AUBURN UNIVERSITY

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PROPOSED RE-CALIBRATION OF AASHTO LRFD SPECIFICATIONS

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Calibration of Design Code

- Bridges have to be designed with an adequate safety margin
- In LRFD Specifications safety is represented by load and resistance factors
- Code calibration is selection of load and resistance factors so that safety is at an acceptable level

Three Important Questions in Code Calibration

- How to measure safety?
- What is acceptable safety level?
- How to select load and resistance factors so that safety is at acceptable level?

What is needed?

- Statistical parameters of load
- Statistical parameters of resistance
- Reliability analysis procedure to calculate the Reliability Index
- Target Reliability Index

Statistical Parameters

- **Mean value**
- **λ = Bias factor = mean/nominal**
- **σ = Standard deviation**
- **V = Coefficient of variation = σ/mean**
- **Type of distribution function**

Calibration of AASHTO LRFD 1994

- Live load parameters based on Ontario truck survey in 1977
- Resistance parameters (concrete, reinforcing steel, prestressing strands, structural steel) based on test results in 1970's
- Reliability analysis procedure based on techniques from 1980's

What is new?

- Over 200 million Weigh-in-Motion (WIM) records of trucks (national data base)
- New material test results (ordinary concrete, light-weight concrete, rebars, prestressing strands, structural steel)
- Simulation techniques (Monte Carlo)
- More efficient reliability analysis procedure (reliability index and design point)

What is the effect of new data?

- Are current live loads different than Ontario data (1977)?
- Are new statistical parameters of resistance different than in 1970’s?
- Are target reliability indices in AASHTO Specifications adequate?
- Are load and resistance factors in AASHTO Specifications adequate?

What is the difference?

- A preliminary analysis of WIM data shows that the bias factor for live load is 5-10% larger than what was assumed in the original calibration, in particular for short spans
- A preliminary analysis of material strength test data shows that the load carrying capacity can be larger than previously assumed by 5-10%

Need for Re-Calibration

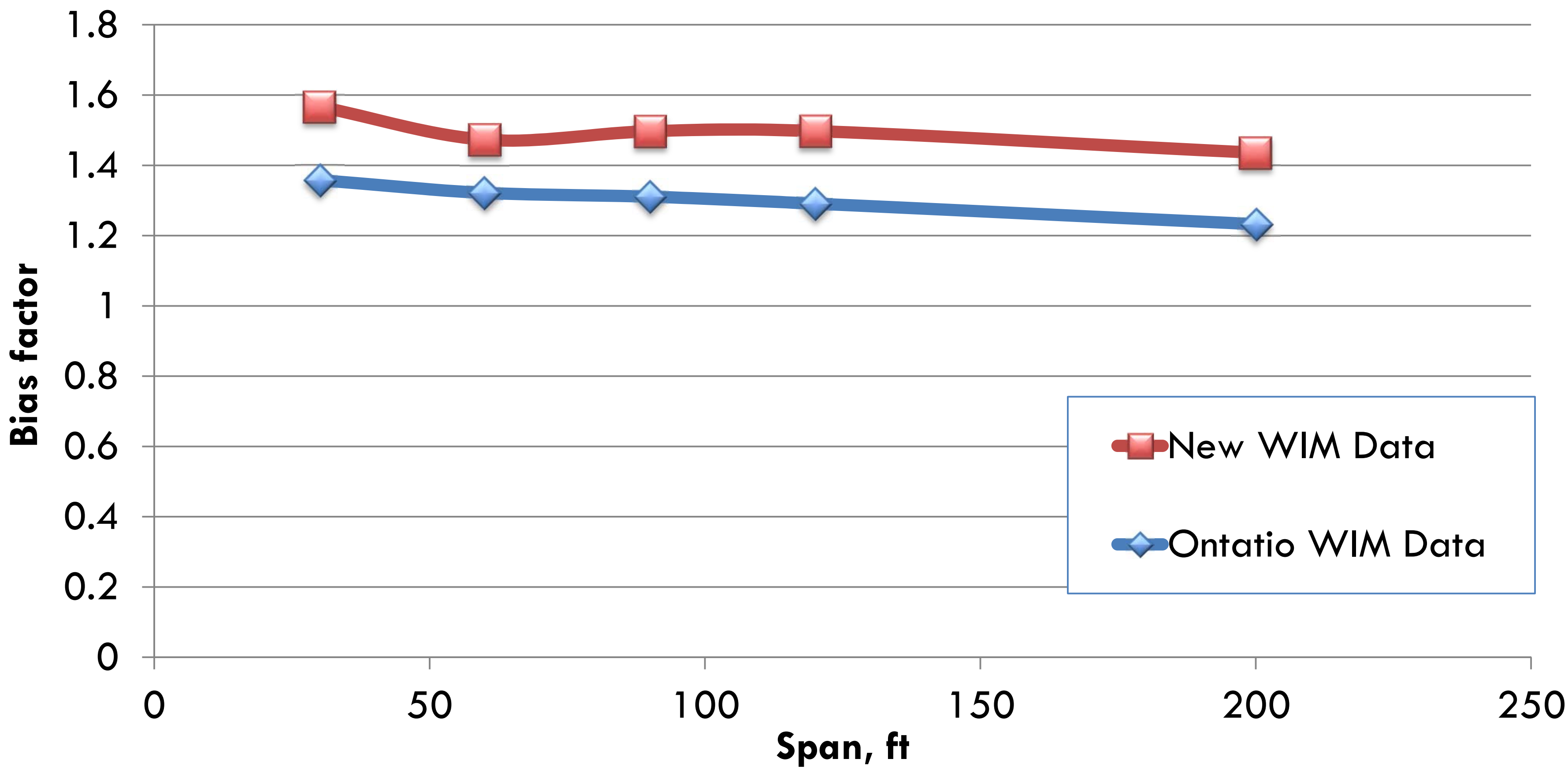
- Revise the statistical parameters of load and resistance
- Select the target reliability index
- Calculate load and resistance factors as coordinates of the "design point"
- Compare with the current load and resistance factors and if needed, make recommendation for changes in AASHTO

Expected Results

- **Design point analysis can result in lower load and resistance factors**
- **Live load factor can be increased because of increase in live load**
- **Resistance factors can be increased because of increase in material strength, however, effect of quality of workmanship has to be assessed**

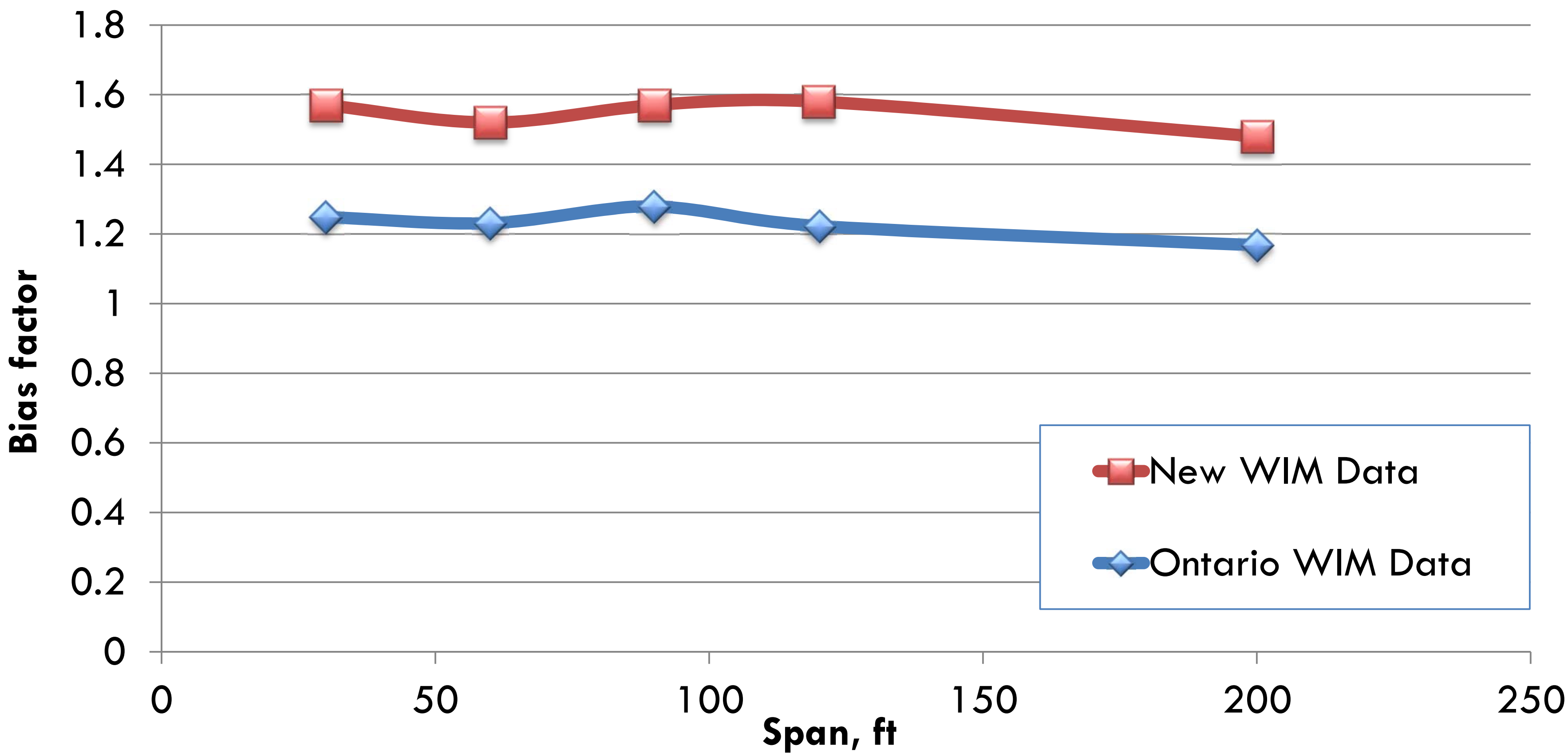
New vs. Old Live Load - Moment

Mean Maximum 75 year Moments for Simple Spans Due to Multiple Trucks in One Lane (Divided by Corresponding HL-93 Moment) – ADTT=1000



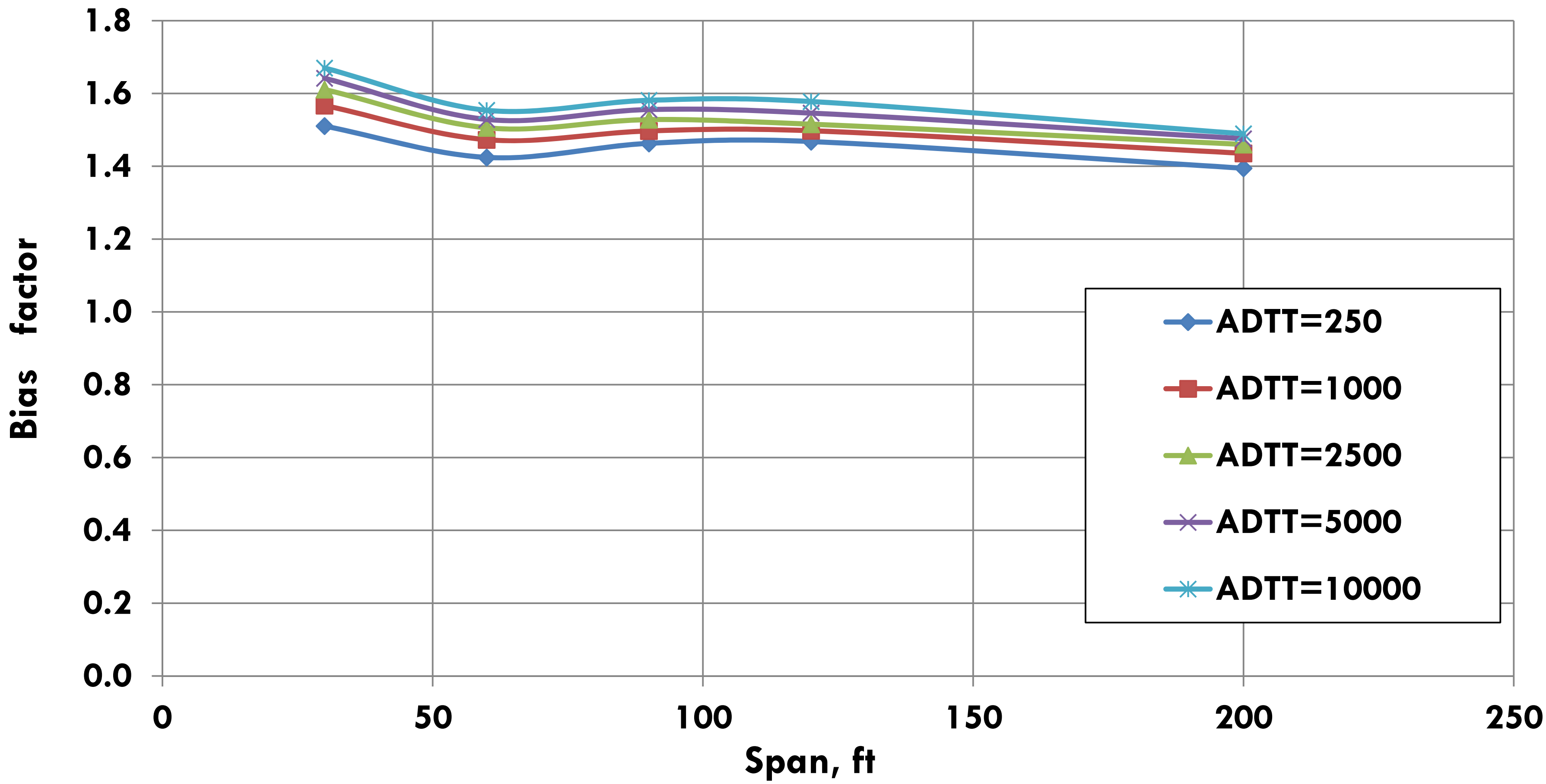
New vs. Old Live Load - Shear

Mean Maximum 75 year Shear Force for Simple Spans Due to Multiple Trucks in One Lane (Divided by Corresponding HL-93 Moment) – ADTT=1000



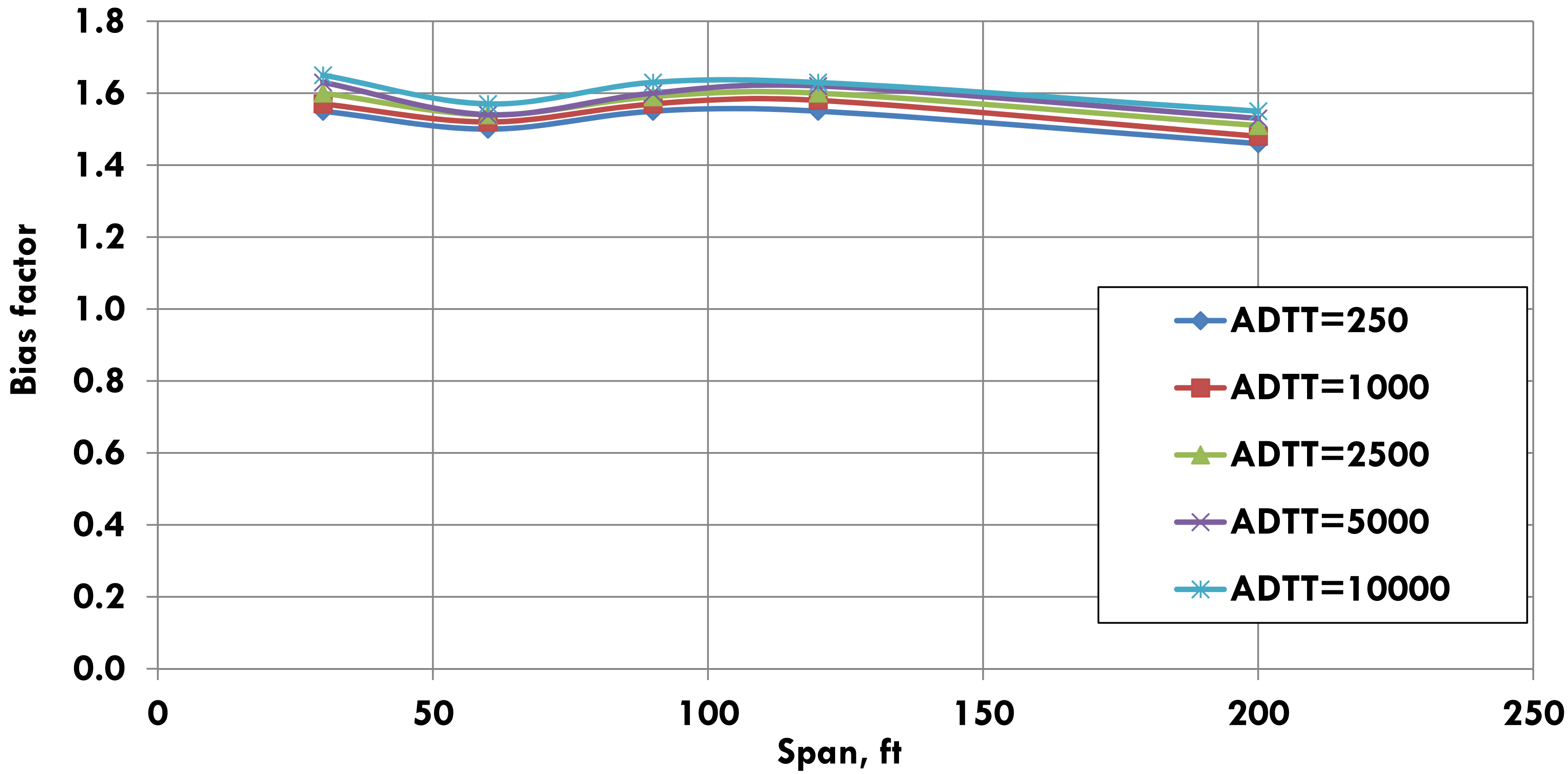
New Live Load – Moment ratios

Mean Maximum 75 year Moment Ratio for Simple Spans Due to Multiple Trucks in One Lane (Divided by Corresponding HL-93 Moment) – ADTT=250…10,000



New Live Load – Shear ratios

Mean Maximum 75 year Moment Ratio for Simple Spans Due to Multiple Trucks in One Lane (Divided by Corresponding HL-93 Shear) – ADTT=250…10,000



Parameters of Resistance

- **M = Material** : uncertainty in the strength of material, modulus of elasticity, cracking stresses, and chemical composition.

- **F = Fabrication** : uncertainty in the overall dimensions of the component which can affect the cross-section area, moment of inertia, and section modulus.

- **P = Analysis** : uncertainty resulting from approximate methods of analysis and idealized stress/strain distribution models.

Resistance (load carrying capacity)

$$R = R_n M F P$$

where :

R_n = nominal value of resistance

M = material factor

F = fabrication factor

P = professional factor

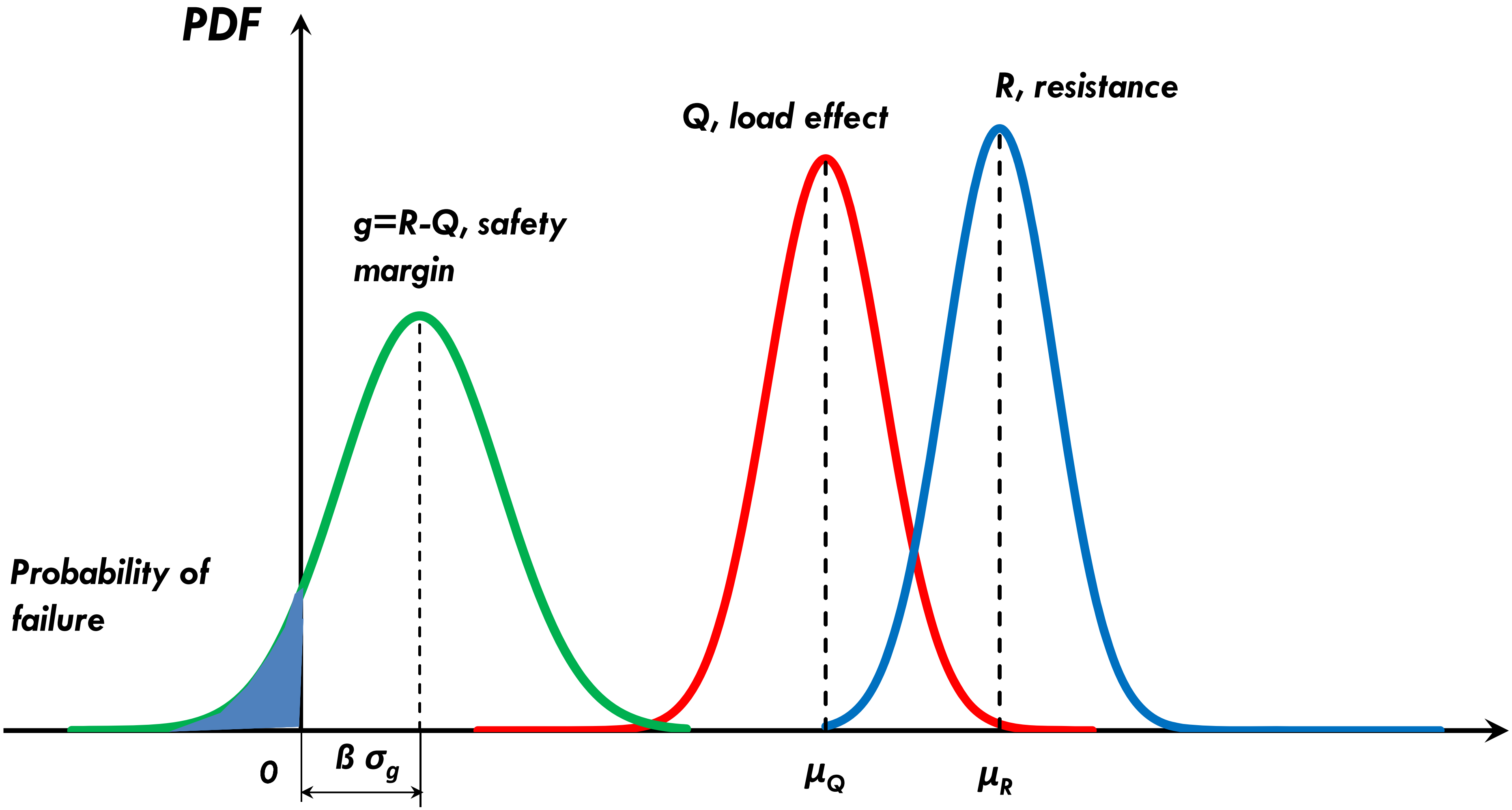
What is affected?

- Bias factor = ratio of mean-to-nominal
  - for f_c' = 1.10-1.30
  - for F_y = 1.12-1.14 (1.12)*
  - for F_{pu} = 1.02-1.04
- Coefficient of variation
  - for f_c' = 11-17% (15-18%)*
  - for F_y = 2-3% (10%)*
  - for F_{pu} = 1.5% (2.5%)*

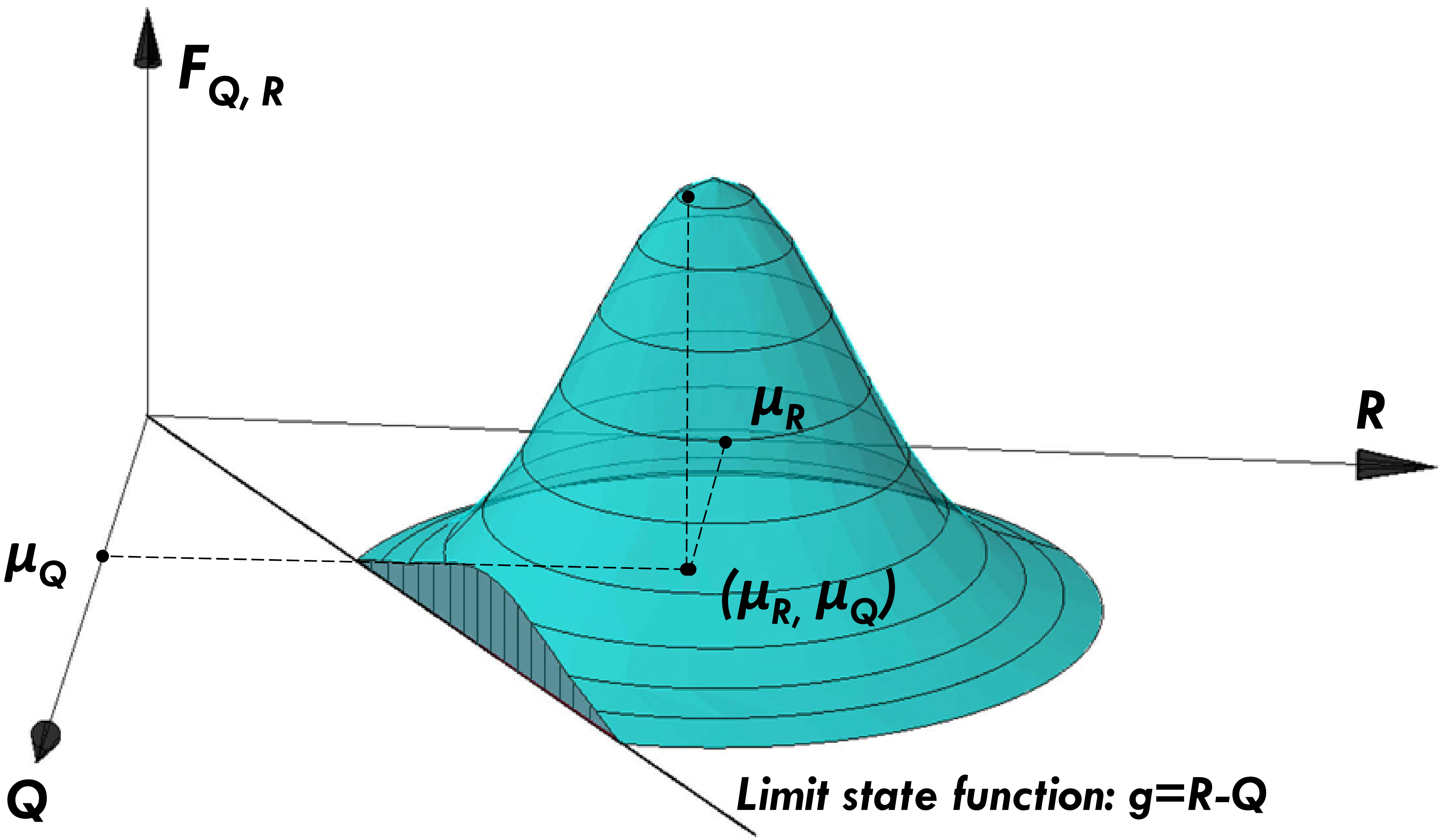
*NBS Report 577 (1980)

Probability of Failure and Reliability Index β

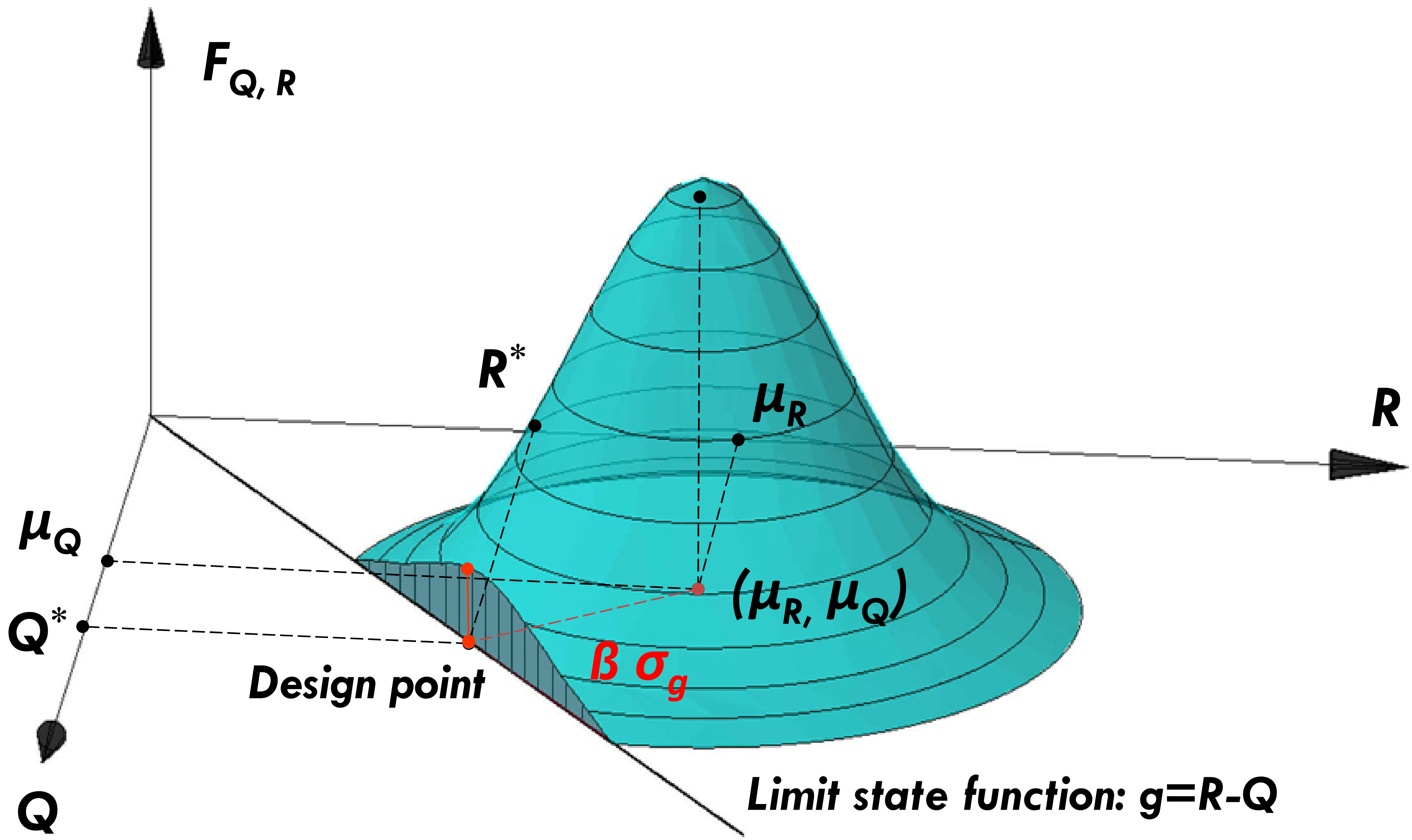
Q = load and R = resistance



Fundamental case



Fundamental case



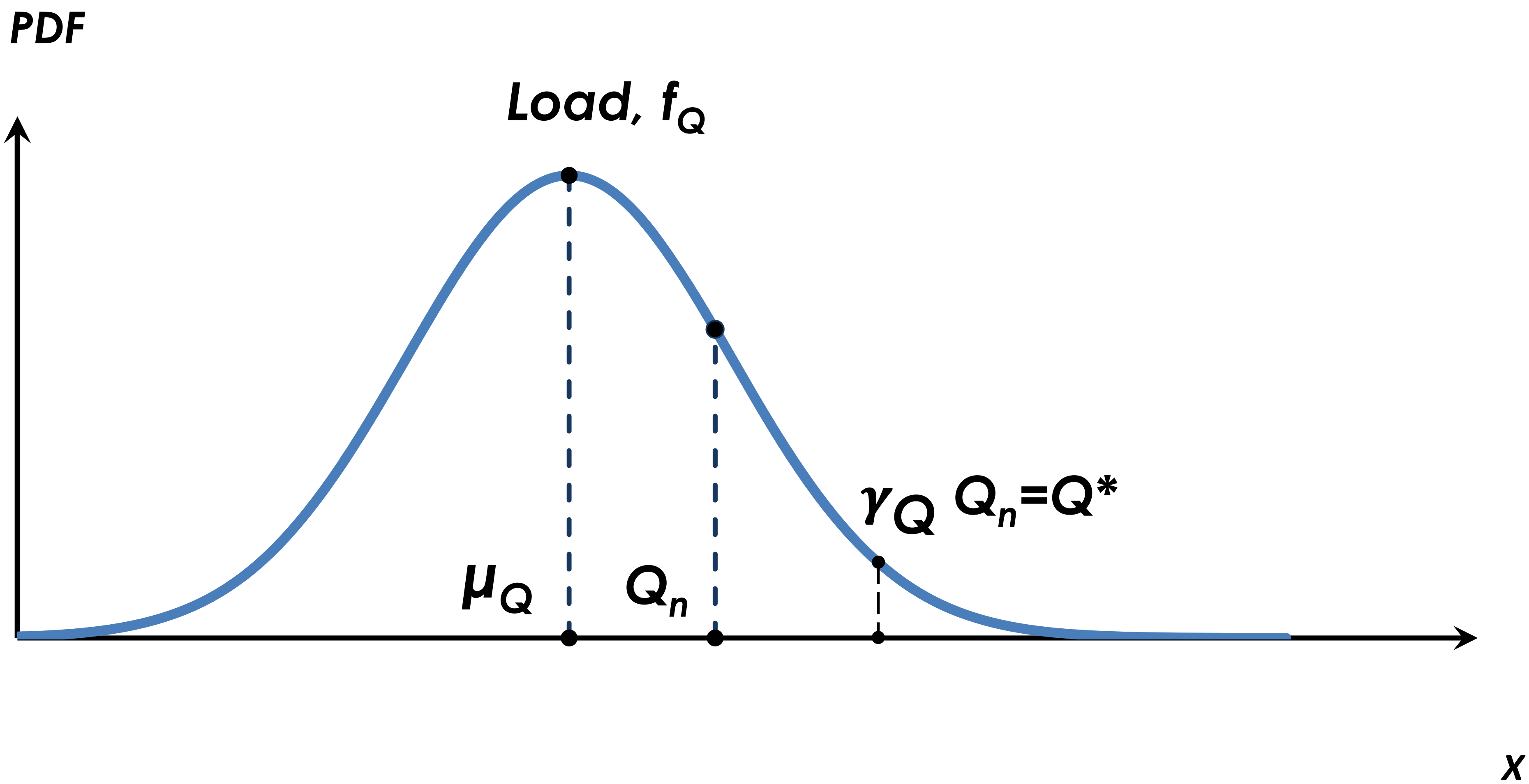
Reliability Index, β

If the limit state function $g = R - Q$, then

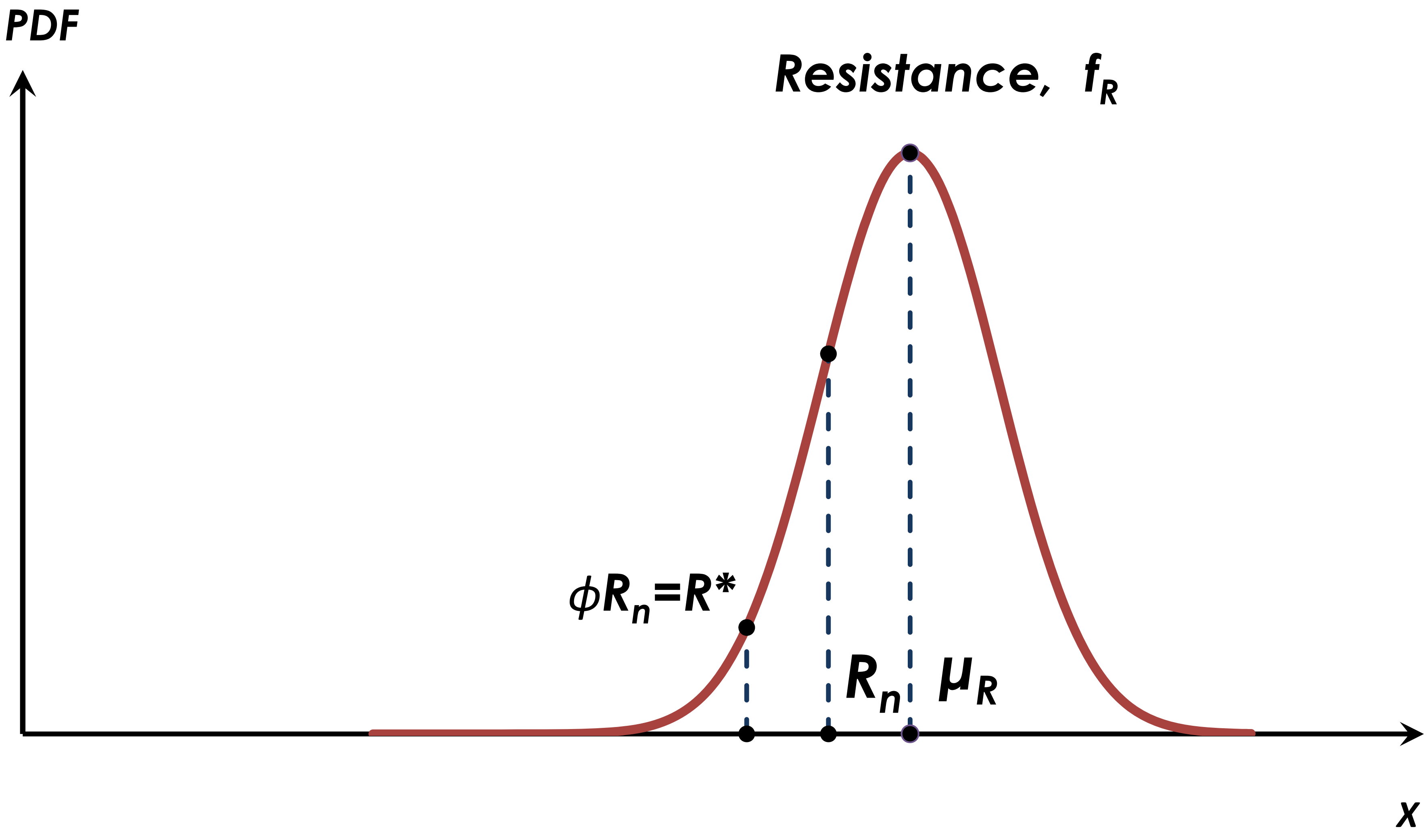
$$\beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

$\beta = -\Phi^{-1}(P_f)$ **or** $P_f = \Phi(-\beta)$

DESIGN POINT



DESIGN POINT



Design Point

The coordinate of the design point, R^*

$$R^* = \mu_R - \beta \frac{\sigma_R^2}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

μ_R = Mean value of resistance

σ_R = Standard deviation of resistance

σ_Q = Standard deviation of load

β = Reliability Index

Design Point

The coordinate of the design point, Q^*

$$Q^* = \mu_Q + \beta \frac{\sigma_Q^2}{\sqrt{\sigma_R^2 + \sigma_Q^2}}$$

μ_Q = Mean value of load

σ_R = Standard deviation of resistance

σ_Q = Standard deviation of load

β = Reliability Index

Load Factor as Design Point

Calculate load factor, γ_Q:

$$\gamma_Q = \frac{\lambda_Q Q^*}{\mu_Q}$$

$$\gamma_Q = \frac{Q^*}{Q_n}$$

Q_n = nominal value of Q

λ_Q = bias factor of Q *(ratio of mean to nominal)*

Q^* = coordinate of the design point for Q

μ_Q = mean value of Q

Resistance Factors as Design Point

Calculate resistance factor, φ

$$\varphi = \frac{\lambda_R R^*}{\mu_R}$$

$$\varphi = \frac{R^*}{R_n}$$

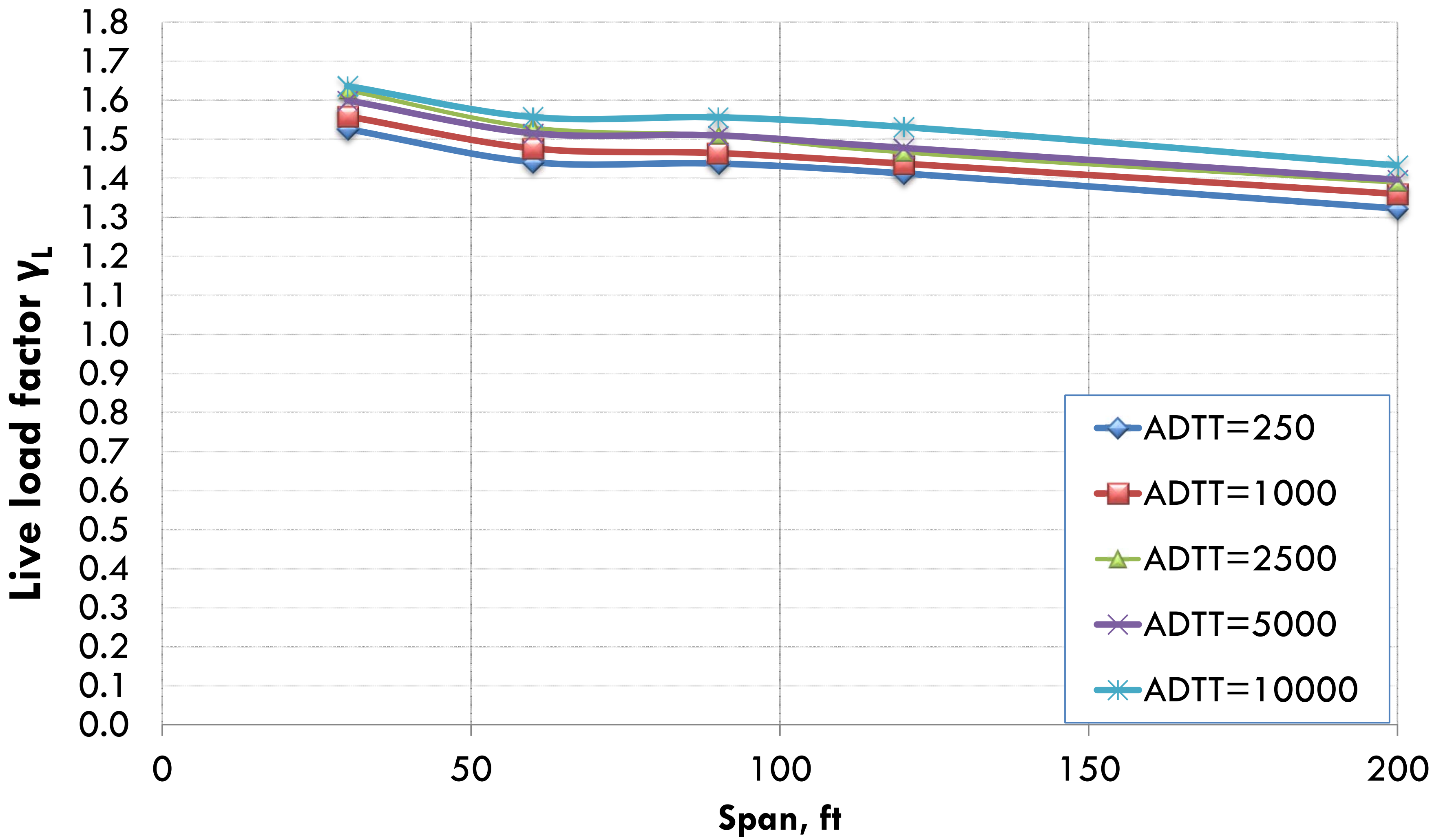
R_n = nominal value of R
λ_R = bias factor of R *(ratio of mean to nominal)*
R^* = coordinate of the design point for R
μ_R = mean value of R

Load Factors as Design Point

The dead load factors calculated are as follows:

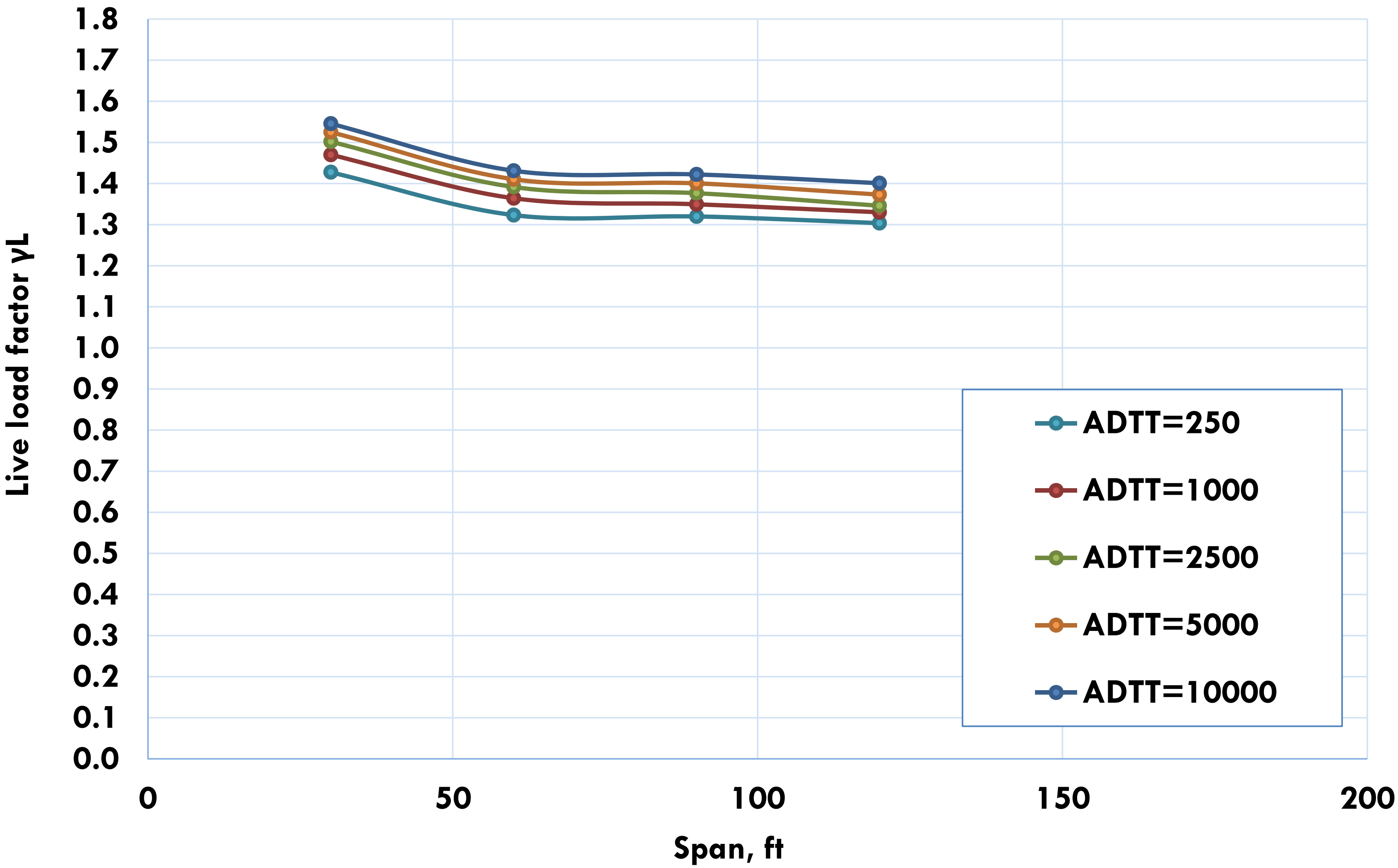
- **for precast** D_1, $\gamma_{D1} = 1.05–1.1$
- **for cast in place** D_2, $\gamma_{D2} = 1.10–1.17$
- **for wearing surface** D_w $\gamma_{Dw} = 1.03–1.1$

Live Load Factor as Design Point



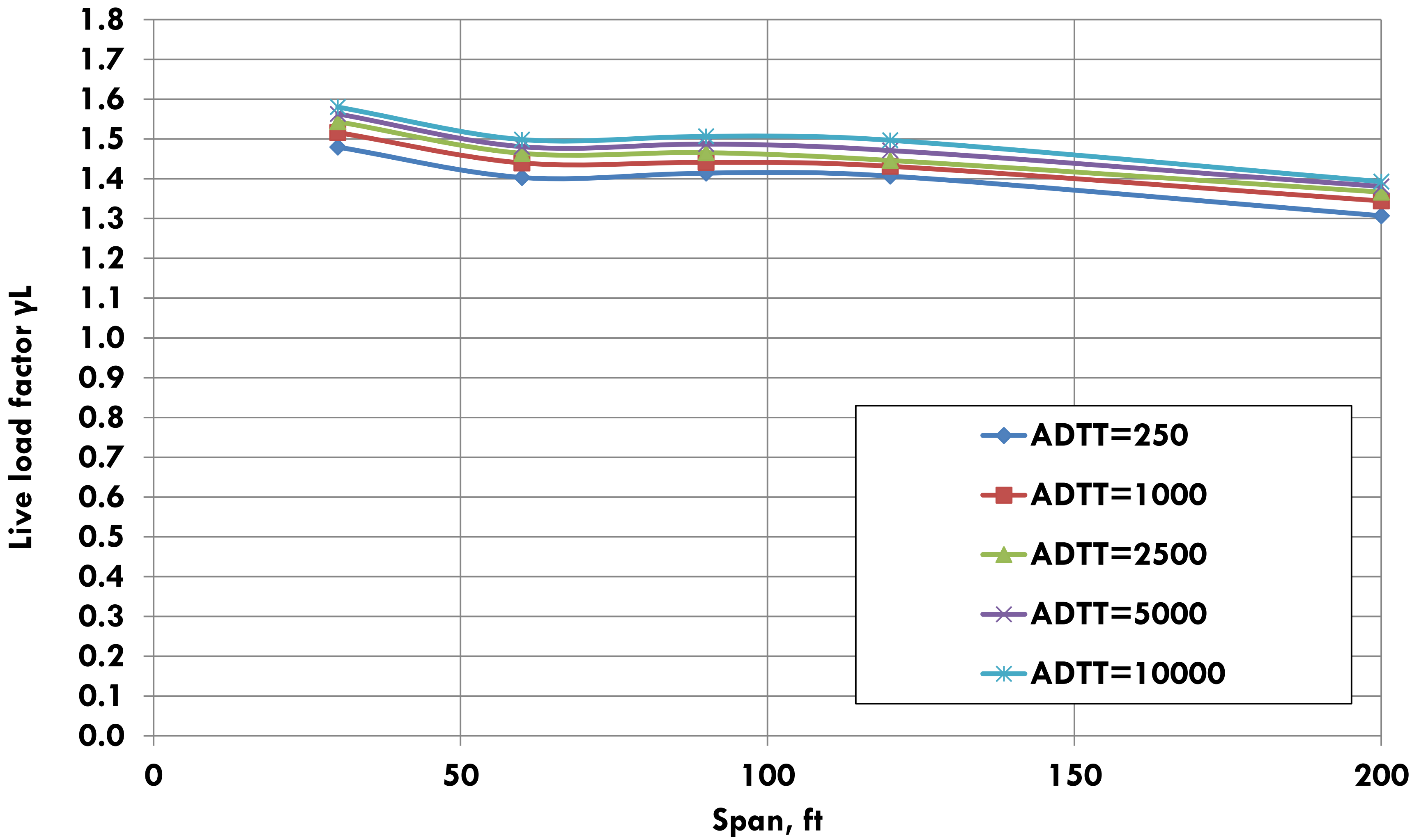
Moment for Prestressed Concrete Girders

Live Load Factor as Design Point



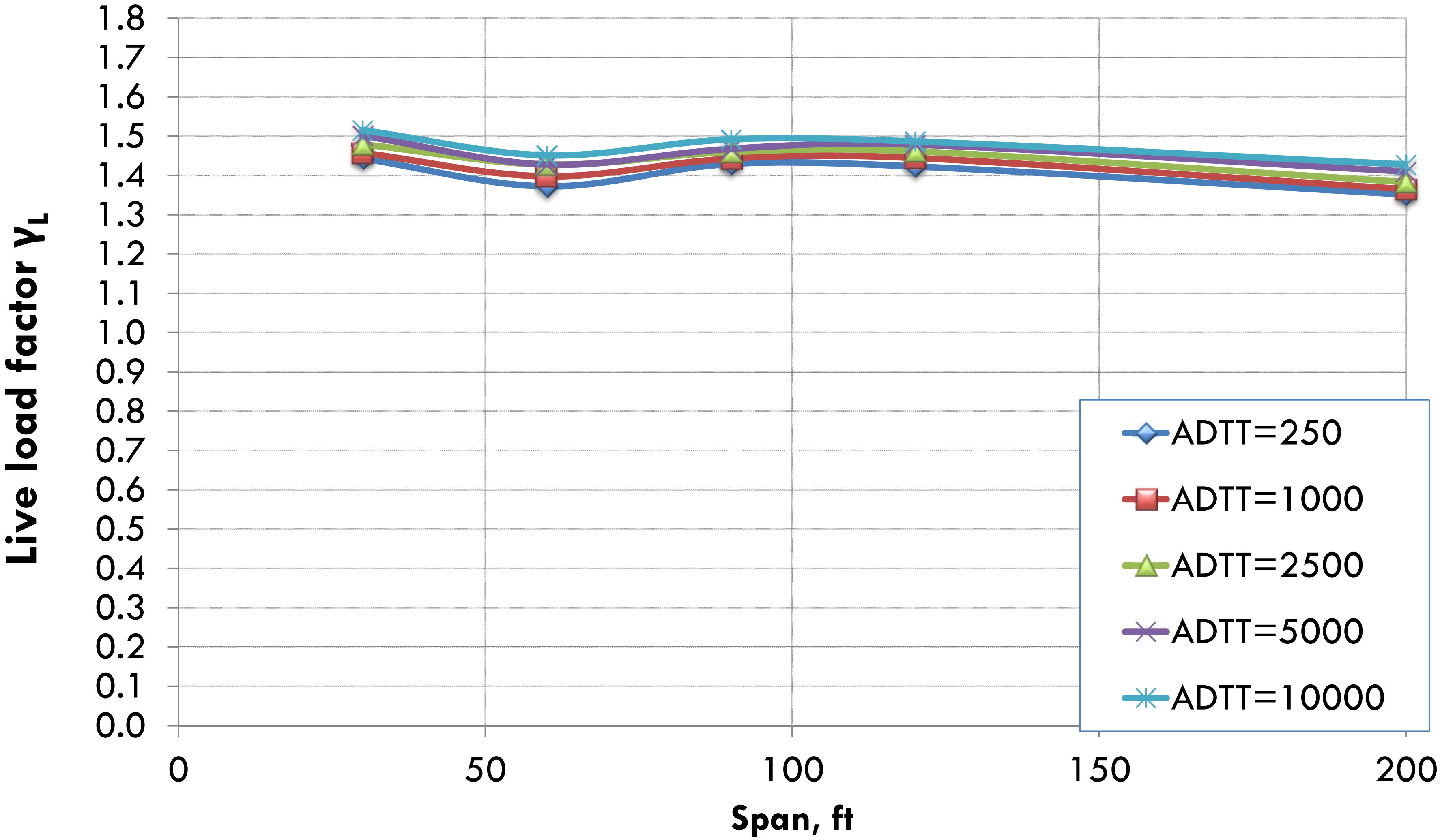
Moment for Reinforced Concrete T-Beams

Live Load Factor as Design Point



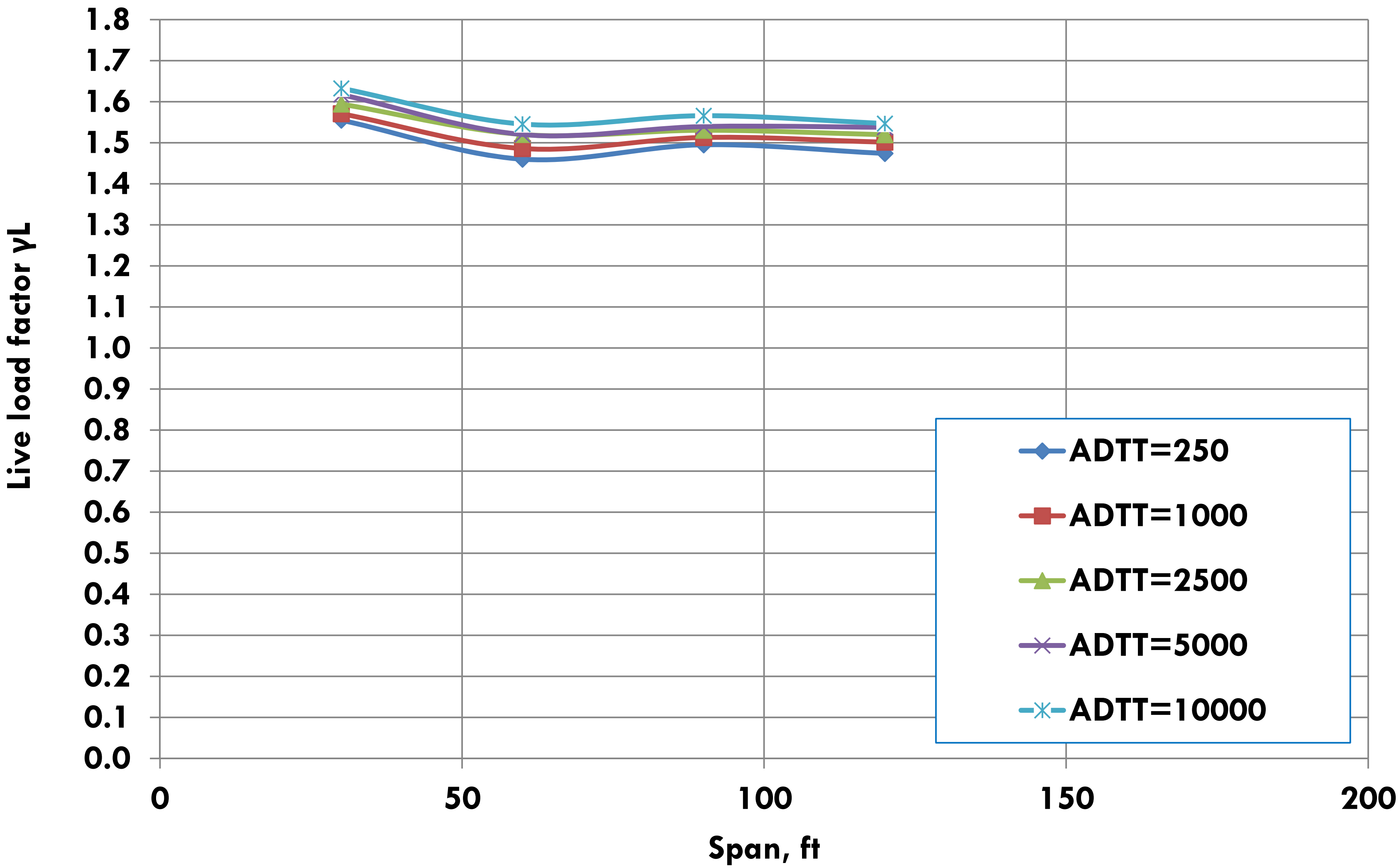
Moment for Steel Girders

Live Load Factor as Design Point



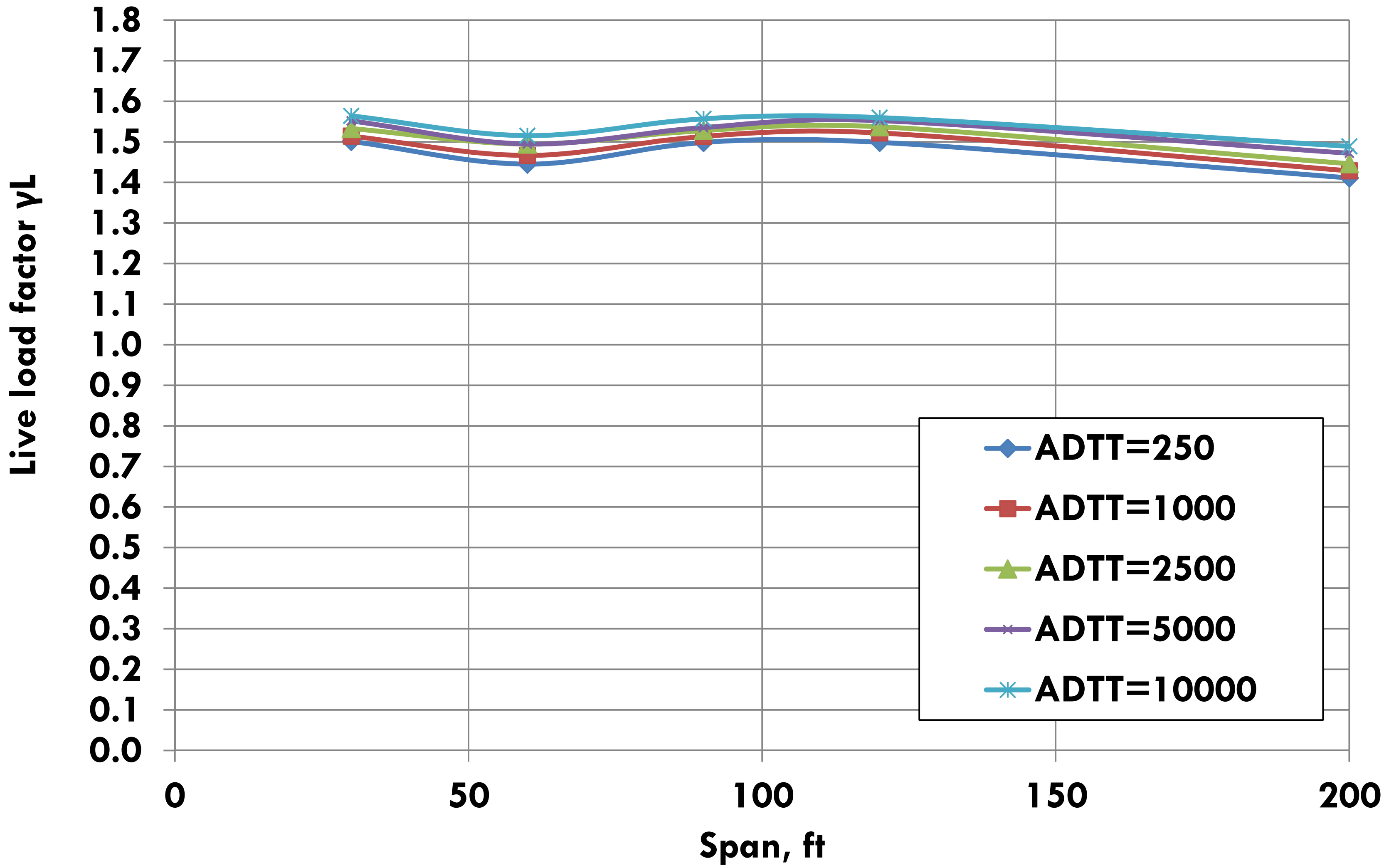
Shear for Prestressed Concrete Girders

Live Load Factor as Design Point



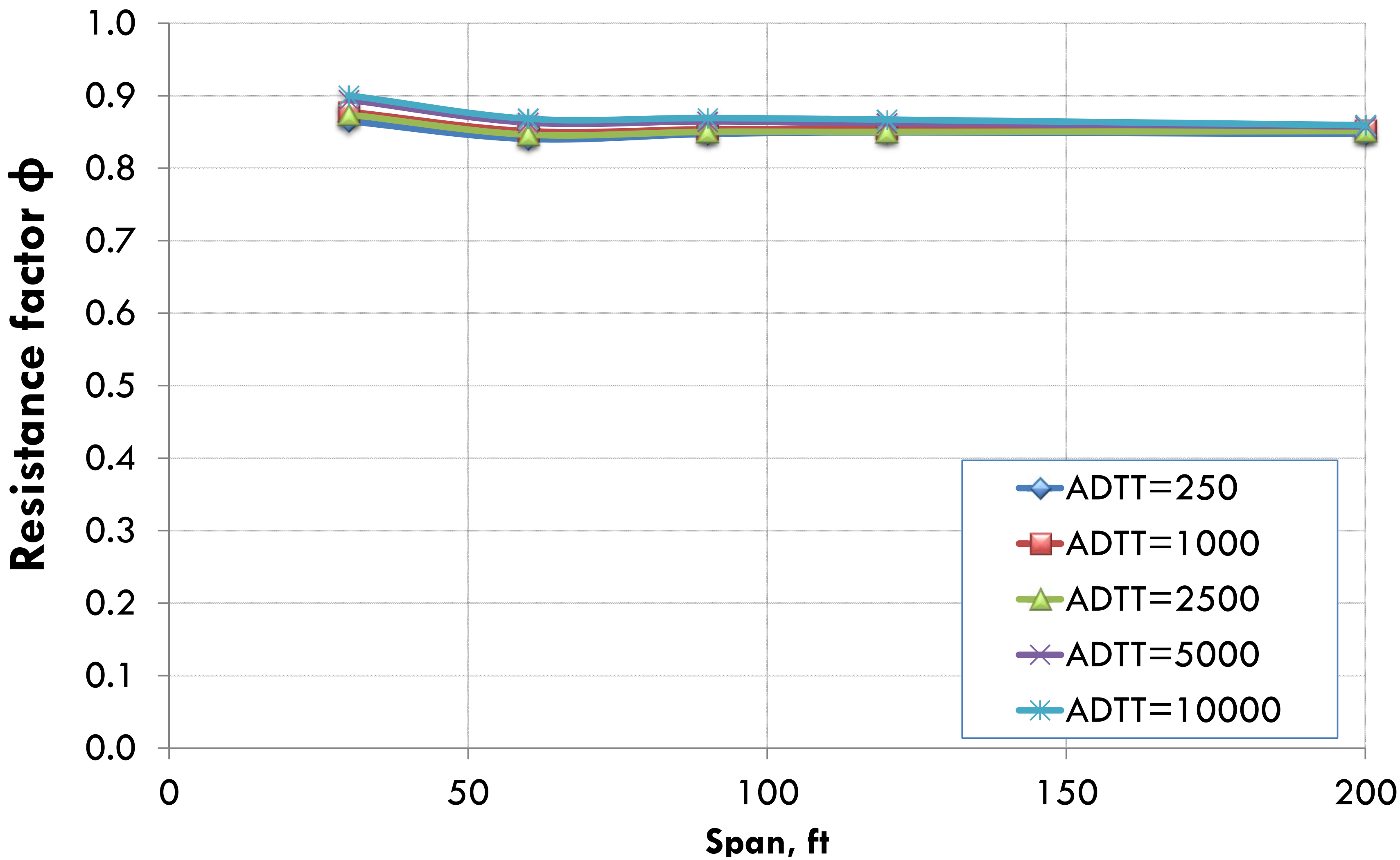
Shear for Reinforced Concrete T-Beams

Live Load Factor as Design Point



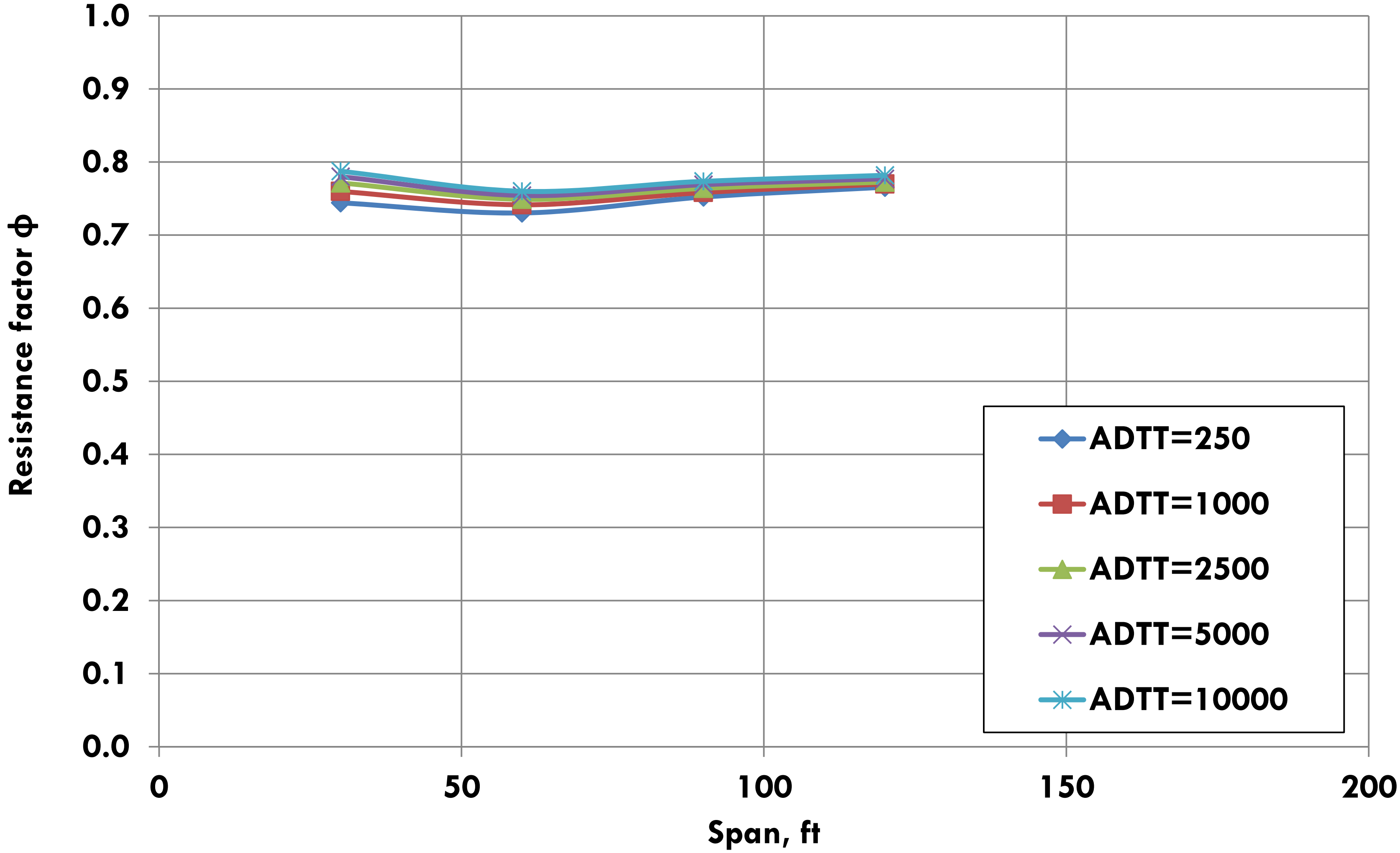
Shear for Steel Girders

Resistance Factor as Design Point



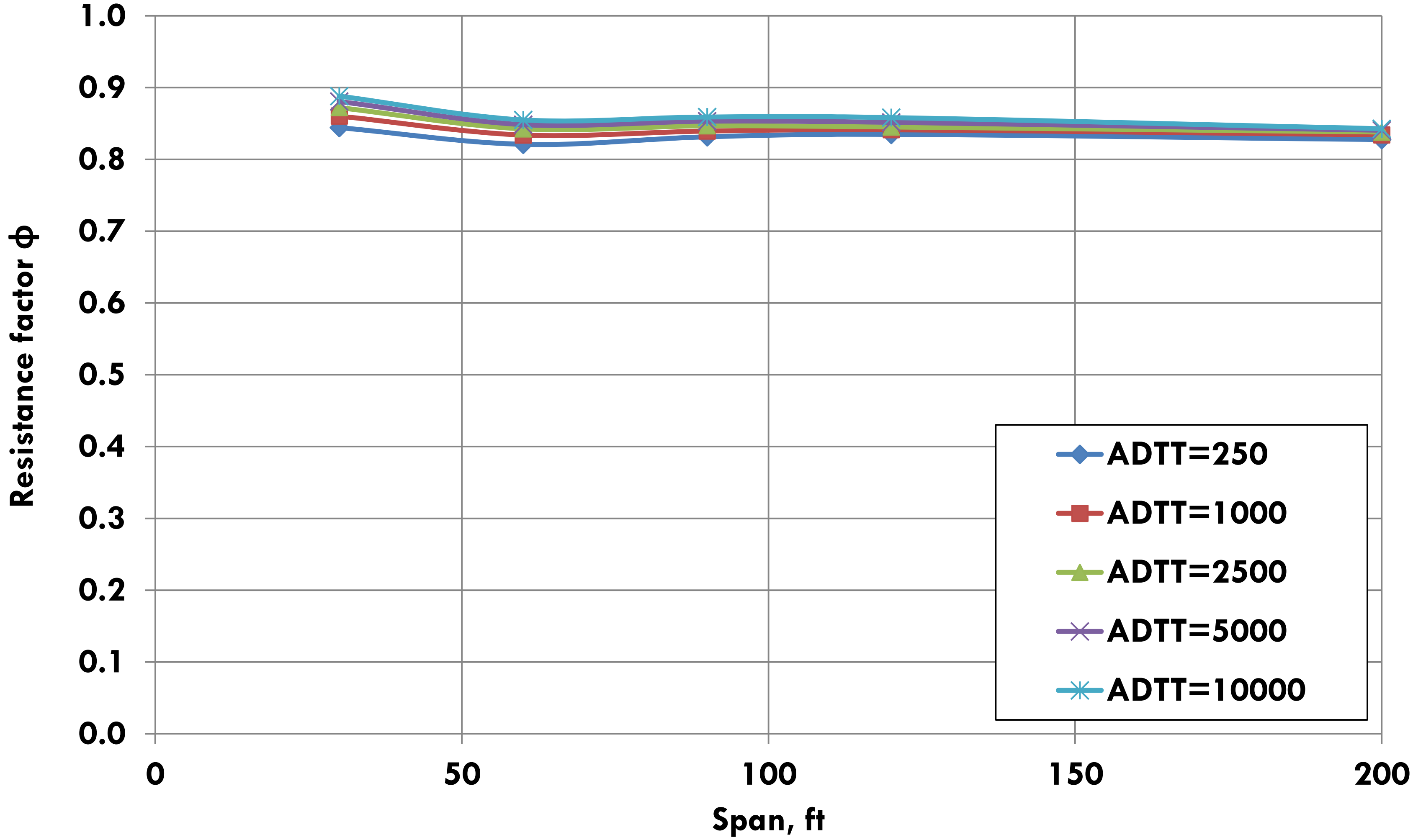
Moment for Prestressed Concrete Girders

Resistance Factor as Design Point



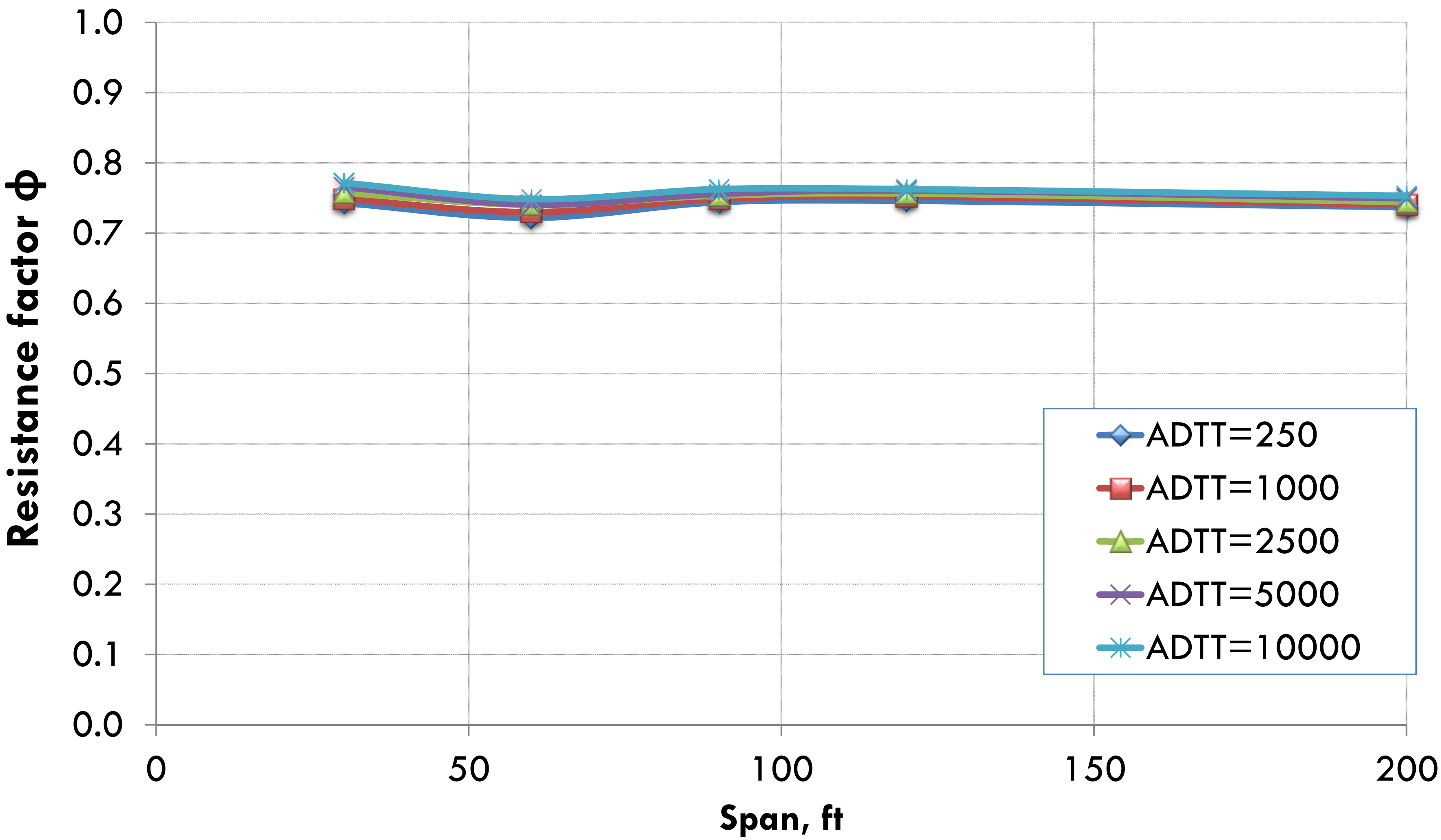
Moment for Reinforced Concrete T-Beams

Resistance Factor as Design Point



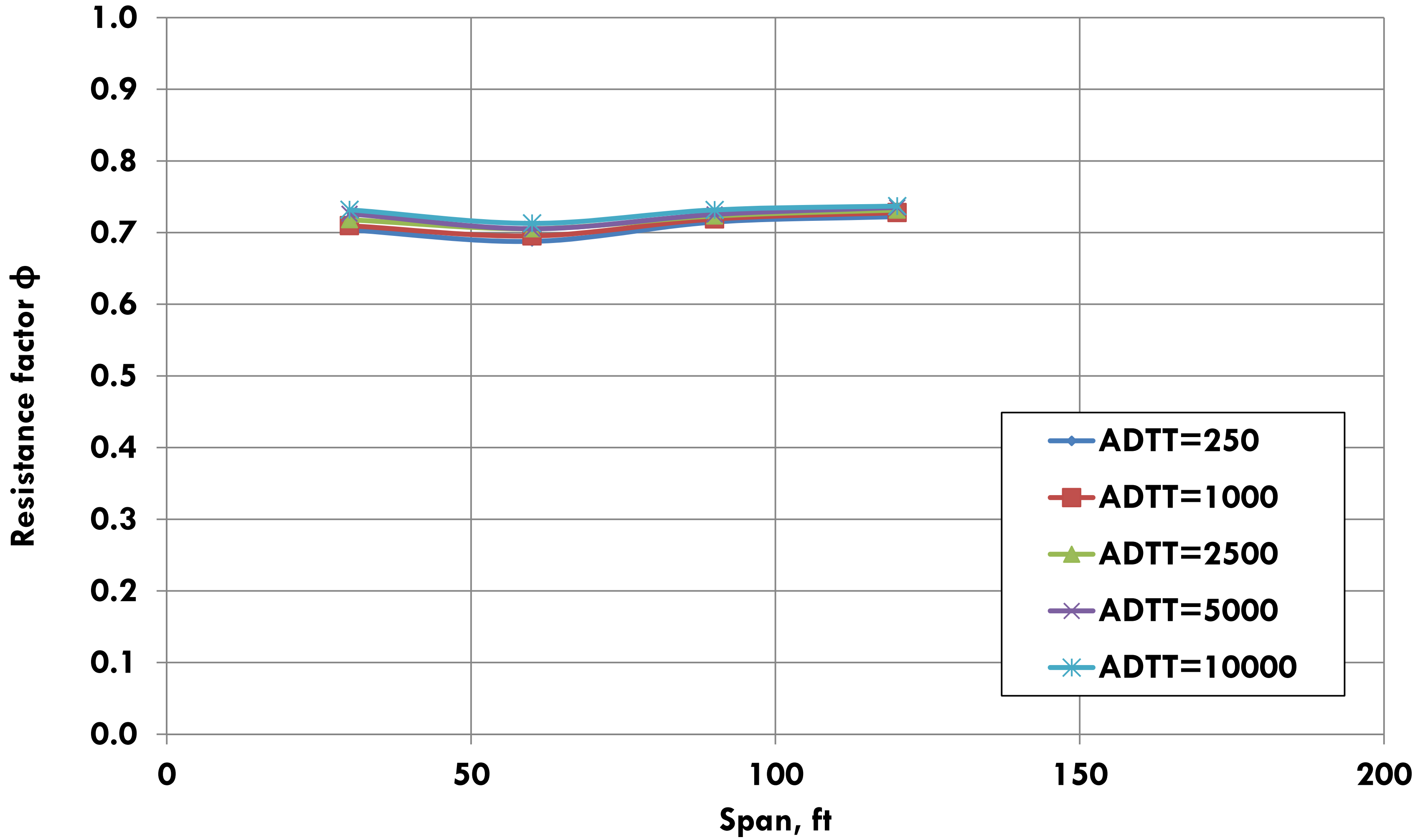
Moment for Steel Girders

Resistance Factor as Design Point



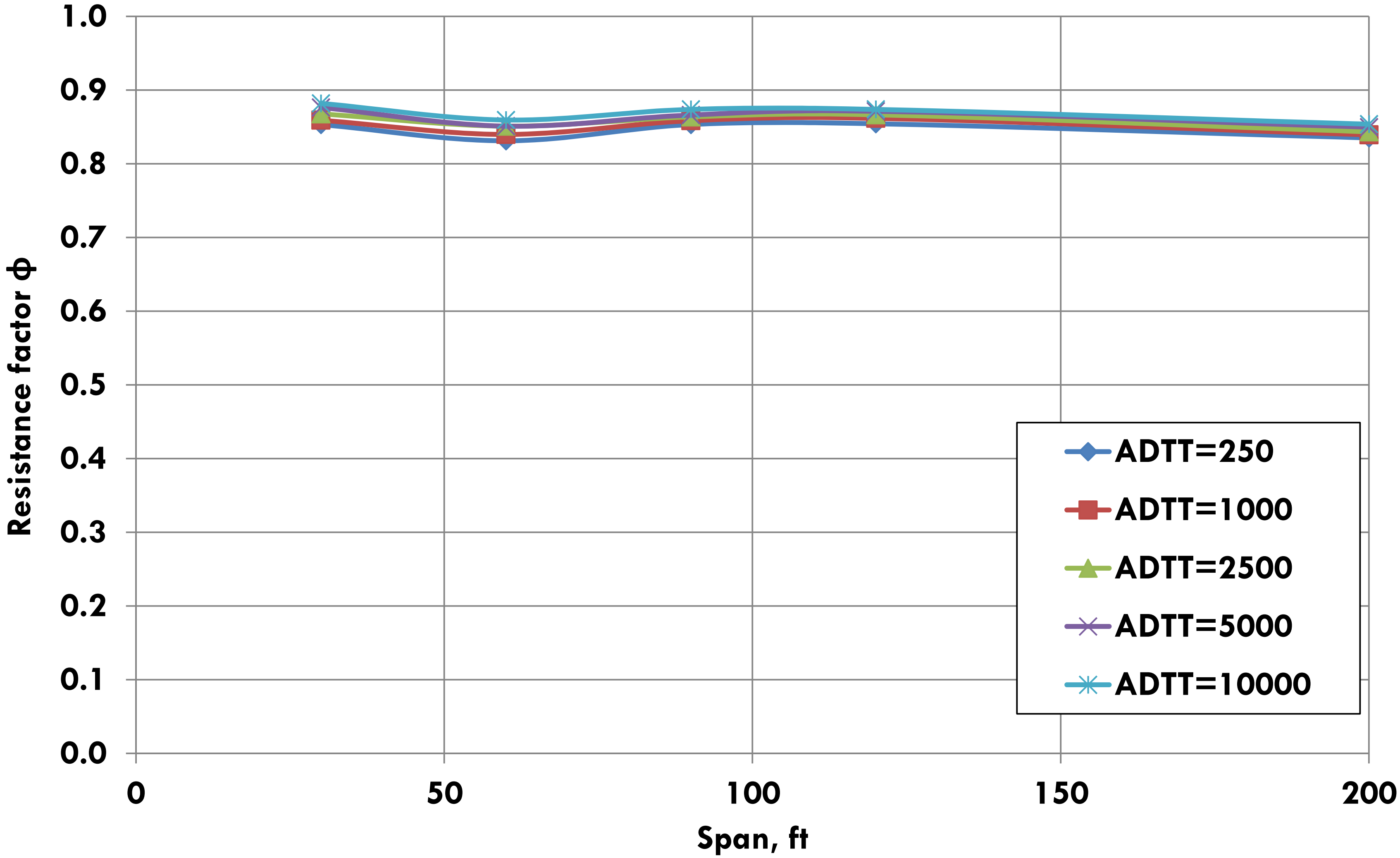
Shear for Prestressed Concrete Girders

Resistance Factor as Design Point



Shear for Reinforced Concrete T-Beams

Resistance Factor as Design Point



Shear for Steel Girders

Resistance Factor as Design Point

Resistance factor for prestressed concrete:

For moment: $\phi = 0.85 - 0.9$

For shear: $\phi = 0.75$

Resistance factor for reinforced concrete:

For moment $\phi = 0.75 - 0.8$

For shear: $\phi = 0.7$

Resistance factor for steel:

For moment $\phi = 0.85 - 0.9$

For shear: $\phi = 0.85$

Considered Cases

Current Design Formula

$$1.25\ DC + 1.50\ DW + 1.75\ LL\ (1 + IM) \leq \mathbf{1.00}\ R$$

If new updated/upgraded live load is used

Live load factor = 1.90

$$1.25\ DC + 1.50\ DW + 1.9\ LL\ (1 + IM) \leq \mathbf{1.00}\ R$$

Considered Cases

Current Design Formula

$$1.25\ DC + 1.50\ DW + 1.75\ LL\ (1 + IM) \leq \mathbf{1.00}\ R$$

If new updated/upgraded resistance statistics is used

$$\phi = \mathbf{1.10}$$

$$1.25\ DC + 1.50\ DW + 1.75\ LL\ (1 + IM) \leq \mathbf{1.10}\ R$$

Considered Cases

Current Design Formula

$$1.25\ DC + 1.50\ DW + 1.75\ LL\ (1 + IM) \leq \mathbf{1.00}\ R$$

If new updated/upgraded resistance and live load statistics are used

$$\phi = \mathbf{1.05}$$

Design Point Factors

Current Design Formula

$$1.25\ DC + 1.50\ DW + 1.75\ LL\ (1 + IM) \leq \mathbf{1.00}\ R$$

Calculated Load Factors – new updated live load

$$1.15\ DC + 1.15\ DW + 1.55\ LL\ (1 + IM) \leq \mathbf{0.85}\ R$$

Proposed Load Factors - new updated live load

$$1.20\ DC + 1.20\ DW + 1.60\ LL\ (1 + IM) \leq \mathbf{0.90}\ R$$

Resistance Factors as Design Point

Moment

Material	Resistance Factor in Current AASHTO LRFD φ	Calculated Resistance Factor φ	Recommended Resistance Factor φ
Steel (Comp. and Non-comp.)	1.00	0.85	0.9
Prestressed concrete	1.00	0.85	0.9
Reinforced concrete	0.90	0.75	0.8

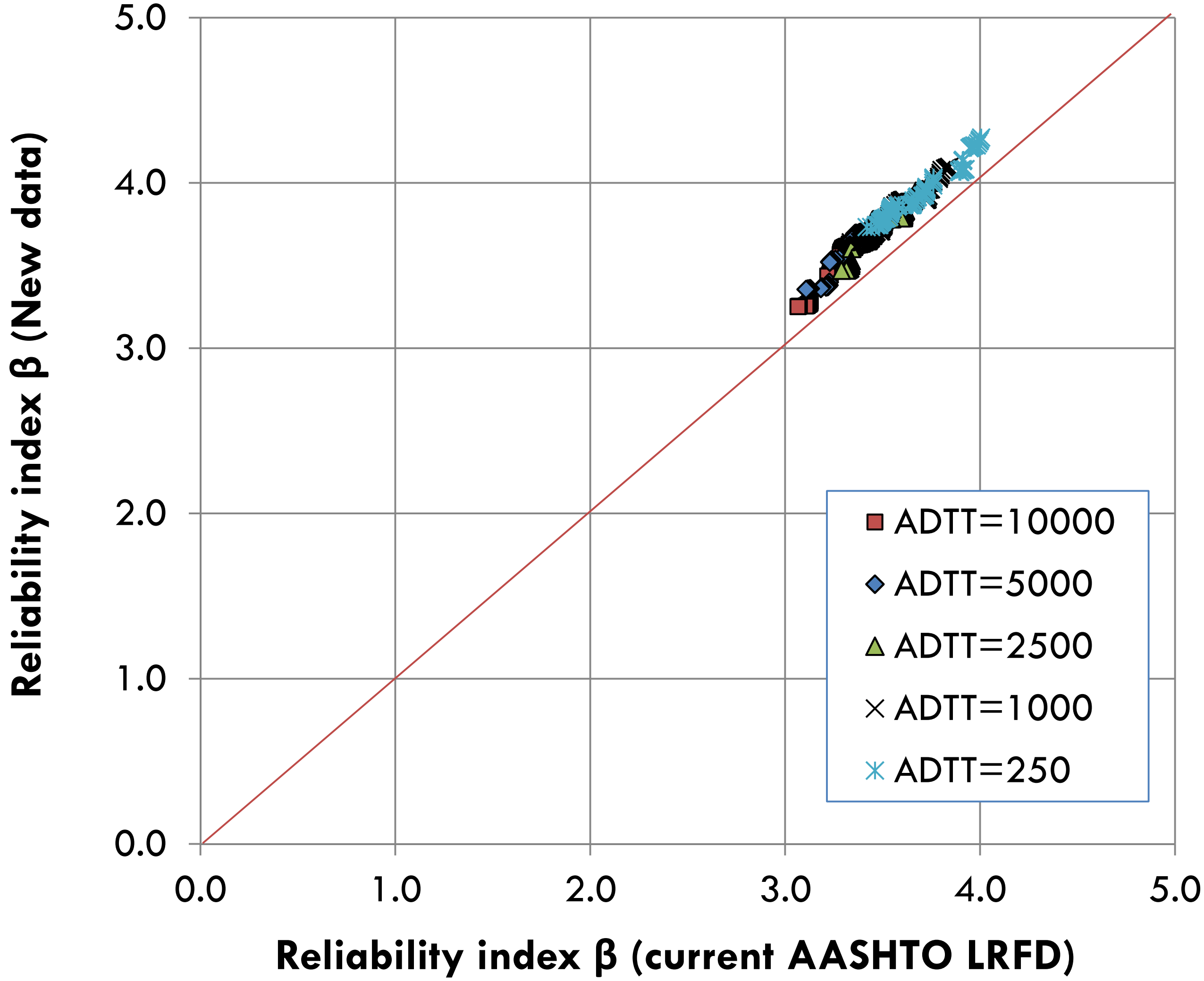
Resistance Factors as Design Point

Shear

Material	Resistance Factor in Current AASHTO LRFD φ	Calculated Resistance Factor φ	Recommended Resistance Factor φ
Steel (Comp. and Non-comp.)	1.00	0.85	0.9
Prestressed concrete	0.9	0.75	0.8
Reinforced concrete	0.85	0.70	0.75

Proposed Load Factors - new live load

1.20 DC + 1.20 DW + 1.60 LL (1 + IM) ≤ 0.90 R



Design Formula – to be confirmed by Re-Calibration, Steel and Prestressed Concrete

Current Design Formula

$$1.25\ DC + 1.50\ DW + 1.75\ LL\ (1 + IM) \leq \mathbf{1.00}\ R$$

Expected Factors - new updated/upgraded live load and resistance

$$1.20\ DC + 1.20\ DW + 1.60\ LL\ (1 + IM) \leq \mathbf{0.95}\ R$$