DESIGN CODES – Part 3

- Role of a Code in the Building Process
- Code levels
- Code Development Procedure
  - Scope of the Code
  - Code objective
  - Demand Function
  - Closeness to the Target
  - Code Format
- Development of a Bridge Design Code (AASHTO)
- Development of a Design Code for Concrete Buildings (ACI 318)

Role of a Design Code

- Parties involved in the building process: owner, designer, contractor, user-occupant
- Conflicting interests
- The Code establishes the acceptance criteria
- Types and magnitude of loads and load combinations
- Required minimum load carrying capacity
- Required safety margin in terms of safety factor, reliability index, or probability of failure

CENTRAL ROLE OF A DESIGN CODE

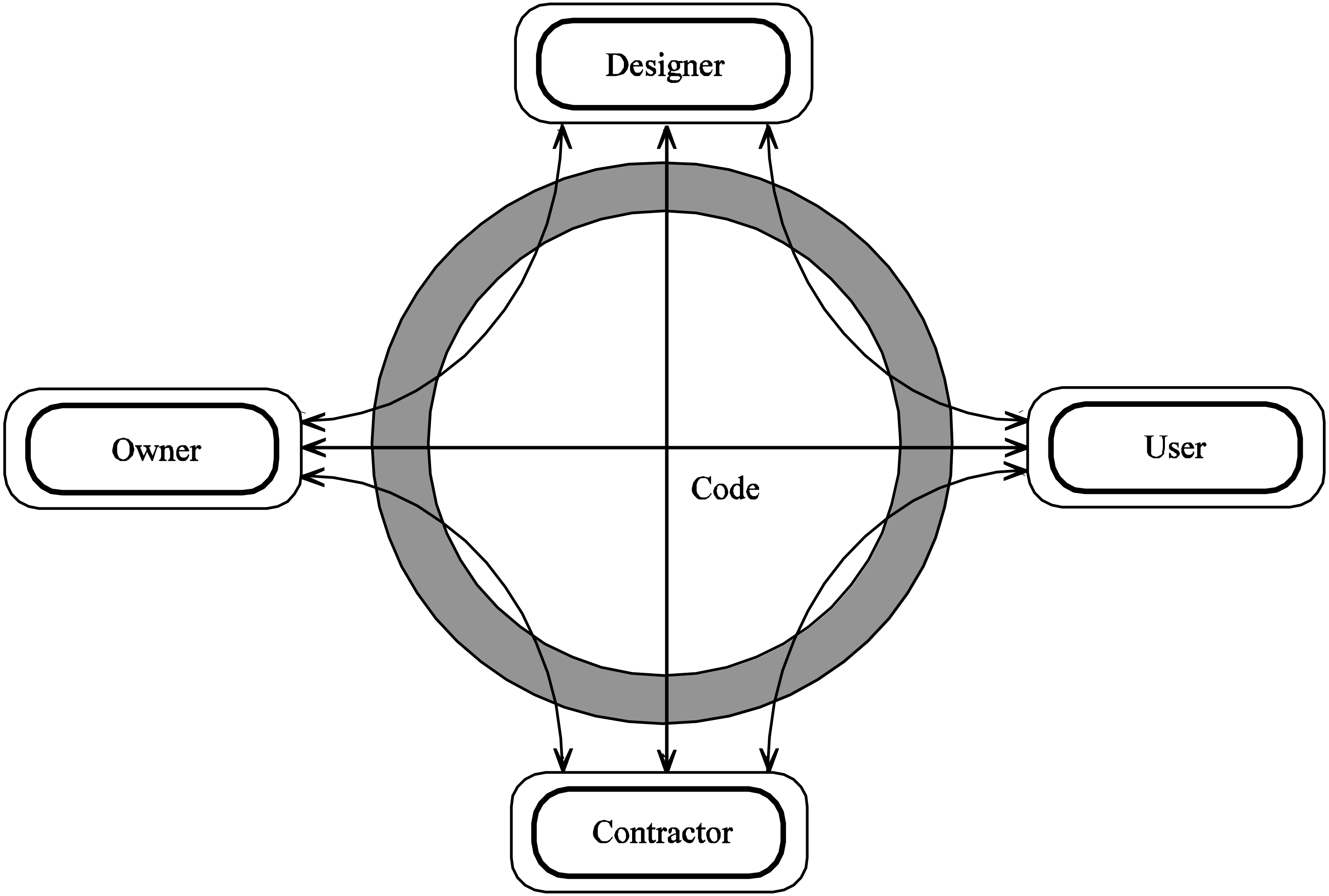


Figure 8-1 Design Code and Parties involved in the Building Process.

DESIGN CODES – HISTORICAL PERSPECTIVE

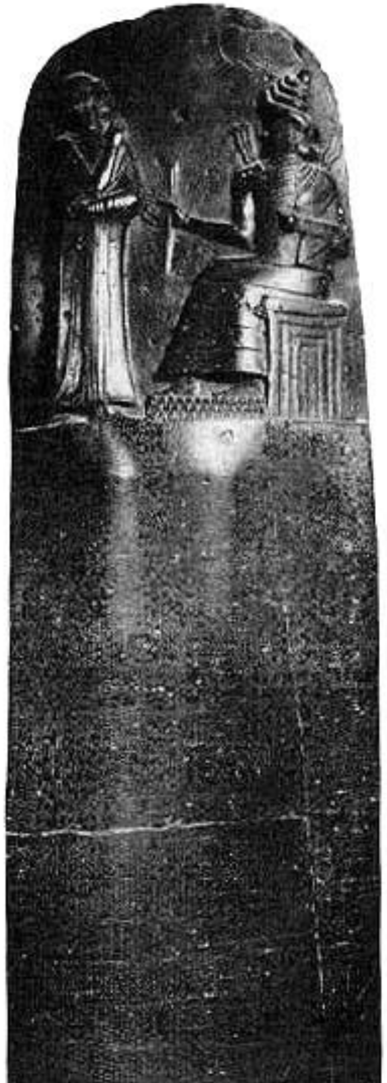
A. If a builder build a house for a man and do not make its construction firm and the house which he has built collapse and cause the death of the owner of the house – that builder shall be put to death.

B. If it cause the death of the son of the owner of the house – they shall put to death a son of that builder.

C. If it cause the death of a slave of the owner of the house – he shall give to the owner of the house a slave of equal value.

D. If it destroy property, he shall restore whatever it destroyed, and because he did not make the house which he built firm and it collapsed, he shall rebuild the house which collapsed at his own expense.

E. If a builder build a house for a man and do not make its construction meet the requirements and a wall fall in, that builder shall strengthen the wall at his own expense.



CODE LEVELS

Depending on the approach to reliability, there are four levels (categories) of design codes:

Level I Codes: use deterministic design formulas.

Level II Codes: reliability index is compared to the target value

Level III Codes: full reliability analysis is performed

Level IV Codes: reliability analysis and cost optimization

CODE LEVELS

Level I Codes: These codes use deterministic design formulas. The safety margin is introduced through central safety factors (ratio of design resistance to design load) or partial safety factors (load and resistance factors).

Level II Codes: These codes define the design acceptance criterion in terms of the "closeness" of the actual reliability index for a design to the target reliability index or other safety related parameters.

CODE LEVELS

- **Level III Codes** require a full reliability analysis to quantify the probability of failure of the structure under various loading scenarios. The acceptance criterion is defined in terms of the closeness of the actual reliability index to the optimum reliability level (or probability of failure).
- **Level IV Codes** use the total expected cost of the design as the optimization criterion. The acceptable design maximizes the utility function which describes the difference between the benefits and costs associated with a particular design.

Code Development Procedure

The major steps involved in the development of a design code include:

Step 1. Define scope and data space.

Step 2. Define code objective(s).

Step 3. Establish frequency of demand.

Step 4. Select code space metric.

Step 5. Select code format(s).

1. Scope of the Code

- Define class of structures (building, bridge)
- Function (office buildings, highway bridge, parking structure)
- Materials (steel, reinforced concrete, wood)
- Loads (wind, earthquake, ice)
- Range of parameters (span range)
- Limit states (flexural capacity, deflection)

2. Define Code Objective

- To achieve a negligible failure frequency with a reasonable material economy
- Minimize total utility (difference between revenues and costs)
- To design structures which can survive a pre-selected period of time with a reasonable probability of failure
- To design structures with β close to β_T (target reliability index)
- To design structures with a safety factor not less than a pre-selected allowable value (allowable stress design)

3. Establish Frequency of Demand

- The basis is analysis of past and present practice
- Determine the frequency of occurrence of a particular safety check
- The most common load cases, e.g. determine frequencies for different ratios of D and L
- Fuzzy values can be assigned: often, sometimes, rarely, unlikely
- Future trends are more important than past and even present
- The code should provide a good fit to β_T for the most frequent design situations (e.g. most frequent load ratios)

4. Closeness to the Target

- Measure of closeness between the code and its objective
- $\beta_T - \beta$, this difference varies
- Minimize $(\beta_T - \beta)^2$, or minimize $|\beta_T - \beta|$
- The best is to minimize

  $(\beta_T - \beta)/d - 1 + \exp[-(\beta_T - \beta)/d]$
- Minimize the total cost

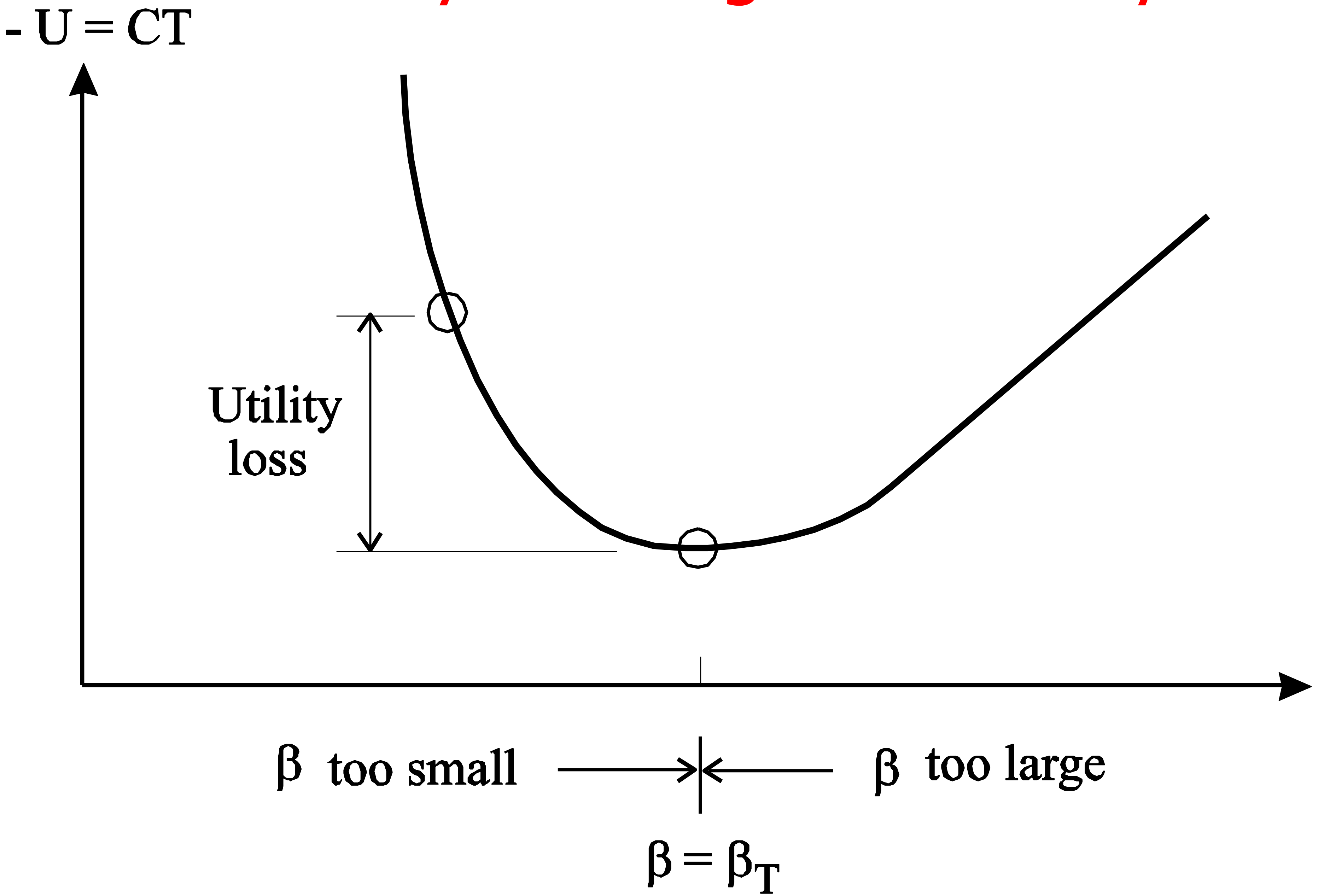
  $C_T = C_I + C_F P_F$
  - where:
  - C_I = initial cost (design and construction)
  - C_F = cost of failure (almost constant)
  - P_T = probability of failure

Target Reliability Index

<u>Selection criteria:</u>

- Consequences of failure
- Marginal cost of reliability (cost to increase or decrease the reliability by a unit)
- Reliability of structures designed using the current (old) code
- Performance of structures designed using the current (old) code

Utility vs. Target Reliability



New Design vs. Existing Structure

- For a new design, reliability can be increased with little extra cost
- For an existing structure any strengthening can be prohibitively expensive
- Current practice accepts lower reliability levels for existing structures

System vs. Component

- Structures are systems made of components
- Series system (weakest link)
- Parallel systems
- Failure of a component may not mean failure of the system
- Ductile and brittle components
- Correlation between components

Examples of the Target Reliability Indices for Bridge Components

- $\beta_T = 3.5$
  - Primary component
  - Multiple load path
- $\beta_T = 5.0$
  - Primary component
  - Single load path
- $\beta_T = 2.0$
  - Secondary component

Examples of the Target Reliability Indices for Bridges

- For steel, reinforced concrete, prestressed concrete girders,
  - $\beta_T = 3.5$
- For sawn wood bridge components,
  - $\beta_T = 2.0$
- For girder bridge as a system,
  - $\beta_T = 5.5\text{-}6.5$

5. Code Format

- Simple or complex
- Simple code – not good for closeness to the target
- Complex code – not good for users
- Allowable stress design

  Stress due to design load < allowable stress

  (safety reserve in the allowable stress)
- Load and resistance factor design (LRFD)

  Factored load < factored resistance

  (safety reserve in load and resistance factors)

Allowable Stress Design

$$D + L \leq F_a$$

where: D = stress due to dead load

L = stress due to live load

F_a = allowable stress

Safety margin is mostly in the allowable stress (conservatively low)

Load and Resistance Factor Design (LRFD), or Limit States Design Codes

- For each limit state

  factored load $\leq$ factored resistance

- Load and resistance factors serve as partial safety factors

- They are determined using the code calibration procedure

LRFD Philosophy

Define limit state function, e.g.

$$g = R - (D + L)$$

so that $g < 0$ means failure.

Safety reserve is represented by load and resistance factors

$$\gamma_D D + \gamma_L L \leq \phi R$$

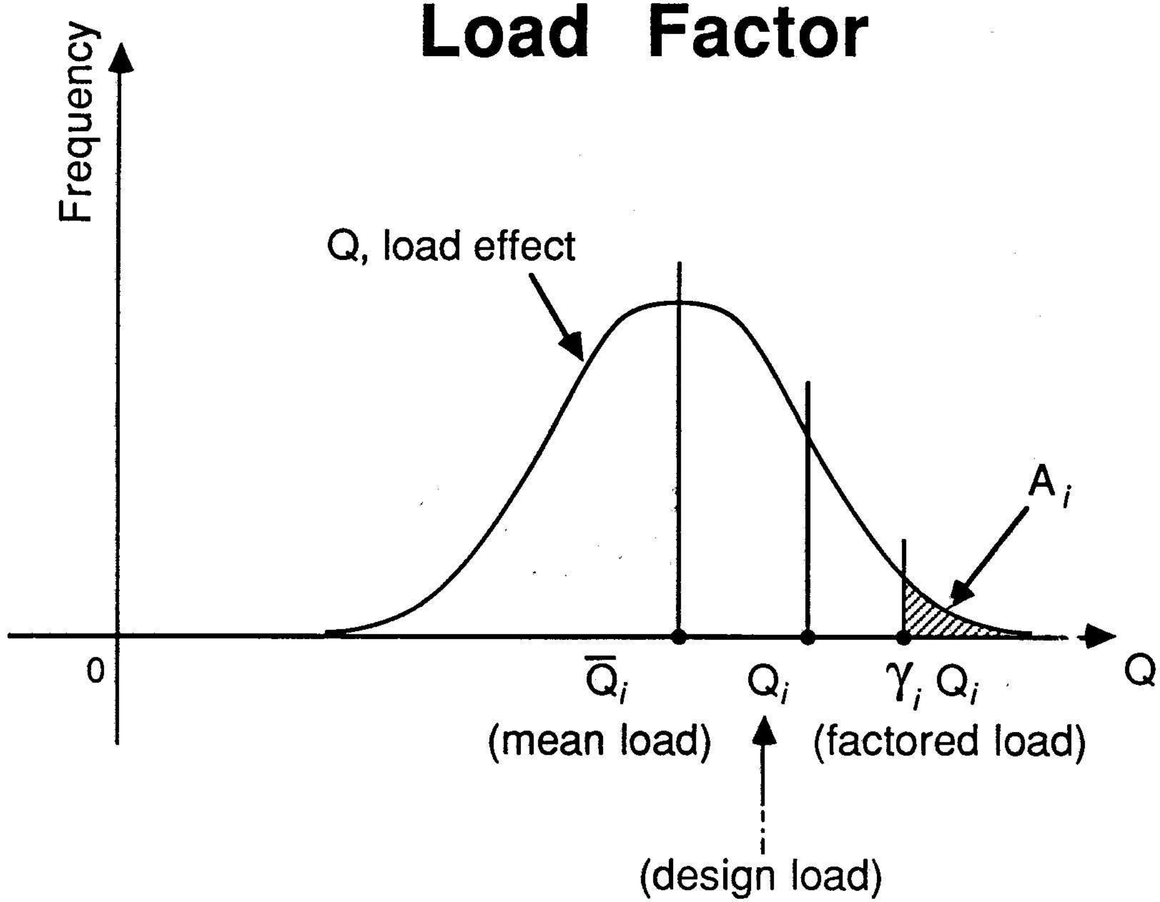
where

$$\gamma_D > 1.0, \gamma_L > 1.0, \phi < 1.0$$

Selection of New Load and Resistance Factors

- Factored load and factored resistance correspond to the "design point"
- The number of different load and resistance factors should be minimized
- Load and resistance factors are rounded to the nearest 0.05
- The same load factors for all materials

Load Factor



Frequency
Q, load effect
A i
0
Q
Q̄i
(mean load)
Qi
γi Qi
(factored load)
(design load)

Load Factors, γ

- Approximate formula for a load factor

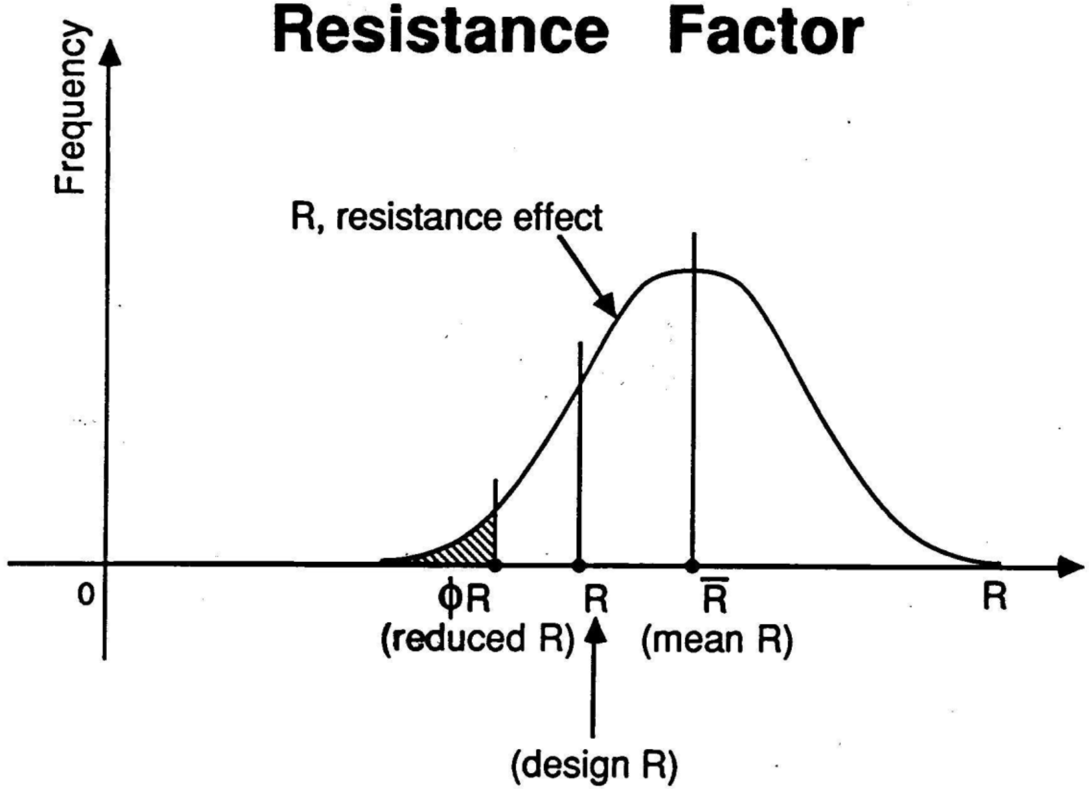
$$\gamma = \lambda\,(1 + n\,V)$$

where λ = bias factor for the considered load component

V = coefficient of variation for the considered load component

n = a constant, equal to about 2 for the ultimate limit states (bridge girders)

Resistance Factor



ϕ is calibrated to get $\beta = \beta_T$

Resistance Factors

- A limited number of different resistance factors, ϕ, is considered (they are rounded to the nearest 0.05)
- Calculate reliability indices for each value of ϕ
- Select ϕ that results in β's closest to the target reliability index

Future Trends in the Development of Design Codes

- Improve statistical data-base for load and resistance parameters
- Consider load sharing, redundancy, and brittleness/ductility
- Develop system reliability models for structures rather than components
- Determine the degree of correlation between load and resistance parameters
- Verify boundary conditions for advanced structural analysis models (finite elements method)

Example of Code Calibration
ACI 318 Building Code

- The basic document for design of concrete (R/C and P/C) buildings in USA
- ACI 318 specifies resistance factors and design resistance
- ACI 318 specifies load factors
- ACI 318 does not specify design load, reference is made to other codes

ACI 318-99
ACI 318R-99

Building Code Requirements for Structural Concrete (318-99) and Commentary (318R-99)

Reported by ACI Committee 318

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Why Calibration of ACI 318?

- Current load factors were adopted in 1950's
- Introduction of the new code with loads and load factors, ASCE 7 (American Society of Civil Engineers)
- Load factors specified in ASCE 7 are already adopted for steel design (AISC) and wood
- Problems with mixed structures (steel and concrete)

ASCE STANDARD

ASCE/SEI 7–05

Includes Supplement No. 1 and Errata

Minimum Design Loads for Buildings and Other Structures

This document uses both the International System of Units (SI) and customary units

ASCE

SEI Structural Engineering Institute of the American Society of Civil Engineers

Load factors specified by ACI 318 and ASCE 7

The design formula specified by ACI 318-99 Code

$1.4\ D + 1.7\ L < \phi\ R$

$0.75\ (1.4\ D + 1.7\ L + 1.7\ W) < \phi\ R$

$0.9\ D + 1.3\ W < \phi\ R$

$0.75\ (1.4\ D + 1.7\ L + 1.87\ E) < \phi\ R$

The design formula specified by ASCE-7 Standard

$1.4\ D < \phi\ R$

$1.2\ D + 1.6\ L < \phi\ R$

$1.2\ D + 1.6\ L + 0.5\ S < \phi\ R$

$1.2\ D + 0.5\ L + 1.6\ S < \phi\ R$

$1.2\ D + 1.6\ W + 0.5\ L + 0.5\ S < \phi\ R$

$1.2\ D + 1.0\ E + 0.5\ L + 0.2\ S < \phi\ R$

$0.9\ D - (1.6\ W \text{ or } 1.0\ E) < \phi\ R$

Objectives of Calibration of ACI 318

- Determine resistance factor, ϕ, corresponding to the new load factors (ASCE 7)
- Reliability of the designed structures cannot be less the predetermined minimum level
- Maintain a competitive position of concrete structures
- If needed, identify the need for changes of load factors in the ASCE 7

Considered Structural Components

- Beams (reinforced concrete, prestressed concrete)
- Slabs (reinforced concrete, prestressed concrete)
- Columns (reinforced concrete, prestressed concrete, tied and spiral)
- Plain concrete

Considered Load Components

- D = dead load
- L = live load
- S = snow
- W = wind
- E = earthquake
- Load combinations

Statistical Load Models

- Time-varying loads
- “Turkstra-Rule” – load combination model
- The load models require further analysis, as the models used in this calibration are too conservative (in particular wind and earthquake)

Assumed Statistical Data

- Dead load
  - λ = 1.03-1.05, V = 0.08-0.10
- Live load
  - λ = 1.00, V = 0.20
- Wind
  - λ = 0.80, V = 0.35
- Snow
  - λ = 0.80, V = 0.25
- Earthquake
  - λ = 0.65, V = 0.55

Considered Materials

- Concrete (cast-in-place and precast)
  - Ordinary concrete
  - Light weight concrete (18 kN/m^3)
  - High strength concrete

    ($f'_c \geq 45$ MPa)
- Reinforcing steel bars
- Prestressing steel strands

Reliability Index

The general format of the limit state function

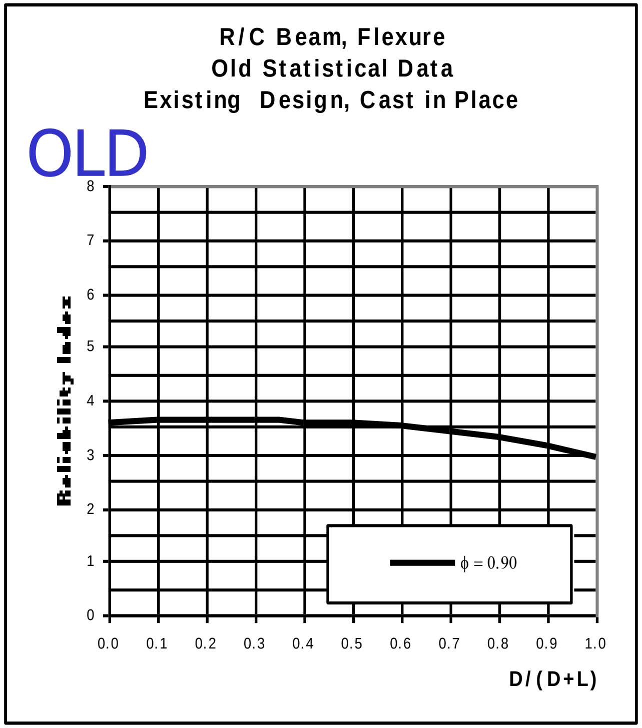
$$g = R - Q = 0$$

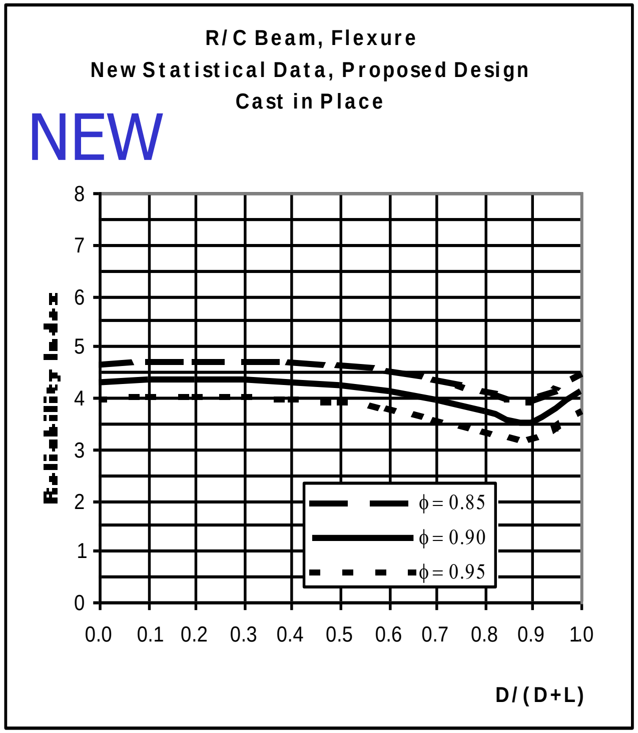
$$\beta = \frac{(\mu_R - \mu_Q)}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

Considered Cases

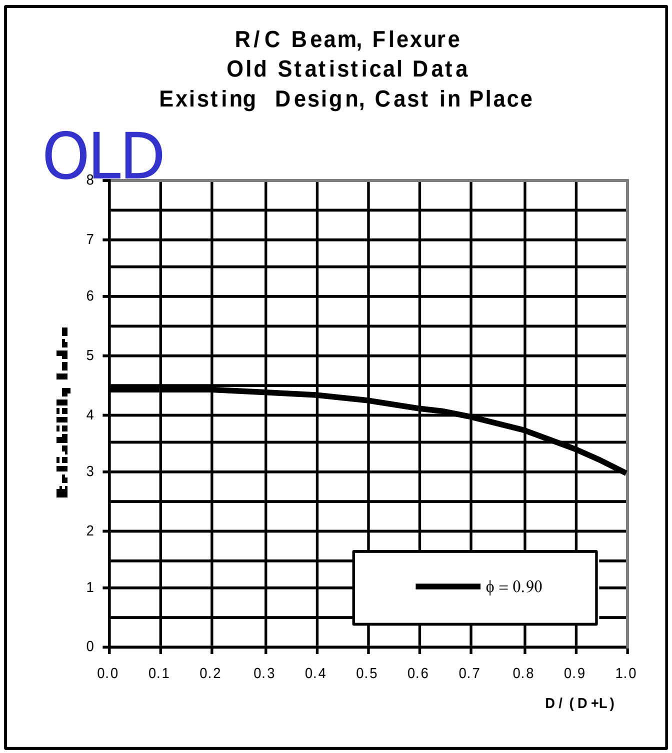
- Old
  - Statistical data for materials from 1970's
  - Design according to ACI 318-99
- New
  - Statistical data for materials from 2001-02
  - Design according to proposed ACI 318

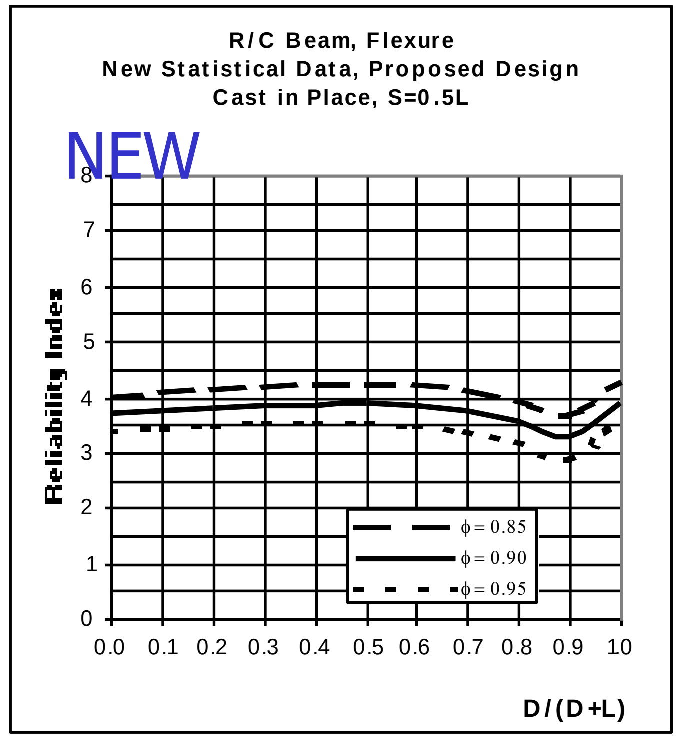
Reliability Indices for R/C Beams, Flexure, Ordinary Concrete (D+L)



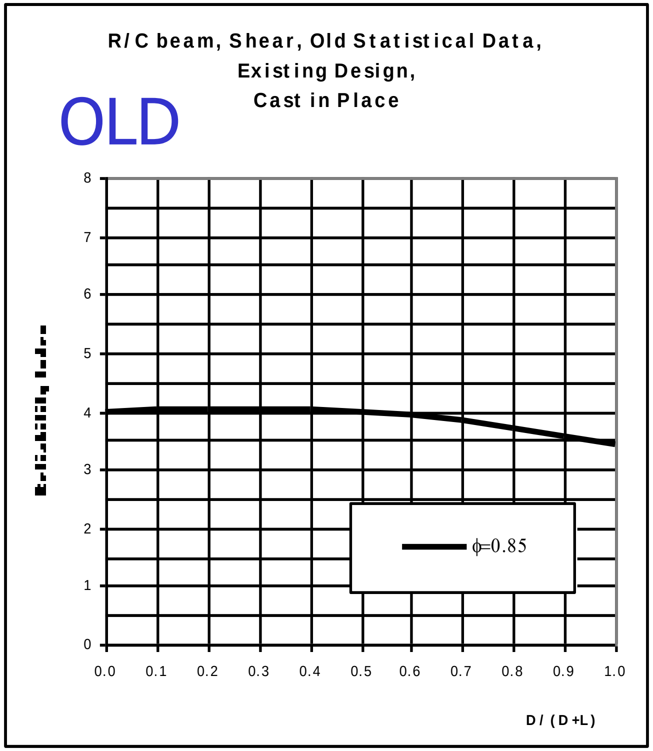


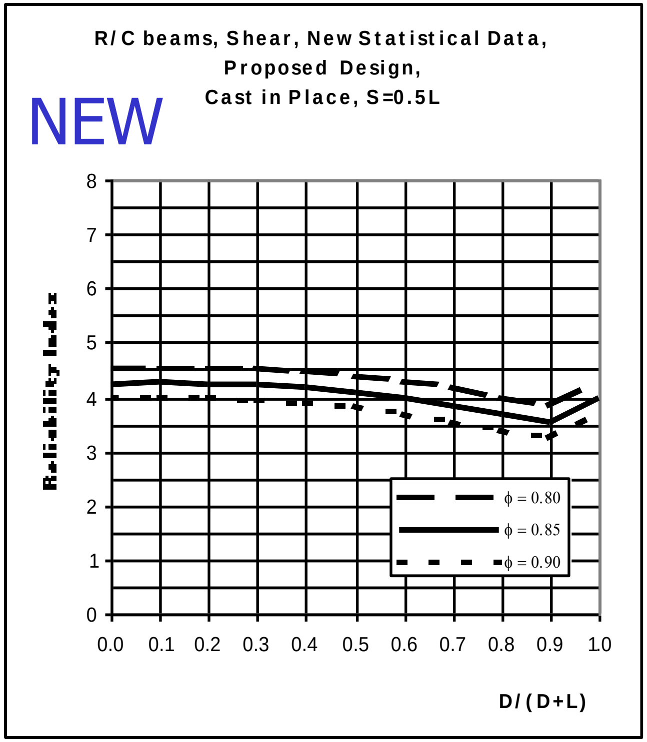
Reliability Indices for R/C Beams, Flexure, High Strength Concrete (D+L)





Reliability Indices for R/C Beams, Shear, Ordinary Concrete (D+L)





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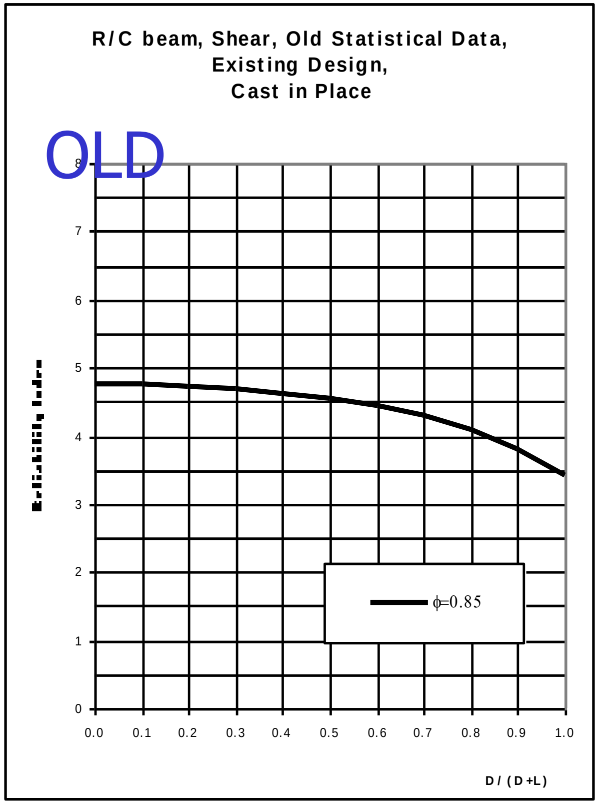
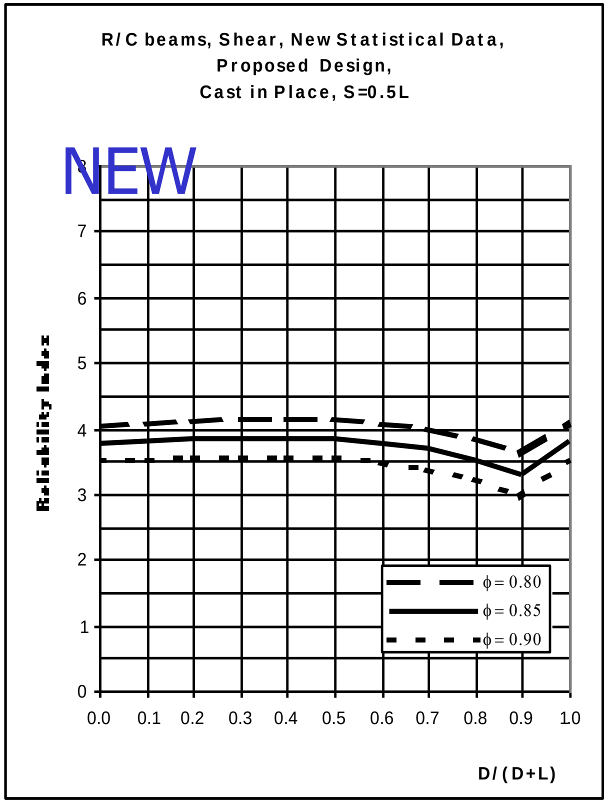
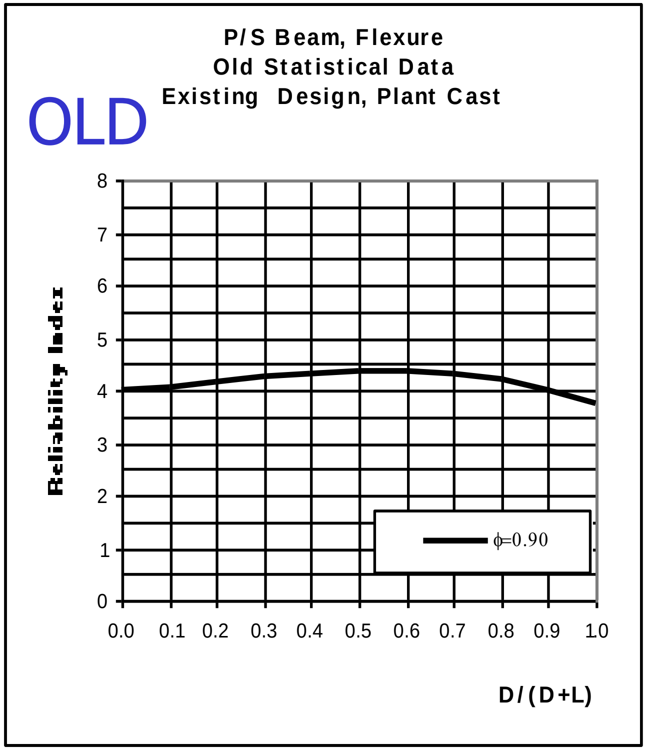
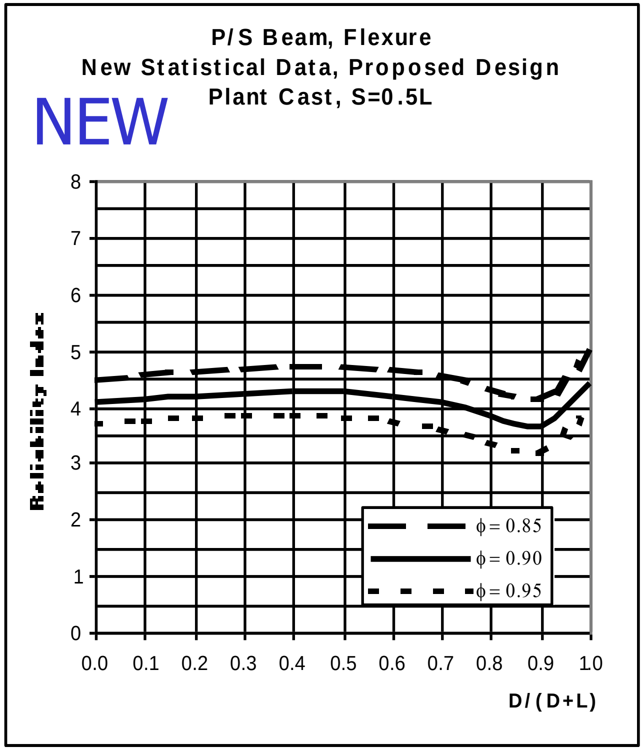




Reliability Indices for P/S Beams, Flexure, Ordinary Concrete (D+L)





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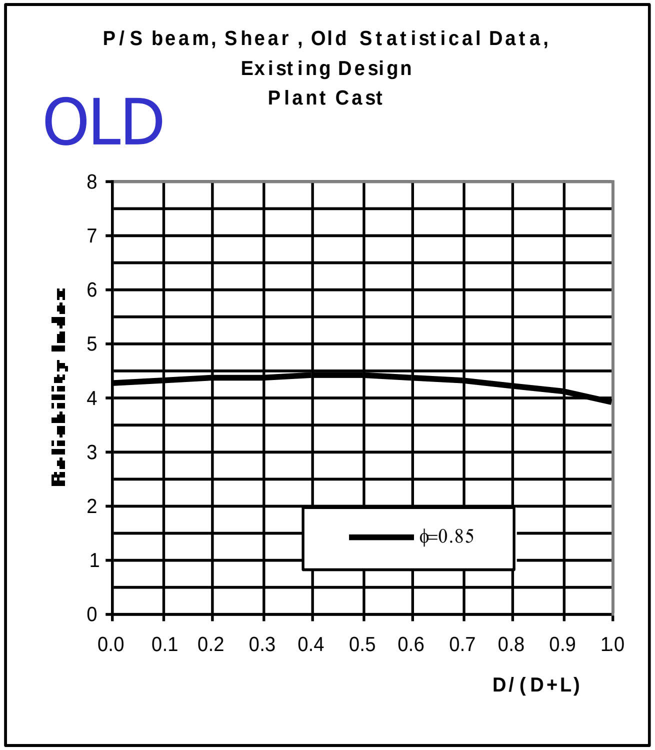
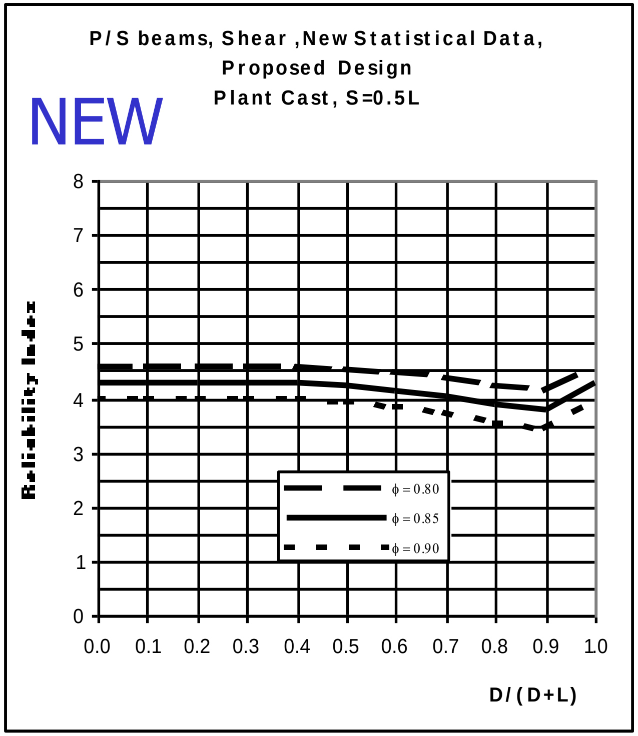
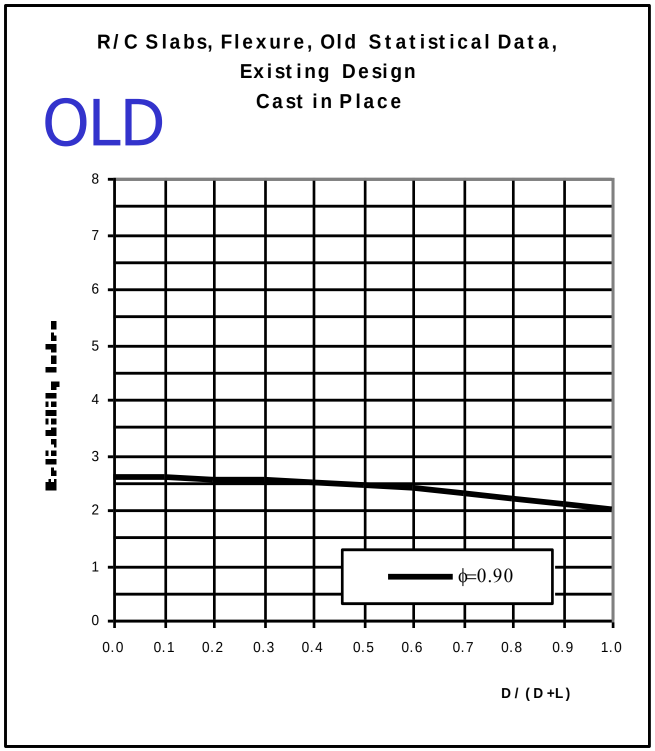
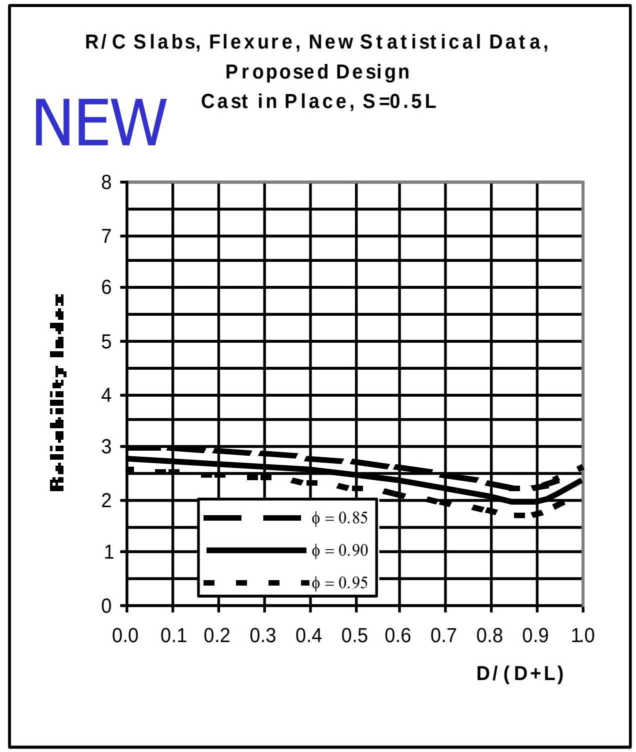


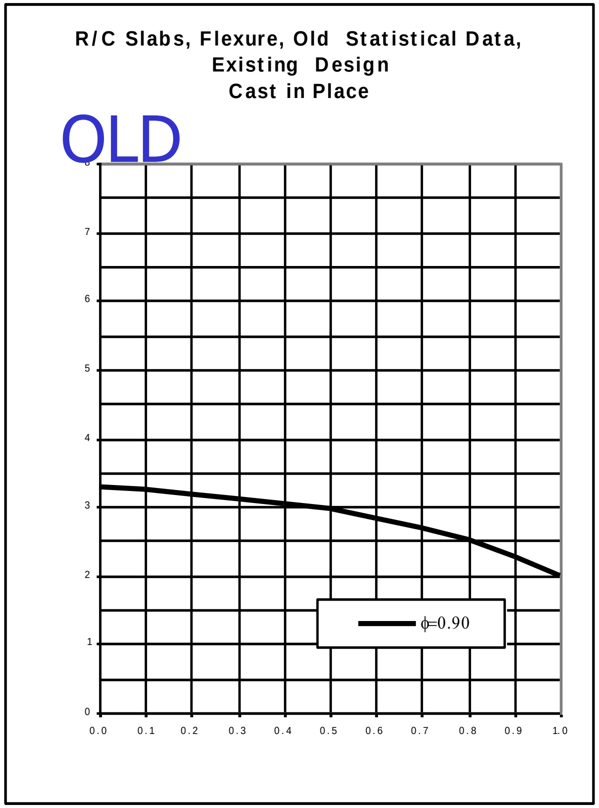


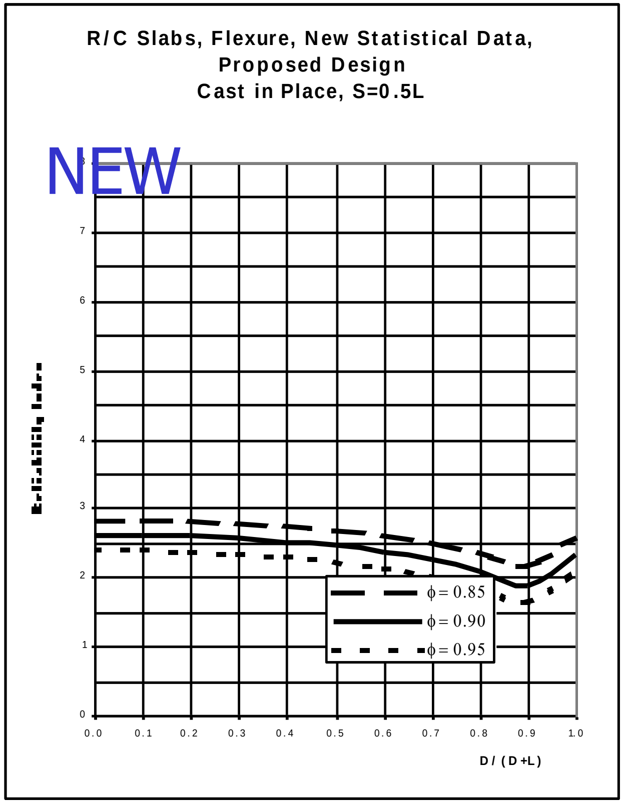
Reliability Indices for R/C Slabs, Flexure, Ordinary Concrete (D+L)



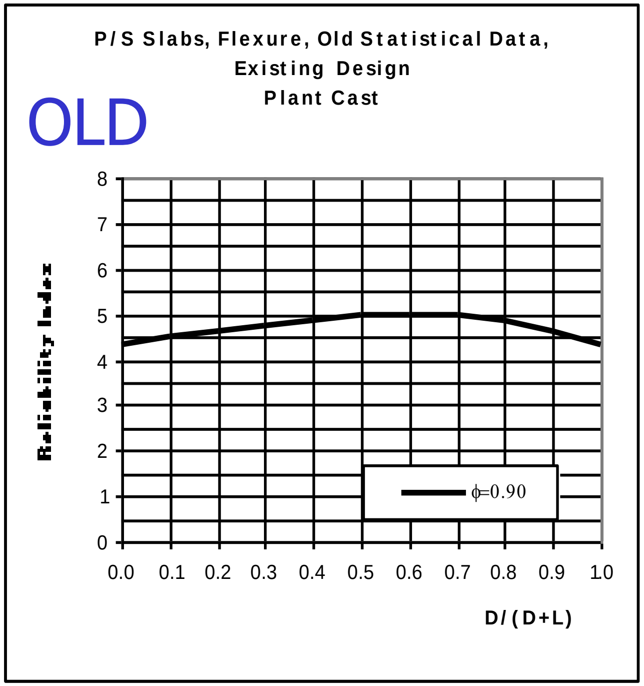


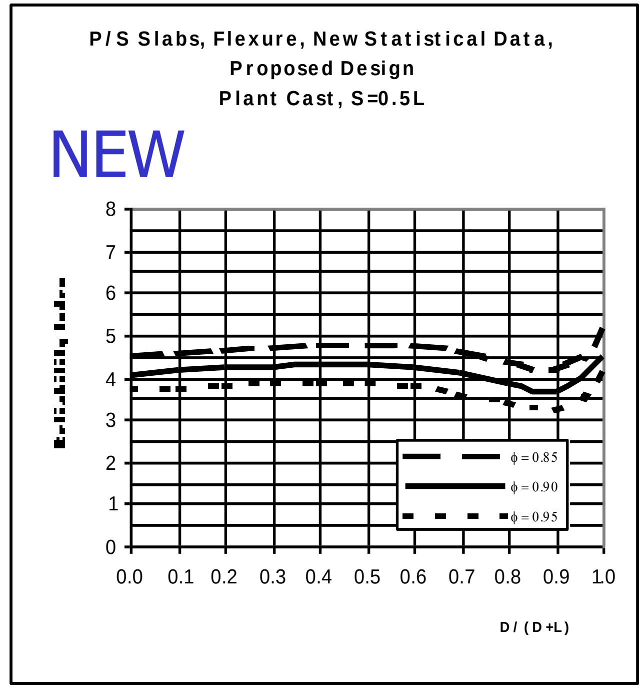
Reliability Indices for R/C Slabs, Flexure, High Strength Concrete (D+L)



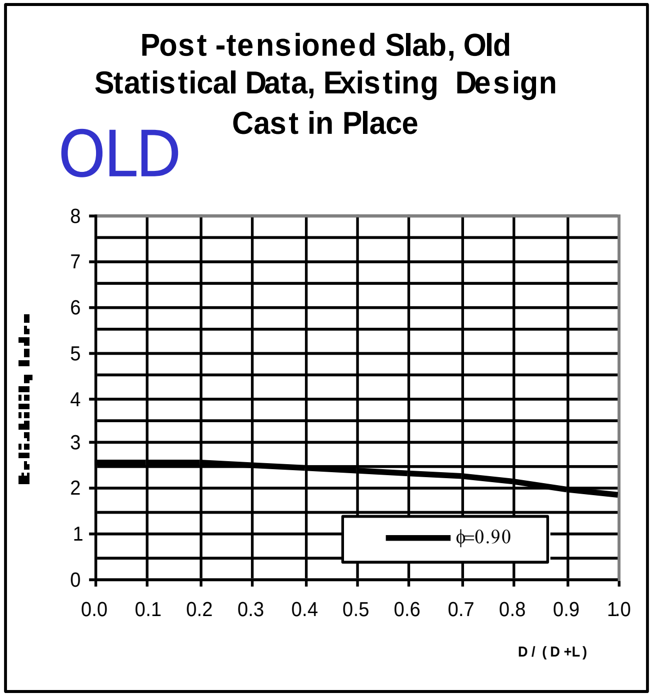


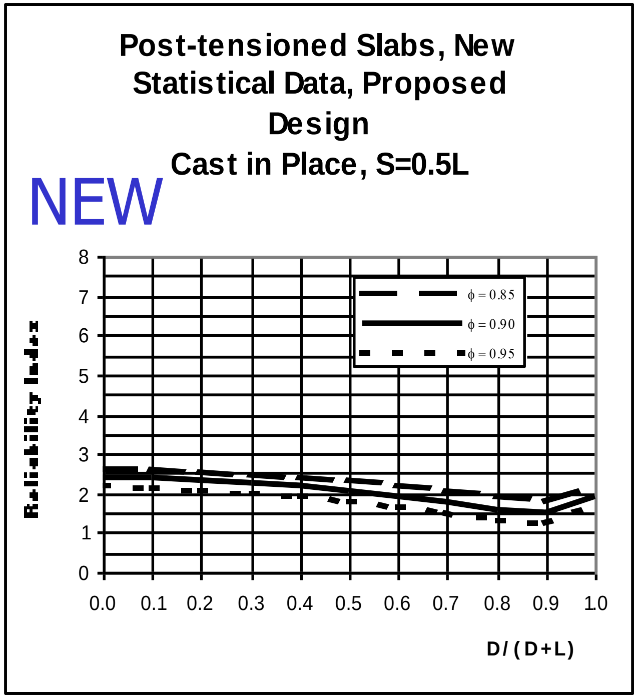
Reliability Indices for P/S Slabs, Flexure, Ordinary Concrete (D+L)



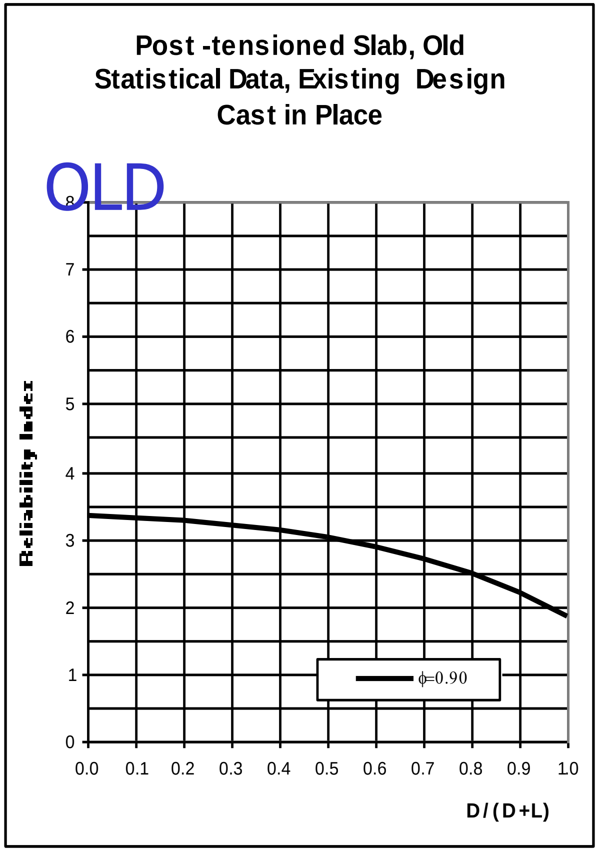


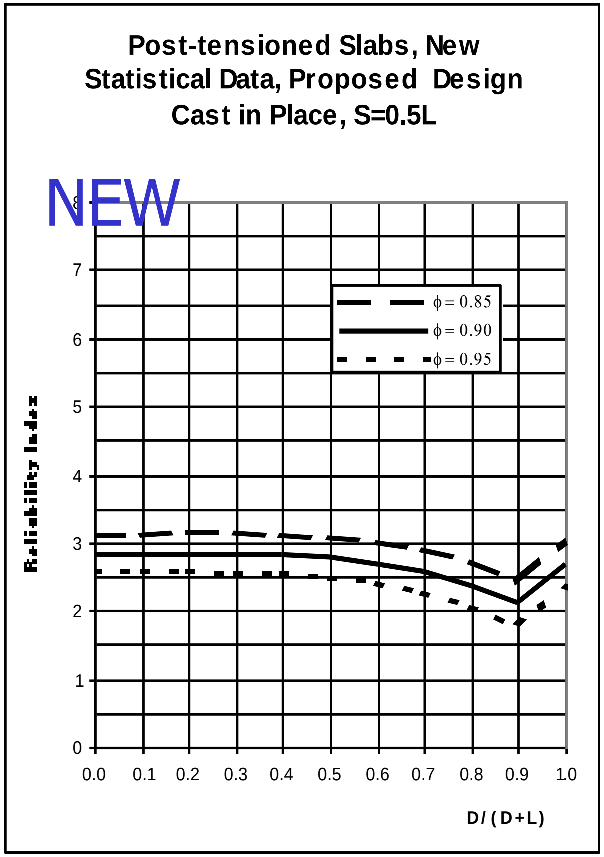
Reliability Indices for Post Tensioned Slabs, Flexure, Ordinary Concrete (D+L)



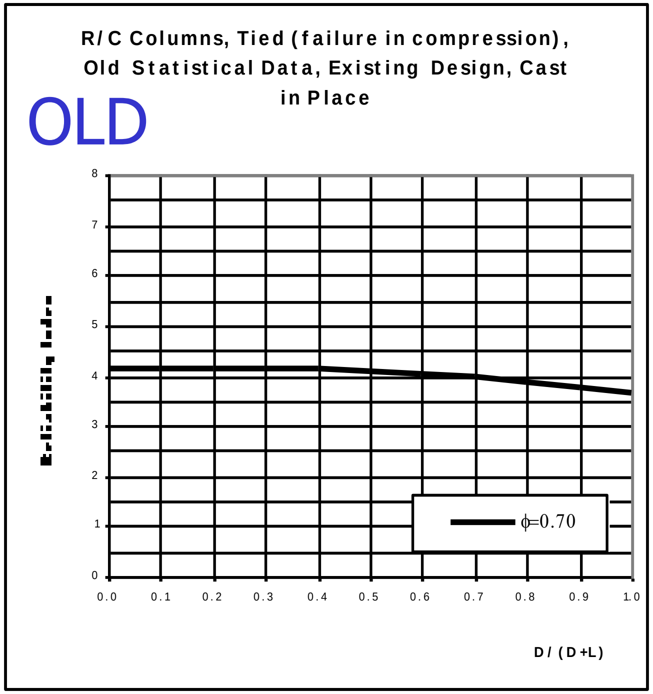


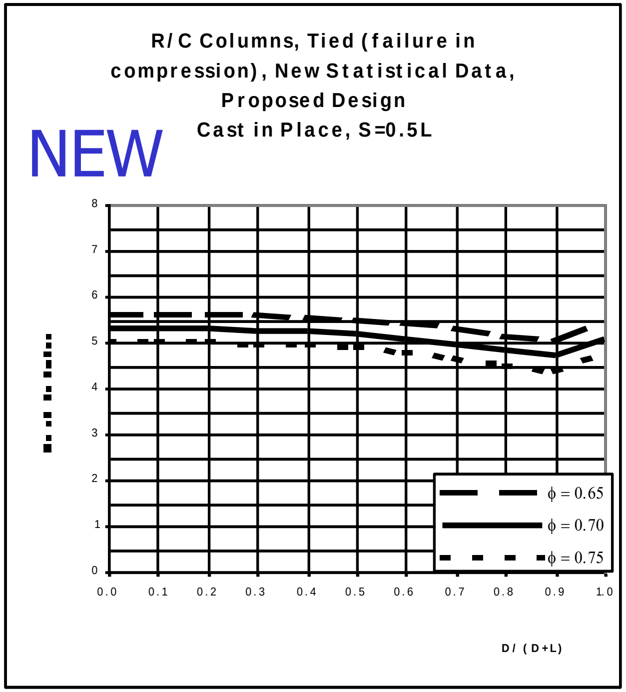
Reliability Indices for Post Tensioned Slabs, Flexure, High Strength Concrete (D+L)



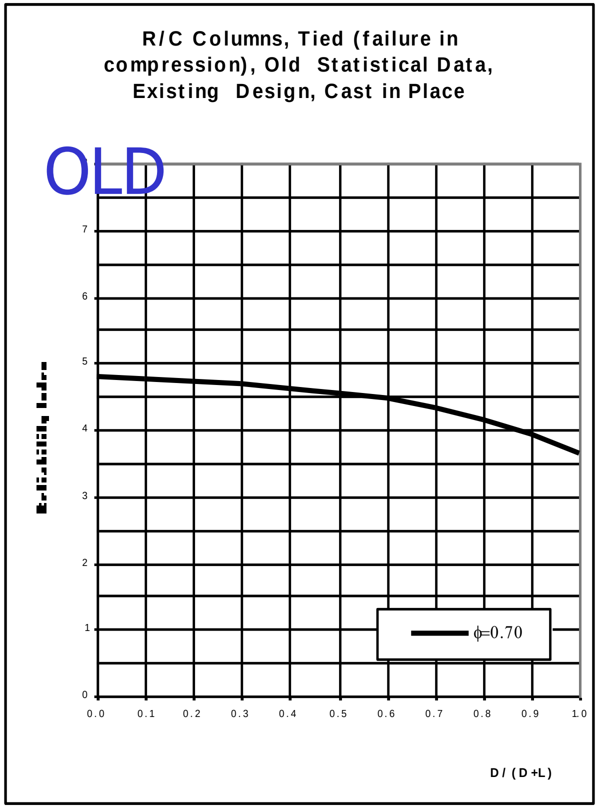


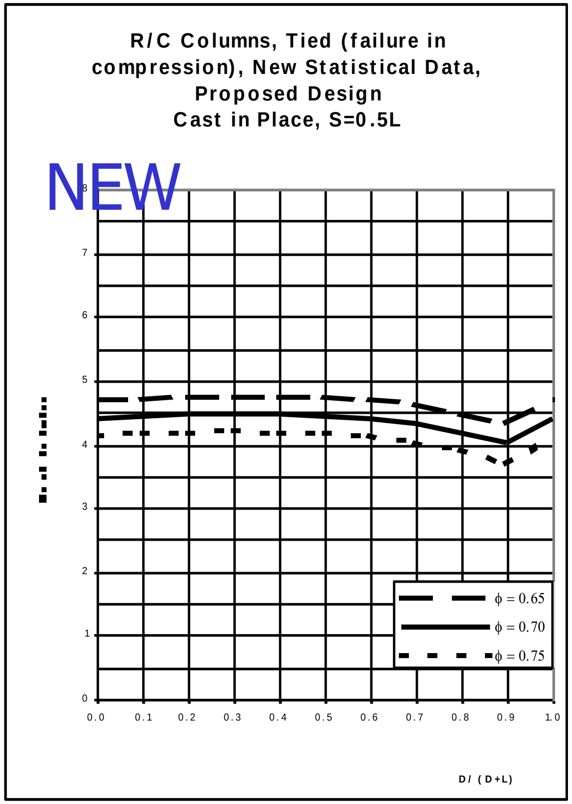
Reliability Indices for R/C Columns, Tied, Ordinary Concrete (D+L)



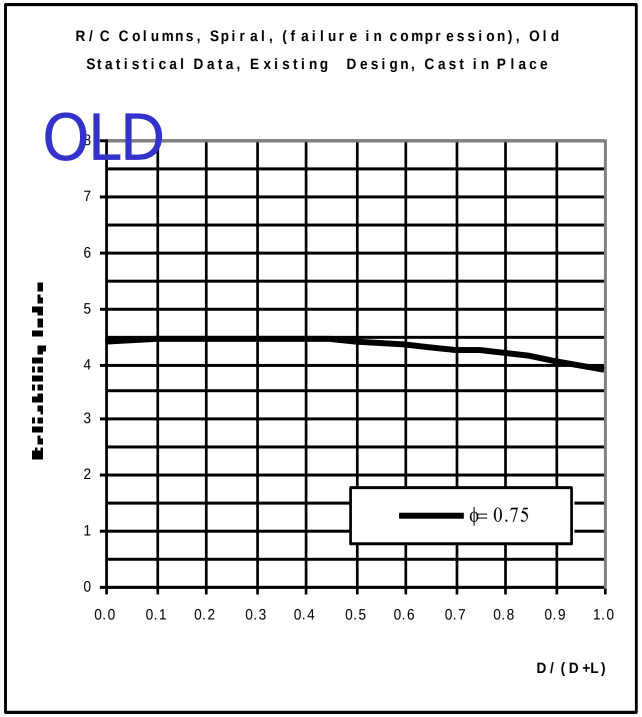


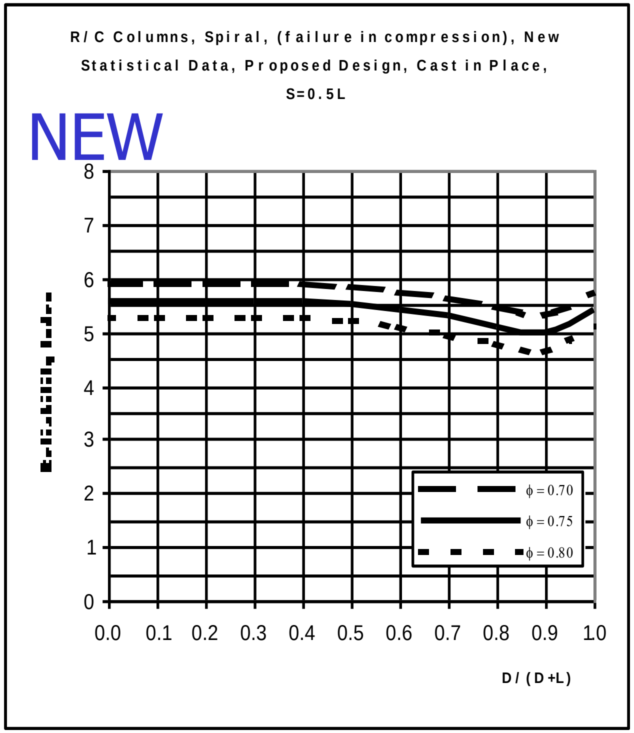
Reliability Indices for R/C Columns, Tied, High Strength Concrete (D+L)



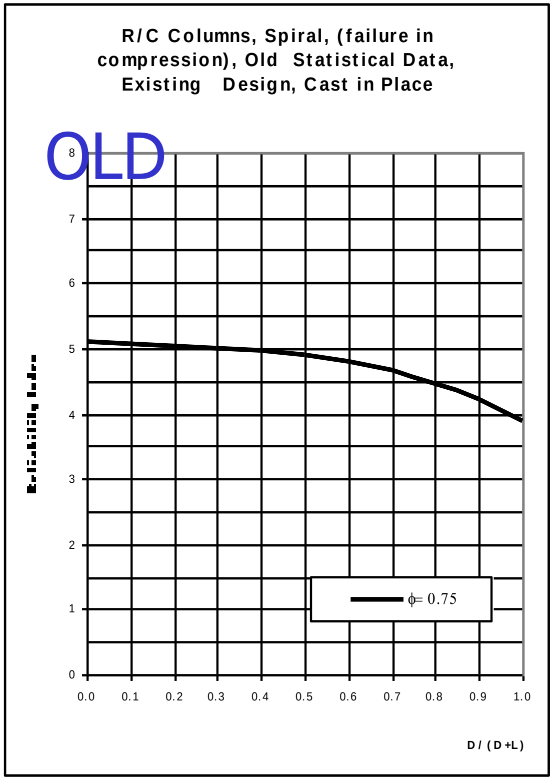


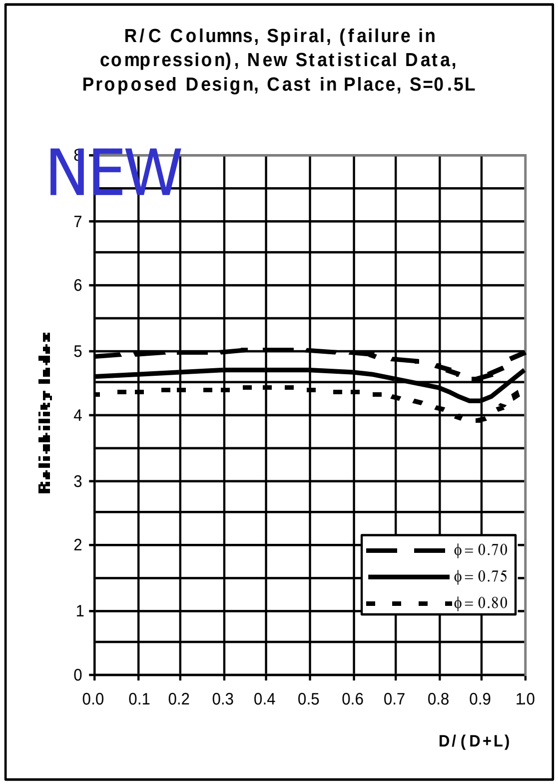
Reliability Indices for R/C Columns, Spiral, Ordinary Concrete (D+L)



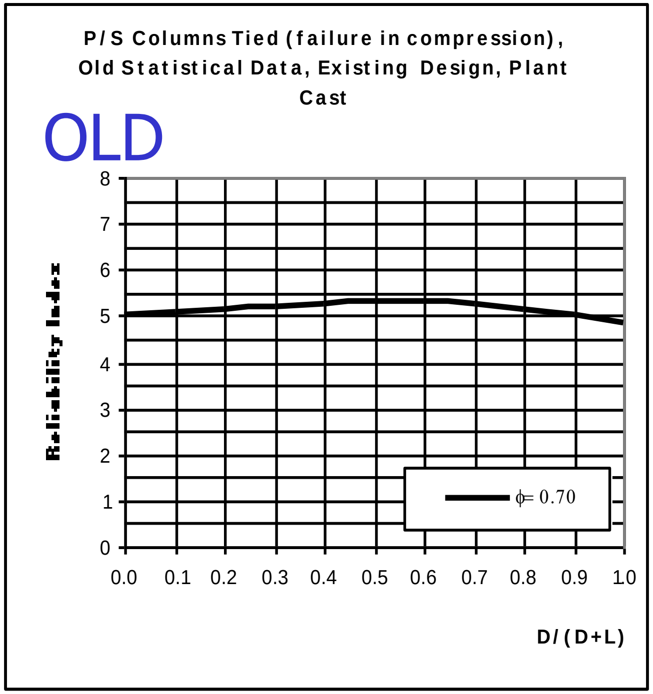


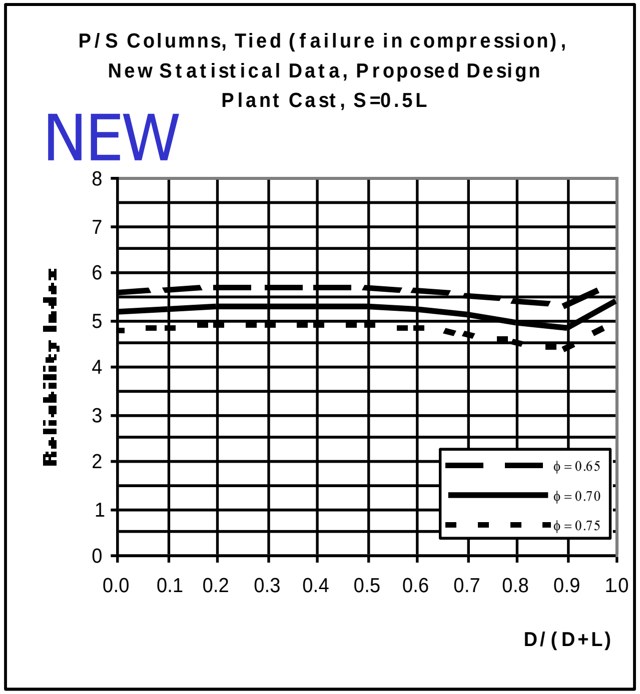
Reliability Indices for R/C Columns, Spiral, High Strength Concrete (D+L)



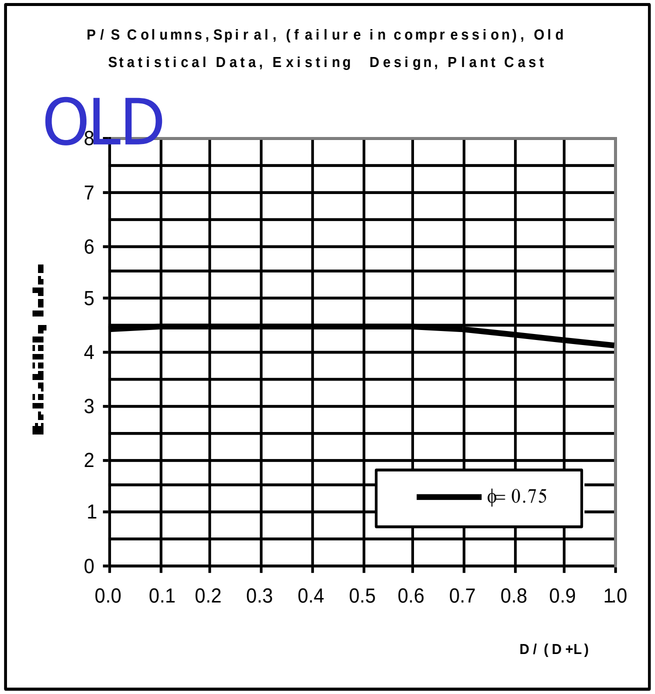


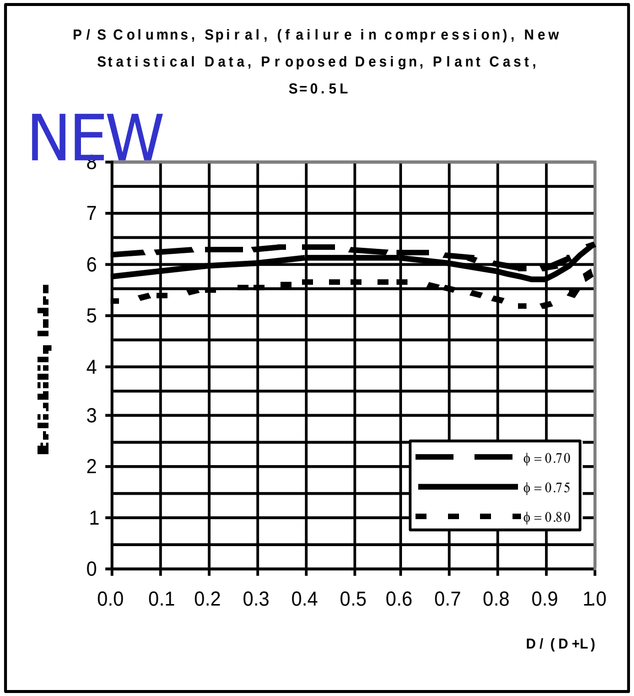
Reliability Indices for P/S Columns, Tied, Ordinary Concrete (D+L)



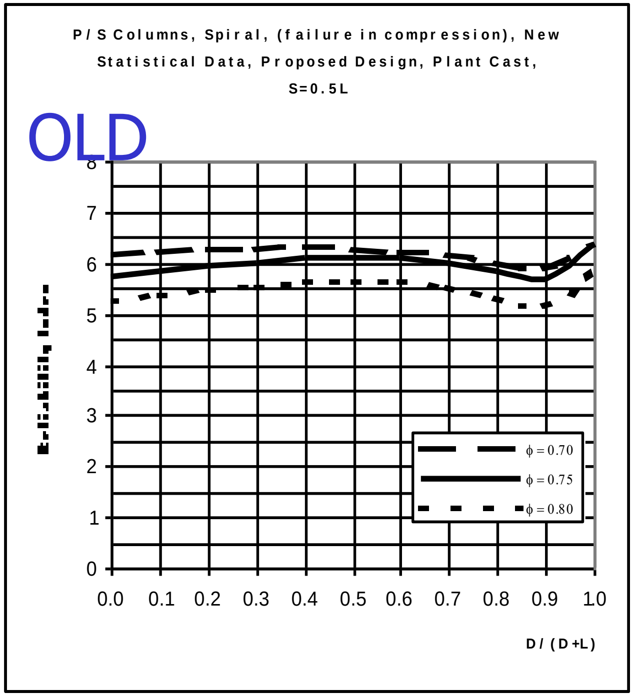


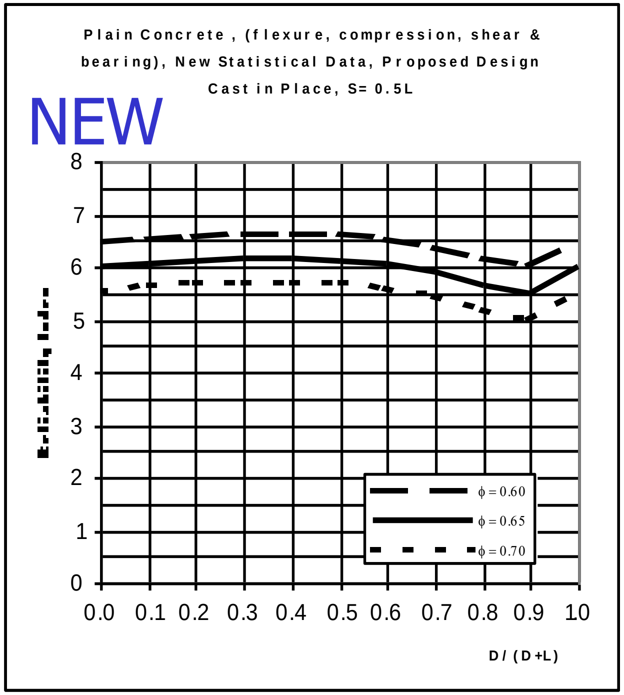
Reliability Indices for P/S Columns, Spiral, Ordinary Concrete (D+L)



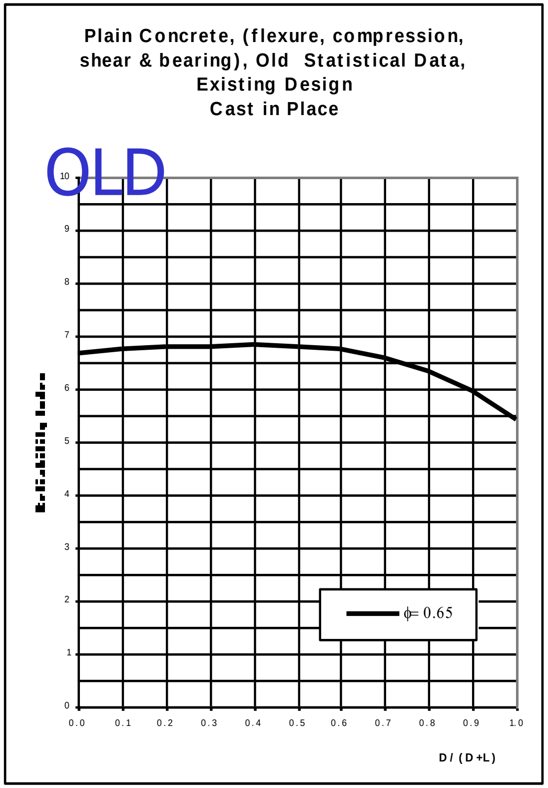


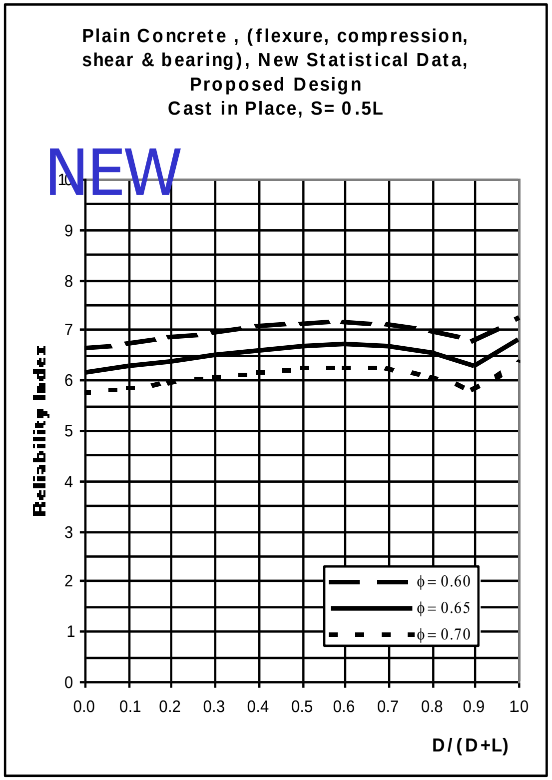
Reliability Indices for Plain Ordinary Concrete Elements, (D+L)



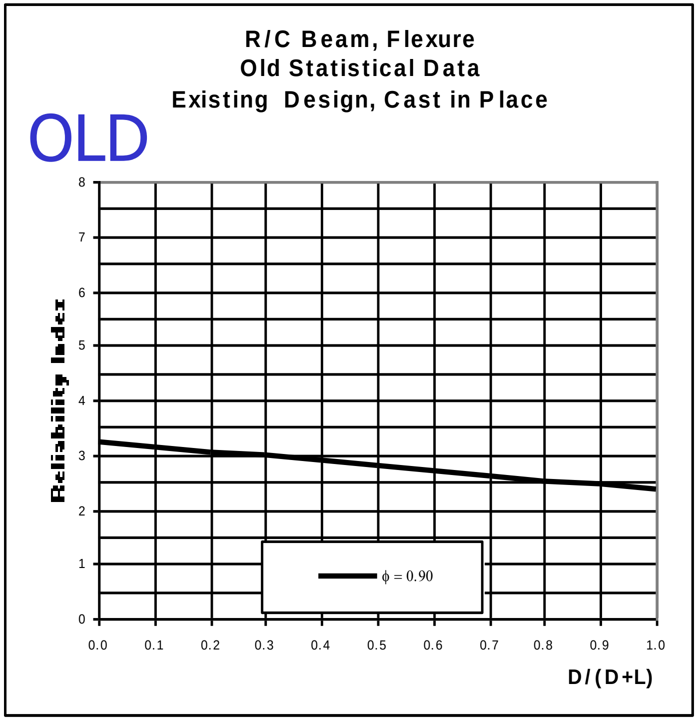


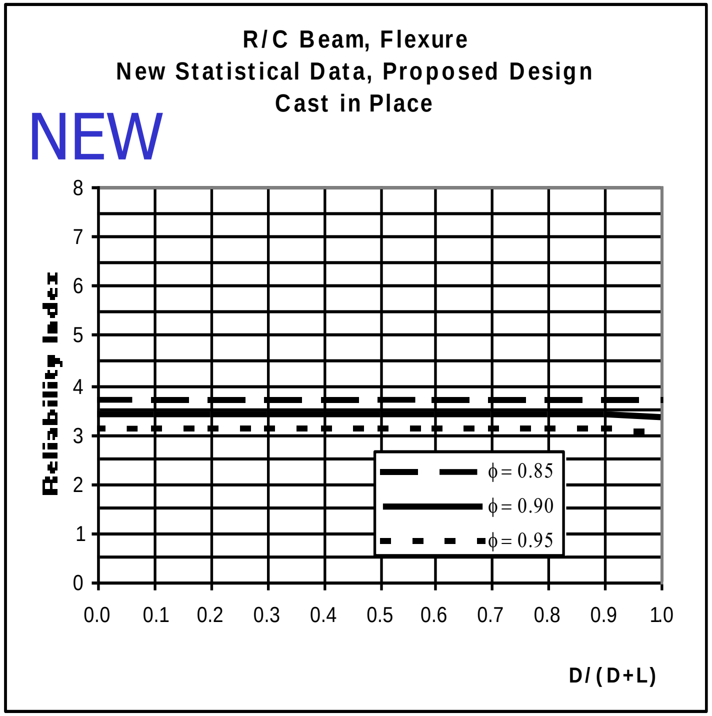
Reliability Indices for Plain High Strength Concrete Elements, (D+L)



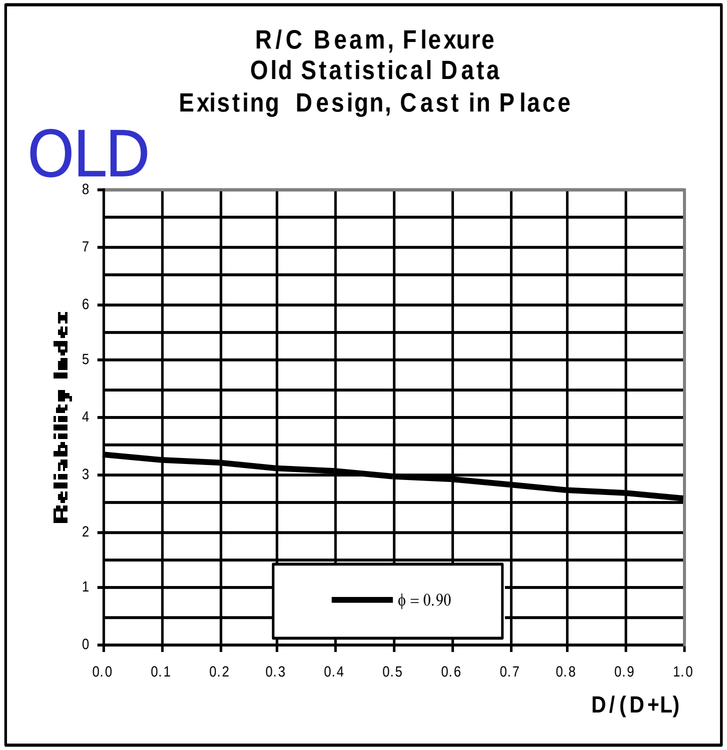


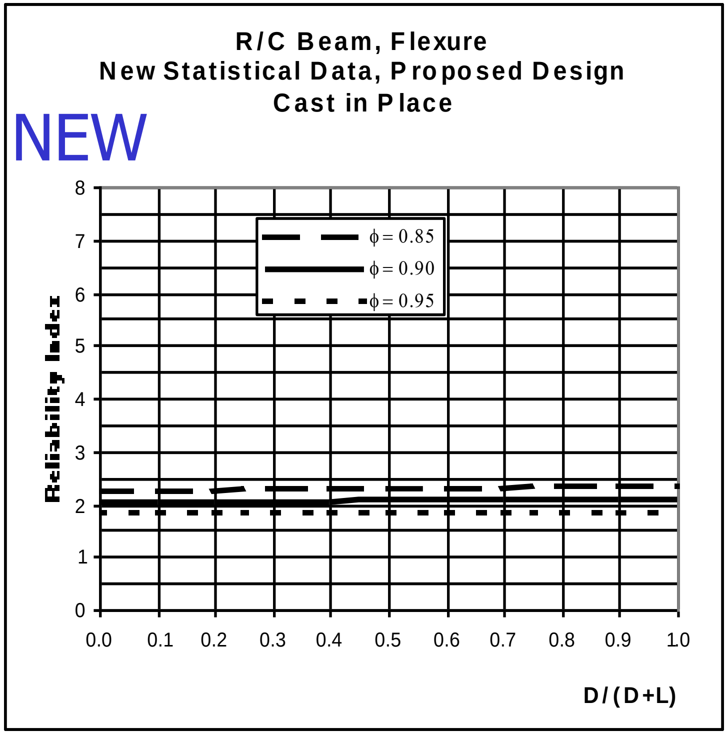
Reliability Indices for R/C Beams, Flexure, Ordinary Concrete, (D+L+W)



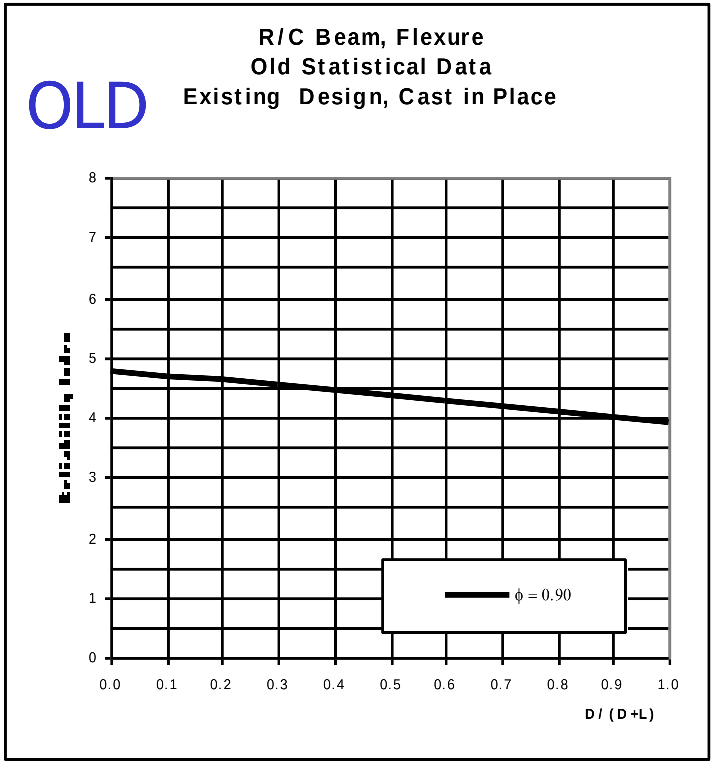


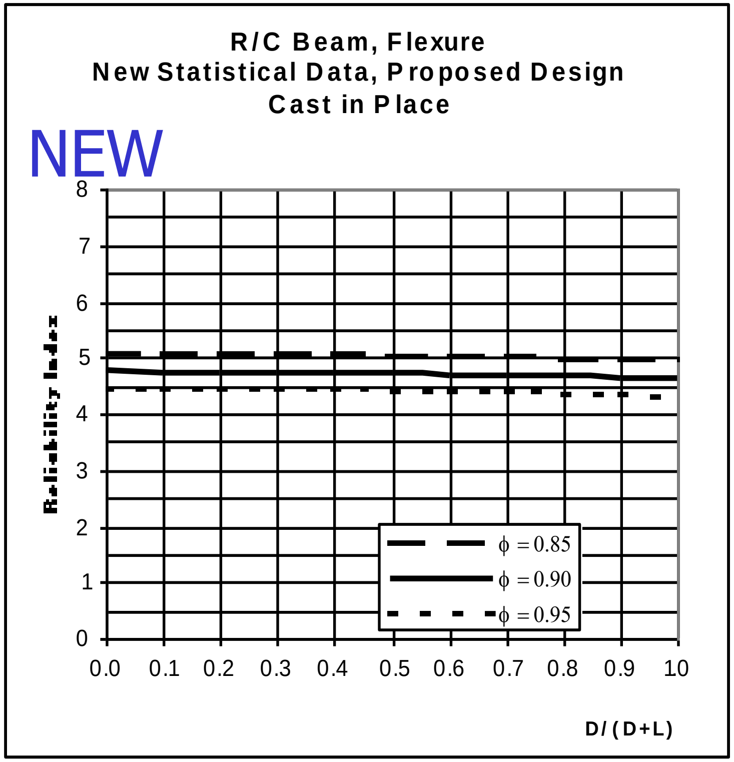
Reliability Indices for R/C Beams, Flexure, Ordinary Concrete, (D+L+E)



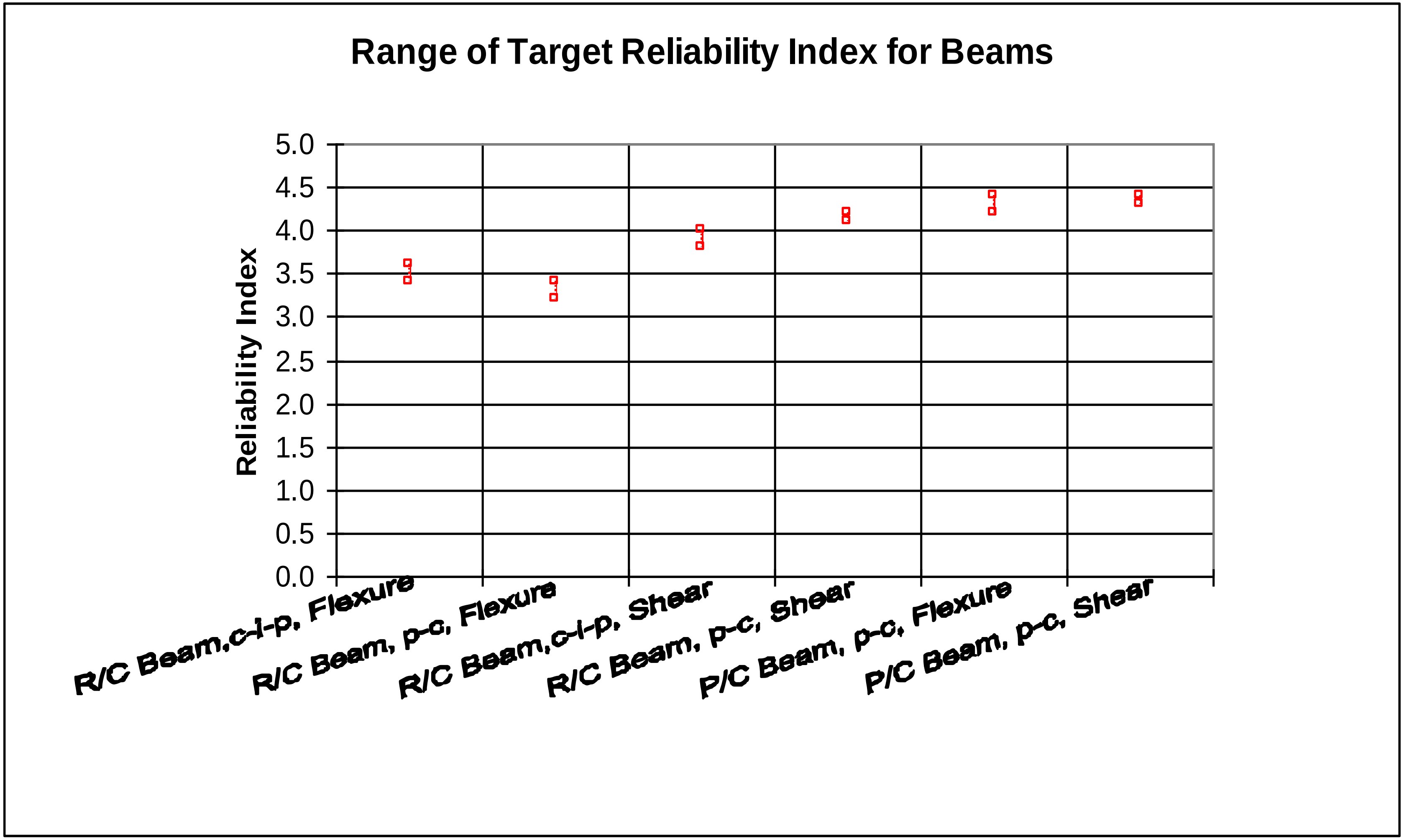


Reliability Indices for R/C Beams, Flexure, Ordinary Concrete, (D+L+S)

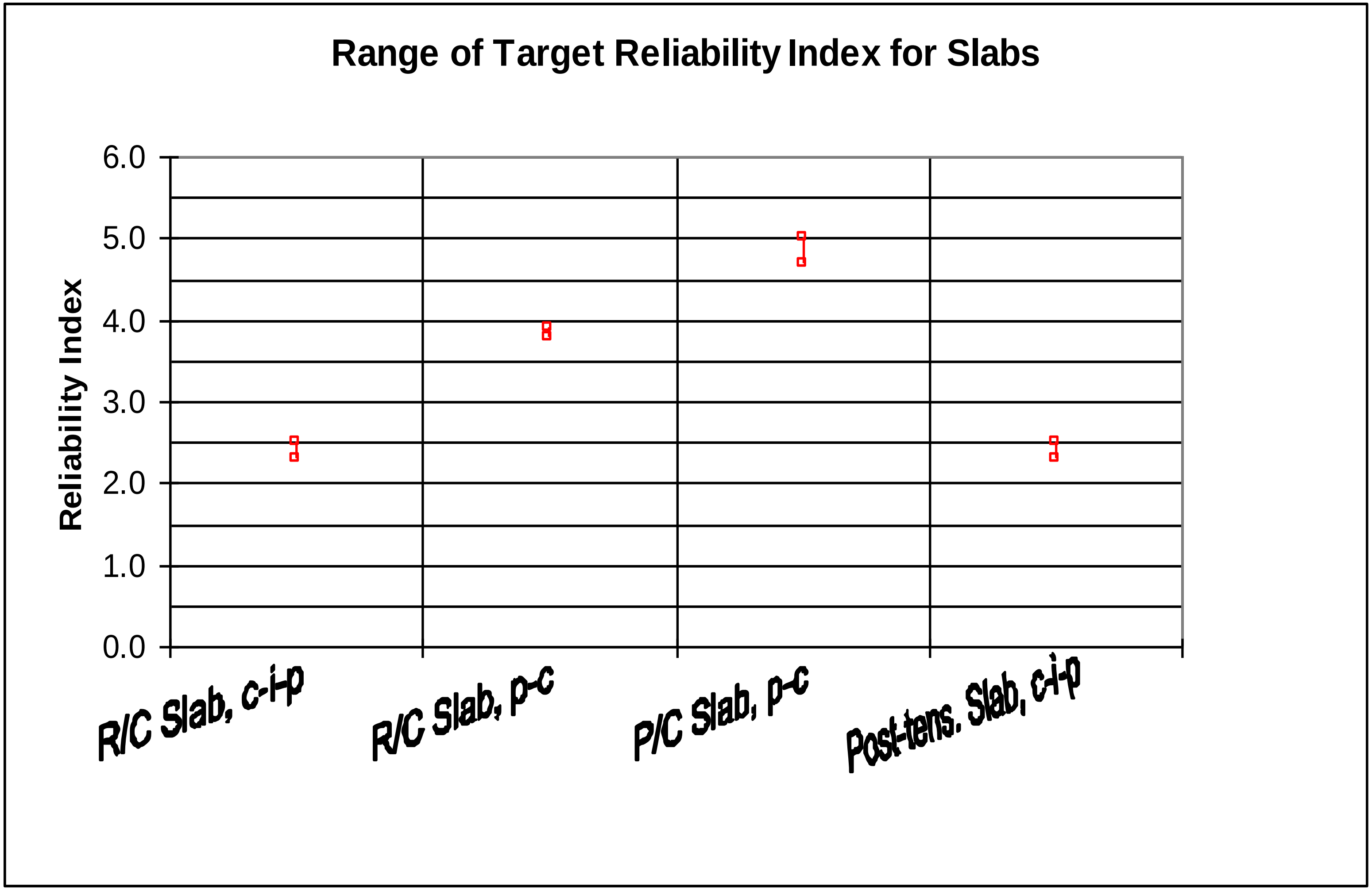




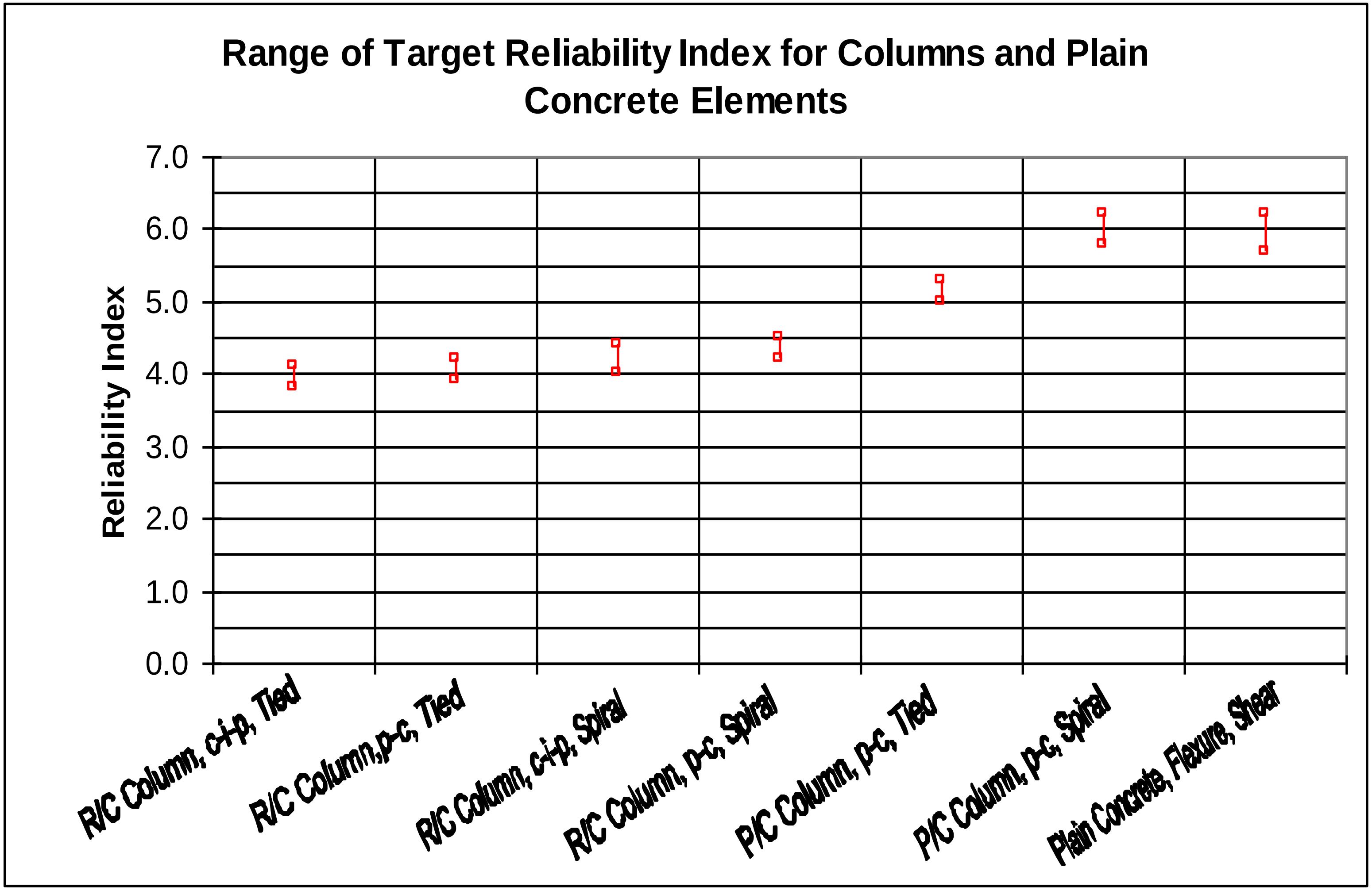
Selected Range of Reliability Indices for Beams, designed according to “old” ACI 318



Selected Range of Reliability Indices for Slabs, designed according to “old” ACI 318



Selected Range of Reliability Indices for Columns and Plain Concrete Elements, designed according to "old" ACI 318



Selected Target Reliability Indices

Structural type and limit state	Range of β	β_T
R/C Beam cast-in-place, flexure	3.4-3.6	3.5
R/C beam plant cast, flexure	3.2-3.4	3.5
R/C Beam cast-in-place, shear	3.8-4.0	3.5
R/C beam plant cast, shear	4.1-4.2	3.5
P/S beam plant cast, flexure	4.2-4.4	3.5
P/C beam plant cast, shear	4.3-4.4	3.5
R/C slab cast-in-place	2.3-2.5	2.5
R/C slab plant cast	3.8-3.9	3.5
P/S slab plant cast	4.7-5.0	3.5
Post-tensioned slab cast-in-place	2.3-2.5	2.5
R/C column cast-in-place, tied	3.8-4.1	4.0
R/C column plant cast, tied	3.9-4.2	4.0
R/C column cast-in-place, spiral	4.0-4.4	4.0
R/C column plant cast, spiral	4.2-4.5	4.0
P/S column plant cast, tied	5.0-5.3	4.0
P/S column plant cast, spiral	5.8-6.2	4.0
Plain concrete, flexure, shear	5.7-6.2	4.0

Recommended Resistance Factors for ACI 318

Structural type and limit state	Resistance factors, φ
R/C Beam cast-in-place, flexure	0.90
R/C beam plant cast, flexure	0.90
R/C Beam cast-in-place, shear	0.85
R/C beam plant cast, shear	0.85
P/S beam plant cast, flexure	0.90
P/C beam plant cast, shear	0.85
R/C slab cast-in-place	0.90
R/C slab plant cast	0.90
P/S slab plant cast	0.90
Post-tensioned slab cast-in-place	0.90
R/C column cast-in-place, tied	0.75
R/C column plant cast, tied	0.75
R/C column cast-in-place, spiral	0.80
R/C column plant cast, spiral	0.80
P/S column plant cast, tied	0.75
P/S column plant cast, spiral	0.80
Plain concrete, flexure, shear	0.65

Proposed Change in Load Factors (ASCE 7)

The design formula specified by ASCE-7 Standard	Proposed
1.4 D < ϕ R	**1.4 (D + L) < ϕ R**

1.2 D + 1.6 L < ϕ R
1.2 D + 1.6 L + 0.5 S < ϕ R
1.2 D + 0.5 L + 1.6 S < ϕ R
1.2 D + 1.6 W + 0.5 L + 0.5 S < ϕ R
1.2 D + 1.0 E + 0.5 L + 0.2 S < ϕ R
0.9 D – (1.6 W or 1.0 E) < ϕ R

ACI 318-02
ACI 318R-02

Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02)

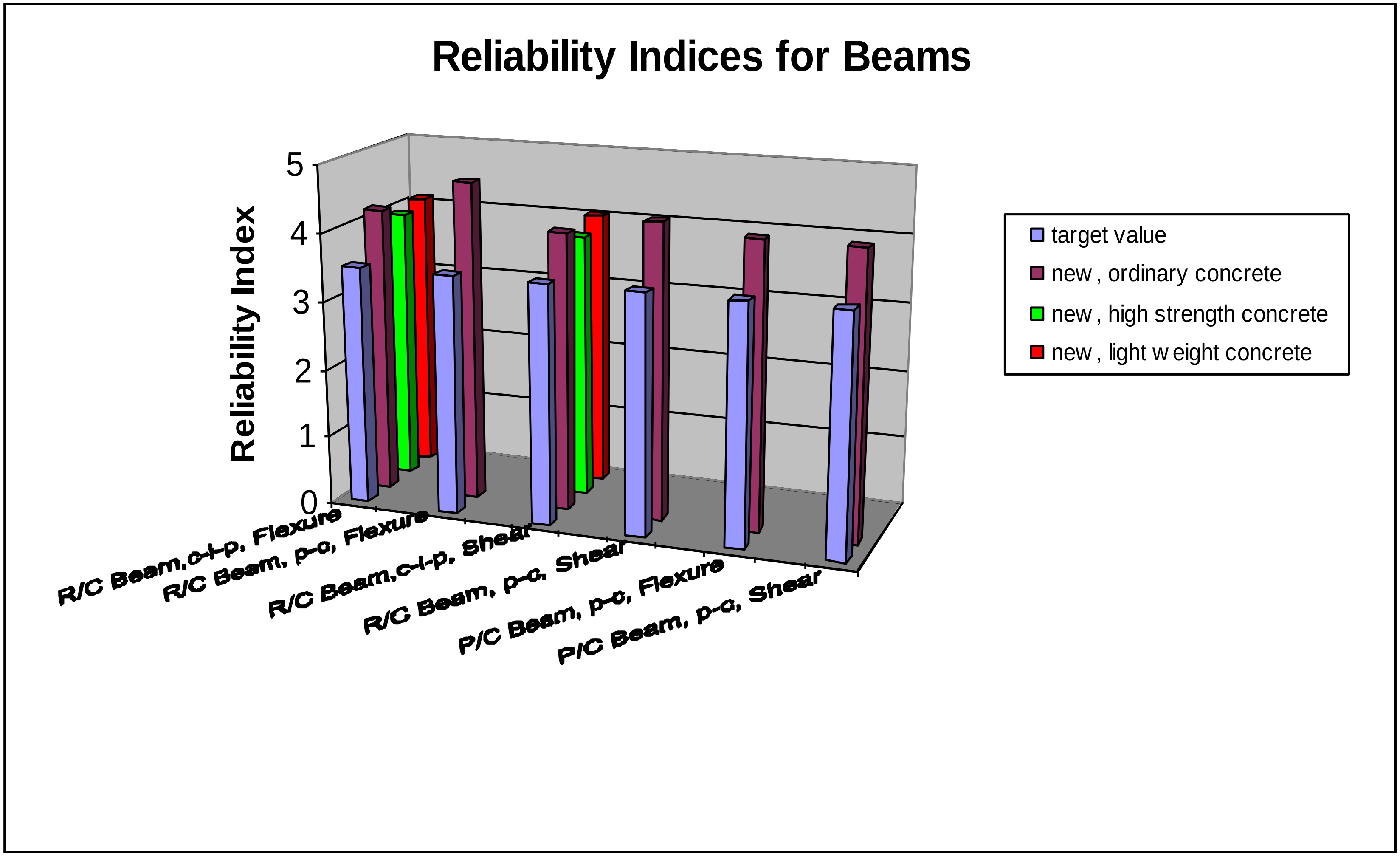
An ACI Standard

Reported by ACI Committee 318

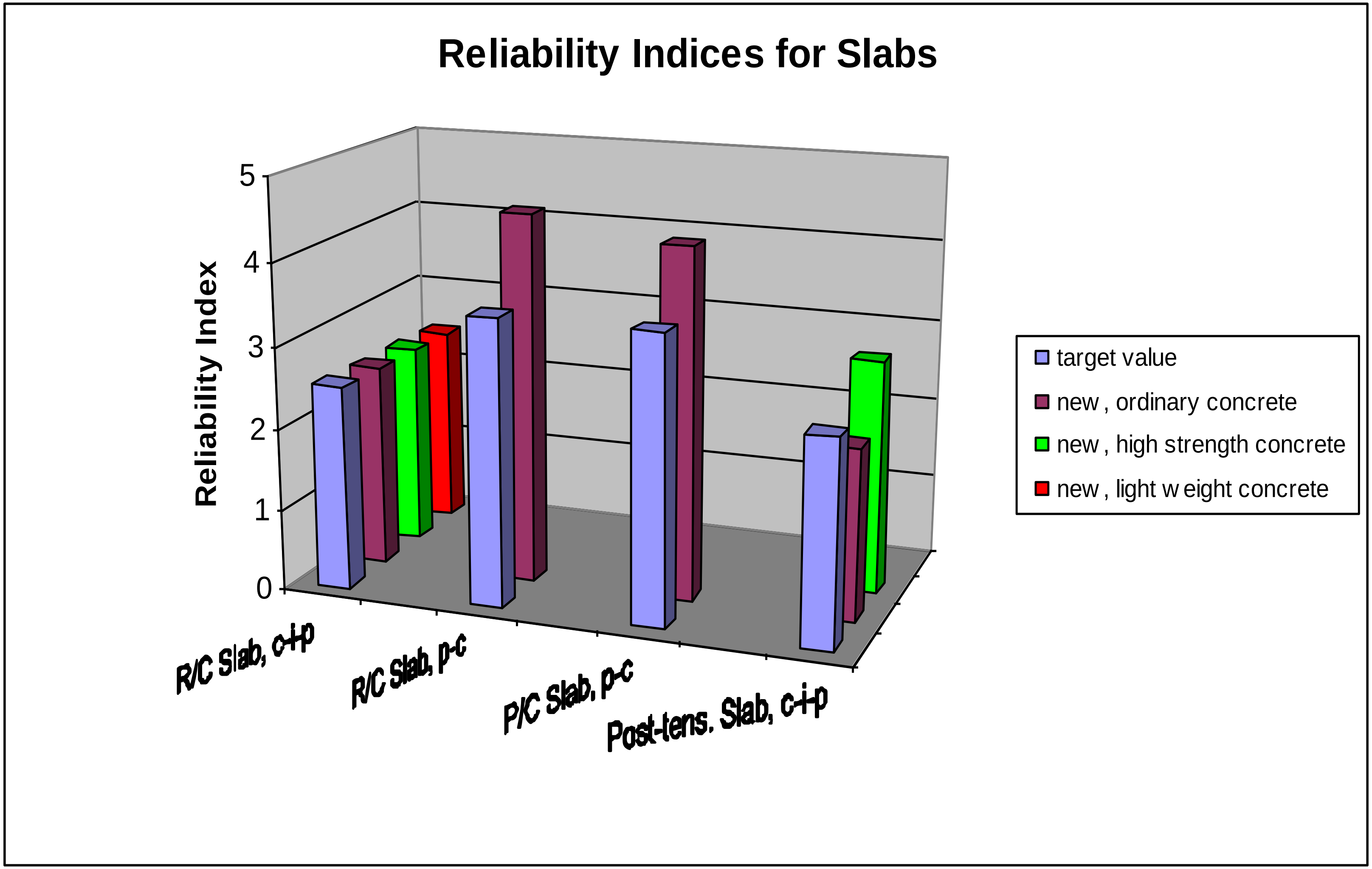
aci international

american concrete institute
P.O. BOX 9094
FARMINGTON HILLS, MICHIGAN 48333-9094

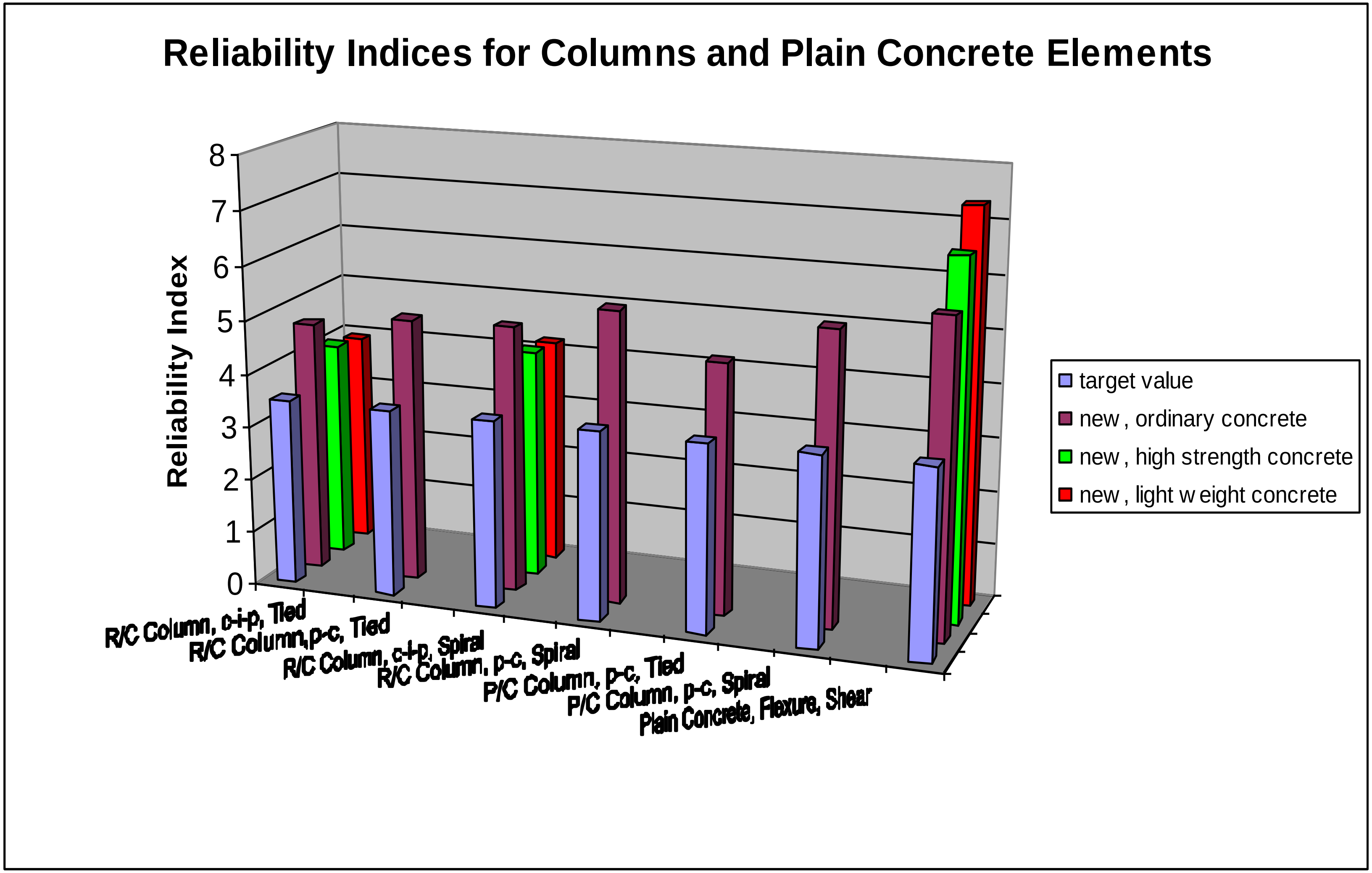
Reliability Indices for Beams, designed according to the "new" ACI 318



Reliability Indices for Slabs, designed according to the "new" ACI 318



Reliability Indices for Columns and Plain Concrete Elements, designed according to the “new” ACI 318



Conclusions for ACI 318 Calibration

- Quality of materials (concrete and reinforcing steel) have improved in the last 20-30 years
- Reliability of structures designed according to “old” ACI 318 is now higher than the minimum acceptable level
- Resistance factors can be increased by 10-15%. Therefore, for the new load factors (ASCE 7), “old” resistance factors are acceptable
- Phase 2 of the Calibration continues, including eccentrically loaded columns, slabs and environmental loads

AASHTO

LRFD BRIDGE DESIGN SPECIFICATIONS

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS
AASHTO
THE VOICE OF TRANSPORTATION

Seventh Edition, 2014
U.S. Customary Units

Part I: Sections 1—6

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Publication Code: LRFDUS-7

Calibration of the AASHTO LRFD Design Code for Bridges

Basic design formula

$$\gamma_D D + \gamma_L L (1 + I) \leq \phi R$$

In the AASHTO Standard Specifications (old)

$$1.30 D + 2.17 L (1 + I) \leq \phi R$$

In the AASHTO LRFD Code (new)

$$1.25 D + 1.75 L (1 + I) \leq \phi R$$

AASHTO LRFD Code

$$1.25\,D + 1.75\,L\,(1 + I) \leq \phi\,R$$

Load factors are determined so that for each factored load, the probability of being exceeded is about the same for all load components.

Resistance factor is determined so that the reliability index, β, is close to the target value, β_T.

Limit States in AASHTO Code for bridges

Four types of limit states:

- Strength limit state
- Service limit state
- Fatigue and fracture limit state
- Extreme event limit state

Strength Limit State

This limit state relates to strength and stability, local and global. The Code specifies five strength limit states:

- Strength I (normal vehicular use, no wind)
- Strength II (permit vehicles, no wind)
- Strength III (wind velocity > 55 mph)
- Strength IV (high dead load to live load ratio)
- Strength V (normal vehicular use with wind of 55 mph)

Service Limit State

This limit state relates to restrictions on stress, deformation, crack width under regular service conditions. The Code specifies three service limit

states:

- Service I (normal use with 55 mph wind, control of crack width in R/C, compression in P/C)
- Service II (overload provision, only for steel structures)
- Service III (only for tension in P/C)

Fatigue and Fracture Limit State

This limit state relates to restrictions on stress range as a result of a single design truck occurring at the number of expected stress range cycles. It is intended to limit crack growth under repetitive loads to prevent fracture during the design life of the bridge.

Extreme Event Limit States

This limit state relates to the structural survival of a bridge during a major earthquake or flood, or when collided by a vessel, vehicle, or ice flow, possibly under scoured conditions. The Code specifies two extreme event limit states:

- Extreme Event I (earthquake)
- Extreme Event II (ice load, collision by vessels and vehicles)

General Form of a Limit State Function

factored load (Q) $\leq$ factored resistance (ϕ R)

$$Q = \Sigma\ \eta_i\ \gamma_i\ Q_i \leq \phi\ R$$

where Q_i = load component "i"

$\eta_i = \eta_D\ \eta_R\ \eta_I$

γ_i = load factor "i"

ϕ = resistance factor

Load Modifiers

$$\eta_i = \eta_D \, \eta_R \, \eta_I$$

η_D = a factor relating to ductility

η_R = a factor relating to redundancy

η_I = a factor relating to operational importance

Ductility

The structural system shall be proportioned and detailed to ensure the development of significant and visible inelastic deformations at the strength and extreme event limit states before failure.

<u>For strength limit state:</u>

η_D = 1.05 for nonductile components

η_D = 1.00 for conventional designs

η_D = 0.95 for components and connections with additional ductility-enhancing measures

<u>For all other limit states:</u>

η_D = 1.00

Redundancy

Multiple load path and continuous structures should be used. Main elements whose failure is expected to cause the collapse of the bridge shall be designated as failure-critical (nonredundant).

For strength limit state:

η_R = 1.05 for nonredundant members

η_R = 1.00 for conventional levels of redundancy

η_R = 0.95 for exceptional levels of redundancy

For all other limit states:

η_R = 1.00

Operational Importance

The owner may declare a bridge or any structural component and connection thereof to be of operational importance.

For strength limit state:

$\eta_I = 1.05$ for important bridges

$\eta_I = 1.00$ for typical bridges

$\eta_I = 0.95$ for relatively less important bridges

For all other limit states:

$\eta_I = 1.00$

AASHTO Standard Specifications Load Factor Design

$$1.3\ D + 1.3\ (5/3)\ L\ (1 + I) \leq \phi R$$

where: D = moment due to dead load

L = moment due to live load

I = dynamic load factor (impact)

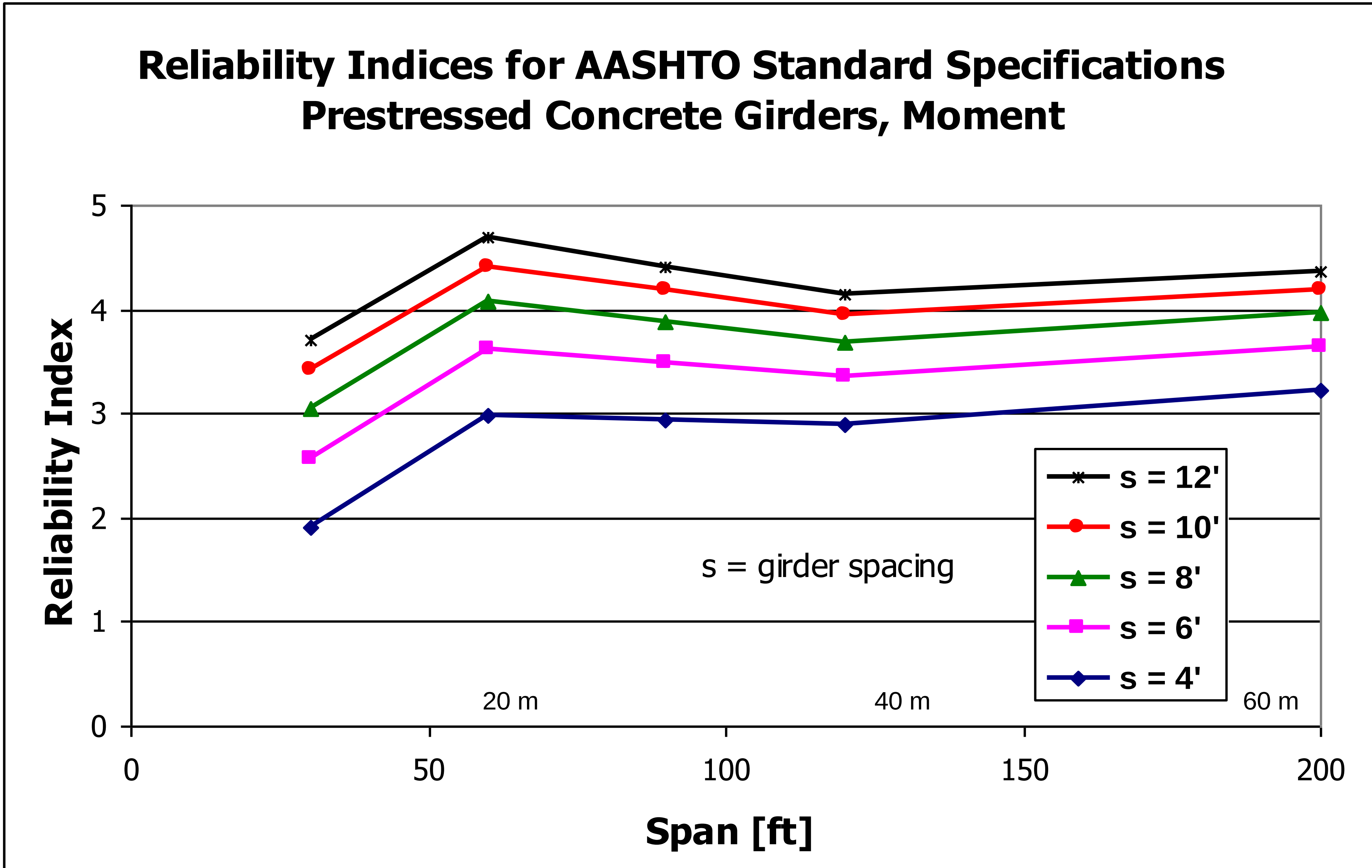
R = moment carrying capacity

ϕ = resistance factor

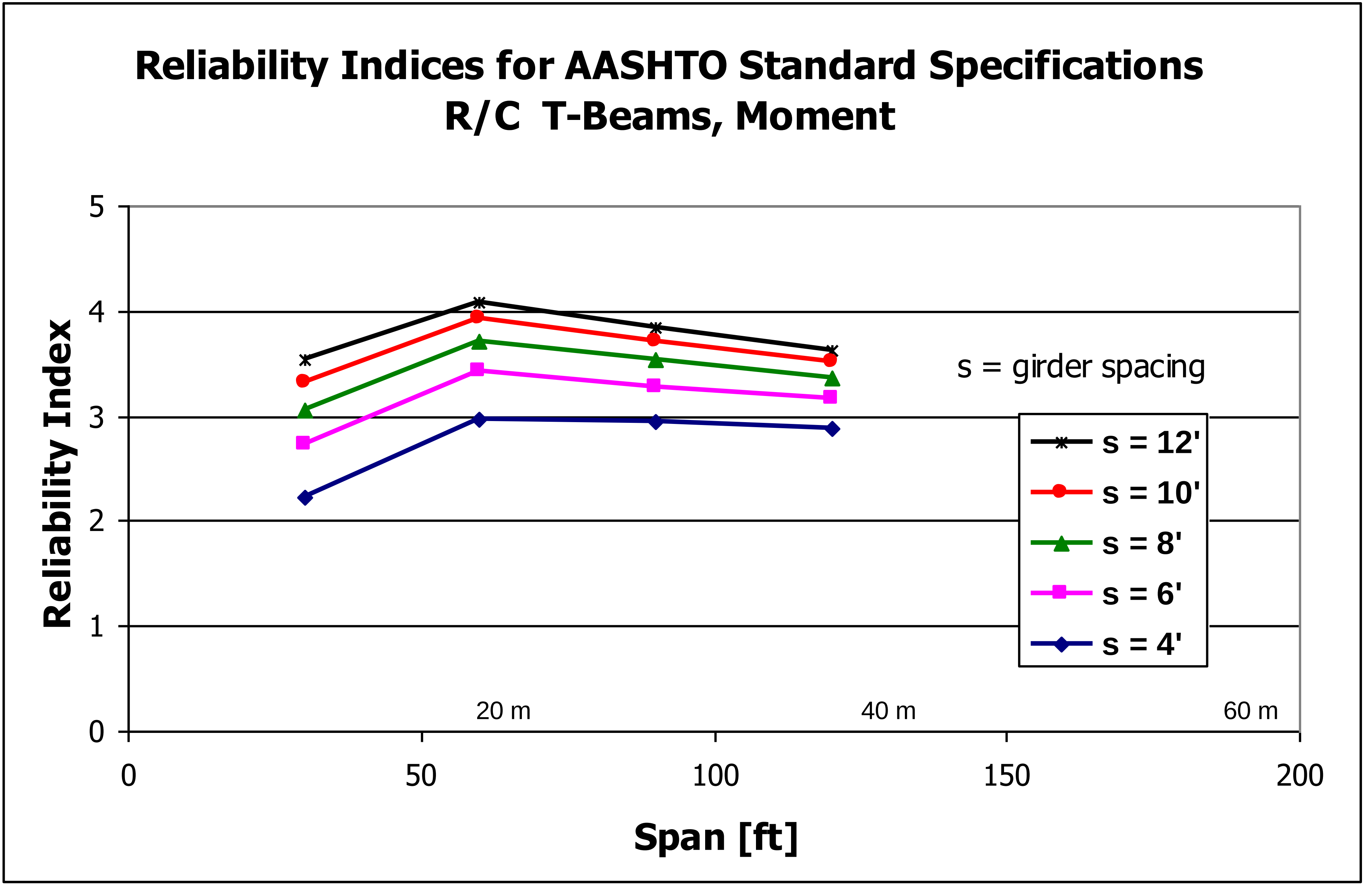
Safety margin is included in load and resistance factors

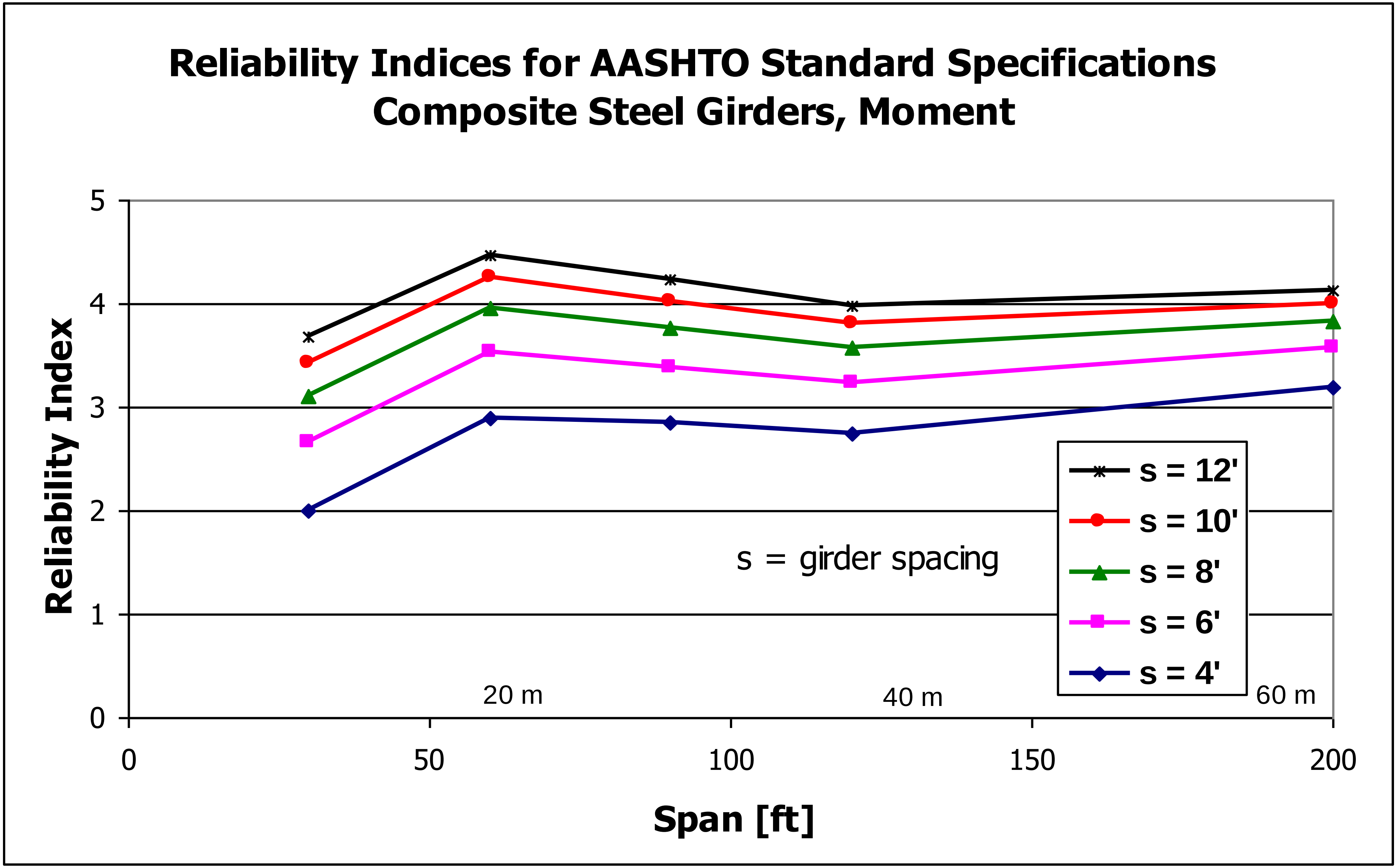
Resistance Factors in AASHTO Standard Specifications (2003)

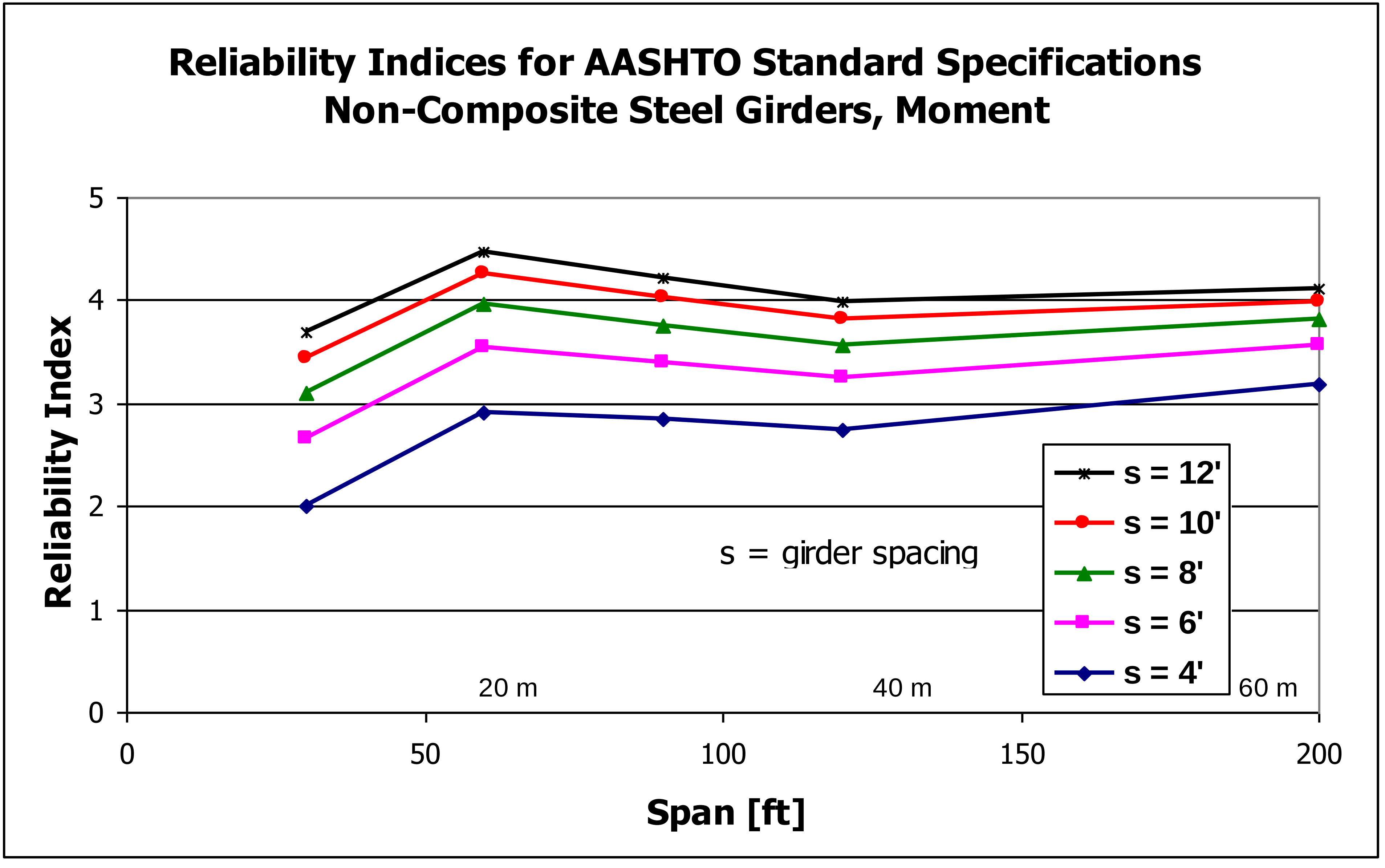
Material	Moment	Shear
Steel	1.00	1.00
Reinforced Concrete	0.90	0.90
Prestressed Concrete	1.00	0.90



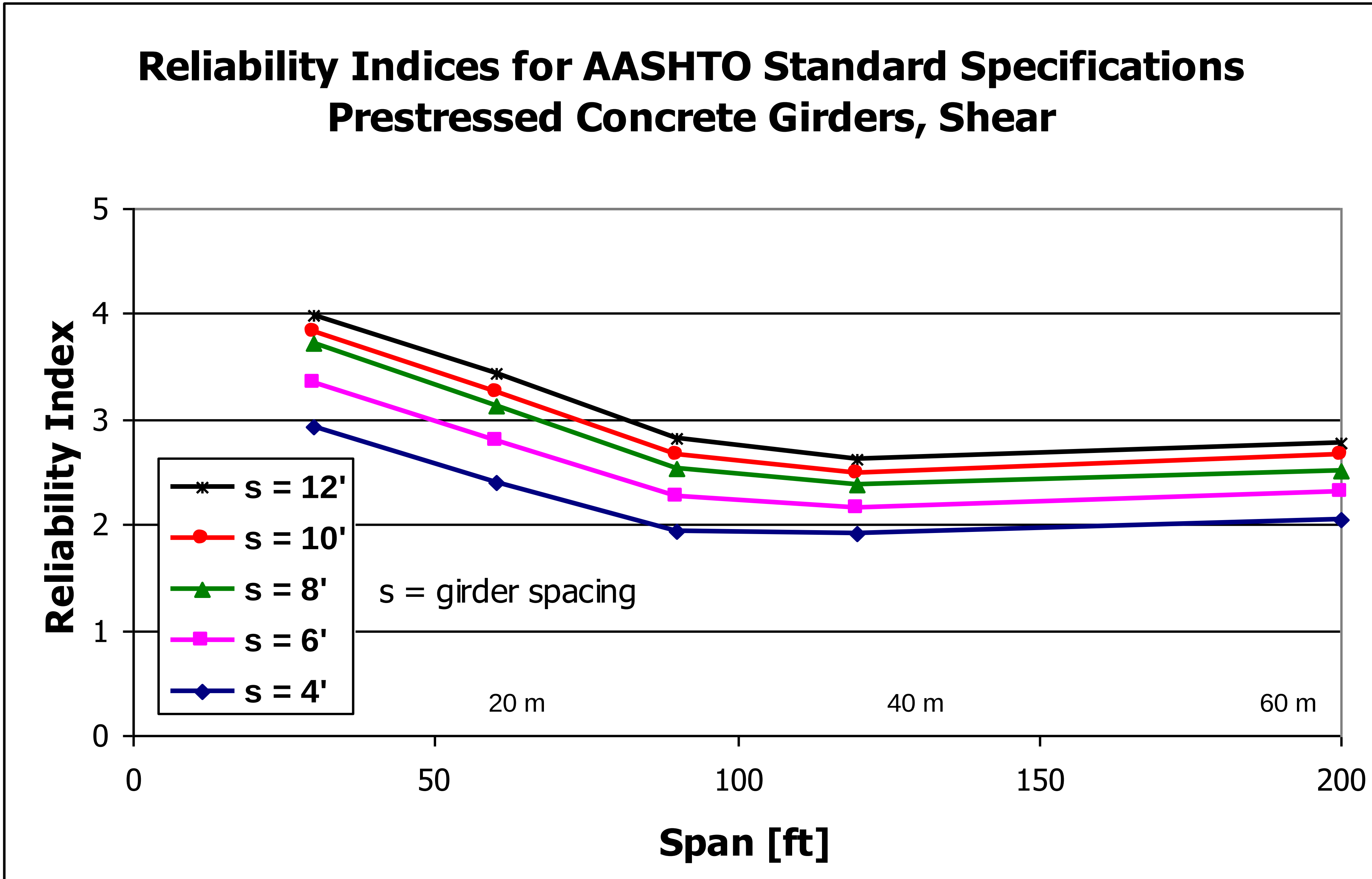
Reliability Indices for AASHTO Standard Specifications
Prestressed Concrete Girders, Moment
Reliability Index
0
1
2
3
4
5
0
50
100
150
200
20 m
40 m
60 m
Span [ft]
s = girder spacing
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'

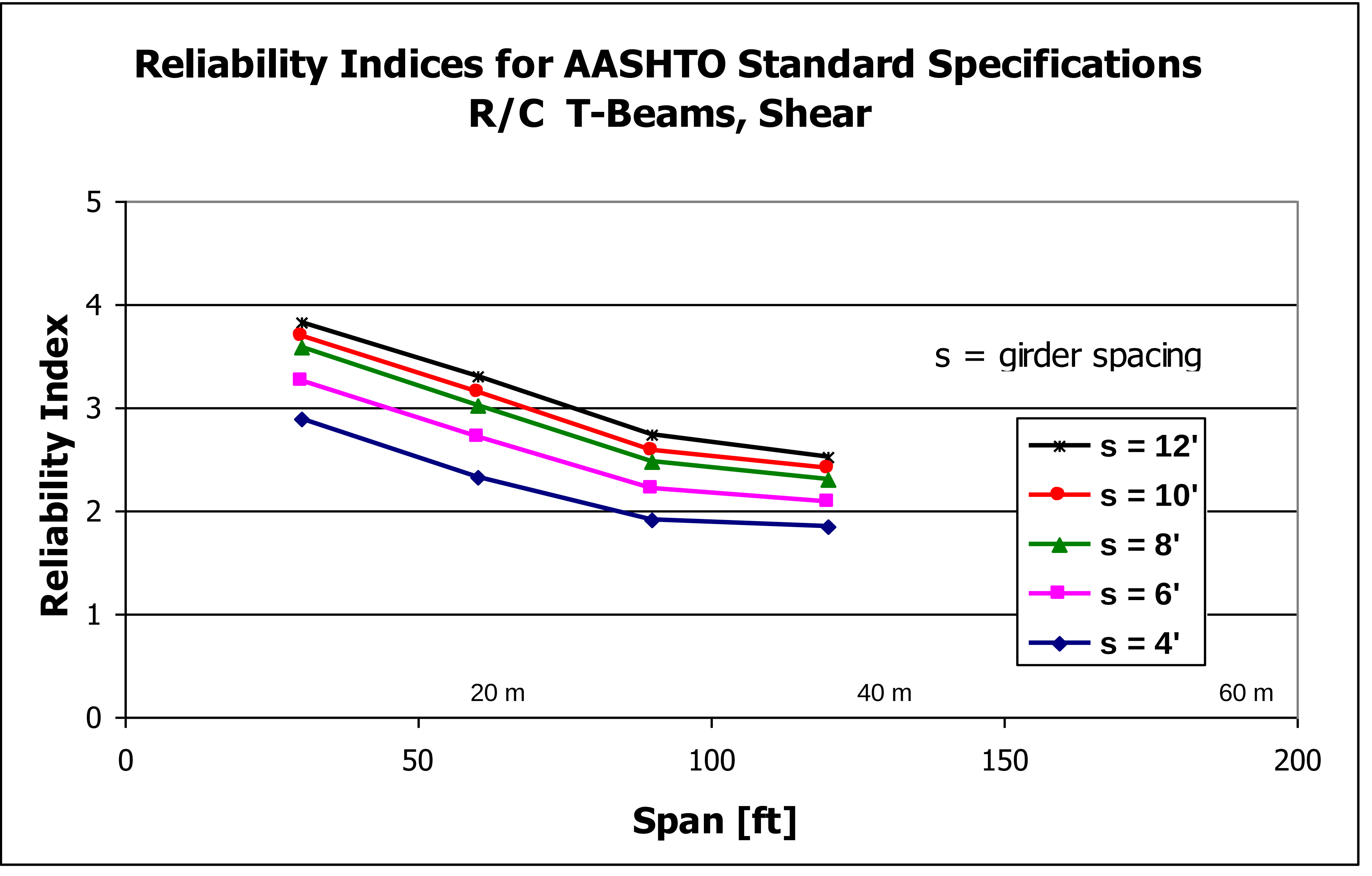

Reliability Indices for AASHTO Standard Specifications
R/C T-Beams, Moment
Reliability Index
5
4
3
2
1
0
s = girder spacing
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'
20 m
40 m
60 m
0
50
100
150
200
Span [ft]

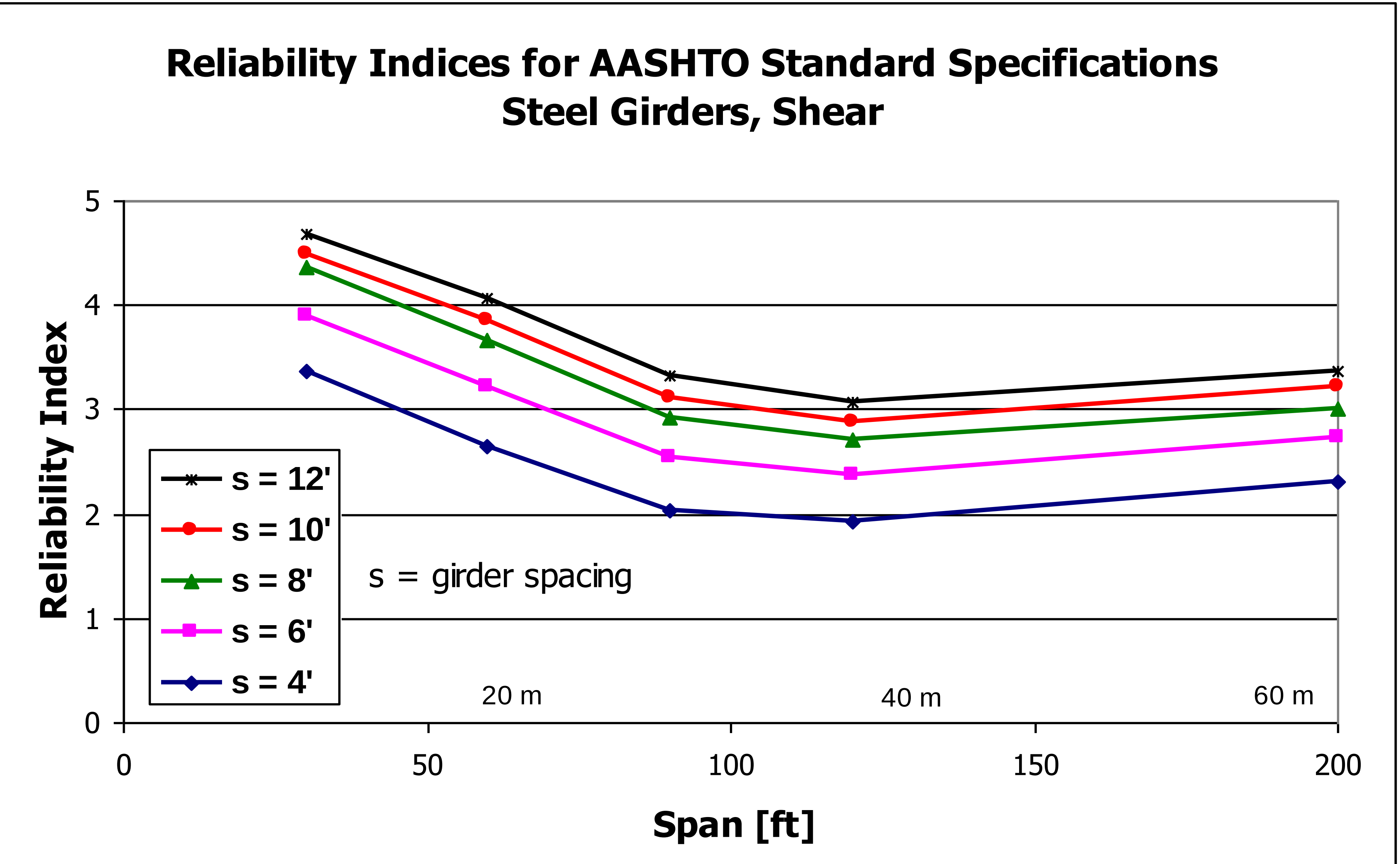

Reliability Indices for AASHTO Standard Specifications
Composite Steel Girders, Moment
Reliability Index
Span [ft]
0
1
2
3
4
5
0
50
100
150
200
20 m
40 m
60 m
s = girder spacing
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'



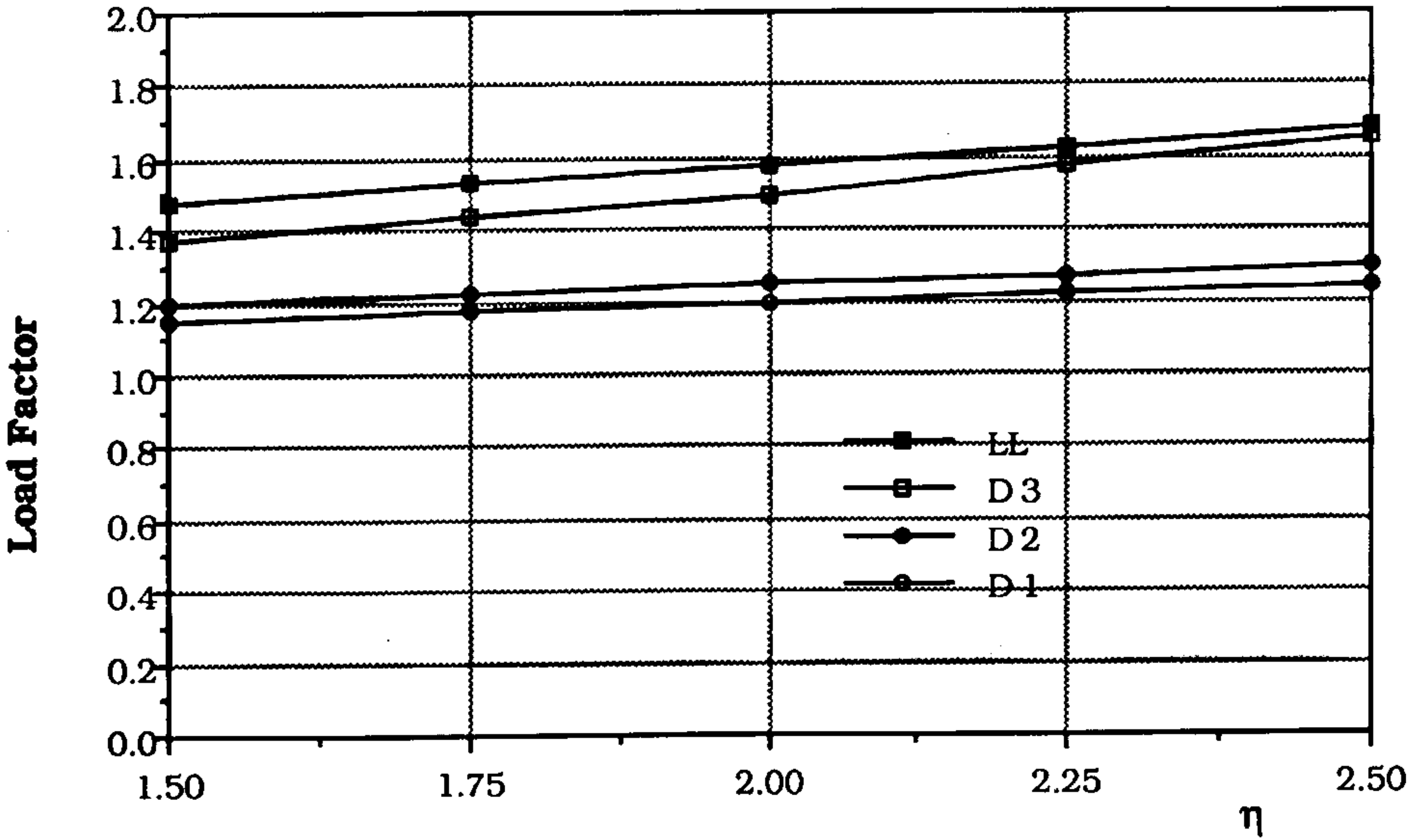
Reliability Indices for AASHTO Standard Specifications
Non-Composite Steel Girders, Moment
Reliability Index
Span [ft]
0
1
2
3
4
5
0
50
100
150
200
20 m
40 m
60 m
s = girder spacing
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'


Reliability Indices for AASHTO Standard Specifications
Prestressed Concrete Girders, Shear
Reliability Index
5
4
3
2
1
0
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'
s = girder spacing
20 m
40 m
60 m
0
50
100
150
200
Span [ft]


Reliability Indices for AASHTO Standard Specifications
R/C T-Beams, Shear
Reliability Index
Span [ft]
s = girder spacing
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'
20 m
40 m
60 m
0
1
2
3
4
5
0
50
100
150
200


Reliability Indices for AASHTO Standard Specifications
Steel Girders, Shear
Reliability Index
5
4
3
2
1
0
0
50
100
150
200
20 m
40 m
60 m
Span [ft]
s = 12'
s = 10'
s = 8'
s = 6'
s = 4'
s = girder spacing

LOAD FACTORS



Load and Resistance Factor Design (AASHTO LRFD Code)

$$1.25\,D + 1.75\,L\,(1 + I) \leq \phi\,R$$

where: D = moment due to dead load

L = moment due to live load

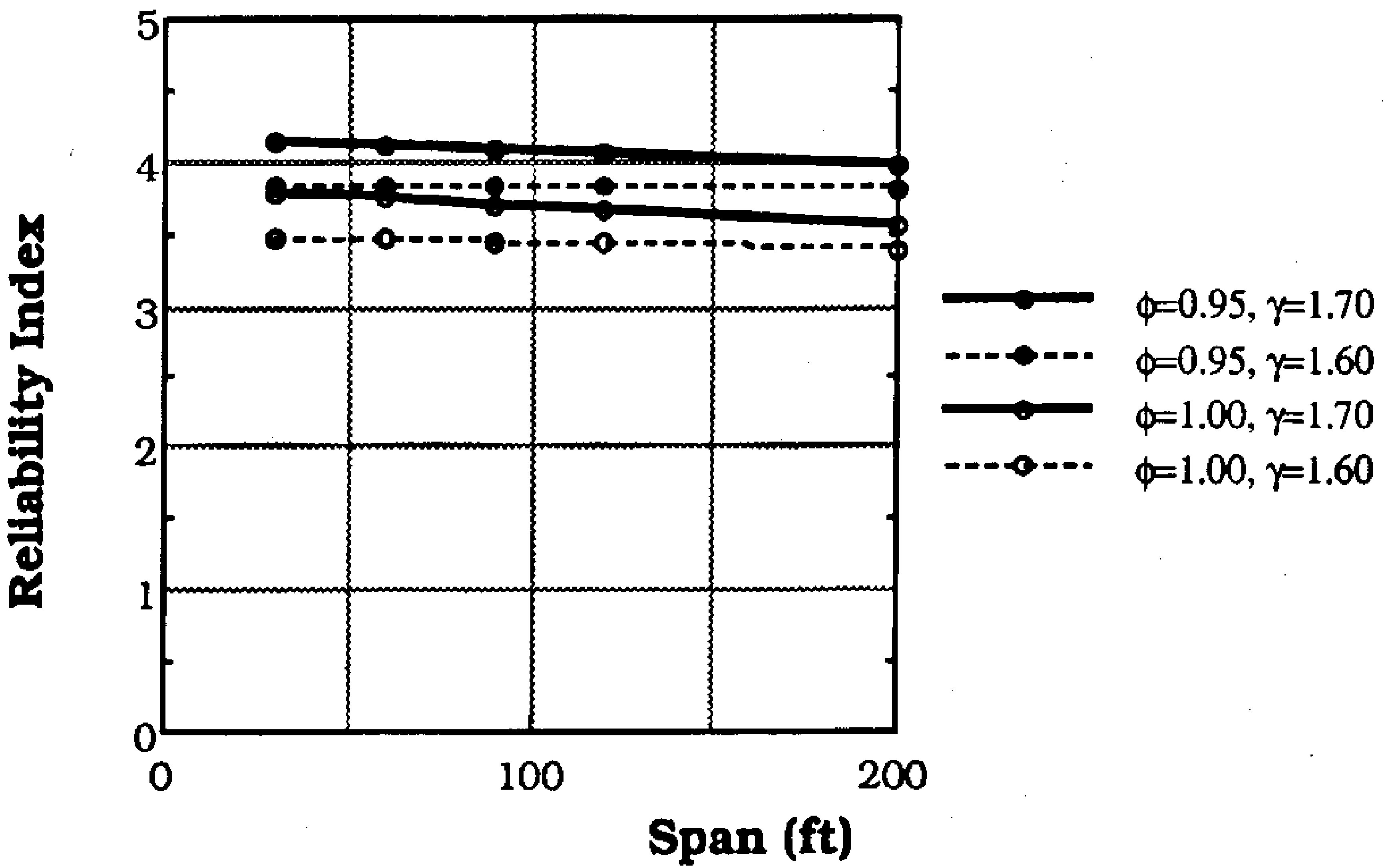
I = dynamic load factor

R = moment carrying capacity

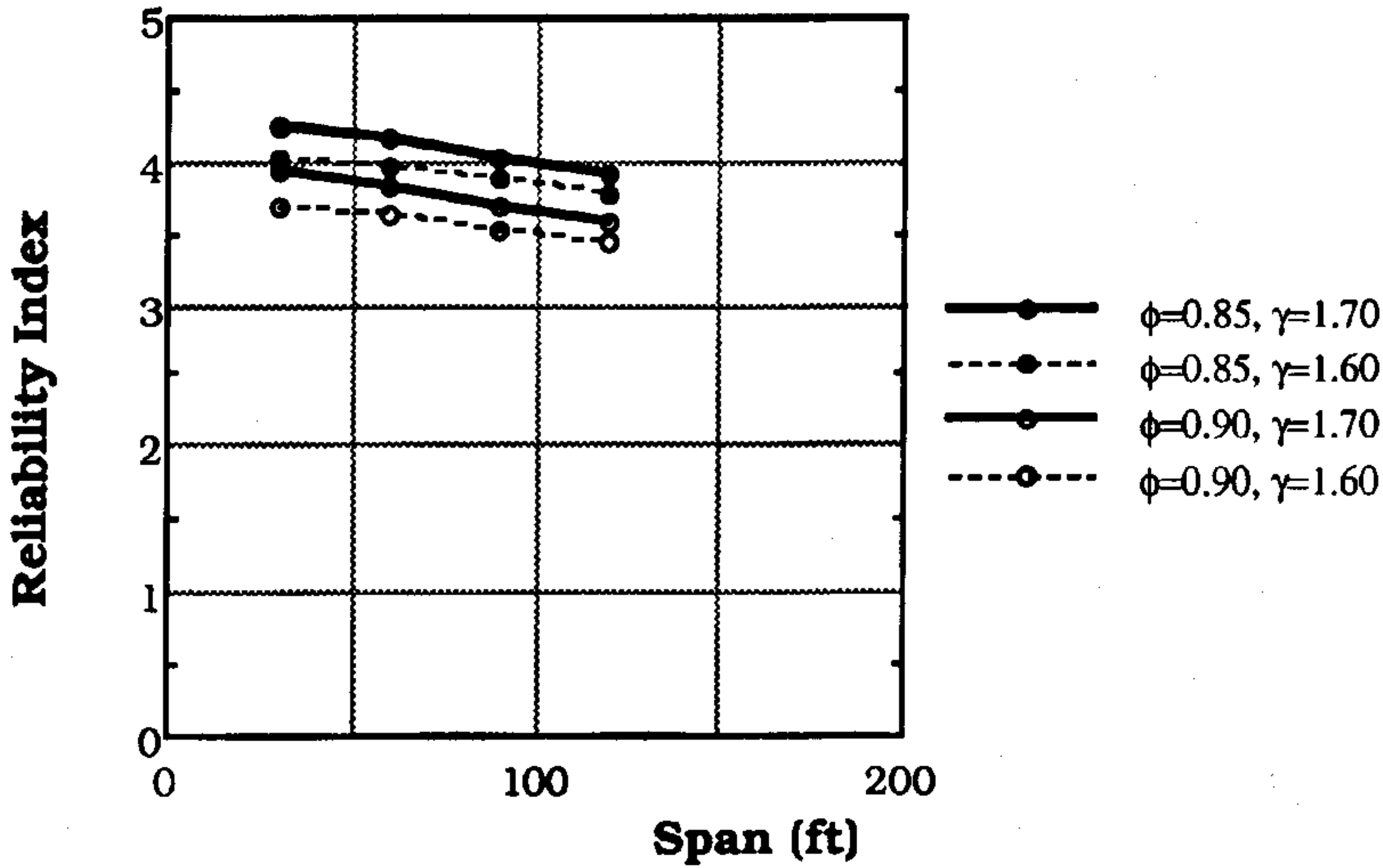
ϕ = resistance factor

Load and resistance factors are determined in the calibration process

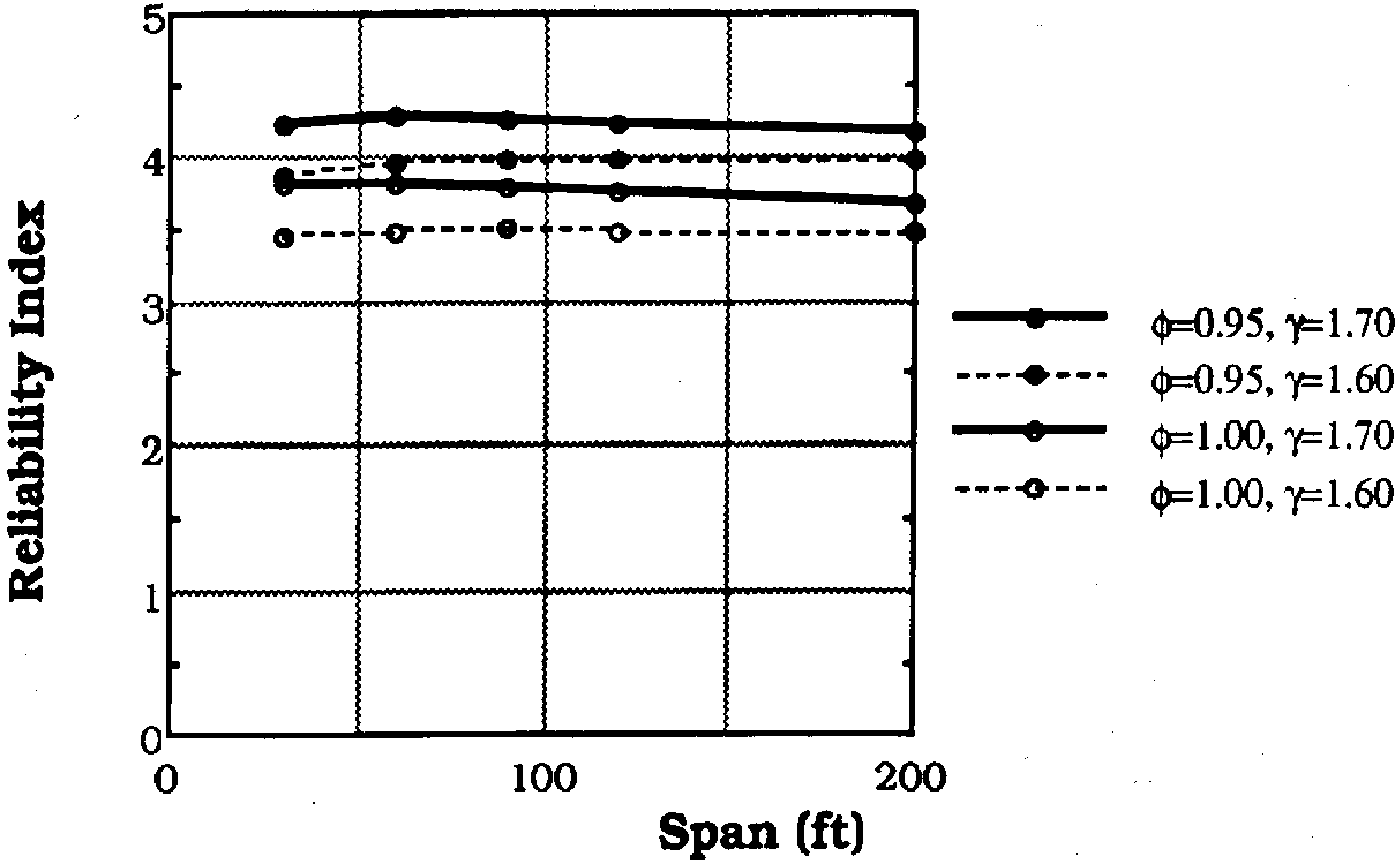
Reliability Indices for AASHTO LRFD (1998), Steel Girders, moment



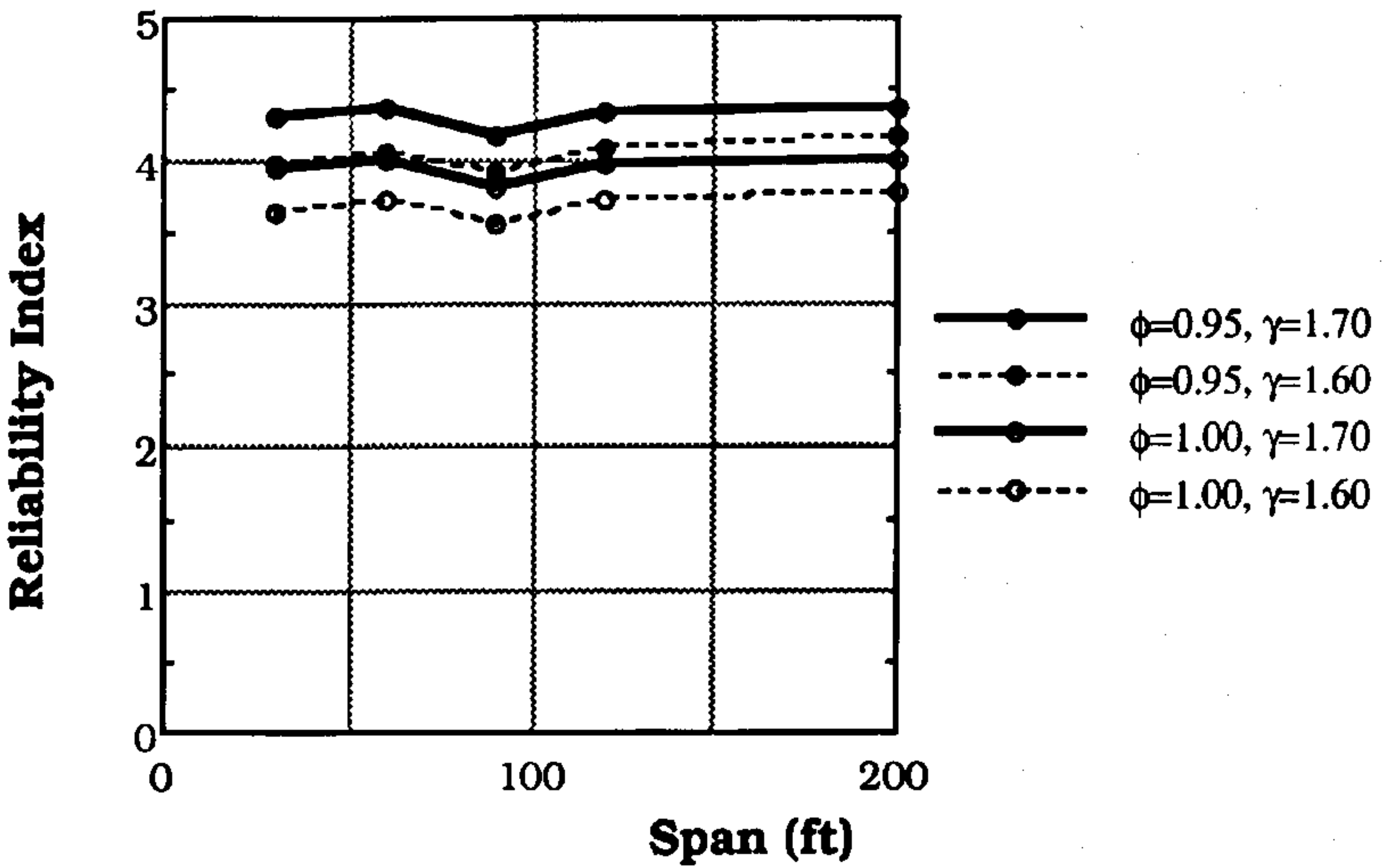
Reliability Indices for AASHTO LRFD (1998), R/C T-Beams, moment



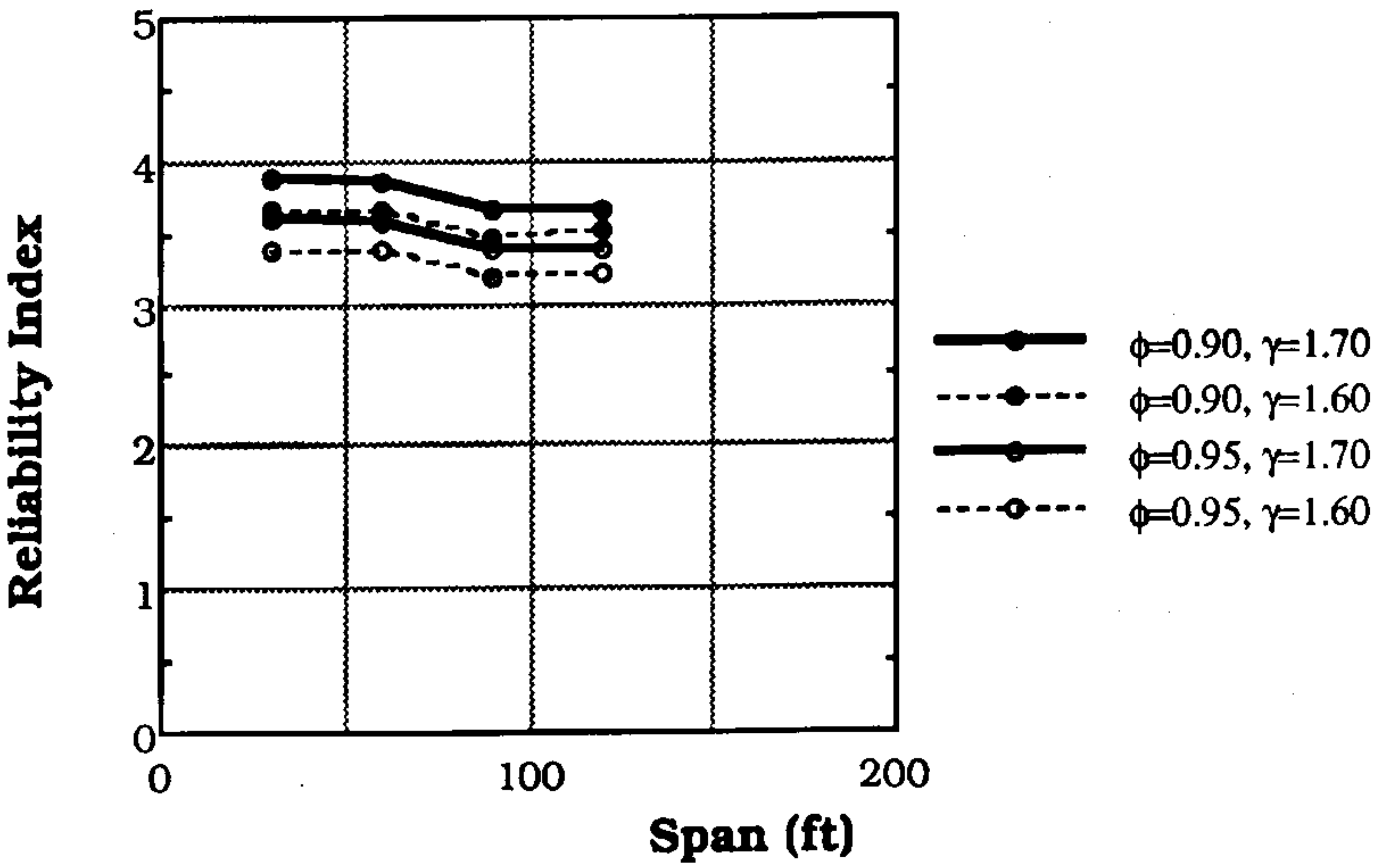
Reliability Indices for AASHTO LRFD (1998), Prestressed Concrete Girders, moment



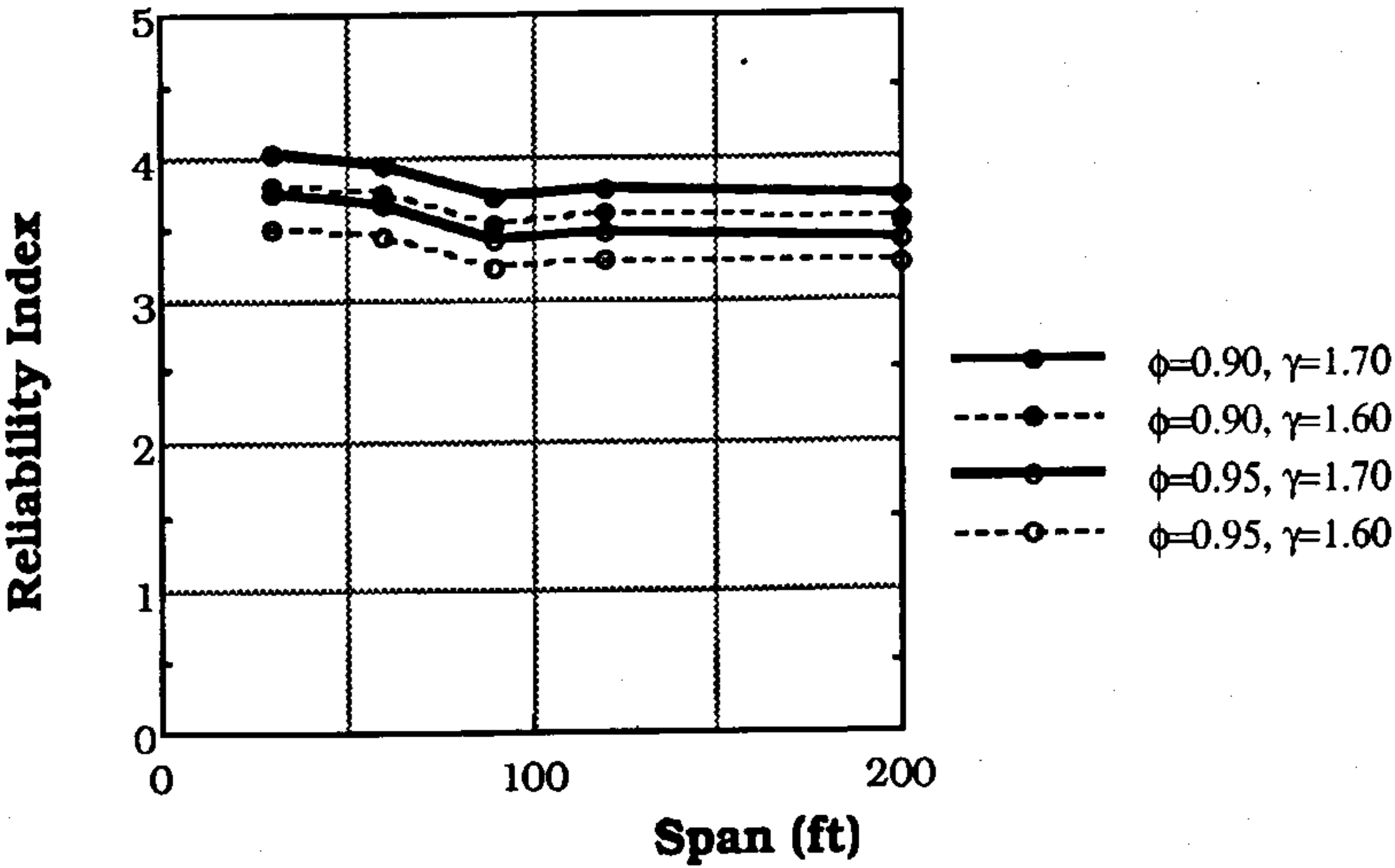
Reliability Indices for AASHTO LRFD (1998), Steel Girders, shear



Reliability Indices for AASHTO LRFD (1998), R/C T-Beams, shear

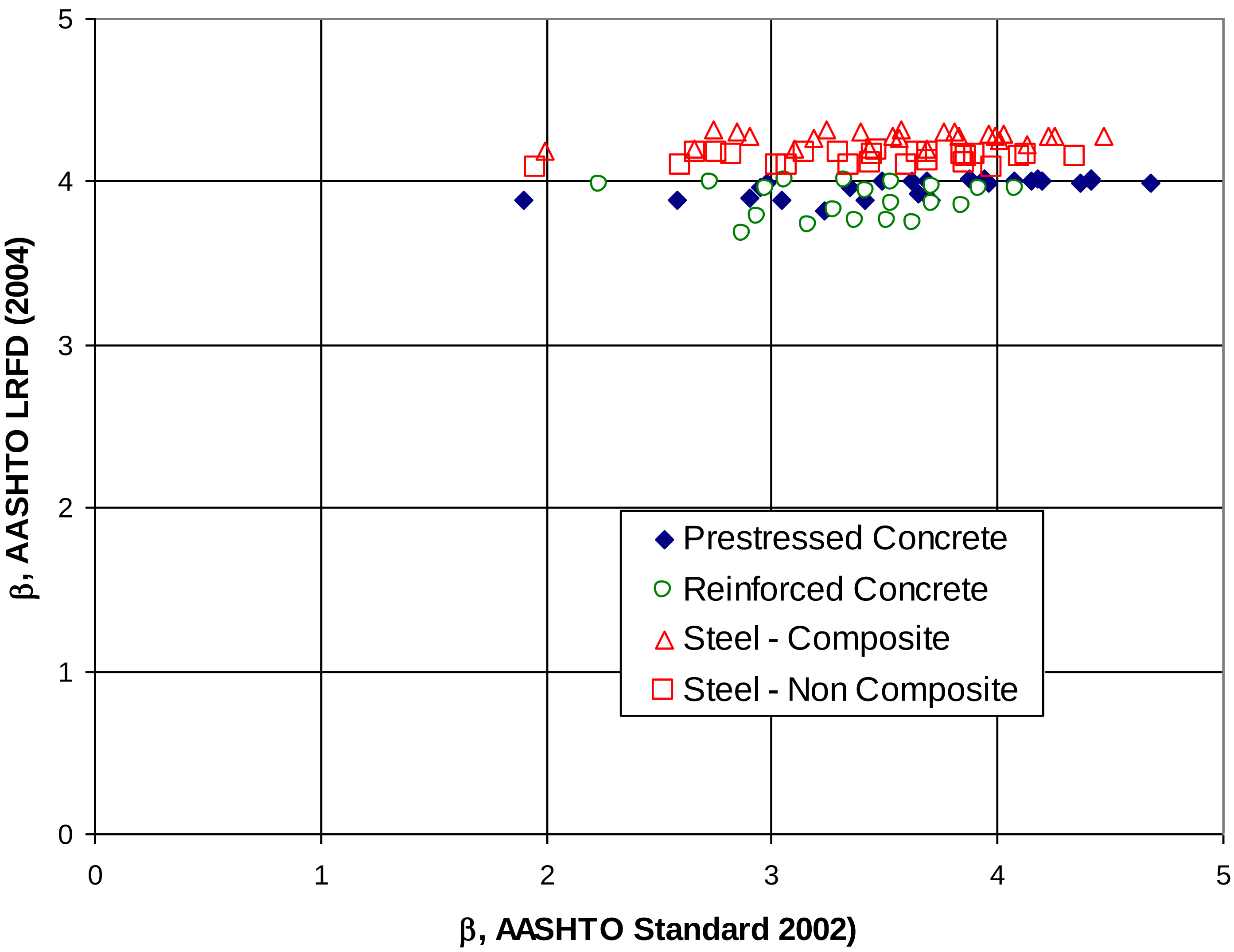


Reliability Indices for AASHTO LRFD (1998), Prestressed Concrete Girders, shear

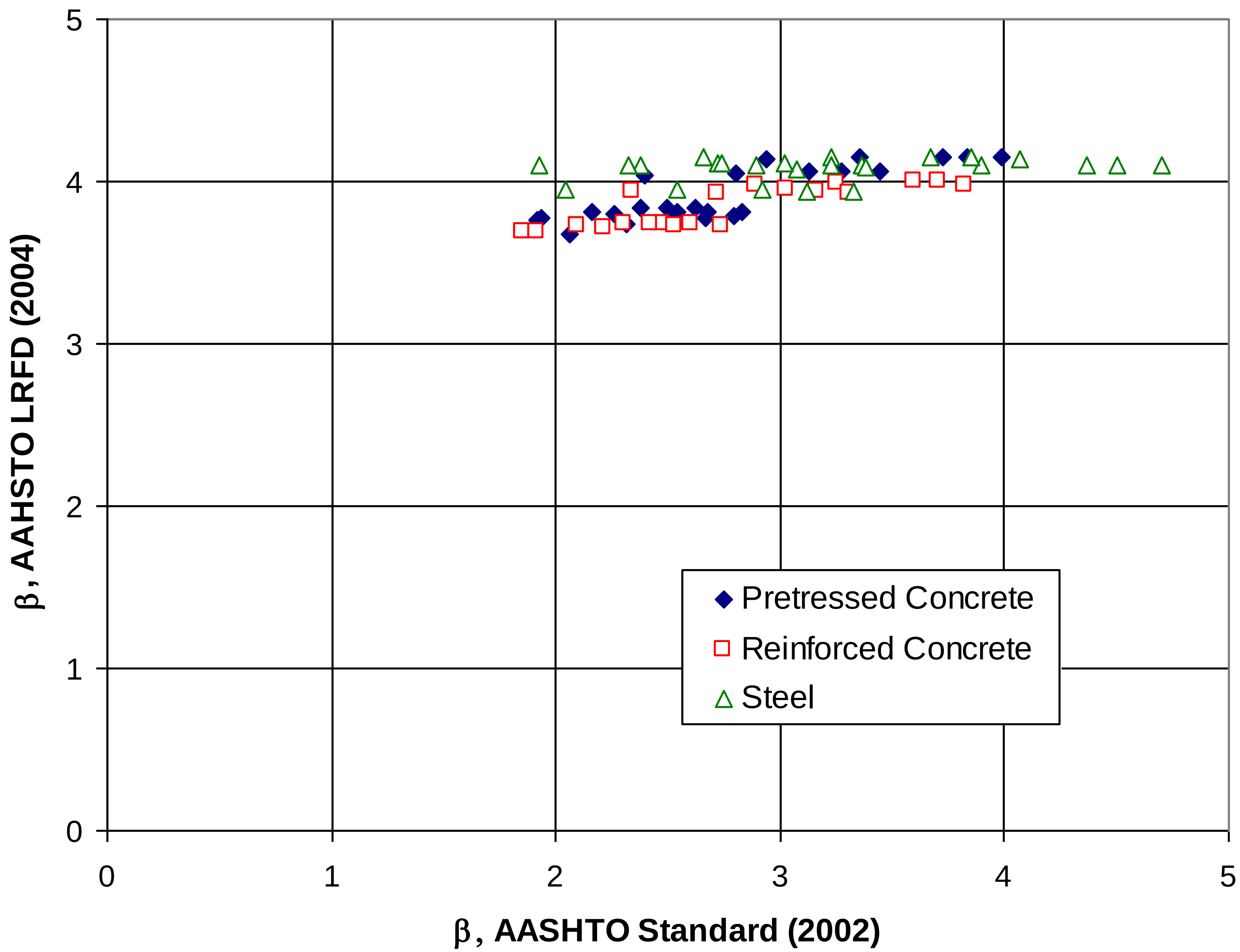


Effect of Code Calibration

- Prior to calibration, there is a considerable spread of reliability indices
- After calibration, the reliability indices are close to the target value
- Example is calibration of the AASHTO code for highway bridges



Reliability Indices for AASHTO (2002) and AAHSTO LRFD (2004) - Moment



Reliability Index for AASHTO (2002) and AASHTO LRFD (2004) -Shear

Conclusions

- Limit state design or LRFD codes provide for a consistent reliability level
- The format is flexible, and it can be used for new structural types, new materials
- Improved quality can be reflected in increased resistance factors and reduced load factors