Load and Resistance Factor Rating of Concrete Segmental Bridges

AASHTO Manual for Bridge Evaluation provisions and special considerations

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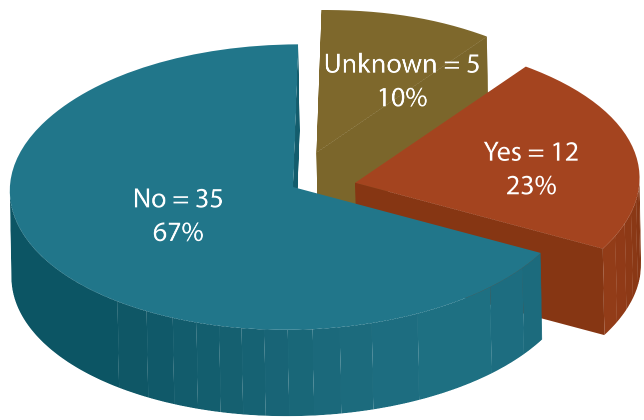
Concrete segmental construction has provided a durable and economical solution for many bridges and, as a result, more than 250 of these types of bridges have been built since the early 1970s in the United States. Concrete segmental construction has been used successfully in the construction of interchanges with complex geometric constraints and long-span bridges across navigational waterways.

Many concrete segmental bridges provide critical links in the U.S. highway system. Consequently, the economic impact resulting from unforeseen closure of one of these bridges due to functional or safety concerns will be significant. Therefore, it is important to load rate these bridges to ensure the safety of the structure and the traveling public. Furthermore, load rating will safeguard the bridge from premature deterioration due to unintended overloads.

Bridge load rating and posting are also mandated by Federal Regulation 23 CFR 650 Subpart C: National Bridge Inspection Standards (NBIS). The *AASHTO Manual for Bridge Evaluation* (MBE) further defines the methology and procedures for load rating and posting, including provisions for segmental bridges.

According to the FHWA Policy Memorandum for Bridge Load Ratings for the National Bridge Inventory dated October 30, 2006, new bridges and totally replaced bridges designed after October 1, 2010, must be load rated with the load and resistance factor rating (LRFR) method.

A questionnaire was sent to Federal Highway Administration (FHWA) Division Bridge Engineers in September 2011 to collect information about the status of the national implementation of the LRFR method. The data collected was used to develop recommendations and services to aid FHWA Division Bridge Engineers in the oversight of load rating, posting, and permitting programs and practices using the LRFR method. The responses to the questionnaire demonstrated that 23% (12) of the states had started to use the LRFR method to rate segmental bridges.



Percentage of states that have used the LRFR method to load rate concrete segmental bridges. All drawings: Federal Highway Administration.

To further support the national implementation of LRFR load rating of segmental bridges, an informational webinar was conducted on January 19, 2012, by FHWA. More than 150 individuals from across the nation participated in this webinar.

LRFR Methodology

Limit States

Since the major concern for bridge load rating is determining the vehicular live load capacity of the structure under its permanent load condition, other transient loads (wind, ice, earthquake, and the like) are generally not required to be included in the analysis. Table 6A.4.2.2-1 of the MBE further defines the limit states that should be considered when load rating different bridge types.

Loads

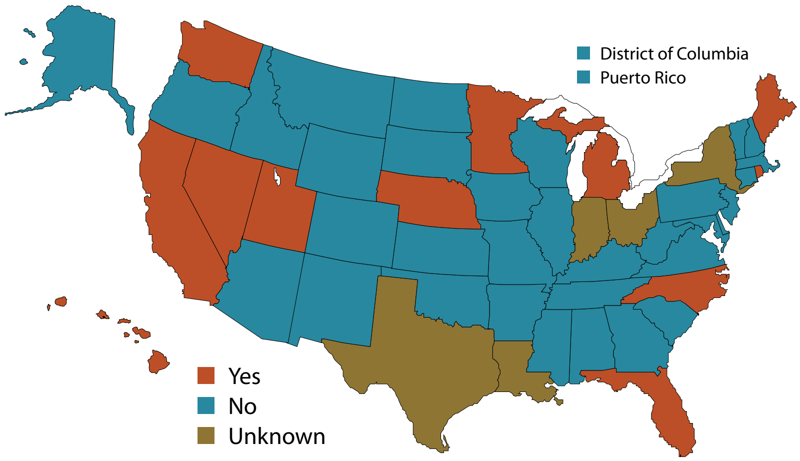
Load rating should consider live loads in the presence of all permanent loads applied to the structure and other loads that may affect the live load carrying capacity of the structure. Live loads should include the design notional load (HL-93), legal vehicles, or permit vehicles, depending on the purpose of the rating.

Legal loads are the vehicles legally allowed to use bridges in the United States or in a specific state. The Bridge Formula in Section 658, Title 23 of the Code of Federal Regulations defines the limits on configuration and axle weight for a vehicle that can legally operate on an interstate highway without special permission (such as a state-issued permit). MBE includes the configuration and axle weight of some common vehicle types to be considered during load rating such as the Routine Commercial Vehicles Type 3, 3S2, and 3-3, and Specialized Hauling Vehicles SU4, SU5, SU6, and SU7. Most states also have state-specific legal loads that also need to be considered. Permit load rating should be conducted based on the actual configuration and axle weight of a permit vehicle or vehicle group.

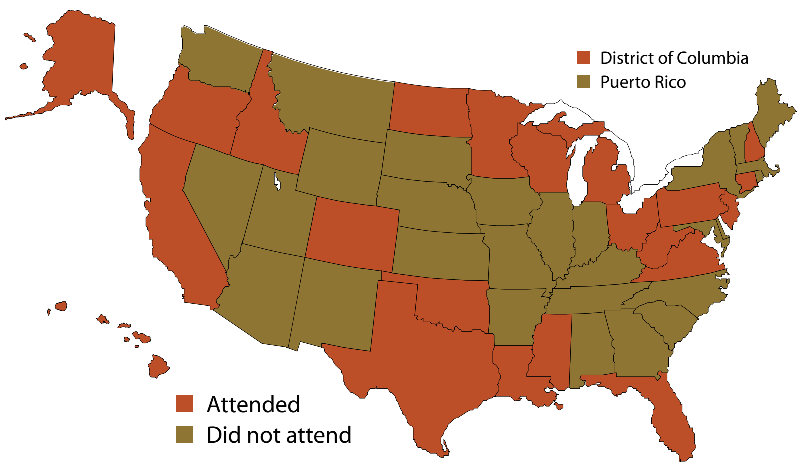
Dynamic load allowance should also be included in a load rating analysis. LRFR allows the use of a reduced dynamic load allowance for legal and permit load rating based on the riding surface condition.

Structural Reliability

In the calibration of LRFR/load and resistance factor design (LRFD),



States that have rated concrete segmental bridges.



Geographic distribution of attendees at the webinar on load rating of concrete segmental bridges.

target reliability indices were used in adjusting the probabilistic models of loads and resistances in order to ensure a consistent level of safety.

The LRFR method adopted two levels of reliability for different rating vehicles based on the expected duration of exposure. Inventory level rating for the notional design load (HL-93) used the same target reliability index of 3.5 as used in the *AASHTO LRFD Bridge Design Specifications*. Operating level rating of the design load was based on a reduced reliability index of 2.5.

To strike a reasonable balance between safety and economy, a lower, operational target reliability of 2.5 and a duration of exposure of five years were initially used for legal load rating at the strength limit state in the LRFR calibration.

For annual routine permits and escorted single-trip permits, a reliability index of 2.5 was initially targeted, and load factors in the MBE were calibrated for this level of reliability. For single-trip and multiple-trip special permits allowed to mix with traffic, a reliability index of 3.5 was used.

Structural Deterioration

Load rating should be based on the current physical condition of the structure. If there is any structural deterioration or section loss, the deterioration or section loss must be considered in load rating. The section loss or other localized deterioration can be taken into account in computing section resistances. For global deterioration, the condition factor, ϕ_c, is used to account for the increased uncertainty in the capacity of deteriorated members and the likelihood that some forms of deterioration will increase more rapidly once deterioration initiates.

Structural Redundancy

Structural redundancy affects the probability of system failure. In LRFR, the system factor, ϕ_s, is used to account for the impact of structural redundancy of the complete superstructure system on load rating. Segmental bridges are different than conventional multi-girder bridges and have unique aspects of system redundancy. These aspects include longitudinal and transverse continuity, and the number of tendons and webs.

Special Considerations for Segmental Bridges

Contract plans, construction and erection plans, as-built drawings, previous inspection and condition evaluations, and most current inspection reports are the main information sources for load rating. The load rating should always be conducted at current structural and loading condition.

Loads

In addition to dead and live loads, segmental bridges should also consider the following in their load rating:

- Locked-in forces in the structure during construction, related to:
  - construction sequence;
  - erection or construction equipment such as segment lifting system and form-travelers; and
  - temporary stressing and temporary supports.
- Primary effects of prestressing and post-tensioning
- Secondary load effects from prestressing and post-tensioning, creep, shrinkage, and other time-dependent behavior
- Temperature and temperature gradient
- Other applicable loads that may lower the live load capacity of the bridge

When applying live loads for operating level rating of the design load, legal load, and permit load at service limit states, the number of load lanes may be taken as the number of striped lanes. However, the loads shall be positioned so as to create maximum effects including, for example, on shoulders if necessary.

Also, in accordance with MBE Article 6A.5.11.3, the multiple presence factor for single lane loaded may be limited to 1.0 for operating level rating of the design load and legal load in the transverse direction.

Longitudinal Analysis

Dead load effects in a segmental bridge are affected by a wide variety of parameters, such as

- construction sequence,
- construction equipment,
- loading and erection age of segments,
- creep and shrinkage of concrete, and
- relaxation of prestressing steel.

Because of the time-dependent behavior, the dead load state of a segmental bridge changes with time. In order to rate a segmental bridge, dead load effects at the time of load rating should be determined through an analysis including the effects from construction sequence, time-dependant material properties, and loading history. Note that restraints and constraints should be appropriately applied to the analysis model to capture the real structural behavior at different stages. The change in restraints or constraints will redistribute forces within the structure. The analysis should be able to capture any locked-in forces during construction and any load redistributions resulting from time-depenent material behavior.

Transverse Analysis

Segmental box girders shall also be load rated for transverse behavior. It is possible that transverse load rating, such as tensile stresses (Service III) in the top slab, governs the live load capacity.

Limit States

According to MBE Articles 6A.5.11.4, 6A.5.11.5.1, and 6A.5.11.5.2, Strength I (or II for permit load rating), Service I, and Service III limit states shall be checked for the design, legal, and permit load rating of segmental bridges. Service III limit state specifically includes the principal tensile stress check of LRFD Article 5.8.5.

Closing Remarks

For segmental bridges, service limit states will likely control the load rating, which is contrary to what typically controls the load rating of conventional nonprestressed concrete bridges. As mentioned previously, strength limit states in LRFR/LRFD have been calibrated for uniform reliability; however, service limit states have not. Because of the growing numbers of segmental bridges that owners are incorporating in their bridge network, the initial drafts of the LRFR methodology and the current rating provisions in the MBE provided type-specific guidance for segmental bridges that had not existed previously. The results of the ongoing and future research may result in even more specific criteria in the AASHTO rating guidelines that bridge owners and engineers will use to better assess the operational performance of segmental bridges under ever-changing loading conditions and traffic demands.

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