ANALYSIS CHARTS FOR ISSUING VEHICLE PERMITS

Conrad P. Heins, Jr., and Richard C. Forbes,
College of Engineering, University of Maryland

A methodology that can be used to ascertain the safety of continuous (two- and three-span) composite girder slab bridges under heavy vehicle (permit) loads is discussed. The method [designed according to the 1969 AASHO code (2)] has been used for developing a series of charts, which predict directly whether a given permit vehicle causes an overstress condition in a given structure. The criteria for safety of the structure are based on the primary moment in the girders and are governed by the girder steel stress. Typical permit vehicles that meet the safety requirements have also been determined.

•THE transport of heavy loads through Maryland requires special vehicles and road permits. Issuance of these permits can only be granted when the travel route, which in most instances contains bridges, has been investigated. The safety of these bridge structures can only be assured by carefully analyzing or rating these various bridges for the proposed loads. These analyses require time that often is not available because the permit requests are generally required immediately or on weekends. The personnel issuing the permits are not engineers; therefore, guidance from the Maryland State Highway Administration bridge section personnel is imperative.

A series of analysis charts were developed (1) to reduce the required investigating time by the bridge engineer and to assure that the issuance of permits can be performed quickly and efficiently. These charts can be used by the permit office (with some guidance) in selecting the proper truck route and issuing permits.

The charts that were developed are limited to two- and three-span prismatic continuous bridges of the following lengths:

1. Two span, 70 ft $\le$ L $\le$ 140 ft and
2. Three span, in which the center span is 70 ft $\le$ L $\le$ 140 ft and the end span is 70 ft $\le$ NL $\le$ 140 ft where 0.5 $\le$ N $\le$ 1.0.

The charts were developed in accordance with the procedures used by the Maryland State Highway Administration and the AASHO code. In particular, the following design criteria were used:

1. Distribution of wheel loads according to S/7.0, where S = girder spacing;
2. Impact of 5 percent; and
3. Steel beam stresses not exceeding 0.75 Fy, where Fy = minimum yield strength.

In issuing the permit, the following restrictions are followed:

1. No other vehicles are allowed on the bridge when the permit vehicles are crossing it,
2. The speed is restricted to a crawl (3 to 4 mph), and
3. The permit vehicle should travel down the middle of the bridge in line with the main girders.

VEHICLE TYPES

The induced girder moments caused by each of these vehicles must be examined so that charts that reflect the load effects of all present permit vehicles may be developed.

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Determination of these girder moments first required the examination of the characteristics of 250 vehicles that were issued permits by the Maryland State Highway Administration. These vehicles had gross weights from 65 to 1,017 kips and lengths from 18.5 to 129.6 ft.

The vehicles were classified into twelve types (Figs. 1 through 3) according to the number of axles. Characteristics of these particular trucks will not exceed allowable bridge stresses and will satisfy allowable chart conditions.

GIRDER MOMENTS

Classifying the permit vehicles by axle number eliminates one independent variable. The other variables considered are wheelbase and gross weight. Comparisons between these variables and induced girder moments (M_{PV}) caused by these permit vehicles have shown that the primary variable is gross weight GW (1). A plot of the induced moment divided by gross weight MGW plotted against span length produced a straight line with scatter about the mean line. The mean equation is found by a linear regression analysis of the data with the scatter prescribed by the deviation 2S. Figure 4 shows a plot of the moments induced at the support and midspan of a two-span structure and moment at the support of a three-span structure for N = 1.0 and 0.9. Similar trends occurred for all other plots.

The induced girder moments caused by the permit trucks were obtained by using computerized influence lines (1, 3). Similar moments were obtained because of AASHO vehicle design loads.

General moment equations have been determined (1) for the permit vehicle and AASHO truck loads. These equations are of the form:

$$M_{PV} = (A + B \cdot L + 2S)\ GW \tag{1}$$

$$M_{AASHO} = (C + D \cdot L)\ 72.0 \tag{2}$$

where

A, B, C, D = coefficients obtained from regression analysis,
S = standard deviation,
L = span length, and
72.0 = vehicle GW.

A wheel-load distribution must be used to account for the interaction of the girders in a system. Therefore, the induced girder moments (Eqs. 1 and 2) are modified as follows:

$$M_{PV} = \frac{M_{PV}}{2} \times \frac{S}{7.0} \tag{3}$$

$$M_{AASHO} = \frac{M_A}{2} \times \frac{S}{5.5} \tag{4}$$

The half factor accounts for the wheel-load effect, because gross weight is used in Eqs. 1 and 2. S/7.0 and S/5.5 are the wheel-load distribution factors, and S is the girder spacing. Ratio R of these equations is

$$R = \frac{M_{PV}}{M_A} \tag{5}$$

or

$$R = \frac{[A + B \cdot L + 2S]\ \frac{GW}{2}\ \frac{S}{7.0}}{[C + D \cdot L]\ \frac{72.0}{2}\ \frac{S}{5.5}} \tag{6}$$

Figure 1. Typical trucks: types 2, 3, 4, and 5.

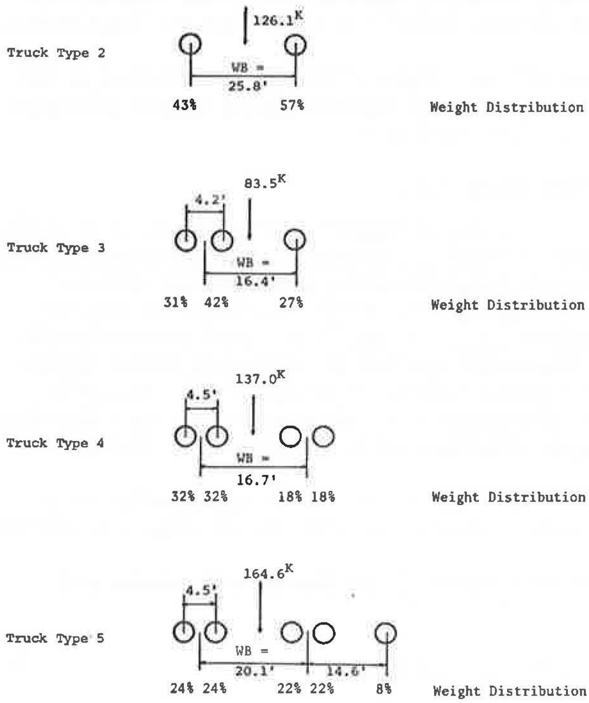


Figure 2. Typical trucks: types 6, 7, 8, and 9.

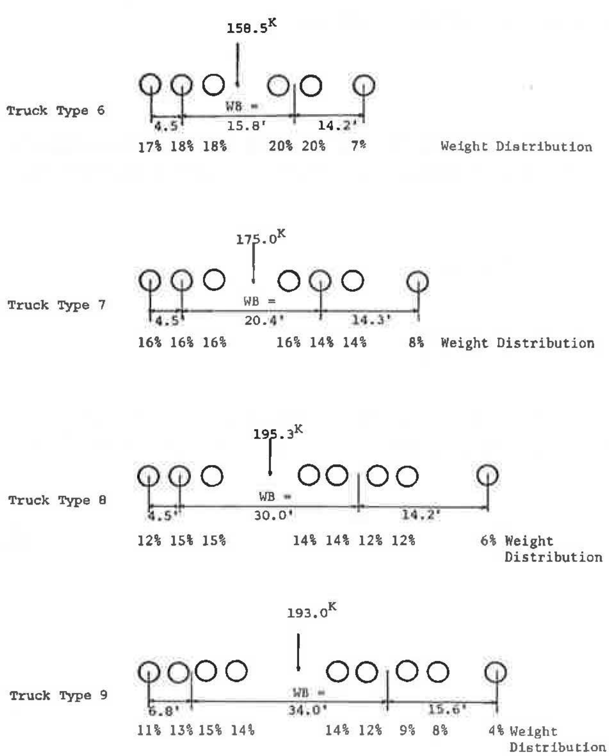


Figure 3. Typical trucks: types 10, 11, 12, and 15.

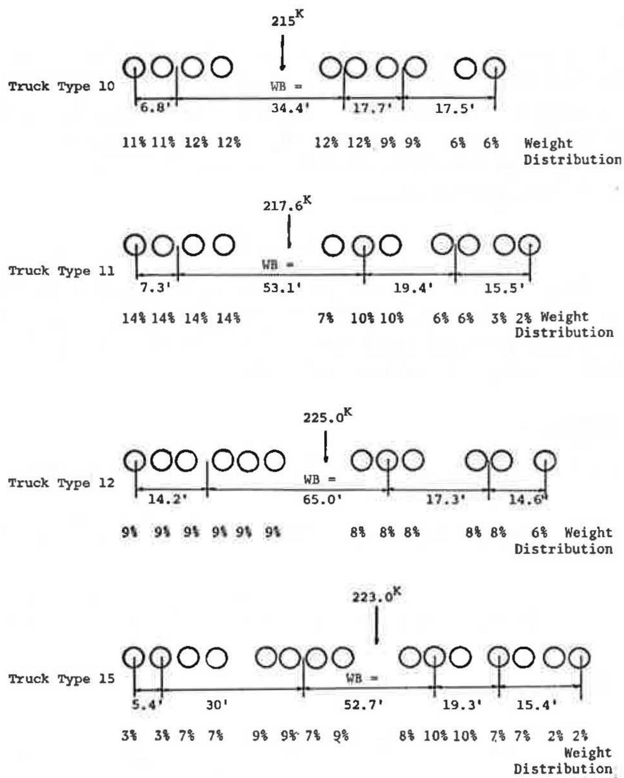
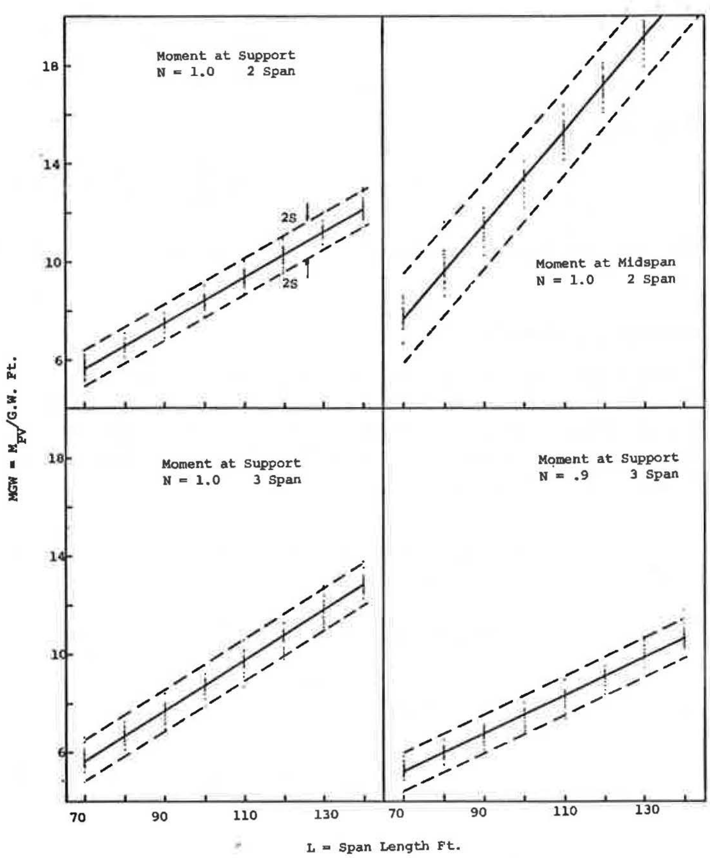


Figure 4. M_{PV}/GW versus span length: truck type 7.



Equation 5 describes the difference in the induced girder moments caused by a permit vehicle and the design loading. Factor R thus can provide a gauge of the safety of the bridge, once the limiting value of R is established. R will be plotted as a function of span length L for the corresponding truck type of gross weights and moment locations. The induced AASHO moment may be governed by lane loading, and this was duly considered in computing M_{AASHO}.

ALLOWABLE RATIO R

The limiting value of R, designated as R_{out}, depends on the initial cross section of the girders and on the permissible increase in stress (allowed by the AASHO code) that is caused by unusual vehicles. The allowable R will be regulated by the type of bridge construction, i.e., shored or unshored.

Shored Construction

By using the basic equation f = M/S, the allowable stress equation is

$$\text{Design stress (AASHO) } f = \frac{M_{DL} + M_A (1.0 + I)}{S} = 0.55 \text{ Fy} \tag{7}$$

$$\text{Permit load stress } f = \frac{M_{DL} + M_{PV} (1.0 + 0.05)}{S} = 0.75 \text{ Fy} \tag{8}$$

Equating Eqs. 7 and 8 gives

$$\frac{M_{PV}}{M_A} = 0.345 \frac{M_{DL}}{M_A} + 1.295 (1.0 + I)$$

However,

$$\frac{M_{PV}}{M_A} = R_{out}$$

Therefore,

$$R_{out_{shored}} = 0.345 \frac{M_{DL}}{M_A} + 1.295 (1.0 + I) \tag{9}$$

For any bridge structure, R_{out} may be calculated by substituting M_{DL}, M_A, and I into Eq. 9.

Unshored Construction

Equations 7 and 8 must reflect section properties S_1 and S_2, noncomposite and composite section moduli respectively, to account for unshored construction. In unshored construction, dead-load stresses are calculated with noncomposite section modulus S_1 and live-load stresses are calculated with composite section modulus S_2. The induced stresses are as follows:

$$\text{Design stress (AASHO) } f = \frac{M_{DL}}{S_1} + \frac{M_A(1.0 + I)}{S_2} = 0.55 \text{ Fy} \tag{10}$$

$$\text{Permit load stress } f = \frac{M_{DL}}{S_1} + \frac{M_{PV}(1.0 + 0.05)}{S_2} = 0.75 \text{ Fy} \tag{11}$$

Equating Eqs. 10 and 11 gives

$$R_{out_{unshored}} = 0.345 \frac{S_2}{S_1} \frac{M_{DL}}{M_A} + 1.295 (1.0 + I) \tag{12}$$

Although a majority of bridges are unshored, $R_{out_{shored}}$ is used in the development of the charts because it is always conservative. However, the more liberal $R_{out_{unshored}}$ (Eq. 12) may be used if the section properties S_1 and S_2 are known.

The dead-load moments for the bridges under study are based on estimations of dead-load weight per girder. These estimates were obtained from design curves developed by FHWA, which helped establish conservative values of girder weight. Examination of bridge plans (4) revealed that an 8½-in. slab at 120 lb/ft³ gave a conservative approximation for slab and wearing surface. The estimated dead load/ft² for the various spans is given by Forbes and Heins (1). Girder spacing of 6.5 ft was used in estimating the M_{DL} for the curves because it yields minimum R_{out} values.

EXACT VALUE OF R

An estimate of M_{DL} (exact dead-load moment) is required to determine R_{out} for Eq. 9. A more rigorous equation has been developed that will account for deviation in dead-load moment estimations. Note that Eq. 9 is only for M_{DL} inasmuch as it is assumed that the term $[M_A\ (1.0 + I) + M_{DL}]$ always equals $(0.55\ Fy \times S)$. According to Eq. 9, when M_{DL} is overestimated, R_{out} increases and when M_{DL} is underestimated, R_{out} decreases because the equation requires the total moment to be equal to the design moment of $(0.55\ Fy \times S)$.

By assuming that a nondimensional quantity δ represents the percentage of deviation of the total actual moment from the design moment of magnitude $(0.55\ Fy \times S)$, Eq. 9 becomes

$$\frac{M_{DL} + M_A\ (1.0 + I)}{0.55 + \delta} = \frac{M_{DL} + M_{PV}\ (1.0 + 0.05)}{0.75}$$

or

$$R_{out} = \frac{M_{PV}}{M_A} = \frac{(0.345 - 1.74\ \delta)}{(1.0 + 1.82\ \delta)} \frac{M_{DL}}{M_A} + \frac{1.295\ (1.0 + I)}{(1.0 + 1.82\ \delta)} \tag{13}$$

However,

$$M_{PV} = \frac{(0.75\ Fy \times S - M_{DL})}{(1.0 + 0.05)}$$

Therefore Eq. 12 gives the value of δ as

$$\delta = \frac{M_{DL} + M_A\ (1.0 + I)}{Fy \times S} - 0.55 \tag{14}$$

A pictorial representation of Eq. 12 is shown in Figure 5. When δ is zero (Fig. 5), the total moment $[M_A\ (1.0 + I) + M_{DL}]$ equals the design moment at a magnitude of $(0.55\ Fy \times S)$, and R_{out} is known exactly. When M_{DL} is overestimated, δ is positive and R_{out} decreases. If M_{DL} is underestimated, δ is negative and R_{out} increases.

When analyzing a particular bridge with known properties, Eq. 12 may be used. Equation 12 can also be used when the bridge is overdesigned. The difference between the design moment $(0.55\ Fy \times S)$ and the known existing moment equals $-\delta$, and, when substituted in Eq. 12, it will produce a larger R_{out} ratio. Thus, a heavier vehicle would be permitted to cross the bridge.

CHARTS

Equation 6 has been plotted as a function of span length, gross weight, and type of structure (1). Some of these charts for truck type 7 are shown in Figures 6 through 10. The limiting value of R (R_{out}, Eq. 8) is plotted on each of these figures.

The only parameters that are required for using these charts are the permit vehicle type [classified by number of axles (Figs. 1 through 3)], gross weight, type of bridge, and span length.

Figure 5. Allowable moment criteria.

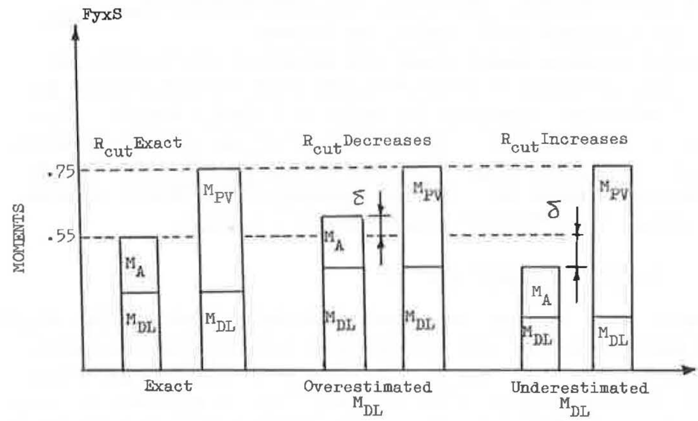


Figure 6. R versus GW: truck type 7.

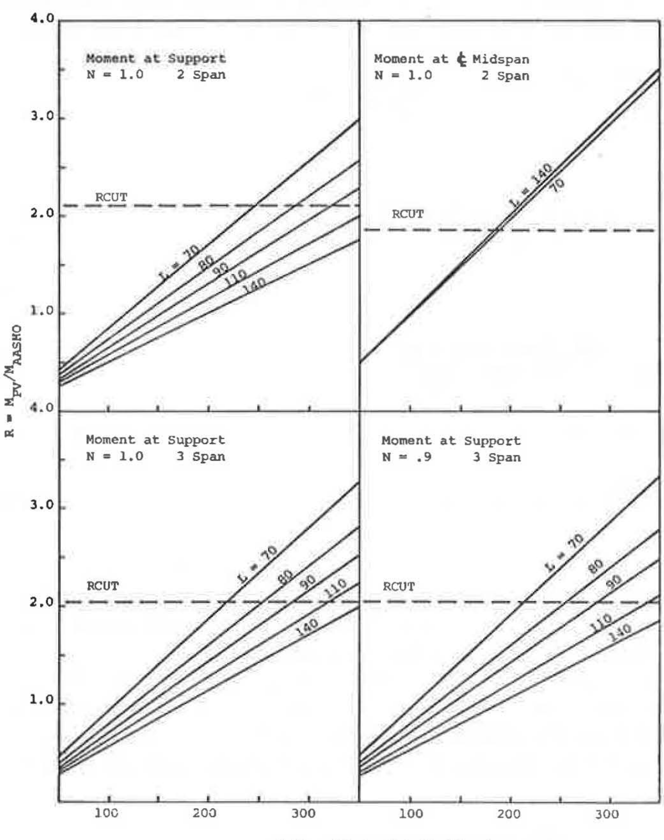


Figure 7. R versus GW: truck type 7.

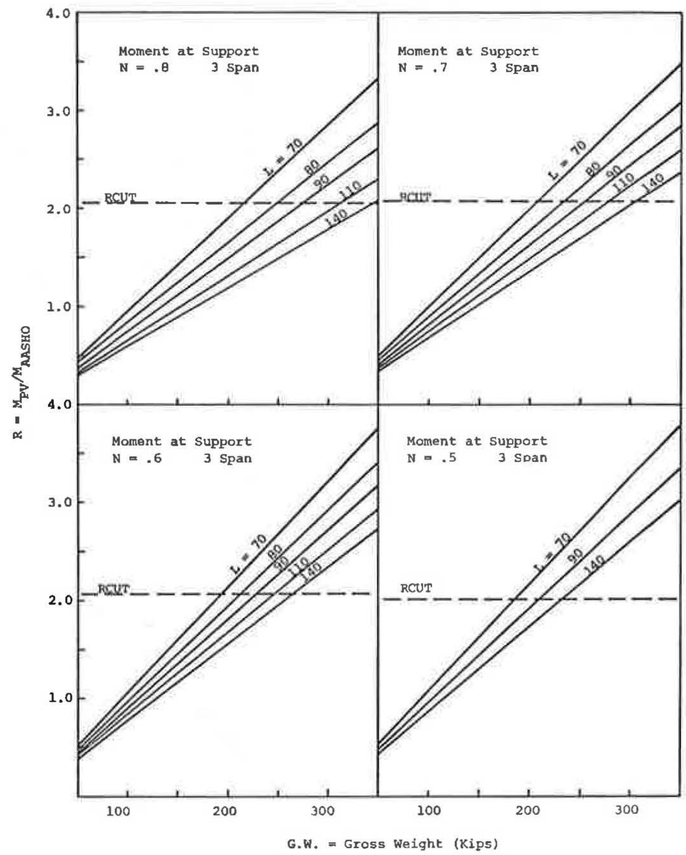


Figure 8. R versus GW: truck type 7.

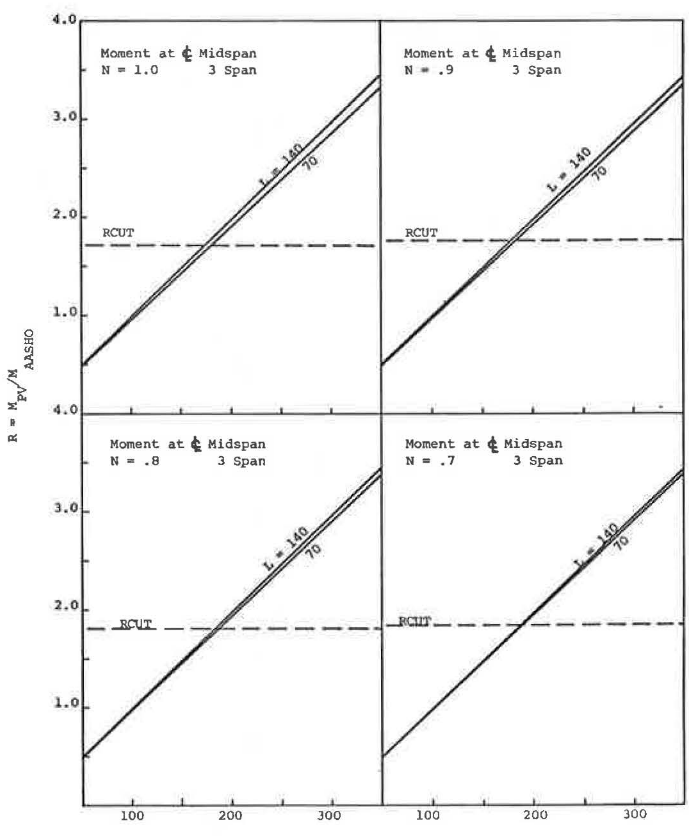


Figure 9. R versus GW: truck type 7.

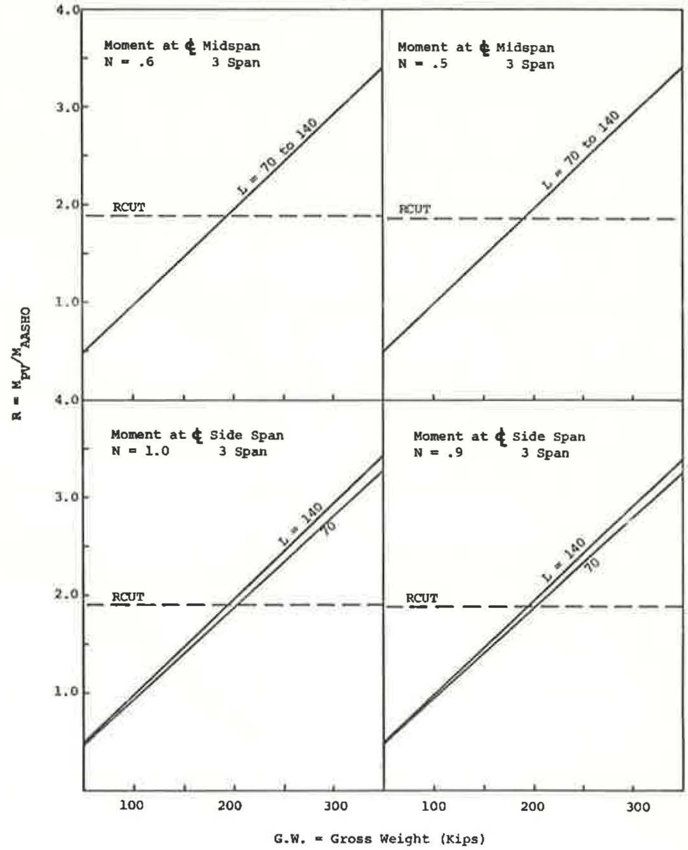


Figure 10. R versus GW: truck type 7.

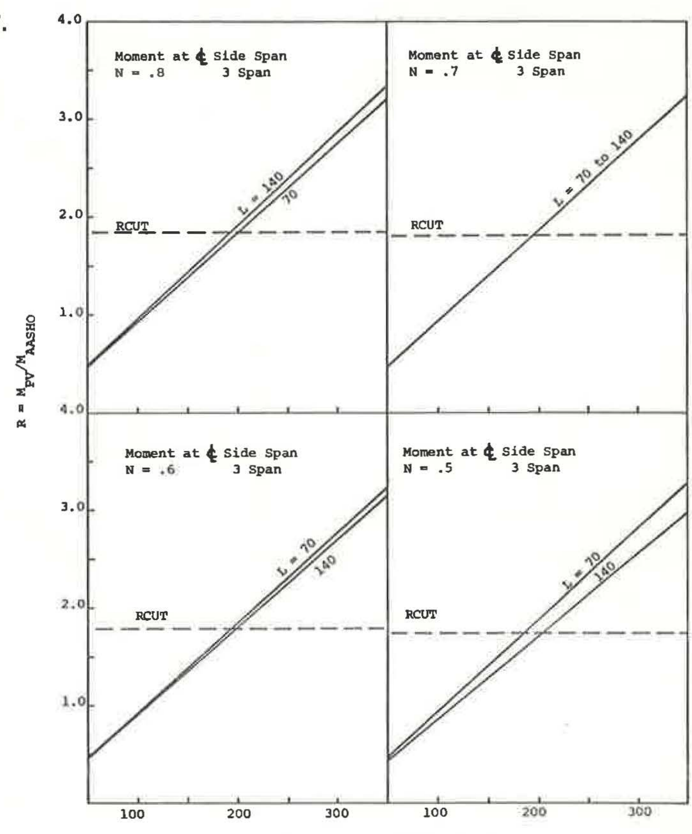


Figure 11. Three-span girder details.

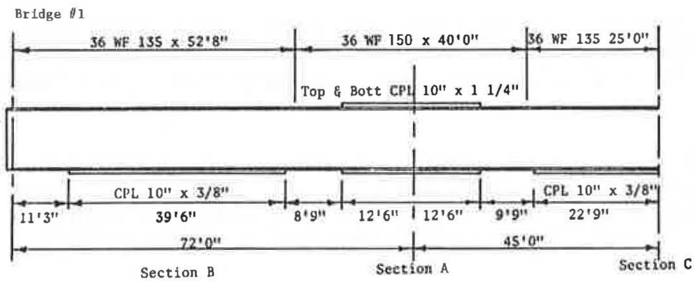


Figure 12. Permit vehicle characteristics.

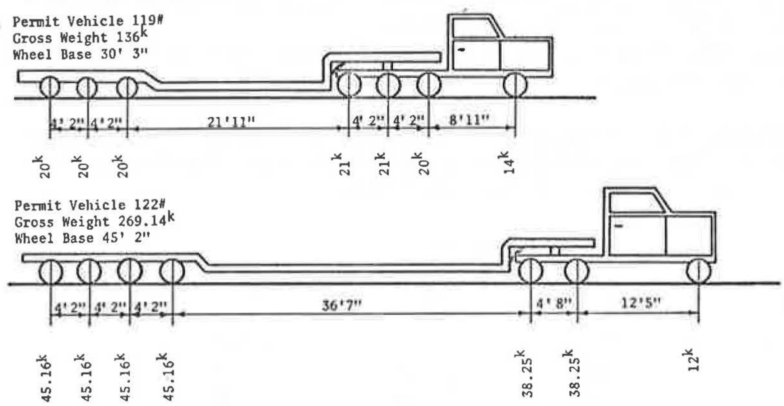


Table 1. Section properties and moments.

		Section Modulus (NC)[a]		Section Modulus (C)[b]						
		Top (in.^{3}), Steel Flange	Bottom (in.^{3}), Steel Flange	Top (in.^{3})		Bottom (in.^{3}), Steel Flange				
Section	Type			Steel Flange	Concrete Slab		M_{DL} (kip-ft)	M_A (kip-ft)	M_{PV1} (kip-ft)	M_{PV2} (kip-ft)
A	NC	849.0	849.0	849.0	—	849.0	-690.9	-635.0	-501.0	-1,000.0
B	C	454.0	530.0	357.0	16,700.0	739.0	371.0	690.0	624.0	1,220.0
C	C	454.0	530.0	357.0	16,700.0	739.0	361.0	716.0	683.0	1,352.0

[a]NC = noncomposite. [b]C = composite.

Table 2. Stresses.

	Dead-Load Stress[a]		Live-Load Stress[a] for AASHO			Live-Load Stress[a] for PV1			Live-Load Stress[a] for PV2		
			Top			Top			Top		
Section	Top, Steel Flange	Bottom, Steel Flange	Steel Flange	Concrete Slab	Bottom, Steel Flange	Steel Flange	Concrete Slab	Bottom, Steel Flange	Steel Flange	Concrete Slab	Bottom, Steel Flange
A	+9.76	-9.76	+9.0	—	-9.0	+7.08	—	-7.08	+14.12	—	-14.12
B	-9.80	+8.40	-2.35	-0.414	+11.37	-2.10	0.374	+10.15	-4.09	0.731	+19.78
C	-9.54	+8.18	-2.40	-0.429	+11.59	-2.29	0.409	+11.09	-4.55	0.810	+22.0

[a]Measured in ksi.

APPLICATION

Nine existing bridges were completely analyzed to show the reliability of the charts and their application in predicting induced maximum stresses caused by permit vehicles (1). Ratios of stresses obtained by an exact analysis were compared to the chart values. In all instances R_{out} values were always conservative and provided safe analysis by use of the charts.

Figure 11 shows the analysis of a three-span continuous bridge. The bridge was composite in the positive moment region; made of A36 steel; and had a 7-in. concrete slab, 2-in. wearing surface, 7-ft, 7-in. girder spacing, and a computed 1.038 kips/ft dead load per girder. The bridge was subjected to two different seven-axle (heavy) trucks, as shown in Figure 12.

The safety of the three-span structure after these trucks had passed over it can be seen in Figures 6 through 10. For an end span ratio of N = 72 ft/90 ft = 0.80 and with examination of $M_{support}$ (Fig. 7), M_{01} at midspan (Fig. 8), and M_{01} at side span (Fig. 10), for GW = 136 kips, and L = 90 ft, the R value is below the R_{out} at all moment locations. Therefore, permit vehicle 1 (PV1) may cross the bridge.

For the 269-kip permit vehicle (PV2), the R value for the moment at M_{01} of midspan and end span exceed R_{out}; therefore, this truck would not be permitted to cross the bridge.

The exact stress analysis of this bridge based on AASHO and permit loads is summarized in Tables 1 and 2. The total dead-load and live-load governing stresses at the critical points (A, B, and C) on the girder are as follows:

	Stress (ksi)		
Loading	A	B	C
AASHO	±18.76	+19.77	+19.77
PV1	±23.88	+18.55	+19.27
PV2	±23.88	+28.18	+30.18

The allowable stress on the steel based on the overloads is 0.75 Fy = 27.0 ksi. PV1 does not cause an overstress at any sections; therefore, it may be issued a permit. PV2 does cause an overstress; thus no permit would be granted. This is the same conclusion that was reached when the charts were used. The concrete stress is less than 0.40 f_c' and does not govern.

CONCLUSIONS

A series of charts have been developed (1) that can be applied toward determining the safety of continuous span composite bridges that are subjected to heavy vehicle loads. These charts are easily used and are functions of vehicle gross weight, truck type based on the number of axles, span length, and location of the moment on the girder.

ACKNOWLEDGMENT

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