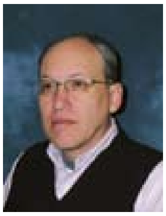
Safety and the LRFD Specifications



by Dr. Dennis R. Mertz

With the collapse of the I-35W Bridge in Minneapolis, bridge safety is a timely subject of discussion. A review of the level of safety inherent in our patrimony of highway bridges is in order.

For over 50 years, beginning with the AASHTO *Standard Specifications for Highway Bridges*, Allowable Stress Design (ASD) was the design methodology employed. The ASD methodology uses a factor of safety (FS) as a multiplier on load to set the required resistance as shown in Equation 1:

$$R \geq (FS) \times Q \qquad (1)$$

where R is the resistance and Q is the load or force effect. The factor of safety varies for different loads and materials. The factors of safety were chosen subjectively by the code writers, but history proved that highway bridges designed to ASD are inherently safe. The question is, how safe?

With the introduction of Load Factor Design (LFD) in the 1960s, the varying uncertainties of different load components were acknowledged. The design equation is similar to the LRFD equation but with load and resistance factors chosen through comparison with bridges designed using ASD. Again, the level of safety is unknown, but bridges apparently are safe enough as failures are very few.

During the late 1970s, the theory of structural reliability evolved into a useable highway bridge design methodology with the development of the Ontario Highway Bridge Design Code. AASHTO followed in the late 1980s with the development of the *LRFD Bridge Design Specifications*, eventually published in 1994. For the first time, a rational quantification of safety was available. The questions now become: Do we have all of the data required to determine safety, and if so, how safe is safe?

To develop an LRFD-format specification, exemplified by Equation 2, where a deterministic approach is made probabilistic through the application of carefully chosen load and resistance factors, a target level of safety is necessary to define the values in the LRFD equation:

$$\sum_i \gamma_i Q_i \leq \phi R_n \qquad (2)$$

where γ and ϕ represent carefully selected load and resistance factors to achieve a target level of safety. Structural reliability provides the tools to select the factors' required values to reach a target level of safety. But, what level of safety? Safety against failure of a member, such as can easily be produced in a laboratory, or safety against failure of the entire bridge system?

Much data exist for the resistance of individual members at failure (in the terminology of LRFD; the nominal resistance); little data exist for failures of whole bridges. The calibration of the *LRFD Specifications* is based upon member resistance, but individual members do not fail in a true system. Consider a multi-girder bridge: as one girder softens due to approaching ductile failure, and a sufficient load path to the adjacent girders exists (and the concrete deck can be such a load path), the load redistributes to the other girders from the softening girder. Before, the complete ductile failure of the one girder, the other girders begin to help carry the load shed from it. Thus, the target level of safety inherent in the *LRFD Specifications* with a probability of failure of 2 in 10,000 (where the reliability index $\beta = 3.5$) for member failure (introduced in this column in the Winter 2007 issue) is much lower for whole system behavior for typical ductile designs. So depending upon the degree of system behavior, the inherent probability of failure of LRFD designs is lower than 2 in 10,000.

The final question with regard to safety and the *LRFD Specifications* is, why 2 in 10,000 as a target failure rate? This question was answered during the development of the first edition of the *LRFD Specifications*. A sample of bridges designed using the LFD methodology of the *Standard Specifications* was analyzed probabilistically to ascertain their inherent probability of member failure. The approximate average failure rate associated with bridges designed using LFD was about 2 in 10,000. Thus, this member failure rate was chosen as the target for the calibration of the load and resistance factors of the *LRFD Specifications*. Some existing bridges (short span bridges) appear to have inherent member failure rates as high as 6 in 100 ($\beta = 1.5$), yet these bridges are not considered unsafe. For load rating, bridges are rated at the operating level in the Load and Resistance Factor Rating (LRFR) methodology at a failure rate of 6 in 1,000 ($\beta = 2.5$).

All of the member failure rates used to calibrate our current design and rating specifications are based upon comparisons with past practice—a practice based upon subjectively chosen factors of safety. Our bridges have proven safe over the last 75 years of the AASHTO specifications, but the question remains, how safe is safe enough? With the *LRFD Specifications*, our nation's new bridges have become more uniformly safe in terms of member failure and extremely safe in terms of system failure, but the level of safety is still relatively subjective.