Introduction to AASHTO
Load and Resistance Factor Design
Structural Supports for Signs, Luminaires Traffic Signals

Overview
Loads
Calibration

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Professor
University of Wyoming
Calibration of Design Equations

\[ \sum \gamma_i Q_i \leq \varphi R_n = R_r \]

- Given the characteristics of the loads and structural materials

What load factors and resistance factors lead to an acceptably safe and consistent design?

- Given the characteristics of the loads and structural materials

\( \gamma_i \) = load factors

\( Q_i \) = load effects

\( \varphi \) = resistance factors

\( R_n \) = resistance

\( R_r \) = factored resistance
Safety or Reliability Index $\beta$

- Failure is defined as the Strength $<$ Load ($S < L$)
- Probability of failure is the Probability ($S < L$)
- Reliability (Safety) Index $\beta$ is a measure of the Probability (Strength $<$ Load)

- Intent of LRFD - $\beta$ high enough for adequate safety and consistent over a range of design scenarios.

$\beta = \text{the number of standard deviations that the mean value of the limit state failure function is on the safe side of failure}$
Statistical Properties

Load & Strength Probability Functions

Central Safety Margin

\[ \mu_{\text{Strength}} - \mu_{\text{Load}} \]

Load

\[ \mu_{\text{Load}} \]

\[ \sigma_{\text{Load}} \]

Strength

\[ \mu_{\text{Strength}} \]

\[ \sigma_{\text{Strength}} \]

Load and Resistance Quantity

(showing normally distributed variables)
Reliability Index

\[ \sigma_{\text{Limit State}} = \sigma_{\text{Strength}} + \sigma_{\text{Load}} \]

\[ \mu_{\text{Limit State}} = \mu_{\text{Strength}} - \mu_{\text{Load}} \]

Limit State Eqn = Strength - Load

Limit State Probability Functions

Probability Density

Limit State Quantity

(showing normally distributed variables)
Reliability Index

Limit State Equations:

\[ \beta = \frac{\mu_{\text{Limit State}}}{\sigma_{\text{Limit State}}} \]

Probability of Failure:

\[ P(\text{Failure}) = \Pr(\text{Strength < Load}) = \Pr(\text{Strength - Load < 0}) \]

Limit State Quantity (showing normally distributed variables)
Calibration

• Determine the statistical properties of loads
• Determine the statistical properties of strength (for optimal design using assumed $\phi$ and $\gamma_i$)
• Determine $\beta$
• Vary $\phi$ and $\gamma_i$ until acceptable safety and consistency achieved (“calibrate” to current accepted practice – current ASD procedures)
Loads Considered

• Dead & Wind
• Ratio of Dead to Wind
• Importance (300/700/1700 year wind)
• Combined Moment & Torsion

Significant Dead Load Effect

Mostly Wind Load
Wind Regions Considered

- Coastal regions
- Central US and Western US
- Southern Alaska
- West Coast

700 Year Basic Wind Speed mph (m/s)
LRFD Reliability Index $\beta$

Assume $\phi$, $\gamma_{D1}$, and $\gamma_W$

Optimized Design $\phi R_n = \gamma_{D1} M_D + \gamma_W M_{MRI}$ Year Wind

Probability Properties

- Strength $R$
  - $\mu_{\ln R}$
  - $\sigma_{\ln R}$
- Load $Q$
  - $\mu_{\ln Q}$
  - $\sigma_{\ln Q}$

Reliability Index (Lognormal Distributions)

$$\beta = \frac{\mu_{\ln R} - \mu_{\ln Q}}{\sqrt{\sigma^2_{\ln R} + \sigma^2_{\ln Q}}}$$

All Reliability Analyses Based On: $M_D + M_{700} = 1.0$

For Equivalent Comparisons
ASD Reliability Index $\beta$

Use LTS – 6 Allowable Stress Design

Optimized Design

$$M_{\text{allowed}} = \left(\frac{4}{3}\right)0.66F_yS_x = M_D + I M_{50}$$

Probability Properties

Strength $R$

- $\mu_{\ln R}$
- $\sigma_{\ln R}$

Load $Q$

- $\mu_{\ln Q}$
- $\sigma_{\ln Q}$

All Reliability Analyses Based On:

$$M_D + M_{700} = 1.0$$

For Equivalent Comparisons

Reliability Index (Lognormal Distributions)

$$\beta = \frac{\mu_{\ln R} - \mu_{\ln Q}}{\sqrt{\sigma_{\ln R}^2 + \sigma_{\ln Q}^2}}$$
700-Year MRI

Minimum of the 4 regions

Average over the 4 regions

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>0.90</th>
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<tbody>
<tr>
<td>$\gamma_D$</td>
<td>1.10 1.25</td>
</tr>
<tr>
<td>$\gamma_W$</td>
<td>1.00 0.00</td>
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700-Year MRI

<table>
<thead>
<tr>
<th></th>
<th>ASD</th>
<th>LRFD</th>
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**Minimum Beta - 700 Year**

- ASD Range of β
- LRFD Range of β

**Minimum of the 4 regions**

- 700 Year MRI
  - Corresponds to
  - ASD I = 1.00

**Average Beta - 700 Year**

- Average over the 4 regions
1700-Year MRI

Minimum Beta - 1700 Year

<table>
<thead>
<tr>
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<th>LRFD</th>
<th>ASD</th>
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<tbody>
<tr>
<td>0.20</td>
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<td>3.00</td>
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<td>0.40</td>
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Average Beta - 1700 Year

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1700 Year MRI Corresponds to ASD I = 1.15
300-Year MRI

Minimum Beta - 300 Year

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300 Year MRI
Corresponds to
ASD I = 0.87

Average Beta - 300 Year

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| φ | 0.90 |
| γ_D | 1.10 | 1.25 |
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Reliability Index with MRI

Minimum Beta - 300, 700, 1700 Year

M Wind/M Total

Beta

300 Yr MRI
700 Yr MRI
1700 Yr MRI
# Midwest & West Reliability Index

## Load Ratio [WL/(DL+WL) = 0.5]

<table>
<thead>
<tr>
<th>Traffic Volume</th>
<th>Typical</th>
<th>High</th>
<th>Low</th>
</tr>
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<tbody>
<tr>
<td>ADT&lt;100</td>
<td>3.03</td>
<td>3.89</td>
<td>3.03</td>
</tr>
<tr>
<td>100&lt;ADT&lt;=1000</td>
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<tr>
<td>ADT&gt;10000</td>
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- **Typical:** Failure could cross travelway
- **High:** Support failure could stop a life-line travelway
- **Low:** Support failure could not cross travelway

Roadway sign supports: Use 10 years (Low)

## Load Ratio [WL/(DL+WL) = 1.0]

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<td>2.77</td>
<td>3.62</td>
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<td>100&lt;ADT&lt;=1000</td>
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- **Typical:** Failure could cross travelway
- **High:** Support failure could stop a life-line travelway
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Roadside sign supports: Use 10 years

**ASD with I=1:** \( \beta = 3.74 \)

**ASD with I=1:** \( \beta = 2.69 \)
Impact – Importance of MRI

LRFD Required Resistance Ratios ($R_{nT}/R_{n700}$)

- $R_{n300}/R_{n700}$
- $R_{n1700}/R_{n700}$

M Wind/M Total

Ratio

0.60 0.70 0.80 0.90 1.00 1.10 1.20

0 0.60 0.70 0.80 0.90 1.00 1.10 1.20
Impact – LRFD vs ASD

WIND has HIGHER Variability Makes Sense
Calibration Summary

- LRFD Calibrated to Current ASD
  - MRI 300 ~ I=0.87,
  - MRI 700 ~ I=1.00,
  - MRI 1700 ~ I=1.15

- LRFD Provides Adequate Safety as Calibrated to Current ASD ($\beta$ high enough)

- LRFD Provides More Consistent Safety over the Range of Design than ASD ($\beta$ more uniform)
Calibration Summary

• LRFD & ASD Result in Same Strength Design for Wind Moment/Total Moment ~ 0.60

• High Mast Pole LRFD Strength ~ 10-15% Higher

• Mast Arm LRFD Strength ~5-8% Lower
Calibration Summary

• Risk Category has Significant Impact
  – High Mast Poles
    • +10% or more for High Risk
    • -10% or more for Low Risk
  – Mast Arm Poles
    • +5% or more for High Risk
    • -5% or more for Low Risk