid.

For $f'_c = 3000$ psi, Ref. 2, Sec. 10.38 requires that the factor n be taken as 9. Effects of creep on the composite section for long-term dead load are considered by taking n as 27, three times the usual value.

Exterior Beam

The exterior beam is not at the edge of the deck and thus may be considered to have a flange on both sides. Based on interpretation of Ref. 2, Sec. 10.38, the flange width must be taken as the smallest of the following:

- 13 7/8 in. + $\frac{L}{8} \leq \frac{L}{4}$

  $13.875 + \frac{(51.25)(12)}{5} = 90.75 \text{ in.} \leq 153.75 \text{ in.} = \frac{(51.25)(12)}{4}$

- 13 7/8 in. + $\frac{S}{2}$

  $13.875 + \frac{116.25}{2} = 72.00$ in., or

- 13 7/8 in. + 6t $\leq$ 12t

  $13.875 + (6)(7.5) = 58.88 \text{ in.} \leq 90.00 \text{ in.} = (12)(7.5)$

Therefore, the flange width is 58.88 in. The centroid elevation and moment-of-inertia computations for the exterior beam are given in Table 5.

Interior Beam

From Ref. 2, Sec. 10.38 the flange width is the smallest of the following:

- $\frac{L}{4} = \frac{(51.25)(12)}{4} = 153.75$ in.
- S = 116.25 in. or
- 12t = (12)(7.5) = 90.00 in.

Therefore, the flange width is 90.00 in. The centroid elevation and moment-of-inertia computations for the interior beam are given in Table 6.

Bridge

Moments of inertia for beams with respect to the bridge's neutral axis are computed from previous results by means of the transfer theorem.

In Table 7, $\bar{z}$ is the new centroid location with respect to the bridge, I_o refers to the previous $I_{\bar{z}}$, and the new $I_{\bar{z}}$ is with respect to the bridge's neutral axis. For the bridge in this example, the

Table 5: Exterior-beam section properties.

(a) Basic Quantities

Item	A	z	Az	Az^2	I_o
Beam W27 × 94	27.65	13.46	372.17	5,009.39	3,266.70
Cover plate 9 in. × 7/16 in.	3.94	-0.22	-0.87	0.19	0.75
Deck, n = 9 58.88 in. × 7 1/2 in.	49.07	29.66	1,455.42	43,167.64	230.02
Deck, n = 27	16.36	29.66	485.24	14,392.15	76.69
Curb 1, n = 9 8 in. × 4 1/2 in.	4.00	35.66	142.64	5,086.54	6.75
Curb 1, n = 27	1.33	35.66	47.43	1,691.28	2.24
Curb 2, n = 9 10 3/8 in. × 6 in.	6.92	40.91	283.10	11,581.51	20.76
Curb 2, n = 27	2.31	40.91	94.50	3,866.08	6.93

(b) Centroid Elevations and Moment of Inertia

Description	$\bar{z} = \dfrac{\Sigma Az}{\Sigma A}$	$I_{\bar{z}} = \Sigma Az^2 + \Sigma I_o - (\Sigma A)(\bar{z})^2$
Steel beam	13.46 in.	3266.70 in.^{4}
Steel beam with coverplate	$\dfrac{371.30}{31.59} = 11.75$ in.	$5009.58 + 3267.45 - (31.59)(11.75)^2 = 3915.64$ in.^{4}
Composite beam with deck and curb, n = 9	$\dfrac{2253.33}{87.64} = 25.71$ in.	$64{,}845.08 + 3524.23 - (87.64)(25.71)^2 = 10{,}438.91$ in.^{4}
Composite beam with deck, curb, and coverplate, n = 9	$\dfrac{2252.46}{91.58} = 24.60$ in.	$64.845.27 + 3524.98 - (91.58)(24.60)^2 = 12{,}949.70$ in.^{4}

Table 5. Continued.

Description	$\bar{z} = \frac{\Sigma Az}{\Sigma A}$	$I_{\bar{z}} = \Sigma Az^2 + \Sigma I_o - (\Sigma A)(\bar{z})^2$
Composite beam with deck and curb, n = 27	$\frac{999.34}{47.65} = 20.97$ in.	$24{,}958.90 + 3352.56$ $- (47.65)(20.97)^2$ $= 7357.81$ in.^{4}
Composite beam with deck, curb, and coverplate, n = 27	$\frac{998.47}{51.59} = 19.35$ in.	$24{,}959.09 + 3353.31$ $- (51.59)(19.35)^2$ $= 8995.94$ in.^{4}

Table 6. Interior-beam section properties.

(a) Basic Quantities

Item	A	z	Az	Az^2	I_o
Beam W30 × 116	34.13	15.63	533.45	8,337.85	4,919.10
Coverplate 9 in. × 1 1/4 in.	11.25	0	0	0	17.58
Deck, n = 9 90 in. × 7 1/2 in.	75.00	33.38	2,503.50	83,566.83	351.56
Deck, n = 27	25.00	33.38	834.50	27,855.61	117.19

(b) Centroid Elevations and Moment of Inertia

Description	$\bar{z} = \frac{\Sigma Az}{\Sigma A}$	$I_{\bar{z}} = \Sigma Az^2 + \Sigma I_o - (\Sigma A)(\bar{z})^2$
Steel beam	15.63 in.	$4919.10.^4$
Steel beam with coverplate	$\frac{533.45}{45.38} = 11.76$ in.	$8337.85 + 4936.68 - (45.38)(11.76)^2 = 6998.58$ in.^{4}
Composite beam with deck, n = 9	$\frac{3036.95}{109.13} = 27.83$ in.	$91{,}904.68 + 5270.66 - (109.13)(27.83)^2 = 12{,}653.18$ in.^{4}
Composite beam with deck and coverplate, n = 9	$\frac{3036.95}{120.38} = 25.23$ in.	$91{,}904.68 + 5288.24 - (120.38)(25.23)^2 = 20{,}564.68$ in.^{4}
Composite beam with deck, n = 27	$\frac{1367.95}{59.13} = 23.13$ in.	$36{,}193.46 + 5036.29 - (59.13)(23.13)^2 = 9595.38$ in.^{4}
Composite beam with deck and coverplate, n = 27	$\frac{1367.95}{70.38} = 19.44$ in.	$36{,}193.46 + 5053.87 - (70.38)(19.44)^2 = 14{,}649.77$ in.^{4}

Table 7. Centroid elevation and moment of inertia with respect to composite bridge.

Bridge Beam Condition, n = 9	$\bar{z} = \frac{\Sigma Az}{\Sigma A}$	Exterior Beam $I_{\bar{z}} = I_o + Ad^2$	Interior Beam $I_{\bar{z}} = I_o + Ad^2$
Coverplates on all beams	$\frac{2252.46 + 3036.95}{91.58 + 120.38}$ $= 24.95$ in.	$12{,}949.70 + (91.58)(24.95 - 24.60)^2 = 12{,}960.92$ in.^{4}	$20{,}564.68 + (120.38)(24.95 - 25.23)^2 = 20{,}574.12$ in.^{4}
Coverplates on interior beams only	$\frac{2253.33 + 3036.95}{87.64 + 120.38}$ $= 25.43$ in.	$10{,}438.91 + (87.64)(25.43 - 25.71)^2 = 10{,}445.78$ in.^{4}	$20{,}564.68 + (120.38)(25.43 - 25.23)^2 = 20{,}569.50$ in.^{4}
No cover-plates	$\frac{2253.33 + 3036.95}{87.64 + 109.13}$ $= 26.89$ in.	$10{,}438.91 + (87.64)(26.89 - 25.71)^2 = 10{,}560.94$ in.^{4}	$12{,}653.18 + (109.13)(26.89 - 27.83)^2 = 12{,}749.61$ in.^{4}

neutral axis elevations fall within a relatively narrow range. With different curb and crown configurations, however, the neutral axis elevations can have more variation, and the computation of neutral axis elevation for the bridge and recomputation of the beam's moments of inertia would have more significance.

5.5. Post-tensioning Design

For several reasons--because the exterior beam is the critical member; because more post-tensioning is required at midspan due to the larger, coverplated beam; and because more post-tensioning is distributed away from the exterior beam at midspan--computation of the required post-tensioning force can be based on the exterior beam's bending tension stress at midspan as computed in Table 8. Stresses at other locations will be checked later, in Sec. 5.6.

The allowable inventory stress [1] is

$$F_b = 0.55\ Fy = 18\ \text{ksi}$$

and, therefore, stress, to be relieved by post-tensioning is

$$f_b = 24.33 - 18 = 6.33\ \text{ksi}$$

In order to determine the required post-tensioning force, assume tendon elevation and anchorage locations and compute distribution factors.

Tendon Elevation and Eccentricity

If the tendons are placed above the bottom flange of the exterior beam, but as close to the flange as possible, the size of the jack

Table 8. Exterior-beam, midspan, coverplate tension stress.

Load	$f_b = \frac{Mc}{I}$
Dead	$\frac{(284.00)(12)(11.75 + 0.44)}{3916} = 10.61$ psi
Long-term dead	$\frac{(49.58)(12)(19.35 + 0.44)}{8996} = 1.31$ psi*
Live plus impact	$\frac{(543.73)(12)(24.60 + 0.44)}{12,950} = 12.41$ psi
Total	24.33 psi

*Use of n = 9 properties gives a smaller stress.

must be considered. One brand of hollow-core hydraulic cylinders with a 120 kips capacity is 6 1/4 in. in diameter [9]. With an 1/8-in. clearance the tendons can be placed 3 1/4 in. above the bottom flanges, as diagrammed in Fig. 9.

Anchorage Location

Using the assumption in Sec. 5.3

$$y = 0.07L = (0.07)(51.25)(12) = 43 \text{ in.}$$

The 43 in. does provide clearance for a jacking chair and an extended jack.

Distribution Factors

Based on Figs. 3 and 4

$$i = \frac{\text{total I for all composite, coverplated beams}}{\text{deck width}}$$

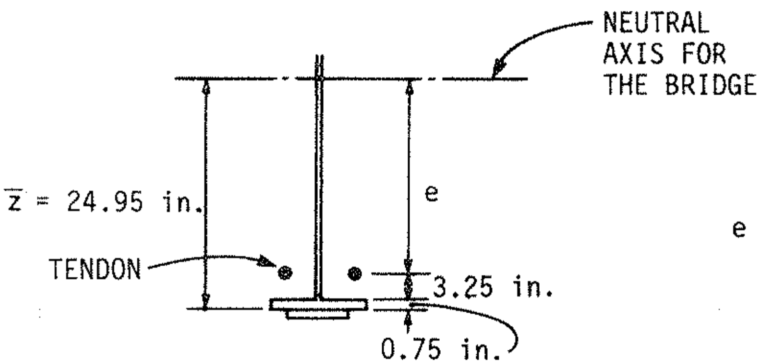
$$= \frac{2(12{,}961 + 20{,}574)}{2(13.88) + 3(116.25)} = 178.14 \text{ in.}^3$$

j = unit, average transverse flexural stiffness, including interior diaphragms

$$= \frac{(1)(7.5)^3}{(12)(9)} + \frac{446.3}{(17.38 + 16.5)(12)/2} = 6.10 \text{ in.}^3$$

$$\text{THETA} = \frac{\text{deck width}/2}{L} \sqrt[4]{i/j}$$

$$= \frac{\frac{(2)(13.88) + (3)(116.25)}{2}}{(51.25)(12)} \sqrt[4]{\frac{178.14}{6.10}} = 0.712$$



EXTERIOR BEAM

$$e = 24.95 - 0.75 - 3.25 = 20.95 \text{ in.}$$

Fig. 9. Tendon elevation and eccentricity.

$$AR = \frac{\text{deck width}}{\text{SPANB}} = \frac{(2)(13.88) + (3)(116.25)}{[1 - (2)(0.07)](51.25)(12)} = 0.712$$

$$\frac{\text{DECKT}}{\text{DECKS}} = \frac{7.5}{116.25} = 0.0645$$

$$\text{IET} = \frac{\text{I for exterior composite coverplated beams}}{\text{I for all composite coverplated beams}}$$

$$= \frac{2(12,961)}{2(12,961 + 20,574)} = 0.386$$

All variables fall within the ranges for the four-beam formulas specified in Fig. 3.

$$\text{FF} = 0.605 - 0.323 \frac{1}{\sqrt{\text{THETA}}} - 0.0720 \frac{1}{\sqrt{\text{AR}}} + 3.87 \frac{\text{DECKT}}{\text{DECKS}}$$

$$= 0.605 - 0.323 \frac{1}{\sqrt{0.712}} - 0.0720 \frac{1}{\sqrt{0.712}} + (3.87)(0.0645)$$

$$= 0.39$$

$$\text{MF} = 0.963 - 0.221 \frac{1}{\sqrt{\text{IET}}} - 0.145 \frac{1}{\sqrt{\text{AR}}} - 2.18 \frac{\text{DECKT}}{\text{DECKS}}$$

$$= 0.963 - 0.221 \frac{1}{\sqrt{0.386}} - 0.145 \frac{1}{\sqrt{0.712}} - (2.18)(0.0645)$$

$$= 0.29$$

The total required force may be computed:

$$f_b = \text{FF} \frac{P}{A} + \text{MF} \frac{Pec}{I}$$

$$6.33 = (0.39) \frac{P}{91.58} + (0.29) \frac{P(20.95)(24.95 + 0.44)}{12,961}$$

$$P = 392k$$

Then, for each exterior beam

$$P_e = \frac{P}{2} = 196k$$

Post-tensioning Loss

For the four-beam regression formulas, there is a -6% maximum error for FF and a -7% maximum error for MF (Fig. 4). To be conservative, use 7% as the potential error for underestimating the post-tensioning force.

For the threadbar tendons stressed to 60% of the ultimate strength for 57 years, the relaxation loss is 3.7% [11].

The maximum possible, adverse temperature difference between tendons and post-tensioned beams is difficult to estimate. Temperature and force measurements for one bridge in Ref. 7, Chapter 4 showed no net loss of post-tensioning for a north-south bridge affected by the sun. Air temperature rise could cause some loss of post-tensioning, however; assuming an adverse 10° F difference (tendons warmer than bridge), which should be quite conservative, the percentage loss can be computed as follows:

$$\text{for temperature, } \delta = \Delta T \ L \ k$$

$$\text{for load, } \delta = \frac{PL}{AE}$$

If the deflections, δ, are equated

$$\Delta T \ L \ k = \frac{PL}{AE} \qquad \text{and } f = \frac{P}{A}$$

then

$$f = \Delta T\ k\ E$$

$$= (10)(0.0000065)(29{,}000)$$

$$= 1.89 \text{ ksi}$$

For 150 ksi threadbars stressed to 60% of ultimate

$$f = (0.60)(150) = 90 \text{ ksi}$$

Loss, then, is 1.89/90 = 0.021 or 2.1%. Gain in post-tensioning force may be estimated as 6% of the truck weight.

$$\Delta P = (0.06)(80) = 4.80 \text{ k}$$

$$\text{Gain is then } \frac{4.80}{196} = 0.024 \text{ or } 2.4\%$$

Tendon Selection

For each exterior beam, accounting for losses, the required initial force is

$$P = \frac{196}{(1 - 0.07 - 0.037 - 0.021 + 0.024)} = 219 \text{ k}$$

Stressed to 60% of ultimate strength, 2 threadbars of 1 1/4 in. diameter have a capacity of

$$P = (2)(112.5) = 225^{k} \ [8]$$

Thus, for the post-tensioning, specify

2 threadbars of 1 1/4 in. diameter with 150 ksi ultimate strength per exterior beam

110^k force per tendon after anchorage.

5.6. Stress Checks and Bracket Location

Stresses are checked at midspan and at coverplate cutoff points for exterior and interior beams. Allowable stresses include--

For steel: $F_b = 18$ ksi for extreme fiber in tension and for extreme fiber in compression with adequate lateral support [2, Sec. 10.32, and 12]

For concrete: $f_c = 0.40\ f_c' = (0.40)(3000) = 1200$ psi or 1.20 ksi for extreme fiber stress in compression [2, Sec. 9.15]

$3\sqrt{f_c'} = 3\sqrt{3000} = 164$ psi or 0.164 ksi for tension in the precompressed tensile zone, bonded reinforcement, severe exposure conditions [2, Sec. 9.15]

In the table of stresses, Table 10(a), all computations are shown in detail. For all locations other than midspan of the exterior beam, only a summary of the stresses is given in Table 10(b)-(f).

Note that post-tensioning distribution fractions to be used in Table 10 are given in Table 9.

Table 9. Force and moment fractions.

Location	FF	MF
Exterior beam--midspan	0.39	0.29
Interior beam--midspan	0.11	0.21
Exterior beam--coverplate cutoff	0.44	0.39
Interior beam--coverplate cutoff	0.04	0.07

Table 10. Stress checks.

(a) Exterior Beam--Midspan

Load	Top of Curb	Top of Deck	Top of Beam	Bottom of Coverplate
1. Dead	--	--	$\frac{(284.00)(12)(26.91 - 11.75)}{3916}$ = -13.19 ksi	$\frac{(284.00)(12)(11.75 + 0.44)}{3916}$ = +10.61 ksi
2. Long-term dead	$\frac{(49.58)(12)(26.91+17-19.35)}{(8996)(27)}$ = -0.060 ksi	$\frac{(49.58)(12)(26.91+6.5-19.35)}{(8996)(27)}$ = -0.034 ksi	$\frac{(49.58)(12)(26.91-19.35)}{8996}$ = -0.50 ksi	$\frac{(49.58)(12)(19.35+0.44)}{8996}$ = +1.31 ksi
3. Live plus impact	$\frac{(534.73)(12)(26.91+17-24.60)}{(12,950)(9)}$ = -1.063 ksi	$\frac{(534.73)(12)(26.91+6.5-24.60)}{(12,950)(9)}$ = -0.485 ksi	$\frac{(534.73)(12)(26.91-24.60)}{12,950}$ = -1.14 ksi	$\frac{(534.73)(12)(24.60+0.44)}{12,950}$ = +12.41 ksi
4. Post-tensioning axial	$\frac{(0.39)(392)}{(91.58)(9)}$ = -0.185 ksi	$\frac{(0.39)(392)}{(91.58)(9)}$ = -0.185 ksi	$\frac{(0.39)(392)}{91.58}$ = -1.67 ksi	$\frac{(0.39)(392)}{91.58}$ = -1.67 ksi
5. Post-tensioning flexural	$\frac{(0.29)(392)(26.91+17-24.95)(20.95)}{(12,961)(9)}$ = +0.387 ksi	$\frac{(0.29)(392)(26.91+6.5-24.95)(20.95)}{(12,961)(9)}$ = +0.173 ksi	$\frac{(0.29)(392)(26.91-24.95)(20.95)}{12,961}$ = +0.36 ksi	$\frac{(0.29)(392)(24.95+0.44)(20.95)}{12,961}$ = -4.67 ksi
1+2+4+5	+0.142 ksi > 0.164 ksi OK	-0.046 ksi > -1.20 ksi OK	-15.00 ksi > -18 ksi OK	+5.58 ksi < 18 ksi OK
1+2+3+4+5	-0.921 ksi > -1.20 ksi OK	-0.531 ksi > -1.20 ksi OK	-16.14 ksi > -18 ksi OK	+17.99 ksi < 18 ksi OK

(b) Interior Beam--Midspan

Load	Top of Deck	Top of Beam	Bottom of Coverplate
1. Dead	--	-12.18 ksi	+7.99 ksi
2. Long-term dead	-0.027 ksi	-0.45 ksi	+0.81 ksi
3. Live plus impact	-0.481 ksi	-1.96 ksi	+9.40 ksi

Table 10. Continued.

Load	Top of Deck	Top of Beam	Bottom of Coverplate
4. Post-tensioning axial	-0.040 ksi	-0.36 ksi	-0.36 ksi
5. Post-tensioning flexural	+0.113 ksi	+0.48 ksi	-2.14 ksi
1+2+4+5	+0.046 ksi < 0.164 ksi OK	-12.51 ksi > -18 ksi OK	+6.30 ksi < 18 ksi OK
1+2+3+4+5	-0.435 ksi > -1.20 ksi OK	-14.47 ksi > -18 ksi OK	+15.70 ksi < 18 ksi OK

(c) Exterior Beam--Coverplate Cutoff with Coverplate

Load	Top of Curb	Top of Deck	Top of Beam	Bottom of Coverplate
1. Dead	--	--	-10.30 psi	+8.28 ksi
2. Long-term dead	-0.047 ksi	-0.027 ksi	-0.39 ksi	+1.02 ksi
3. Live plus impact	-0.856 ksi	-0.391 ksi	-0.92 ksi	+9.99 ksi
4. Post-tensioning axial	-0.209 ksi	-0.209 ksi	-1.88 ksi	-1.88 ksi
5. Post-tensioning flexural	+0.521 ksi	+0.232 ksi	+0.48 ksi	-6.27 ksi
1+2+4+5	+0.265 ksi > 0.164 ksi*	-0.004 ksi > -1.20 ksi OK	-12.09 ksi > -18 ksi OK	+1.15 ksi < 18 ksi OK
1+2+3+4+5	-0.591 ksi > -1.20 ksi OK	-0.395 ksi > -1.20 ksi OK	-13.01 ksi > -18 ksi OK	+11.14 ksi < 18 ksi OK

*Reinforcing bars provided in the curb, not considered in the computations, should be capable of resisting the tension overstress.

Table 10. Continued.

(d) Exterior Beam--Coverplate Cutoff without Coverplate

Load	Top of Curb	Top of Deck	Top of Beam	Bottom of Beam
1. Dead	--	--	-10.96 ksi	+10.96 ksi
2. Long-term dead	-0.054 ksi	-0.029 ksi	-0.37 ksi	+1.32 ksi
3. Live plus impact	-1.001 ksi	-0.424 ksi	-0.59 ksi	+12.73 ksi
4. Post-tensioning axial	-0.219 ksi	-0.219 ksi	-1.97 ksi	-1.97 ksi
5. Post-tensioning flexural	+0.644 ksi	+0.278 ksi	+0.46 ksi	-7.98 ksi
1+2+4+5	+0.371 ksi > 0.164 ksi*	+0.030 ksi < 0.164 ksi OK	-12.84 ksi > -18 ksi OK	+2.33 ksi < 18 ksi OK
1+2+3+4+5	-0.630 ksi > -1.20 ksi OK	-0.394 ksi > -1.20 ksi OK	-13.43 ksi > -18 ksi OK	+15.06 ksi < 18 ksi OK

*Reinforcing bars provided in the curb, not considered in the computations, should be capable of resisting the tension overstress.

(e) Interior Beam--Coverplate Cutoff with Coverplate

Load	Top of Deck	Top of Beam	Bottom of Coverplate
1. Dead	--	-7.14 ksi	+4.68 ksi
2. Long-term dead	-0.016 ksi	-0.27 ksi	+0.48 ksi
3. Live plus impact	-0.298 ksi	-1.22 ksi	+5.82 ksi
4. Post-tensioning axial	-0.014 ksi	-0.13 ksi	-0.13 ksi
5. Post-tensioning flexural	+0.037 ksi	+0.15 ksi	-0.74 ksi
1+2+4+5	+0.007 ksi < 0.164 ksi OK	-7.34 ksi > -18 ksi OK	+4.29 ksi < 18 ksi OK
1+2+3+4+5	-0.291 ksi > -1.20 ksi OK	-8.61 ksi > -18 ksi OK	+10.11 ksi < 18 ksi OK

Table 10. Continued.

(f) Interior Beam--Coverplate Cutoff without Coverplate

Load	Top of Deck	Top of Beam	Bottom of Beam
1. Dead	--	-8.07 ksi	+8.07 ksi
2. Long-term dead	-0.019 ksi	-0.27 ksi	+0.82 ksi
3. Live plus impact	-0.378 ksi	-1.02 ksi	+9.95 ksi
4. Post-tensioning axial	-0.016 ksi	-0.14 ksi	-0.14 ksi
5. Post-tensioning flexural	+0.056 ksi	+0.18 ksi	-1.29 ksi
1+2+4+5	+0.021 ksi < 0.164 ksi OK	-8.30 ksi > -18 ksi OK	+7.46 ksi < 18 ksi OK
1+2+3+4+5	-0.357 ksi > -1.20 ksi OK	-9.32 ksi > -18 ksi OK	+17.41 ksi < 18 ksi OK

Exterior Beam--Selection of Bracket Location

If the bracket is bolted to the bottom flange, the flange cross section will be reduced by the bolt holes. If the average stress in the flange is not to exceed 18 ksi, the computed stress must be less at the holes.

The full flange width is

$$b_f = 9.990 \text{ in.}$$

Then, the net flange width assuming 2 bolts of 1-in. diameter is

$$b_{fn} = 9.990 - 2(1.125) = 7.740 \text{ in.} \quad [2, \text{Sec. } 10.16]$$

and the maximum computed stress should not exceed

$$f_b = \frac{7.740}{9.990} (18) = 13.95 \text{ ksi}$$

The computed bottom flange stresses at y = 2 ft and y = 6 ft, without post-tensioning stresses, are given in Table 11. From the computed bottom flange stress, the bolt holes can be located at 6 ft, or a slightly greater distance, from the support. Based on experience, the brackets for a set of two tendons are approximately 2 ft long. Thus, the anchorage for the tendons will occur at approximately 4 ft from the support.

For the anchorage location check, compute

$$\frac{4}{51.25} = 0.078.$$

Table 11. Bottom flange stresses.

Load	Bottom Flange Stress, y = 2 ft	Bottom Flange Stress, y = 6 ft
Dead	+2.11 ksi	+5.81 ksi
Long-term dead	+0.25 ksi	+0.70 ksi
Live plus impact	+2.77 ksi	+7.23 ksi
Total	+7.48 ksi	+13.74 ksi

This is satisfactory since it is approximately 0.07L as assumed for force and moment fractions. The stress check for the anchorage location follows in Table 12. Post-tensioning distribution fractions used in the table are

$$FF = 0.49$$

$$MF = 0.48$$

Exterior Beam--Bottom Flange, Compression-Stress Check Near Anchorage

The compression stress near the anchorage is caused by a combination of axial and flexural stresses and varies over the unbraced bottom flange length. A check, which should be reasonable, is to compare the maximum computed compression stress with the compression stress permitted for an unbraced flange subjected to bending.

$$F_b = 0.55\ Fy \left[1 - \frac{\left(\frac{\ell}{r'}\right)^2 F_y}{4\pi^2 E}\right],\ (r')^2 = \frac{b^2}{12} \qquad [2,\ Sec.\ 10.32]$$

$$(r')^2 = \frac{b^2}{12} = \frac{(9.990)^2}{12} = 8.32\ in.^2,\ r' = 2.88$$

$$F_b = 0.55\ Fy \left[1 - \frac{\left(\frac{\ell}{r'}\right)^2 F_y}{4\pi^2 E}\right]$$

$$= (0.55)(33) \left[1 - \frac{\left(\frac{(17.375)(12)}{2.88}\right)^2 (33)}{(4)(\pi^2)(29,000)}\right] = 15.41\ ksi$$

$$-15.41\ ksi < -8.73\ ksi\ OK$$

Table 12. Stress check.

Exterior Beam--Anchorage (y = 4 feet)

Load	Top of Curb	Top of Deck	Top of Beam	Bottom of Beam
1. Dead	--	--	-3.95 ksi	+3.95 ksi
2. Long-term dead	-0.019	-0.010	-0.14 ksi	+0.48 ksi
3. Live plus impact	-0.393 ksi	-0.166 ksi	-0.23 ksi	+5.00 ksi
4. Post-tensioning axial	-0.244 ksi	-0.244 ksi	-2.19 ksi	-2.19 ksi
5. Post-tensioning flexural	+0.771 ksi	+0.295 ksi	+0.01 ksi	-10.97 ksi
1+2+4+5	+0.508 ksi >0.164 ksi*	+0.041 ksi <0.164 ksi OK	-6.27 ksi >-18 ksi OK	-8.73 ksi†
1+2+3+4+5	+0.115 ksi >0.164 ksi OK	-0.125 ksi >-1.20 ksi OK	-6.50 ksi >-18 ksi OK	-3.73 ksi†

Table 12. Continued.

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*Without the truck load, the total tension force in the curb is approximately 76 k; the two #5 bars in the curb, if carrying the entire tension would be stressed to 42 ksi, an obvious overstress. If the curb is neglected for all stress computations, the maximum deck tension is 0.100 ksi < 0.164 ksi. Also, with the curb neglected, the bottom of the beam is stressed to a maximum compression of 10.75 ksi which, although greater than 8.73 ksi is within the allowable given in the compression stress check in the text. Even if the curb concrete cracks and the bars yield, the bridge itself will remain within the allowable stress range.

†The compression stress in the bottom flange of the beam should be checked, since the flange is braced only at the support and effectively at the interior diaphragm (although rail brackets may provide some bracing). The stress check is contained in the text.

A review of the stress tables and the stress diagrams given in Fig. 10 indicates that the post-tensioning produces a finely tuned bridge. Application of the post-tensioning relieves the tension overstress in the exterior beams at midspan and also removes a slight tension overstress in the interior beams at midspan. If the post-tensioning force were increased significantly, it could overstress the exterior beam's top flange in compression at midspan. There also would be some danger of compression overstress near the tendon anchorages.

Application of the post-tensioning generally causes a net tension in the curbs and, in a few locations, tension in the bridge deck. If the post-tensioning force were increased or lowered (in terms of elevation), the curb and deck tension would increase. With curbs as part of the bridge, the deck tension fell within the allowable range for plain concrete, but the curb tension generally did not. Without a truck load on the bridge, the curb reinforcing apparently is overstressed, an undesirable condition. From the author's experience, curb tension does not appear to cause a problem, quite possibly because various restraints, higher-than-assumed concrete strength, and the wearing surface are neglected in the computations. A curb tension greater than the allowable should not be permitted, however, without a check of the bridge with curbs removed.

Based on this section and the previous section, the post-tensioning design for each exterior beam is summarized in Fig. 11.

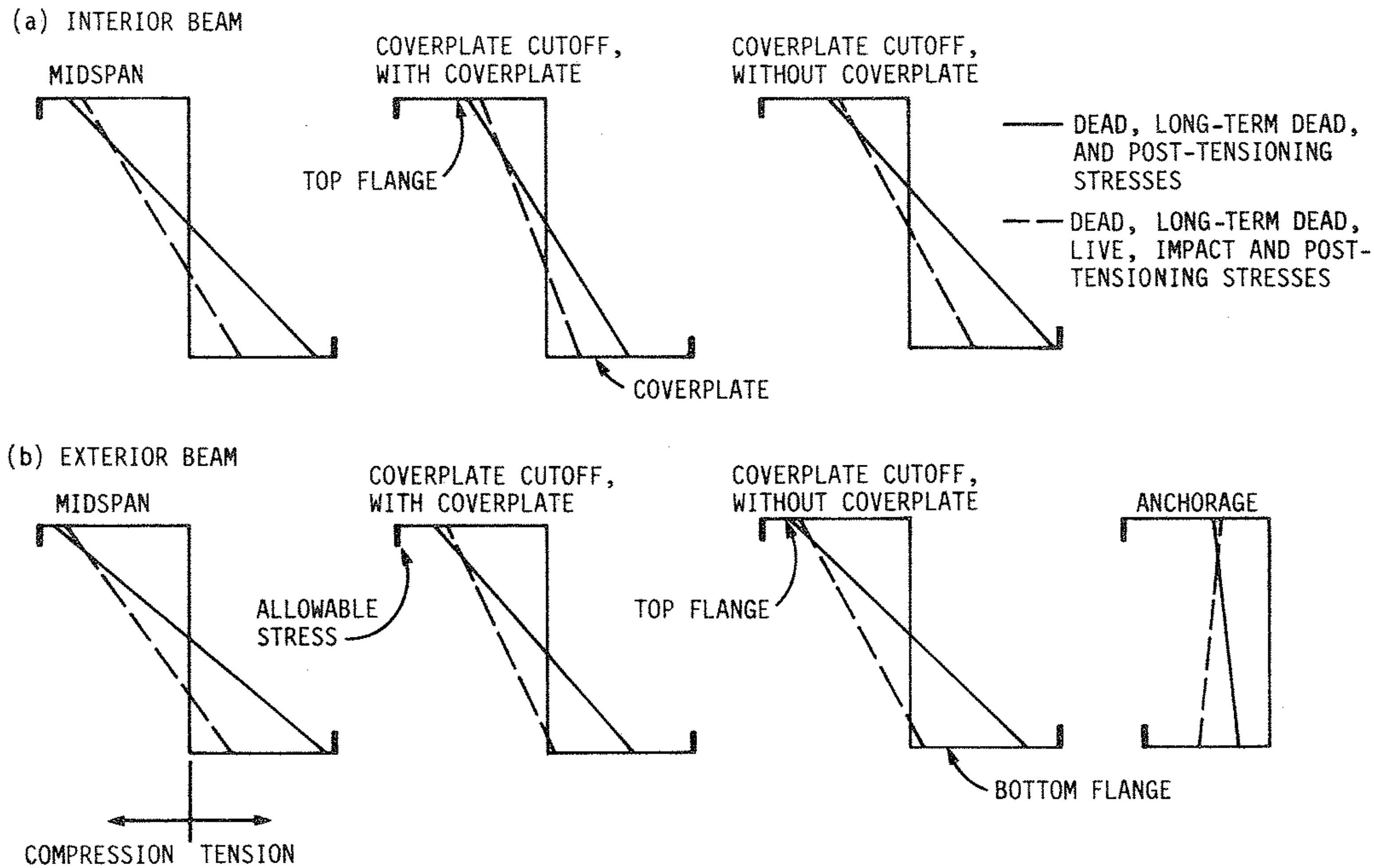

Fig. 10. Stress diagrams for steel bridge beams.

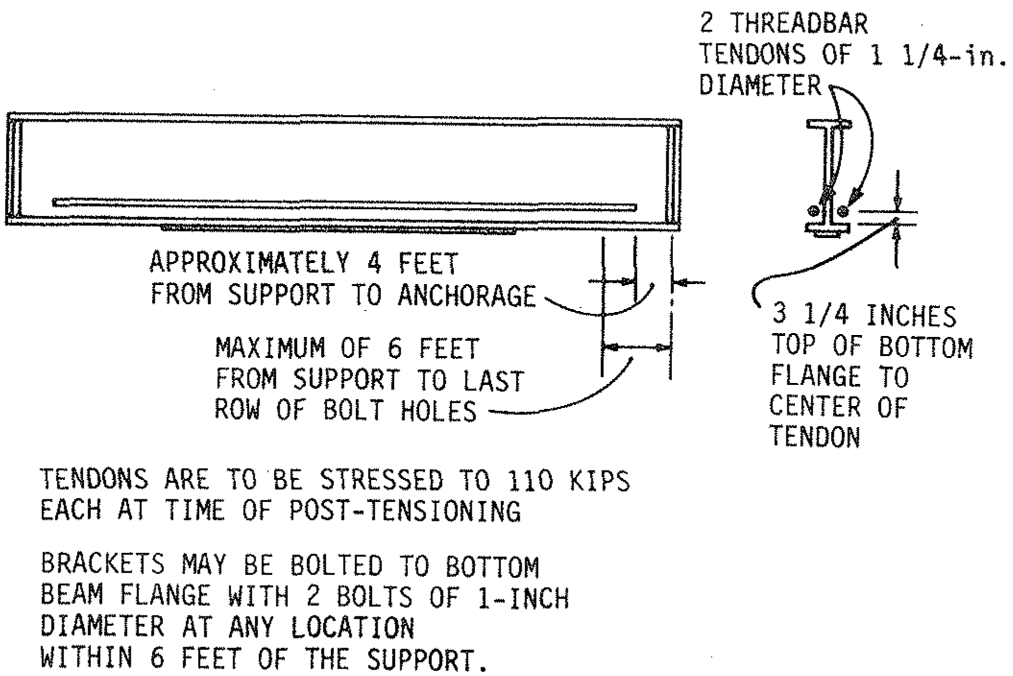

Fig. 11. Post-tensioning design.

5.7. Brackets and Anchorages

In general, the bracket design would proceed within the limitations of tendon elevation, region for location of bracket bolts, and manufacturer's anchorage hardware. Reference 2, Sec. 10.19 requires that the bracket connection be designed for a force greater than the specified tendon force. Welds within the bracket must be designed for axial and flexural stresses, and bolts must be designed for both shear and tension forces depending on the configuration of the bracket. Because the stress in the bracket will vary only because of the change in tendon force when a truck comes onto or leaves the bridge, stress ranges will be small, and fatigue should not control.

The brackets and anchorages for this example will not be designed here. An example of the bracket actually used for the bridge in this example is given in Ref. 13.

5.8. Additional Design Considerations

Post-tensioning can relieve only the bending stress deficiencies in a given bridge. Other potential deficiencies, such as shear connectors, may also require strengthening. At the time some bridges were designed, the shear connection often was assumed to consist of both shear connectors and bond between the deck and top flange of the beam. Since bond is no longer considered a valid shear connection, additional shear connectors may be required. See Ref. 13 for high-strength, bolt shear connectors developed by the authors for use in strengthening the shear connection.

In the authors' experience, a well-maintained bridge of the type in question generally will not require additional strengthening beyond the post-tensioning and the addition of shear connectors. Every bridge must be rated and evaluated individually, however, and the strengthening program tailored to the specific bridge deficiencies.

6. SUMMARY

Strengthening of composite steel beam and concrete deck bridges by post-tensioning is feasible whether all beams or only exterior beams are post-tensioned. When all beams are not post-tensioned, the distribution of the forces and moments induced in the bridge must be considered. Since the bridge is a structural unit, forces and moments are distributed away from the post-tensioned beams. Some redistribution will occur, even if all beams are post-tensioned, but all of the beams do not have equal stiffness.

In earlier sections of this manual, simple formulas for force and moment fractions were given for one-lane, three-beam bridges and two-lane, four-beam bridges with symmetrical exterior beam post-tensioning. The fractions are valid for bridges with skews of 45° or less and are valid within the limits of variables stated in the manual. Any use of the distribution fraction formulas beyond the limits given in the manual is not recommended.

Post-tensioning will reduce elastic, flexural tension stresses in bridge beams, will induce a small amount of camber, and will increase the strength of the bridge. Post-tensioning does not, however, significantly reduce live load deflection or significantly affect truck live load distribution. If qualified contractors perform the actual post-tensioning with due care, relatively little short-term loss of post-tensioning force will occur. For long-term preservation of the post-tensioning force, tendons and anchorages must be protected against corrosion. It also should be noted that removal of portions of the bridge deck or integral curbs after post-tensioning will cause losses and possibly redistribution of post-tensioning.

Post-tensioning is a valid method for correcting flexural stress deficiencies; however, it cannot correct other deficiencies. Shear connectors, fatigue, and other factors related to the bridge rating must be considered in the decision to repair and strengthen a bridge or to replace the bridge.

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APPENDIX: Tables of Moments for 1980 Iowa DOT Rating Trucks,
H 20-44 and HS 20-44 Trucks,
Simple Spans 30-100 ft

Notes:
(1) 1980 Iowa DOT rating trucks are illustrated in Fig. A-1.
(2) H 20-44 and HS 20-44 trucks are as illustrated in Ref. 10, Sec. 3.7.
(3) Impact is not included in the tables.
(4) All moments are given in ft-kips per wheel line.
(5) In the H 20-44 and HS 20-44 tables, moments are the maximum of the standard truck load and standard lane load.

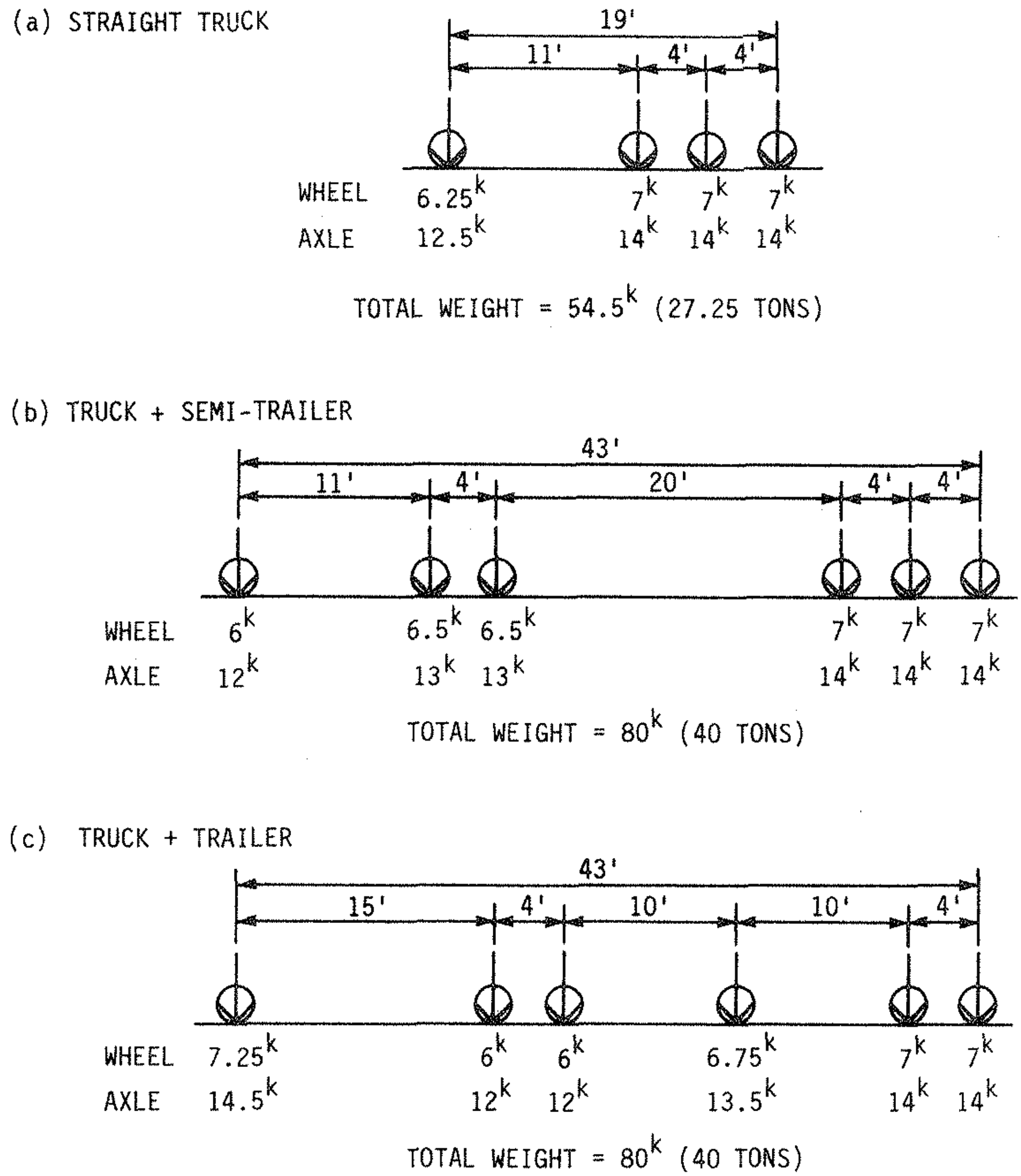

Fig. A-1. 1980 Iowa DOT rating trucks (legal loads).

Table A-1.

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCKS, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	1	2	3	4	5	6	7	8	9	10
30	19.58	37.35	53.30	67.43	79.75	90.25	98.94	106.87	115.55	122.42
31	19.83	37.90	54.22	68.78	81.57	92.61	101.90	109.55	118.83	126.36
32	20.06	38.42	55.08	70.03	83.28	94.83	104.67	112.81	121.91	130.05
33	20.28	38.91	55.89	71.21	84.89	96.91	107.28	116.00	124.80	133.52
34	20.49	39.37	56.65	72.32	86.40	98.87	109.74	119.00	127.52	136.78
35	20.68	39.80	57.37	73.37	87.82	100.72	112.05	121.83	130.08	139.86
36	20.86	40.21	58.04	74.36	89.17	102.46	114.24	124.50	133.25	142.77
37	21.03	40.60	58.68	75.30	90.44	104.11	116.31	127.03	136.28	145.52
38	21.20	40.96	59.29	76.19	91.65	105.67	118.26	129.42	139.15	148.12
39	21.35	41.31	59.87	77.03	92.79	107.16	120.12	131.69	141.87	150.64
40	21.50	41.64	60.41	77.83	93.88	108.56	121.89	133.85	144.45	153.69
42	21.91	42.25	61.43	79.31	95.89	111.18	125.17	137.86	149.25	159.35
44	22.46	43.37	62.73	80.66	97.73	113.56	128.15	141.50	153.62	164.49
46	23.22	44.70	64.44	82.96	100.00	115.73	130.87	144.83	157.60	169.19
48	23.92	46.17	66.75	85.67	102.92	119.25	134.17	147.88	161.25	173.49
50	24.56	47.52	68.88	88.64	106.80	123.36	138.33	152.65	165.61	177.60
52	25.15	48.77	70.85	91.38	110.38	127.85	143.77	158.15	171.01	185.08
54	25.70	49.93	72.67	93.93	113.70	132.00	148.81	164.15	178.00	192.00
56	26.21	51.00	74.36	96.29	116.79	135.86	153.50	169.71	184.50	198.43
58	26.69	52.00	75.93	98.48	119.66	139.45	157.86	174.90	190.55	204.83
60	27.13	52.93	77.40	100.53	122.33	142.80	161.93	179.73	196.20	211.33
62	27.55	53.81	78.77	102.45	124.84	145.94	165.74	184.26	201.48	217.42
64	27.94	54.62	80.06	104.25	127.19	148.87	169.31	188.50	206.44	223.12
66	28.30	55.39	81.27	105.94	129.39	151.64	172.67	192.48	211.09	228.48
68	28.65	56.12	82.41	107.53	131.47	154.24	175.82	196.24	215.47	233.53
70	28.97	56.80	83.49	109.03	133.43	156.69	178.80	199.77	219.60	238.29
72	29.28	57.44	84.50	110.44	135.28	159.00	181.61	203.11	223.50	242.78
74	29.57	58.05	85.46	111.78	137.03	161.19	184.27	206.27	227.19	247.03
76	29.84	58.63	86.37	113.05	138.68	163.26	186.79	209.26	230.68	251.05
78	30.10	59.18	87.23	114.26	140.26	165.23	189.18	212.10	234.00	254.87
80	30.35	59.70	88.05	115.40	141.75	167.10	191.45	214.80	237.15	258.50
82	30.59	60.20	88.83	116.49	143.17	168.88	193.61	217.37	240.15	261.95
84	30.81	60.67	89.57	117.52	144.52	170.57	195.67	219.81	243.00	265.24
86	31.02	61.12	90.28	118.51	145.81	172.19	197.63	222.14	245.72	268.37
88	31.23	61.55	90.95	119.45	147.05	173.73	199.50	224.36	248.32	271.36
90	31.42	61.96	91.60	120.36	148.22	175.20	201.29	226.49	250.80	274.22
92	31.61	62.35	92.22	121.22	149.35	176.61	203.00	228.52	253.17	276.96
94	31.79	62.72	92.81	122.04	150.43	177.96	204.64	230.47	255.45	279.57
96	31.96	63.08	93.37	122.83	151.46	179.25	206.21	232.33	257.62	282.08
98	32.12	63.43	93.92	123.59	152.45	180.49	207.71	234.12	259.71	284.49
100	32.28	63.76	94.44	124.32	153.40	181.68	209.16	235.84	261.72	286.80

Table A-1. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCKS, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUFPORT, FEET

SPAN, FEET	11	12	13	14	15	16	17	18	19	20
30	127.47	130.70	132.12	131.72	129.50					
31	132.12	136.13	138.38	138.88	137.61					
32	136.49	141.22	144.25	145.58	145.21	143.13				
33	140.59	146.00	149.77	151.88	152.35	151.16				
34	144.44	150.50	154.96	157.81	159.06	158.71	156.75			
35	148.08	154.75	159.85	163.40	165.40	165.83	164.71			
36	151.52	158.75	164.48	168.68	171.38	172.56	172.23	170.38		
37	154.77	162.54	168.85	173.68	177.04	178.92	179.34	178.28		
38	157.84	166.13	172.99	178.41	182.40	184.95	186.07	185.75	184.00	
39	160.77	169.54	176.92	182.90	187.48	190.67	192.46	192.85	191.84	
40	163.54	172.78	180.65	187.17	192.32	196.10	198.53	199.59	199.29	197.63
42	168.69	178.79	187.59	195.09	201.29	206.19	209.80	212.11	213.12	212.84
44	174.13	184.25	193.89	202.29	209.45	215.37	220.05	223.49	225.70	226.66
46	179.59	189.24	199.64	208.86	216.89	223.74	229.41	233.88	237.18	239.29
48	184.60	194.56	204.92	214.89	223.72	231.42	237.98	243.41	247.70	250.86
50	189.37	200.97	211.21	220.43	230.00	238.48	245.87	252.17	257.38	261.50
52	197.92	209.23	219.01	228.86	237.40	245.00	253.16	260.26	266.32	271.33
54	205.85	218.22	229.11	238.52	246.46	254.68	261.64	267.75	274.60	280.43
56	213.21	226.57	238.50	249.00	258.07	265.71	271.94	278.66	284.16	288.88
58	220.07	234.34	247.24	258.76	268.90	277.65	285.03	291.03	295.67	300.98
60	226.47	241.60	255.40	267.87	279.00	288.80	297.27	304.40	310.20	314.67
62	232.45	248.39	263.03	276.39	288.45	299.23	308.71	316.90	323.81	329.42
64	238.56	254.75	270.19	284.37	297.31	309.00	319.44	328.62	336.56	343.25
66	244.67	260.73	276.91	291.88	305.64	318.18	329.51	339.64	348.55	356.24
68	250.41	266.35	283.23	298.94	313.47	326.82	339.00	350.00	359.82	368.47
70	255.83	272.23	289.20	305.60	320.86	334.97	347.94	359.77	370.46	380.00
72	260.94	278.00	294.83	311.89	327.83	342.67	356.39	369.00	380.50	390.89
74	265.78	283.46	300.16	317.84	334.43	349.95	364.38	377.73	390.00	401.19
76	270.37	288.63	305.84	323.47	340.68	356.84	371.95	386.00	399.00	410.95
78	274.72	293.54	311.33	328.82	346.61	363.38	379.13	393.85	407.54	420.20
80	278.85	298.20	316.55	333.90	352.25	369.60	385.95	401.30	415.65	429.00
82	282.78	302.63	321.51	339.41	357.61	375.51	392.44	408.39	423.37	437.37
84	286.52	306.86	326.24	344.67	362.71	381.14	398.62	415.14	430.71	445.33
86	290.09	310.88	330.74	349.67	367.67	386.51	404.51	421.58	437.72	452.93
88	293.50	314.73	335.05	354.45	372.95	391.64	410.14	427.73	444.41	460.18
90	296.76	318.40	339.16	359.02	378.00	396.53	415.51	433.60	450.80	467.11
92	299.87	321.91	343.09	363.39	382.83	401.39	420.65	439.22	456.91	473.74
94	302.85	325.28	346.85	367.57	387.45	406.47	425.57	444.60	462.77	480.08
96	305.71	328.50	350.46	371.58	391.87	411.33	430.29	449.75	468.37	486.17
98	308.45	331.59	353.92	375.43	396.12	416.00	435.06	454.69	473.75	492.00
100	311.08	334.56	357.24	379.12	400.20	420.48	439.96	459.44	478.92	497.60

Table A-1. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCKS, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	21	22	23	24	25	26	27	28	29	30
40										
42	211.25									
44	226.39	224.88								
46	240.21	239.95	238.50							
48	252.88	253.76	253.52	252.13						
50	264.53	266.47	267.32	267.08	265.75					
52	275.29	278.21	280.07	280.89	280.66	279.38				
54	285.25	289.07	291.87	293.67	294.46	294.24	293.00			
56	294.50	299.16	302.83	305.54	307.27	308.03	307.82	306.63		
58	305.12	308.55	313.25	317.63	320.62	322.23	322.47	321.40	320.25	
60	317.81	322.27	327.88	333.44	337.67	340.56	342.12	342.35	341.24	338.80
62	333.74	337.55	341.87	348.23	353.61	357.70	360.50	362.01	362.23	361.16
64	348.69	352.87	357.31	362.10	368.56	373.77	377.74	380.45	381.91	382.12
66	362.73	368.00	372.06	377.09	382.61	388.87	393.93	397.77	400.40	401.82
68	375.94	382.23	387.35	391.76	396.88	403.08	409.16	414.07	417.80	420.35
70	388.40	395.66	401.77	406.74	411.71	416.69	423.53	429.44	434.20	437.83
72	400.17	408.33	415.39	421.33	426.17	431.67	437.10	443.95	449.70	454.33
74	411.30	420.32	428.27	435.13	440.92	445.84	451.62	457.69	464.36	469.95
76	421.84	431.68	440.47	448.21	454.89	460.53	465.95	471.58	478.24	484.74
78	431.85	442.46	452.05	460.61	468.15	474.67	480.15	486.05	491.54	498.77
80	441.35	452.70	463.05	472.40	480.75	488.10	494.45	499.80	506.15	512.10
82	450.39	462.44	473.51	483.61	492.73	500.88	508.05	514.24	520.05	526.24
84	459.00	471.71	483.48	494.29	504.14	513.05	521.00	528.00	534.05	540.28
86	467.21	480.56	492.98	504.46	515.02	524.65	533.35	541.12	547.95	553.86
88	475.04	489.00	502.04	514.18	525.41	535.73	545.14	553.64	561.23	567.91
90	482.53	497.07	510.71	523.47	535.33	546.31	556.40	565.60	573.91	581.33
92	489.70	504.78	519.00	532.35	544.83	556.43	567.17	577.04	586.04	594.17
94	496.55	512.17	526.94	540.85	553.91	566.13	577.49	588.00	597.66	606.47
96	503.12	519.25	534.54	549.00	562.62	575.42	587.37	598.50	608.79	618.25
98	509.43	526.04	541.84	556.82	570.98	584.33	596.86	608.57	619.47	629.55
100	515.48	532.56	548.84	564.32	579.00	592.88	605.96	618.24	629.72	640.40

Table A-1. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCKS, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	31	32	33	34	35	36	37	38	39	40
60										
62	358.80									
64	381.09	378.80								
66	402.02	401.02	398.80							
68	421.73	421.93	420.95	418.80						
70	440.31	441.65	441.84	440.89	438.80					
72	457.85	460.27	461.57	461.76	460.83	458.80				
74	474.45	477.88	480.23	481.49	481.68	480.78	478.80			
76	490.18	494.57	497.90	500.19	501.42	501.60	500.73	498.80		
78	505.10	510.40	514.68	517.93	520.15	521.35	521.53	520.68	518.80	
80	519.27	525.44	530.61	534.78	537.95	540.12	541.29	541.46	540.63	538.80
82	532.75	539.75	545.77	550.81	554.88	557.97	560.09	561.23	561.39	560.58
84	546.33	553.37	560.20	566.08	571.00	574.97	577.99	580.06	581.17	581.33
86	560.51	566.42	573.96	580.63	586.37	591.18	595.06	598.01	600.03	601.12
88	574.04	580.73	587.10	594.53	601.04	606.65	611.35	615.14	618.03	620.00
90	587.87	594.40	600.93	607.80	615.07	621.44	626.92	631.52	635.23	638.04
92	601.43	607.83	614.74	621.13	628.48	635.58	641.82	647.18	651.68	655.30
94	614.42	621.53	627.96	635.06	641.32	649.12	656.08	662.18	667.43	671.83
96	626.87	634.67	641.62	648.42	655.37	662.10	669.74	676.55	682.52	687.67
98	638.82	647.26	654.90	661.71	668.86	675.67	682.85	690.33	697.00	702.86
100	650.28	659.36	667.64	675.12	681.80	689.28	695.96	703.57	710.90	717.44

SPAN, FEET	41	42	43	44	45	46	47	48	49	50
80										
82	558.80									
84	580.54	578.80								
86	601.27	600.50	598.80							
88	621.06	621.22	620.46	618.80						
90	639.97	641.01	641.16	640.43	638.80					
92	658.06	659.95	660.96	661.11	660.39	658.80				
94	675.38	678.08	679.92	680.92	681.06	680.36	678.80			
96	691.97	695.45	698.09	699.90	700.87	701.02	700.32	698.80		
98	707.89	712.11	715.52	718.11	719.88	720.83	720.97	720.29	718.80	
100	723.18	728.11	732.25	735.58	738.12	739.86	740.79	740.93	740.26	738.80

Table A-2.

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 STRAIGHT TRUCK, FT-KIPS PER WHEEL LINE

	DISTANCE FROM SUPPORT, FEET									
SPAN, FEET	1	2	3	4	5	6	7	8	9	10
30	19.58	37.35	53.30	67.43	79.75	90.25	98.94	106.87	115.55	122.42
31	19.83	37.90	54.22	68.78	81.57	92.61	101.90	109.55	118.83	126.36
32	20.06	38.42	55.08	70.03	83.28	94.83	104.67	112.81	121.91	130.05
33	20.28	38.91	55.89	71.21	84.89	96.91	107.28	116.00	124.80	133.52
34	20.49	39.37	56.65	72.32	86.40	98.87	109.74	119.00	127.52	136.78
35	20.68	39.80	57.37	73.37	87.82	100.72	112.05	121.83	130.08	139.86
36	20.86	40.21	58.04	74.36	89.17	102.46	114.24	124.50	133.25	142.77
37	21.03	40.60	58.68	75.30	90.44	104.11	116.31	127.03	136.28	145.52
38	21.20	40.96	59.29	76.19	91.65	105.67	118.26	129.42	139.15	148.12
39	21.35	41.31	59.87	77.03	92.79	107.16	120.12	131.69	141.87	150.64
40	21.50	41.64	60.41	77.83	93.88	108.56	121.89	133.85	144.45	153.69
42	21.77	42.25	61.43	79.31	95.89	111.18	125.17	137.86	149.25	159.35
44	22.02	42.81	62.35	80.66	97.73	113.56	128.15	141.50	153.62	164.49
46	22.25	43.32	63.20	81.89	99.40	115.73	130.87	144.83	157.60	169.19
48	22.46	43.78	63.97	83.02	100.94	117.72	133.37	147.88	161.25	173.49
50	22.65	44.21	64.68	84.06	102.35	119.55	135.66	150.68	164.61	177.45
52	22.83	44.61	65.34	85.02	103.65	121.24	137.78	153.27	167.71	181.11
54	22.99	44.97	65.94	85.91	104.86	122.81	139.74	155.67	170.58	184.49
56	23.14	45.31	66.51	86.73	105.98	124.26	141.56	157.89	173.25	187.64
58	23.28	45.63	67.03	87.50	107.03	125.61	143.26	159.97	175.73	190.56
60	23.42	45.93	67.53	88.22	108.00	126.88	144.84	161.90	178.05	193.29
62	23.54	46.20	67.98	88.89	108.91	128.06	146.32	163.71	180.22	195.85
64	23.66	46.46	68.41	89.52	109.77	129.16	147.71	165.41	182.25	198.24
66	23.77	46.70	68.82	90.11	110.57	130.21	149.02	167.00	184.16	200.49
68	23.87	46.93	69.20	90.66	111.32	131.18	150.24	168.50	185.96	202.61
70	23.96	47.15	69.56	91.19	112.04	132.11	151.40	169.92	187.65	204.61
72	24.06	47.35	69.90	91.68	112.71	132.98	152.49	171.25	189.25	206.49
74	24.14	47.55	70.22	92.15	113.35	133.80	153.53	172.51	190.76	208.28
76	24.22	47.73	70.52	92.59	113.95	134.59	154.51	173.71	192.20	209.97
78	24.30	47.90	70.81	93.01	114.52	135.33	155.44	174.85	193.56	211.57
80	24.38	48.07	71.08	93.41	115.06	136.03	156.32	175.93	194.85	213.09
82	24.45	48.23	71.34	93.79	115.58	136.70	157.16	176.95	196.08	214.54
84	24.51	48.38	71.59	94.16	116.07	137.34	157.96	177.93	197.25	215.92
86	24.58	48.52	71.83	94.50	116.54	137.95	158.72	178.86	198.37	217.24
88	24.64	48.65	72.05	94.83	116.99	138.53	159.45	179.75	199.43	218.50
90	24.69	48.78	72.27	95.14	117.42	139.08	160.15	180.60	200.45	219.70
92	24.75	48.91	72.47	95.45	117.83	139.61	160.81	181.41	201.42	220.84
94	24.80	49.03	72.67	95.73	118.22	140.12	161.45	182.19	202.36	221.94
96	24.85	49.14	72.86	96.01	118.59	140.61	162.06	182.94	203.25	223.00
98	24.90	49.25	73.04	96.28	118.95	141.08	162.64	183.65	204.11	224.01
100	24.95	49.36	73.22	96.53	119.30	141.53	163.21	184.34	204.93	224.98

Table A-2. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 STRAIGHT TRUCK, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	11	12	13	14	15	16	17	18	19	20
30	127.47	130.70	132.12	131.72	129.50					
31	132.12	136.13	138.38	138.88	137.61					
32	136.49	141.22	144.25	145.58	145.21	143.13				
33	140.59	146.00	149.77	151.88	152.35	151.16				
34	144.44	150.50	154.96	157.81	159.06	158.71	156.75			
35	148.08	154.75	159.85	163.40	165.40	165.83	164.71			
36	151.52	158.75	164.48	168.68	171.38	172.56	172.23	170.38		
37	154.77	162.54	168.85	173.68	177.04	178.92	179.34	178.28		
38	157.84	166.13	172.99	178.41	182.40	184.95	186.07	185.75	184.00	
39	160.77	169.54	176.92	182.90	187.48	190.67	192.46	192.85	191.84	
40	163.54	172.78	180.65	187.17	192.32	196.10	198.53	199.59	199.29	197.63
42	168.69	178.79	187.59	195.09	201.29	206.19	209.80	212.11	213.12	212.84
44	174.13	184.25	193.89	202.29	209.45	215.37	220.05	223.49	225.70	226.66
46	179.59	189.24	199.64	208.86	216.89	223.74	229.41	233.88	237.18	239.29
48	184.60	194.56	204.92	214.89	223.72	231.42	237.98	243.41	247.70	250.86
50	189.20	199.86	209.77	220.43	230.00	238.48	245.87	252.17	257.38	261.50
52	193.45	204.75	215.00	225.55	235.80	245.00	253.16	260.26	266.32	271.33
54	197.39	209.28	220.16	230.29	241.17	251.04	259.90	267.75	274.60	280.43
56	201.05	213.48	224.95	235.44	246.15	256.65	266.16	274.71	282.28	288.88
58	204.45	217.40	229.41	240.48	250.80	261.86	271.99	281.18	289.43	296.74
60	207.63	221.05	233.57	245.18	255.88	266.74	277.44	287.23	296.11	304.09
62	210.60	224.47	237.46	249.57	260.81	271.29	282.53	292.88	302.36	310.95
64	213.38	227.67	241.11	253.70	265.43	276.31	287.30	298.18	308.21	317.39
66	216.00	230.68	244.54	257.57	269.77	281.15	291.78	303.16	313.71	323.44
68	218.46	233.52	247.77	261.22	273.86	285.71	296.75	307.85	318.89	329.14
70	220.79	236.19	250.81	264.65	277.72	290.00	301.51	312.27	323.77	334.50
72	222.98	238.71	253.68	267.90	281.36	294.06	306.00	317.19	328.38	339.57
74	225.06	241.10	256.40	270.97	284.80	297.89	310.25	321.87	332.76	344.37
76	227.02	243.36	258.98	273.88	288.06	301.53	314.28	326.31	337.63	348.91
78	228.89	245.50	261.42	276.64	291.16	304.98	318.10	330.52	342.25	353.27
80	230.66	247.54	263.74	279.26	294.10	308.25	321.73	334.52	346.63	358.06
82	232.34	249.48	265.95	281.75	296.89	311.37	325.18	338.32	350.81	362.62
84	233.95	251.32	268.05	284.13	299.55	314.33	328.47	341.95	354.78	366.97
86	235.48	253.08	270.05	286.39	302.09	317.16	331.60	345.40	358.57	371.11
88	236.94	254.76	271.97	288.55	304.52	319.86	334.59	348.70	362.19	375.06
90	238.33	256.37	273.80	290.62	306.83	322.45	337.45	351.85	365.65	378.83
92	239.67	257.90	275.54	292.59	309.05	324.91	340.19	354.87	368.95	382.45
94	240.95	259.37	277.22	294.49	311.17	327.28	342.80	357.75	372.12	385.91
96	242.17	260.78	278.82	296.30	313.20	329.54	345.31	360.52	375.15	389.22
98	243.35	262.13	280.36	298.04	315.15	331.72	347.72	363.17	378.06	392.40
100	244.48	263.43	281.84	299.71	317.03	333.80	350.03	365.72	380.86	395.45

Table A-2. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 STRAIGHT TRUCK, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	21	22	23	24	25	26	27	28	29	30
40										
42	211.25									
44	226.39	224.88								
46	240.21	239.95	238.50							
48	252.88	253.76	253.52	252.13						
50	264.53	266.47	267.32	267.08	265.75					
52	275.29	278.21	280.07	280.89	280.66	279.38				
54	285.25	289.07	291.87	293.67	294.46	294.24	293.00			
56	294.50	299.16	302.83	305.54	307.27	308.03	307.82	306.63		
58	303.12	308.55	313.04	316.59	319.20	320.88	321.61	321.40	320.25	
60	311.15	317.31	322.56	326.90	330.34	332.86	334.48	335.19	334.99	333.88
62	318.67	325.51	331.47	336.55	340.75	344.08	346.52	348.08	348.77	348.58
64	325.72	333.20	339.82	345.60	350.52	354.59	357.81	360.18	361.69	362.36
66	332.34	340.42	347.67	354.09	359.69	364.47	368.41	371.53	373.83	375.30
68	338.58	347.22	355.05	362.09	368.33	373.76	378.39	382.22	385.25	387.48
70	344.45	353.62	362.02	369.63	376.47	382.52	387.80	392.30	396.03	398.97
72	350.00	359.68	368.59	376.75	384.16	390.80	396.69	401.82	406.20	409.82
74	355.25	365.40	374.81	383.49	391.43	398.63	405.10	410.83	415.82	420.08
76	360.23	370.82	380.71	389.87	398.32	406.05	413.06	419.36	424.94	429.80
78	364.94	375.97	386.30	395.93	404.86	413.09	420.62	427.45	433.59	439.02
80	369.43	380.86	391.61	401.68	411.07	419.77	427.80	435.14	441.80	447.78
82	373.78	385.51	396.66	407.15	416.97	426.13	434.63	442.45	449.62	456.12
84	378.50	389.94	401.47	412.36	422.60	432.19	441.13	449.42	457.06	464.06
86	383.01	394.28	406.06	417.33	427.96	437.96	447.33	456.06	464.16	471.63
88	387.31	398.94	410.44	422.07	433.08	443.47	453.25	462.40	470.93	478.85
90	391.42	403.40	414.77	426.60	437.97	448.74	458.90	468.46	477.41	485.75
92	395.35	407.66	419.38	430.94	442.65	453.78	464.31	474.25	483.60	492.36
94	399.11	411.74	423.79	435.26	447.14	458.60	469.49	479.80	489.53	498.68
96	402.72	415.65	428.02	439.81	451.43	463.23	474.46	485.12	495.21	504.74
98	406.18	419.40	432.07	444.19	455.74	467.66	479.22	490.22	500.66	510.55
100	409.50	423.01	435.97	448.38	460.25	471.92	483.79	495.11	505.89	516.13

Table A-2. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 STRAIGHT TRUCK, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	31	32	33	34	35	36	37	38	39	40
60										
62	347.50									
64	362.17	361.13								
66	375.94	375.76	374.75							
68	388.91	389.53	389.36	388.38						
70	401.13	402.52	403.13	402.95	402.00					
72	412.68	414.78	416.13	416.72	416.55	415.63				
74	423.60	426.38	428.43	429.74	430.32	430.15	429.25			
76	433.94	437.37	440.08	442.08	443.35	443.91	443.75	442.88		
78	443.76	447.80	451.14	453.78	455.72	456.97	457.51	457.36	456.50	
80	453.08	457.70	461.64	464.90	467.47	469.37	470.58	471.11	470.96	470.13
82	461.95	467.13	471.63	475.47	478.65	481.16	483.01	484.19	484.71	484.57
84	470.40	476.10	481.15	485.55	489.30	492.40	494.85	496.65	497.81	498.31
86	478.46	484.65	490.22	495.15	499.45	503.11	506.14	508.53	510.30	511.42
88	486.15	492.82	498.88	504.32	509.13	513.33	516.91	519.87	522.21	523.94
90	493.49	500.63	507.15	513.08	518.39	523.10	527.21	530.71	533.60	535.89
92	500.52	508.09	515.07	521.45	527.25	532.45	537.06	541.07	544.50	547.33
94	507.25	515.24	522.65	529.48	535.73	541.40	546.49	551.00	554.93	558.28
96	513.70	522.09	529.91	537.16	543.85	549.97	555.52	560.51	564.93	568.77
98	519.88	528.66	536.88	544.54	551.65	558.20	564.19	569.63	574.51	578.84
100	525.82	534.96	543.56	551.62	559.13	566.09	572.51	578.39	583.72	588.50

SPAN, FEET	41	42	43	44	45	46	47	48	49	50
80										
82	483.75									
84	498.17	497.38								
86	511.92	511.78	511.00							
88	525.04	525.52	525.39	524.63						
90	537.58	538.65	539.13	538.99	538.25					
92	549.57	551.22	552.27	552.73	552.60	551.88				
94	561.05	563.24	564.86	565.89	566.34	566.21	565.50			
96	572.06	574.77	576.92	578.49	579.50	579.95	579.82	579.13		
98	582.61	585.82	588.48	590.59	592.13	593.12	593.56	593.43	592.75	
100	592.74	596.44	599.59	602.19	604.25	605.77	606.74	607.16	607.04	606.38

Table A-3.

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + SEMI-TRAILER, FT-KIPS PER WHEEL LINE

	DISTANCE FROM SUPPORT, FEET									
SPAN, FEET	1	2	3	4	5	6	7	8	9	10
30	17.72	33.61	48.30	61.60	73.50	84.00	93.10	100.80	107.10	112.00
31	18.04	34.30	48.79	62.32	74.52	85.35	94.84	102.97	109.74	115.16
32	18.33	34.95	49.84	63.02	75.47	86.63	96.47	105.00	112.22	118.13
33	18.61	35.56	50.83	64.44	76.39	87.82	98.00	106.91	114.55	120.91
34	19.06	36.13	51.76	65.78	78.19	88.97	99.44	108.71	116.74	123.53
35	19.49	37.03	52.64	67.05	79.88	91.14	100.83	110.40	118.80	126.00
36	19.89	37.89	54.00	68.24	81.48	93.19	103.38	112.04	120.75	128.33
37	20.27	38.70	55.30	70.06	83.00	95.14	105.79	114.95	122.64	130.56
38	20.63	39.48	56.53	71.79	85.27	96.97	108.07	117.72	125.92	133.62
39	20.98	40.21	57.70	73.44	87.44	99.70	110.23	120.34	129.39	138.16
40	21.30	40.90	58.80	75.00	89.50	102.31	113.41	122.83	133.11	142.51
42	21.91	42.19	60.86	77.91	93.34	107.15	119.34	129.91	140.01	150.58
44	22.46	43.37	62.73	80.55	96.82	111.55	124.73	136.37	146.46	157.92
46	23.22	44.70	64.44	82.96	100.00	115.57	129.66	142.27	153.40	164.62
48	23.92	46.17	66.75	85.67	102.92	119.25	134.17	147.67	159.76	170.76
50	24.56	47.52	68.88	88.64	106.80	123.36	138.33	152.65	165.61	177.60
52	25.15	48.77	70.85	91.38	110.38	127.85	143.77	158.15	171.01	185.08
54	25.70	49.93	72.67	93.93	113.70	132.00	148.81	164.15	178.00	192.00
56	26.21	51.00	74.36	96.29	116.79	135.86	153.50	169.71	184.50	198.43
58	26.69	52.00	75.93	98.48	119.66	139.45	157.86	174.90	190.55	204.83
60	27.13	52.93	77.40	100.53	122.33	142.80	161.93	179.73	196.20	211.33
62	27.55	53.81	78.77	102.45	124.84	145.94	165.74	184.26	201.48	217.42
64	27.94	54.62	80.06	104.25	127.19	148.87	169.31	188.50	206.44	223.12
66	28.30	55.39	81.27	105.94	129.39	151.64	172.67	192.48	211.09	228.48
68	28.65	56.12	82.41	107.53	131.47	154.24	175.82	196.24	215.47	233.53
70	28.97	56.80	83.49	109.03	133.43	156.69	178.80	199.77	219.60	238.29
72	29.28	57.44	84.50	110.44	135.28	159.00	181.61	203.11	223.50	242.78
74	29.57	58.05	85.46	111.78	137.03	161.19	184.27	206.27	227.19	247.03
76	29.84	58.63	86.37	113.05	138.68	163.26	186.79	209.26	230.68	251.05
78	30.10	59.18	87.23	114.26	140.26	165.23	189.18	212.10	234.00	254.87
80	30.35	59.70	88.05	115.40	141.75	167.10	191.45	214.80	237.15	258.50
82	30.59	60.20	88.83	116.49	143.17	168.88	193.61	217.37	240.15	261.95
84	30.81	60.67	89.57	117.52	144.52	170.57	195.67	219.81	243.00	265.24
86	31.02	61.12	90.28	118.51	145.81	172.19	197.63	222.14	245.72	268.37
88	31.23	61.55	90.95	119.45	147.05	173.73	199.50	224.36	248.32	271.36
90	31.42	61.96	91.60	120.36	148.22	175.20	201.29	226.49	250.80	274.22
92	31.61	62.35	92.22	121.22	149.35	176.61	203.00	228.52	253.17	276.96
94	31.79	62.72	92.81	122.04	150.43	177.96	204.64	230.47	255.45	279.57
96	31.96	63.08	93.37	122.83	151.46	179.25	206.21	232.33	257.62	282.08
98	32.12	63.43	93.92	123.59	152.45	180.49	207.71	234.12	259.71	284.49
100	32.28	63.76	94.44	124.32	153.40	181.68	209.16	235.84	261.72	286.80

Table A-3. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + SEMI-TRAILER, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	11	12	13	14	15	16	17	18	19	20
30	118.30	123.20	126.70	128.80	129.50					
31	121.03	126.45	130.52	133.23	134.58					
32	123.59	129.50	134.09	137.38	139.34	140.00				
33	126.00	132.36	137.45	141.27	143.82	145.09				
34	129.09	135.06	140.62	144.94	148.03	149.88	150.50			
35	132.00	137.60	143.60	148.40	152.00	154.40	155.60			
36	134.75	140.06	146.42	151.67	155.75	158.67	160.42	161.00		
37	138.24	144.43	149.14	154.76	159.30	162.70	164.97	166.11		
38	141.82	148.58	153.89	157.75	162.66	166.53	169.29	170.95	171.50	
39	145.23	152.51	158.39	162.85	165.91	170.15	173.38	175.54	176.62	
40	150.21	156.25	162.67	167.71	171.38	173.67	177.27	179.90	181.47	182.00
42	159.53	166.87	172.58	176.72	181.52	185.02	187.20	188.07	190.50	192.00
44	168.01	176.56	183.56	189.01	192.92	195.33	198.67	200.75	201.58	201.17
46	175.75	185.40	193.58	200.27	205.49	209.23	211.49	212.33	214.32	215.12
48	182.84	193.51	202.76	210.59	217.01	222.01	225.60	227.76	228.52	228.52
50	189.37	200.97	211.21	220.09	227.61	233.77	238.57	242.01	244.10	244.82
52	197.92	209.23	219.01	228.86	237.40	244.63	250.55	255.17	258.48	260.48
54	205.85	218.22	229.11	238.52	246.46	254.68	261.64	267.35	271.79	274.98
56	213.21	226.57	238.50	249.00	258.07	265.71	271.94	278.66	284.16	288.44
58	220.07	234.34	247.24	258.76	268.90	277.65	285.03	291.03	295.67	300.98
60	226.47	241.60	255.40	267.87	279.00	288.80	297.27	304.40	310.20	314.67
62	232.45	248.39	263.03	276.39	288.45	299.23	308.71	316.90	323.81	329.42
64	238.56	254.75	270.19	284.37	297.31	309.00	319.44	328.62	336.56	343.25
66	244.67	260.73	276.91	291.88	305.64	318.18	329.51	339.64	348.55	356.24
68	250.41	266.35	283.23	298.94	313.47	326.82	339.00	350.00	359.82	368.47
70	255.83	272.23	289.20	305.60	320.86	334.97	347.94	359.77	370.46	380.00
72	260.94	278.00	294.83	311.89	327.83	342.67	356.39	369.00	380.50	390.89
74	265.78	283.46	300.16	317.84	334.43	349.95	364.38	377.73	390.00	401.19
76	270.37	288.63	305.84	323.47	340.68	356.84	371.95	386.00	399.00	410.95
78	274.72	293.54	311.33	328.82	346.61	363.38	379.13	393.85	407.54	420.20
80	278.85	298.20	316.55	333.90	352.25	369.60	385.95	401.30	415.65	429.00
82	282.78	302.63	321.51	339.41	357.61	375.51	392.44	408.39	423.37	437.37
84	286.52	306.86	326.24	344.67	362.71	381.14	398.62	415.14	430.71	445.33
86	290.09	310.88	330.74	349.67	367.67	386.51	404.51	421.58	437.72	452.93
88	293.50	314.73	335.05	354.45	372.95	391.64	410.14	427.73	444.41	460.18
90	296.76	318.40	339.16	359.02	378.00	396.53	415.51	433.60	450.80	467.11
92	299.87	321.91	343.09	363.39	382.83	401.39	420.65	439.22	456.91	473.74
94	302.85	325.28	346.85	367.57	387.45	406.47	425.57	444.60	462.77	480.08
96	305.71	328.50	350.46	371.58	391.87	411.33	430.29	449.75	468.37	486.17
98	308.45	331.59	353.92	375.43	396.12	416.00	435.06	454.69	473.75	492.00
100	311.08	334.56	357.24	379.12	400.20	420.48	439.96	459.44	478.92	497.60

Table A-3. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + SEMI-TRAILER, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	21	22	23	24	25	26	27	28	29	30
40										
42	192.50									
44	202.52	203.00								
46	214.72	213.12	213.50							
48	229.27	228.60	226.76	224.08						
50	245.30	246.02	245.38	243.38	240.02					
52	260.09	262.09	262.79	262.17	260.25	257.02				
54	276.90	276.98	278.91	279.57	278.98	277.13	274.02			
56	291.51	293.37	293.87	295.73	296.37	295.80	294.02	291.02		
58	305.12	308.08	309.88	310.77	312.57	313.19	312.64	310.92	308.02	
60	317.81	322.27	325.40	327.20	327.68	329.42	330.02	329.49	327.82	325.02
62	333.74	337.55	341.87	344.90	346.64	347.10	346.28	346.86	346.34	344.73
64	348.69	352.87	357.31	361.50	364.44	366.12	366.56	365.75	363.71	363.21
66	362.73	368.00	372.06	377.09	381.15	384.00	385.64	386.06	385.27	383.27
68	375.94	382.23	387.35	391.76	396.88	400.82	403.59	405.18	405.59	404.82
70	388.40	395.66	401.77	406.74	411.71	416.69	420.51	423.20	424.74	425.14
72	400.17	408.33	415.39	421.33	426.17	431.67	436.50	440.22	442.83	444.33
74	411.30	420.32	428.27	435.13	440.92	445.84	451.62	456.32	459.95	462.49
76	421.84	431.68	440.47	448.21	454.89	460.53	465.95	471.58	476.16	479.68
78	431.85	442.46	452.05	460.61	468.15	474.67	480.15	486.05	491.54	496.00
80	441.35	452.70	463.05	472.40	480.75	488.10	494.45	499.80	506.15	511.50
82	450.39	462.44	473.51	483.61	492.73	500.88	508.05	514.24	520.05	526.24
84	459.00	471.71	483.48	494.29	504.14	513.05	521.00	528.00	534.05	540.28
86	467.21	480.56	492.98	504.46	515.02	524.65	533.35	541.12	547.95	553.86
88	475.04	489.00	502.04	514.18	525.41	535.73	545.14	553.64	561.23	567.91
90	482.53	497.07	510.71	523.47	535.33	546.31	556.40	565.60	573.91	581.33
92	489.70	504.78	519.00	532.35	544.83	556.43	567.17	577.04	586.04	594.17
94	496.55	512.17	526.94	540.85	553.91	566.13	577.49	588.00	597.66	606.47
96	503.12	519.25	534.54	549.00	562.62	575.42	587.37	598.50	608.79	618.25
98	509.43	526.04	541.84	556.82	570.98	584.33	596.86	608.57	619.47	629.55
100	515.48	532.56	548.84	564.32	579.00	592.88	605.96	618.24	629.72	640.40

Table A-3. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + SEMI-TRAILER, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	31	32	33	34	35	36	37	38	39	40
60										
62	342.02									
64	361.64	359.02								
66	380.08	378.56	376.02							
68	402.88	399.76	395.49	393.02						
70	424.40	422.51	419.49	415.31	410.02					
72	444.72	444.00	442.17	439.22	435.17	430.00				
74	463.95	464.32	463.62	461.84	458.97	455.03	450.00			
76	482.16	483.58	483.95	483.26	481.53	478.74	474.89	470.00		
78	499.44	501.85	503.23	503.59	502.92	501.23	498.51	494.77	490.00	
80	515.85	519.20	521.55	522.90	523.25	522.60	520.95	518.30	514.65	510.00
82	531.46	535.71	538.97	541.27	542.58	542.93	542.29	540.68	538.10	534.54
84	546.33	551.43	555.57	558.76	561.00	562.28	562.62	562.00	560.43	557.90
86	560.51	566.42	571.39	575.44	578.56	580.74	582.00	582.32	581.72	580.19
88	574.04	580.73	586.50	591.36	595.32	598.36	600.50	601.73	602.04	601.45
90	587.87	594.40	600.93	606.58	611.33	615.20	618.18	620.27	621.47	621.78
92	601.43	607.83	614.74	621.13	626.65	631.30	635.09	638.00	640.04	641.22
94	614.42	621.53	627.96	635.06	641.32	646.72	651.28	654.98	657.83	659.83
96	626.87	634.67	641.62	648.42	655.37	661.50	666.79	671.25	674.87	677.67
98	638.82	647.26	654.90	661.71	668.86	675.67	681.67	686.86	691.22	694.77
100	650.28	659.36	667.64	675.12	681.80	689.28	695.96	701.84	706.92	711.20

SPAN, FEET	41	42	43	44	45	46	47	48	49	50
80										
82	530.00									
84	554.43	550.00								
86	577.72	574.33	570.00							
88	599.95	597.54	594.23	590.00						
90	621.20	619.73	617.38	614.13	610.00					
92	641.52	640.96	639.52	637.22	634.04	630.00				
94	660.98	661.28	660.72	659.32	657.06	653.96	650.00			
96	679.62	680.75	681.04	680.50	679.12	676.92	673.87	670.00		
98	697.51	699.43	700.53	700.82	700.28	698.94	696.77	693.80	690.00	
100	714.68	717.36	719.24	720.32	720.60	720.08	718.76	716.64	713.72	710.00

Table A-4.

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + TRAILER, FT-KIPS PER WHEEL LINE

SPAN, FEET	DISTANCE FROM SUPPORT, FEET 1	2	3	4	5	6	7	8	9	10
30	17.17	32.17	45.58	57.21	67.05	75.11	82.79	89.09	94.00	97.52
31	17.67	33.24	46.70	58.82	69.20	77.87	84.81	91.57	96.99	101.78
32	18.15	34.24	48.30	60.32	71.22	80.45	88.01	93.89	100.20	106.08
33	18.59	35.19	49.81	62.44	73.12	82.88	91.01	97.53	103.61	110.13
34	19.00	36.08	51.23	64.46	75.76	85.16	93.85	100.96	108.37	113.93
35	19.40	36.92	52.58	66.36	78.27	88.31	96.51	104.72	112.89	119.19
36	19.77	37.72	53.85	68.16	80.65	91.32	100.17	108.31	117.16	124.20
37	20.12	38.47	55.05	69.85	82.89	94.16	103.66	111.71	121.21	128.93
38	20.45	39.18	56.18	71.46	85.02	96.85	106.96	115.35	125.04	133.42
39	20.77	39.85	57.26	72.99	87.04	99.41	110.10	119.11	128.67	137.68
40	21.07	40.50	58.29	74.44	88.96	101.84	113.08	122.68	132.12	141.73
42	21.62	41.69	60.19	77.13	92.52	106.34	118.61	129.32	138.53	149.24
44	22.13	42.77	61.92	79.58	95.76	110.44	123.64	135.35	145.57	156.07
46	22.90	44.07	63.50	81.82	98.71	114.18	128.23	140.85	152.05	162.31
48	23.62	45.57	65.85	84.47	101.42	117.61	132.44	145.90	158.00	168.73
50	24.27	46.94	68.02	87.49	105.36	121.63	136.31	150.54	163.47	175.08
52	24.88	48.22	70.02	90.28	109.00	126.18	141.83	155.94	168.52	182.31
54	25.44	49.39	71.87	92.86	112.37	130.40	146.95	162.01	175.60	189.33
56	25.96	50.49	73.59	95.26	115.50	134.31	151.70	167.66	182.19	195.86
58	26.44	51.50	75.19	97.49	118.41	137.96	156.12	172.91	188.32	202.34
60	26.89	52.45	76.68	99.57	121.13	141.36	160.25	177.81	194.04	208.93
62	27.32	53.34	78.08	101.52	123.68	144.54	164.12	182.40	199.39	215.10
64	27.71	54.17	79.39	103.35	126.06	147.52	167.74	186.70	204.41	220.87
66	28.08	54.96	80.62	105.07	128.30	150.33	171.14	190.74	209.13	226.30
68	28.44	55.69	81.78	106.68	130.41	152.96	174.34	194.54	213.56	231.41
70	28.77	56.39	82.87	108.21	132.40	155.45	177.36	198.13	217.75	236.23
72	29.08	57.04	83.90	109.64	134.28	157.80	180.21	201.51	221.70	240.78
74	29.37	57.66	84.88	111.01	136.05	160.02	182.91	204.71	225.44	245.08
76	29.65	58.25	85.80	112.29	137.74	162.13	185.46	207.75	228.98	249.16
78	29.92	58.81	86.68	113.52	139.33	164.12	187.89	210.63	232.34	253.03
80	30.17	59.34	87.51	114.68	140.85	166.02	190.19	213.36	235.53	256.70
82	30.41	59.84	88.30	115.79	142.29	167.82	192.38	215.96	238.57	260.19
84	30.64	60.32	89.06	116.84	143.67	169.54	194.47	218.44	241.46	263.52
86	30.86	60.78	89.78	117.84	144.98	171.18	196.46	220.80	244.21	266.70
88	31.06	61.22	90.46	118.80	146.23	172.75	198.35	223.05	246.85	269.73
90	31.26	61.64	91.12	119.72	147.42	174.24	200.17	225.21	249.36	272.62
92	31.45	62.03	91.75	120.59	148.57	175.67	201.90	227.27	251.76	275.39
94	31.63	62.42	92.35	121.43	149.66	177.04	203.57	229.24	254.07	278.04
96	31.81	62.78	92.92	122.23	150.71	178.35	205.16	231.13	256.27	280.58
98	31.98	63.13	93.48	123.00	151.71	179.61	206.69	232.95	258.39	283.02
100	32.14	63.47	94.01	123.74	152.68	180.82	208.15	234.69	260.42	285.36

Table A-4. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + TRAILER, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	11	12	13	14	15	16	17	18	19	20
30	102.10	105.63	107.77	108.53	107.91					
31	105.27	109.35	112.10	113.50	113.57					
32	110.30	112.84	116.15	118.16	118.87	118.29				
33	115.02	118.30	119.95	122.53	123.85	123.92				
34	119.47	123.44	125.83	126.65	128.54	129.21	128.66			
35	123.66	128.28	131.37	132.93	132.96	134.21	134.26			
36	129.41	132.86	136.60	138.86	139.63	138.92	139.56	139.04		
37	134.89	139.08	141.55	144.47	145.95	145.98	145.96	147.09		
38	140.08	145.02	148.24	149.79	151.93	152.66	152.98	154.94	155.17	
39	145.01	150.66	154.64	156.93	157.60	159.00	159.64	162.39	163.46	
40	149.69	156.02	160.71	163.77	165.18	165.03	165.97	169.47	171.33	171.55
42	158.39	165.97	172.00	176.47	179.38	180.73	180.52	182.61	185.94	187.71
44	166.29	175.02	182.26	188.02	192.28	195.06	196.34	196.14	199.23	202.41
46	173.50	183.28	191.63	198.56	204.06	208.14	210.80	212.03	211.84	215.82
48	180.12	190.85	200.22	208.22	214.86	220.14	224.05	226.59	227.77	228.12
50	186.20	197.82	208.12	217.11	224.80	231.17	236.23	239.99	242.43	243.56
52	194.88	205.91	215.41	225.32	233.97	241.36	247.48	252.35	255.96	258.31
54	202.92	215.02	225.64	234.78	242.46	250.79	257.90	263.80	268.49	271.97
56	210.39	223.49	235.16	245.40	254.21	261.60	267.57	274.43	280.12	284.65
58	217.34	231.37	244.01	255.28	265.17	273.68	280.81	286.57	290.96	296.45
60	223.83	238.72	252.28	264.51	275.40	284.96	293.19	300.08	305.64	309.87
62	229.90	245.60	260.01	273.14	284.97	295.51	304.76	312.72	319.39	324.77
64	236.09	252.05	267.26	281.22	293.94	305.40	315.61	324.57	332.29	338.75
66	242.27	258.11	274.07	288.82	302.36	314.69	325.81	335.71	344.40	351.88
68	248.08	263.81	280.48	295.98	310.29	323.43	335.40	346.19	355.80	364.23
70	253.57	269.76	286.53	302.72	317.77	331.68	344.45	356.07	366.55	375.89
72	258.74	275.60	292.23	309.09	324.83	339.47	352.99	365.40	376.70	386.89
74	263.64	281.12	297.63	315.11	331.51	346.83	361.07	374.23	386.30	397.30
76	268.28	286.36	303.38	320.82	337.84	353.81	368.73	382.59	395.40	407.16
78	272.69	291.32	308.93	326.24	343.85	360.43	375.99	390.52	404.03	416.51
80	276.87	296.04	314.21	331.38	349.55	366.72	382.89	398.06	412.23	425.40
82	280.85	300.53	319.23	336.96	354.98	372.70	389.45	405.23	420.03	433.85
84	284.64	304.80	324.01	342.27	360.14	378.40	395.70	412.06	427.46	441.90
86	288.25	308.87	328.57	347.33	365.16	383.83	401.66	418.57	434.54	449.58
88	291.70	312.76	332.92	352.16	370.50	389.02	407.35	424.78	441.30	456.91
90	295.00	316.48	337.08	356.78	375.60	393.97	412.79	430.72	447.76	463.91
92	298.15	320.03	341.05	361.20	380.48	398.89	417.99	436.40	453.94	470.61
94	301.17	323.44	344.86	365.43	385.15	404.02	422.97	441.84	459.85	477.02
96	304.06	326.70	348.51	369.48	389.62	408.93	427.74	447.05	465.52	483.17
98	306.83	329.83	352.01	373.37	393.92	413.65	432.56	452.05	470.96	489.06
100	309.50	332.83	355.37	377.10	398.04	418.18	437.51	456.85	476.18	494.72

Table A-4. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + TRAILER, FT-KIPS PER WHEEL LINE

SPAN, FEET	DISTANCE FROM SUPPORT, FEET									
	21	22	23	24	25	26	27	28	29	30
40										
42	187.92									
44	204.10	204.30								
46	218.86	220.48	220.67							
48	232.40	235.31	236.86	237.05						
50	244.85	248.96	251.76	253.24	253.42					
52	259.40	261.56	265.51	268.20	269.63	269.80				
54	274.23	277.54	280.76	282.49	284.63	286.01	286.17			
56	288.00	293.06	297.59	300.69	302.36	302.60	302.39	302.55		
58	300.82	307.50	313.25	317.63	320.62	322.23	322.47	321.32	318.92	
60	312.78	320.99	327.88	333.44	337.67	340.56	342.12	342.35	341.24	338.80
62	328.86	333.60	341.56	348.23	353.61	357.70	360.50	362.01	362.23	361.16
64	343.96	347.92	354.39	362.10	368.56	373.77	377.74	380.45	381.91	382.12
66	358.15	363.20	367.04	375.13	382.61	388.87	393.93	397.77	400.40	401.82
68	371.49	377.58	382.48	387.39	395.82	403.08	409.16	414.07	417.80	420.35
70	384.08	391.13	397.04	401.81	408.28	416.48	423.53	429.44	434.20	437.83
72	395.97	403.93	410.79	416.53	421.17	429.13	437.10	443.95	449.70	454.33
74	407.21	416.04	423.79	430.46	436.05	441.10	449.93	457.69	464.36	469.95
76	417.86	427.52	436.12	443.66	450.16	455.60	462.09	470.69	478.24	484.74
78	427.97	438.40	447.80	456.18	463.54	469.87	475.17	483.04	491.41	498.77
80	437.57	448.74	458.91	468.08	476.25	483.42	489.59	494.76	503.93	512.10
82	446.70	458.57	469.47	479.39	488.34	496.31	503.31	509.33	515.83	524.78
84	455.40	467.94	479.53	490.17	499.86	508.59	516.37	523.20	529.08	536.86
86	463.69	476.87	489.13	500.45	510.84	520.30	528.83	536.43	543.10	548.84
88	471.61	485.40	498.28	510.25	521.32	531.47	540.72	549.05	556.48	563.00
90	479.17	493.55	507.03	519.63	531.33	542.15	552.08	561.12	569.27	576.53
92	486.41	501.34	515.40	528.59	540.91	552.36	562.95	572.66	581.50	589.48
94	493.34	508.80	523.41	537.17	550.08	562.14	573.35	583.71	593.22	601.87
96	499.97	515.95	531.09	545.40	558.87	571.52	583.32	594.30	604.44	613.75
98	506.34	522.81	538.46	553.29	567.31	580.51	592.89	604.46	615.21	625.14
100	512.46	529.39	545.53	560.86	575.40	589.14	602.07	614.21	625.54	636.08

Table A-4. Continued

MAXIMUM LIVE LOAD MOMENT FOR IOWA DOT 1980 TRUCK + TRAILER, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	31	32	33	34	35	36	37	38	39	40
60										
62	358.80									
64	381.09	378.80								
66	402.02	401.02	398.80							
68	421.73	421.93	420.95	418.80						
70	440.31	441.65	441.84	440.89	438.80					
72	457.85	460.27	461.57	461.76	460.83	458.80				
74	474.45	477.88	480.23	481.49	481.68	480.78	478.80			
76	490.18	494.57	497.90	500.19	501.42	501.60	500.73	498.80		
78	505.10	510.40	514.68	517.93	520.15	521.35	521.53	520.68	518.80	
80	519.27	525.44	530.61	534.78	537.95	540.12	541.29	541.46	540.63	538.80
82	532.75	539.75	545.77	550.81	554.88	557.97	560.09	561.23	561.39	560.58
84	545.59	553.37	560.20	566.08	571.00	574.97	577.99	580.06	581.17	581.33
86	557.83	566.36	573.96	580.63	586.37	591.18	595.06	598.01	600.03	601.12
88	569.52	578.76	587.10	594.53	601.04	606.65	611.35	615.14	618.03	620.00
90	582.91	590.61	599.65	607.80	615.07	621.44	626.92	631.52	635.23	638.04
92	596.58	602.82	611.66	620.50	628.48	635.58	641.82	647.18	651.68	655.30
94	609.68	616.63	623.16	632.66	641.32	649.12	656.08	662.18	667.43	671.83
96	622.22	629.87	636.67	644.32	653.62	662.10	669.74	676.55	682.52	687.67
98	634.26	642.56	650.05	656.72	665.43	674.55	682.85	690.33	697.00	702.86
100	645.82	654.75	662.89	670.22	676.76	686.50	695.43	703.57	710.90	717.44

SPAN, FEET	41	42	43	44	45	46	47	48	49	50
80										
82	558.80									
84	580.54	578.80								
86	601.27	600.50	598.80							
88	621.06	621.22	620.46	618.80						
90	639.97	641.01	641.16	640.43	638.80					
92	658.06	659.95	660.96	661.11	660.39	658.80				
94	675.38	678.08	679.92	680.92	681.06	680.36	678.80			
96	691.97	695.45	698.09	699.90	700.87	701.02	700.32	698.80		
98	707.89	712.11	715.52	718.11	719.88	720.83	720.97	720.29	718.80	
100	723.18	728.11	732.25	735.58	738.12	739.86	740.79	740.93	740.26	738.80

Table A-5.

MAXIMUM LIVE LOAD MOMENT FOR H 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	1	2	3	4	5	6	7	8	9	10
30	17.47	33.60	48.40	61.87	74.00	84.80	94.27	102.40	109.20	114.67
31	17.55	33.81	48.77	62.45	74.84	85.94	95.74	104.26	111.48	117.42
32	17.62	34.00	49.12	63.00	75.62	87.00	97.12	106.00	113.62	120.00
33	17.70	34.18	49.45	63.52	76.36	88.00	98.42	107.64	115.64	122.42
34	17.76	34.35	49.76	64.00	77.06	88.94	99.65	109.18	117.53	124.71
35	17.83	34.51	50.06	64.46	77.71	89.83	100.80	110.63	119.31	126.86
36	17.89	34.67	50.33	64.89	78.33	90.67	101.89	112.00	121.00	128.89
37	17.95	34.81	50.59	65.30	78.92	91.46	102.92	113.30	122.59	130.81
38	18.00	34.95	50.84	65.68	79.47	92.21	103.89	114.53	124.11	132.63
39	18.05	35.08	51.08	66.05	80.00	92.92	104.82	115.69	125.54	134.36
40	18.10	35.20	51.30	66.40	80.50	93.60	105.70	116.80	126.90	136.00
42	18.19	35.43	51.71	67.05	81.43	94.86	107.33	118.86	129.43	139.05
44	18.27	35.64	52.09	67.64	82.27	96.00	108.82	120.73	131.73	141.82
46	18.35	35.83	52.43	68.17	83.04	97.04	110.17	122.43	133.83	144.35
48	18.42	36.00	52.75	68.67	83.75	98.00	111.42	124.00	135.75	146.67
50	18.48	36.16	53.04	69.12	84.40	98.88	112.56	125.44	137.52	148.80
52	18.54	36.31	53.31	69.54	85.00	99.69	113.62	126.77	139.15	150.77
54	18.59	36.44	53.56	69.93	85.56	100.44	114.59	128.00	140.67	152.59
56	18.64	36.57	53.79	70.29	86.07	101.14	115.50	129.14	142.07	154.29
58	18.69	36.69	54.00	70.62	86.55	101.79	116.34	130.21	143.38	155.86
60	18.73	36.80	54.20	70.93	87.00	102.40	117.13	131.20	144.60	157.33
62	18.77	36.90	54.39	71.23	87.42	102.97	117.87	132.13	145.74	158.71
64	18.94	37.28	55.01	72.15	88.68	104.62	119.95	134.68	148.81	162.34
66	19.26	37.93	56.01	73.50	90.39	106.69	122.40	137.51	152.03	165.96
68	19.59	38.59	57.01	74.84	92.09	108.76	124.83	140.33	155.24	169.56
70	19.91	39.25	58.00	76.18	93.79	110.81	127.26	143.13	158.43	173.14
72	20.23	39.90	58.99	77.52	95.47	112.86	129.67	145.92	161.59	176.70
74	20.56	40.55	59.99	78.85	97.16	114.90	132.08	148.70	164.75	180.24
76	20.88	41.21	60.97	80.19	98.84	116.94	134.48	151.46	167.89	183.76
78	21.20	41.86	61.96	81.51	100.52	118.97	136.87	154.22	171.01	187.26
80	21.53	42.51	62.95	82.84	102.19	120.99	139.25	156.96	174.13	190.75
82	21.85	43.16	63.93	84.16	103.86	123.01	141.62	159.70	177.23	194.22
84	22.17	43.81	64.92	85.49	105.52	125.02	143.99	162.42	180.32	197.69
86	22.50	44.46	65.90	86.81	107.18	127.03	146.35	165.14	183.40	201.13
88	22.82	45.11	66.88	88.12	108.84	129.04	148.71	167.85	186.48	204.57
90	23.14	45.76	67.86	89.44	110.50	131.04	151.06	170.56	189.54	208.00
92	23.46	46.41	68.84	90.75	112.15	133.04	153.41	173.26	192.60	211.42
94	23.78	47.06	69.82	92.07	113.81	135.03	155.75	175.95	195.64	214.83
96	24.11	47.70	70.80	93.38	115.46	137.02	158.09	178.64	198.69	218.22
98	24.43	48.35	71.77	94.69	117.10	139.01	160.42	181.32	201.72	221.62
100	24.75	49.00	72.75	96.00	118.75	141.00	162.75	184.00	204.75	225.00

Table A-5. Continued

MAXIMUM LIVE LOAD MOMENT FOR H 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	11	12	13	14	15	16	17	18	19	20
30	118.80	121.60	123.07	123.20	122.00					
31	122.06	125.42	127.48	128.26	127.74					
32	125.12	129.00	131.62	133.00	133.12	132.00				
33	128.00	132.36	135.52	137.45	138.18	137.70				
34	130.71	135.53	139.18	141.65	142.94	143.06	142.00			
35	133.26	138.51	142.63	145.60	147.43	148.11	147.66			
36	135.67	141.33	145.89	149.33	151.67	152.89	153.00	152.00		
37	137.95	144.00	148.97	152.86	155.68	157.41	158.05	157.62		
38	140.11	146.53	151.89	156.21	159.47	161.68	162.84	162.95	162.00	
39	142.15	148.92	154.67	159.38	163.08	165.74	167.38	168.00	167.59	
40	144.10	151.20	157.30	162.40	166.50	169.60	171.70	172.80	172.90	172.00
42	147.71	155.43	162.19	168.00	172.86	176.76	179.71	181.71	182.76	182.86
44	151.00	159.27	166.64	173.09	178.64	183.27	187.00	189.82	191.73	192.73
46	154.00	162.78	170.70	177.74	183.91	189.22	193.65	197.22	199.91	201.74
48	156.75	166.00	174.42	182.00	188.75	194.67	199.75	204.00	207.42	210.00
50	159.28	168.96	177.84	185.92	193.20	199.68	205.36	210.24	214.32	217.60
52	161.62	171.69	181.00	189.54	197.31	204.31	210.54	216.00	220.69	224.62
54	163.78	174.22	183.93	192.89	201.11	208.59	215.33	221.33	226.59	231.11
56	165.79	176.57	186.64	196.00	204.64	212.57	219.79	226.29	232.07	237.14
58	167.66	178.76	189.17	198.90	207.93	216.28	223.93	230.90	237.17	242.76
60	169.40	180.80	191.53	201.60	211.00	219.73	227.80	235.20	241.93	248.00
62	171.20	183.10	194.39	205.07	215.14	224.60	233.45	241.69	249.32	256.34
64	175.26	187.59	199.31	210.44	220.96	230.88	240.20	248.92	257.03	264.55
66	179.30	192.04	204.19	215.75	226.72	237.09	246.87	256.06	264.65	272.65
68	183.31	196.46	209.03	221.02	232.42	243.24	253.47	263.12	272.18	280.66
70	187.28	200.85	213.83	226.24	238.07	249.33	260.00	270.10	279.63	288.57
72	191.23	205.20	218.59	231.42	243.67	255.36	266.47	277.02	286.99	296.40
74	195.16	209.53	223.33	236.56	249.23	261.34	272.89	283.87	294.29	304.15
76	199.07	213.83	228.03	241.67	254.75	267.28	279.26	290.67	301.53	311.83
78	202.96	218.10	232.70	246.74	260.24	273.18	285.57	297.42	308.71	319.45
80	206.83	222.36	237.35	251.79	265.69	279.04	291.85	304.11	315.83	327.00
82	210.68	226.59	241.97	256.81	271.10	284.86	298.08	310.76	322.90	334.50
84	214.52	230.81	246.57	261.80	276.49	290.65	304.28	317.37	329.92	341.94
86	218.34	235.01	251.15	266.77	281.85	296.41	310.44	323.93	336.90	349.34
88	222.14	239.19	255.72	271.71	287.19	302.14	316.56	330.46	343.84	356.69
90	225.94	243.36	260.26	276.64	292.50	307.84	322.66	336.96	350.74	364.00
92	229.72	247.51	264.79	281.55	297.79	313.52	328.73	343.42	357.60	371.27
94	233.49	251.65	269.30	286.43	303.06	319.17	334.77	349.86	364.44	378.50
96	237.26	255.78	273.80	291.30	308.31	324.80	340.79	356.26	371.24	385.70
98	241.01	259.90	278.28	296.16	313.54	330.41	346.78	362.64	378.01	392.86
100	244.75	264.00	282.75	301.00	318.75	336.00	352.75	369.00	384.75	400.00

Table A-5. Continued

MAXIMUM LIVE LOAD MOMENT FOR H 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	21	22	23	24	25	26	27	28	29	30
40										
42	182.00									
44	192.82	192.00								
46	202.70	202.78	202.00							
48	211.75	212.67	212.75	212.00						
50	220.08	221.76	222.64	222.72	222.00					
52	227.77	230.15	231.77	232.62	232.69	232.00				
54	234.89	237.93	240.22	241.78	242.59	242.67	242.00			
56	241.50	245.14	248.07	250.29	251.79	252.57	252.64	252.00		
58	247.66	251.86	255.38	258.21	260.34	262.22	263.80	264.74	265.06	
60	253.89	259.16	263.81	267.84	271.25	274.04	276.21	277.76	278.69	279.00
62	262.74	268.54	273.73	278.31	282.27	285.63	288.38	290.51	292.04	292.95
64	271.46	277.78	283.49	288.60	293.11	297.02	300.32	303.03	305.13	306.64
66	280.06	286.88	293.10	298.73	303.77	308.22	312.07	315.33	318.00	320.07
68	288.55	295.86	302.58	308.72	314.28	319.25	323.63	327.44	330.65	333.28
70	296.94	304.73	311.95	318.58	324.64	330.13	335.03	339.36	343.11	346.29
72	305.23	313.50	321.19	328.32	334.87	340.86	346.27	351.12	355.39	359.10
74	313.44	322.17	330.34	337.95	344.99	351.46	357.38	362.73	367.52	371.74
76	321.58	330.76	339.40	347.47	354.99	361.95	368.35	374.20	379.49	384.22
78	329.64	339.27	348.36	356.90	364.88	372.32	379.20	385.54	391.32	396.55
80	337.63	347.71	357.25	366.24	374.69	382.59	389.95	396.76	403.03	408.75
82	345.56	356.08	366.06	375.50	384.40	392.76	400.59	407.87	414.61	420.82
84	353.43	364.38	374.80	384.69	394.04	402.85	411.13	418.88	426.09	432.77
86	361.25	372.63	383.48	393.80	403.59	412.86	421.59	429.79	437.47	444.61
88	369.02	380.82	392.10	402.85	413.08	422.78	431.96	440.62	448.75	456.35
90	376.74	388.96	400.66	411.84	422.50	432.64	442.26	451.36	459.94	468.00
92	384.42	397.05	409.17	420.77	431.86	442.43	452.48	462.02	471.05	479.56
94	392.06	405.10	417.63	429.65	441.16	452.16	462.64	472.62	482.08	491.03
96	399.66	413.10	426.05	438.48	450.41	461.82	472.74	483.14	493.04	502.42
98	407.22	421.07	434.42	447.26	459.60	471.44	482.77	493.60	503.92	513.75
100	414.75	429.00	442.75	456.00	468.75	481.00	492.75	504.00	514.75	525.00

Table A-5. Continued

MAXIMUM LIVE LOAD MOMENT FOR H 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	31	32	33	34	35	36	37	38	39	40
60										
62	293.26									
64	307.54	307.84								
66	321.55	322.44	322.74							
68	335.33	336.79	337.67	337.96						
70	348.88	350.90	352.35	353.21	353.50					
72	362.23	364.80	366.79	368.22	369.07	369.36				
74	375.40	378.50	381.03	383.01	384.41	385.26	385.54			
76	388.40	392.02	395.08	397.58	399.53	400.93	401.76	402.04		
78	401.23	405.37	408.95	411.97	414.45	416.38	417.76	418.58	418.86	
80	413.93	418.56	422.65	426.19	429.19	431.64	433.55	434.91	435.73	436.00
82	426.48	431.61	436.20	440.24	443.75	446.72	449.14	451.03	452.38	453.19
84	438.92	444.53	449.60	454.14	458.15	461.62	464.56	466.97	468.84	470.17
86	451.23	457.32	462.87	467.90	472.40	476.37	479.81	482.72	485.11	486.96
88	463.44	469.99	476.02	481.53	486.52	490.97	494.91	498.32	501.20	503.56
90	475.54	482.56	489.06	495.04	500.50	505.44	509.86	513.76	517.14	520.00
92	487.55	495.03	501.99	508.43	514.36	519.78	524.68	529.06	532.93	536.28
94	499.47	507.40	514.81	521.72	528.11	533.99	539.37	544.22	548.57	552.41
96	511.31	519.68	527.55	534.90	541.76	548.10	553.94	559.26	564.09	568.40
98	523.06	531.88	540.19	548.00	555.30	562.10	568.40	574.19	579.48	584.26
100	534.75	544.00	552.75	561.00	568.75	576.00	582.75	589.00	594.75	600.00

SPAN, FEET	41	42	43	44	45	46	47	48	49	50
80										
82	453.46									
84	470.97	471.24								
86	488.28	489.07	489.34							
88	505.40	506.71	507.50	507.76						
90	522.34	524.16	525.46	526.24	526.50					
92	539.11	541.43	543.24	544.53	545.30	545.56				
94	555.73	558.55	560.85	562.64	563.92	564.68	564.94			
96	572.21	575.50	578.30	580.58	582.36	583.62	584.39	584.64		
98	588.54	592.32	595.59	598.36	600.63	602.39	603.65	604.41	604.66	
100	604.75	609.00	612.75	616.00	618.75	621.00	622.75	624.00	624.75	625.00

Table A-6.

MAXIMUM LIVE LOAD MOMENT FOR HS 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	1	2	3	4	5	6	7	8	9	10
30	23.60	44.80	64.00	81.07	96.00	108.80	119.47	128.00	134.40	138.67
31	24.00	45.68	65.03	82.58	98.06	111.48	122.84	132.13	139.35	144.52
32	24.38	46.50	66.38	84.00	100.00	114.00	126.00	136.00	144.00	150.00
33	24.73	47.27	67.64	85.82	101.82	116.36	128.97	139.64	148.36	155.15
34	25.06	48.00	68.82	87.53	104.12	118.59	131.76	143.06	152.47	160.00
35	25.37	48.69	69.94	89.14	106.29	121.37	134.40	146.29	156.34	164.57
36	25.67	49.33	71.00	90.67	108.33	124.00	137.67	149.33	160.00	168.89
37	25.95	49.95	72.00	92.11	110.27	126.49	140.76	153.08	163.46	172.97
38	26.21	50.53	72.95	93.47	112.11	128.84	143.68	156.63	167.68	176.84
39	26.46	51.08	73.85	94.77	113.85	131.08	146.46	160.00	171.69	181.54
40	26.70	51.60	74.70	96.00	115.50	133.20	149.10	163.20	175.50	186.00
42	27.14	52.57	76.29	98.29	118.57	137.14	154.00	169.14	182.57	194.29
44	27.55	53.45	77.73	100.36	121.36	140.73	158.45	174.55	189.00	201.82
46	27.91	54.26	79.04	102.26	123.91	144.00	162.52	179.48	194.87	208.70
48	28.25	55.00	80.25	104.00	126.25	147.00	166.25	184.00	200.25	215.00
50	28.56	55.68	81.36	105.60	128.40	149.76	169.68	188.16	205.20	220.80
52	28.85	56.31	82.38	107.08	130.38	152.31	172.85	192.00	209.77	226.15
54	29.11	56.89	83.33	108.44	132.22	154.67	175.78	195.56	214.00	231.11
56	29.36	57.43	84.21	109.71	133.93	156.86	178.50	198.86	217.93	235.71
58	29.59	57.93	85.03	110.90	135.52	158.90	181.03	201.93	221.59	240.00
60	29.80	58.40	85.80	112.00	137.00	160.80	183.40	204.80	225.00	244.00
62	30.00	58.84	86.52	113.03	138.39	162.58	185.61	207.48	228.19	247.74
64	30.19	59.25	87.19	114.00	139.69	164.25	187.69	210.00	231.19	251.25
66	30.36	59.64	87.82	114.91	140.91	165.82	189.64	212.36	234.00	254.55
68	30.53	60.00	88.41	115.76	142.06	167.29	191.47	214.59	236.65	257.65
70	30.69	60.34	88.97	116.57	143.14	168.69	193.20	216.69	239.14	260.57
72	30.83	60.67	89.50	117.33	144.17	170.00	194.83	218.67	241.50	263.33
74	30.97	60.97	90.00	118.05	145.13	171.24	196.38	220.54	243.73	265.95
76	31.11	61.26	90.47	118.74	146.05	172.42	197.84	222.32	245.84	268.42
78	31.23	61.54	90.92	119.38	146.92	173.54	199.23	224.00	247.85	270.77
80	31.35	61.80	91.35	120.00	147.75	174.60	200.55	225.60	249.75	273.00
82	31.46	62.05	91.76	120.59	148.54	175.61	201.80	227.12	251.56	275.12
84	31.57	62.29	92.14	121.14	149.29	176.57	203.00	228.57	253.29	277.14
86	31.67	62.51	92.51	121.67	150.00	177.49	204.14	229.95	254.93	279.07
88	31.77	62.73	92.86	122.18	150.68	178.36	205.23	231.27	256.50	280.91
90	31.87	62.93	93.20	122.67	151.33	179.20	206.27	232.53	258.00	282.67
92	31.96	63.13	93.52	123.13	151.96	180.00	207.26	233.74	259.43	284.35
94	32.04	63.32	93.83	123.57	152.55	180.77	208.21	234.89	260.81	285.96
96	32.12	63.50	94.13	124.00	153.12	181.50	209.12	236.00	262.13	287.50
98	32.20	63.67	94.41	124.41	153.67	182.20	210.00	237.06	263.39	288.98
100	32.28	63.84	94.68	124.80	154.20	182.88	210.84	238.08	264.60	290.40

Table A-6. Continued

MAXIMUM LIVE LOAD MOMENT FOR HS 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	11	12	13	14	15	16	17	18	19	20
30	140.80	140.80	138.67	134.40	130.00					
31	147.61	148.65	147.61	144.52	141.42					
32	154.00	156.00	156.00	154.00	152.13	148.00				
33	160.00	162.91	163.88	162.91	162.18	159.27				
34	165.65	169.41	171.29	171.29	171.65	169.88	166.00			
35	170.97	175.54	178.29	179.20	180.57	179.89	177.14			
36	176.00	181.33	184.89	186.67	189.00	189.33	187.67	184.00		
37	180.76	186.81	191.14	193.73	196.97	198.27	197.62	195.03		
38	185.26	192.00	197.05	200.42	204.53	206.74	207.05	205.47	202.00	
39	189.54	196.92	202.67	206.77	211.69	214.77	216.00	215.38	212.92	
40	194.70	201.60	208.00	212.80	218.50	222.40	224.50	224.80	223.30	220.00
42	204.29	212.57	219.14	224.00	231.14	236.57	240.29	242.29	242.57	241.14
44	213.00	222.55	230.45	236.73	242.64	249.45	254.64	258.18	260.09	260.36
46	220.96	231.65	240.78	248.35	254.35	261.22	267.74	272.70	276.09	277.91
48	228.25	240.00	250.25	259.00	266.25	272.00	279.75	286.00	290.75	294.00
50	234.96	247.68	258.96	268.80	277.20	284.16	290.80	298.24	304.24	308.80
52	241.15	254.77	267.00	277.85	287.31	295.38	302.08	309.54	316.69	322.46
54	246.89	261.33	274.44	286.22	296.67	305.78	313.56	320.00	328.22	335.11
56	252.21	267.43	281.36	294.00	305.36	315.43	324.21	331.71	338.93	346.86
58	257.17	273.10	287.79	301.24	313.45	324.41	334.14	342.62	349.86	357.79
60	261.80	278.40	293.80	308.00	321.00	332.80	343.40	352.80	361.00	368.00
62	266.13	283.35	299.42	314.32	328.06	340.65	352.06	362.32	371.42	379.35
64	270.19	288.00	304.69	320.25	334.69	348.00	360.19	371.25	381.19	390.00
66	274.00	292.36	309.64	325.82	340.91	354.91	367.82	379.64	390.36	400.00
68	277.59	296.47	314.29	331.06	346.76	361.41	375.00	387.53	399.00	409.41
70	280.97	300.34	318.69	336.00	352.29	367.54	381.77	394.97	407.14	418.29
72	284.17	304.00	322.83	340.67	357.50	373.33	388.17	402.00	414.83	426.67
74	287.19	307.46	326.76	345.08	362.43	378.81	394.22	408.65	422.11	434.59
76	290.05	310.74	330.47	349.26	367.10	384.00	399.95	414.95	429.00	442.10
78	292.77	313.85	334.00	353.23	371.54	388.92	405.38	420.92	435.54	449.23
80	295.35	316.80	337.35	357.00	375.75	393.60	410.55	426.60	441.75	456.00
82	297.80	319.61	340.54	360.59	379.76	398.05	415.46	432.00	447.66	462.44
84	300.14	322.29	343.57	364.00	383.57	402.29	420.14	437.14	453.29	468.57
86	302.37	324.84	346.46	367.26	387.21	406.33	424.60	442.05	458.65	474.42
88	304.50	327.27	349.23	370.36	390.68	410.18	428.86	446.73	463.77	480.00
90	306.53	329.60	351.87	373.33	394.00	413.87	432.93	451.20	468.67	485.33
92	308.48	331.83	354.39	376.17	397.17	417.39	436.83	455.48	473.35	490.43
94	310.34	333.96	356.81	378.89	400.21	420.77	440.55	459.57	477.83	495.32
96	312.12	336.00	359.12	381.50	403.13	424.00	444.12	463.50	482.12	500.00
98	313.84	337.96	361.35	384.00	405.92	427.10	447.55	467.27	486.24	504.49
100	315.48	339.84	363.48	386.40	408.60	430.08	450.84	470.88	490.20	508.80

Table A-6. Continued

MAXIMUM LIVE LOAD MOMENT FOR HS 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	21	22	23	24	25	26	27	28	29	30
40										
42	238.00									
44	259.00	256.00								
46	278.17	276.87	274.00							
48	295.75	296.00	294.75	292.00						
50	311.92	313.60	313.84	312.64	310.00					
52	326.85	329.85	331.46	331.69	330.54	328.00				
54	340.67	344.89	347.78	349.33	349.56	348.44	346.00			
56	353.50	358.86	362.93	365.71	367.21	357.43	366.36	364.00		
58	365.45	371.86	377.03	380.97	383.66	385.10	385.31	384.28	382.00	
60	376.60	384.00	390.20	395.20	399.00	401.60	403.00	403.20	402.20	400.00
62	387.03	395.35	402.52	408.52	413.35	417.03	419.55	420.90	421.10	420.13
64	397.69	406.00	414.06	421.00	426.81	431.50	435.06	437.50	438.81	439.00
66	408.55	416.00	424.91	432.73	439.45	445.09	449.64	453.09	455.45	456.73
68	418.76	427.06	435.12	443.76	451.35	457.88	463.35	467.76	471.12	473.41
70	428.40	437.49	445.54	454.17	462.57	469.94	476.29	481.60	485.89	489.14
72	437.50	447.33	456.17	464.00	473.17	481.33	488.50	494.67	499.83	504.00
74	446.11	456.65	466.22	474.81	483.19	492.11	500.05	507.03	513.03	518.05
76	454.26	465.47	475.74	485.05	493.42	502.32	511.00	518.74	525.53	531.37
78	462.00	473.85	484.77	494.77	503.85	512.00	521.38	529.85	537.38	544.00
80	469.35	481.80	493.35	504.00	513.75	522.60	531.25	540.40	548.65	556.00
82	476.34	489.37	501.51	512.78	523.17	532.68	541.32	550.44	559.37	567.41
84	483.00	496.57	509.29	521.14	532.14	542.29	551.57	560.00	569.57	578.29
86	489.35	503.44	516.70	529.12	540.70	551.44	561.35	570.42	579.30	588.65
88	495.41	510.00	523.77	536.73	548.86	560.18	570.68	580.36	589.23	598.55
90	501.20	516.27	530.53	544.00	556.67	568.53	579.60	589.87	599.33	608.00
92	506.74	522.26	537.00	550.96	564.13	576.52	588.13	598.96	609.00	618.26
94	512.04	528.00	543.19	557.62	571.28	584.17	596.30	607.66	618.26	628.08
96	517.13	533.50	549.12	564.00	578.12	591.50	604.13	616.00	627.12	637.50
98	522.00	538.78	554.82	570.12	584.69	598.53	611.63	624.00	635.63	646.53
100	526.68	543.84	560.28	576.00	591.00	605.28	618.84	631.68	643.80	655.20

Table A-6. Continued

MAXIMUM LIVE LOAD MOMENT FOR HS 20-44, FT-KIPS PER WHEEL LINE

DISTANCE FROM SUPPORT, FEET

SPAN, FEET	31	32	33	34	35	36	37	38	39	40
60										
62	418.00									
64	438.06	436.00								
66	456.91	456.00	454.00							
68	474.65	474.82	473.94	472.00						
70	491.37	492.57	492.74	491.89	490.00					
72	507.17	509.33	510.50	510.67	509.83	508.00				
74	522.11	525.19	527.30	528.43	528.59	527.78	526.00			
76	536.26	540.21	543.21	545.26	546.37	546.53	545.74	544.00		
78	549.69	554.46	558.31	561.23	563.23	564.31	564.46	563.69	562.00	
80	562.45	568.00	572.65	576.40	579.25	581.20	582.25	582.40	581.65	580.00
82	574.59	580.88	586.29	590.83	594.49	597.27	599.17	600.20	600.34	599.61
84	586.14	593.14	599.29	604.57	609.00	612.57	615.29	617.14	618.14	618.29
86	597.16	604.84	611.67	617.67	622.84	627.16	630.65	633.30	635.12	636.09
88	607.68	616.00	623.50	630.18	636.05	641.09	645.32	648.73	651.32	653.09
90	617.73	626.67	634.80	642.13	648.67	654.40	659.33	663.47	666.80	669.33
92	627.35	636.87	645.61	653.56	660.74	667.13	672.74	677.56	681.61	684.87
94	637.15	646.64	655.96	664.51	672.30	679.32	685.57	691.06	695.79	699.74
96	647.12	656.00	665.88	675.00	683.37	691.00	697.87	704.00	709.38	714.00
98	656.69	666.12	675.39	685.06	694.00	702.20	709.67	716.41	722.41	727.67
100	665.88	675.84	685.08	694.72	704.20	712.96	721.00	728.32	734.92	740.80

SPAN, FEET	41	42	43	44	45	46	47	48	49	50
80										
82	598.00									
84	617.57	616.00								
86	636.23	635.53	634.00							
88	654.05	654.18	653.50	652.00						
90	671.07	672.00	672.13	671.47	670.00					
92	687.35	689.04	689.96	690.09	689.43	688.00				
94	702.94	705.36	707.02	707.91	708.04	707.40	706.00			
96	717.87	721.00	723.37	725.00	725.88	726.00	725.37	724.00		
98	732.20	736.00	739.06	741.39	742.98	743.84	743.96	743.35	742.00	
100	745.96	750.40	754.12	757.12	759.40	760.96	761.80	761.92	761.32	760.00