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A Pragmatic Approach in Rating Highway Bridges

SHIH C. PENG

ABSTRACT

A procedure is presented for rating highway bridges for regulation loads without causing yielding of the bridge materials. The procedure consists of three major parts: the measurement of regulation loads with a load measure, the yield capacity calculations of bridge members, and the ratings for various traffic conditions. The importance of accurate ratings, which will form the basis for making decisions pertaining to bridge upgrading and traffic control, is recognized. The results of the actual application of the procedure were found to be satisfactory in the strengthening programs of many existing bridges and in issuing overload permits. The procedure is considered to be simple, direct, and practical.

Highway bridges can have different ratings under different loading conditions. Because the actual traffic conditions are basically controlled by state regulations, it is logical to assume that regulation or legal loads resemble the various highway loadings. For upgrading an existing bridge economically, issuing overload permits, or posting for load limits, more reliable ratings for the regulation loads are desirable. Because any standard loading, such as HS20, as given in the AASHTO specifications (1) or a statistical truck model, is incapable of simulating all the load effects caused by the action of regulation loads of innumerable combinations of axle loads and spacings on various bridge members, it cannot yield reliable ratings. But by using a load measure, the actual traffic condition can be closely measured and thus more reliable ratings can be obtained.

A standard loading can easily be made into a load measure, for instance, by changing HS20 to HSW, where W is the variable combined weight on the first two axles. This simple transformation will make HS no longer a standard loading but rather a system of measurement. Like feet or meters for measuring lengths, the HS load measure may be used to obtain the load effects of various highway loadings. The proportional configuration of the HS load measure suggested is identical to that of the HS loading, which consists of either a three-axle truck or the corresponding lane loading. The only exception is that the spacing of the last two axles is fixed at 14 ft for the HS load measure.

The basic principle followed in this paper is to rate highway bridges for regulation loads without causing yielding of the bridge materials. Because the bridges will not be considered usable after permanent yielding, the ultimate strength of the bridge members beyond yield will not be used in the rating.

It is estimated that without changing the design criteria, such as impact and load distribution, and by adopting the modified capacity formulas for the load-factor design as given in the current AASHTO specifications, a rating procedure for the regulation loads of any state could be developed and made operational within a short period, say, 2 to 3 months, by using the approach described in this paper.

BRIDGE LOADS

Three basic loads--dead, live, and impact--are considered in the rating of most highway bridges. For any existing bridge, the dead loads can be accurately estimated from plans or field measurements, the live loads are the regulation loads, and the impact loads may be calculated according to the AASHTO specifications.

Because it is rather cumbersome to apply the regulation loads directly in structural analyses and calculations, the HS load measurements are substituted for the regulation loads. The method of determining the HS measurements is described in the following.

Almost all the regulation loads have numerous truck configurations. In order to determine the maximum load effects (moment and shear in a simple span), repetitious calculations for the numerous configurations are apparently inevitable. However, because the main features of most regulations are similar in defining the maximum axle load, the minimum axle spacing, and the combinations of the axles, a simple structural rule, that the heaviest total load within the shortest distance will produce the largest load effect, can be used to eliminate many truck configurations. Once the maximum load effect has been found, the equivalent HS loading or HS measurement can be determined by proportion. The HS measurement represents a loading that will produce the same load effect as that produced by the governing regulation loads. The word "governing" is used to indicate that the loads will cause the maximum load effect.

Listed in Table 1 are the maximum load effects (moments and shears) caused by HS20 loading acting on simple spans. A similar table may be found in Appendix A of the AASHTO specifications.

To illustrate for typical regulation loads, listed in Table 2 are the maximum moments and shears and their corresponding HS measurements for the Northwest Territories (NWT) governing regulation loads (2) on simple spans. To account for the multiple presence of regulation trucks on short-span bridges, only two trucks tailgating at an assumed spacing of 40 ft between the rear axle of the first truck and the front axle of the following truck were used. The values in Table 2 would differ if different regulation loads and truck spacings were chosen, and they are not recommended for use except in this paper. A graphic representation of the HS measurements for spans up to 300 ft is shown in Figure 1.

As an example, for a moment of 759.3 ft•kip caused by an NWT governing truck acting on a 50-ft span (Table 2), the HS measurement is calculated as follows:

$$HS_m \; [(759.3 \times 20)/627.9] = HS_m 24.2,$$

where 627.9 is the maximum moment in foot kips caused by HS20 loading acting on the 50-ft span (Table 1).

Table 2 is the most important tool in rating and it also requires the most time to develop. Table 2 remains useful as long as the regulations are enforced and provided that there is no substantial change in the traffic pattern.

APPLICATION OF HS LOAD MEASURE

The HS measurements for the maximum load effects of the NWT regulation loads in a structural member can be found in Table 2 if the equivalent simple-span length is known. It is assumed that the equivalent simple-span length is equal to the loaded-span length for the structural member obtained by using the principle of influence lines. The loaded-span length is the length on which the loads can be placed to produce the maximum load effect in a structural member and is not necessarily the length of the member. The technique for determining the loaded-span length, or the equivalent simple-span length, is to match the general shapes of the influence lines for the structural member concerned with the maximum moment or shear influence line for a simple span as shown in Figure 2.

It is quite clear that for a simple beam, the loaded-span length is equal to the length of the beam for both the maximum moment and maximum shear.

TABLE 1 Maximum Moments and Shears of HS20 on Simple Spans (One Lane)

Span (ft)	Moment (ft·kips)	Shear (kips)	Span (ft)	Moment (ft·kips)	Shear (kips)	Span (ft)	Moment (ft·kips)	Shear (kips)	Span (ft)	Moment (ft·kips)	Shear (kips)	Span (ft)	Moment (ft·kips)	Shear (kips)
1	8.0	32.0	21	168.0	42.7	42	485.3	56.0	100	1,524.0	65.3	400	14,600.0	154.0
2	16.0	32.0	22	176.0	43.6	44	520.9	56.7	110	1,703.6	65.9	420	16,002.0	160.4
3	24.0	32.0	23	184.0	44.5	46	556.5	57.3	120	1,883.3	66.4	440	17,468.0	166.8
4	32.0	32.0	24	192.7	45.3	48	592.1	58.0	130	2,063.1	67.6	460	18,998.0	173.2
5	40.0	32.0	25	207.4	46.1	50	627.9	58.5	140	2,242.8	70.8	480	20,592.0	179.6
6	48.0	32.0	26	222.2	46.8	52	663.6	59.1	150	2,475.1	74.0	500	22,250.0	186.0
7	56.0	32.0	27	237.0	47.4	54	699.3	59.6	160	2,768.0	77.2	520	23,972.0	192.4
8	64.0	32.0	28	252.0	48.0	56	735.1	60.0	170	3,077.1	80.4	540	25,758.0	198.8
9	72.0	32.0	29	267.0	48.8	58	770.8	60.4	180	3,402.0	83.6	560	27,608.0	205.2
10	80.0	32.0	30	282.1	49.6	60	806.5	60.8	190	3,743.1	86.8	580	29,522.0	211.6
11	88.0	32.0	31	297.3	50.3	62	842.4	61.2	200	4,100.0	90.0	600	31,500.0	218.0
12	96.0	32.0	32	312.5	51.0	64	878.1	61.5	220	4,862.0	96.4			
13	104.0	32.0	33	327.8	51.6	66	914.0	61.9	240	5,688.0	102.8			
14	112.0	32.0	34	343.5	52.2	68	949.7	62.1	260	6,578.0	109.2			
15	120.0	34.1	35	361.2	52.8	70	985.6	62.4	280	7,532.0	115.6			
16	128.0	36.0	36	378.9	53.3	75	1,075.1	63.1	300	8,550.0	122.0			
17	136.0	37.7	37	396.6	53.8	80	1,164.9	63.6	320	9,632.0	128.4			
18	144.0	39.1	38	414.3	54.3	85	1,254.7	64.1	340	10,778.0	134.8			
19	152.0	40.4	39	432.1	54.8	90	1,344.4	64.5	360	11,988.0	141.2			
20	160.8	41.6	40	449.8	55.2	95	1,434.1	64.9	380	13,262.0	147.6			

TABLE 2 Maximum Moments, Shears, and HS Measurements of NWT Regulation Loads on Simple Spans (One Lane)

L_s (ft)	M (ft-kips) (1)	M (ft-kips) (2)	V (kips) (1)	V (kips) (2)	HS_m (tons) (1)	HS_m (tons) (2)	HS_v (tons) (1)	HS_v (tons) (2)
1	5.0		20.0		12.5		12.5	
2	10.0		20.0		12.5		12.5	
3	15.0		20.0		12.5		12.5	
4	20.0		21.4		12.5		13.4	
5	25.0		23.4		12.5		14.6	
6	30.4		25.4		12.7		15.9	
7	36.7		26.9		13.1		16.8	
8	44.8		27.9		14.0		17.4	
9	52.9		28.9		14.7		18.1	
10	61.2		29.8		15.3		18.6	
11	70.1		30.5		15.9		19.1	
12	79.1		31.3		16.5		19.6	
13	88.1		32.1		16.9		20.1	
14	97.9		32.6		17.5		20.4	
15	107.8		33.0		18.0		19.4	
16	117.7		33.5		18.4		18.6	
17	128.0		34.8		18.8		18.5	
18	138.6		36.7		19.3		18.8	
19	149.1		38.5		19.6		19.1	
20	160.0		40.3		20.0		19.4	
21	171.7		41.9		20.4		19.6	
22	183.4		43.4		20.8		19.9	
23	195.1		45.0		21.2		20.2	
24	207.7		46.3		21.6		20.4	
25	220.3		47.6		21.2		20.7	
26	232.9		48.9		21.0		20.9	
27	248.2		50.0		20.9		21.1	
28	264.4		50.9		21.0		21.2	
29	280.6		51.9		21.0		21.3	
30	299.2		52.9		21.2		21.3	
31	320.6		53.9		21.6		21.4	
32	341.9		54.9		21.9		21.5	
33	363.3		55.9		22.2		21.7	
34	384.6		56.8		22.4		21.8	
35	406.0		57.7		22.5		21.9	
36	427.3		58.6		22.6		22.0	
37	448.9		59.4		22.6		22.1	
38	470.5		60.2		22.7		22.2	
39	492.1		61.1		22.8		22.3	
40	514.1		61.8		22.9		22.4	
42	558.6		63.0		23.0		22.5	
44	603.7		65.3		23.2		23.0	
46	649.4		68.2		23.3		23.8	
48	704.3		70.0		23.8		24.1	
50	759.3		71.3		24.2		24.4	
52	814.6		73.1		24.6		24.7	
54	869.6		74.4		24.9		25.0	
56	924.5		75.7		25.2		25.5	
58	979.8		76.9		25.4		25.5	
60	1,035.1		78.0		25.7		25.7	
62	1,090.4		79.0		25.9		25.8	
64	1,145.3		80.0		26.1		26.0	
66	1,200.2		81.1		26.3		26.2	
68	1,255.5		81.9		26.4		26.4	
70	1,310.6		82.7		26.6		26.5	
75	1,448.4		84.6		26.9		26.8	
80	1,585.9		86.0		27.2		27.0	
85	1,724.1		87.4		27.5		27.3	
90	1,861.6		88.7	89.7	27.7		27.5	27.8
95	1,992.2		89.9	92.6	27.9		27.7	28.5
100	2,137.0		90.5	95.5	28.0		27.8	29.2
110	2,412.8		92.6	102.8	28.3		28.1	31.2
120	2,688.2		94.2	110.3	28.5		28.4	33.2
130	2,964.0	2,984.1	95.5	117.1	28.7	28.9	28.3	34.6
140	3,239.2	3,358.9	96.4	125.2	28.9	30.0	27.2	35.4
150	3,514.8	3,845.7	97.3	131.4	28.4	31.1	26.3	35.5
160	3,790.5	4,346.3	98.1	137.2	27.4	31.4	25.4	35.5
170	4,066.3	4,847.7	98.9	142.0	26.4	31.5	24.6	35.3
180	4,341.4	5,349.0	99.4	146.4	25.5	31.4	23.8	35.0
190	4,617.1	5,867.7	100.0	150.2	24.7	31.4	23.0	34.6
200	4,892.9	6,412.4	100.5	153.7	23.9	31.3	22.3	34.2
220	5,443.6	7,503.4	101.4	159.9	22.4	30.9	21.0	33.2
240	5,995.1	8,596.5	102.1	164.9	21.1	30.2	19.9	32.1
260	6,546.0	9,691.0	102.8	169.1	19.9	29.5	18.8	31.0
280	7,096.8	10,787.0	103.4	172.9	18.8	28.6	17.9	29.9
300	7,648.0	11,883.0	103.9	176.0	17.9	27.8	17.0	28.9
320	8,199.1	12,980.4	104.2	180.1	17.0	27.0	16.2	28.1
340	8,752.7	14,078.6	104.5	181.3	16.2	26.1	15.5	26.9
360	9,304.0	15,176.7	105.0	183.5	15.5	25.3	14.9	26.0
380	9,855.2	16,275.6	105.2	185.4	14.9	24.5	14.3	25.1
400	10,406.5	17,375.2	105.4	187.2	14.3	23.8	13.7	24.3
420	10,957.7	18,474.8	105.6	188.7	13.7	23.1	13.2	23.5
440	11,509.0	19,574.4	105.8	190.1	13.2	22.4	12.7	22.8
460	12,060.2	20,674.8	106.1	191.4	12.7	21.8	12.3	22.1
480	12,611.5	21,774.4	106.3	192.7	12.2	21.1	11.8	21.5
500	13,162.7	22,875.4	106.4	193.8	11.8	20.6	11.4	20.8
520	13,714.0	23,975.8	106.5	194.9	11.4	20.0	11.1	20.3
540	14,265.2	25,076.8	106.7	195.8	11.1	19.5	10.7	19.7
560	14,816.5	26,177.1	106.8	196.7	10.7	19.0	10.4	19.2
580	15,367.7	27,278.2	106.9	197.6	10.4	18.5	10.1	18.7
600	15,919.0	28,379.2	107.0	198.2	10.1	18.0	9.8	18.2

Note: L_s = span length, M = moment of governing regulation loads, V = shear of governing regulation loads, HS_m = HS measurement for moment effect, HS_v = HS measurement for shear effect, (1) = single regulation truck, and (2) = two regulation trucks with 40-ft spacing between them.

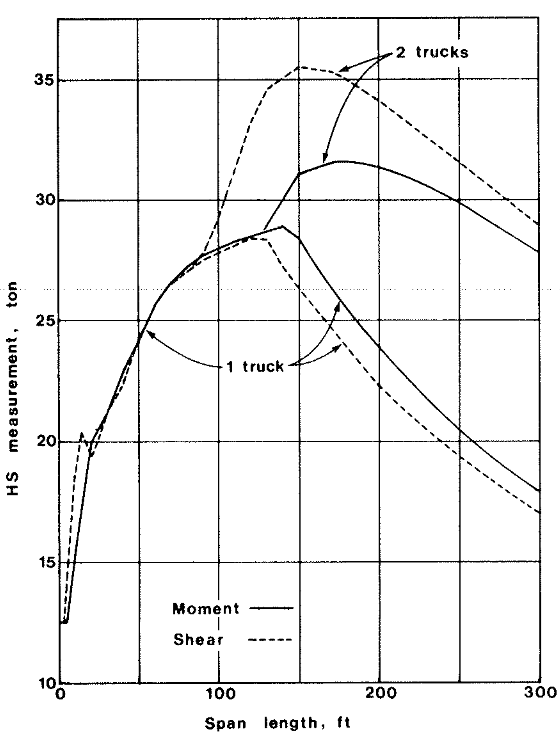

FIGURE 1 HS measurements of NWT regulation loads.

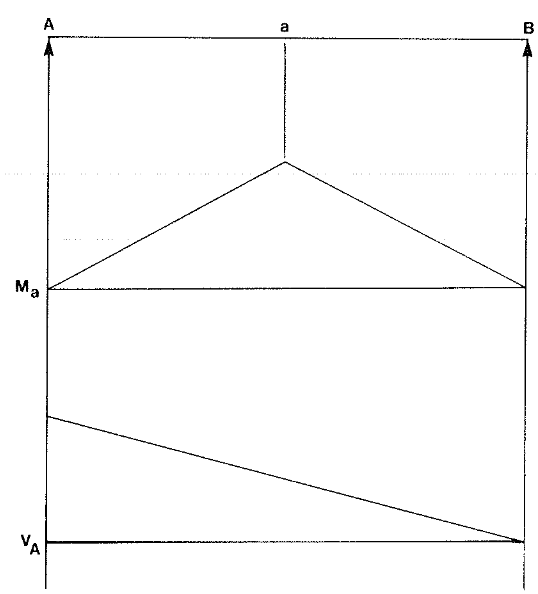

FIGURE 2 Influence lines of maximum moment and shear for a simple span.

Thus the corresponding HS measurements can be obtained easily from Table 2.

For a continuous beam as shown in Figure 3, the HS measurement for moment (HS_m) is selected when the shape of the influence line appears to be a moment influence line for a simple span and the HS measurement for shear (HS_v) is selected when the shape of the influence line appears to be a shear influence line for a simple span. For the reaction R_B at the interior support B, because the shape of the influence line ABC is similar to that of the moment influence line for the simple span AC, the loaded-span length of 220 ft is used and HS_m30.9 is selected for two trucks tailgating.

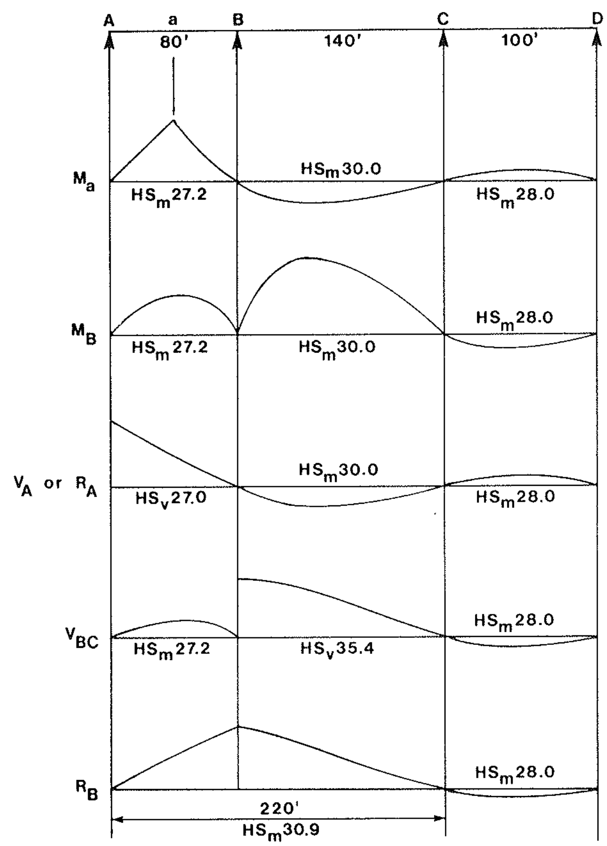

FIGURE 3 Influence lines and HS measurements for a continuous beam.

For a truss, as shown in Figure 4, the loaded-span length for the chord members is the length of the truss, whereas for the diagonals and verticals, the loaded-span lengths are determined by their corresponding influence lines. It can be seen that whether to select HS_m or HS_v is not so clear as it was in the case of beams. However, HS_m may be used for chord members and hangers and HS_v for diagonals and verticals other than hangers.

For floor beams perpendicular to traffic, the loaded-span lengths are determined by using the beam spacings rather than the lengths of the beams, as shown in Figure 5. Otherwise the determination of the loaded-span lengths for selection of the HS measurements for these beams is similar to that for the reactions in a continuous beam, as shown in Figure 3.

A concrete deck slab with main reinforcement perpendicular to traffic (Figure 6) may be assumed a continuous beam just as it is if the main reinforcement is parallel to traffic. In most state regulations the minimum axle spacings are generally less than but could be close to the wheel spacing of HS trucks as specified in the AASHTO specifications. The approximately equal axle and wheel spacings make Table 2 also useful for slabs. The HS measurements would be slightly conservative, because the minimum

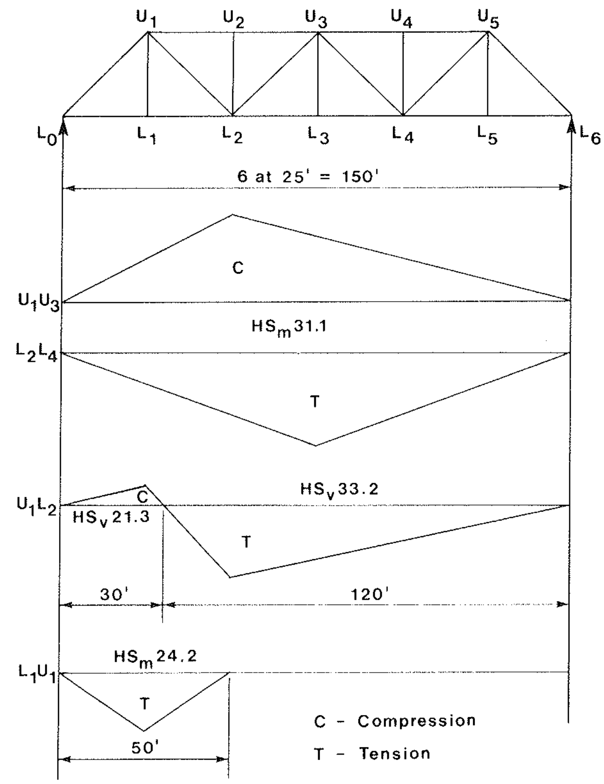

FIGURE 4 Influence lines and HS measurements for a truss.

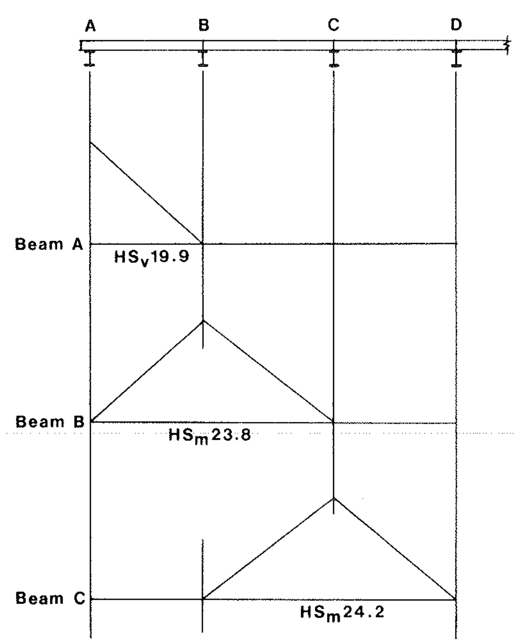

FIGURE 5 Influence lines and HS measurements for floor beams.

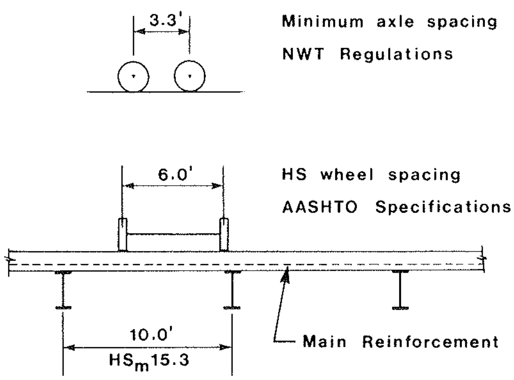

FIGURE 6 HS measurement for concrete deck slab with main reinforcement perpendicular to traffic.

axle spacing given in the NWT regulations is less than the wheel spacing of HS trucks.

BRIDGE MEMBER CAPACITIES

The bridge member capacities may be calculated by using the capacity formulas in the load-factor designs as given in the AASHTO specifications (1). All the formulas given for the reinforced-concrete design are directly applicable to the rating. The capacity formulas for the prestressed-concrete and the structural-steel bridges require two modifications. One is to introduce a capacity or strength reduction factor (ϕ) to all the formulas. The other is to replace the ultimate strength with the yield strength if the ultimate strength is present in the formula.

The capacity reduction factor is normally less than 1, which will reduce the yield capacity to an available capacity for the estimated dead, live, and impact loads and other important loads if required. The remaining capacity ($1 - \phi$) is reserved to account for all the miscellaneous effects acting simultaneously with the estimated loads. These miscellaneous effects include aging and deterioration of the structures, variations in material strength, workmanship and dimensions, and so forth. The values of ϕ found in many design codes (1,3-5) do not take aging and deterioration into consideration. For use in the rating exercise, these values may be adjusted to suit the existing general conditions of the structures.

The use of the material yield strength instead of the ultimate strength is simply to emphasize the concept that the failure modes and permanent deformation are not considered in the rating of the bridges.

The following are a few commonly used capacity formulas for prestressed concrete and structural steel, which have been modified:

1. The flexural strength of a rectangular section of prestressed concrete is expressed as follows:

$$\phi M_y = \phi A_s^* f_y^* d[1 - 0.6p^*(f_y^*/f_c')] \tag{1}$$

where

A_s^* = area of prestressing steel,
d = distance from extreme compressive fiber to centroid of prestressing force,
f_c' = compressive strength of concrete at 28 days,
f_y^* = yield stress of prestressing steel,
M_y = yield moment strength of a section,
p^* = ratio of prestressing steel, and
ϕ = capacity reduction factor.

The preceding formula is identical to that for reinforced concrete.

2. For structural steel Equations 2, 3, and 4 give bending, axial tension, and axial compression, respectively:

$$\phi M_y = \phi S F_y \tag{2}$$

$$\phi T_y = \phi A_n F_y \tag{3}$$

$$\phi P_y = 0.85 \phi A_s F_{cr} \tag{4}$$

where

A_n = net effective area,
A_s = gross effective area,
F_{cr} = buckling stress,
F_y = yield stress of steel,
P_y = yield compressive strength,
S = elastic section modulus, and
T_y = yield tensile strength.

The compact sections will be treated the same as the noncompact sections, and the plastic section modulus will not be used.

BRIDGE RATING

The bridge rating is a measure of the bridge member capacity available for the maximum live and impact loads and is expressed as a number in terms of the regulation loads. A rating of 1.3 for a bridge member means that the member can carry 1.3 times the regulation load. Also, the rating can be regarded as the live-load factor.

The general equation for rating is as follows:

$$\text{Rating} = [(\phi - D)/\Sigma L(1 + I)]\,(HSW/HS) \tag{5}$$

where

D = dead-load effect expressed as a fraction of yield capacity,
I = impact fraction,
L = live-load effect expressed as a fraction of yield capacity,
HS = HS loading used in analysis, and
HSW = HS measurements for the regulation loads.

If HS measurements are used in the analysis, Equation 5 becomes

$$\text{Rating} = (\phi - D)/\Sigma L(1 + I) \tag{6}$$

An example of the rating of an interior steel girder of a two-lane bridge for NWT regulation loads is outlined in the following. Girder characteristics are as follows: length, 85 ft; spacing, 8 ft; section: W36 x 260, S = 952 in.^{3}, F_y = 36 ksi; dead load, 0.8 kip/ft of girder length; live load, HS20 used for analysis; and design code, AASHTO specifications for 1977 (1).

1. Compute the yield moment capacity of W36 x 260:

$\phi M_y = \phi S F_y = \phi(952)(36)(1/12) = 2{,}856\phi$ ft•kip,
$M_y = 2{,}856$ ft•kip.

2. Compute dead-load moment and D at midspan:

$M_D = 0.125(0.8)(85)^2 = 722.5$ ft•kip,
$D = 722.5/2{,}856 = 0.253$ ft•kip.

3. Compute maximum live-load moment (M_L) and L. The distributions of wheel loads for the concrete deck are 8/5.5 = 1.455 for two lanes and 8/7.0 = 1.143 for one lane. From Table 1, for an 85-ft span the maximum moment near midspan is 1,254.7 ft•kip per lane for HS20. Then M_L and L are calculated as follows:

M_L = 0.5(1,254.7)(1.455) = 912.8 ft•kip for two lanes,
M_L = 0.5(1,254.7)(1.143) = 717.1 ft•kip for one lane,
L = 912.8/2,856 = 0.320 for two lanes, and
L = 717.1/2,856 = 0.251 for one lane.

4. Compute impact fraction:

I = 50/(85 + 125) = 0.238.

5. Compute the rating for a girder in good condition with $\phi = 0.9$. From Table 2, for L_s = 85 ft, HS_m = 27.5. The following calculations are for both lanes loaded and one lane loaded:

Rating (both lanes) = [(0.9 - 0.253)/0.320(1 + 0.238)](20/27.5) = 1.188.

Rating (one lane) = [(0.9 - 0.253)/0.251(1 + 0.238)] x (20/27.5) = 1.514

The results indicate that the girder could carry about 20 percent overload for both lanes loaded and about 50 percent overload for only one lane loaded.

6. Compute the rating for a girder in a heavily corroded condition with $\phi = 0.75$:

Rating (both lanes) = [(0.75 - 0.253)/0.320(1 + 0.238)](20/27.5) = 0.912.

Rating (one lane) = [(0.75 - 0.253)/0.251(1 + 0.238)] x (20/27.5) = 1.163.

The rating of 0.912 indicates that the girder would require either strengthening or posting if both lanes were frequently loaded.

7. Compute rating for the same condition as in step 6 except that only one-half the impact load is used:

Rating (both lanes) = [(0.75 - 0.253)/0.320(1 + 0.119)](20/27.5) = 1.009.

Rating (one lane) = [(0.75 - 0.253)/0.251(1 + 0.119)] x (20/27.5) = 1.287.

Low speed may be posted to reduce impact. The girder could still carry about 30 percent overload if single-lane traffic at reduced speed is enforced.

DISCUSSION

Instead of indiscriminately using a standard loading in the evaluation of bridges, the approach and the method of rating presented here would enable practicing engineers to use their own judgment in dealing with local and many particular traffic conditions.

The rating example shows that there are many ratings for many different traffic conditions. It is believed that the rating results are easily understood by engineers, truckers, and regulation enforcement agencies. On the other hand, a rating based on a standard loading would only indicate whether the structure was adequate for that loading. Decisions made according to such a rating would be questionable if the regulation loads are actually carried by the bridges. Any loading that does not represent the actual traffic loads could result in either an uneconomical use of the bridge materials or an unsafe structure. In general, upgrading for the standard HS loading would often result in higher cost for shorter bridge members and lower cost for longer members, whereas upgrading for the regulation loads would yield the opposite results.

In order to have accurate ratings, many aspects need to be considered. One way of simulating the regulation loads is offered in this paper. Other aspects, such as the determination of member capacities and the methods of structural analyses, must depend on the judgment of the practicing engineers for accuracy. The reason for choosing the HS configuration as a measuring device is that the HS loading has been commonly used in the past and thus it is familiar to bridge engineers and will retain the usefulness of the old calculations.

The technique used in the rating could also be adopted in design. The corresponding HS measurements may be used instead of the standard HS20 loading if the bridge is to be designed to carry the regulation loads. It is seen in Table 2 and Figure 1 that bridge members having different span lengths would have different HS measurements. If the design live loads closely resembled the regulation loads, the load factor applied to the live load in the AASHTO specifications could be appreciably reduced.

The treatment of other load effects, such as live-load deflection, fatigue, and the uncracked condition of the prestressed-concrete section, are beyond the scope of this paper. In the current codes (1,3-5) these effects are dealt with under specified service loads. It is suggested that the service loads also be scrutinized and that some of the effects may be redefined. For instance, suppose that a live-load deflection under a given service load exceeds the code limit. What is to be done about this? Is the strengthening of the member required or should the deflection be ignored? Also, how can the tension allowed in the precompressed tensile zone of a prestressed-concrete section with bonded reinforcement be maintained under a load heavier than the service load? The tension would disappear forever when the service load was exceeded and the section became permanently cracked.

The concept of the load measure is quite different from that of the standard loading. Essentially, a standard loading must be related to a set of traffic conditions, which are largely based on a survey, and the method of determining a standard loading is usually a statistical one. Unless the survey data are inclusive and timeless and the statistical assumptions are accurate enough, the standard loading would not be able to cope with all traffic conditions. On the other hand, because a load measure has no built-in assumptions of any traffic condition, it is able to measure the load effects of any loading adequately.

CONCLUSION

For more realistic ratings, it is important to use the regulation loads in conjunction with local traffic conditions. There will be different ratings for different traffic conditions. A load measure is more adaptable than a standard loading in simulating the regulation loads. The rating procedure presented has been applied satisfactorily in the strengthening programs of many Canadian federal bridges and is believed to be simple, direct, and practical.

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A Rational Procedure for Overweight Permits

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ABSTRACT

A rational procedure for calculating safe permit loads for vehicles as governed by the bridges on the route without having to analytically evaluate all the bridges is given. The basis of the procedure is the worst combination of maximum vehicle weights that a bridge is likely to have sustained during its lifetime. With the severest load combination as the datum, maximum increases over legal loads for normal traffic are calculated for control vehicles. Expressions for calculating the modification factors corresponding to two- and three-lane loadings are also provided.

Applications are quite often made for permission to let a much heavier vehicle cross a bridge than that legally permitted for normal traffic. The maximum safe weight for such a vehicle can be obtained by an analytical evaluation of the bridge. Alternatively, according to the procedures developed in this paper, the maximum safe weight of a special-permit vehicle can be obtained from the heavy vehicle traffic that a bridge is known to have carried during its lifetime.

The design capacity of a highway bridge carrying normal traffic safely implicitly takes account of the following factors:

1. Legally permitted normal vehicle weights as represented by the design vehicle and possibly a portion of the live-load factor,
2. Bridge type,
3. Number of lanes on a bridge,
4. Length of span,
5. Accidental and deliberate exceedance of legally permitted weights,
6. Transverse vehicle position,
7. Simultaneous presence of more than one vehicle in the transverse direction,
8. Simultaneous presence of more than one vehicle in a lane,
9. Vehicle width, and
10. Vehicle speed as represented by the dynamic load allowance or impact factor.

In the case of a special-permit vehicle, factors 5-10 are either known beforehand with some degree of certainty or can be prescribed as a condition for the permit. More reliable knowledge of these factors can be used to advantage to permit a substantially heavy special-permit vehicle without compromising the safety of the structure.

A safe estimate of the maximum load of a special-permit vehicle for a bridge can be obtained by the procedure given here without analytical evaluation of the structure. This procedure requires the knowledge of one of the following:

1. The maximum vehicle weights corresponding to the code-specified factors 1-10, given previously, that a bridge is capable of sustaining and
2. The worst combination of maximum vehicle weights that the bridge is likely to have sustained in its lifetime.

The former can be obtained from the design calculations but only if the design vehicle has a direct relationship with the actual vehicle weights, as it does, for example, in the case of the Ontario Highway Bridge Design Code (1,2). As pointed out by Buckland and Sexsmith (3), the AASHTO (4) design loads are not in close correspondence with actual traffic. Therefore, the knowledge that a bridge has been designed to AASHTO specifications is not always sufficient to establish the maximum vehicle weights that the bridge can sustain.

The determination of the maximum loads that a bridge is likely to have sustained in the past requires a probabilistic analysis, which is given in the following section.

PROBABILISTIC ANALYSIS

Factors 5-10 listed earlier are probabilistic in