***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

Name	1986 Affiliation
James E. Roberts	Caltrans
H. Henrie Henson	CODOH
Paul F. Csagoly	FLDOT
Charles S. Gloyd	WashDOT

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.

May 1987 HSCOBS - A Turning Point

- 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

$$\sum Q_i \leq R_E / FS$$

where:

- Q_i = a load
- R_E = elastic resistance
- F_S = factor of safety

Load Factor Design

$$\Sigma \gamma_i \; Q_i \leq \phi \; R$$

where:

- γ_i = a load factor
- Q_i = a load
- R = resistance
- ϕ = a strength reduction factor

Load and Resistance Factor Design

$$\Sigma \eta_i \gamma_i Q_i \leq \phi R_n = R_r$$

in which:

- $\eta_i = \eta_D \eta_R \eta_I \geq 0.95$ for loads for max
- $= 1/(\eta_I \eta_D \eta_R) \leq 1.0$ for loads for min

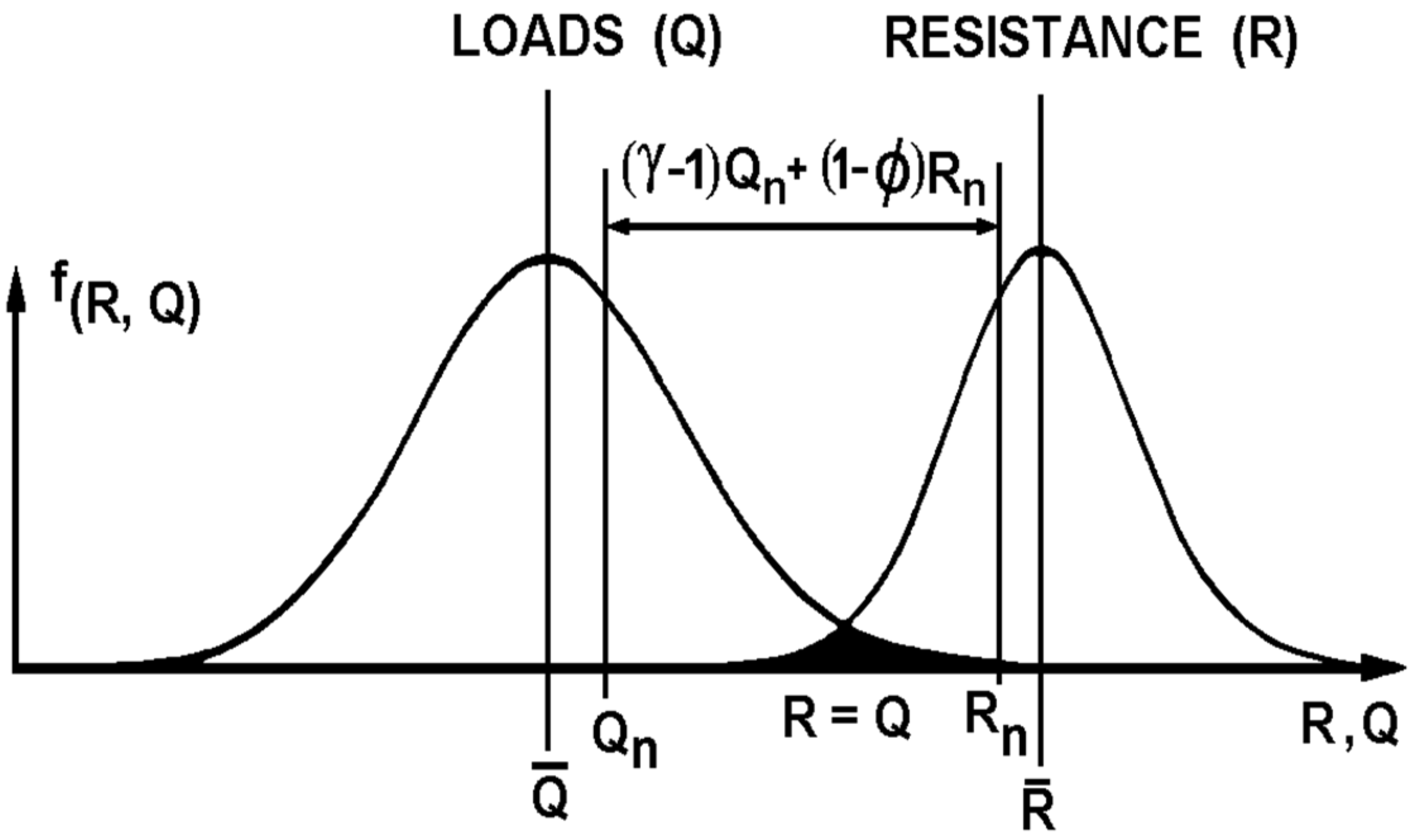
where:

- γ_i = load factor: a statistically based multiplier on force effects
- ϕ = resistance factor: a statistically based multiplier applied to nominal resistance

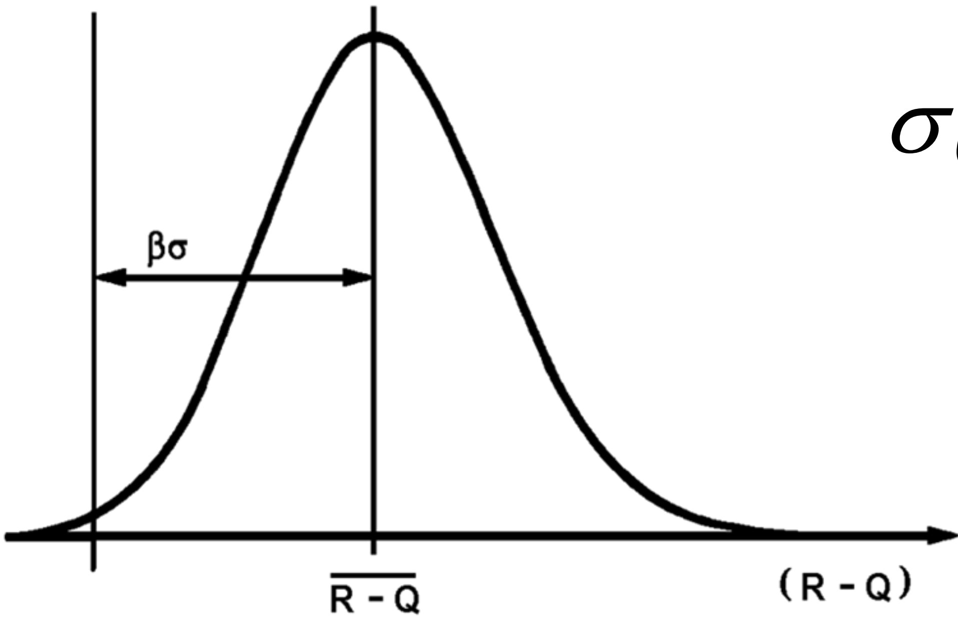
LRFD (Continued)

- η_i = load modifier
- η_D = a factor relating to ductility
- η_R = a factor relating to redundancy
- η_I = a factor relating to importance
- Q_i = nominal force effect: a deformation, stress, or stress resultant
- R_n = nominal resistance
- R_r = factored resistance: ϕR_n

LRFD - Basic Design Concept



Some Algebra



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

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

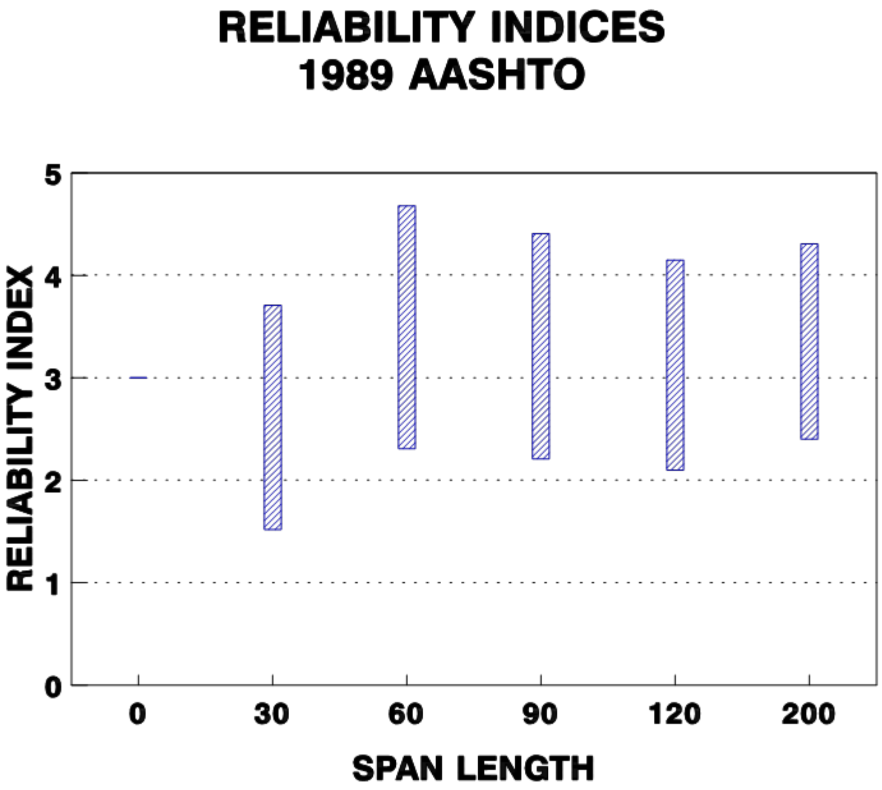
$$\overline{R} = \overline{Q} + \beta\sqrt{\sigma_R^2 + \sigma_Q^2} = \lambda R = \frac{1}{\phi}\lambda \Sigma \gamma_i x_i$$

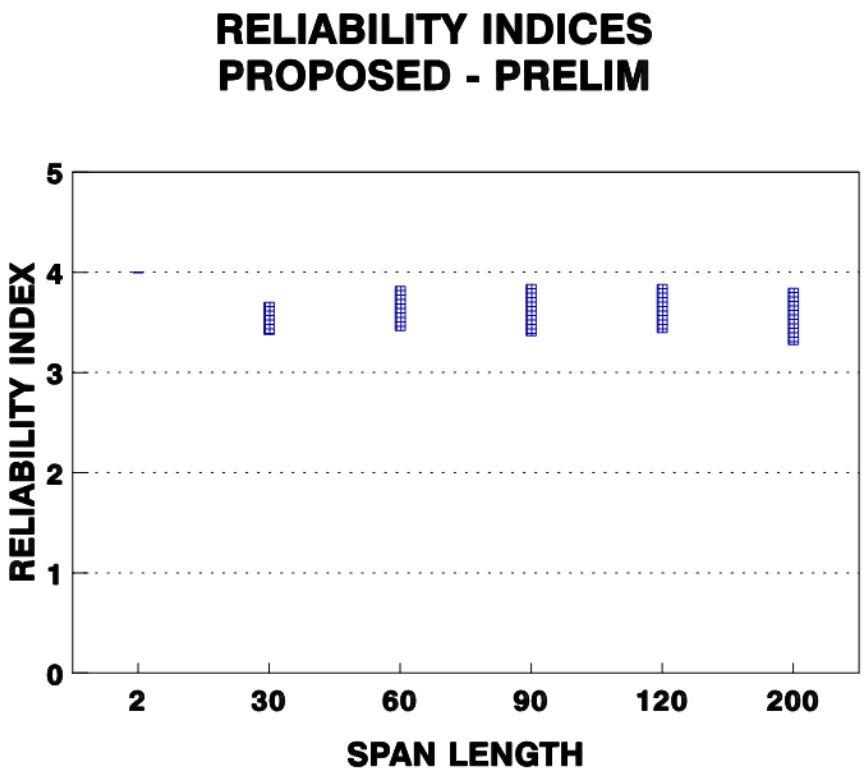
$$\phi = \frac{\lambda \Sigma \gamma_i x_i}{\overline{Q} + \beta\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

Reliability Calcs Done for M and V – Simulated Bridges Based on Real Ones

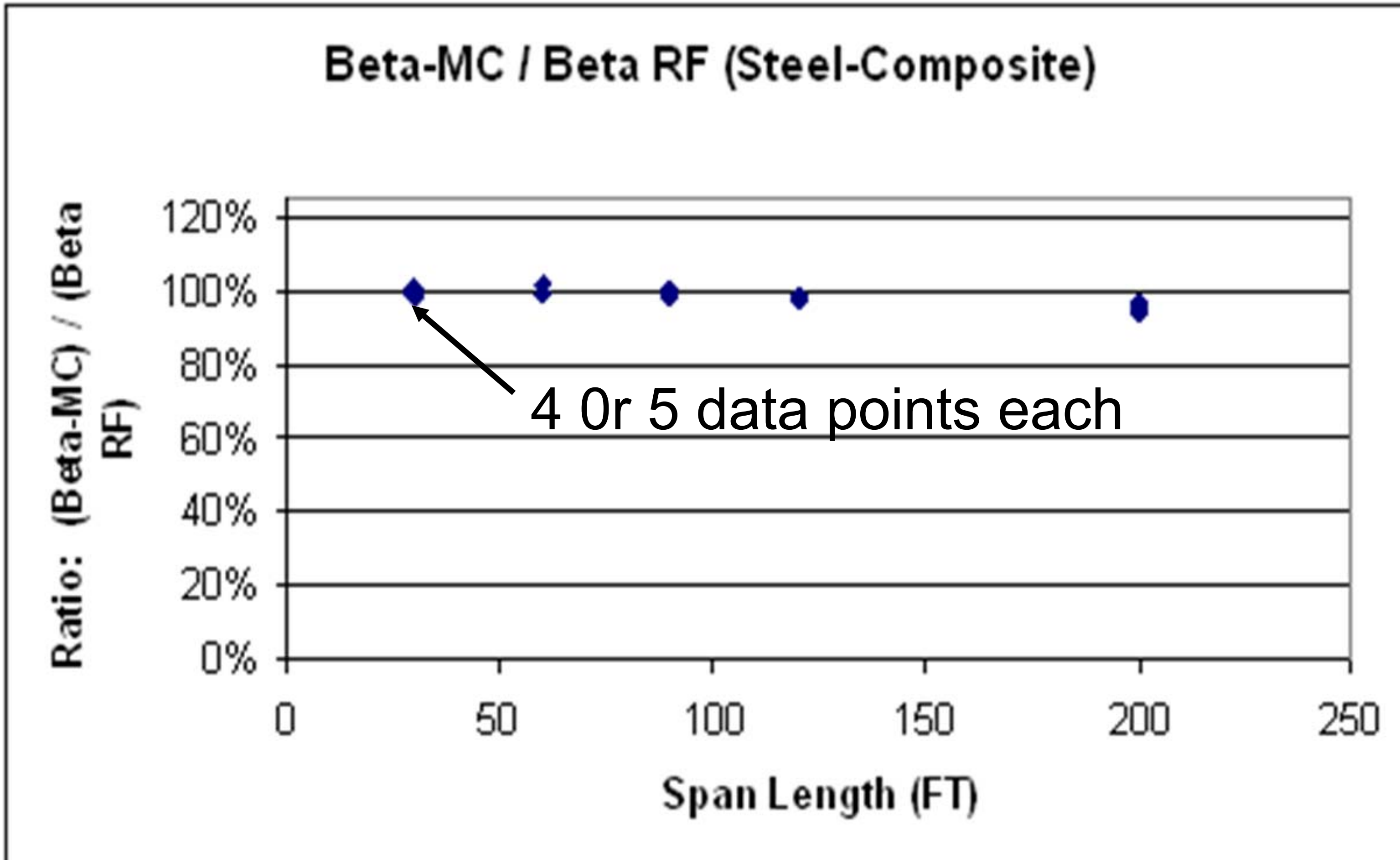
- 25 non-composite steel girder bridge simulations with spans of 30,60,90,120,and 200 ft, and spacings of 4,6,8,10,and 12 ft.
- Composite steel girder bridges having the same parameters identified above.
- P/C I-beam bridges with the same parameters identified above.
- R/C T-beam bridges with spans of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

Reliability of Std Spec vs. LRFD – 175 Data Points

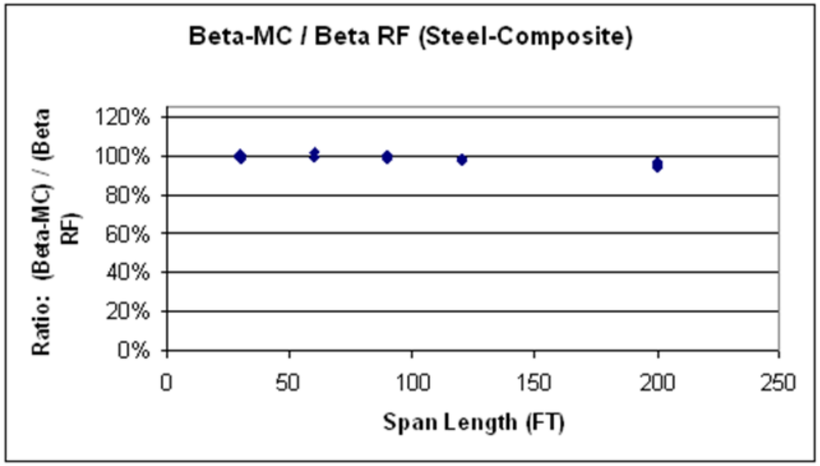


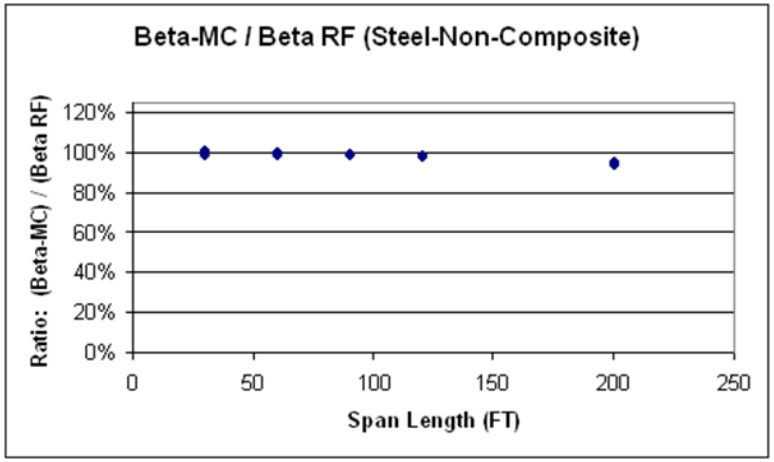


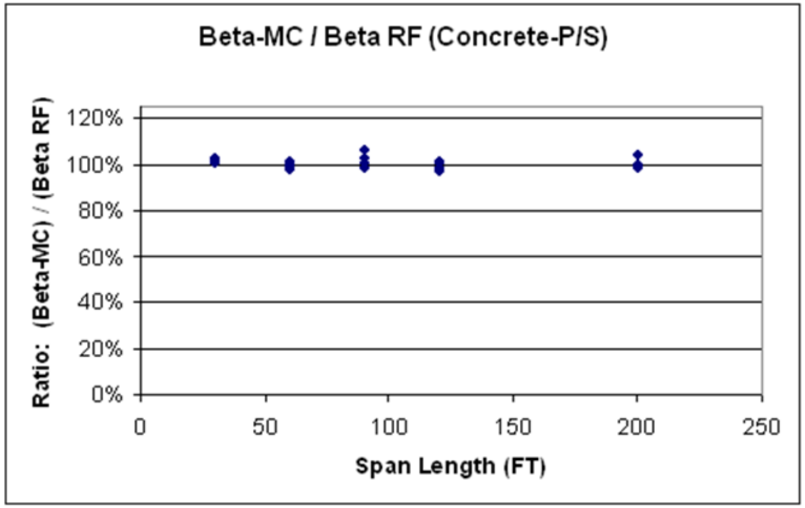
2006 Monte Carlo Reanalysis of 1993 Beta

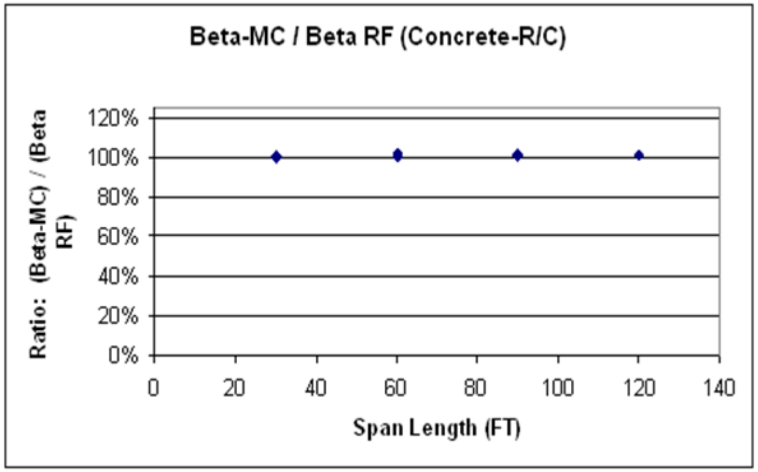


2006 Monte Carlo Reanalysis of 1993 Beta

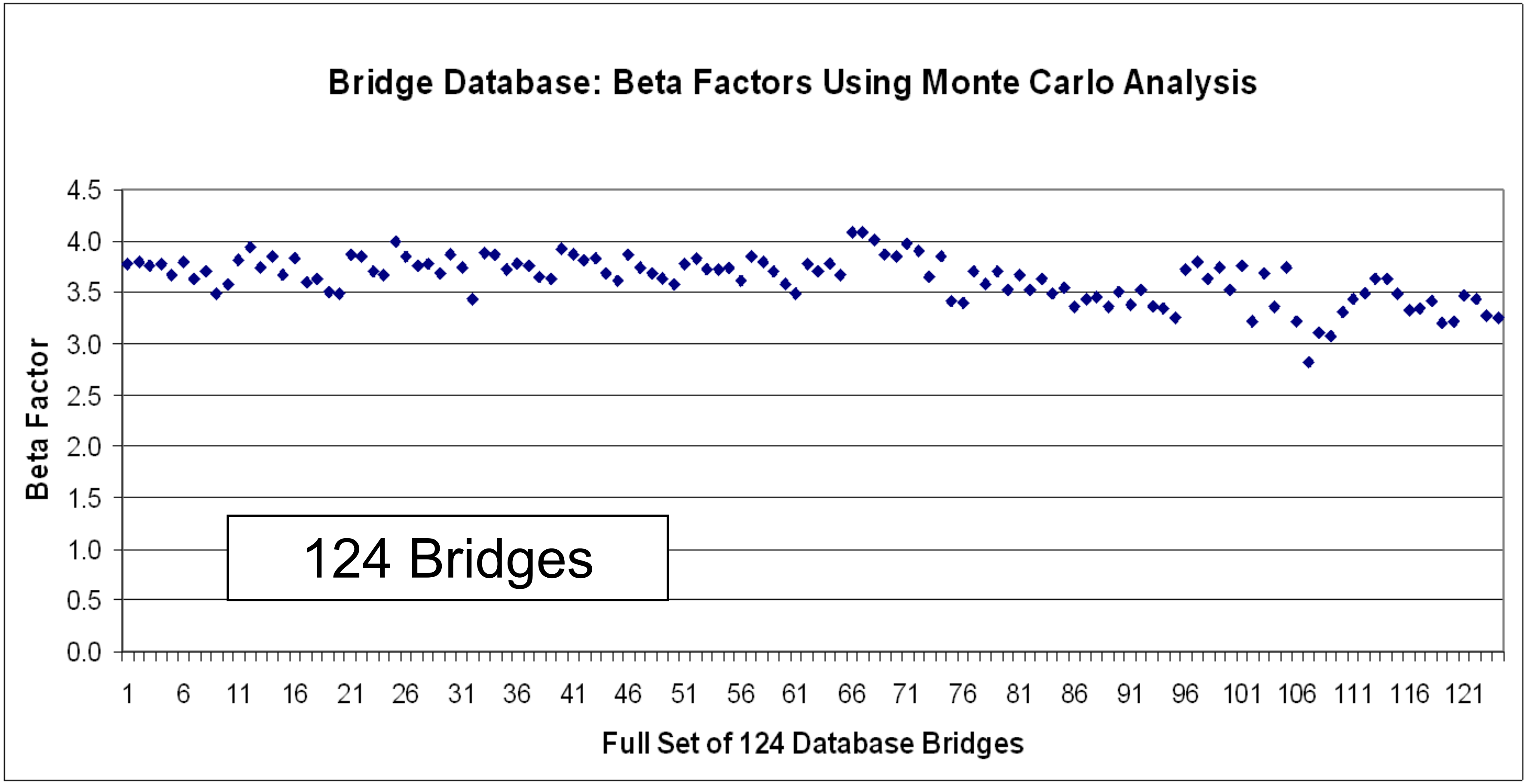




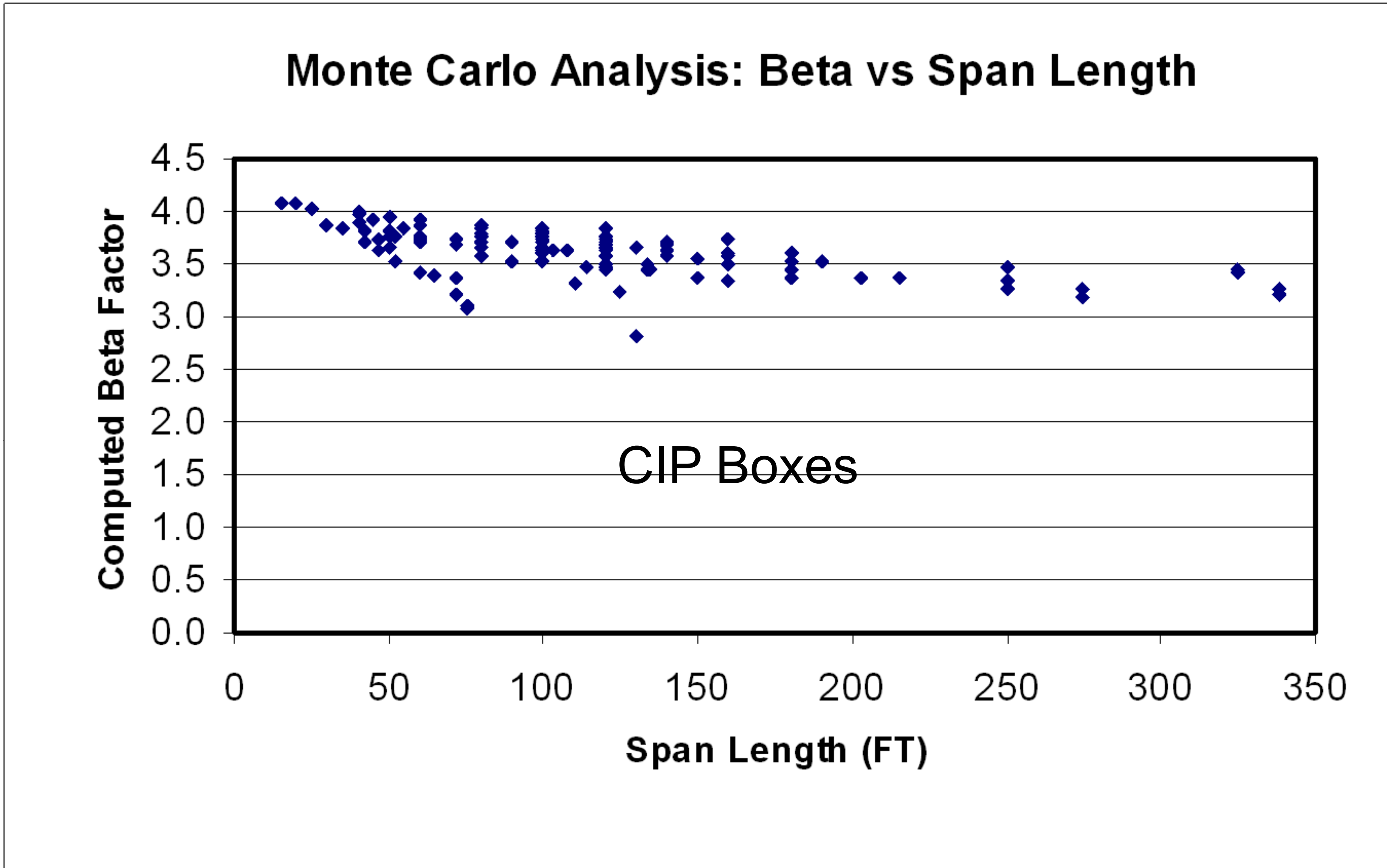




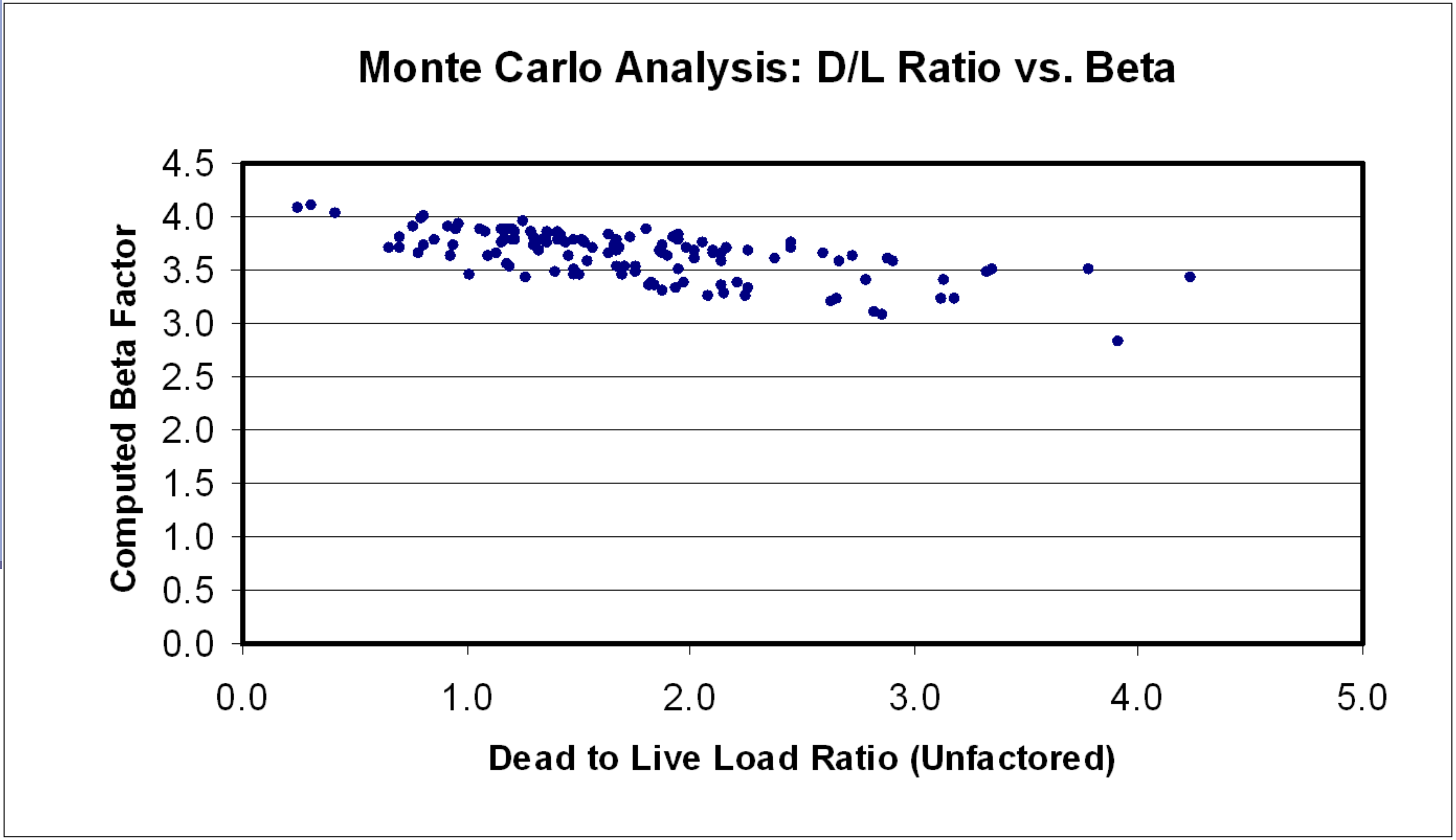
2006 Monte Carlo Analysis of Beta for New Bridge Data Base



2006 Monte Carlo Analysis



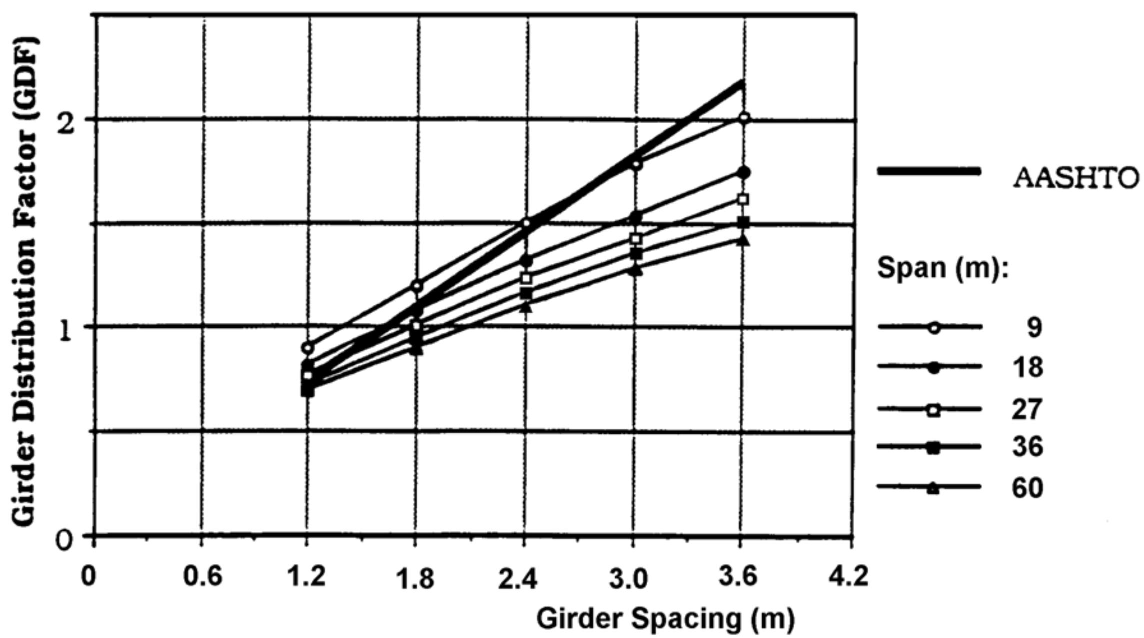
2006 Monte Carlo Analysis



Major Changes

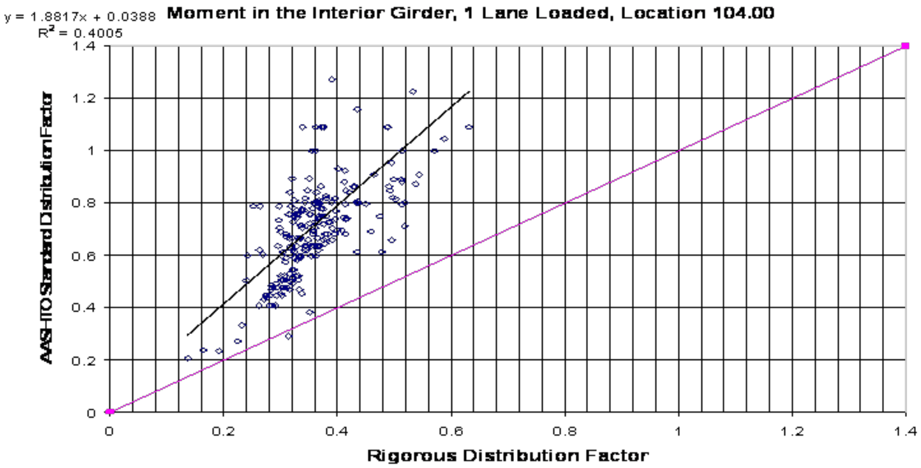
- Revised calculation of load distribution

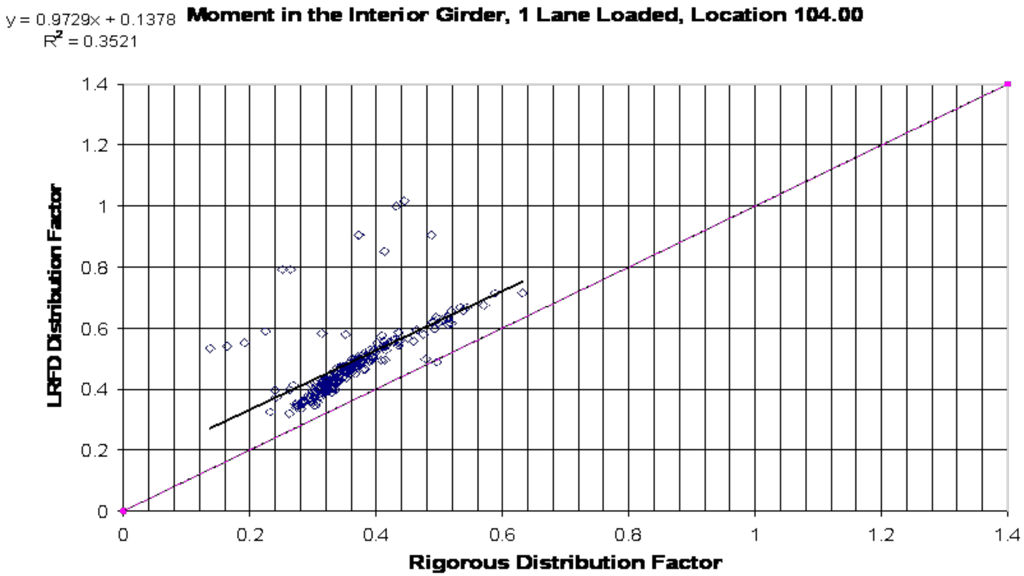
$$g = 0.075 + \left(\frac{S}{2900}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{Lt_s^3}\right)^{0.1}$$



Circa 1990

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.
- Guidance on the design of segmental concrete bridges – from Guide Spec.
- The development of a parallel commentary.

- **New Live Load Model – HL93**
- **Continuation of a long story**

1912 Article Published in *Transactions* of ASCE, Henry B. Seaman

- It would thus seem that 80 lb/sf would be a maximum load, if indeed it should not be much less, for long spans.

Bridge Engineering, Published in 1916, J.A. Waddell

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.

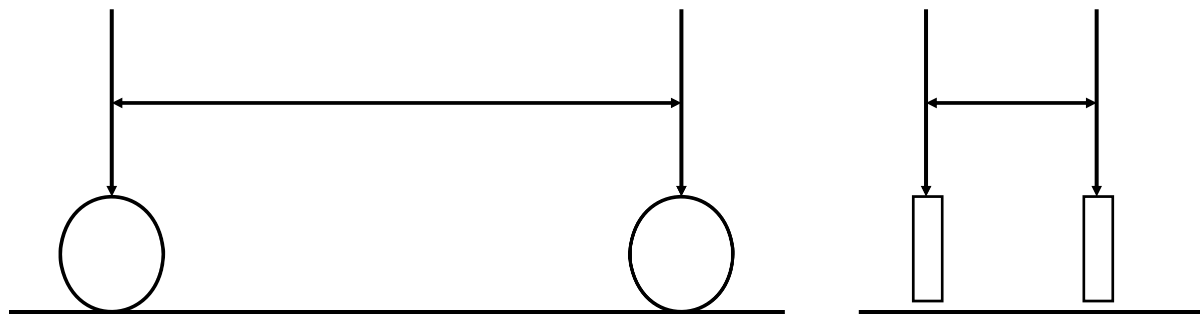
L.R. Manville and R.W. Gastmeyer, *Engineering News*, September 1914

"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."

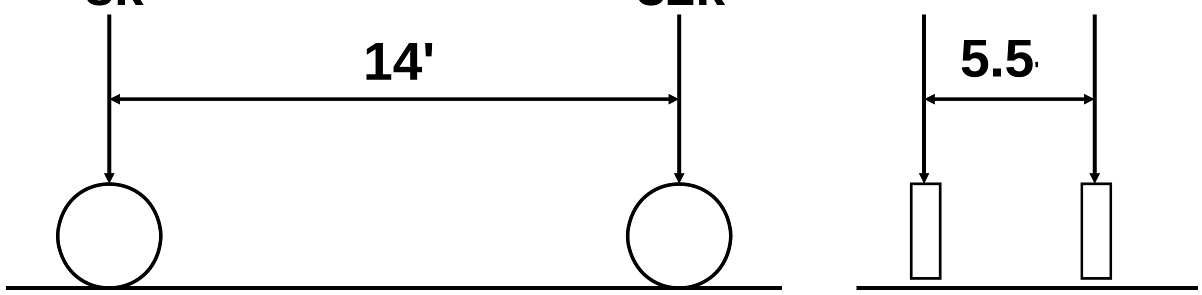
L.R. Manville and R.W. Gastmeyer, *Engineering News*, September 1914

4-Ton	3k	8'	5k	5'
10-Ton	4k	12'	16k	6'
12-Ton	6k	12'	18k	6'
14-Ton	4k	12'	24k	6'
17-Ton	14k	12'	20k	6'
20-Ton	**12k**	**12'**	**28k**	**6'**



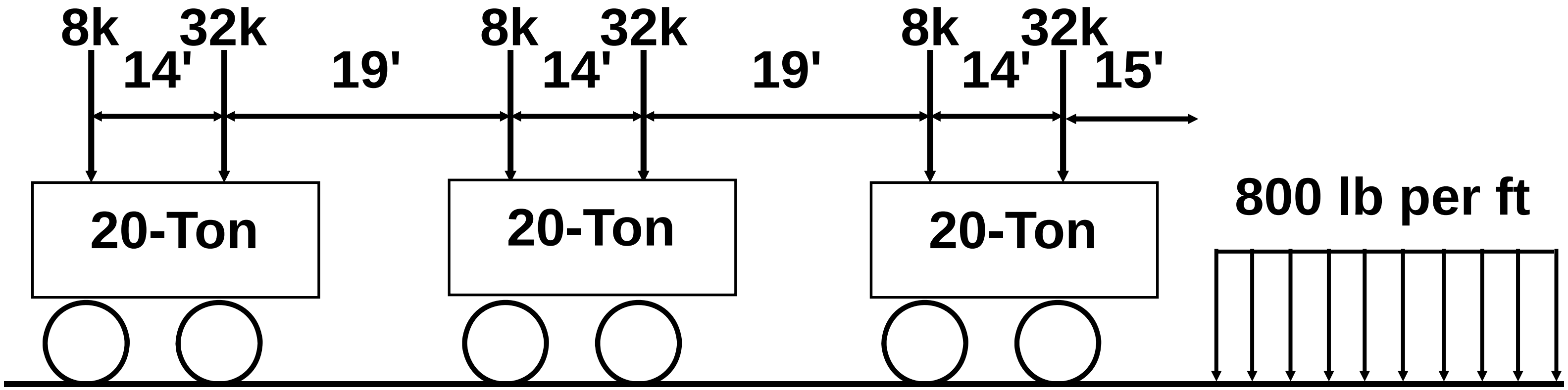
1923 AREA Specification

10-Ton	4k	16k
15-Ton	6k	24k
20-Ton	8k	32k

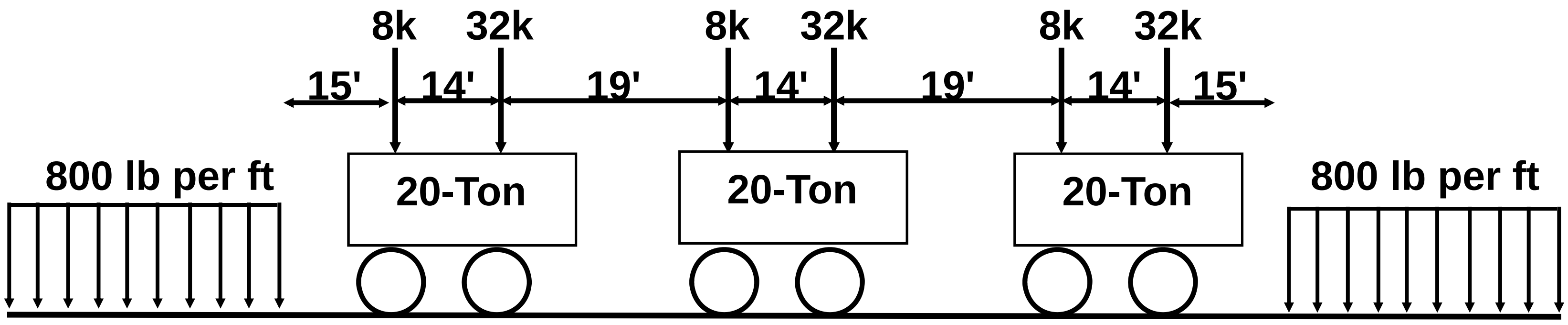


VERY CLOSE!!

1923 AREA Specification



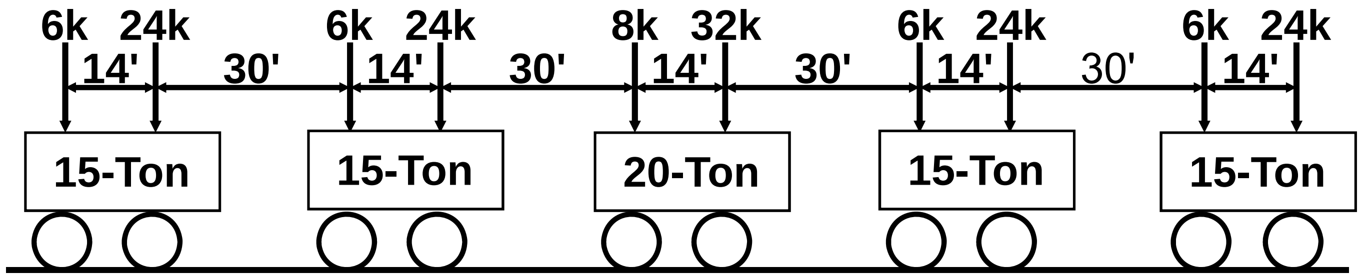
1924 AREA Specification

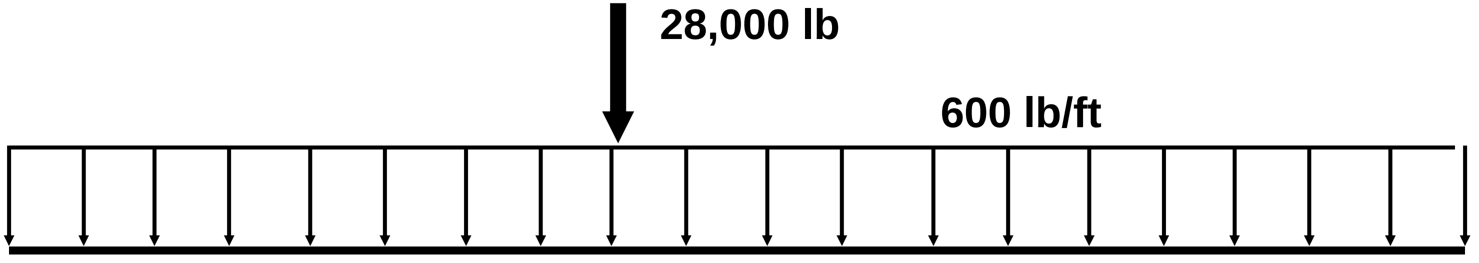


Shoemaker's Truck Train and Equivalent Load (Bold Added)-1923

- 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.

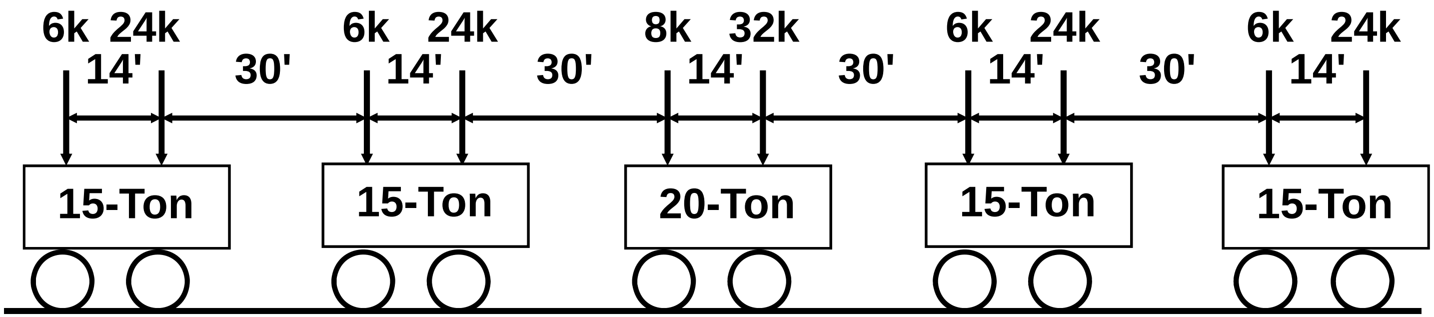
Shoemaker's Truck Train and Equivalent Load - 1923

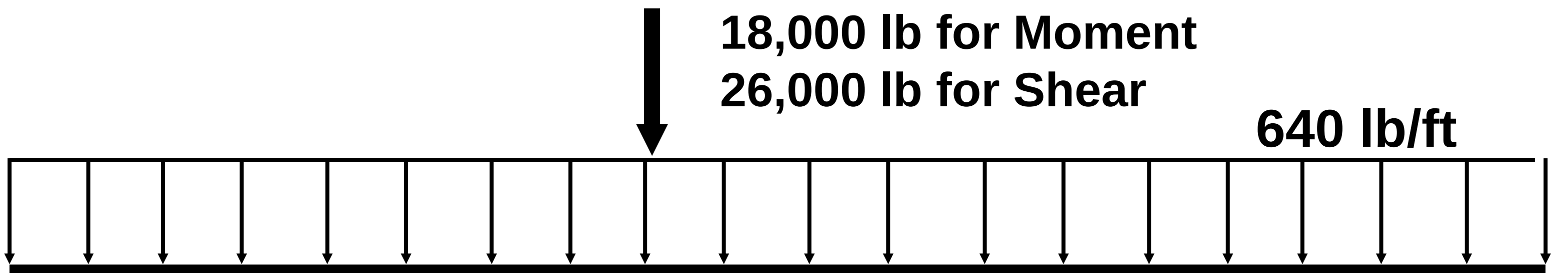




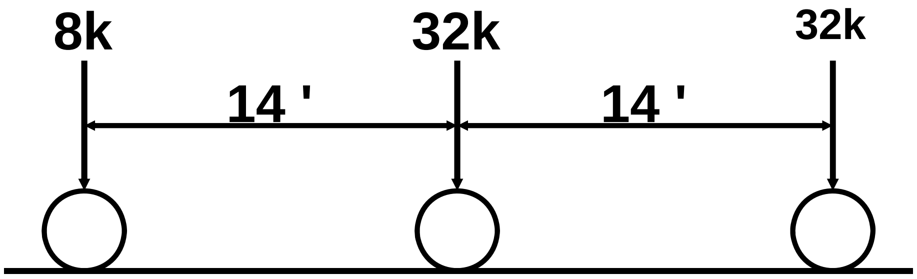
By 1929 Lane Load becomes what we have today

1928-1929 Conference Specification

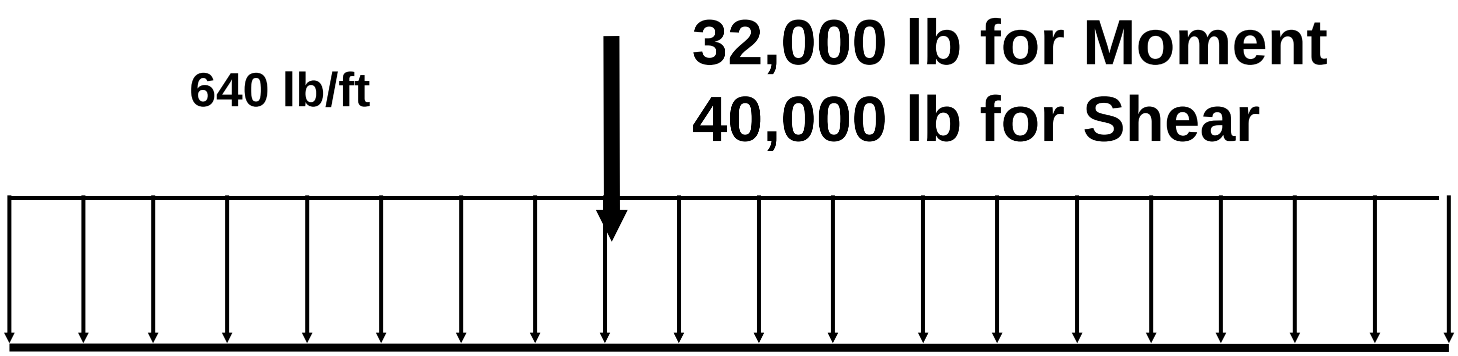




1941 AASHTO----HS20 (Almost)



H20 - S16



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”

1941-1944 Rebellion & Chaos!!

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

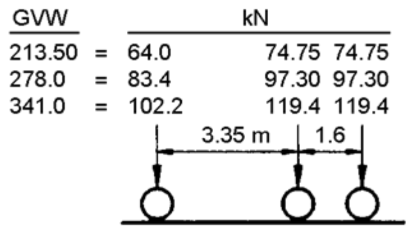
Live Load Continued to be Debated

- 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.

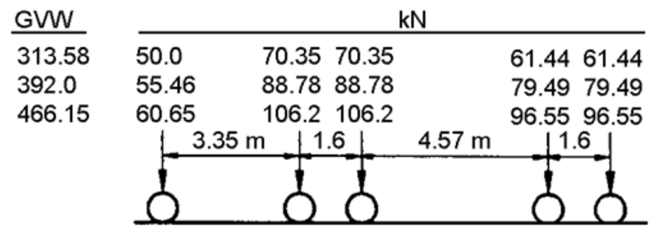
Live Load Continued to be Debated

- 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

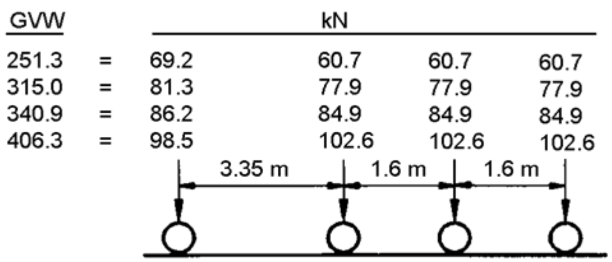
"Exclusion Loads" – Based on TRB Special Report 225, 1990



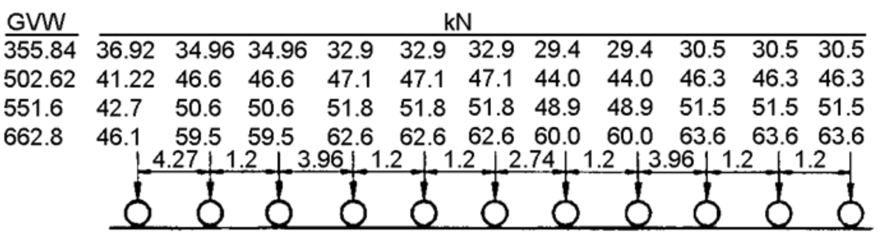
EX 3A (WB 4.95)



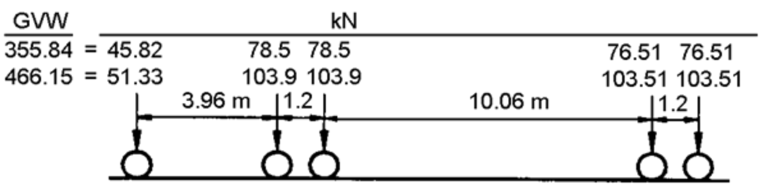
EX 3 - S2 (WB 11.12)



EX 4A (WB 6.55)

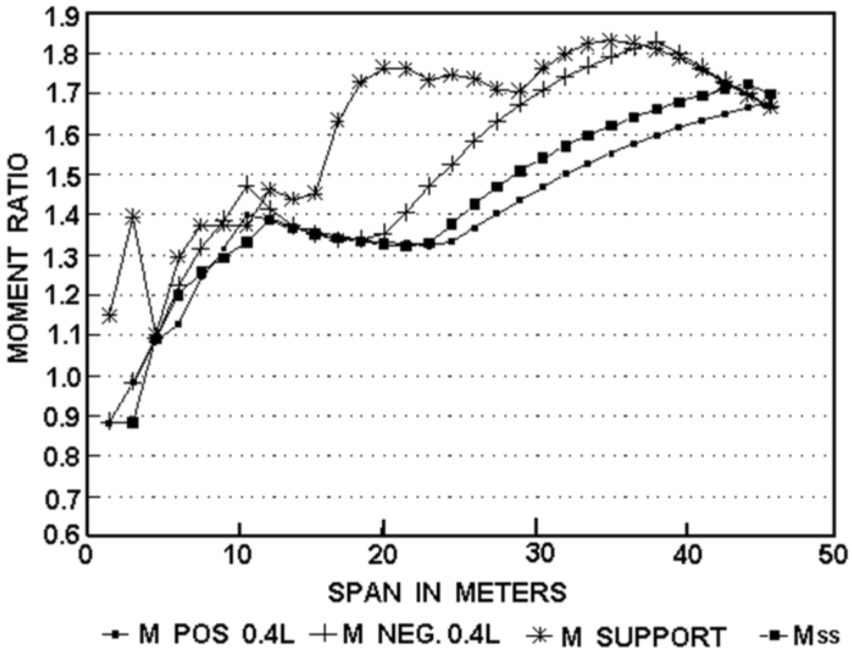


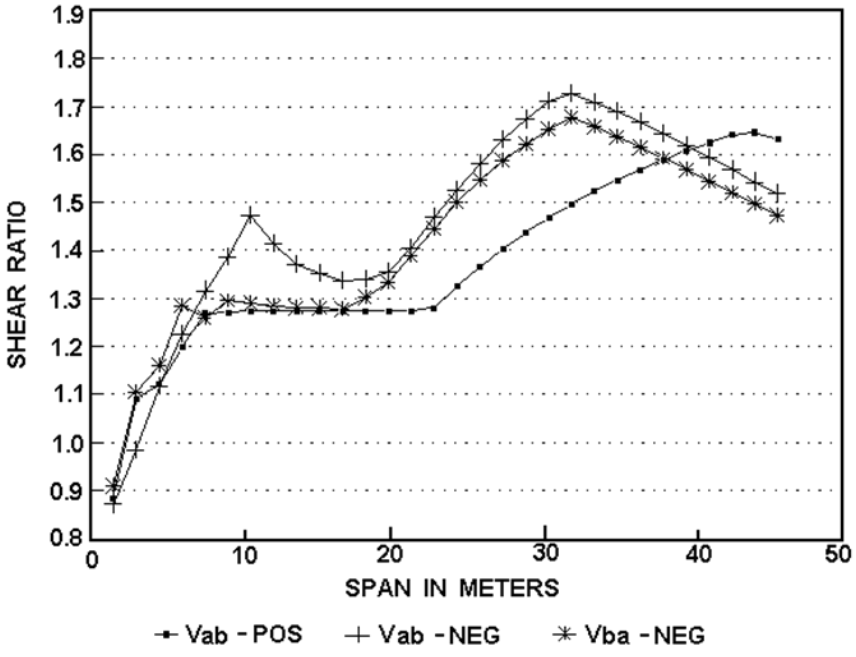
EX 3 - S3 - 5 (WB 22.13)



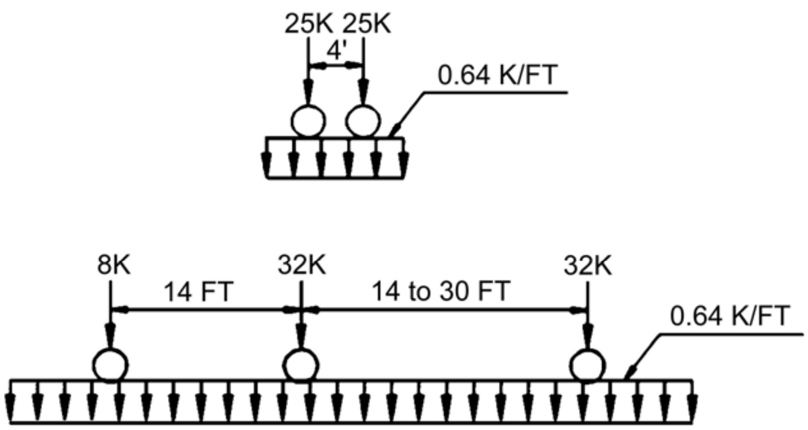
EX 3 - S2 (WB16.42)

EXCL/HS20 Truck or Lane or 2 – 110 kN Axles @ 1.2 m



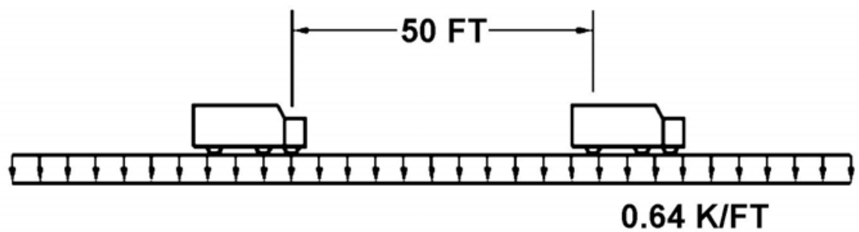


Selected Notional Design Load



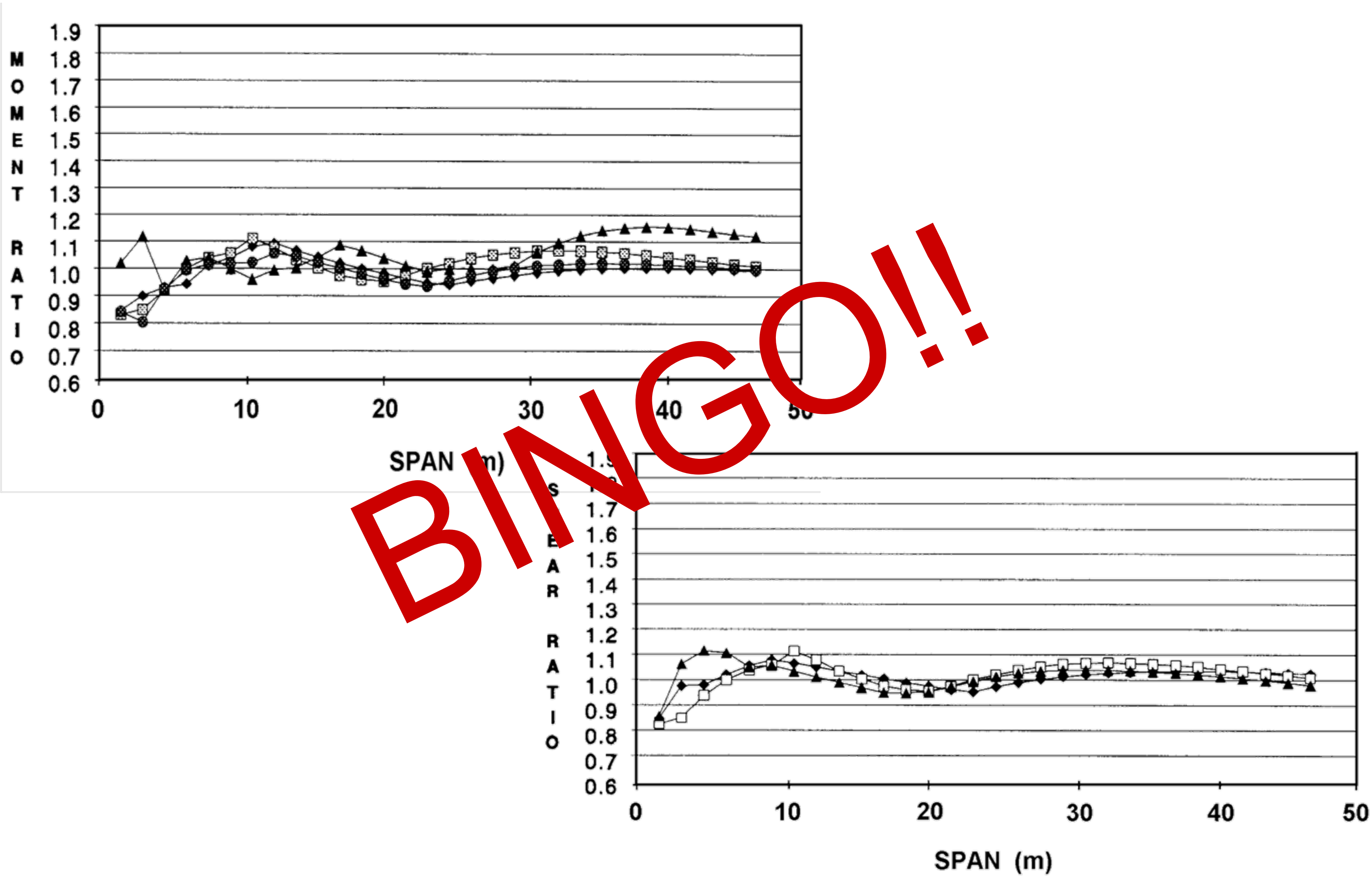
PROPOSED LOADS

HL-93



- 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.
- Federal deadline: 2007.
- By 2007:
  - 5,000 LRFD bridges
  - More than half of states doing part or all LRFD

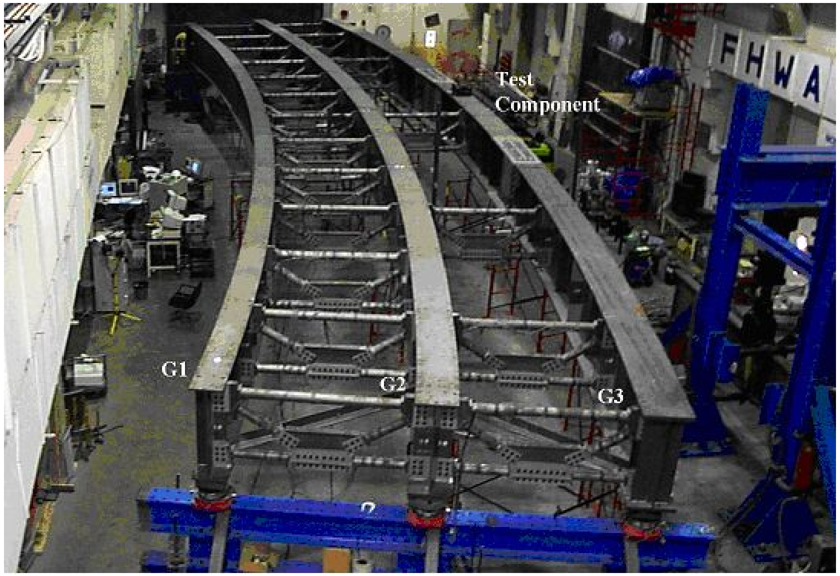
First LRFD Major Bridge Opened 1997

Upgrades and Changes to 1990 Technology

- 1996 foundation data reinserted.
- New wall provisions – ongoing upgrade.
- 2002 upgraded to ASBI LFRD Segmental Guide Specs.
- MCF Shear in concrete simplified and clarified several times – major update in 2002.
- Load distribution application limits expanded several time 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

Upgrades and Changes (Continued)

- 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

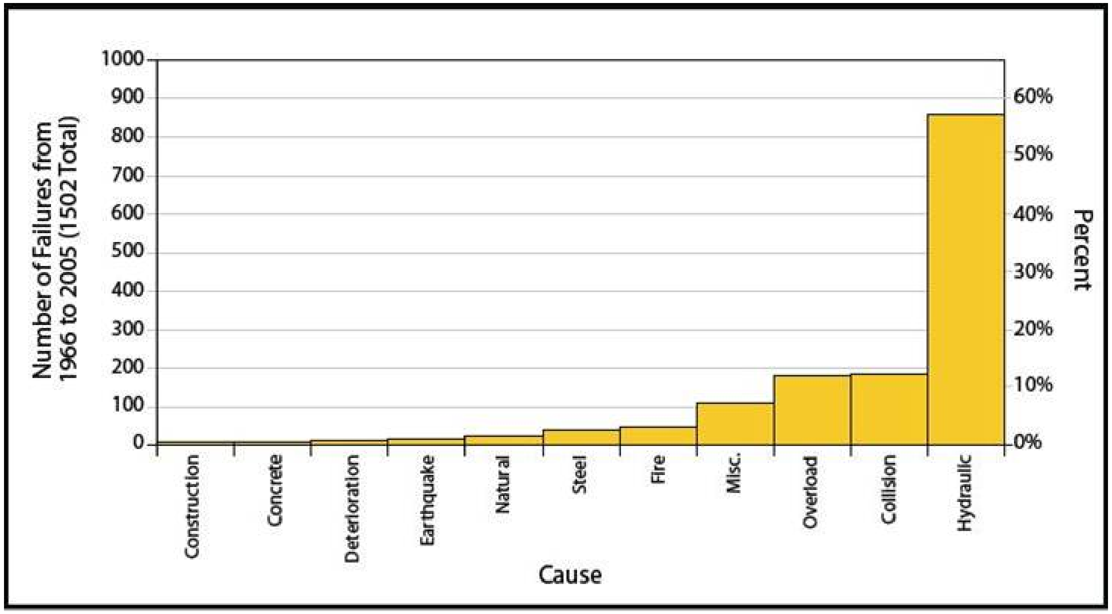
- Quantifying Redundancy.
- Expanded database of loads, etc.
- Refinement of foundation provisions.
- Simplification of load distribution.
- Improvements in reliability procedures.
- Joint probability procedures
  - LL with EQ?
  - Ship and scour?
  - EQ and scour?
  - Ice and wind?
  - Etc.

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.

Joint Probability of Occurrence

- 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

“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