Evaluation of existing highway bridges for overloaded trucks

Evaluation of Existing Highway Bridges for Overloaded Trucks

Évaluation des ponts autoroutiers existants pour camions surchargés

Beurteilung bestehender Autobahnbrücken für überladene Lastwagen

Gongkang FU
Head, Structural Research
NY Dept of Transportation
Albany, NY, USA

Gongkang Fu received his Ph.D. in civil engineering from Case Western Reserve University, Cleveland, OH, USA. He has been involved in bridge engineering since 1987.

Osman HAG-ELSAFI
Eng. Research Specialist
NY Dept of Transportation
Albany, NY, USA

Osman Hag-Elsafi, born in 1954, received his B.Sc. from the University of Khartoum, Sudan, and Ph.D. in civil engineering from the University of Pittsburgh, PA, USA. He worked as a development engineer for West Virginia DOT, and currently is with New York State DOT.

SUMMARY

Overloaded trucks exceeding legal weight limits commonly cross highway bridges. Some of these bridges are subjected to deterioration or were constructed for out-of-date, lower design loads. Many US states adopt the AASHTO rating concept with or without an overstress criterion, and the basis of these overstress criteria has not been well documented. This paper presents the development of a new overload-permit checking procedure for bridge evaluation, based on uniform bridge safety and in the format of load-and-resistance factors. Annual and trip overload permits are covered. This procedure may be included in bridge evaluation codes for overload checking.

RÉSUMÉ

Des camions, dont le poids maximal excèdent la charge limite autorisée, continuent à circuler sur certains ponts autoroutiers, bien que ceux-ci soient déjà vétustes ou qu'ils aient été dimensionnés pour des charges de trafic inférieures. De nombreux états des USA appliquent la classification AASHTO avec ou sans concept de dépassement de contraintes, dont il est mal aisé de vérifier l'origine. Le présent article expose une nouvelle méthode de contrôle des surcharges, mise au point pour évaluer un type de sécurité uniforme des ponts, à partir de facteurs de charge et de résistance. Ce procédé tient compte d'autorisations de surcharges à caractère unique et annuel. Il serait possible d'inclure une telle procédure dans des normes d'évaluation des ponts.

ZUSAMMENFASSUNG

Autobahnbrücken werden von Lastwagen befahren, die das zulässige Gesamtgewicht überschreiten, obwohl einige dieser Brücken verfallen oder für antiquierte, niedrigere Verkehrslasten bemessen wurden. Einige US-Staaten verwenden die AASHTO-Einstufung mit oder ohne Ueberspannungskriterien, deren Herleitung schlecht nachzuvollziehen ist. Der Beitrag berichtet von der Entwicklung eines Ueberlastprüfverfahrens auf der Basis gleichförmiger Brückensicherheit mittels Last- und Widerstandsfaktoren. Jährliche und einmalige Ueberlastbewilligungen werden berücksichtigt. Das Verfahren könnte in Brückenbewertungsnormen einfliessen.

1. INTRODUCTION

It has become a common practice that overweight trucks exceeding legal limits may be permitted to operate in highway systems. On the other hand, some bridges in these systems may be inadequate for these overloads, due to various reasons such as out-of-date design requirements and/or structural deterioration. Overweight trucks in the United States are now accommodated by special permit systems in the states, for economic advantages of heavy freight transportation. However, many state transportation agencies are faced with increasing weights and numbers of overload trucks, and how much reserve strength can be used to meet the growing demand remains an issue. At the same time, overload is indeed recognized as one of the major modes of bridge failure [Shirole et al 1991]. A common approach to permit issuance is to evaluate bridges according to current AASHTO rating requirements [AASHTO 1983, 1989, 1992] against the overload vehicle, with or without a set of overstress criteria. The overstress allowance is justified by overweight vehicles' lower frequency of appearance on the highway system than normal truck loads due to their small volume. On the other hand, the basis of these overstress requirements has not been well documented, and the AASHTO rating requirements are intended to cover only normal traffic.

With respect to bridge capacity, two types of overload truck permit are currently issued in New York State for divisible and nondivisible loads. Divisible loads are those that can be readily shipped separately. A nondivisible load is defined as one piece or item that cannot be separated into units of less weight without affecting its physical integrity. Note that all states in the US now issue permits, under special circumstances, to trucks carrying nondivisible loads exceeding federal and/or state weight-limits, and about half the states also issue exceptions for divisible loads. Two types of nondivisible permits are used by the New York State Department of Transportation (NYSDOT) with respect to frequency of operation: trip and annual permits, which are valid for a few weeks and a year, respectively. During Federal Fiscal Year 1988-89, for example, NYSDOT issued over 23,000 trip permits and over 2,800 annual permits for nondivisible overloads. For a trip permit, 50-percent overstress is allowed using the AASHTO allowable stress method. For an annual permit, 25-percent overstress is allowed. These overstress criteria are based on the inventory rating, which is equivalent to the design requirement [AASHTO 1983]. This study focuses on the nondivisible overload-permits, and develops a new overload checking procedure for bridge evaluation based on uniform bridge safety.

2. PROPOSED FORMAT FOR BRIDGE EVALUATION CONSIDERING OVERLOADS

A load and resistance factor format for overload permit checking is proposed here for evaluation of primary highway-bridge components:

$$\phi R_n > \gamma_D D_n + \gamma_p L_p \tag{1}$$

where ϕ, γ_D, and γ_p are respectively factors for resistance reduction, dead load effect, and permit load effect. R_n, D_n, and L_p are respectively nominal values of the component resistance, dead load effect, and permit load effect including dynamic impact for the structural component. Note that resistance and load factors ϕ, γ_D, and γ_p are applied only to the nominal values. They will influence the safety of bridges to be evaluated, and are to be prescribed here to assure a target safety level. Safety of bridges is assessed using the following model.

3. SAFETY MODELING FOR BRIDGES SUBJECTED TO OVERLOADING

Consider the same component in Eq.(1). Its safety is measured by a safety index β:

$$\beta = \Phi^{-1}(1-P_f) \tag{2}$$

where $\Phi(.)$ is the cumulative probability function of the standard normal variable, and P_f is the failure probability of the component. For conservative estimation,

$$P_f = P_{f1} + P_{f2} \tag{3}$$

$$P_{f1} = \text{Probability } [Z_1 < 0] \quad \text{and} \quad P_{f2} = \text{Probability } [Z_2 < 0] \tag{4}$$

$$Z_1 = R - D - g\,I\,M\,m \quad \text{and} \quad Z_2 = R - D - g\,I\,M_p \tag{5}$$

where Z_1 and Z_2 are safety margins respectively for general truck traffic and the permit overload truck. R and D are resistance and dead load effects. g and I are load distribution factor and dynamic impact factor. M is the maximum load effect of general truck traffic without impact, and M_p is the maximum static load effect of the overload truck. m is a factor to cover configuration variation of trucks in traffic. Due to such uncertainties as variations in design, construction, and service condition, R, D, g, I, M, and m are modeled by independent lognormal random variables.

The statistics of resistance R, dead load effect D, distribution factor g, impact factor I, and configuration factor m were based on data collected to cover variations in US practice [Moses et al 1987, Imbsen et al 1987, Fu et al 1992]. The statistics of static live load effect M were obtained by convolution to include all possible contribution from trucks of various weights at various locations on the bridge, with respectively associated probabilities of occurrence:

$$\text{Probability}[M_0] = \Sigma_i \Sigma_j \text{ Probability}[\text{weight}_i] \text{ Probability}[\text{location}_j] \tag{6}$$

where M_0 is a realization of maximum moment M. The probabilities under the summations were obtained by weigh-in-motion data from sites over US [Moses et al 1987, Imbsen et al 1987, Fu et al 1992] and data from NYSDOT 1991 overload permits whose histograms are shown in Fig.1. Note that the weight frequencies are given within each (annual or trip) permit group, and the general legal gross-weight-limit is 80 kips. The double summation in Eq.(6) is taken over all the combinations of weight and location that induce maximum load effect of magnitude M_0. The probabilistic distribution of maximum load effect due to an event of trucks presence on a bridge is readily obtained by varying M_0 in Eq.(6) including overload trucks. This distribution is then projected to that of M by covering a period of 2 years for a traffic volume of 2000 annual-average-daily-trucks (AADT). This period is the maximum interval of inspection for US highway bridges. Based on the NYSDOT permit data, 2.65, 0.22, and 0.05 percent were used as equivalent volume ratios of divisible-, nondivisible-annual-, and nondivisible-trip-permit traffic to normal traffic, respectively, in including permit load effects. The mean and standard deviation of the maximum load effect M were calculated based on this projected distribution, and then used in computation of β in Eq.(2).

4. OVERLOAD CHECKING PROCEDURE BASED ON UNIFORM BRIDGE SAFETY

Given load effects D_n and L_p, the mean value of random variable R of Eqs.(2) to (5) varies depending on the safety factors ϕ, γ_D, and γ_p, and so in turn does the safety index β. This mechanism allows adjustment of these safety factors in order to reach a target safety index β. The relative magnitudes between the dead and live load factors in Eq.(1) are determined to produce relatively uniform β over bridge span lengths.

The checking procedure in Eq.(1) is similar to AASHTO load factor design or rating [AASHTO 1983, 1992] and the load and resistance factor rating [AASHTO 1989]. To be consistent with these codes, $\phi=0.95$ was selected for steel and prestressed concrete and 0.90 for reinforced concrete, and $\gamma_D=1.2$. γ_p was determined to reach a target safety index $\beta=2.3$, which represents the average highway bridge safety assured by these AASHTO codes [Moses et al 1987, 1989]. For load effect of bending moment, Fig.2 shows the relation between the required γ_p and the overload-vehicle gross-weight, respectively for annual and trip permits. γ_p for annual permits is shown to be lower than 1.0 for heavier than 120 kips, using multiple lane checking (assuming simultaneous presence of the overload-permit truck in more than one lane), indicating that simultaneous presence is unlikely for such heavy trucks in two or more lanes. Thus the permit load factor need not be higher than 1. Considering the relative low appearance frequencies of trip-permit trucks, γ_p for trip permits was obtained for one-lane checking (assuming presence of the overload-permit truck only in one lane). In general, the reduced likelihood of simultaneous presence of heavy trucks is reflected in these curves by γ_p decreasing with increasing gross weight. This covers low appearance frequencies of relatively heavy trucks.

In order to assure these results are not sensitive to the input data, a comprehensive sensitivity analysis was conducted by inspecting variation of the safety index β due to possible changes in the statistical data for R, D, g, I, and M. These changes include those due to variation in total traffic volume, load spectra among sites, and degree of compliance with weight limits for permit truck operation. Results [Fu et al 1995] show that γ_p in Fig.2 is not sensitive to these variations.

For practical application, a simplified procedure is proposed in Table 1, based on γ_p discussed above. Note that decreasing γ_p with increasing permit load is maintained as shown in Table 1, indicating the reduced likelihood of having heavy trucks simultaneously on the bridge. The grouping points (130 and 200 kips) for practical application were selected by conservatively recognizing significant frequency changes in the weight distributions (Fig.1).

5. APPLICATION EXAMPLES

Consider a truck with three axles weighing 30.5, 32.67, and 32.67 kips and longitudinally spaced by 11.7 and 6.5 ft. A 200-ft span steel girder bridge with HS-20 inventory strength [AASHTO 1983] is checked here. Using the checking equation Eq.(1), Table 1 gives $\phi = 0.95$, $\gamma_D = 1.20$, and $\gamma_P = 1.35$ (for gross weight ≈ 96 kips) for annual permit. Assume the girder spacing to be 8 ft and dead to live load ratio $D_n/L_{HS20} = 0.0132$ Span Length [Moses et al 1987], where L_{HS20} is the maximum moment induced by HS-20 truck includingdynamic impact. D_n = 9,083 kip-ft and L_P = 5,201 (8/11) = 3,783 kip-ft, using the AASHTO load distribution factor [AASHTO 1992]. Required R_n = (1.20 * 9,083 + 1.35 * 3,783)/0.95 = 16,849 kip-ft. Available R_n = (9,083 + 3,442)/0.55 = 22,773 kip-ft, according to the inventory rating of HS-20 strength by the allowable stress method. Available R_n > Required R_n. OK. Consider the same truck and the same bridge for trip permit. Using the checking criterion Eq.(1), Table 1 gives ϕ = 0.95, γ_D = 1.20, and γ_P = 1.55 (gross weight ≈ 96 kips). D_n = 9,083 kip-ft and L_P = 5,201 (8/14) = 2,972 kip-ft. Required R_n = (1.20 * 9,083 + 1.55 * 2,972)/0.95 = 16,323 kip-ft. Available R_n = (9,083 + 3,442)/0.55 = 22,773 kip-ft. Available R_n > Required R_n. OK.

6. SUMMARY AND CONCLUSIONS

A permit checking procedure based on relatively uniform safety was developed to take into account low appearance frequencies of overweight trucks. The average bridge safety assured by the current AASHTO codes was used as the safety target in determining the live load factor γ_P of the proposed load-and-resistance-factor checking requirement. This checking procedure may be included in codes of bridge evaluation for overweight trucks.

7. ACKNOWLEDGEMENTS

J.Lall, F.P.Pezze, R.D.Wright, and J.Tang with NYSDOT Engineering Research and Development Bureau assisted in preparing the figure, data collection, and current practice review. Thanks are due to D.B.Beal, G.A.Christian, R.C.Holt, J.M.Robb, D.F.Rose, and S.S.Kulkarni with Structures Design and Construction Division and R.DeRocco with Traffic Safety Division of NYSDOT for their information and discussions. USDOT Federal Highway Administration (FHWA) provided partial financial support. The contents of this paper reflect the views of the authors, and do not necessarily reflect the views of NYSDOT or FHWA.

REFERENCES1.

1. AASHTO Guide Specifications for Strength Evaluation of Existing Steel and Concrete Bridges, Washington, D.C., 1989
2. AASHTO Manual for Maintenance Inspection of Bridges, Washington,D.C., 1983
3. AASHTO Standard Specifications for Highway Bridges, Washington,D.C., 15th Ed. 1992
4. Fu,G. and Moses,F. "Overload Permit Checking Based on Structural Reliability", TRB TRR 1290, 1991, Vol.1, p.279
5. Fu,G. and Tang,J. "Proof Load Formula for Highway Bridge Rating", TRB TRR 1371, p.129, 1992
6. Fu,G. and Hag-Elsafi,O. "Safety-Based Bridge Overstress Criteria for Nondivisible Overloads", (in print) Engineering R & D Bureau, New York State Dept. of Transportation, 1995
7. Imbsen,R.A., Liu,W.D., Schamber,R.A., and Nutt,R.V. "Strength of Existing Reinforced 8. Concrete Bridges", Report 292, NCHRP, TRB, 1987
8. Moses,F. and Verma,D. "Load Capacity Evaluation of Existing Bridges". Report 301, NCHRP, TRB, 1987
9. Shirole,A.M. and Holt,R.C. "Planing for A Comprehensive Bridge Safety Assurance Program", TRB TRR 1290, 1991, Vol.1, p.39

Fig. 1 Histogram of Nondivisible Permit Loads in New York, 1991

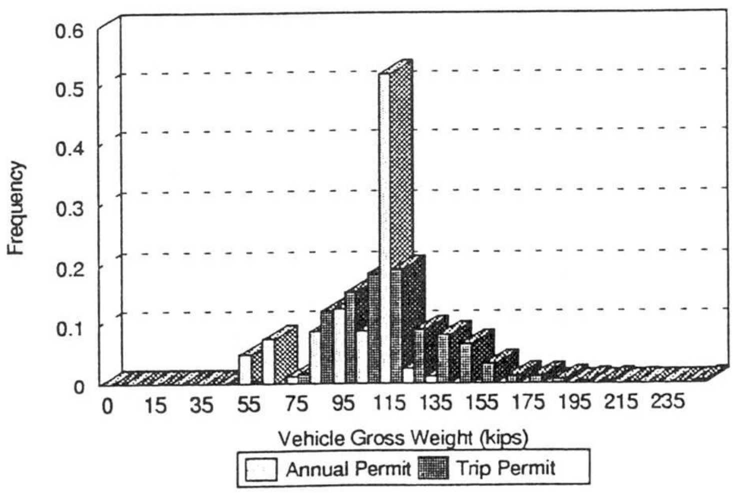
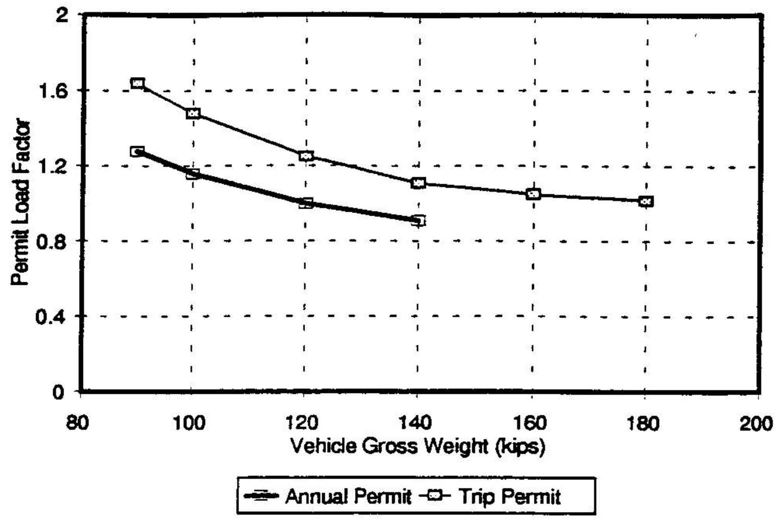


Fig. 2 Permit Load Factor γ_P Versus Vehicle Gross Weight



Permit Type	Annual (Multilane Checking)		Trip (One-lane Checking)		
Vehicle Gross Weight (kips)	≤ 130	> 130	≤ 130	> 130 ≤ 200	> 200
γ_P	1.35	1.05	1.55	1.15	1.05
ϕ	0.90 (reinforced concrete), 0.95 (steel and prestressed concrete)				
γ_D	1.20				

Table 1 Proposed Load and Resistance Factors of Eq.(1) for Bridge Evaluation