A PROFESSOR'S PERSPECTIVE

# Calibration of Rating Factors for Segmental Bridges

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Concrete segmental bridges in the United States have evolved from the pioneering structures of the 1970s into a mainstream solution for medium- to long-span crossings (**Fig. 1**). However, many are still load rated using procedures calibrated primarily for girder-type bridges. Using these load-rating methodologies for concrete segmental bridges can produce overly conservative load ratings, especially at service limit states, which typically govern the design of concrete segmental systems. The overarching objective of National Cooperative Highway Research Program (NCHRP) Project 12-123, "Proposed AASHTO Guideline for Load Rating of Segmental Bridges" was to conduct a reliability-based calibration of load and resistance factors specifically for the Service III limit state. The work refined the design and evaluation of concrete segmental bridges by aligning inventory and operating load ratings for concrete segmental bridges with rational target reliability indices.[1] The results of this project have been published as NCHRP Report 1128.[2]

## Challenges

The original calibration of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[3] was applied to strength limit states in girder bridges. That calibration is documented in NCHRP Report 368, *Calibration of LRFD Bridge Design Code*.[4] The load components in NCHRP Project 12-33 included live load, dynamic load, and three components of dead load.

Figure 1. A concrete segmental bridge structure is constructed using precast concrete segments. Figure: Datai Crane.

The statistical parameters used in NCHRP Report 368 were based on a very limited truck survey from Ontario, Canada, in 1978. In particular, resistance parameters were very limited and required verification. Furthermore, the parameters were, to a large extent, based on the engineering judgment of experts, and the supporting material had a large degree of variation.

In NCHRP Project 12-123, the research team had access to new data on materials and loads in addition to advanced reliability analysis procedures. However, calibration of load and resistance factors for design and evaluation of concrete segmental bridges involved other challenges, including selection of representative bridges; structural analysis (two-dimensional versus three-dimensional [3-D]); live-load distribution; multilane reduction factors for three or four lanes; striped lanes versus design lanes; loss of prestress (which required a separate study); temperature effects (uniform temperature [TU] and thermal gradient [TG]); condition factor, and system factor. The representative concrete segmental bridges were selected out of a considerable variety of structural types and spans. Therefore, a larger number of bridges had to be considered to capture a representative sample. The structural analysis required 3-D models to consider longitudinal and transverse distribution of loads. Segments are typically one- or two-cell boxes; therefore, the load distribution is very different than that in girder bridges.

## Calibration Procedure

The calibration performed in NCHRP Project 12-123 followed a classical reliability framework adapted to concrete segmental bridges, as follows:

1. Selection of representative structures and limit states. The selected

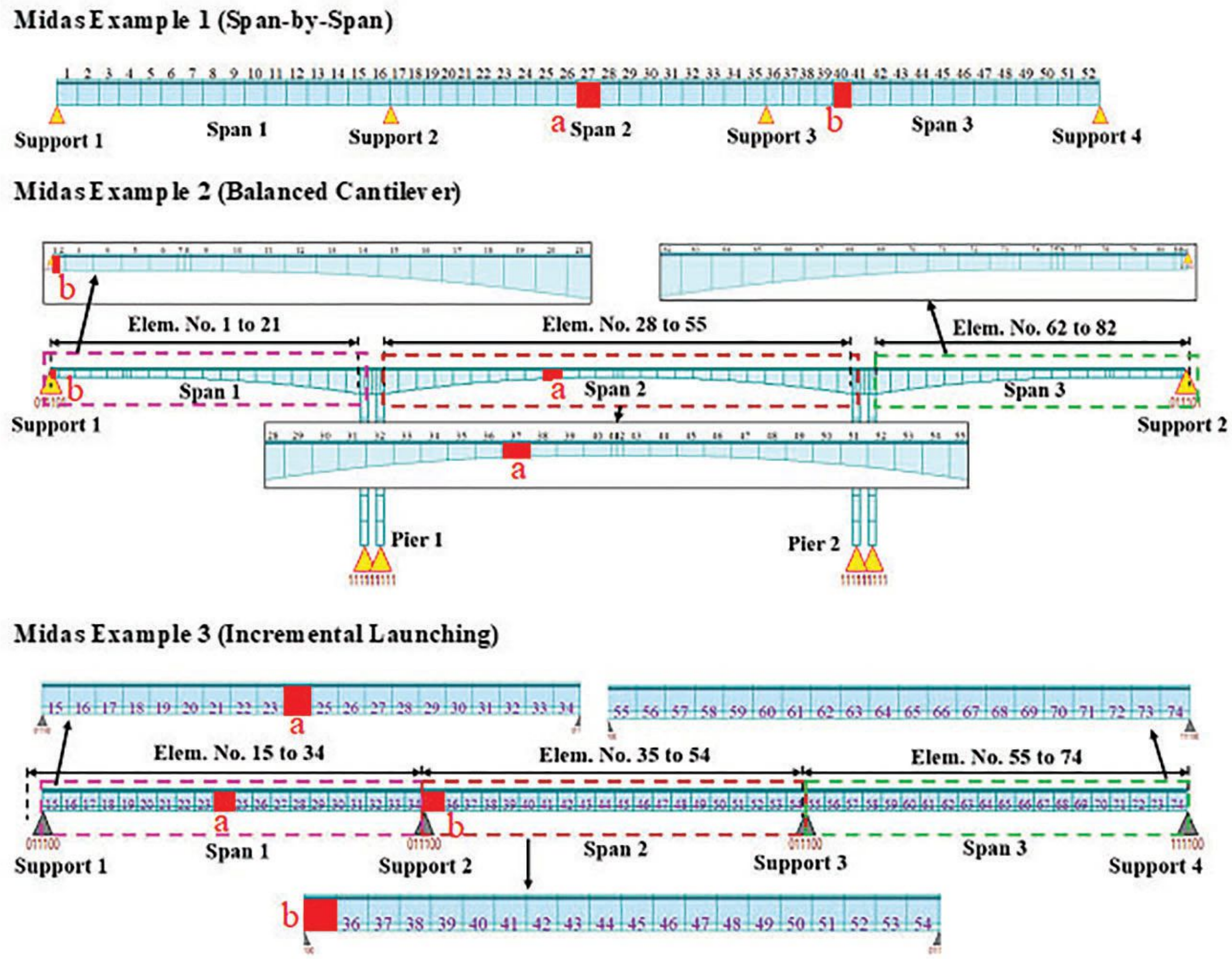
structures included span-by-span, balanced-cantilever, and incremental launching configurations (**Fig. 2**). Four limit states were chosen: service flexure (tensile stress), service principal tension in webs, flexural strength, and shear strength.

2. Development of statistical models for load and resistance. Two key parameters are the bias factor $\lambda$, which is the ratio of the mean to the nominal value, and the coefficient of variation $V$. Live-load parameters were derived from the weigh-in-motion data and adapted to segmental bridge configurations, whereas TG models accounted for climatic zones and structural depth effects unique to box-girder systems. For resistance, statistical parameters were obtained from material properties, fabrication variability, and analytical model factors.
3. Reliability analysis. The reliability indices were calculated for representative structures and limit states. The wide spectrum of obtained results indicated reliability indices for already-constructed concrete segmental bridges.
4. Selection of the target reliability index for the considered limit states. It was agreed that the existing concrete segmental bridges have acceptable reliability. The mean values were taken as a base, then adjusted based on specific target reliability index criteria. Therefore, the target reliability index can be considered close to the center of the obtained spectrum.
5. Selection of the limit state–specific load and resistance factors. Candidates for load and resistance factors were limited because the values were rounded to the nearest 0.05. For each set of load and resistance candidates, representative structures were redesigned accordingly and the resulting reliability values were compared with the target.

## Findings and Recommendations

Concrete segmental bridge–specific reliability calibration is critical at the Service III limit state. Applying girder-based calibration to segmental bridges misrepresents their reliability performance. The proposed calibration methodology, including updated load and resistance factors, achieves

Figure 2. Locations where reliability index $\beta$ is critical for load ratings for the service flexure limit state: (a) in the bottom fiber; (b) in the top fiber.[2]



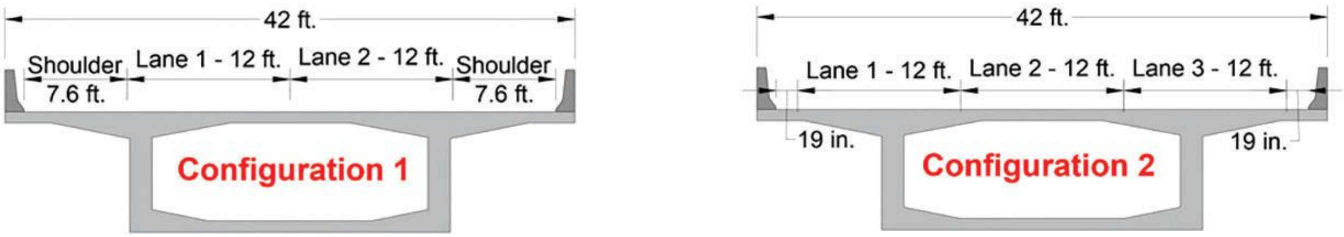


Figure 3. Lane configurations for a box-girder cross section of a concrete segmental bridge: (a) two-lane striped configuration; (b) three-lane design configuration.[2]

uniform reliability while accounting for the quality, continuity, and redundancy of concrete segmental construction. Specific recommendations are as follows:

- Retain the use of design lanes for inventory load ratings, and use design lanes instead of striped lanes, (**Fig. 3**) with reduced live-load factors for Service III limit state operating load ratings in AASHTO's *Manual for Bridge Evaluation*.[5] This approach rationally reduces live-load demand and aligns with reliability targets for service limit states ($\beta = 1.0$ for inventory load rating, $\beta = 0$ for operating load rating).
- Retain LRFD strength-level live-load factors for concrete segmental boxes. Strength limit states remain governed by $\gamma_{LL} = 1.75$ for inventory load ratings and $\gamma_{LL} = 1.35$ for operating load ratings, ensuring consistency with LRFD calibration lineage. Maintain $\gamma_{LL} = 0.8$ for Service III inventory load ratings with resistance factor of $\phi = 1.0$. Apply reduced live-load factor of $\gamma_{LL} = 0.65$ for Service III operating ratings since reliability analysis confirms alignment with $\beta$ targets (**Fig. 4**), with a resistance factor of $\phi = 1.0$.
- Include TG in Service III limit state checks. The calibrated load combinations 0.5 TG with live load and 1.0 TG without live load are essential for accurately capturing joint and web stresses that often control the load ratings of concrete segmental bridges.
- Adopt updated resistance statistics and fabrication factors. The research introduces refined models for material properties, fabrication variability, and professional factors, including updated fabrication-factor distributions specific to precast, prestressed concrete construction, which is typical for concrete segmental bridges. These models improve reliability predictions for flexural capacity and shear strength, particularly in systems with a mix of bonded and unbonded tendons.

A reliability-based calibration was performed for load and resistance factors specifically for the Service III limit state. It refined the design and evaluation of concrete segmental bridges by aligning inventory and operating load ratings for concrete segmental bridges with rational target reliability indices (Fig. 4).

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## References

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Figure 4. Computed minimum reliability indices $\beta$ in the representative bridges (service flexure limit state): (a) using $\gamma_{LL} = 0.8$ (inventory load rating); (b) using $\gamma_{LL} = 0.65$ (operating load rating).[2]