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MCEER EARTHQUAKE ENGINEERING TO EXTREME EVENTS

THE DEPARTMENT OF CIVIL, STRUCTURAL AND ENVIRONMENTAL ENGINEERING

# Evolution of the AASHTO Bridge Design Specifications

## A Story in Two Parts

John M. Kulicki, Ph.D.,

Chairman/CEO

Modjeski and Masters, Inc.

# *Part 1*

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

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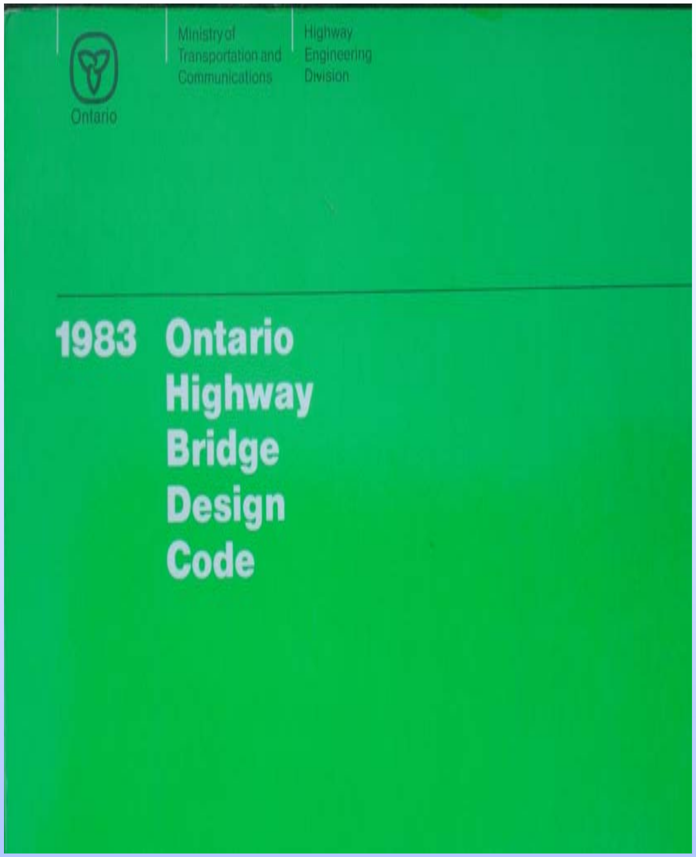
# OHBDC – Especially 1983 Edition



# 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

$$\Sigma Q_i \leq R_E / FS$$

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:

- $\gamma_i$ = a load factor
- $Q_i$ = a load
- $R$ = resistance
- $\phi$ = 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

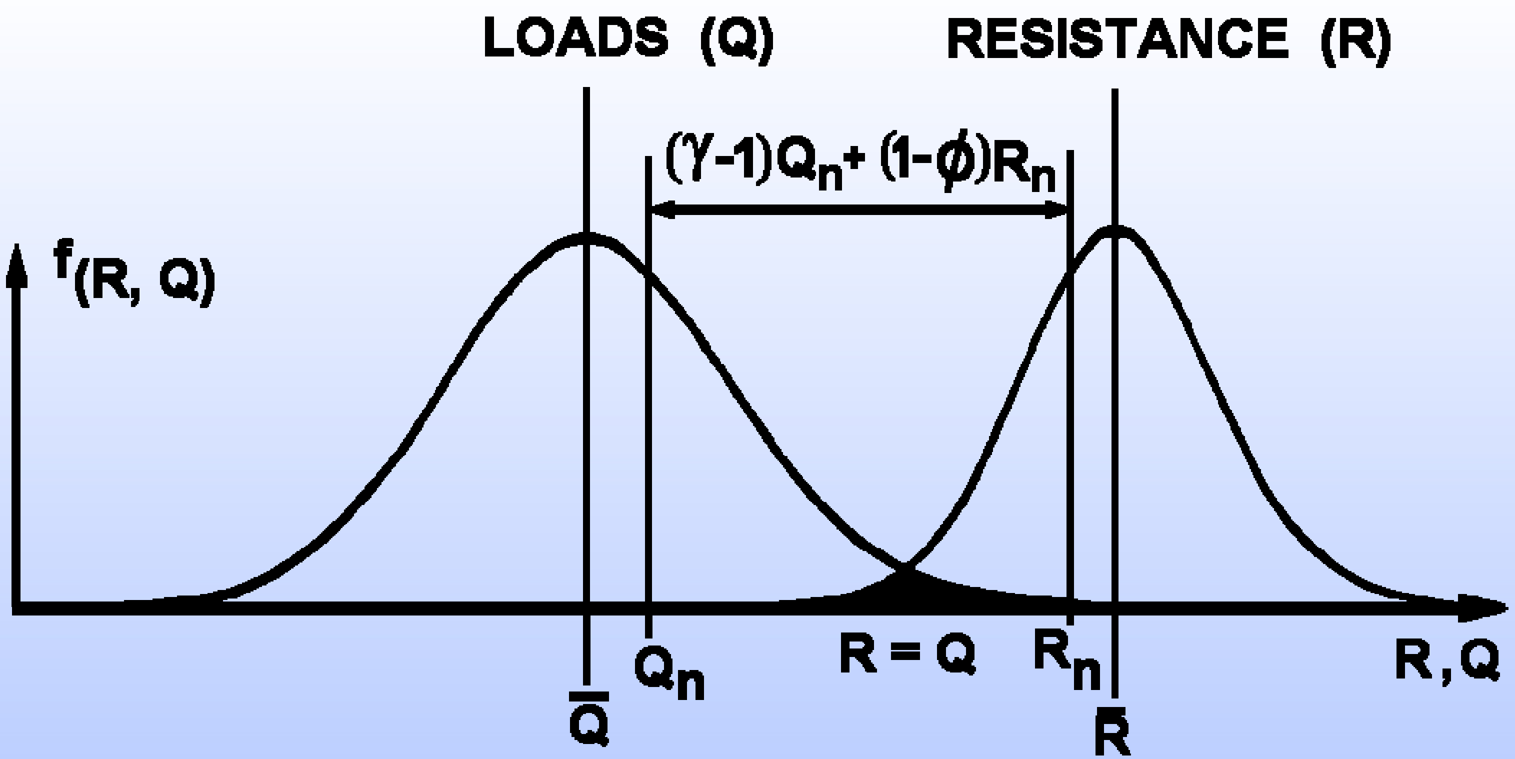
where:

- $\gamma_i$ = load factor: a statistically based multiplier on force effects
- $\phi$ = resistance factor: a statistically based multiplier applied to nominal resistance

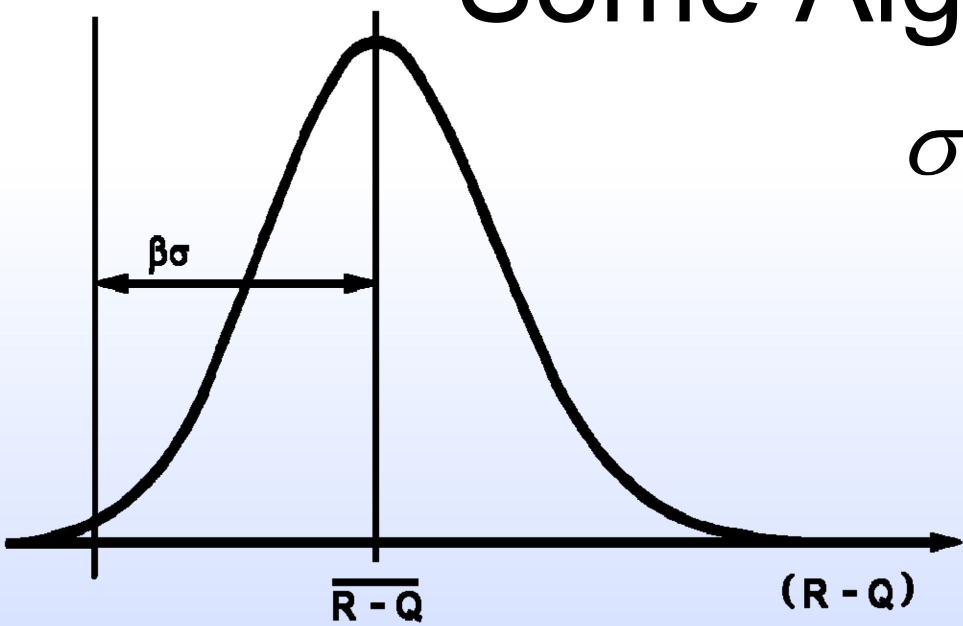
# LRFD (Continued)

- $\eta_i$ = load modifier
- $\eta_D$ = a factor relating to ductility
- $\eta_R$ = a factor relating to redundancy
- $\eta_I$ = a factor relating to importance
- $Q_i$ = nominal force effect: a deformation stress, or stress resultant
- $R_n$ = nominal resistance
- $R_r$ = factored resistance: $\phi R_n$

# LRFD - Basic Design Concept



# Some Algebra




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

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

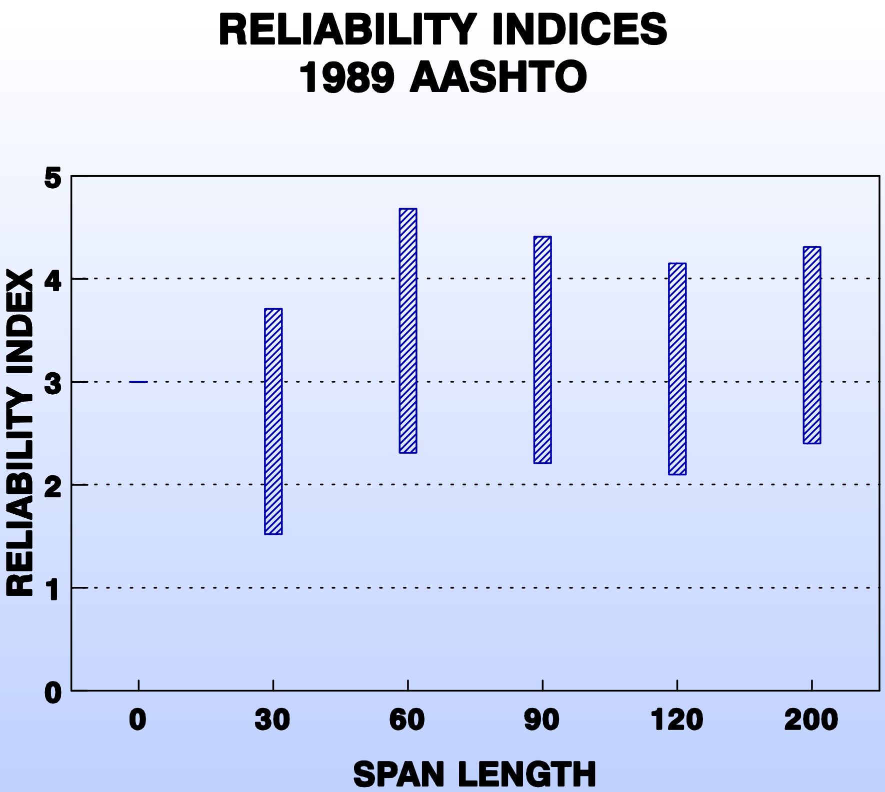
$$\overline{R} = \overline{Q} + \beta \sqrt{\sigma_R^2 + \sigma_Q^2} = \lambda R = \frac{1}{\phi} \lambda \Sigma \gamma_i x_i$$

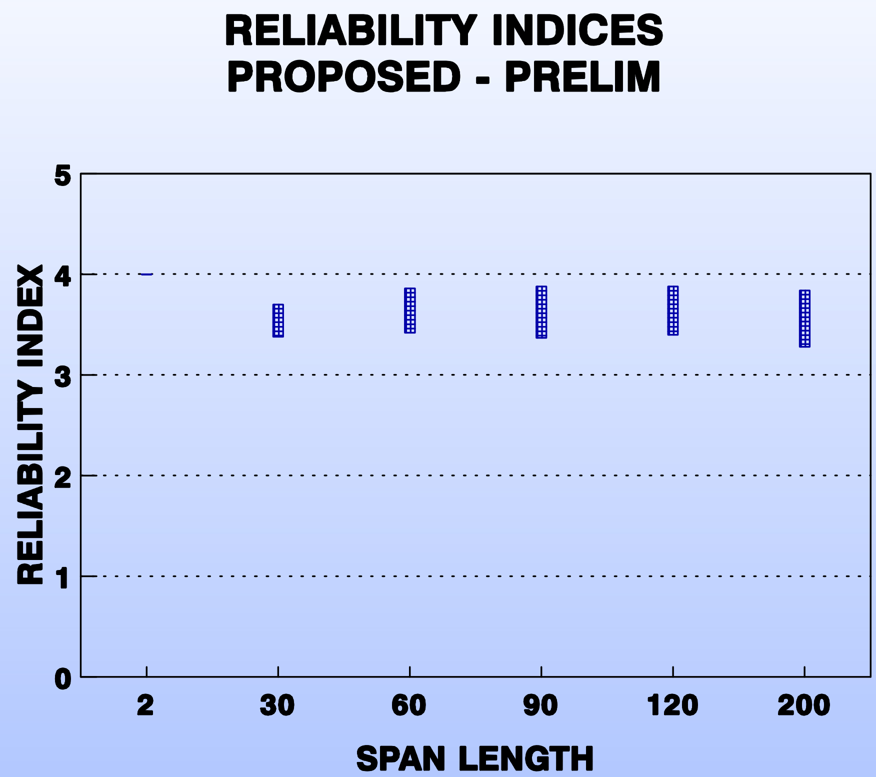
$$\phi = \frac{\lambda \Sigma \gamma_i x_i}{\overline{Q} + \beta \sqrt{\sigma_R^2 + \sigma_Q^2}}$$

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

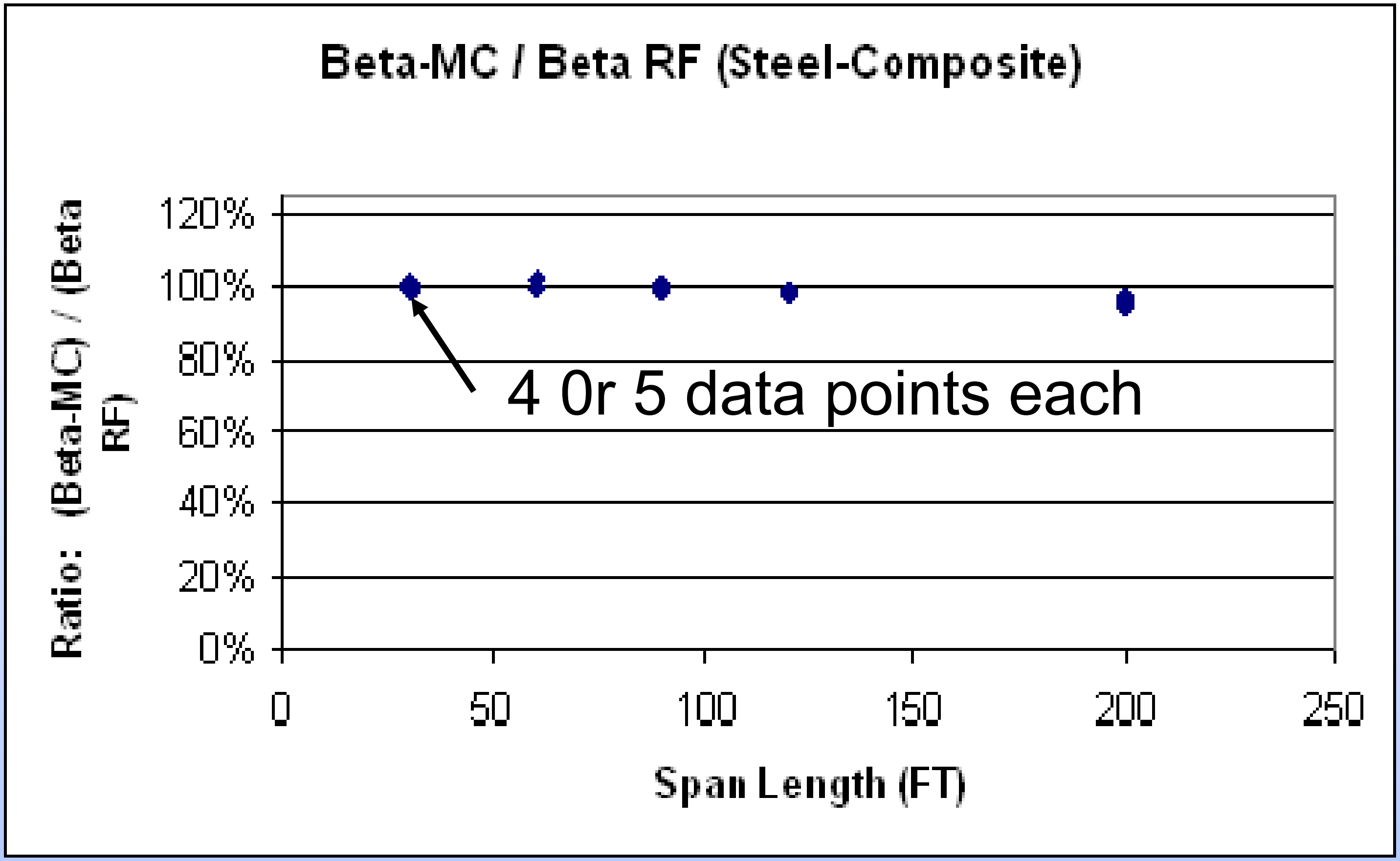
- 25 non-composite steel girder bridge simulations with spans of 30,60,90,120,and 200 ft, and spacings of 4,6,8,10,and 12 ft.
- Composite steel girder bridges having the same parameters identified above.
- P/C I-beam bridges with the same parameters identified above.
- R/C T-beam bridges with spans of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

# Reliability of Std Spec vs. LRFD – 175 Data Points

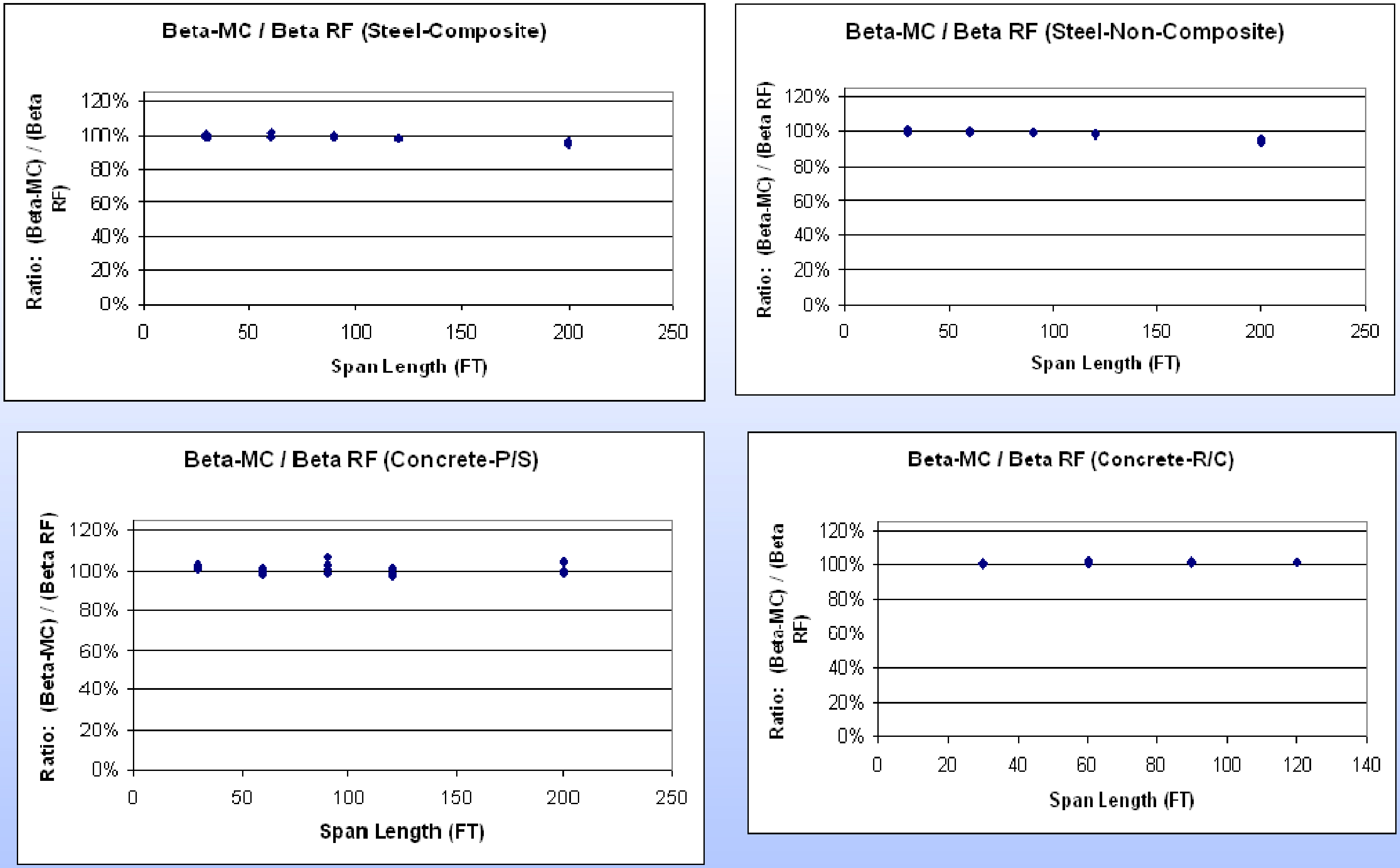


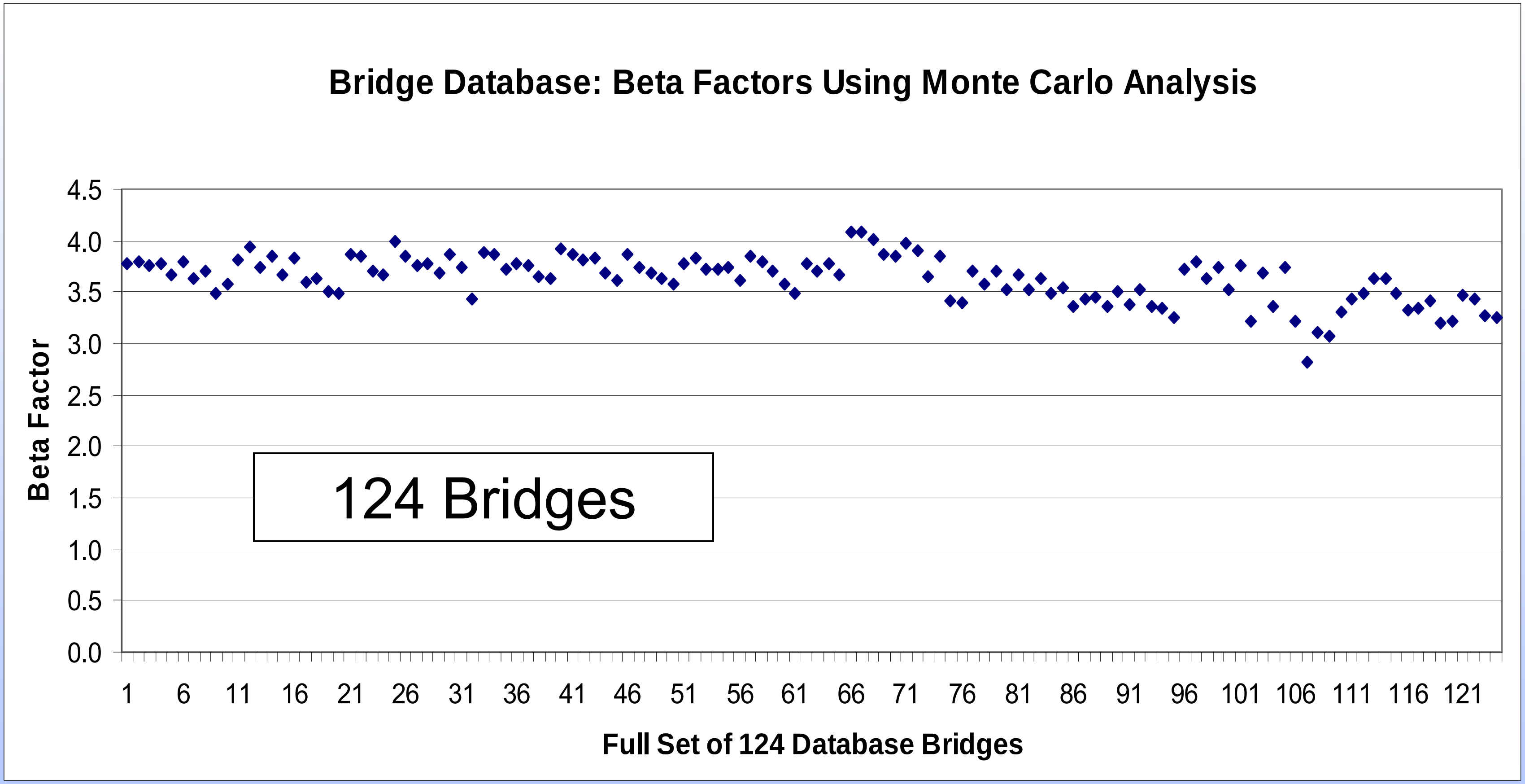
# 2006 Monte Carlo Reanalysis of 1993 Beta



# 2006 Monte Carlo Reanalysis of 1993 Beta



# 2006 Monte Carlo Analysis of Beta for New Bridge Data Base



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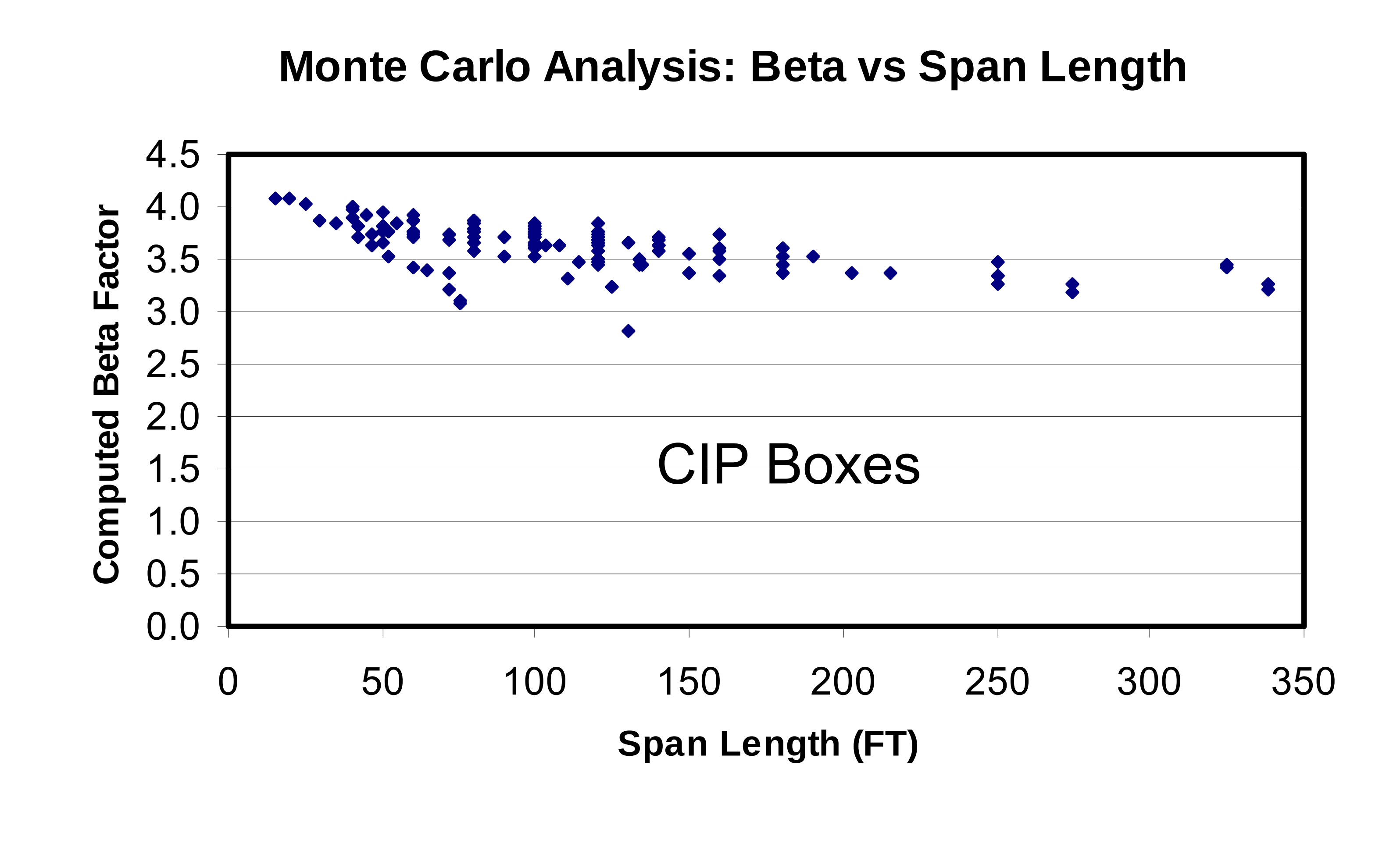
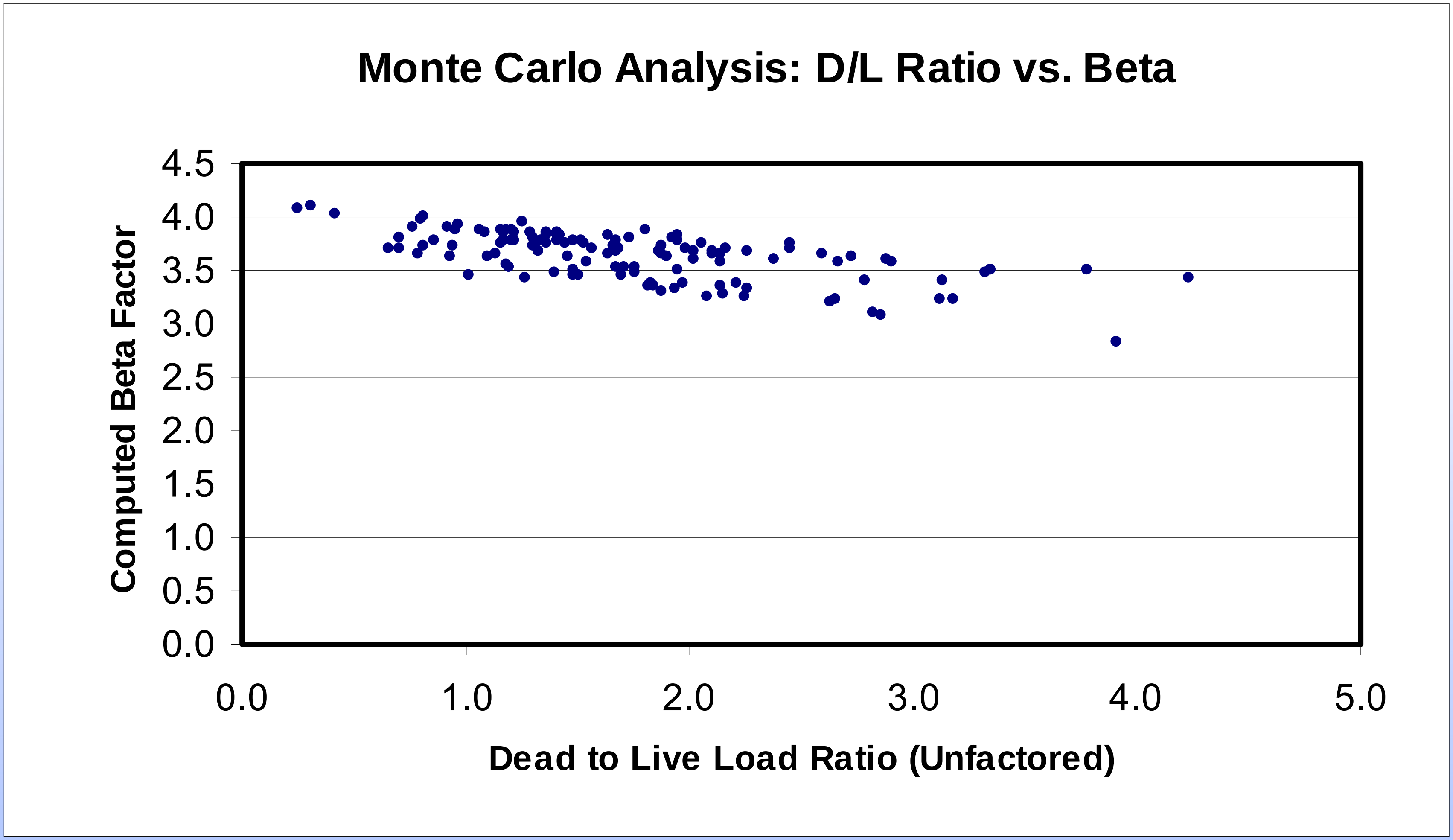
# 2006 Monte Carlo Analysis



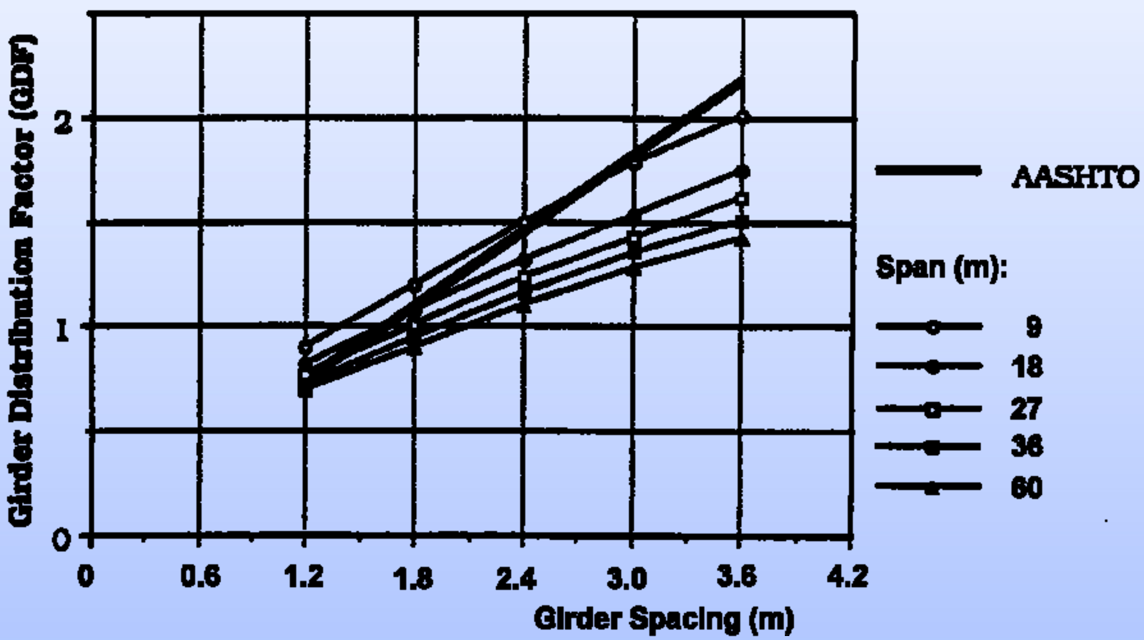
# 2006 Monte Carlo Analysis



# 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

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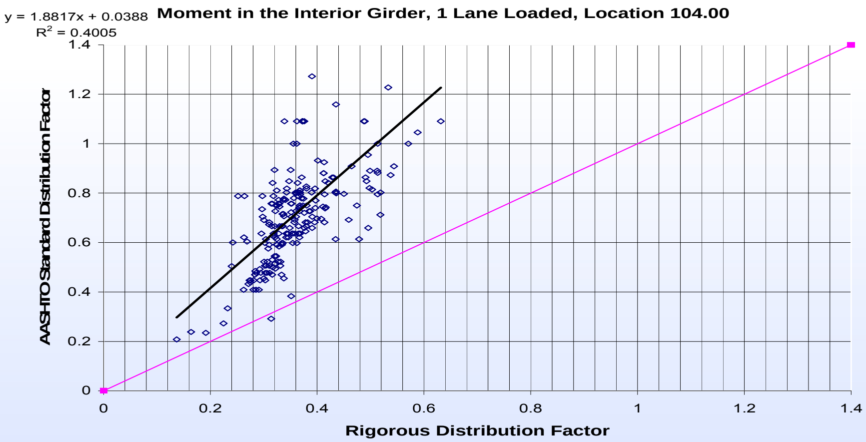
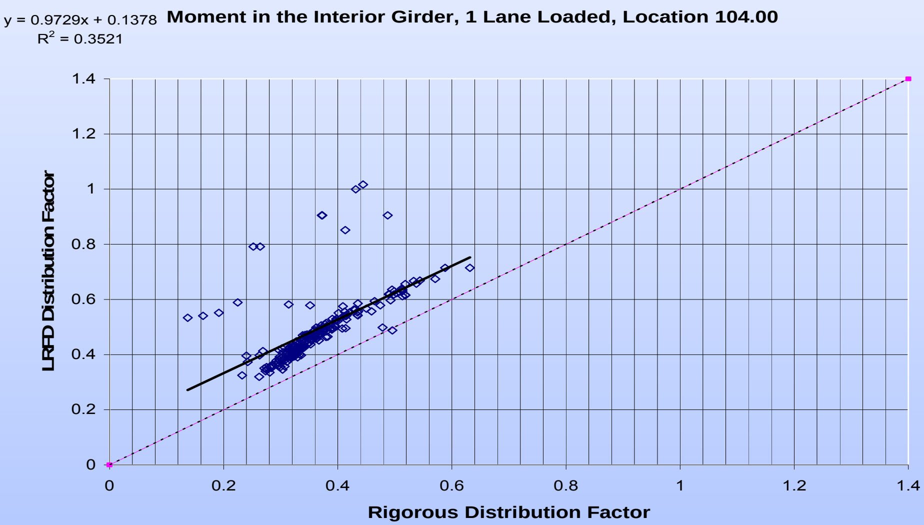
# Distribution Factors Revisited (2005) On-Going Work – NCHRP 12-62




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.

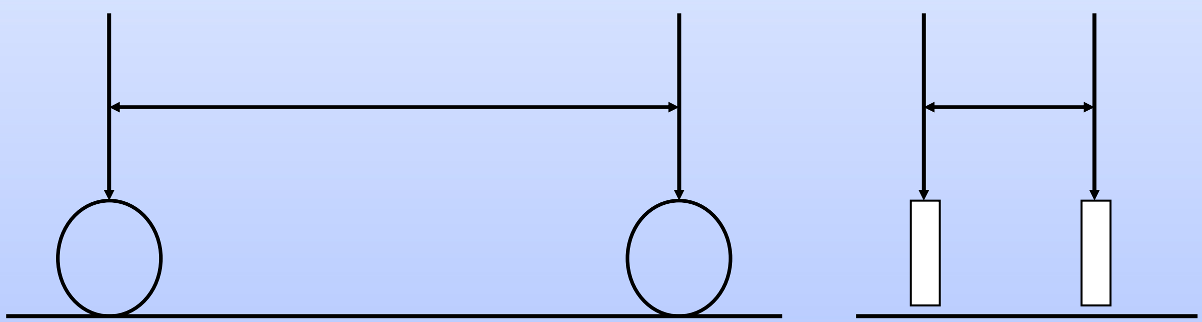
# L.R. Manville and R.W. Gastmeyer, *Engineering News,* September 1914

"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….

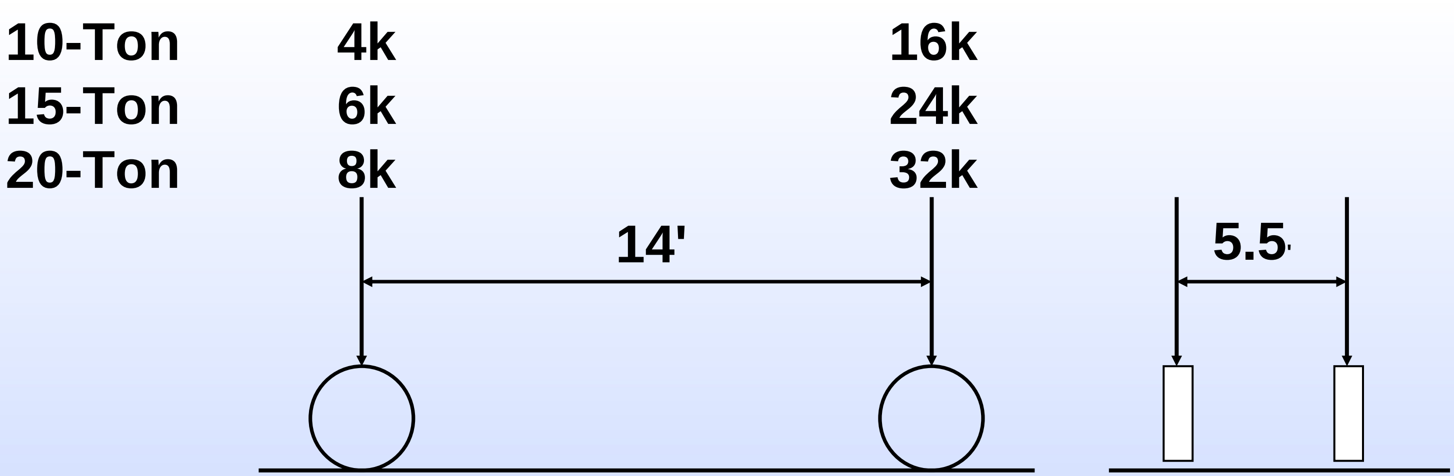
**But these older types of loading are inadequate for purposes of design to take care of modern conditions; they should be replaced by some types of typical motor trucks.**"

# 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'** |

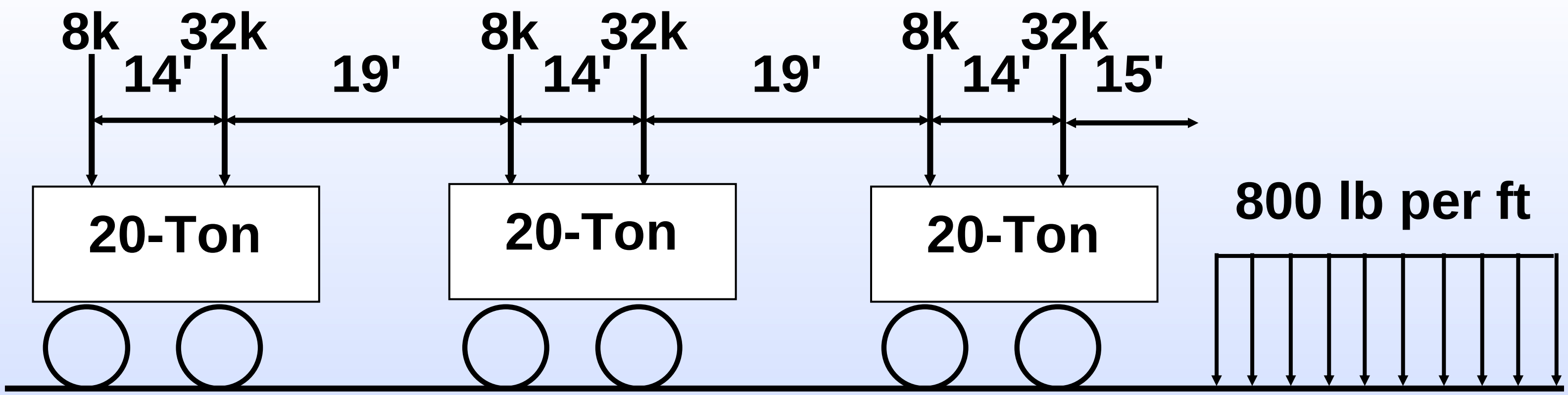


# 1923 AREA Specification

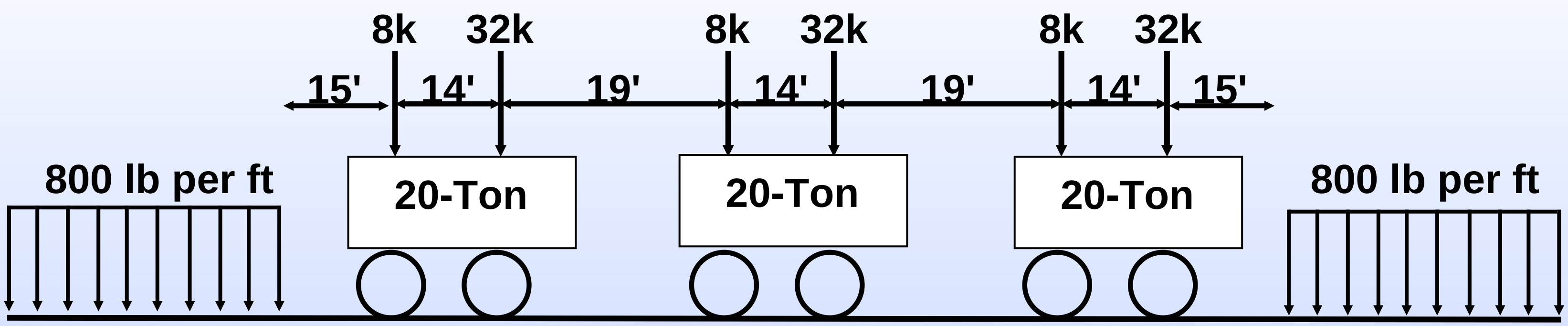



VERY CLOSE!!

# 1923 AREA Specification



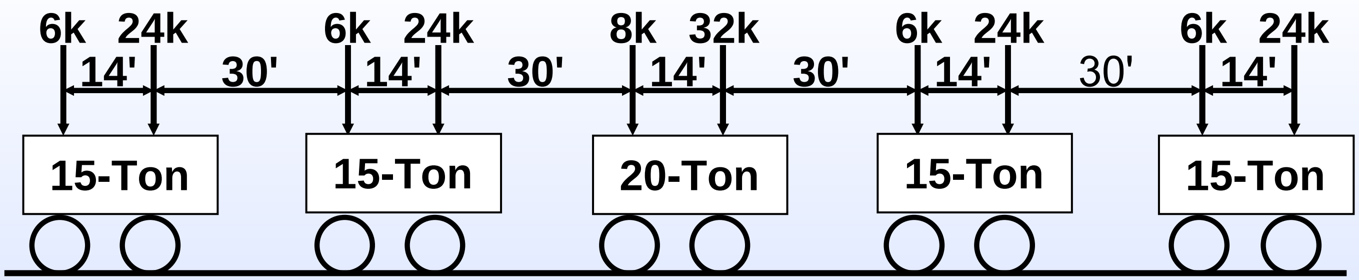
# 1924 AREA Specification

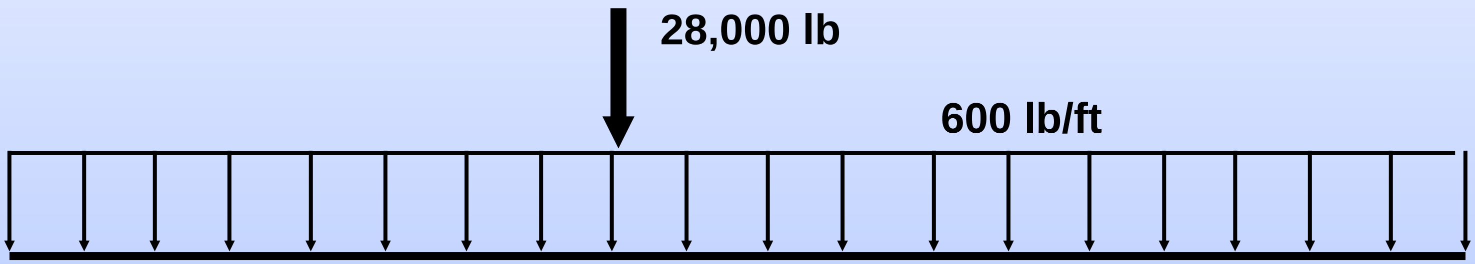


# Shoemaker's Truck Train and Equivalent Load (Bold Added)-1923

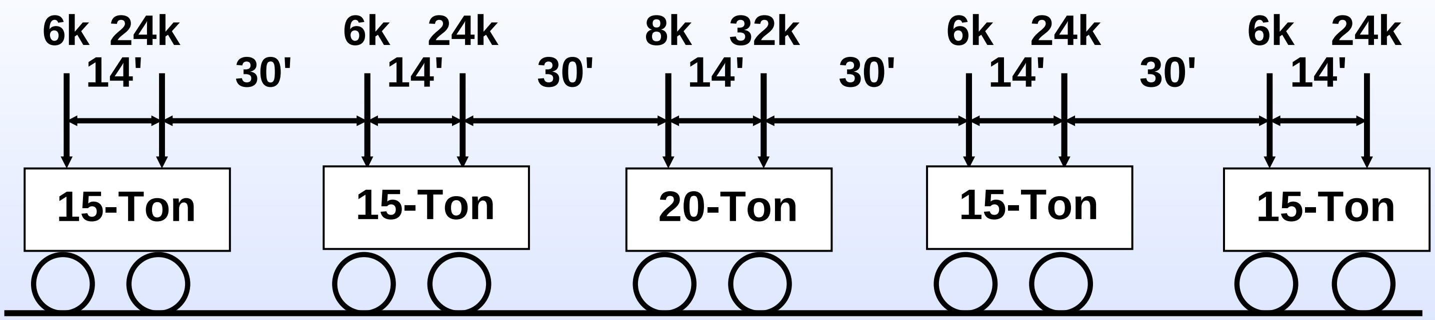
- The 7.5-ton [capacity] truck, which weighs about 15 tons when loaded to capacity and **which can be overloaded to weigh about 20 tons**, is the heaviest commonly used.
- A large part of traffic, however, is carried in trucks of 5 tons capacity or less. It would not appear to be necessary, therefore, to provide for a succession of 20-ton loads.

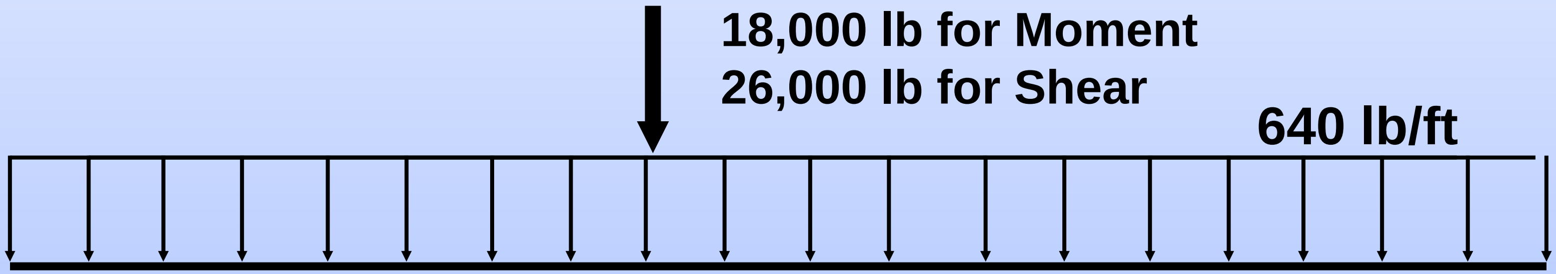
# Shoemaker's Truck Train and Equivalent Load - 1923



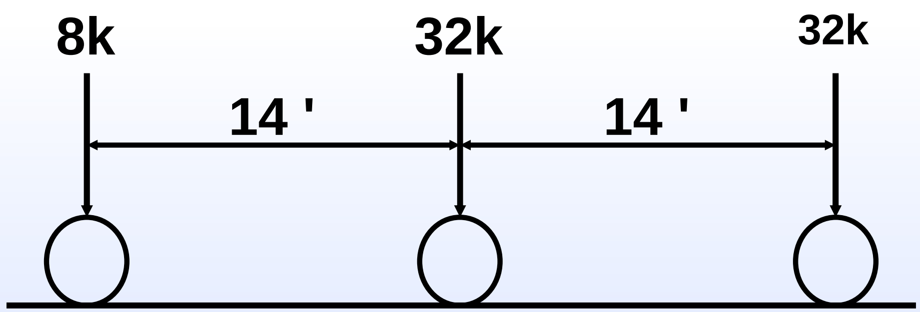
# 1928-1929 Conference Specification



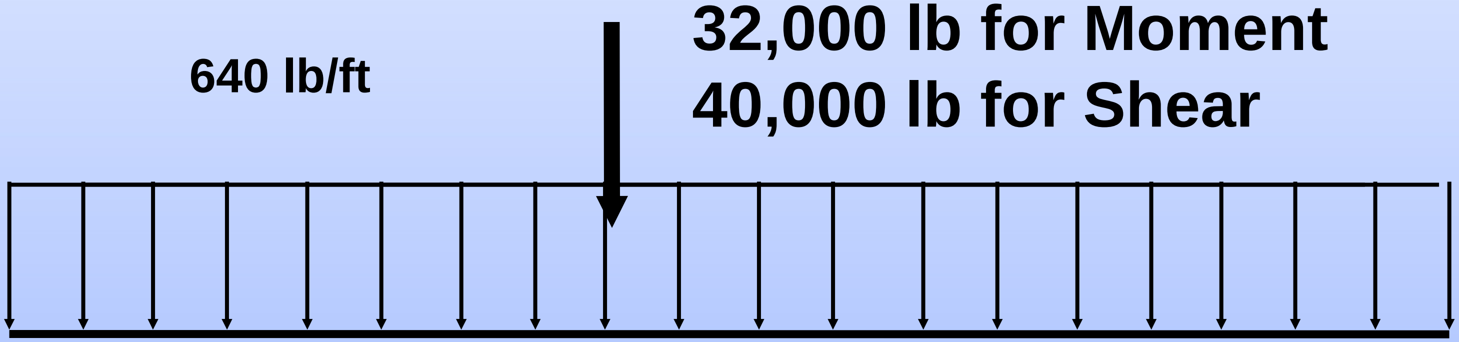




By 1929 lane load becomes what we have today

# 1941 AASHTO----HS20 (Almost)




**H20 - S16**




**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"

# 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

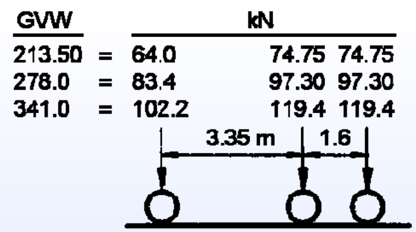
# Live Load Continued to be Debated

- 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.

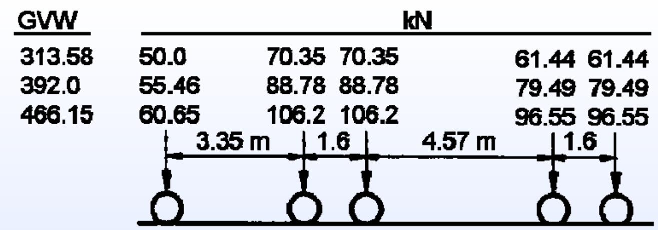
# Live Load Continued to be Debated

- 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

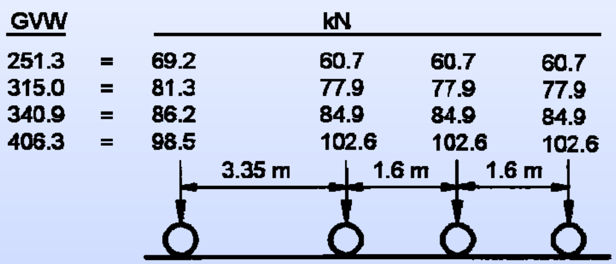
# "Exclusion Loads" – Based on TRB Special Report 225, 1990



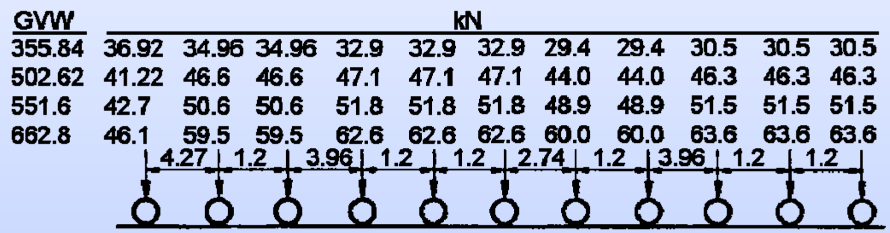

EX 3A (WB 4.95)



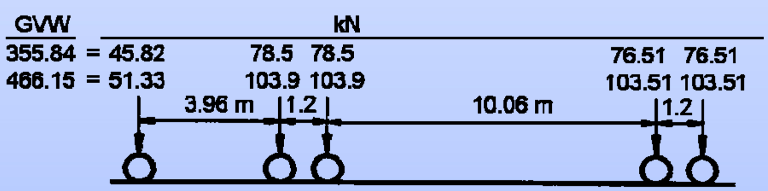

EX 3 - S2 (WB 11.12)




EX 4A (WB 6.55)




EX 3 - S3 - 5 (WB 22.13)




EX 3 - S2 (WB16.42)

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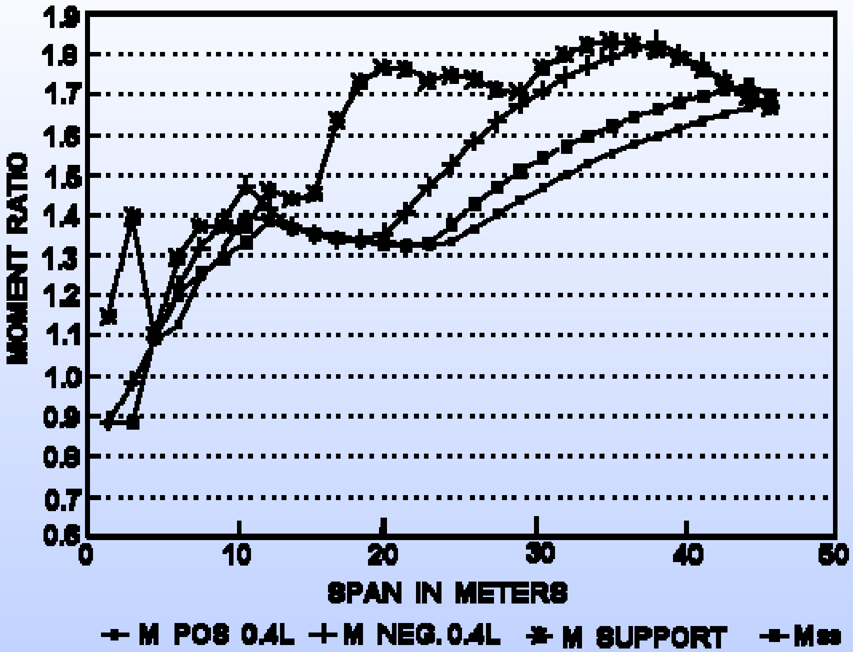
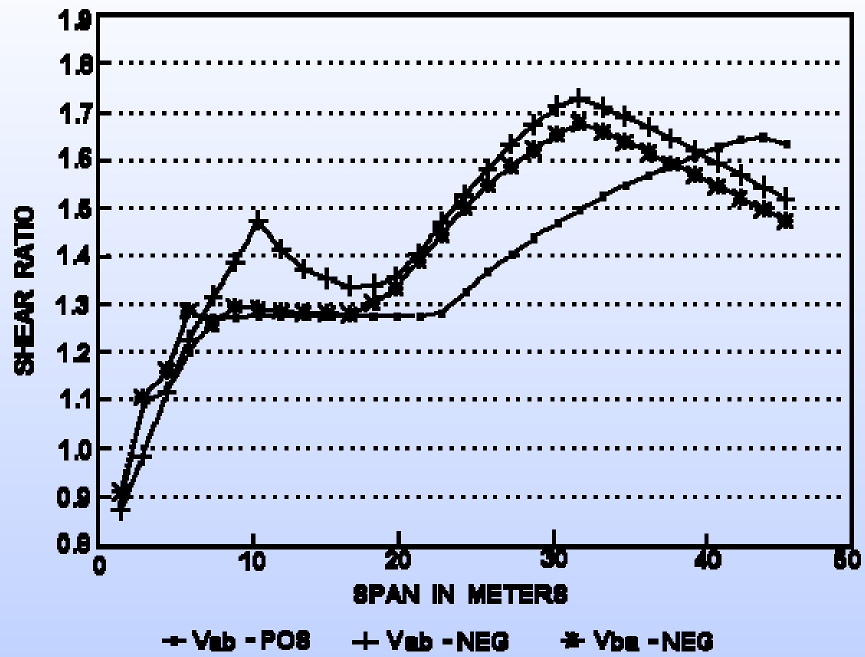
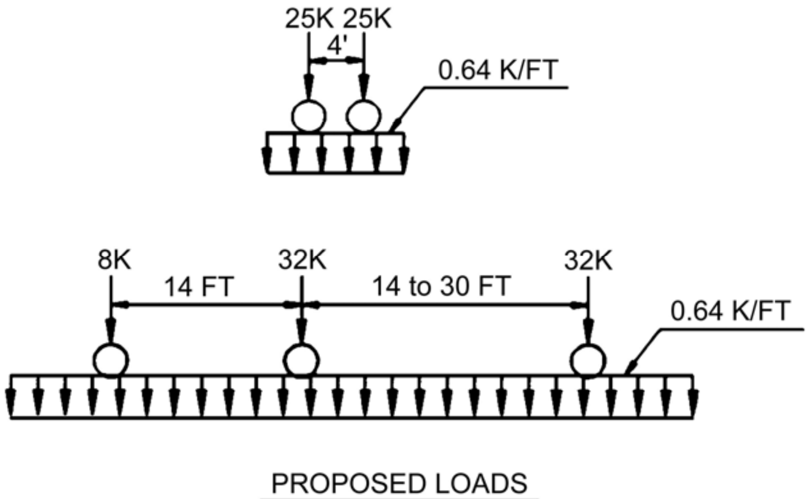
# EXCL/HS20 Truck or Lane or 2 – 110 kN Axles @ 1.2 m

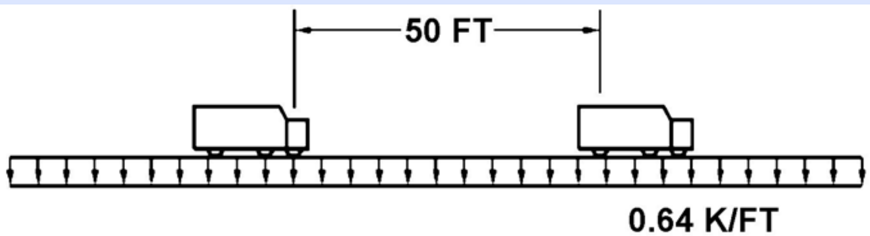


# Selected Notional Design Load

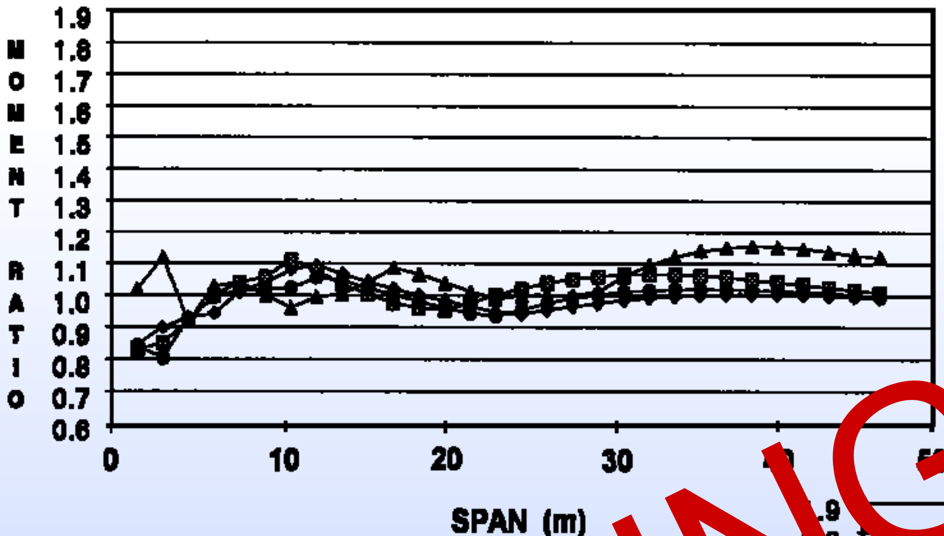



## HL-93

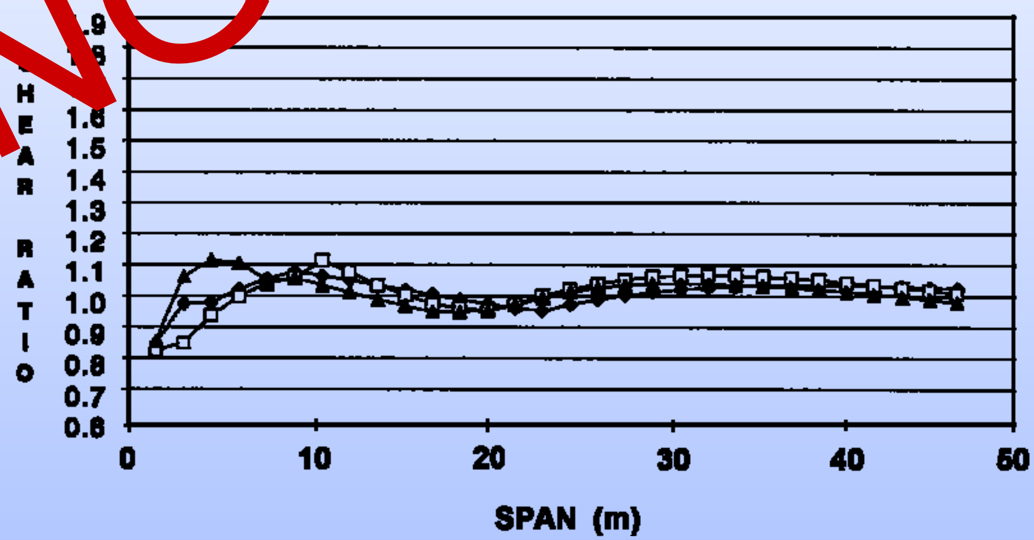



- NEGATIVE MOMENT AND INTERIOR REACTIONS
- ≥ 50 FT
- FIXED WHEELBASE ON TRUCK = 14 FT
- 90%

# EXCL/HL 93 – Circa 1992




BINGO!!



# 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 – just getting there now!!.

# 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

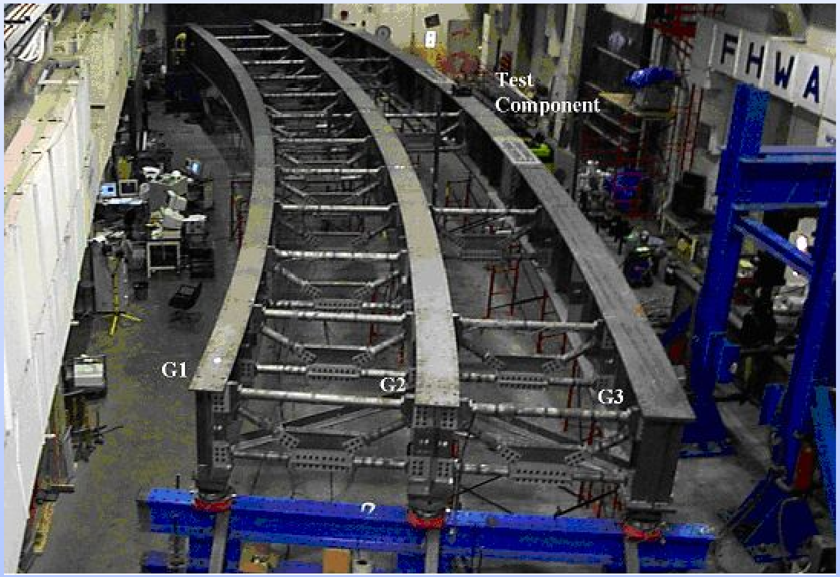
# First LRFD Major Bridge Opened 1997

# 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
- 2007 - big year
  - Streamline MCF for concrete shear design
  - 1,000 year EQ maps and collateral changes
  - Seismic Guide Spec - displacement based
  - Pile construction update
- 2008 - Coastal bridge Guide Spec

# 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

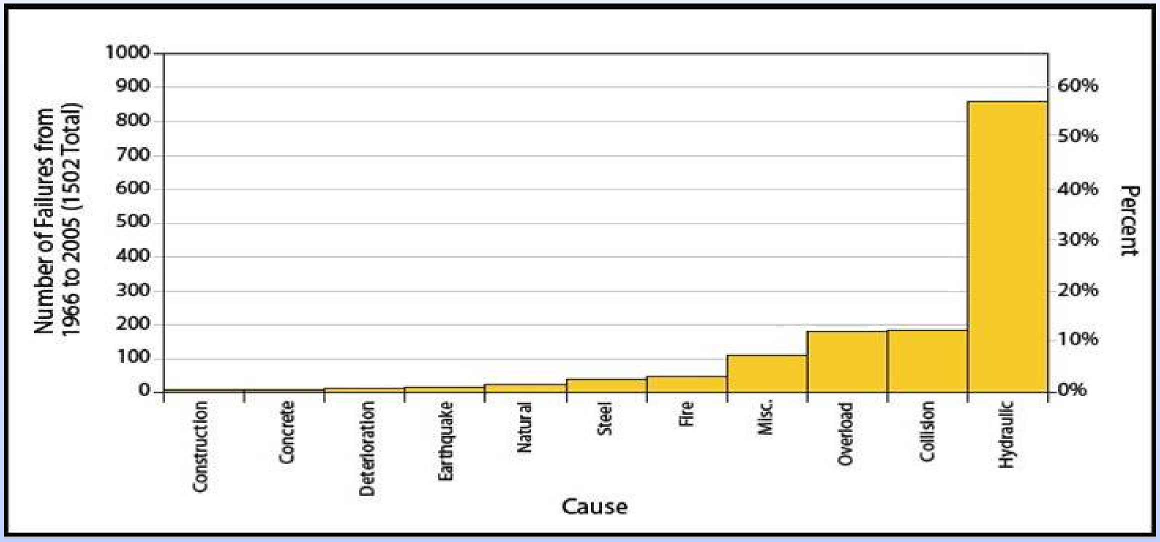
- Quantifying Redundancy.
- Expanded database of loads, etc.
- Refinement of foundation provisions.
- Simplification of load distribution.
- Improvements in reliability procedures.
- Joint probability procedures
  - LL with EQ?
  - Ship and scour?
  - EQ and scour?
  - Ice and wind?
  - Etc.

# 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 and NCHRP 12-83 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 LTBPP 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 ongoing
- ASCE Committee on Bridge Security formed – James Ray, Chair
- First fledgling steps towards specification – NCHRP 12-72

# 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 – MCEER – Concurrent and Cascading events.

# 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!

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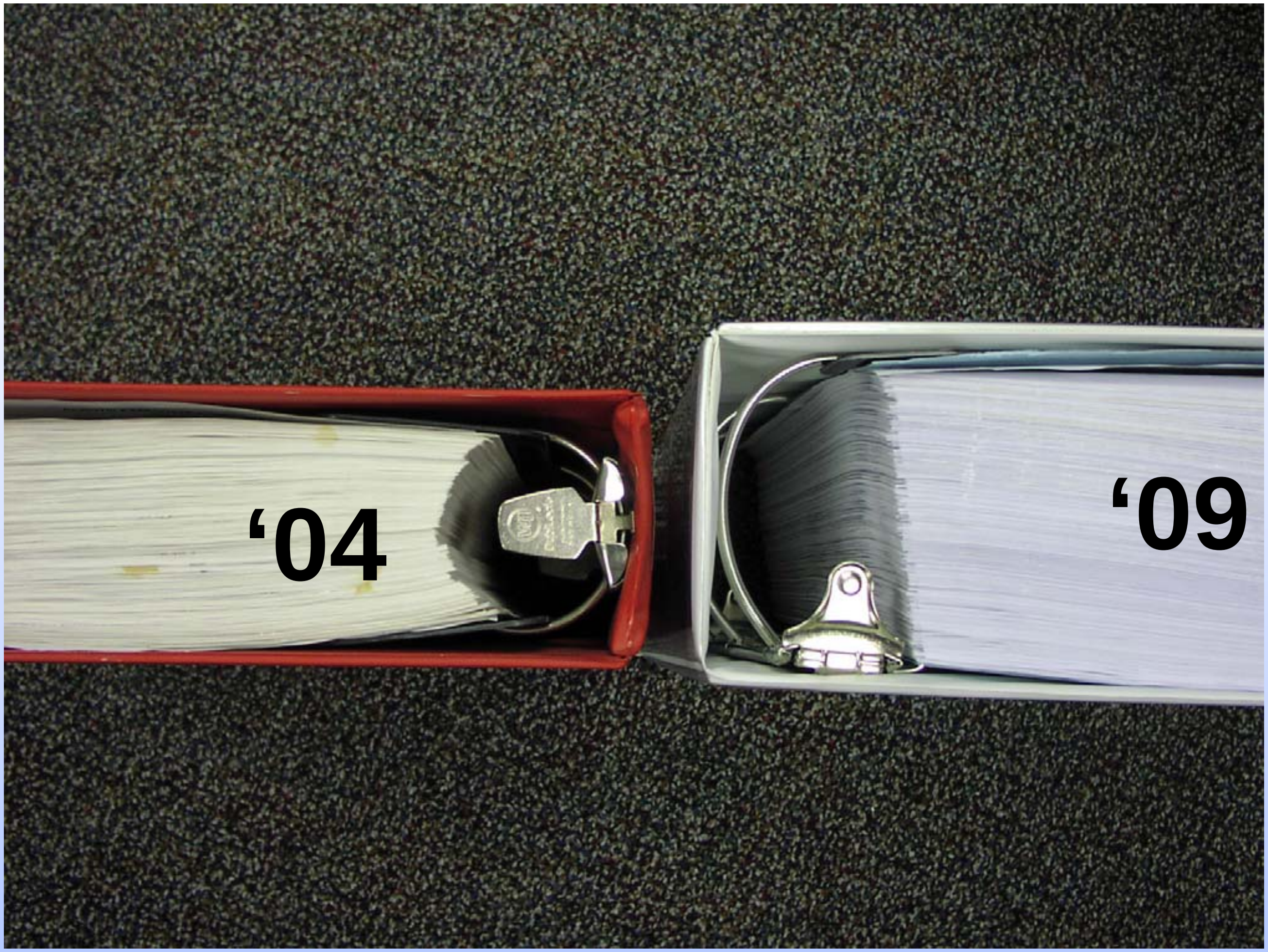
# Net Effect So Far



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# "Accessory For 5th Edition???

# 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