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Autor(en): **Nowak, Andrzej S. / Kulicki, John M.**

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New Generation of U.S. Bridge Design Codes

Andrzej S. NOWAK
Professor of Civil Engineering
University of Michigan
Ann Arbor, MI
USA

John M. KULICKI
Senior Vice-President
Modjeski & Masters
Harrisburg, PA
USA

Andrzej S. Nowak received his PhD from Warsaw University of Technology, Poland, and has been at University of Michigan since 1979. He has been involved in reliability-based development of the LRFD bridge design codes in the United States and Canada.

John M. Kulicki received his PhD from Lehigh University in 1974. He has over 25 years of bridge design experience. He was selected to lead a 50-member team of experts to develop a new LRFD bridge design specification which was adoped by AASHTO in 1993.

Summary

The paper presents the development of a new load and resistance factor design (LRFD) bridge code in the United States. It is based on a probability-based approach. Structural performance is measured in terms of the reliability index. The major steps include selection of representative structures, calculation of reliability for the selected bridges, selection of the target reliability index and calculation of load and resistance factors. Load and resistance factors are derived so that the reliability of bridges designed using the proposed provisions will be at the predefined target level.

1. Introduction

The need for a new bridge design code in the United States was formulated as a result of an earlier NCHRP Project 20-7/31. The objectives in the development of this new specification may be summarized as:

- To develop a technically state-of-art specification which would put U.S. practice at or near the leading edge of bridge design.
- To make the specfication as comprehensive as possible and include new developments in structural forms, methods of analysis and models of resistance.
- To the extent consistant with the thoughts above, keep the specfication readable and easy to use, bearing in mind that there is a broad spectrum of people and organizations involved in designs.
- To keep specification-type wording.
- To encourage a multi-disciplinary approach to bridge design, particularly in the area of hydraulics and scour, foundation design and bridge siting.
- To place increasing importance on the redundancy and ductility of structures.

Many changes had to be made in the content and appearance of the AASHTO Standard Specifcication (1992) to achieve the objectives outlines above. The major changes are identified below:

- The introduction of a new philosophy of safety.
- The identification of four limit states.
- The development of new load factors.
- The development of new resistance factors.
- The relationship of the chosen reliability level, the load and resistance factors, and load models through the process of calibration.
- The development of improved load models necessary to achieve adequate calibration, including a new live load model.
- Revised techniques for analysis and the calculation of load distribution.
- A combined presentation of plain, reinforced and prestressed concrete.
- The introduction of limit state-based provisions for foundation design and soil mechanics.
- Expanded coverage on hydraulics and scour.
- Changes to the earthquake provisions to eliminate the seismic performance category concept by making the method of analysis a functions of the importance of the structure.
- Inclusion of large portions of the Guide Specification for Segmental Concrete Bridge Design.
- Inclusion of large portions of the FHWA Specfication for ship collision.
- Expanded coverage of bridge rails based on crash testing, with the inclusion of methods of analysis for designing the crash specimen.
- The introduction of the isotropic deck design process.
- The development of a parallel commentary.

The objective of this paper is to present the calibration procedure, in particular calculation of load and resistance factors for the ultimate limit states. The resistance factors are considered for slab on girder bridges including non-composite and composite steel girders, reinforced concrete T-beams and prestressed concrete AASHTO type girders.

2. Calibration Procedure

The calibration procedure was developed as a part of the project FHWA/RD-87/069 (Nowak et al. 1987). In this project, the work on the new bridge design code was formulated including the following steps:

(a) Selection of representative bridges

About 200 structures are selected from various geographical regions of the United States. These structures cover materials, types and spans which are characteristic for the region. Emphasis is placed on current and future trends, rather than very old bridges. For each selected bridge, load effects (moments, shears, tensions and compressions) are calculated for various components. Load carrying capacities are also evaluated.

(b) Establishing the statistical data base for load and resistance parameters.

The available data on load components, including results of surveys and other measurements, is gathered. Truck survey and weigh-in-motion (WIM) data are used for modeling live load. There is little field data available for dynamic load therefore a numerical procedure is developed for simulation of the dynamic bridge behavior. Statistical data for resistance include material tests, component tests and field measurements. Numerical procedures are developed for simulation of behavior of large structural components and systems.

(c) Development of load and resistance models.

Loads and resistance are treated as random variables. Their variation is described by cumulative distribution functions (CDF) and correlations. For loads, the CDF's are derived using the available statistical data base (Step b). Live load model includes multiple presence of trucks in one lane and in adjacent lanes. Multilane reduction factors are calculated for wider bridges. Dynamic load is modeled for single trucks and two trucks side-by-side. Resistance models are developed for girder bridges. The variation of the ultimate strength is determined by simulations. System reliability methods are used to quantify the degree of redundancy.

(d) Development of the reliability analysis procedure.

Structural performance is measured in terms of the reliability, or probability of failure. Limit states are defined as mathematical formulas describing the state (safe or failure). Reliability is measured in terms of the reliability index, β. Reliability index is calculated using an iterative procedure. The developed load and resistance models (Step c) are part of the reliability analysis procedure.

(e) Selection of the target reliability index.

Reliability indices are calculated for a wide spectrum of bridges designed according to the current AASHTO (1992). The performance of existing bridges is evaluated to determine whether their reliability level is adequate. The target reliability index, β_T, is selected to provide a consistent and uniform safety margin for all structures.

(f) Calculation of load and resistance factors.

Load factors, γ, are calculated so that the factored load has a predetermined probability of being exceeded. Resistance factors, ϕ, are calculated so that the structural reliability is close to the target value, β_T.

3. Load and Resistance Models

Load and resistance parameters are random variables. For prestressed concrete bridges the statistical models of resistance were developed by Nowak, Yamani and Tabsh (1994), Tabsh and Nowak (1991) and Nowak and Yamani (1995). Bridge load models were developed by Nowak (1995), Nowak and Hong (1991), and Hwang and Nowak (1991).

It was determined, that the bias factor (ratio of mean to nominal) for dead load is λ = 1.03-1.05, and coefficient of variation is V = 0.08-0.10. For live load, λ = 1.6-2.1 (depending on span length) and V = 0.12. The nominal live load is representeed by HS-20 truck (AASHTO 1992). HS20 loading consists of either three axles: 35kN, 142kN and 142kN, spaced at 4.3m, or a uniformly distributed lane load of 9.3kN/m with a moving concentrated force of 80kN. In the new LRFD AASHTO Code (1994), live load is a combination of HS-20 truck and a uniformly distributed load of 9.3 kN/m. Therefore, the bias factor for live load is λ = 1.25-1.35. Dynamic load associated with an extreme value of truck load is about 0.10-0.15 of the static portion of live load, with V = 0.80. For a combined static and dynamic live load V = 0.18.

The basic random variables considered in development of resistance models are dimensions, concrete compressive strength, and properties of structural steel, prestressing and nonprestressing strands. The parameters for moment carrying capacity are $\lambda = 1.12$ and $V = 0.10$, for non-composite and composite steel girders, $\lambda = 1.14$ and $V = 0.13$, for reinforced concrete T-beams, and $\lambda = 1.05$ and $V = 0.075$, for prestressed concrete AASHTO-type girders. For shear capacity the parameters are $\lambda = 1.14$ and $V = 0.105$ for steel girders, $\lambda = 1.20$ and $V = 0.155$ for reinforced concrete T-beams, and $\lambda = 1.15$ and $V = 0.14$ for prestressed concrete AASHTO-type girders.

4. Reliability Analysis Procedure

Reliability indices, β, are calculated using a specially developed computer procedure based on the first order reliability method. The available reliability methods are reviewed in several textbooks (Thoft-Christensen and Baker 1982). The methods vary with regard to accuracy, required input data, computational effort and special features (time-variance). In some cases, a considerable advantage can be gained by use of the system reliability methods. The structure is considered as a system of components. In the traditional reliability analysis, the analysis is performed for individual components. Systems approach allows to quantify the redundancy and complexity of the structure. The new LRFD code is based on element reliability. However, system reliability methods are used to verify the selection of redundancy factors.

Structural performance is measured in terms of the reliability index, β (Thoft-Christensen and Baker 1982). Reliability index is defined as a function of the probability of failure, P_F,

$$\beta = - \Phi^{-1}(P_F) \tag{1}$$

where Φ^{-1} = inverse standard normal distribution function.

It is assumed that the total load, Q, is a normal random variable. The resistance, R, is considered as a lognormal random variable. The formula for reliability index can be expressed in terms of the given data (R_n, l_R, V_R, m_Q, s_Q) and parameter k as follows (Nowak 1995),

$$\beta = \frac{R_n \lambda_R (1 - kV_R)[1 - \ln(1 - kV_R)] - m_Q}{\sqrt{[R_n V_R \lambda_R (1 - kV_R)]^2 + \sigma_Q^2}} \tag{2}$$

where R_n = nominal (design) value of resistance; λ_R = bias factor of R; V_R = coefficient of variation of R; m_Q = mean load; σ_Q = standard deviation of load. Value of parameter k depends on location of the design point. In practice, k is about 2.

5. Reliability Analysis for AASHTO (1992)

Reliability indices, β, are calculated for girders designed using the AASHTO Specifications (1992). The basic design requirement is expressed in terms of moments or shears (Load Factor Design),

$$1.3\,D + 2.17\,(L + I) < \phi\,R \tag{3}$$

where D, L and I are moments (or shears) due to dead load, live load and impact, R is the moment (or shear) carrying capacity, and ϕ is the resistance factor. Values of the resistance factor are $\phi = 1.00$ for moment and shear in steel girders, $\phi = 0.90$ and 0.85 for moment and shear in reinforced concrete T-beams, respectively, $\phi = 1.00$ and 0.90 for moment and shear in prestressed concrete AASHTO-type girders, respectively.

The results of calculations show a considerable variation in reliability indices depending on limit state and span length, from about 2 for short span (10m) and short girder spacing (1.2m) to over 4 for larger spans and girder spacing. The target reliability index was selected $\beta_T = 3.5$.

6. New Load and Resistance Factors

The results of the reliability analysis for the current AASHTO Specifications (1992) served as a basis for the development of more rational design criteria for the considered girders. The load factors developed for the LRFD AASHTO Code (1994) are

$$1.25\, D + 1.50\, D_A + 1.75\, (L + I) < \phi\, R_n \tag{4}$$

where D = deal load, D_A = dead load due to asphalt wearing surface, L = live load (static), I = dynamic load, R_n = resistance (load carrying capacity), and ϕ = resistance factor.

In the selection of resistance factors, the acceptance criterion is closeness to the target value of the reliability index, β_T. The recommended resistance factors are $\phi = 1.00$ for moment and shear in steel girders, $\phi = 0.90$ for moment and shear in reinforced concrete T-beams, $\phi = 1.00$ and 0.90 for moment and shear in prestressed concrete AASHTO-type girders, respectively.

Reliability indices calculated for bridges designed using the new LRFD AASHTO code (1994) are close to the target value of 3.5 for all materials and spans. The calculated load and resistance factors produce a uniform spectrum of reliability indices.

For comparison, the ratio of the required load carrying capacity by the new LRFD AASHTO code (1994) and the AASHTO 1992 varies from 0.9 to 1.2.

Conclusions

The calculated load and resistance factors provide a rational basis for the design of bridges. They also provide a basis for comparison of different materials and structural types.

The study has several important implications. The calculated load and resistance factors for the new LRFD code provide a uniform safety level for various bridges. The statistical analysis of load and resistance models served as a basis for the development of more rational design criteria.

Bridge components designed using the proposed LRFD Code have reliability index from 3.5 to 4.0.

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References

AASHTO, 1992, "Standard Specifications for Highway Bridges", American Association of State Highway and Transportation Officials, Washington, DC.

AASHTO, 1994, "LRFD Bridge Design Specifications", American Association of State Highway and Transportation Officials, Washington, DC.

Ellingwood, B. Galambos, T.V., MacGregor, J.G. and Cornell C.A., "Development of a Probability Based Load Criterion for American National Standard A58", National Bureau of Standards, NBS Special Publication 577, Washington, D.C. (1980).

Hwang, E-S. and Nowak, A.S., 1991, "Simulation of Dynamic Load for Bridges," ASCE Journal of Structural Engineering, Vol. 117, No. 5, pp. 1413-1434.

Kulicki, J.M. and Mertz, D.R., "Development of Comprehensive Bridge Specifications and Commentary", Final Report submitted to NCHRP, December 1993.

Nowak, A. S., Czernecki, J., Zhou, J. and Kayser, R., "Design Loads for Future Bridges," Report UMCE 87-1, University of Michigan, Ann Arbor, MI (1987).

Nowak, A.S., 1993, "Live Load Model for Highway Bridges", Journal of Structural Safety, Vol. 13, Nos. 1+2, December, pp. 53-66.

Nowak, A.S., 1995, "Calibration of LRFD Bridge Code", ASCE Journal of Structural Engineering, Vol. 121, No. 8, pp. 1245-1251.

Nowak, A.S. and Yamani, A.S., 1995, "Reliability Analysis for Girder Bridges", Structural Engineering Review, Vol. 7, No. 3, Aug. 1995, pp. 251-256.

Nowak, A.S., Yamani, A.S. and Tabsh, S.W., 1994, "Probabilistic Models for Resistance of Concrete Bridge Girders", ACI Structural Journal, Vol. 91, No. 3, pp. 269-276.

Nowak, A.S. and Hong, Y-K., 1991, "Bridge Live Load Models," ASCE Journal of Structural Engineering, Vol. 117, No. 9, pp. 2757-2767.

Tabsh, S.W. and Nowak, A.S., "Reliability of Highway Girder Bridges," ASCE Journal of Structural Engineering, Vol. 117, No. 8, (1991), pp. 2373-2388.

Thoft-Christensen, P. and Baker, M.J., 1982, "Structural Reliability Theory and Its Application", Springer-Verlag, p. 267.