Operational, Redundancy, and Ductility Factors for Bridge Structures

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The structural design of buildings and bridges is currently based on the Load and Resistance Factor Design (LRFD) method. The main structural design philosophy is to maintain the factored resistance (the strength of the entire structure and all its elements) above the maximum demand from the worst possible combination of loads on the structure. The ratio of the strength to the demand represents the safety of the structure, where the nominal resistance is reduced by multiplying factors < 1.0, while the loads are increased by multiplying factors >1.0. These multipliers are the safety factors prescribed by the design codes and specifications for both building and bridge structures. For simplicity, all strength-reducing or load-demand-increasing factors are called safety factors in this article.

The basic LRFD bridge design equation is: $\Sigma \eta_i \gamma_i Q_i < \phi R_n$,

where ϕR_n is the factored resistance/strength of the structure, and $\Sigma \eta_i \gamma_i Q_i$ is the factored load combination.

The code safety coefficients in structural analysis and design have worked satisfactorily, ensuring the general safety of building and bridge structures. Over the years, structural design codes have been developed, evolved, and enhanced. Building and bridge structures have their individual specifics with different governing design codes while using the same general philosophies and similar approaches in design.

Historically, the design and construction of building and bridge structures have influenced each other, borrowing structural systems and construction methods. Building codes prescribe importance factors, depending on the building occupancy categories, to increase the demand for more important structures. Until recently, the bridge design specifications did not differentiate between the bridge's importance. Now, AASHTO has introduced in its design specifications a new load modifier η_I, the product of three "safety factors": operational importance η_I, redundancy η_R, and ductility η_D, or ($\eta_i = \eta_I \times \eta_R \times \eta_D$).

For each of these factors, the required upper values are 1.05 maximum for critical or essential bridges and for design having non-redundant and non-ductile elements; a lower value of 0.95 is allowed for less important bridges, for design with higher levels of redundancy, and with ductility beyond those required per specifications. Operational importance applies to the strength and extreme event limit states only.

While the bridge "safety" factors for operational importance, redundancy, and ductility are from 1.05 to 0.95 or combined are up to 1.16, the respective ASCE 7 building factors are from 1.0 to 1.5 or combined are up to 1.95 (1.5 Importance Factor Category IV, 1.3 Redundancy Factor), almost seventy percent higher.

Introducing the load modifier, η_i, was a positive decision; however, the upper and lower values (1.05 to 0.95) do not correctly represent the significant difference between critical essential bridges and regular bridges. For example, no difference is considered between bridges carrying a few hundred, or 200,000 to 300,000 vehicles daily, or for a bridge located on a critically important road. This approach has been criticized by other engineers, like Theodore P. Zoli in his article, *Operational Importance, Redundancy, & Ductility – Code Considerations for AASHTO LRFD*.

Regarding the redundancy, 1.05 is a very low value for a non-redundant bridge structure; 1.25 would probably better represent the increased risk of using a single or very few members of the structure without back-up for eventual failure. The reduction to 0.95 for the redundancy factor should be removed as it reduces safety; the use of redundant elements is a requirement.

Regarding ductility, non-ductile components and connections should not be allowed for bridges in seismic areas, similar to what is required for building structures in California.

Using safety factors for importance, redundancy, and ductility is necessary, but current provisions are not sufficient. It is not acceptable that the current safety of some bridges on essential roads, carrying 200,000 to 300,000 vehicles per day, should be less than the safety of a two-story building with 30 to 40 occupants. Bridge design specification should be improved as follows:

a) Importance factor:1.3 to 0.95 based on the amount of average daily traffic and the importance of the road:

b) Redundancy factor: 1.0 for 5 or more elements capable of redistributing loads; 1.1 for 3 such elements; 1.15 for two such elements; 1.25 for a single element without a "back-up";

c) Non-ductile structures, elements, and connections should not be allowed in earthquake-prone areas.

The proposed change would improve the combined value for the η_i *load modifier* for bridges varying from 0.95 to 1.63, from the current value from 0.86 to 1.16.

AASHTO may consider a reliability factor to be assigned by the Engineer of Record, depending on the reliability of the design, construction, control, and maintenance of the structure. Such a factor could be between 1.10 (for not completely reliable) and 0.95 (for a very reliable project).

In conclusion, bridge design specifications need to be updated, correcting the combined load modifier η_i based on the discussion above. Also, it may be necessary to ensure that state Departments of Transportation likewise amend their specifications to coincide with AASHTO's specifications, provided that the state requirements are equal or more stringent; these amended requirements should not use lower loads or lower safety factors than those provided by AASHTO.▪

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