The AASHTO LRFD Bridge Design Specifications: Yesterday, Today and Tomorrow

John M. Kulicki, Ph.D., Chairman/CEO
Modjeski and Masters, Inc.
OHBDC – Especially 1983 Edition
# Spring 1986 – Gang of Four

<table>
<thead>
<tr>
<th>Name</th>
<th>1986 Affiliation</th>
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<tr>
<td>James E. Roberts</td>
<td>Caltrans</td>
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<td>H. Henrie Henson</td>
<td>CODOH</td>
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<tr>
<td>Paul F. Csagoly</td>
<td>FLDOT</td>
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<td>Charles S. Gloyd</td>
<td>WashDOT</td>
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NCHRP 20-7/31 “Development of Comprehensive Bridge Specs and Comm.”

- Task 1 - Review of other specifications for coverage and philosophy of safety.
- Task 2 - Review AASHTO documents for possible inclusion into specification.
- Task 3 - Assess the feasibility of a probability-based specification.
- Task 4 - Prepare an outline for a revised AASHTO specification.
Findings of NCHRP Project 20-7/31 presented.
Seven options for consideration.
Funding requested to initiate an NCHRP project to develop a new, modern bridge design specification.
NCHP Project 12-33 - “Development of Comprehensive Specification and Commentary”.
Modjeski and Masters, Inc. began work in July, 1988.
Getting Organized

- Editorial Team
  - Frank Sears
  - Paul Csagoly
  - Dennis Mertz
  - John Kulicki

- Code Coordinating Committee

- Task Forces – Essentially by Section and Calibration

- 56 Members – Only 1 defector in 5 years
- Not always peace in the valley!
Development Objectives

- Technically state-of-the-art specification.
- Comprehensive as possible.
- Readable and easy to use.
- Keep specification-type wording – do not develop a textbook.
- Encourage a multi-disciplinary approach to bridge design.
Constraints

- Do not allow for further deterioration.
- Do not explicitly allow future increase in truck weights.
- No requirement to make bridges uniformly “heavier” or “lighter”.
Major Changes

- A new philosophy of safety - LRFD.
- The identification of four limit states.
- The relationship of the chosen reliability level, the load and resistance factors, and load models through the process of calibration
  - new load factors
  - new resistance factors.
Allowable Stress Design

$$\sum Q_i \leq \frac{R_E}{FS}$$

where:
- $Q_i$ = a load
- $R_E$ = elastic resistance
- $F_S$ = factor of safety
Load Factor Design

\[ \sum \gamma_i Q_i \leq \phi R \]

where:
- \( \gamma_i \) = a load factor
- \( Q_i \) = a load
- \( R \) = resistance
- \( \phi \) = a strength reduction factor
Load and Resistance Factor Design

\[ \sum \eta_i \gamma_i Q_i \leq \phi \ R_n = R_r \]

in which:

- \( \eta_i = \eta_D \eta_R \eta_I \geq 0.95 \) for loads for max
- \( \eta_i = \frac{1}{\eta_I \eta_D \eta_R} \leq 1.0 \) for loads for min

where:

- \( \gamma_i \) = load factor: a statistically based multiplier on force effects
- \( \phi \) = resistance factor: a statistically based multiplier applied to nominal resistance
<table>
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<th>Symbol</th>
<th>Definition</th>
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<td>$\eta_i$</td>
<td>load modifier</td>
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<tr>
<td>$\eta_D$</td>
<td>a factor relating to ductility</td>
</tr>
<tr>
<td>$\eta_R$</td>
<td>a factor relating to redundancy</td>
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<tr>
<td>$\eta_I$</td>
<td>a factor relating to importance</td>
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<tr>
<td>$Q_i$</td>
<td>nominal force effect: a deformation, stress, or stress resultant</td>
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<tr>
<td>$R_n$</td>
<td>nominal resistance</td>
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<tr>
<td>$R_r$</td>
<td>factored resistance: $\phi R_n$</td>
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LRFD - Basic Design Concept
Some Algebra

\[ \sigma_{(R-Q)} = \sqrt{\sigma_R^2 + \sigma_Q^2} \]

\[ \beta = \frac{\overline{R} - \overline{Q}}{\sqrt{\sigma_R^2 + \sigma_Q^2}} \]

\[ \overline{R} = \overline{Q} + \beta \sqrt{\sigma_R^2 + \sigma_Q^2} = \lambda R = \frac{1}{\phi} \lambda \sum \gamma_i x_i \]

\[ \phi = \frac{\lambda \sum \gamma_i x_i}{\overline{Q} + \beta \sqrt{\sigma_R^2 + \sigma_Q^2}} \]
Reliability Calcs Done for M and V – Simulated Bridges Based on Real Ones

- 25 non-composite steel girder bridge simulations with spans of 30, 60, 90, 120, and 200 ft, and spacings of 4, 6, 8, 10, and 12 ft.
- Composite steel girder bridges having the same parameters identified above.
- P/C I-beam bridges with the same parameters identified above.
- R/C T-beam bridges with spans of 30, 60, 90, and 120 ft, with spacing as above.
Reliability of Std Spec vs. LRFD – 175 Data Points

![Graphs showing reliability indices for 1989 AASHTO and proposed preliminaries.](Image)

**Reliability Indices**

- **1989 AASHTO:**
  - Graph showing reliability index against span length.

- **Proposed Preliminary:**
  - Graph showing reliability index against span length.
2006 Monte Carlo Reanalysis of 1993 Beta

4 or 5 data points each
2006 Monte Carlo Reanalysis of 1993 Beta

- Beta-MC / Beta RF (Steel-Composite)
- Beta-MC / Beta RF (Steel-Non-Composite)
- Beta-MC / Beta RF (Concrete-P/S)
- Beta-MC / Beta RF (Concrete-R/C)
2006 Monte Carlo Analysis of Beta for New Bridge Data Base

Bridge Database: Beta Factors Using Monte Carlo Analysis

Full Set of 124 Database Bridges

124 Bridges
2006 Monte Carlo Analysis

Monte Carlo Analysis: Beta vs Span Length

Computed Beta Factor vs Span Length (FT)

CIP Boxes
2006 Monte Carlo Analysis

Monte Carlo Analysis: D/L Ratio vs. Beta

Computed Beta Factor

Dead to Live Load Ratio (Unfactored)
Major Changes

- Revised calculation of load distribution

\[ g = 0.075 + \left( \frac{S}{2900} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \left( \frac{Kg}{Lt_s^3} \right)^{0.1} \]
Distribution Factors Revisited (2005)
On-Going Work – NCHRP 12-62

Courtesy of
Prof. Jay Puckett
Major Changes (Continued)

- Combine plain, reinforced and prestressed concrete.
- Modified compression field/strut and tie.
- Limit state-based provisions for foundation design.
- Expanded coverage on hydraulics and scour.
- The introduction of the isotropic deck design.
- Expanded coverage on bridge rails.
- Inclusion of large portions of the AASHTO/FHWA Specification for ship collision.
Major Changes (Continued)

- Changes to the earthquake provisions to eliminate the seismic performance category concept by making the method of analysis a function of the importance of the structure.
- The development of a parallel commentary.

- New Live Load Model – HL93
- Continuation of a long story
It would thus seem that 80 lb/sf would be a maximum load, if indeed it should not be much less, for long spans.
Waddell discusses the source of distributed load used in the design of bridges:

Some people have the idea that a herd of cattle will weigh more per square foot than a crowd of people, but such is not the case, as the actual limit for the former is about 60 lb/ft².

“The customary loading assumed for the design of highway bridges in the past has been a certain uniform live load alone, possibly a typical heavy wagon or road-roller, or a uniform live load with a concentration.... But these older types of loading are inadequate for purposes of design to take care of modern conditions; they should be replaced by some types of typical motor trucks.”

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4-Ton 10-Ton 12-Ton 14-Ton 17-Ton 20-Ton
1923 AREA Specification

VERY CLOSE!!
1923 AREA Specification

800 lb per ft
1924 AREA Specification

800 lb per ft

20-Ton

8k  32k

15'  14'  19'  14'  19'  14'  15'

20-Ton

20-Ton

800 lb per ft
Shoemaker’s Truck Train and Equivalent Load (Bold Added)-1923

- The 7.5-ton [capacity] truck, which weighs about 15 tons when loaded to capacity and which can be overloaded to weigh about 20 tons, is the heaviest commonly used.

- A large part of traffic, however, is carried in trucks of 5 tons capacity or less. It would not appear to be necessary, therefore, to provide for a succession of 20-ton loads.
Shoemaker’s Truck Train and Equivalent Load - 1923

By 1929 Lane Load becomes what we have today
1928-1929 Conference Specification

- 6k 24k 14' 30' 6k 24k 14' 30' 8k 32k 14' 30' 6k 24k 14' 30' 6k 24k 14'

- 15-Ton 15-Ton 20-Ton 15-Ton 15-Ton

- 18,000 lb for Moment
- 26,000 lb for Shear

- 640 lb/ft
1941 AASHTO----HS20 (Almost)

8k 14' 32k 14' 32k

H20 - S16

640 lb/ft

32,000 lb for Moment
40,000 lb for Shear
1941-1944 Rebellion & Chaos!!

- Much disagreement over HS Loading
- “An Analysis of Highway Loads Based on the Special Loadometer Study of 1942” by Dr. A.A. Jakkulka
- Recommended HS20 Truck “Because it was the more common stress producing truck on the road”
At the December 1944 Bridge Committee Group Meeting, a progress report on a truck loading study conducted at Texas A and M College was presented. The minutes of the meeting state that:

the discussion that followed ....soon developed into a “free for all” over “them” good old fighting words “what design loading should be used.” After the meeting got down to normalcy again, Mr. Paxon presented...
1944 Agreement

- No HS Lane Load---use H20 Lane Load
- Variable axle spacing adopted – more closely approximates “the tractor tailors now in use”
- HS20-S16-44…..44 added to reduce confusion from so many changes
Live Load Continued to be Debated

- Early 1950’s – discussion to remove the lane load as too heavy and wasteful for continuous spans.
- Throughout 50’s there are discussions about increasing the design truck
- 1958 – decision to do nothing until after AASHO Road Tests are completed.
Live Load Continued to be Debated

- Late 60’s – H40, HS25 and HS30 discussed
- 1969 – SCOBS states unanimous opposition to increasing weight of design truck – “wasteful obsolescence” of existing bridges
- 1978 – HS25 proposed again
- 1979 – HS25 again – commentary –
  - need for heavier design load seems unavoidable
  - HS25 best present solution
  - 5% cost penalty
- Motion soundly defeated
“Exclusion Loads” – Based on TRB Special Report 225, 1990

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EX 3A (WB 4.95)

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EX 3 - S3 - 5 (WB 22.13)

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EX 3 - S2 (WB16.42)
EXCL/HS20 Truck or Lane or 2 – 110 kN Axles @ 1.2 m
Selected Notional Design Load

PROPOSED LOADS

- NEGATIVE MOMENT AND INTERIOR REACTIONS
- ≥ 50 FT
- FIXED WHEELBASE ON TRUCK = 14 FT
- 90%
EXCL/HL 93 – Circa 1992
NCHRP 12-33 Project Schedule

- First Draft - 1990 – general coverage
- Second Draft - 1991 – workable
- Third Draft - 1992 – pretty close
- Two sets of trial designs - 1991 and 1992
- Fourth Draft - 1993 – ADOPTED!!
- 12,000 comments
- Reviewed by hundreds
- Printed and available - 1994
Implementation Starts Slowly

- Lack of software.
- Early lack of training – but several thousand have taken NHI courses with more to come.
- Perceived difficulties
  - Load distribution
  - Shear in concrete
  - Foundations
  - Load cases seemed numerous but that may be because they are all stated
  - Continual changes – more later
- Similar story with EUROCode plus national issues.
Implementation (Continued)

- Down size, right size, capsize.
- To SI or not to SI? That’s the question.
- But things are moving, especially compared to other major changes.
- By 2007:
  - 5,000 LRFD bridges
  - More than half of states doing part or all LRFD
First LRFD Major Bridge Opened
1997
Upgrades and Changes to 1990 Technology

- 1996 foundation data reinserted.
- New wall provisions – ongoing upgrade.
- MCF Shear in concrete simplified and clarified several times – major update in 2002.
- Load distribution application limits expanded several times in 1990’s due to requests to liberalize.
- More commentary added.
Upgrades and Changes

- 2004 – major change in steel girder design in anticipation of………
- 2005 – seamless integration of curved steel bridges ending three decade quest.
Curved Girder Leaders

- Dr. Bill Wright
- Dr. Don White
- Mr. Mike Grubb
- Dr. Dennis Mertz
- Mr. Ed Wasserman
2005 – P/C loses updated

2006 – complete replacement of Section 10 – Foundation Design

2006 – more concrete shear options

Some 2007 Ballot Items......

- Streamline MCF for concrete shear design
- 1,000 year EQ maps and collateral changes
- Seismic Guide Spec - displacement based
- Pile construction update
- Simplified load distribution
HSCOBS Asserts Ownership

- LRFD Oversight Committee – Circa 2002

“The mission … is to promote LRFD as the national standard for bridge design and develop a strategic plan to successfully implement LRFD by 2007 for all new bridge designs.

…to develop a strategic plan to identify and prioritize educational and training needs…..
Where Do We Go From Here?
Future as Seen in 1993 – Continued Development

- Quantifying Redundancy.
- Expanded database of loads, etc.
- Refinement of foundation provisions.
- Simplification of load distribution.
- Improvements in reliability procedures.
- Joint probability procedures
  - LL with EQ?
  - Ship and scour?
  - EQ and scour?
  - Ice and wind?
  - Etc.
Calibration of Service Limit State

- Deformation, cracking, service stress limits.
- What quantitative criteria can be established?
- What is the structural penalty for violating a non-strength limit state?
- How often can the limit state be exceeded in the design life?
- What is an appropriate reliability index?
- What is the appropriate loading in terms of magnitude, configuration, and placement? How does this relate to multiple presence factors?
- Should permit loads and illegal loads be considered?
- Will SHRP 2 do it??
Other Limit States??

- Does current design address the real culprits?
- Where are owners spending maintenance $$?
- Do we know the impact of changes?

Will FHWA LTBP Tell Us??
Rehabilitation

- Applying new standards to existing bridges has always been a challenge.
- Are other limit states or load combinations or reliability targets appropriate for rehab?
- Do we need and “Application Manual” for rehab?
Bridge Security

- Per 2003 BRC recommendations, T–1 formed several years ago
- Much research on-going
- ASCE Committee on Bridge Security formed – James Ray, Chair
- First fledgling steps towards specifications accepted in 2007 – NCHRP 12-72
Coastal Storms
TASK ORDER DTFH61-06-T-70006 (2006)
DEVELOPMENT OF GUIDE SPECIFICATIONS
AND HANDBOOK OF RETROFIT OPTIONS FOR BRIDGES VULNERABLE TO COASTAL STORMS

Modjeski and Masters, Inc.
Moffatt & Nichol, Inc.
Ocean Engineering Associates, Inc.
Dennis R. Mertz
D’ Appolonia
Quantification of Redundancy

2005 – T-5 commits to work with results of:
- NCHRP 406 – redundancy of super
- NCHRP 458 – redundancy of sub

Goals:
- Multiplier table for routine girder bridges.
- Process for evaluating more complex bridges for a reliability index in damaged state.
2005 – T-5 also commits to continued review of:

- FHWA Synthesis Report on Extreme Loading Combinations by Nowak, Knott and Dumas, August, 1996
- NCHRP 489 – extreme events, 1999

2005 T-5 presentation by Sue Hida on CALTrans in-house study of joint probability of scour and EQ-----non-issue.

Focus shifting to “all hazard “ approach.
Fatigue and Fracture

Should new load histograms be obtained?
- Traffic changes after 1970’s oil embargo
- Increases in legal loads
- CB’s etc.
- Load bandwidth increase

Having said that – still seeing little load induced damage

Have we given up on F and F Spec changes for HPS?
Perfection is Still an Illusive Goal

But Improvement Is Possible and Demanded By Society
Summary

- The object was to switch to a more robust, more expandable, more adaptable platform---------like Windows vs. DOS.
- As with the switch to Windows, there were some transitional learning curves and headaches----but many developers can see benefits, users can see the logic.
- It is unrealistic to expect the LRFD Specs to become static-----researches will always have new ideas, nature will continue to teach us lessons.
- But LRFD was intended to adapt and grow!
Net Effect So Far

'06

'94
‘08 Interim Accessory???
Thank You

And A Special “Thank You” To All Who Helped Over The Last Two Decades!!
But Some Must Be Mentioned

- NCHRP – Ian Friedland, Scott Sabol, Dave Beal
- SCOBS – Bob Cassano, Clellon Loveall, Jim Siebels, Dave Pope, Mal Kerley
- Panel – Jim Roberts, Chairman
- AASHTO – Kelley Rehm, Ken Kobetsky
- Modjeski and Masters – Dennis Mertz, Wagdy Wassef, Diane Long