Bridge Design Specifications for the Future

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In 1931 the American Association of State Highway and Transportation Officials published *Standard Specifications for Highway Bridges and Incidental Structures*, the first bridge design standard ever undertaken in the United States. The specifications quickly became a national U.S. standard and were copied and used by many other countries as their national standard. The sections on *Incidental Structures* were dropped in the second edition, published in 1935. By 1986, more than 50 years and 12 editions later, the specifications were still in effect in the United States.

During that time, however, bridge engineering theory and technology changed significantly. Materials and construction methods improved. Computers became standard design and evaluation tools and provided engineers with a better understanding of how bridges carried and responded to loads. Finally, the need to carry more frequent and heavier loads put a strain on the entire process of bridge design, construction, and inspection.

State of AASHTO's Specifications

In recognition of these changes, the AASHTO Highway Subcommittee on Bridges and Structures (chaired at that time by Robert Cassano, then Chief Bridge Engineer of the California Department of Transportation) requested that the AASHTO-sponsored National Cooperative Highway Research Program initiate a study to assess current U.S. bridge design specifications, review foreign codes and alternative specification philosophies, and report to AASHTO with a series of options for improving the specifications and overall bridge design process.

In response to this request, an NCHRP project was initiated in 1986 and completed a year later. The study found that the existing specifications had a number of major gaps and inconsistencies, which were compounded by the lack of a commentary explaining the intent or background of many of the specification provisions. In addition, the study reported that a number of other countries that previously used the AASHTO specifications, including Canada and many European nations, had adopted their own specifications based in most cases on a limit-states design approach. The report concluded with a recommendation that AASHTO develop completely new bridge design specifications, basing them on the limit-states design philosophy. The inclusion of comprehensive commentary was also recommended.

The AASHTO Bridge Subcommittee reviewed the options and recommendations in the report and decided to request an NCHRP study to develop a limit-states code.

New Bridge Design Specifications

NCHRP Project 12-33 was initiated in mid-1988 with the objective of developing new bridge design specifications that could be recommended for adoption by AASHTO. It was anticipated that the new specifications would incorporate state-of-the-art bridge design technology and be based on the limit-states design approach, now known as load and resistance factor design (LRFD). It would also consolidate a number of separate AASHTO design documents.

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AASHTO allocated $1.75 million for the project, spread over fiscal years 1988 through 1991. A project management team composed of John M. Kulicki and Dennis R. Mertz, of Modjeski and Masters Consulting Engineers, was selected by NCHRP Project Panel C12-33. The panel also selected an eight-member Code Coordinating Committee to work with Kulicki and Mertz in setting the overall specification philosophy and approach, and to manage the activities of 14 task groups.

Four engineering firms, 47 paid consultants, and more than 20 state and industry volunteers have worked on the project since its inception. By the time the project is complete in the spring of 1992, three complete specifications and commentary drafts will have been completed by the project team and reviewed by more than 250 individuals and organizations. More than 10,000 comments will have been received from state, federal, university, and industry engineers.

The underlying philosophy of the new specifications is based on multiple goals including more uniform safety, redundancy, ductility, scour protection, constructibility, long-term serviceability, and maintainability.

Load and Resistance Factor Design

Until the early 1970s, the AASHTO *Standard Specifications* contained only one design philosophy, known as working stress design (WSD). WSD requires that the total stress caused by all design loads be less than a specified percentage of the material's load-carrying capacity (see Figure 1). For example, the allowable tensile stress in a steel member in flexure is limited to 55 percent of the nominal yield strength of the steel. Similar percentages are specified for the design of steel members in axial tension, compression, shear, and torsion and for the design of other materials such as concrete and wood. These percentages were primarily derived from acceptable historical performance of the specific materials in response to the applied stress.

However, loads are rarely completely predictable although some can be estimated more accurately than others. For example, dead loads (the weight of a steel beam or a concrete deck) can usually be calculated with reasonable accuracy. Other loads, such as vehicle weights and wind forces, have a large variability and can change over time. Responding to this and other issues, the *Standard Specifications* were modified by AASHTO in the early 1970s to include load factor design (LFD) for bridge superstructure components. LFD accounts to some degree for this variability in loads by using variable design factors applied to each load component. The effect of loading is then compared with the nominal member strength, which has been reduced by a specified amount for safety (see Figure 2). To use a steel member in flexure again as an example, the dead loads (fairly predictable) would be multiplied by 1.3 and added to the vehicle live loads multiplied by a factor of 2.17 (less predictable and more variable). The effect of these factored loads would then be compared with the nominal yield strength of the steel member multiplied by a reduction factor. For steel beams, the reduction factor is typically 1.0; however, for concrete beams, it would typically be 0.85.

$$\Sigma D + \Sigma L \leq f F$$

FIGURE 1 Typical working stress design equation.

$$1.3\,\Sigma D + 2.17\,\Sigma L \leq \phi F$$

FIGURE 2 Typical load factor design equation.

$$\Sigma \gamma_{D_i} D_i + \Sigma \gamma_{L_i} L_i \leq \Sigma \phi_i F_i$$

FIGURE 3 Typical load and resistance factor design equation.

where
- D = **dead loads,**
- L = **line loads,**
- γ_i = **load factors, and**
- ϕ_i = **resistance factors.**

Principal and co-principal investigators for NCHRP Project 12-33, (*above*) John Kulicki and (*below*) Dennis Mertz, Modjeski and Masters Consulting Engineers.

Just as there is variability in the predictability of loads, there is significant variability in material properties. This is considered to a small degree in load factor design. However, LRFD explicitly accounts for these variabilities in properties on the load and the material resistance sides of the design equation by using a series of load factors *and* resistance factors (see Figure 3). To use steel as an example once again, the specified yield strength of typical bridge steels may be 36,000 psi. In reality, however, the average yield strength is closer to 42,000 psi, which provides a margin for steel producers to ensure that the minimum required strength of 36,000 psi is provided. LRFD-based specifications employ statistical methods and probability theory to define these variations both in loading and in material properties (structural resistance), and the likelihood that various com-

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binations of loads will occur at the same time. The statistically based derivation of these factors, however, is transparent to the designer using the specifications; what the designer sees are simple load factors, resistance factors, and load combination formulas that are used for the various design equations.

Status of Specifications

The second draft of the specifications and commentary was completed in May 1991 and widely circulated for review and evaluation. Fourteen states performed trial designs using the draft specifications, and the results were presented at a special AASHTO Bridge Subcommittee meeting held in St. Louis in mid-September.

The second draft received a positive reception during the St. Louis meeting. Many state bridge engineers noted that the new specifications looked different and took some getting used to. However, most of them said that once they became familiar with the new format, it was relatively easy to use for design and much more logically structured than the existing design specifications.

On the basis of the results of these trial designs, several minor problems were identified that will be corrected during the development of the final draft of the specifications. It is anticipated that the final draft will be completed and submitted in early April 1992 and that AASHTO will consider it for adoption in 1993.

To assist the states in converting to the new LRFD specifications, the Federal Highway Administration will develop a training course that should be available to the states shortly after the specifications are adopted by AASHTO.

Conclusion

The importance of NCHRP Project 12-33 and the new bridge design specifications is underscored by the national and international attention they have already received. Numerous presentations have been made at meetings and conferences in the United States and several other countries during the past three years. In March 1991 the 3rd TRB Bridge Engineering Conference featured a session on the new specifications, which was attended by 400 people. In addition, the project was highlighted as the cover story in the July 15, 1991, edition of the international weekly magazine *Engineering News-Record.*

When the specifications are eventually adopted by AASHTO, they will serve the bridge engineering profession into the next century with state-of-the-art design methods. The new specifications will be easier to keep technically up to date, and will have a commentary available to help bridge engineers interpret their provisions.

Will LRFD result in bridges built with thinner or lighter members? Not necessarily. Will bridges cost less to design or build? Not likely. Will it be more complicated to design with LRFD? No! The specifications will encourage bridge designers to use more accurate analysis methods and computer programs, but they will also allow the use of simple hand calculations.

What LRFD will do is result in the construction of bridges that exhibit a more uniform level of safety and that provide better long-term serviceability and maintainability. In addition, the new specifications will restore AASHTO to a leadership position in the international bridge engineering community.

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rail lines could increase speeds substantially. So could the use of modern signaling systems and improved grade crossings. Special 'tilt' trains would enable trains to round curves faster without slinging passengers from side to side.

"The kinds of high-speed trains found in Europe or Japan are feasible in our country only in areas with the necessary rights-of-way. Trains are available that can operate safely at speeds of up to 200 miles per hour, and new ones are being developed to go even faster. A specially modified French train has achieved a maximum speed of 322 miles per hour.

"These systems are expensive. Estimates of building a system in the United States have ranged from about $10 million per mile to as high as $63 million per mile. This wide variation in estimates will shrink as we gain experience, but the cost will remain high. The most likely market is intercity trips in the range of approximately 150 to 500 miles, where high-speed ground transportation would compete principally with air travel for ridership. We find it very unlikely that farebox revenues could cover the capital and operating costs along likely U.S. routes. Several factors, such as the limited use of passenger rail and the popularity of automobile and air travel in the United States, suggest one needs to be cautious in extrapolating foreign experience with high-speed rail to the U.S. market.

"This, then, raises the basic question: Should the United States build the systems anyway? Well, that's a political as well as a technical question, and one not addressed directly by our committee. But we are urging everyone to be clear that construction costs probably cannot be amortized with revenues alone, and that operating costs will add to the bill. Subsidies will be needed. And, at least initially, the most likely source for subsidies will be other transportation funds, such as those for highways or air travel.

"As one who has been in the transportation business a long time, I know this suggestion will meet with resistance. But the only way rapid rail or maglev will happen is as part of a larger transportation system. Other modes may benefit, so perhaps they also should help pay the cost.

"There's a larger point that goes beyond which pots of money should be tapped, and it is that we need a new approach to making these kinds of transportation decisions in general. It's now very difficult—too difficult—to introduce any new transportation mode. Our institutional and financial arrangements for transportation are oriented toward existing modes. We need a