Load Rating and Permit Review Using Load and Resistance Factor Philosophy

CHARLES M. MINERVINO, P.E.
BALA SIVAKUMAR, P.E.
A.G. Lichtenstein & Associates, Inc.
Paramus, N.J.

ABSTRACT

The new AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating of Bridges being developed under NCHRP Project 12-46 will be consistent with the AASHTO LRFD Bridge Design Specifications in using a reliability based limit states philosophy. The primary goal of this project is to produce a practical evaluation manual that is easy to understand and use, which will receive broad support for adoption and distribution by the AASHTO Subcommittee on Bridges and Structures. The reliability aspects will remain invisible to the evaluation engineer through the use of calibrated load and resistance factors, as was done in the LRFD Specifications. A pre-final Draft Manual was submitted for review and testing in March 1999 and the final Draft Manual is scheduled for completion by the end of 1999. The new Manual provides procedures and calibrated load and resistance factors for load rating and for overweight permit review.

INTRODUCTION

The 1994 LRFD Specifications for highway bridge design introduce a limit states design philosophy, based on structural reliability methods, to achieve a more uniform level of safety (reliability) throughout the system. The current AASHTO Manual for Condition Evaluation of Bridges (MCE) contains provisions for only the conventional (deterministic) Allowable Stress and Load Factor methods of load rating existing bridges. Hence, there is an acute need for a comprehensive new evaluation manual that will not only be consistent in philosophy and approach with the LRFD Specifications but will also be technologically current. NCHRP Project 12-46 was initiated in March 1997 to develop a new AASHTO Load and Resistance Factor Evaluation Manual for highway bridges that will introduce reliability based evaluation methods. A Lichtenstein led Research Team was awarded the contract for the project. Mr. Charles Minervino is the Principal Investigator and Mr. Bala Sivakumar is the Co-Principal Investigator. Dr. Fred Moses and Dr. Dennis Mertz serve as consultants. A pre-final Draft Manual was completed in March 1999. The Manual is to undergo extensive testing through trial ratings by several volunteer States later this year. The final Draft Manual is scheduled for completion by the end of 1999. Once adopted by AASHTO the new Manual will replace the existing MCE.

Major revisions to the existing MCE include:

- A new section on load rating bridges using the Load and Resistance Factor philosophy.

- Load rating procedures that are contingent upon the live load model and the intended use of evaluation results.
- Procedures to determine site-specific load factors for load rating.
- Customized load factors by permit type for overload permit review.
- A new section on fatigue evaluation of steel bridges.
- A new section on non-destructive load testing of bridges.
- Parallel commentary with several illustrative load rating examples.

RELIABILITY BASED DESIGN VS. EVALUATION

Bridge design and evaluation, though similar in overall approach, differ in important aspects. In the design stage there is greater uncertainty in loading over the life of the bridge whereas in evaluation there is greater uncertainty on the resistance side, especially in the case of degraded bridges. Upgrading an in-service bridge is far more costly than incorporating extra capacity at the design stage. Therefore, a more refined approach to evaluating the load capacity of an existing bridge can be economically justified.

Structural reliability methods contain the necessary ingredients to provide a more rational, a more flexible, and a more powerful evaluation strategy for existing bridges. In a reliability based approach the evaluation could provide a uniform safety level, without resorting to traffic restrictions or strengthening, by reducing uncertainties. This can be done by obtaining improved resistance data, site-specific traffic data, and improved load distribution analysis. In evaluation, uncertainties can be reduced based upon site-specific considerations that were unavailable to the designer.

In the LRFD Specifications much of the emphasis and calibration of design factors was based on multi-girder steel and concrete bridges that were considered representative of current and future trends in bridge design. In developing a compatible evaluation manual it is important to recognize that the existing inventory of bridges is comprised of a wide array of bridge types, structural systems, material types, and physical conditions. Additionally, the evaluation criteria pertaining to reliability indices, limit states, and load and resistance models could be different from those used for new bridge design in the LRFD Specifications.

KEY TECHNICAL ISSUES PERTINENT TO EVALUATION

Reliability Indices

In LRFD code calibrations, the target reliability index (beta) of 3.5 for the strength limit state was selected as it was considered indicative (average) of the reliability indices inherent in girder bridges designed by the AASHTO Standard Specifications. The level of reliability in existing multi-girder bridges designed to the AASHTO Standard Specifications was found to vary from a low of 2.0 to a beta as high as 4.5.

For design, a relatively high target reliability index was chosen as the cost of compliance is only marginal. For evaluation, a lower bound on acceptable reliability is more appropriate as the cost impact due to bridge strengthening or traffic restrictions could be quite significant. The reliability index for evaluation was selected based on calibration with existing practice, which generally allows up to operating stress levels to be used for redundant bridges. The operating level (beta = 2.5) has served as an acceptable safety level for posting and permit decisions for redundant systems in the past and was selected as an acceptable basis for the new Manual calibrations.

Limit States

The new LRFD Specifications introduce the philosophy of limit states design, which in essence is a systematic way of considering all applicable design criteria by grouping them into limit states. This philosophy has now been extended to the evaluation of existing bridges. Differences exist between the application of limit states to design vs. evaluation. As in the case of a reliability index, there may be a high cost penalty for imposing certain non-strength related limit states in evaluation compared to design, where the cost impact may be negligible.

The very nature of evaluation calls for different limit states to be applied. If the evaluator is concerned about accumulating excessive fatigue damage during normal usage, the fatigue-and-fracture limit state should be considered for evaluation. On the other hand, if the evaluator is only interested in precluding damage from more limited, perhaps single, passages of permit vehicles, the service and strength limit states would only be considered, and not the fatigue-and-fracture limit state.

Live Load Models

As a result of the exclusions permitted by the grandfathered rights the HS loading does not bear a uniform relationship (for varying span lengths) to many of the vehicles allowed on the roads. In developing the LRFD design specifications it was determined that if the objective of developing a new specification was a more uniform and consistent safety of bridges, a new live load model (designated as HL93 loading) would be necessary. While this notional load provides a convenient and uniform basis for design, it bears no resemblance or correlation to any vehicle type on the roads. Practical difficulties are therefore bound to arise in using HL93 rating results for load posting. Additionally, the local live load environment is often less severe than the prescribed design loading.

The AASHTO legal loads (TYPE 3, TYPE 3S2, TYPE 3–3) model three portions of the Federal Bridge Formula which control short, medium, and long spans. Therefore, the combined use of these three AASHTO legal loads results in uniform reliability over all span lengths, as was achieved with the HL93 notional load model. These vehicles are presently widely used for load rating and load posting purposes. They are based on present legal load limits. These AASHTO vehicles model most of the configurations of present truck traffic. They are appropriate for use as rating vehicles as they satisfy the major aim of providing uniform reliability over all span lengths.

LOAD AND RESISTANCE FACTOR RATING PROCEDURES

Bridge load ratings are performed for specific purposes, such as: NBI and BMS reporting, local planning and programming, determining load posting or bridge strengthening needs, and overload permit review. The new Manual promotes a needs-specific approach to evaluation, wherein the evaluation criteria and procedures are selected based upon the intended use of the evaluation results.

The Manual provides three load rating procedures for bridges that use different live load models and evaluation criteria. The load rating of a bridge is generally expressed as a rating factor for a particular load or vehicle model.

Design Load Check

This is a first level evaluation of bridges performed using the HL-93 loading and dimensions and properties for the bridge in its present condition. Under this check existing bridges are screened at the design level reliability (Inventory Level) or at a second lower level reliability (comparable to the Operating Level reliability in past practice) for the strength limit state. The evaluation also considers all other applicable serviceability limit states and identifies vulnerable limit states. The results are suitable for NBI and BMS reporting. It also serves as a screening process to identify bridges that should be load rated for legal loads. Bridges that pass the design load check will have satisfactory load rating for all legal loads.

Load Rating for Legal Loads

This second level evaluation provides a single safe load capacity applicable to AASHTO and State legal loads. Live load factors are selected based upon the traffic conditions at the site. Strength is the primary limit state for evaluation. Service and fatigue limit states are selectively applied. The results of the load rating for legal loads could be used as a basis for decision making related to load posting or bridge strengthening.

Overweight Permit Review

Procedures are provided for checking the safety and serviceability of bridges for the issuance of permits for the passage of vehicles above the legally established weight limitations. Calibrated load factors by permit type and traffic conditions at the site have been provided for use in checking the load effects induced by the passage of the overweight truck. Guidance is also provided on the serviceability criteria that should be checked when reviewing permit applications.

GENERAL LOAD RATING EQUATION

The following general expression shall be used in determining the load rating of each component and connection subjected to a single force effect, e.g., axial force, flexural bending, or shear. The rating procedure shall be carried out at each applicable limit state and load effect with the lowest value determining the controlling rating factor.

$$RF = \frac{C - \gamma_{DC}\, DC - \gamma_{DW}\, DW \pm \gamma_p\, P}{\gamma_L\, L\,(1 + IM)}$$

For the Strength Limit States:

$C = \phi_c \phi_s \phi R$

For the Service Limit States:

$C = f_R$

Where:

RF = rating factor
γ_{DC} = LRFD load factor for structural components and attachments
γ_{DW} = LRFD load factor for wearing surfaces and utilities
γ_p = LRFD load factor for permanent loads other than dead loads
γ_L = Evaluation live load factor
ϕ_c = Condition factor
ϕ_s = System factor
ϕ = LRFD resistance factor
C = Capacity
f_R = Allowable stress
R = Nominal member resistance (as-inspected)
DC = Dead load effect due to structural components and attachments
DW = Dead load effect due to wearing surface and utilities
P = Permanent loads other than dead loads
L = Live load effect
IM = Dynamic load allowance.

LOAD RATING FOR LEGAL LOADS

Load rating for legal loads determines a single safe load capacity of a bridge for the AASHTO family of legal loads and state legal loads, using more optimum safety and serviceability criteria considered appropriate for evaluation. The results are suitable for determining the need to load post or strengthen a bridge. Evaluation procedures are provided in the Manual to establish a safe load capacity for an existing bridge that recognizes a balance between safety and economics. The previously existing distinction of Operating and Inventory level ratings is no longer maintained when load rating for legal loads. The single safe load capacity produced by the guidelines presented in the Manual will provide a level of reliability corresponding to the Operating level reliability for redundant bridges in good condition.

The nominal live loading is the maximum of the three AASHTO vehicle effects. In computing load effects for simple spans up to 200 ft, only one vehicle should be considered present in each lane. A lane loading has been defined for simple spans between 200 and 300 ft, and for checking negative moments in continuous spans.

This Manual provides live load factors for load rating that have been calibrated to provide a uniform and acceptable level of reliability. Load factors appropriate for use with the AASHTO and State legal vehicles are defined based upon the traffic and load data available for the site. The load factors are characterized as generalized load factors and site-specific load factors.

Generalized Load Factors

Most bridge sites are characterized only by traffic volume. Generalized load factors are representative of bridges nationwide with similar traffic volumes (Table 1).

Table 1: Generalized Live Load Factors for Legal Loads

Traffic Volume	Limit State	Load Factor
Unknown	S TRENGTH	1.8
ADTT > 5000	STRENGTH	1.8
ADTT = 1000	STRENGTH	1.6
ADTT < 100	STRENGTH	1.4

Site-Specific Live Load Factors

Live load varies systematically from site-to-site. More refined load factors appropriate for a specific bridge site may be estimated if more detailed traffic and load data are available for the site. ADTT and truck loads through weigh-in-motion measurements recorded over a period of time allow the estimation of site-specific load factors that are characteristic of a particular bridge site. The new Manual provides a simplified procedure for calculating site-specific load factors that follow the same format used in the derivation of live load factors contained in the AASHTO LRFD Bridge Design Specification

OVERWEIGHT PERMIT REVIEW

Bridge owners usually have established procedures which allow the passage of vehicles above the legally established weight limitations on the highway system. These procedures involve the issuance of a permit which describes the features of the vehicle, its load, and route of travel. Routine permits are usually valid for multiple trips over a period of time, and are expected to mix in the random traffic stream and move at normal times and speeds. Special or controlled permits are usually valid for a single trip only, or for a limited number of trips. These permit vehicles are usually heavier than those vehicles issued routine permits for multiple trips. Depending on the authorization, these special vehicles may be allowed to mix with random traffic or may be required to be escorted in a manner which controls speed and/or lane position, and the presence of other vehicles on the bridge.

The new Manual provides procedures for checking overweight trucks that are analogous to load rating for legal loads except that load factors are selected based upon the permit type. The actual permit vehicle will be the live load used in the evaluation. The reliability level for permit crossings is established as the same level as for legal loads. Load superposition is modeled by the live load factor, which is sensitive to the permit type and the ADTT of the site and the number of permit crossings. In the case of routine permits, the expected number of such permits is unknown so a conservative approach to dealing with the possibility of multiple presence is adopted. The permit live load factors were derived to account for the possibility of simultaneous presence of non-permit heavy trucks on the bridge when the permit vehicle crosses the span. Thus the load factors are higher for spans with higher ADTT and smaller for heavier permits. For situations where the upper limit on routine permits is below 100 kips, the live load factors are the same as those given for evaluating legal loads.

The frequency of Special permits is assumed to be relatively few in number, so the influence of simultaneous presence of heavy vehicles in adjacent lanes is less important than for routine permits. For special permits that are valid for a limited number of trips (below 100 crossings), the probability of simultaneous presence of heavy vehicles alongside the permit vehicle is small. The live load distribution shall be based on only a single lane loaded condition without including any built-in multiple presence factor. Where it is known that the vehicle will be escorted such that there are no other vehicles alongside the permit vehicle, then the live load factors given for escorted permits may be used. The following table (Table 2) of permit load factors suitable for most commonly encountered permit situations is provided in the new Manual.

Table 2: Permit Load Factors

Permit Type	Loading Condition	DF[a]	ADTT Trucks/Day	Load Factor by Permit Weight[b]	
				$80^k - 100^k$	140^k
Routine	Mix with traffic	Two or more Lanes	< 100 = 1000 > 5000	1.4 1.6 1.8	1.10 1.20 1.30
				All Weight Values	
Special	Escorted[c]	One Lane	< 100 = 1000 > 5000	1.10 1.10 1.15	
Special	Mix with traffic	One Lane	< 100 = 1000 > 5000	1.30 1.40 1.45	

<u>Notes</u>

[a] DF = LRFD distribution factor.

[b] For Routine Permits between 100^k and 140^k interpolate the load factor, considering also the ADTT value.

[c] No other vehicles alongside the permit vehicle.

ACKNOWLEDGMENTS

This project is funded by the Transportation Research Board with David Beal as Program Manager. The research work leading to this paper was performed jointly by the Research Team.