Introduction to LRFR

Learning Outcomes

- Identify the primary purposes of load rating highway bridges
- Understand the benefits of LRFR
- Identify key differences between LRFR and LFR
What is a Load Rating?

- Vehicular live load capacity of a bridge
  - Using as-built bridge plans
  - Using latest field inspection (NBIS)
- Expressed as a Rating Factor (RF) or in tonnage for a particular vehicle

Purposes of Load Rating

- Ensure bridge safety
- Rehabilitation or replacement needs
- Submit data to the National Bridge Inventory - Comply with NBI Standards
- Posting needs
- Processing of overload permits
**LRFR Rating Process**

Design Load Rating (HL-93)  NBI data

Legal Load Rating  Posting
(AASHTO and State Legal Loads)

Permit Load Rating  Permits
(Overweight Trucks)

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**NBIS – 23 CFR 650 Subpart C**

- **650.313 Inspection Procedures**
  - (c) ‘Rate each bridge as to its safe load carrying capacity in accordance with the AASHTO Manual. Post or restrict the bridge in accordance with the AASHTO Manual when unrestricted legal loads or State routine permit loads exceed….’
When Should a Load Rating be Performed?

- Design stage
- Initial inventory inspection
- Change in the live loading
- Change in the dead load on the structure
- Physical change in any structural member of the bridge

Elements of a Bridge to be Load Rated (cont.)

Typical Stringer Bridge

- Interior Stringer
- Dead Load Considerations
- Exterior Stringer
Elements of a Bridge to be Load Rated (cont.)

Deck Truss Bridge

- Stringer
- Floorbeam
- Truss Member
- Truss Connection
- Steel Pier Bent

LRFR Limit States and Reliability Index

**Strength Limit State** has been calibrated to achieve uniform safety using structural reliability methods.

**Reliability Index** \( \beta \) provides a new measure of safety that is statistically based.

**Service Limit State** not calibrated. Several works underway to move to calibrated limit states.
LRFR Serviceability Considerations

- **SERVICE I** – Permanent deformation of reinforcing steel in R/C & P/S concrete members for permit loads
- **SERVICE II** – Permanent deformation of steel members
- **SERVICE III** – Cracking of P/S concrete members
- **FATIGUE** – Fatigue of steel members

Probabilistic Design and Evaluation

![Diagram of probabilistic design and evaluation](image)
Probabilistic Design and Evaluation (cont.)

As-built-Q
Increase over time-Q

As-built-R
Decrease over time-R

Reliability Index, ‘\( \beta \)’

Design Level Reliability: \( \beta = 3.5 \)
or 1 in 5,000 notional probability of exceedence

Minimum for Evaluation: \( \beta = 2.5 \)
or 1 in 1,200 notional probability of exceedence
Reliability Indices

Minimum Reliability for LRFR

\[ \beta = 2.5 \]

- Comparable to average reliability inherent in load factor ratings at Operating Level
- Shown to be an acceptable minimum level of safety for bridge evaluation

*Exposure period for evaluation is 2-5 years vs. 75 years for design*
Reliability Index vs. LRFR and LFR

**Study’s Key Findings**

- **LRFR** ratings *correlate well* with limit state exceedence rates
- **LFR** ratings *did not correlate well*
Uniform Reliability Predictors

- Live load model
- Distribution factors
- Multiple presence of live loads
- Resistance formulations (LRFD)

Live Load Effect on Reliability

- Uniform reliability requires uniform bias for load effects across all span lengths
- Force effects from HS20 load model to “exclusion vehicles” does not provide a uniform bias
- New live load model needed to achieve uniform reliability
Actual vs. Design Load Moments

What are Exclusion Loads?

- Trucks exempted from Federal weight laws
- Comply with state vehicle weight regulations
- Allowed to operate on non-interstate highways
Michigan “Exclusion Truck”
Load: 3-S3-5

Total weight = 77 ton
Total length = 72.4 ft.

What makes this an “Exclusion Truck?”
AASHTO Standard Spec. Distribution Factors (DF)

\[ g = \frac{S}{D} \]

Where:
- \( g \) = distribution factor, DF (wheel load fraction)
- \( S \) = average stringer spacing
- \( D \) = function of # lanes and deck type

S/D Distribution Factor and Reliability Index

Simple Span Moments in Steel Girders

Influence of DF
S/D Distribution Factor and Reliability Index

Simple Span Shear in Steel Girders

- Distribution Factor for moment
- Distribution Factor for shear

LRFD Distribution Factor: Interior Longitudinal Member
DF for Moment: Interior Beams

- One Lane Loaded
  \[ g_{m1} = 0.06 + \left( \frac{S}{14} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left( \frac{K_g}{12Lt_s^3} \right)^{0.1} \]

- Two or More Lanes Loaded
  \[ g_{m2} = 0.075 + \left( \frac{S}{9.5} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \left( \frac{K_g}{12Lt_s^3} \right)^{0.1} \]

DF for Shear: Interior Beams

- One Lane Loaded
  \[ g_{v1} = 0.36 + \left( \frac{S}{25} \right) \]

- Two or More Lanes Loaded
  \[ g_{v2} = 0.2 + \left( \frac{S}{12} \right) - \left( \frac{S}{35} \right)^{2.0} \]
Vehicular Live Loads

- Design load (national)
- Legal loads (local)
- Permit loads (local)

LRFR Load Rating Process

Design (HL-93) -> NBI reporting

Legal

- RF ≥ 1
  - RF < 1
    - RF < 1
      - RF < 1
        - RF < 1
          - RF < 1

- Post or Restrict For Routine Permits

- Load Posting
- Strengthening

Permit
Federal Weight Limits

- Single Axle Limit – 20,000 lbs
- Tandem Axle Limit – 34,000 lbs
- Gross Vehicle Limit – 80,000 lbs
- Bridge Formula ‘B’

\[ W = 500 \left( \frac{LN}{N - 1} + 12N + 36 \right) \]

Where  
N = # of axles  
L = distance between first and last axle (ft)  
W = weight (lbs)

LRFD Live Load (HL-93)

Design Truck
PLUS
Design Lane

- 8 kips
- 14’
- 32 kips
- Varies (14’ to 30’)
- 32 kips

Design Tandem
PLUS
Design Lane

- 25 kips
- 4’
- 0.64 kips/foot

or

Design Tandem
PLUS
Design Lane

- 25 kips
- 0.64 kips/foot
Legal Load Rating

- Provides single level load rating
- **RF ≥ 1.0** Safe for unrestricted indefinite use
- **RF < 1.0** Need for posting or bridge strengthening

Routine Commercial Traffic

Truck Models

1. **Type 3** W=50 kips
   - 16k
   - 15'
   - 17k
   - 4'
   - 17k

2. **Type 3S2** W=72 kips
   - 10k
   - 11'
   - 15.5k
   - 4'
   - 15.5k
   - 22'
   - 4'

3. **Type 3-3** W=80 kips
   - 12k
   - 15'
   - 12k
   - 4'
   - 12k
   - 15'
   - 15k
   - 16'
   - 14k
   - 4'
   - 14k
### Routine Commercial Traffic
### AASHTO Legal Loads

<table>
<thead>
<tr>
<th>Strength I 1-Way Traffic Volume</th>
<th>Live Load Factor, $\gamma_{LL}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>1.45</td>
</tr>
<tr>
<td>ADTT $\geq$ 5000</td>
<td>1.45</td>
</tr>
<tr>
<td>ADTT $\leq$ 1000</td>
<td>1.30</td>
</tr>
<tr>
<td><strong>Service Limits</strong></td>
<td></td>
</tr>
<tr>
<td>SERVICE II</td>
<td>1.30</td>
</tr>
<tr>
<td>SERVICE III</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Specialized Hauling Vehicles (SHV)

Adopted by AASHTO in 2005 to represent new truck models

- Trucks comply with Formula ‘B’ – and meet all Federal weight regulations
- High axle loads concentrated over shorter distance
- Moveable axles – raise/lower as needed for weight
Examples of SHVs

SHVs with lift axles

Why SHVs?

AASHTO Type 3
Weight = 50 kips

16k
17k 17k

15’
4’
19’
Example Overstresses for SHVs

<table>
<thead>
<tr>
<th>Force Effect</th>
<th>Max Overstress Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Span Bending</td>
<td>1.49</td>
</tr>
<tr>
<td>Simple Span Shear</td>
<td>1.37</td>
</tr>
<tr>
<td>Two-Span Continuous Positive Bending</td>
<td>1.48</td>
</tr>
<tr>
<td>Two-Span Continuous Negative Bending</td>
<td>1.26</td>
</tr>
<tr>
<td>Two-Span Continuous Shear</td>
<td>1.36</td>
</tr>
<tr>
<td>Three-Span Continuous Positive Bending</td>
<td>1.48</td>
</tr>
<tr>
<td>Three-Span Continuous Negative Bending</td>
<td>1.39</td>
</tr>
<tr>
<td>Three-Span Continuous Shear</td>
<td>1.35</td>
</tr>
<tr>
<td>Four-Span Continuous Positive Bending</td>
<td>1.48</td>
</tr>
<tr>
<td>Four-Span Continuous Negative Bending</td>
<td>1.34</td>
</tr>
<tr>
<td>Four-Span Continuous Shear</td>
<td>1.34</td>
</tr>
</tbody>
</table>

AASHTO SHV Posting Loads

SU4 Truck
GVW = 54 kips

SU5 Truck
GVW = 62 kips
**AASHTO SHV Posting Loads**

- **SU6 Truck**
  - GVW = 69.5 kips
  - Load distribution:
    - 11.5k
    - 8k
    - 8k
    - 17k
    - 17k
    - 8k
  - Spread: 10' (10 feet)
  - Spacing: 4' (4 feet)

- **SU7 Truck**
  - GVW = 77.5 kips
  - Load distribution:
    - 11.5k
    - 8k
    - 8k
    - 17k
    - 17k
    - 8k
  - Spread: 10' (10 feet)
  - Spacing: 4' (4 feet)

**SHVs AASHTO Legal Loads**

<table>
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<tr>
<th>STRENGTH I 1-Way Traffic Volume</th>
<th>Live Load Factor, $\gamma_{LL}$</th>
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<td>1.30</td>
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<td>SERVICE III</td>
<td>1.00</td>
</tr>
</tbody>
</table>
 Permit Load Rating

- Single level rating
- Permits only allowed on bridges having $RF \geq 1.0$ for legal loads or HL-93
- $RF \geq 1.0$ safe for permit crossing
- Permit rating based on permit type:
  - Routine / Annual Permits
  - Special / Single-Trip Permits

Overload Permits

- LRFR procedures for permit review
- Permit Types:
  - Routine/Annual Permits $\leq 150$ K
  - Special Permits $> 150$ K
Example: Special Permit

Oversized Superloads
Example: Routine Permit

Oregon 8-Axle Continuous Trip Permit 105.5 k

LRFR Routine Permit Load Factors: STRENGTH II

<table>
<thead>
<tr>
<th>Distribution Factor</th>
<th>ADTT (1-Way)</th>
<th>Load Factor by Permit Weight Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GVW/AL &lt; 2.0</td>
</tr>
<tr>
<td>Two or More Lanes</td>
<td>&gt; 5000</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>= 1000</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>&lt; 100</td>
<td>1.30</td>
</tr>
</tbody>
</table>

Permit Weight Ratio = GVW/AL
GVW = Gross Vehicle Weight (kips)
AL = Front axle to rear axle length (ft) (use only axles on the bridge)
**LRFR Special Permit Load Factors: STRENGTH II**

<table>
<thead>
<tr>
<th>Trips</th>
<th>Other Traffic</th>
<th>DF</th>
<th>ADTT</th>
<th>Load Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Trip</td>
<td>Escorted, no other vehicles</td>
<td>1 Lane</td>
<td>N/A</td>
<td>1.10</td>
</tr>
<tr>
<td>Single Trip</td>
<td>Mix with traffic (other vehicles may be on the bridge)</td>
<td>1 Lane</td>
<td>All ADTTs</td>
<td>1.20</td>
</tr>
<tr>
<td>Multiple Trips (&lt; 100)</td>
<td>Mix with traffic (other vehicles may be on the bridge)</td>
<td>1 Lane</td>
<td>All ADTTs</td>
<td>1.40</td>
</tr>
</tbody>
</table>

**Load Posting Signs**

- **BRIDGE WEIGHT LIMIT - TONS**
  - Single Vehicle: 17 Tons
  - Combinations 3 or 4 Axles: 21 Tons
  - 5 or More Axles: 23 Tons

- **WEIGHT LIMIT 6 TONS**

- **WEIGHT LIMIT**
  - Gross Weight: T T T T
Bridge Posting in LRFR

- LRFR posting analysis deviates from past practice
- Maintains same reliability for posted and non-posted bridges
- Load posted bridges = high overload probabilities
  - A more conservative posting is required to maintain the same reliability

LRFR Posting Analysis

When
- RF < 0.3 for a vehicle, restrict that vehicle type
- RF < 0.3 for all posting vehicles, close bridge to all truck traffic

When 0.3 < RF < 1.0
- Posting Load = \((W / 0.7) \times [(RF) - 0.3]\)
  - \(W\) = Weight of rating vehicle (tons)
  - \(RF\) = Legal load rating factor (controlling)
- Any posting load < 3 tons, close bridge
LRFR Loading Rating Equation

\[ RF = \frac{C - (\gamma_{DC})(DC) - (\gamma_{DW})(DW) \pm (\gamma_{P})(P)}{\gamma_{LL}(LL + IM)} \]

\[ C = \varphi_c \varphi_s \varphi R_n \]

\[ C = f_R \]
Differences between LRFR and LFR

- Design load model, distribution factors, capacity reduction factors, load factors
- Routine service limit state evaluation
- LRFR consistently correlates well to probability of exceedance
- Single level evaluation for posting and permitting for LRFR
- Resistance calculations similar, but some advances in LRFR

Summary of Benefits of LRFR

- Uniform reliability in bridge analysis
- More uniform posting levels
- Guidance for evaluation of overloads
- Procedures to ensure more consistency and uniformity in rating ($\phi_c$, $\phi_s$, DLA)
- Optimal load factors for lower volume roads
- Introduces state-of-the-art technologies that could benefit existing bridges
- Evaluation of serviceability or service limit states
Questions or Discussion?