FINAL REPORT

LIVE LOAD RATING OF SHORT SPAN HIGHWAY BRIDGES AS CONTROLLED BY THE EXTERIOR GIRDER

by

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Faculty Research Engineers

Virginia Highway and Transportation Research Council
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SUMMARY

The 1973 AASHTO Standard Specifications for Highway Bridges introduced the requirement that "In no case shall an exterior stringer have less carrying capacity than an interior stringer". This statement resulted from the concern that many original exterior stringers became interior stringers when bridges were widened. Since current specifications are used when rating the live load capacity of existing bridges, this newly introduced requirement has in some cases resulted in an unnecessary reduction in live load ratings. This study examines a number of cases in which the exterior stringers are lighter than the interior ones and illustrates the effects of the new provision. The report concludes with a recommendation for an exemption provision from this requirement in the appropriate article of the *Manual for Maintenance Inspection of Bridges, 1974*, 2nd ed., AASHTO.

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0925

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INTRODUCTION

The 1973 11th ed. of the *American Association of State Highway Officials* [*AASHTO*] *Standard Specifications for Highway Bridges* introduced the requirement that "In no case shall an exterior stringer have less carrying capacity than an interior stringer". This new requirement, along with the instructions in the *Manual for Maintenance Inspection of Bridges, 1974* to conform to the current AASHTO specifications in the live load rating of existing bridges, when taken literally, as is often the case, causes an artificial and frequently an unnecessary lower rating of the live load capacity than if a rational conventional live load rating is calculated. Therefore, it appeared worthwhile to review the relative load carrying requirements of interior and exterior girders and to determine the effect of rating bridges according to the new AASHTO requirement on exterior girder design.

A study of the minutes of the 1969 and 1971 meetings of the AASHTO Operating Committee on Bridges and Structures revealed that the new requirement evolved from the bridge engineers' anticipating the widening of many bridges so as to make exterior girders become interior girders. While it was recognized that this requirement may reflect a very prudent decision governing the design of new structures, it was believed that the requirement also might impose an unnecessary limitation on ratings of existing structures where the exterior girders have less carrying capacities.

OBJECTIVES

The objectives of the study reported here included 1) the determination of the effects on live load ratings of highway bridges of the requirement concerning the carrying capacity of exterior girders in the 1973 AASHO specifications, and 2) the preparation of a recommendation to the American Association of State Highway and Transportation Officials for omitting this provision in the instructions for rating live load capacities of existing highway bridges in the next edition of its *Manual of Maintenance Inspection of Bridges*, if such a recommendation were found to be justified.

BACKGROUND

Distribution factors for proportioning live loads to stringers in short and intermediate span highway bridges have been a matter of concern and a subject of discussions among bridge design engineers for a number of years. The subject frequently has been on the agendas of the AASHTO Operating Subcommittee on Bridges and Structures, and in 1970 the Highway Research Board published *NCHRP Report No. 83*, "Distribution of Wheel Loads on Highway Bridges", authored by Professors W. W. Sanders, Jr., and H. A. Elleby of Iowa State University. That report presented the results of an exhaustive survey of the many experimental and analytical studies on the subject of wheel load distributions to bridge elements including stringers. Sanders and Elleby concluded the report with recommendations for revising the sections of the AASHTO bridge specifications concerned with wheel load distributions. They suggested that the AASHTO specifications, although simple, were somewhat conservative, and they recommended distribution factors in a somewhat more complex form. It was felt the resulting economy justified the use of more complex live load distribution equations. Other investigators, including the authors of this paper, have found in numerous experimental bridge tests that the percentages of the live load carried by stringers were always considerably less than those required by the AASHTO specifications. To quote the results of two field tests:

1. A 65' - 0" (19.83 m) clear span slab and stringer bridge with 4 stringers spaced at 7' - 8" (2.34 m) on centers resulted in a maximum of 44.6% of a line of wheels being supported by an exterior stringer against 64.8% required by the AASHTO specifications.(1) The maximum determined experimentally for an interior stringer was 36.4% for a line of wheels and 69.8% was required by the specifications.

2. A 60' - 0" (18.30 m) clear span slab and stringer bridge with 5 stringers spaced at 5' - 7" (1.70 m) on centers resulted in a maximum 43.5% of a line of wheels being supported by an exterior stringer versus 50.8% required by the AASHTO specifications. The maximum determined experimentally for an interior stringer was 31.5% for a line of wheels and, again, 50.8% was required by the specifications.(2)

The five most recent editions of the AASHTO bridge specifications (7th ed., 1957; 8th ed., 1961; 9th ed., 1965; 10th ed., 1969; and 11th ed., 1973) have specified distribution factors for exterior and interior stringers in essentially the same form.[3] Briefly, these are as given below:

Interior Stringers:

Typical distribution factors for interior stringers generally range from $\frac{S}{5}$ to $\frac{S}{6}$, depending on the type of stringer. For example, the distribution factor for a concrete deck on a steel stringer is $\frac{S}{5.5}$ for $S < 10'$ (3.05 m), where S is the average stringer spacing in feet.

Exterior Stringers:-

Distribution factors for exterior stringers are generally prescribed to be

$$\frac{S}{5.5} \text{ for } S \leq 6' \text{ (1.83)},$$

and

$$\frac{S}{4 + 0.25S} \text{ for } 6'(1.83\text{ m}) < S \leq 14'(4.27\text{ m})$$

Since the 9th (1965) ed. of the AASHTO specifications, the designer has been permitted to increase the allowable stress 25% when the total load on exterior stringers includes a combination of dead load, sidewalk live load, live load, and impact. All of these requirements are minimum distribution factors, and the exterior girder live load must also be checked for the load resulting from simple beam moment about the first interior support. These distribution requirements have been found to be quite conservative, as pointed out by Sanders and Elleby in *NCHRP Report No. 83*, and also by the authors in the examples quoted above.

However, in addition to the requirements summarized above, the present 1973 11th ed. of the *AASHTO Standard Specifications for Highway Bridges*, as noted earlier, is the first edition to include the requirement that "In no case shall an exterior stringer have less carrying capacity than an interior stringer", in Article 1.3.1(B)(2)(a). As revealed by a review of the minutes of several meetings of the AASHTO Operating Subcommittee on Bridges and Structures, and confirmed in discussions with several committee members, the subcommittee's concern has been the increasing number of bridges in the U. S. highway systems that have had to be widened, thus transforming what were formerly exterior girders into interior girders. This provision eliminates the requirement of modifying existing exterior girders as they would already have the same carrying capacity as an interior girder. While this is a very prudent decision governing the design of new structures, its application to the rating of existing bridges may, in some instances, impose an unnecessary limitation on the ratings of those structures where the exterior stringers have less carrying capacities than the interior stringers.

An important element in the design of exterior stringers is the amount of the dead load of the curb, parapets, railing, posts, brackets, etc., that is supported by the exterior stringers. Also, the light exterior girder depends upon the relative placement of the stringers. Nevertheless, this situation of smaller exterior stringers is a very common one and exists extensively throughout the U.S. in bridges built during the early part of this century.

All of the foregoing comments have a direct relation and an impact on the biannual live load rating program required by the 1968 Federal-Aid Highway Act. The present guide for rating bridges is the *Manual for Maintenance Inspection of Bridges*, 2nd ed., 1974 prepared by the aforementioned Operating Subcommittee on Bridges and Structures.(4) Article 5.1.2, p. 31 of this manual informs the bridge inspector that "the current standard specifications used for the design of new bridges shall be used as a guide" in rating the older structures for live load capacity. The awkward situation in which the bridge inspector is placed is immediately apparent. Under these instructions, the larger interior stringers are theoretically reduced to the lesser carrying capacity of the exterior stringer, and the bridge's live load rating is artificially reduced to a smaller capacity than it can actually safely carry. It is true that later statements in the manual, also on p. 31, allow that an

> engineer, based on his knowledge of the condition and performance characteristics of a bridge under traffic, may make a judgement that the action of a member within the structure is not consistent with the design concept of the controlling specifications. In this situation, he may modify the design criteria within safe limitations and following sound principles of engineering mechanics base his capacity analysis for the member on its known action under load. *Deviations from controlling specifications shall be fully documented.* (italics added)

This last paragraph provides a professional engineer a legal escape from the use of the current AASHTO specifications in rating a bridge. On the other hand, engineering technicians many times are charged with the much more frequent inspection and rating of bridges that have recently been made mandatory, and they are certainly going to be reluctant to make exceptions and depart from the spelled out procedures in the *Manual for*

Maintenance Inspection; i.e., they are very apt to rate the bridge as though all of the stringers had the same carrying capacity as the exterior stringers.

In view of the implicit contradiction between the intent of those parts of the AASHTO specifications and the guidelines for bridge rating which deal with exterior stringers, it certainly appears desirable to resolve this situation by modifying either the AASHTO specifications or the manual for bridge rating to bring the two into conformance. At this time, it appears more appropriate to slightly modify Article 5.3.1 in the manual for bridge rating. While such a modification is obviously a logical step, it seemed appropriate before making such a recommendation to determine the effect of the current AASHTO provisions on the rating of actual bridges. Accordingly, a brief study was undertaken to provide such a determination.

METHODOLOGY AND RESULTS

Thirteen bridges, five with steel stringers and eight with concrete T-beam stringers, were selected for study. Inventory ratings of these structures were calculated based on the capacities of only the girders. The results of these analyses are presented in Table 1 and the detailed calculations are shown in the Appendix. The first column indicates bridge type and span characteristics. The figures in the columns designated (1) and (2) are inventory ratings (H-loadings) based on only the exterior and interior stringer, respectively. Column (3) is the corresponding rating of the interior stringer if it is modified, consistent with AASHTO specifications, to be the same size as the exterior stringer.

The effect of modifying the interior grider on bridge rating is illustrated by the ratios in columns (4) and (5). The ratios in column (4) refer to the reduction in capacity considering only the interior stringer, while the ratios in column (5) refer to the reduction in capacity of the modified interior stringer compared with the exterior stringer capacity. Entries in these columns indicate modification ratios ranging from 0.42 to 1.75. These figures indicate that adhering to the requirement for stringer reduction may result in a significant, but artificial, reduction in the rating of existing bridges.

Many states — perhaps most states, including Virginia — have noted this new requirement concerning exterior stringers in the 1973 specifications and its practical inapplicability in rating older slab-stringer bridges, and have issued instructions to their personnel to ignore this requirement.

TABLE 1

INVENTORY RATINGS

(H-Loadings)

Bridge	(1) Exterior Stringers	(2) Interior Stringers	(3) Mod. Interior Stringers[(a)]	(4) (3)/(2) Ratio	(5) (3)/(1) Ratio
SC-24-150-18'-9"[(b)] St. Through Truss	22.4	29.7	21.0	.71	.94
SC-24-90-15'-0" Low Truss	18.8	29.1	17.8	.61	.95
SM-24-105-15'-0" Low Truss	14.9	20.1	14.0	.70	.94
SC-24-40 Steel Beam	13.7	26.1	14.8	.57	1.08
WS-26-55 Steel Beam	8.9	21.5	15.6	.73	1.75
C-24-25 Reinf. Concrete	31.3	38.9	16.5	.42	.53
C-24-30 Reinf. Concrete	38.5	28.0	19.6	.70	.51
C-24-40 Reinf. Concrete	28.3	25.6	18.1	.71	.64
C-30-25 Reinf. Concrete	24.1	31.9	18.6	.58	.77
CBS-24-25 Reinf. Concrete	10.9	21.7	9.5	.44	.87
CBS-24-30 Reinf. Concrete	15.5	22.9	12.0	.52	.77
WC-24-30 Reinf. Concrete	19.1	17.2	13.9	.81	.73
WC-26-40 Reinf. Concrete	17.4	31.6	18.0	.57	1.03

NOTE: Inventory Ratings are based on 0.55 yield stress, 18,000 psi (124 MPa).

[(a)] Interior Stringer modified to size of Exterior Stringer.

[(b)] SC-24-150-18'-9" indicates a 24' (7.32 m) roadway width, a 150' (45.75m) truss span and an 18'-9" (5.72 m) panel length.

However, this new insertion in Article 1.3.1 (B)(2)(a) concerning exterior stringers has been a source of concern for a number of persons charged with the responsibility of rating older highway bridges.

RECOMMENDATIONS

It is recommended that the AASHTO Operating Subcommittee on Bridges and Structures give serious consideration to exempting this provision in the *Specifications for Highway Bridges* when preparing the sections concerned with rating bridges in the next edition (3rd) of the *Manual for Maintenance Inspection of Bridges*.

The authors suggest that a very adequate clarification of the intent of the *Manual for Maintenance Inspection of Bridges* could be accomplished by simply adding the following sentence at the end of Article 5.3.1. "The requirement of the *AASHTO Specifications for Highway Bridges* in Article 1.3.1(B)(2) that exterior stringers have at least the same carrying capacity as interior stringers shall not apply to the rating of bridges".

0932

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G. D. Newlen, graduate research assistant, contributed significantly to the study in the calculations of live load ratings of the thirteen slab-stringer and concrete T-beam bridges investigated.

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3. American Association of State Highway and Transportation Officials, *Specifications for Highway Bridges*, 7th, 8th, 9th, 10th, and 11th eds.

4. American Association of State Highway and Transportation Officials, *Manual for Maintenance Inspection of Bridges*, 2nd ed., 1974.

APPENDIX

STRINGER ANALYSIS

(Calculations are based on conventional elastic theory using a ratio of elastic modulus of steel to elastic modulus of concrete (n) equal to ten [AASHTO specifications, assuming f'_c = 3000 - 3900 psi }). Calculations for five steel stringer bridges and eight concrete tee-beam bridges follow.

A = Average stringer spacing

B = Effective flange width (for steel beam bridges, B=A)

DLW = Dead load weight

DLM = Dead load moment

f_{DL} = Dead load flexural stress

$f_{DL(MOD)}$* = Modified dead load flexural stress

f_{LL} = Live load flexural stress

$f_{LL(MOD)}$* = Modified live load flexural stress

L = Effective span length (for steel truss bridges, L = Panel length)

P = Maximum wheel load

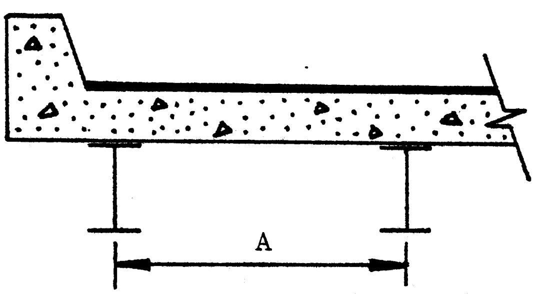
S_E = Section modulus of exterior stringer

S_I = Section modulus of interior stringer

$S_{I(MOD)}$* = Section modulus of modified interior stringer

*NOTE: The modified interior stringer means that the interior stringer is assumed to be the same size as the exterior stringer.

Exterior Stringer



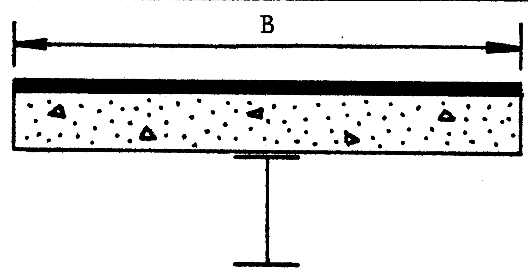
The uniform dead load weight (DLW) is obtained by applying simple beam moments about the first interior stringer and dividing the result by the stringer spacing.

DLW = ________ K/ft.

$$DLM = \frac{DLW \times L^2}{8} = \_\_\_\_\_\_\_ \text{ft.-K}$$

$$f_{DL} = \frac{DLM \times 12}{S_E} = \_\_\_\_\_\_\_ \text{ksi}$$

Interior Stringer



DLW = ________ K/ft.

$$DLM = \frac{DLW \times L^2}{8} = \_\_\_\_\_\_\_ \text{ft.-K}$$

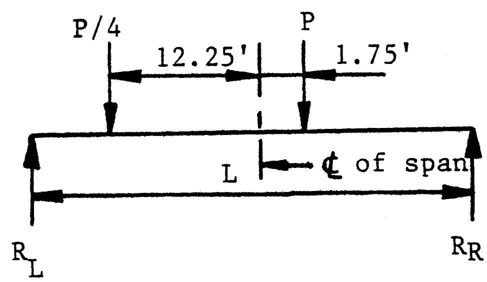
$$f_{DL} = \frac{DLM \times 12}{S_I} = \_\_\_\_\_\_\_ \text{ksi}$$

The dead load flexural stress, assuming the interior stringer to be the same size as the exterior stringer (modified):

$$f_{DL(MOD)} = \frac{DLM \times 12}{S_E} = \_\_\_\_\_\_\_ \text{ksi}$$

For concrete tee-beam bridges substitute $S_{I(MOD)}$ for S_E.

Exterior Stringer



The live load moments (LLM) were interpolated from the AASHTO Specifications for Highway Bridges, 1973, Appendix A. The effective live load moment (Eff.M) was obtained by determining the reactions at supports when wheel loads are placed on the span so as to produce absolute maximum moment (impact and distribution factors included; $f_{allowable}$ = 18 ksi). For bridges with spans less than 14.5 feet, one load of P was placed at the centerline.

LLM = __________ft.-K

$f_{LL} = \frac{LLM \times 12}{S_E}$ = ______ksi

Eff.M = _________(in terms of P)

$18 - f_{DL} = \frac{Eff.M \times 12}{S_E}$

Solve for P:

P + P/4 = H________ Loading

Interior Stringer

LLM = _________ft.-K

$f_{LL} = \frac{LLM \times 12}{S_I}$ = ______ksi

$f_{LL(MOD)} = \frac{LLM \times 12}{S_E}$ = ______ksi

For concrete tee-beam bridges, substitute $S_{I(MOD)}$ for S_E.

Maximum Loading:

Eff.M = ________(in terms of P)

$18 - f_{DL} = \frac{Eff.M \times 12}{S_I}$

Adding the total loading on the span gives the maximum H-loading:

P + P/4 = H______Loading

Maximum loading, assuming the interior stringer to be the same size as the exterior stringer (modified):

$18 - f_{DL(MOD)} = \frac{Eff.M \times 12}{S_E}$

For concrete tee-beam bridges, substitute $S_{I(MOD)}$ for S_E.

P + P/4 = H_______Loading

Standard Through Truss Bridge (SC-24-150)
Panel Length = L = 18.75′; A = 5.5′; S_E = 88.4 in^3; S_I = 116.9 in^3
(For explanations, refer to pages A1 and A2).

Exterior Stringers	Interior Stringers
$DLW = 0.537$ k/ft $DLM = \frac{0.537 \times (18.75)^2}{8} = 23.61$ ft-k $f_{DL} = \frac{23.61 \times 12}{88.4} = 3.20$ KSI	$DLW = 0.688$ k/ft $DLM = \frac{0.688 \times (18.75)^2}{8} = 30.22$ ft-k $f_{DL} = \frac{30.22 \times 12}{116.9} = 3.11$ KSI $f_{DL(MOD)} = \frac{30.22 \times 12}{88.4} = 4.10$ KSI
$LLM = 73.13$ ft-k $f_{LL} = \frac{73.13 \times 12}{88.4} = 9.93$ KSI	For H15-44 Loading: $LLM = 73.13$ ft-k $f_{LL} = \frac{73.13 \times 12}{116.9} = 7.50$ KSI $f_{LL(MOD)} = \frac{73.13 \times 12}{88.4} = 9.93$ KSI
Eff. $M = 6.10P$ $18 - 3.2 = \frac{6.10P \times 12}{88.4}$ $P = 17.9$; $P/4 = 4.5$ $17.9 + 4.5 =$ H22.4 Loading	Maximum Loading: Eff $M = 6.10P$ $18 - 3.11 = \frac{6.10P \times 12}{116.9}$ $P = 23.8$; $P/4 = 5.9$ $23.8 + 5.9 =$ H29.7 Loading
	For Mod. Int. Stringer: $18 - 4.10 = \frac{6.10P \times 12}{88.4}$ $P = 16.8$; $P/4 = 4.2$ $16.8 + 4.2 =$ H21.0 Loading

0940

Standard Low Truss Bridge (SC-24-90)
Panel Length = L = 15.0'; A = 5.5'; S_E = 58.9 in^3; S_I = 88.4 in^3
(For explanations, refer to pages A1 and A2.)

Exterior Stringers

DLW = 0.531 K/ft

$$DLM = \frac{0.531 \times (15)^2}{8} = 14.94 \text{ ft-K}$$

$$f_{DL} = \frac{14.94 \times 12}{58.9} = 3.04 \text{ KSI}$$

LLM = 58.5 ft-K

$$f_{LL} = \frac{58.5 \times 12}{58.9} = 11.92 \text{ KSI}$$

Eff. M = 4.88 P

$$18 - 3.04 = \frac{4.88 P \times 12}{58.9}$$

P = 15.0 ; P/4 = 3.8

15.0 + 3.8 = H 18.8 Loading

Interior Stringers

DLW = 0.677 K/ft

$$DLM = \frac{0.677 \times (15)^2}{8} = 19.04 \text{ ft-K}$$

$$f_{DL} = \frac{19.04 \times 12}{88.4} = 2.58 \text{ KSI}$$

$$f_{DL(MOD)} = \frac{19.04 \times 12}{58.9} = 3.88 \text{ KSI}$$

For H15-44 Loading:
LLM = 58.5 ft-K

$$f_{LL} = \frac{58.5 \times 12}{88.4} = 7.94 \text{ KSI}$$

$$f_{LL(MOD)} = \frac{58.5 \times 12}{58.9} = 11.92 \text{ KSI}$$

Maximum Loading:
Eff. M = 4.88 P

$$18 - 2.58 = \frac{4.88 P \times 12}{88.4}$$

P = 23.3 ; P/4 = 5.8
23.3 + 5.8 = H 29.1 Loading

For Mod. Int. Stringer:

$$18 - 3.88 = \frac{4.88 P \times 12}{88.4}$$

P = 14.2 ; P/4 = 3.6

14.2 + 3.6 = H 17.8 Loading

Standard Low Truss Bridge (SM-24-105)
Panel Length = $L = 15.0'$; $A = 5.5'$; $S_E = 48.5\,in^3$; $S_I = 64.4\,in^3$
(For explanations, refer to pages A1 and A2.)

Exterior Stringers

$DLW = 0.522$ K/ft

$$DLM = \frac{0.522 \times (15)^2}{8} = 14.69 \text{ ft-K}$$

$$f_{DL} = \frac{14.69 \times 12}{48.5} = 3.64 \text{ KSI}$$

$LLM = 58.5$ ft-K

$$f_{LL} = \frac{58.5 \times 12}{48.5} = 14.49 \text{ KSI}$$

Eff. $M = 4.88P$

$$18 - 3.64 = \frac{4.88P \times 12}{48.5}$$

$P = 11.9$; $P/4 = 3.0$

$11.9 + 3.0 = H\,14.9$ Loading

Interior Stringers

$DLW = 0.642$ K/ft

$$DLM = \frac{0.642 \times (15)^2}{8} = 18.06 \text{ ft-K}$$

$$f_{DL} = \frac{18.06 \times 12}{64.4} = 3.36 \text{ KSI}$$

$$f_{DL(MOD)} = \frac{18.06 \times 12}{48.5} = 4.47 \text{ KSI}$$

For H15-44 Loading:
$LLM = 58.5$ ft-K

$$f_{LL} = \frac{58.5 \times 12}{64.4} = 10.89 \text{ KSI}$$

$$f_{LL(MOD)} = \frac{58.5 \times 12}{48.5} = 14.49 \text{ KSI}$$

Maximum Loading:
Eff. $M = 4.88P$

$$18 - 3.36 = \frac{4.88P \times 12}{64.4}$$

$P = 16.1$; $P/4 = 4.0$

$16.1 + 4.0 = H\,20.1$ Loading

For Mod. Int. Stringer:

$$18 - 4.47 = \frac{4.88P \times 12}{48.5}$$

$P = 11.2$; $P/4 = 2.8$

$11.2 + 2.8 = H\,14.0$ Loading

0942

Standard Steel Beam Bridge (SC-24-40)

$L = 41.25'$; $A = 7.17'$; $S_E = 299.2\,in^3$; $S_I = 413.6\,in^3$

(For explanations, refer to pages A1 and A2.)

Exterior Stringers

DLW = 1.183 K/ft

$$DLM = \frac{1.183 \times (41.25)^2}{8} = 251.6\ ft\text{-}K$$

$$f_{DL} = \frac{251.6 \times 12}{299.2} = 10.09\ KSI$$

LLM = 216.3 ft-K

$$f_{LL} = \frac{216.3 \times 12}{299.2} = 8.67\ KSI$$

Eff. M = 18.01 P

$$18 - 10.09 = \frac{18.01 P \times 12}{299.2}$$

$P = 11.0$; $P/4 = 2.7$

11.0 + 2.7 = H 13.7 Loading

Interior Stringers

DLW = 1.057 K/ft

$$DLM = \frac{1.057 \times (41.25)^2}{8} = 224.8\ ft\text{-}K$$

$$f_{DL} = \frac{224.8 \times 12}{413.6} = 6.52\ KSI$$

$$f_{DL(MOD)} = \frac{224.8 \times 12}{299.2} = 9.02\ KSI$$

For H 15-44 Loading:

LLM = 227.8 ft-K

$$f_{LL} = \frac{227.8 \times 12}{413.6} = 6.61\ KSI$$

$$f_{LL(MOD)} = \frac{227.8 \times 12}{299.2} = 9.14\ KSI$$

Maximum Loading:

Eff. M = 18.97 P

$$18 - 6.52 = \frac{18.97 P \times 12}{413.6}$$

$P = 20.9$; $P/4 = 5.2$

20.9 + 5.2 = H 26.1 Loading

For Mod. Int. Stringer:

$$18 - 9.02 = \frac{18.97 P \times 12}{299.2}$$

$P = 11.8$; $P/4 = 3.0$

11.8 + 3.0 = H 14.8 Loading

Standard 55' Steel Beam Span (WS-26-55)

$L = 56.25'$; $A = 6.25'$; $S_E = 413.6\ in^3$; $S_I = 486.4\ in^3$

(For explanations, refer to pages A1 and A2.)

Exterior Stringers	Interior Stringers
$DLW = 1.161\ K/ft$ $DLM = \frac{1.161 \times (56.25)^2}{8} = 459.2\ ft\text{-}K$ $f_{DL} = \frac{459.2 \times 12}{413.6} = 13.32\ KSI$	$DLW = 0.837\ K/ft$ $DLM = \frac{0.837 \times (56.25)^2}{486.4} = 331.0\ ft\text{-}K$ $f_{DL} = \frac{331.0 \times 12}{486.4} = 8.17\ KSI$ $f_{DL(MOD)} = \frac{331.0 \times 12}{413.6} = 9.61\ KSI$
$LLM = 280.1\ ft\text{-}K$ $f_{LL} = \frac{280.1 \times 12}{8} = 8.13\ KSI$	For H15-44 Loading: $LLM = 283.3\ ft\text{-}K$ $f_{LL} = \frac{283.3 \times 12}{486.4} = 6.99\ KSI$ $f_{LL(MOD)} = \frac{283.3 \times 12}{413.6} = 8.22\ KSI$
$Eff\ M = 15.88\ P$ $18 - 13.32 = \frac{15.88 P \times 12}{413.6}$ $P = 7.1$; $P/4 = 1.8$ $7.1 + 1.8 =$ H 8.9 Loading	Maximum Loading: $Eff.\ M = 23.10 P$ $18 - 8.17 = \frac{23.10 P \times 12}{486.4}$ $P = 17.2$; $P/4 = 4.3$ $17.2 + 4.3 =$ H 21.5 Loading
	For Mod. Int. Stringer: $18 - 9.61 = \frac{23.10 P \times 12}{413.6}$ $P = 12.5$; $P/4 = 3.1$ $12.5 + 3.1 =$ H 15.6 Loading

0944

Standard Reinforced Concrete Bridge (C-24-25)

$L = 26.25'$; $A = 7.23'$; $B = 6.56'$; $S_E = 1899.1\ in^3$; $S_I = 2864.5\ in^3$

$S_{I(MOD)} = 1648.1\ in^3$ (For explanations, refer to pages A1 and A2.)

Exterior Stringers

DLW = 1.290 K/ft.

$$DLM = \frac{1.290 \times (26.25)^2}{8} = 111.11\ ft\text{-}K$$

$$f_{DL} = \frac{111.11 \times 12}{1899.2} = 7.02\ KSI$$

LLM = 83.63 ft-K

$$f_{LL} = \frac{83.63 \times 12 \times 10}{1899.1} = 5.28\ KSI$$

Eff. M = 6.94 P

$$18 - 7.02 = \frac{6.94P \times 12 \times 10}{1899.1}$$

$P = 25.0$; $P/4 = 6.3$

25.0 + 6.3 = H31.3 Loading

Interior Stringers

DLW = 1.309 K/ft

$$DLM = \frac{1.309 \times (26.25)^2}{8} = 112.75\ ft\text{-}K$$

$$f_{DL} = \frac{112.75 \times 12 \times 10}{2864.5} = 4.72\ KSI$$

$$f_{DL(MOD)} = \frac{112.75 \times 12 \times 10}{1648.1} = 8.21\ KSI$$

For H15-44 Loading:

LLM = 122.99 ft-K

$$f_{LL} = \frac{122.99 \times 12 \times 10}{2864.5} = 5.15\ KSI$$

$$f_{LL(MOD)} = \frac{122.99 \times 12 \times 10}{1648.1} = 8.96\ KSI$$

Maximum Loading:

Eff. M = 10.20 P

$$18 - 4.72 = \frac{10.20P \times 12 \times 10}{2864.5}$$

$P = 31.1$; $P/4 = 7.8$

31.1 + 7.8 = H38.9 Loading

For Mod. Int. Stringer:

$$18 - 8.21 = \frac{10.20P \times 12 \times 10}{1648.1}$$

$P = 13.2$; $P/4 = 3.3$

13.2 + 3.3 = H16.5 Loading

Standard Reinforced Concrete Bridge (C-21-30)
$L = 31.25'$; $A = 7.23'$; $B = 7.23'$; $S_E = 2826.0\ in^3$; $S_I = 2949.8\ in^3$
$S_{I(MOD)} = 2382.5\ in^3$ (For explanations, refer to pages A1 and A2.)

Exterior Stringers	Interior Stringers
$DLW = 1.307\ K/ft$ $DLM = \dfrac{1.307 \times (31.25)^2}{8} = 159.6\ ft\text{-}K$ $f_{DL} = \dfrac{159.6 \times 12 \times 10}{2826.0} = 6.77\ KSI$	$DLW = 1.300\ K/ft$ $DLM = \dfrac{1.300 \times (31.25)^2}{8} = 158.7\ ft\text{-}K$ $f_{DL} = \dfrac{158.7 \times 12 \times 10}{2949.8} = 6.46\ KSI$ $f_{DL(MOD)} = \dfrac{158.7 \times 12 \times 10}{2382.5} = 7.99\ KSI$
$LLM = 102.90\ ft\text{-}K$ $f_{LL} = \dfrac{102.90 \times 12 \times 10}{2826.0} = 4.37\ KSI$	For H15-44 Loading: $LLM = 151.95\ ft\text{-}K$ $f_{LL} = \dfrac{151.95 \times 12 \times 10}{2949.8} = 6.18\ KSI$ $f_{LL(MOD)} = \dfrac{151.95 \times 12 \times 10}{1648.1} = 7.65\ KSI$
$Eff.\ M = 8.58\ P$ $18 - 6.77 = \dfrac{8.58P \times 12 \times 10}{2826.0}$ $P = 30.8$; $P/4 = 7.7$ $30.8 + 7.7 = H38.5$ Loading	Maximum Loading: $Eff.\ M = 12.67\ P$ $18 - 6.46 = \dfrac{12.67P \times 12 \times 10}{2949.8}$ $P = 22.4$; $P/4 = 5.6$ $22.4 + 5.6 = H28.0$ Loading
	For Mod. Int. Stringer: $18 - 7.99 = \dfrac{12.67P \times 12 \times 10}{2382.5}$ $P = 15.7$; $P/4 = 3.9$ $15.7 + 3.9 = H19.6$ Loading

Standard Reinforced Concrete Bridge (C-24-40)

$L = 41.25'$; $A = 7.23'$; $B = 7.23'$; $S_E = 3663.0\,in^3$; $S_I = 4406.6\,in^3$

$S_{I(MOD)} = 3713.1\,in^3$ (For explanations, refer to pages A1 and A2)

Exterior Stringers

$DLW = 1.308\ K/ft$

$$DLM = \frac{1.308 \times (41.25)^2}{8} = 278.2\ ft\text{-}K$$

$$f_{DL} = \frac{278.2 \times 12 \times 10}{3663.0} = 9.20\ KSI$$

$LLM = 142.57\ ft\text{-}K$

$$f_{LL} = \frac{142.57 \times 12 \times 10}{3663.0} = 4.67\ KSI$$

$Eff.M = 11.88\,P$

$$18 - 9.20 = \frac{11.88P \times 12 \times 10}{3663.0}$$

$P = 22.6$; $P/4 = 5.7$

$22.6 + 5.7 =$ H28.3 Loading

Interior Stringers

$DLW = 1.421\ K/ft$

$$DLM = \frac{1.421 \times (41.25)^2}{8} = 302.2\ ft\text{-}K$$

$$f_{DL} = \frac{302.2 \times 12 \times 10}{4406.6} = 8.23\ KSI$$

$$f_{DL(MOD)} = \frac{302.2 \times 12 \times 10}{3713.1} = 9.77\ KSI$$

For H15-44 Loading:

$LLM = 210.54\ ft\text{-}K$

$$f_{LL} = \frac{210.54 \times 12 \times 10}{4406.6} = 5.73\ KSI$$

$$f_{LL(MOD)} = \frac{210.54 \times 12 \times 10}{3713.1} = 6.80\ KSI$$

Maximum Loading:

$Eff.\ M = 17.54\,P$

$$18 - 8.23 = \frac{17.54P \times 12 \times 10}{4406.6}$$

$P = 20.5$; $P/4 = 5.1$

$20.5 + 5.1 =$ H25.6 Loading

For Mod. Int. Stringer:

$$18 - 9.77 = \frac{17.54P \times 12 \times 10}{3713.1}$$

$P = 14.5$; $P/4 = 3.6$

$14.5 + 3.6 =$ H18.1 Loading

Standard Reinforced Concrete Bridge (C-30-25)

$L = 26.25'$; $A = 6.96'$; $B = 7.00'$; $S_E = 1676.7\ in^3$; $S_I = 2417.0\ in^3$

$S_{I(MOD)} = 1719.4\ in^3$ (For explanations, refer to pages A1 and A2)

Exterior Stringers

$DLW = 1.407\ K/ft$

$$DLM = \frac{1.407 \times (26.25)^2}{8} = 121.2\ ft\text{-}K$$

$$f_{DL} = \frac{121.2 \times 12 \times 10}{1676.7} = 8.67\ KSI$$

$LLM = 81.59\ ft\text{-}K$

$$f_{LL} = \frac{81.59 \times 12 \times 10}{1676.7} = 5.84\ KSI$$

$Eff.\ M = 6.77P$

$$18 - 8.67 = \frac{6.77P \times 12 \times 10}{1676.7}$$

$P = 19.3$; $P/4 = 4.8$

$19.3 + 4.8 = H24.1$ Loading

Interior Stringers

$DLW = 1.276\ K/ft$

$$DLM = \frac{1.276 \times (26.25)^2}{8} = 109.9\ ft\text{-}K$$

$$f_{DL} = \frac{109.9 \times 12 \times 10}{2417.0} = 5.46\ KSI$$

$$f_{DL(MOD)} = \frac{109.9 \times 12 \times 10}{1719.4} = 7.67\ KSI$$

For H15-44 Loading:

$LLM = 119.59\ ft\text{-}K$

$$f_{LL} = \frac{119.59 \times 12 \times 10}{2417.0} = 5.94\ KSI$$

$$f_{LL(MOD)} = \frac{119.59 \times 12 \times 10}{1719.4} = 8.35\ KSI$$

Maximum Loading:

$Eff.\ M = 9.92P$

$$18 - 5.46 = \frac{9.92P \times 12 \times 10}{2417.0}$$

$P = 25.5$; $P/4 = 6.4$

$25.5 + 6.4 = H31.9$ Loading

For Mod. Int. Stringer:

$$18 - 7.67 = \frac{9.92P \times 12 \times 10}{1719.4}$$

$P = 14.9$; $P/4 = 3.7$

$14.9 + 3.7 = H18.6$ Loading

Standard Reinforced Concrete Bridge (CBS-24-25)
$L = 26.25'$; $A = 5.96'$; $B = 6.04'$; $S_E = 911.2\ in^3$; $S_I = 1497.5\ in^3$
$S_{I(MOD)} = 940.7\ in^3$ (For explanations, refer to pages A1 and A2.)

Exterior Stringers	Interior Stringers
$DLW = 1.080\ K/ft$ $DLM = \frac{1.080 \times (26.25)^2}{8} = 93.0\ ft\text{-}K$ $f_{DL} = \frac{93.0 \times 12 \times 10}{911.2} = 12.25\ KSI$	$DLW = 0.883$ $DLM = \frac{0.883 \times (26.25)^2}{8} = 76.1\ ft\text{-}K$ $f_{DL} = \frac{76.1 \times 12 \times 10}{1497.5} = 6.09\ KSI$
$LLM = 60.17\ ft\text{-}K$ $f_{LL} = \frac{60.17 \times 12 \times 10}{911.2} = 7.92\ KSI$	$f_{DL(MOD)} = \frac{76.1 \times 12 \times 10}{940.7} = 9.70\ KSI$
$Eff.M = 4.99P$ $18 - 12.25 = \frac{4.99P \times 12 \times 10}{911.2}$ $P = 8.7$; $P/4 = 2.2$ $8.7 + 2.2 = H\ 10.9$ Loading	For H15-44 Loading: $LLM = 103.19\ ft\text{-}K$ $f_{LL} = \frac{103.19 \times 12 \times 10}{14.97.5} = 8.27\ KSI$ $f_{LL(MOD)} = \frac{103.19 \times 12 \times 10}{940.7} = 13.16\ KSI$
	Maximum Loading: $Eff.M = 8.56P$ $18 - 6.09 = \frac{8.56P \times 12 \times 10}{1497.5}$ $P = 17.4$; $P/4 = 4.3$ $17.4 + 4.3 = H\ 21.7$ Loading
	For Mod. Int. Stringer: $18 - 9.70 = \frac{8.56P \times 12 \times 10}{940.7}$ $P = 7.6$; $P/4 = 1.9$ $7.6 + 1.9 = H\ 9.5$ Loading

Standard Reinforced Concrete Bridge (CBS-24-30)

$L = 31.25'$; $A = 5.96'$; $B = 6.04'$; $S_E = 1451.8 in^3$; $S_I = 2095.6 in^3$

$S_{I(MOD)} = 1479.4 in^3$ (For explanations, refer to pages A1 and A2.)

Exterior Stringers	Interior Stringers
$DLW = 1.156 \ K/ft$ $DLM = \frac{1.156 \times (31.25)^2}{8} = 141.1 \ ft\text{-}K$ $f_{DL} = \frac{141.1 \times 12 \times 10}{1451.8} = 11.66 \ KSI$	$DLW = 0.985 \ K/ft$ $DLM = \frac{0.985 \times (31.25)^2}{8} = 120.2 \ ft\text{-}K$ $f_{DL} = \frac{120.2 \times 12 \times 10}{2095.6} = 6.89 \ KSI$ $f_{DL(MOD)} = \frac{120.2 \times 12 \times 10}{1479.4} = 9.75 \ KSI$
$LLM = 99.74 \ ft\text{-}K$ $f_{LL} = \frac{99.74 \times 12 \times 10}{1451.8} = 8.24 \ KSI$	For H15-44 Loading: $LLM = 171.0 \ ft\text{-}K$ $f_{LL} = \frac{171.0 \times 12 \times 10}{2095.6} = 9.79 \ KSI$ $f_{LL(MOD)} = \frac{171.0 \times 12 \times 10}{1479.4} = 13.87 \ KSI$
$Eff. M = 6.18 P$ $18 - 11.66 = \frac{6.18 P \times 12 \times 10}{1451.8}$ $P = 12.4$; $P/4 = 3.1$ $12.4 + 3.1 = H \ 15.5$ Loading	Maximum Loading: $Eff. M = 10.59 P$ $18 - 6.89 = \frac{10.59 P \times 12 \times 10}{2095.6}$ $P = 18.3$; $P/4 = 4.6$ $18.3 + 4.6 = H \ 22.9$ Loading
	For Mod. Int. Stringer: $18 - 9.75 = \frac{10.59 P \times 12 \times 10}{1479.4}$ $P = 9.6$; $P/4 = 2.4$ $9.6 + 2.4 = H \ 12.0$ Loading

Standard Reinforced Concrete Bridge (WC-29-30)

$L = 31.25'$; $A = 7.58'$; $B = 7.67'$; $S_E = 2108.5\,in^3$; $S_I = 2164.3\,in^3$

$S_{I(MOD)} = 1999.7\,in^3$ (For explanations, refer to pages A1 and A2.)

Exterior Stringers	Interior Stringers
$DLW = 1.549\ K/ft$ $DLM = \frac{1.549 \times (31.25)^2}{8} = 189.1\ ft\text{-}K$ $f_{DL} = \frac{189.1 \times 12 \times 10}{2108.5} = 10.76\ KSI$	$DLW = 1.230\ K/ft$ $DLM = \frac{1.230 \times (31.25)^2}{8} = 150.6\ ft\text{-}K$ $f_{DL} = \frac{150.6 \times 12 \times 10}{2164.3} = 8.32\ KSI$ $f_{DL(MOD)} = \frac{150.6 \times 12 \times 10}{1999.7} = 9.01\ KSI$
$LLM = 133.16\ ft\text{-}K$ $f_{LL} = \frac{133.16 \times 12 \times 10}{2108.5} = 7.58\ KSI$	For H15-44 Loading: $LLM = 215.21\ ft\text{-}K$ $f_{LL} = \frac{215.21 \times 12 \times 10}{2164.3} = 11.93\ KSI$ $f_{LL(MOD)} = \frac{215.21 \times 12 \times 10}{1999.7} = 12.91\ KSI$
$Eff\ M = 8.32\ P$ $18 - 10.76 = \frac{8.32\,P \times 12 \times 10}{2108.5}$ $P = 15.3$; $P/4 = 3.8$ $15.3 + 3.8 = H\,19.1$ Loading	Maximum Loading: $Eff.\ M = 13.44\ P$ $18 - 8.32 = \frac{13.44\,P \times 12 \times 10}{2164.3}$ $P = 13.0$; $P/4 = 4.2$ $13.0 + 4.2 = H\,17.2$ Loading
	For Mod. Int. Stringer: $18 - 9.01 = \frac{13.44\,P \times 12 \times 10}{1999.7}$ $P = 11.1$; $P/4 = H\,13.9$ Loading

Standard Reinforced Concrete Bridge (WC-26-40)
$L = 41.25'$; $A = 6.17'$; $B = 6.25'$; $S_E = 3201.8 in^3$; $S_I = 4269.7 in^3$
$S_{I(MOD)} = 3166.7 in^3$ (For explanations, refer to pages A1 and A2.)

Exterior Stringers	Interior Stringers
$DLW = 1.484$ k/ft $DLM = \frac{1.484 \times (41.25)^2}{8} = 315.6$ ft-k $f_{DL} = \frac{315.6 \times 12 \times 10}{3201.8} = 11.83$ KSI	$DLW = 1.209$ k/ft $= \frac{1.209 \times (41.25)^2}{8} = 257.2$ ft-k $f_{DL} = \frac{257.2 \times 12 \times 10}{4269.7} = 7.23$ KSI $f_{DL(MOD)} = \frac{257.2 \times 12 \times 10}{3166.7} = 9.74$ KSI
$LLM = 179.38$ ft-k $f_{LL} = \frac{179.38 \times 12 \times 10}{3201.8} = 6.73$	For H15-44 Loading: $LLM = 242.67$ ft-k $f_{LL} = \frac{242.67 \times 12 \times 10}{4269.7} = 6.82$ KSI $f_{LL(MOD)} = \frac{242.67 \times 12 \times 10}{3166.7} = 9.20$ KSI
Eff. $M = 11.88 P$ $18 - 11.83 = \frac{11.88 P \times 12 \times 10}{3201.8}$ $P = 13.9$; $P/4 = 3.5$ $13.9 + 3.5 = H17.4$ Loading	Maximum Loading: Eff. $M = 15.17 P$ $18 - 7.23 = \frac{15.17 P \times 12 \times 10}{4269.7}$ $P = 25.3$; $P/4 = 6.3$ $25.3 + 6.3 = H31.6$ Loading
	For Mod. Int. Stringer: $18 - 9.74 = \frac{15.17 P \times 12 \times 10}{3166.7}$ $P = 14.4$; $P/4 = 3.6$ $14.4 + 3.6 = H18.0$ Loading