Loads on Bridge

- **DD** = downdrag (wind)
- **DC** = dead load of structural and nonstructural components
- **DW** = dead load of wearing surface
- **EH** = earth pressure (horizontal)
- **EL** = secondary forces such as from posttensioning
- **ES** = earth surcharge load (vertical)
- **EV** = earth pressure (vertical)

**Outline**

- Loads on Bridges
  - Typical Loads
    - Dead Load
    - Live Load
      - Live load of vehicle
      - Pedestrian load
      - Dynamic load allowance
  - Other Loads
    - Fatigue
    - Wind
    - Earthquake
  - Dynamic Load Allowance
- Other Loads
  - Fatigue
  - Wind
  - Earthquake
  - …
- Load and Resistance Factor Design

**Loads on Bridge**

- **BR** = breaking force of vehicle
- **CE** = centrifugal force of vehicle (at curves)
- **CR** = creep of concrete
- **CT** = vehicle collision force (on bridge or at piers)
- **CV** = vessel collision force (bridge piers over river)
- **EQ** = earthquake
- **FR** = friction
- **IC** = ice
- **IM** = dynamic load of vehicles
- **LL** = live load of vehicle (static)
- **LS** = live load surcharge
- **PL** = pedestrian load
- **SE** = settlement
- **SH** = shrinkage of concrete
- **TG** = load due to temperature differences
- **TU** = load due to uniform temperature
- **WA** = water load/stream pressure
- **WL** = wind on vehicles on bridge
- **WS** = wind load on structure
Typical Loads

Dead Loads: DC/DW
Live Loads of Vehicles: LL
Pedestrian Load: PL
Dynamic (Impact) Loads: IM

Dead Load: DC
- Dead load includes the self weight of:
  - structural components such as girder, slabs, cross beams, etc…
  - nonstructural components such as medians, railings, signs, etc…
- But does not include the weight of wearing surface (asphalt)
- We can estimate dead load from its density

### Density Table

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (Normal Weight.)</td>
<td>2400</td>
</tr>
<tr>
<td>Concrete (Lightweight)</td>
<td>1775-1925</td>
</tr>
<tr>
<td>Steel</td>
<td>7850</td>
</tr>
<tr>
<td>Aluminum Alloy</td>
<td>2800</td>
</tr>
<tr>
<td>Wood</td>
<td>800-960</td>
</tr>
<tr>
<td>Stone Masonry</td>
<td>2725</td>
</tr>
</tbody>
</table>

Dead Load of Wearing Surface: DW
- It is the weight of the wearing surface (usually asphalt) and utilities (pipes, lighting, etc…)
- Different category is needed due to large variability of the weight compared with those of structural components (DC)
  - Asphalt surface may be thicker than designed and may get laid on top of old layer over and over
- Density of asphalt paving material = 2250 kg/m³
- Average Thickness of asphalt on bridge = 9 cm

Live Loads of Vehicles: LL
Live Loads of Vehicles: LL

- Live load is the force due to vehicles moving on the bridge
- There are several types of vehicles:
  - Car
  - Van
  - Buses
  - Trucks
  - Semi-Trailer
  - Special vehicles
  - Military vehicles

- The effect of live load on the bridge structures depends on many parameters including:
  - Span length
  - Weight of vehicle
  - Axle loads (load per wheel)
  - Axle configuration
  - Position of the vehicle on the bridge (transverse and longitudinal)
  - Number of vehicles on the bridge (multiple presence)
  - Girder spacing
  - Stiffness of structural members (slab and girders)

Live Loads of Vehicles: LL

Bridge LL vs. Building LL

- **BRIDGE**
  - LL is very heavy (several tons per wheel)
  - LL can be series of point loads (wheel loads of trucks) or uniform loads (loads of smaller vehicles)
  - Need to consider the placement within a span to get the maximum effect
  - Loads occur in one direction within lanes
  - Need to consider also the placement of loads in multiple spans (for continuous span bridges)
  - Dynamic effects of live load cannot be ignored

- **BUILDING**
  - LL is not very heavy, typical 300-500 kg/m²
  - LL is assumed to be uniformly distributed within a span
  - Do not generally consider placement of load within a span
  - Loads are transferred in to 2 directions
  - Need to consider various placements of loads for the entire floor
  - Do not generally consider dynamic/impact effect of live loads
Analysis Strategy for LL

- Various Live Loads
  - Place them to get maximum effects on span

- Consider dynamic effects
  - Distribute Load to each girder
  - Moment/Shear from Live Load to be used in the design of girders

Design Lane

- Need to know how many lanes there is on the bridge
- Design Lane ≠ Actual Traffic Lane
  - 3.0 m ≠ 3.3 m to 4.6 m (3.6 m recommended)
- Number of Design Lanes = Roadway width / 3.6 m ≥ No. of Actual Traffic Lane
- Number of Lane must be an integer (1, 2, 3, ...) – there is no fraction of lane (no 2.5 lanes, for example)
- For roadway width from 6 m to 7.2 m, there should be 2 design lanes, each equal ½ of the roadway width

Live Loads of Vehicles: LL

- For design purpose, we are interested the kind of vehicle that produce the worst effect
- AASHTO has 3 basic types of LL called the HL-93 loading (stands for Highway Loading, year 1993)
  - Design truck
  - Design tandem
  - Uniform lane load

I. Design Truck

- The design truck is called HS-20 (stands for Highway Semi-Trailer with 20-kips weight on first two axles)
- Weight shown are for each one axle = 2 wheels
- Total Wt = 325 kN ~ 33 t.
- Distance between second and third axles may be varied to produce maximum effect
- Need to multiply this load by dynamic allowance factor (IM)
### 2. Design Tandem

- Two axle vehicle with 110 kN on each axle
- Need to multiply this load by dynamic allowance factor (IM)
- Lead to larger moment than the HS20 truck for simple-support spans less than about 13.4 m

### 3. Uniform Lane Loading

- Uniform load of 9.3 kN/m acting over a tributary width of 3 m. (i.e. the load is 3.1 kN/m²)
- May be apply continuously or discontinuously over the length of the bridge to produce maximum effect
- No dynamic allowance factor (IM) for this load

### Analysis Strategy for LL

- Various Live Loads: Place them to get maximum effects on span
- Consider dynamic effects
- Distribute Load to each girder
- Moment/Shear from Live Load to be used in the design of girders

### Live Load Combinations

- 3 ways to add the design truck, design tandem, and uniform load together
  - Combination 1: one HS20 truck on top of a uniform lane load per design lane
  - Combination 2: one Design Tandem on top of a uniform lane load per design lane
  - Combination 3: (for negative moments at interior supports of continuous beams) place two HS20 design truck, one on each adjacent span but not less than 15 m apart (measure from front axle of one truck to the rear axle of another truck), with uniform lane load. Use 90% of their effects as the design moment/shear
- The loads in each case must be positioned such that they produce maximum effects (max M or max V)
- The maximum effect of these 3 cases is used for the design
Live Load Placement

- Need to consider two dimensions
  - Transversely (for designs of slabs and overhangs)
  - Longitudinally (for design of main girder)

Live Load Placement - Transverse

- The design truck or tandem shall be positioned transversely such that the center of any wheel load is not closer than:
  - 30 cm from the face of the curb or railing for the design of the deck overhang
  - 60 cm from the edge of the design lane for the design of all other components

- Note that if the sidewalk is not separated by a crashworthy traffic barrier, must consider the case that vehicles can be on the sidewalk

Live Load Placement - Longitudinal

- Need to place the LL along the span such that it produces the maximum effect
- For simple 1-point loading, the maximum moment occurs when the load is placed at the midspan

- However, truck load is a group of concentrated loads. It is not clear where to place the group of loads to get the maximum moment
- **REMEMBER:** MAXIMUM MOMENT DOES NOT ALWAYS OCCURS AT MIDSPAN !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
Live Load Placement – Influence Line

- Influence line is a graphical method for finding the variation of the "structural response" at a point as a concentrated live load moves across the structure.
  - Structural response can be support reaction, moment, shear, or displacement.

![Diagram of Live Load Placement – Influence Line](image1)

![Diagram of Live Load Placement – Influence Line](image2)

![Diagram of Live Load Placement – Influence Line](image3)

![Diagram of Live Load Placement – Influence Line](image4)
Müller-Breslau Principle: “If a function at a point on a beam, such as reaction, or shear, or moment, is allowed to act without restraint, the deflected shape of the beam, to some scale, represent the influence line of the function.

Influence line is a powerful visualization tool for the effects of live load placements to the structural response.
Notes

- Influence line tells you how to place the LL such that the maximum moment at a point occurs; i.e. you pick a point then you try to find what is the maximum moment at that point when loads are moved around.
- It does not tell you where the absolute maximum moment in the span occurs; i.e. the maximum moment on the point you picked is not always the absolute maximum moment that can occur in the span (which will occur at a different point and under a different arrangement of loads).

For series of concentrated load (such as the design truck), the placement of load for maximum moment, shear, or reaction may not be apparent.

The maximum always occur under one of the concentrated loads – but which one?

Two methods
- **Trial and Errors:** Move the series of concentrated loads along the span by letting each load on the peak of IL
  - Use when you have only 2-3 concentrated loads
  - Can be tedious when you have a lot of concentrated loads

Train Loading

(AREA: American Railroad Engineers Association)
Live Load Placement – Influence Line

- **Increase/Decrease Method**
  - This method determines whether the response (moment, shear, or reaction) increases or decreases as the series of concentrated loads move into the span.
  - As the series of loads move into the span, the response increases. When it starts to decrease, you’ll know that the last position was the one that produced the maximum effect.

- **Note:** not all loads may be in the span at the same time. Loads that have just moved in or moved out may travel on the slope at a distance less than the distance moved between 2 concentrated loads.

**Example**

- **Sloping Line**
  \[ \Delta V = Ps(x_2 - x_1) \]

- **Jump**
  \[ \Delta V = P(y_2 - y_1) \]

**IL for moment** has no jumps!
Live Load Placement – Influence Line

- For Statically Indeterminate Structures, the Müller-Breslau Principle also holds
- "If a function at a point on a beam, such as reaction, or shear, or moment, is allowed to act without restraint, the deflected shape of the beam, to some scale, represent the influence line of the function"
- For indeterminate structures, the influence line is not straight lines!

Live Load Placement - Longitudinal

- Methods of finding maximum moment and shear in span
  - Influence Line (IL) – Simple and Continuous spans
  - Design Equation – Simple span only
  - Design Chart – Simple span only

Live Load Placement – Design Equation

- Another Method: Using Barre’s Theorem for simply supported spans
  - The absolute maximum moment in the span occurs under the load closest to the resultant force and placed in such a way that the centerline of the span bisects the distance between that load and the resultant
Live Load Placement – Design Equation

If we combine the truck/tandem load with uniform load, we can get the following equations for maximum moment in spans:

\[
M_{\text{max}} = 81.25l + \frac{172.1}{l} - 387 \text{ kN-m}
\]

\[
M_{\text{max}} = 55l + \frac{19.8}{l} - 66 \text{ kN-m}
\]

\[M_{\text{max}}\text{ occurs at a section under middle axle located a distance 0.73 m from midspan.}\]

\[M_{\text{max}}\text{ occurs at a section under one of the axles located a distance 0.30 m from midspan.}\]

Live Load Placement - Longitudinal

- **Methods of finding maximum moment and shear in span**
  - Influence Line (IL) – Simple and Continuous spans
  - Design Equation – Simple span only
  - Design Chart – Simple span only
Bending Moment in Simple Span for AASHTO HL-93 Loading for a fully loaded lane

Moment in kips-ft
IM is included

1 ft = 0.3048 m
1 kips = 4.448 kN
1 kips-ft = 1.356 kN-m

Shear in Simple Span for AASHTO HL-93 Loading for a fully loaded lane

Shear in kips
IM is included

1 ft = 0.3048 m
1 kips = 4.448 kN

Pedestrian Live Load: PL

- Use when has sidewalk wider than 60 cm
- Considered simultaneously with truck LL
- Pedestrian only: 3.6 kN/m²
- Pedestrian and/or Bicycle: 4.1 kN/m²
- No IM factor (Neglect dynamic effect of pedestrians)
Analysis Strategy for LL

- Various Live Loads → Place them to get maximum effects on span
- Consider dynamic effects
- Distribute Load to each girder
- Moment/Shear from Live Load to be used in the design of girders

Dynamic Load Allowance: IM

- Sources of Dynamic Effects
  - Hammering effect when wheels hit the discontinuities on the road surface such as joints, cracks, and potholes
  - Dynamic response of the bridge due to vibrations induced by traffic
- Actual calculation of dynamic effects is very difficult and involves a lot of unknowns
- To make life simpler, we account for the dynamic effect of moving vehicles by multiplying the static effect with a factor

- This IM factor in the code was obtained from field measurements

Dynamic Load Allowance: IM

- Effect due to Static Load
- Dynamic Load Allowance Factor: IM
- Effect due to Dynamic Load

Dynamic Load Allowance: IM

- Add dynamic effect to the following loads:
  - Design Truck
  - Design Tandem
- But NOT to these loads:
  - Pedestrian Load
  - Design Lane Load

<table>
<thead>
<tr>
<th>Component</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Joint</td>
<td>75%</td>
</tr>
<tr>
<td>All limit states</td>
<td></td>
</tr>
<tr>
<td>All other components above ground</td>
<td>15%</td>
</tr>
<tr>
<td>Fatigue/Fracture Limit States</td>
<td>33%</td>
</tr>
<tr>
<td>All Other Limit States</td>
<td></td>
</tr>
<tr>
<td>Foundation components below ground</td>
<td>0%</td>
</tr>
</tbody>
</table>

* Reduce the above values by 50% for wood bridges

Figure 3.3. Dynamic and Static Strain under a Truck at Highway Speed.
Analysis Strategy for LL

Various Live Loads → Place them to get maximum effects on span → Consider dynamic effects → Distribute Load to each girder → Moment/Shear from Live Load to be used in the design of girders

Multiple Presence of LL

- We've considered the effect of load placement in ONE lane
- But bridges have more than one lane
- It's almost impossible to have maximum load effect on ALL lanes at the same time
- The more lanes you have, the lesser chance that all will be loaded to maximum at the same time

Multiple Presence Factor

- Use care of this by using Multiple Presence Factor
- 1.0 for two lanes and less for 3 or more lanes
- This is already included (indirectly) into the GDF Tables in AASHTO code so we do not need to multiply this again
- Use this only when GDF is determined from other analysis (such as computer model or FEM)

Multiple Presence of LL

- We take care of this by using Multiple Presence Factor
- 1.0 for two lanes and less for 3 or more lanes
- This is already included (indirectly) into the GDF Tables in AASHTO code so we do not need to multiply this again
- Use this only when GDF is determined from other analysis (such as computer model or FEM)

Distribution of LL to Girders

- A bridge usually have more than one girder so the question arise on how to distribute the lane load to the girders

- Two main methods
  - Using AASHTO's table: for typical design, get an approximate (conservative) value
    - No need to consider multiple presence factor
  - Refined analysis by using finite element method
    - Need to consider multiple presence factor

<table>
<thead>
<tr>
<th>Number of Loaded Lane</th>
<th>Multiple Presence Factor “m”</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.20</td>
</tr>
<tr>
<td>2</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>0.85</td>
</tr>
<tr>
<td>&gt; 3</td>
<td>0.65</td>
</tr>
</tbody>
</table>
**AASHTO Girder Distribution Factor**

- DFs are different for different kinds of superstructure system
- DFs are different for interior and exterior beam
- DFs are available for one design lane and two or more design lanes (the larger one controls)
- Must make sure that the bridge is within the range of applicability of the equation

Factors affecting the distribution factor includes:

- Span Length (L)
- Girder Spacing (S)
- Modulus of elasticity of beam and deck
- Moment of inertia and Torsional inertia of the section
- Slab Thickness (ts)
- Width (b), Depth (d), and Area of beam (A)
- Number of design lanes (NL)
- Number of girders (Nb)
- Width of bridge (W)

**Diagram:**

- Types (Continued)

**Table 4.2.2.1-1 - Common Deck Superstructures Covered in Articles 4.2.2.2 and 4.2.2.3**

- Supporting Components
- Type of Deck
- Typical Cross-Section

**DF**

- For AASHTO method first we must identify the type of superstructure (support beam & deck types)
### DF_M

**Distribution factor for moment in Interior Beams**

Table 4.6.2.2-2.2a-1: Distribution of Live Loads Per Lane for Moment in Interior Beams

<table>
<thead>
<tr>
<th>Type of Beams</th>
<th>Applicable Cross-Section from Table 4.6.2.2-4.1</th>
<th>Distribution Factors</th>
<th>Range of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>a, 1</td>
<td>See Table 4.6.2.2-2a-1</td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>d</td>
<td>One Design Lane Loaded:</td>
<td></td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid or Partially Filled Grid on Steel or Concrete Beams, T-Beams, T- and Double T-Sections</td>
<td>a, b, 6, and other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiconcrete Box Beams</td>
<td>b, c</td>
<td>One Design Lane Loaded:</td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Concrete Spread Box Beams</td>
<td>b, c</td>
<td>One Design Lane Loaded:</td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Used in Multispan Beams</td>
<td>g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Other than Box Beams Used in Multispan Beams</td>
<td>h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Grid Deck on Steel Beams</td>
<td>a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Beams</td>
<td>b, c</td>
<td>As specified in Table 4.5.2.2-8.1</td>
<td></td>
</tr>
</tbody>
</table>

### DF_M (continued)

**Distribution factor for moment in Exterior Beams**

Table 4.6.2.2-2.2a-1 (continued): Distribution of Live Loads Per Lane for Moment in Exterior Beams

<table>
<thead>
<tr>
<th>Type of Superstructure</th>
<th>Applicable Cross-Section from Table 4.6.2.2-4.1</th>
<th>One Design Lane Loaded</th>
<th>Two or More Design Lanes Loaded</th>
<th>Range of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Deck on Steel Beams</td>
<td>a, 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Steel Beams</td>
<td>i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid or Partially Filled Grid on Steel or Concrete Beams, T-Beams, T- and Double T-Sections</td>
<td>a, b, 6, and other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiconcrete Box Beams</td>
<td>b, c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Concrete Spread Box Beams</td>
<td>b, c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Used in Multispan Beams</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Other than Box Beams Used in Multispan Beams</td>
<td>h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Grid Deck on Steel Beams</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Beams</td>
<td>b, c</td>
<td>As specified in Table 4.5.2.2-8.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### DF_V

**Distribution factor for shear in Interior Beams**

Table 4.6.2.2-3.3a-1: Distribution of Live Loads Per Lane for Shear in Interior Beams

<table>
<thead>
<tr>
<th>Type of Superstructure</th>
<th>Applicable Cross-Section from Table 4.6.2.2-4.1</th>
<th>One Design Lane Loaded</th>
<th>Two or More Design Lanes Loaded</th>
<th>Range of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>a, 1</td>
<td>See Table 4.6.2.2-2a-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid or Partially Filled Grid on Steel or Concrete Beams, T-Beams, T- and Double T-Sections</td>
<td>a, b, 6, and other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiconcrete Box Beams</td>
<td>b, c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Concrete Spread Box Beams</td>
<td>b, c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Used in Multispan Beams</td>
<td>g</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Other than Box Beams Used in Multispan Beams</td>
<td>h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Grid Deck on Steel Beams</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Beams</td>
<td>b, c</td>
<td>As specified in Table 4.5.2.2-8.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DF

- Distribution factor for shear in Exterior Beams

<table>
<thead>
<tr>
<th>Type of Superstructure</th>
<th>Applicable Condition</th>
<th>One Design Lane Loaded</th>
<th>Two or More Design Lanes Loaded</th>
<th>Range or Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>a, f</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>i</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid or Partially Filled Grid on Steel or Concrete Beams</td>
<td>a, e, i and other j if sufficiently supported or act as a unit</td>
<td>Lever Rule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multispan Concrete Box Beams, Box Sections</td>
<td>d</td>
<td>Lever Rule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Deck on Concrete-Spread Box Beams</td>
<td>b, c</td>
<td>Lever Rule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Box Beams Used in Multispan Decks</td>
<td>1, g</td>
<td>Lever Rule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Beams Other Than Box Beams Used in Multispan Decks</td>
<td>h</td>
<td>Lever Rule</td>
<td></td>
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<tr>
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</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Beams</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

GDF – Finite Element Analysis

Bridge Model

Load distribution in model

Boundary Conditions
Moment and Shear in Typical Girder

- At any section, if not using AASHTO's GDF
  \[ M_{LL+IM} = DFM \times M_{LL+IM,\text{Lane}} \times m \]
  \[ V_{LL+IM} = DF_V \times V_{LL+IM,\text{Lane}} \]

- At any section, if using AASHTO's GDF
  \[ M_{LL+IM} = DF_M \times M_{LL+IM,\text{Lane}} \]
  \[ V_{LL+IM} = DF_V \times V_{LL+IM,\text{Lane}} \]

Outline

- Loads on Bridges
  - Typical Loads
    - Dead Load
    - Live Load
      - Live Load of Vehicle
      - Pedestrian Load
      - Dynamic Load Allowance
  - Other Loads
    - Fatigue
    - Wind
    - Earthquake
    - ... 
  - Load and Resistance Factor Design

Live Loads (Truck, Tandem and Lane Loads)

- Place them to get maximum static effects
- Increase the static load by IM to account for dynamic effects
- Multiply by DF
- Moment/Shear from Live Load to be used in the design of girders

Other Loads

- Fatigue
- Wind
- Earthquake

Fatigue Load

- Fatigue load depends on two factors
  - Magnitude of Load:
    - use design truck with 9m between 145 kN axles placed on the bridge to produce maximum effect PLUS IM
  - Frequency of Occurrence:
    - Have to estimate \( \text{ADTT}_{SL} \) = average daily truck traffic in a single lane
Fatigue Load

**ADT**
*Average Daily Traffic* (All Vehicles/1 Direction)
From Survey (and extrapolate to future)
Max ~ 20,000 vehicles/day

<table>
<thead>
<tr>
<th>% of Truck in Traffic</th>
<th>0.803 or more</th>
<th>0.852</th>
<th>1.001</th>
</tr>
</thead>
</table>

**Number of Lanes Available to Trucks**

<table>
<thead>
<tr>
<th>Class of Hwy</th>
<th>% of Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural Interstate</td>
<td>0.20</td>
</tr>
<tr>
<td>Urban Interstate</td>
<td>0.15</td>
</tr>
<tr>
<td>Other Rural</td>
<td>0.15</td>
</tr>
<tr>
<td>Other Urban</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**Wind Load**

- Horizontal loads
- There are two types of wind loads on the structure
  - **WS** = wind load on structure
    - Wind pressure on the structure itself
  - **WL** = wind on vehicles on bridge
    - Wind pressure on the vehicles on the bridge, which the load is transferred to the bridge superstructure

- For small and low bridges, wind load typically do not control the design
- For longer span bridge over river/sea, wind load on the structure is very important
  - Need to consider the aerodynamic effect of the wind on the structure (turbulence) → wind tunnel tests
  - Need to consider the dynamic effect of flexible long-span bridge under the wind → dynamic analysis

<table>
<thead>
<tr>
<th>Number of Lanes Available to Trucks</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
</tr>
<tr>
<td>3 or more</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Pont de Normandie (1995)
France
856 m span
Wind Load

- For bridges or parts of bridges more than 10 m above low ground or water level, the **design wind velocity**, $V_{DZ}$, should be adjusted according to:

$$V_{DZ} = 2.5V_0 \left( \frac{V_{10}}{V_B} \right) \ln \left( \frac{Z}{Z_0} \right)$$

where:

- $V_{DZ}$ = design wind velocity at design elevation, $Z$ (km/h)
- $V_{10}$ = wind velocity at 10 m above low ground or above design water level (km/h) (needs to be measured at the site or assume as equal to 160 km/h)
- $V_B$ = base wind velocity of 160 km/h at 10 m
- $Z$ = height of structure at which wind loads are being calculated > 10 m
- $V_0$ = friction velocity depends on terrains
- $Z_0$ = friction length of upstream fetch depends on terrain

- After having the wind velocity, we can calculate the **pressure** on the structure (in MPa)

$$P_D = P_B \left( \frac{V_{DZ}}{V_B} \right)^2 = P_B \frac{V_{DZ}^2}{25,600}$$

<table>
<thead>
<tr>
<th>Structural component</th>
<th>Windward load, MPa</th>
<th>Leeward load, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trusses, columns and arches</td>
<td>0.0024</td>
<td>0.0012</td>
</tr>
<tr>
<td>Beams</td>
<td>0.0024</td>
<td>NA</td>
</tr>
<tr>
<td>Large flat surfaces</td>
<td>0.0019</td>
<td>NA</td>
</tr>
</tbody>
</table>

- We must also consider different angles of winds

Earthquake Load: EQ

- Horizontal load

- The magnitude of earthquake is characterized by return period
  - Large return period (e.g. 500 years) → strong earthquake
  - Small return period (e.g. 50 years) → minor earthquake

- For large earthquakes (rarely occur), the bridge structure is allowed to suffer **significant structural damage but must not collapse**

- For small earthquakes (more likely to occur), the bridge should still be in the **elastic range** (no structural damage)

- Tacoma Narrows Bridge (Tacoma, Washington, USA)
  - The bridge collapsed in 1940 shortly after completion under wind speed lower than the design wind speed but at a frequency near the natural frequency of the bridge
  - The "resonance" effect was not considered at the time
**Earthquake Load: EQ**

- Analysis Methods to determine EQ
  - Nonlinear Dynamic Method (most complex)
  - Linear Dynamic Method (still complex)
  - Nonlinear Static Method (many programs can do it)
  - Linear Static Method (we're familiar with this)

**Earthquake Load: EQ**

- To do the Nonlinear Dynamic Method you probably have to learn:
  - Structural Dynamics – to do the dynamic part
  - Advanced Design of RC/PC/Steel – to properly model the nonlinear behavior of materials
  - Earthquake Design – to understand the earthquake behaviors and the design requirements
  - Numerical Methods and/or Finite Elements – to be able to solve the problems correctly

**Too Complex !!!**
only use for very important structures

**Earthquake Load: EQ**

- The January 17, 1995 Kobe earthquake had its epicenter right between the two towers of the Akashi-Kaikyo Bridge
- The earthquake has the magnitude of 7.2 on Richter scale
- The uncompleted bridge did not have any structural damages
- The original planned length was 1990 meters for the main span, but the seismic event moved the towers apart by almost a meter!
Earthquake Load: EQ

- To do the Linear Static Method you only need:
  - Structural Analysis (already known)
  - Earthquake Design (still need to learn this!!)
- Basic concept of the method
  - Model a structure in a program using linear elastic behavior of materials
  - Apply and equivalent horizontal force to a structure
  - Press the “Run” button
  - Get the forces (moment, shear, axial force, etc…) and deformations at the points interested
  - Modified these force and deformations by some factor
  - Use these values in the design of members

- For static linear elastic structural analysis method, what happen are:
  - The forces are too large
  - The deformations are too small
- Therefore, we need to modified the forces and deformations by some factors in order to get the “true” forces and deformations under nonlinear behavior
- Factors influencing the earthquake load
  - How frequent is the seismic activity and the maximum ground acceleration expected in the area
    - Seismic Zone 1 to 4, from less to frequent
  - What is the soil condition of the area
    - Soil Profile Type I to IV - I is rock and IV is soft clay

Water Loads: WA

- Static Pressure
- Buoyancy
- Stream pressure

Vehicular Collision Force: CT

- For structures that are not protected by either:
  - Embankment
  - Crashworthy barriers 1.37m height located within 3 m
  - Any barriers 1.07 m height located more than 3 m
- For piers and abutment located within 9 m from edge of roadway or 15 m from the centerline of railway track
  - Use equivalent static force of 1800 kN acting horizontally at 1.2 m above ground
AASHTO LRFD Designs

Introduction
Design Criteria
Load Multiplier
Load Factor and Load Combinations
Resistance Factors

Historical Development

- The first US standard for bridges in 1931 (AASHO), the 17th edition of AASHTO Specifications in 2002
- Working stress design (WSD), based on allowable stresses
- In 1975-79 work on the new code, Ontario Ministry of Transportation, the 1st edition of the OHBDC in 1979
- In 1986-87 feasibility study initiated by a group of bridge engineers
- Work on the new code 1988-93
- By 2007, only AASHTO LRFD in the USA
Major Changes in LRFD Codes

- Introduction of a new philosophy of safety
- Identification of four limit states (strength, service, fatigue, extreme event)
- Development of new load models (including new live load)
- Development of new load and resistance factors
- Revised techniques for the analysis and load distribution
- Combined presentation of plain, reinforced and prestressed concrete; shear design based on strut and tie model
- Introduction of limit state-based provisions for foundation design and soil mechanics
- Expanded coverage on hydraulics and scour
- Changes to the earthquake provisions
- Inclusion of FHWA Spec for ship collision
- Coverage of bridge rails based on crash testing
- Introduction of isotropic deck design process
- Development of parallel commentary

Design Criteria

- AASHTO LRFD Specifications
- For each limit state:
  - Factored Load ≤ Factored Resistance

- Load and resistance factors serve as partial safety factors
- They are determined using the code calibration procedure

Design Criteria

General format in AASHTO LRFD Code:

\[
\sum \eta_i Q_i \leq \Phi R_n
\]

Load Multiplier
Load Factor
Nominal Load Effect
Resistance Factor
Nominal Resistance

\( \eta = \eta_l \eta_D \eta_R \)
Load Multiplier

\[ \eta = \eta_I \eta_D \eta_R \]

- \( \eta_I \) = Importance factor
  - The owner may declare a bridge or any structural component and connection thereof to be of operational importance.
  - For strength and extreme event limit states
    - 1.05 for bridge considered of operational importance e.g. the only bridge crossing the river
    - 1.00 for typical bridges
    - 0.95 for bridge considered nonimportant
  - For all other limit states
    - 1.00 for all bridges

- \( \eta_D \) = Ductility factor (Brittle v.s. Ductile failure)
  - 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.
  - For strength limit states
    - 1.05 for nonductile components & connection which may fail in a brittle manner
    - 1.00 for conventional designs
    - 0.95 for components with enhanced ductility e.g. has additional stirrups for shear reinforcements
  - For all other limit states
    - 1.00

- \( \eta_R \) = Redundant factor
  - 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 states
    - 1.05 for nonredundant members e.g. a simple span bridges
    - 1.00 for conventional level of redundancy
    - 0.95 for exceptional level of redundancy e.g. multi-girder continuous beam bridge
  - For all other limit states
    - 1.00
Load Factor & Load Combinations

\[ \gamma_i \]

**Loads & Probabilities**

- How do we use all the loads for the structural analysis?
  - Add all the mean value of loads together?
    - No, because we must consider the chance that the load may be larger or smaller than calculated.
  - Add all the extreme value of loads together?
    - No, because then the bridge must have to resist an enormous load and that would make it really expensive!
    - The chance that the maximum value of one load occurring at the same time as the maximum value of another load is very small.
  - We need to consider several cases where each case we have one load at its maximum value expected while other loads are around their mean values.

**Limit States**

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

- There are 4 types of “limit states”
  - Ultimate limit states – involving the strength and stability of the structure, both local and global
    - Strength I, II, III, IV
  - Extreme Event limit states - relates to the structural survival of a bridge during a major earthquake, flood, or collision
    - Extreme Event I, II
  - Serviceability limit states – involving the usability of the structure including stress, deformation, and crack widths
    - Service I, II, III
  - Fatigue limit state - relates to restrictions on stress range to prevent crack growth as a result of repetitive loads during the design life of the bridge
    - Fatigue
  - All limit states are equally important (AASHTO LRFD 1.3.2.1)
Permanent Loads

- DC = dead load of structural components and nonstructural attachments
- DW = dead load of wearing surface and utilities
- EL = accumulated locked-in force effects resulting from the construction process
- DD = downdrag
- EH = horizontal earth pressure load
- ES = earth surcharge load
- EV = vertical pressure from dead load of earth fill

Transient Loads

- LL = vehicular live load
- IM = vehicular dynamic load allowance
- PL = pedestrian live load
- LS = live load surcharge
- BR = vehicular braking force
- CE = vehicular centrifugal force
- CT = vehicular collision force
- CV = vessel collision force
- EQ = earthquake

Load Combinations

<table>
<thead>
<tr>
<th>Load Combination</th>
<th>DC</th>
<th>DD</th>
<th>DW</th>
<th>EH</th>
<th>EV</th>
<th>EL</th>
<th>LL</th>
<th>IM</th>
<th>CE</th>
<th>BR</th>
<th>PL</th>
<th>LS</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength-I (unless noted)</td>
<td>Y_v</td>
<td>1.75</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.03</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strength-II</td>
<td>Y_v</td>
<td>1.35</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strength-III</td>
<td>Y_v</td>
<td>-</td>
<td>1.00</td>
<td>1.40</td>
<td>-</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strength-IV (EH, EV, ES, DW) DC ONLY</td>
<td>Y_v</td>
<td>1.35</td>
<td>1.00</td>
<td>0.40</td>
<td>1.0</td>
<td>1.00</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Strength-V</td>
<td>Y_v</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extreme Event-I</td>
<td>Y_v</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Extreme Event-II</td>
<td>Y_v</td>
<td>0.50</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>Service-I</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.30</td>
<td>1.0</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Service-II</td>
<td>1.00</td>
<td>1.30</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Service-III</td>
<td>1.00</td>
<td>0.80</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fatigue-LL, IM &amp; CE ONLY</td>
<td>-</td>
<td>0.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Use One of These at a Time

<table>
<thead>
<tr>
<th>EQ</th>
<th>IC</th>
<th>CT</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Load Combinations

- **STRENGTH I**: Basic load combination relating to the normal use of bridge. Maximum combination is used when LL produces the same effect as DC. Minimum combination is used when LL produces opposite effect to DC.
- **STRENGTH II**: load combination for special vehicles specified by owner
- **STRENGTH III**: load combination where the bridge is subjected to high wind (> 90 km/h) and traffic is prevented
- **STRENGTH IV**: load combination for long span bridges (>67 m span) which has large ratio of DC to LL
- **STRENGTH V**: load combination where bridge and traffic on the bridge is subjected to wind velocity of 90 km/h

**Example of combinations:**
- 1.25DC + 1.50DW + 1.75(LL+IM) (Strength I)
- 1.25DC + 1.50DW + 1.4WS (Strength III)
- 0.90DC + 0.65DW + 1.4WS (Strength III)
- 1.50DC + 1.50DW (Strength IV)
- 1.25DC + 1.50DW + 1.35(LL+IM) + 0.4(WS+WL) (Strength V)
- 1.25DC + 1.50DW + 0.5(LL+IM) + 1.0EQ (Extreme I)
- 0.90DC + 0.65DW + 0.5(LL+IM) + 1.0EQ (Extreme I)
- 1.25DC + 1.50DW + 0.5(LL+IM) + 1.0 (CT or CV) (Extreme I)
- 0.90DC + 0.65DW + 0.5(LL+IM) + 1.0 (CT or CV) (Extreme I)

**EXTREME EVENT I**: load combination for structural survival under major earthquake

**EXTREME EVENT II**: load combination for structural survival under combination of events such as flood and vessel collision

**SERVICE I**: load combination for normal operation of the bridge and for checking compression in prestressed concrete

**SERVICE II**: load combination for steel bridges to control yielding

**SERVICE III**: load combination relating to tension in prestressed concrete during service

**FATIGUE**: load combination for fatigue and fracture due to repetitive LL and IM
Load Combinations

- For slabs and girders designs, we normally have only DC, DW, and (LL+IM)
  - $1.25\text{DC} + 1.50\text{DW} + 1.75(\text{LL+IM})$ (Strength I)
  - $1.50\text{DC} + 1.50\text{DW}$ (Strength IV)
  - $1.00\text{DC} + 1.00\text{DW} + 1.00(\text{LL+IM})$ (Service I)
  - $1.00\text{DC} + 1.00\text{DW} + 1.30(\text{LL+IM})$ (Service II, Steel)
  - $1.00\text{DC} + 1.00\text{DW} + 0.80(\text{LL+IM})$ (Service III, Prestressed)

Resistance Factors

- Resistance factors are different for different types of action (moment or shear, for example) and for different types of materials (steel or concrete). They are specified under each section of materials.

<table>
<thead>
<tr>
<th>Types</th>
<th>$\Phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexure and Tension</td>
<td>0.90</td>
</tr>
<tr>
<td>in Reinforced Concrete</td>
<td></td>
</tr>
<tr>
<td>in Prestressed Concrete</td>
<td>1.00</td>
</tr>
<tr>
<td>Shear in Normal Weight Concrete</td>
<td>0.90</td>
</tr>
<tr>
<td>Axial Compression</td>
<td>0.75</td>
</tr>
<tr>
<td>Bearing on Concrete</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Resistance and Probabilities

- Resistance factor is determined so that the reliability index, $\beta$, is close to the target value, $\beta_T$ (about 3.5)
## Resistance Factors

### Steel Structures

<table>
<thead>
<tr>
<th>Types</th>
<th>Φ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexure</td>
<td>1.00</td>
</tr>
<tr>
<td>Shear</td>
<td>1.00</td>
</tr>
<tr>
<td>Axial Compression (steel or composite)</td>
<td>0.90</td>
</tr>
<tr>
<td>Block shear</td>
<td>0.80</td>
</tr>
<tr>
<td>Tension</td>
<td></td>
</tr>
<tr>
<td>Yielding limit state</td>
<td>0.95</td>
</tr>
<tr>
<td>Fracture limit state</td>
<td>0.80</td>
</tr>
</tbody>
</table>
### Design Equation

**Case** | **Load Configuration** | **Moments (kips-ft) and shears (kips)** | **Loading and limitations** (x and l in feet)
---|---|---|---
A | ![Image A](image) | \( M(x) = P \left[ 4.5 \left( 1 - \frac{x}{l} \right) - 42 \frac{x}{l} \right] \) | Truck loading
\( P = 16 \) kips
\( M_x \geq M_y \) for:
\( l > 28 \)
\( x \leq l/3 \)
\( x + 28 \leq l \)
\( V_x > V_y \) for any x

B | ![Image B](image) | \( M(x) = P \left[ 4.5 \left( 1 - \frac{x}{l} \right) - 21 \frac{x}{l} \right] \) | Truck loading
\( P = 16 \) kips
\( M_x \geq M_y \) for:
\( l > 28 \)
\( x > l/3 \)
\( 14 \leq x \leq l/2 \)

C | ![Image C](image) | \( M(x) = 50x \left( 1 - \frac{x}{l} \right) \) | Tandem loading is more severe than truck loading for \( l \leq 37 \) ft

D | ![Image D](image) | \( M(x) = 0.64 \frac{(l-x)}{2} \) | Lane loading

**SI units:**

| Combination * | Load configuration | Absolute maximum moment in span (kN-m)
---|---|---
1 | HS20 truck + uniform lane load: | \( (M_{\text{max}})_{LL+IM} = (1 + I)M_{\text{truck}} + M_{\text{unif-lane}} \) \( M_{\text{truck}} = 81.25l + \frac{x_1}{l} (473 - 1397.5x_1) - 387 \) \( M_{\text{unif-lane}} = 1.1625 \left( l^2 - 4x_1^2 \right) \) where \( x_1 = \frac{473}{650 + 9.3l} \) m

2 | Tandem + uniform lane load: | \( (M_{\text{max}})_{LL+IM} = (1 + I)M_{\text{tandem}} + M_{\text{unif-lane}} \) \( M_{\text{tandem}} = 27.5l + \frac{x_2}{l} (66 - 110x_2) \) - 33 \( M_{\text{unif-lane}} = 1.1625 \left( l^2 - 4x_2^2 \right) \) where \( x_2 = \frac{132}{440 + 9.3l} \) m

* Combination 1 is more severe than Combination 2 for \( l > 12 \) m.
Bending Moment in Simple Span for AASHTO HL-93 Loading for a fully loaded lane
Moment in kips-ft
IM is included
1 ft = 0.3048 m
1 kips = 4.448 kN
1 kips-ft = 1.356 kN-m
Shear in Simple Span for AASHTO HL-93 Loading for a fully loaded lane

Shear in kips
IM is included

\[ l \text{ ft} = 0.3048 \text{ m} \]
\[ 1 \text{ kips} = 4.448 \text{ kN} \]
Design Chart for Negative Moment due to Live Load Combination 3 at Interior Support of Continuous Beams with Equal Spans
For one lane loading
IM is included
<table>
<thead>
<tr>
<th>SUPPORTING COMPONENTS</th>
<th>TYPE OF DECK</th>
<th>TYPICAL CROSS-SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Beam</td>
<td>Cast-in-place concrete slab, precast concrete slab, steel grid, glued/spiked panels, stressed wood</td>
<td>(a)</td>
</tr>
<tr>
<td>Closed Steel or Precast Concrete Boxes</td>
<td>Cast-in-place concrete slab</td>
<td>(b)</td>
</tr>
<tr>
<td>Open Steel or Precast Concrete Boxes</td>
<td>Cast-in-place concrete slab, precast concrete deck slab</td>
<td>(c)</td>
</tr>
<tr>
<td>Cast-in-Place Concrete Multicell Box</td>
<td>Monolithic concrete</td>
<td>(d)</td>
</tr>
<tr>
<td>Cast-in-Place Concrete Tee Beam</td>
<td>Monolithic concrete</td>
<td>(e)</td>
</tr>
<tr>
<td>Precast Solid, Voided or Cellular Concrete Boxes with Shear Keys</td>
<td>Cast-in-place concrete overlay</td>
<td>(f)</td>
</tr>
<tr>
<td>SUPPORTING COMPONENTS</td>
<td>TYPE OF DECK</td>
<td>TYPICAL CROSS-SECTION</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------</td>
<td>------------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>Precast Solid, Voided, or Cellular Concrete Box with Shear Keys and with or without Transverse Post-Tensioning</td>
<td>Integral concrete</td>
<td>(g)</td>
</tr>
<tr>
<td>Precast Concrete Channel Sections with Shear Keys</td>
<td>Cast-in-place concrete overlay</td>
<td>(h)</td>
</tr>
<tr>
<td>Precast Concrete Double Tee Section with Shear Keys and with or without Transverse Posttensioning</td>
<td>Integral concrete</td>
<td>(l)</td>
</tr>
<tr>
<td>Precast Concrete Tee Section with Shear Keys and with or without Transverse Posttensioning</td>
<td>Integral concrete</td>
<td>(j)</td>
</tr>
<tr>
<td>Precast Concrete I or Bulb-Tee Sections</td>
<td>Cast-in-place concrete, precast concrete</td>
<td>(k)</td>
</tr>
<tr>
<td>Wood Beams</td>
<td>Cast-in-place concrete or plank, glued/spiked panels or stressed wood</td>
<td>(l)</td>
</tr>
<tr>
<td>Type of Beams</td>
<td>Applicable Cross-Section from Table 4.6.2.2.1-1</td>
<td>Distribution Factors</td>
</tr>
<tr>
<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>a, l</td>
<td>See Table 4.6.2.2.2a-1</td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>l</td>
<td>One Design Lane Loaded: ( \frac{S}{3700} )</td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid, or Partially Filled Grid on Steel or Concrete Beams; Concrete T-Beams, T- and Double T-Sections</td>
<td>a, e, k and also i, j if sufficiently connected to act as a unit</td>
<td>Two or More Design Lanes Loaded: [ 0.06 \cdot \left( \frac{S}{4300} \right)^{0.4} \left( \frac{S}{L} \right)^{0.3} \left( \frac{K_g}{L_t^2} \right)^{0.1} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two or More Design Lanes Loaded: [ 0.075 \cdot \left( \frac{S}{2900} \right)^{0.6} \left( \frac{S}{L} \right)^{0.2} \left( \frac{K_g}{L_t^3} \right)^{0.1} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>use lesser of the values obtained from the equation above with ( N_b = 3 ) or the lever rule</td>
</tr>
<tr>
<td>Multicell Concrete Box Beam</td>
<td>d</td>
<td>One Design Lane Loaded: [ 1.75 \cdot \left( \frac{S}{1100} \right) \left( \frac{300}{L} \right)^{0.35} \left( \frac{1}{N_c} \right)^{0.45} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two or More Design Lanes Loaded: [ \frac{13}{N_c} \left( \frac{S}{430} \right)^{0.3} \left( \frac{1}{L} \right)^{0.25} ]</td>
</tr>
<tr>
<td>Concrete Deck on Concrete Spread Box Beams</td>
<td>b, c</td>
<td>One Design Lane Loaded: [ \left( \frac{S}{910} \right)^{0.35} \left( \frac{S d}{L^2} \right)^{0.25} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Two or More Design Lanes Loaded: [ \left( \frac{S}{1900} \right)^{0.6} \left( \frac{S d}{L^2} \right)^{0.125} ]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use Lever Rule</td>
</tr>
<tr>
<td>Type of Beams</td>
<td>Applicable Cross-Section from Table 4.6.2.2.1</td>
<td>Distribution Factors</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Concrete Beams used in Multibeam Decks</td>
<td>f</td>
<td>One Design Lane Loaded: &lt;br&gt; [ k \left( \frac{b}{2.8L} \right)^{0.8} \left( \frac{J}{J} \right)^{0.25} ] &lt;br&gt; where: [ k = 2.5(N_o)^{0.2} &gt; 1.5 ] Two or More Design Lanes Loaded: &lt;br&gt; [ k \left( \frac{b}{7600} \right)^{0.8} \left( \frac{b}{L} \right)^{0.2} \left( \frac{J}{J} \right)^{0.05} ]</td>
</tr>
<tr>
<td>g if sufficiently connected to act as a unit</td>
<td>h</td>
<td>Regardless of Number of Loaded Lanes: S/D &lt;br&gt; where: [ C = K(W/L) ] [ D = 300 \left[ 11.5 - N_i + 1.4N_o (1 - 0.2C^2) \right] ] [ D = 300 \left[ 11.5 - N_i \right] ] [ K = \sqrt{\frac{(1 - \mu)^2}{J}} ] for preliminary design, the following values of K may be used: &lt;br&gt; Beam Type</td>
</tr>
<tr>
<td>g,i,j if connected only enough to prevent relative vertical displacement at the interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Grids on Steel Beams</td>
<td>a</td>
<td>One Design Lane Loaded: &lt;br&gt; S/2300 If ( t_o &lt; 100) mm ( S/3050 ) If ( t_o \geq 100) mm Two or More Design Lanes Loaded: &lt;br&gt; S/2400 If ( t_o &lt; 100) mm ( S/3050 ) If ( t_o \geq 100) mm</td>
</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Girders</td>
<td>b, c</td>
<td>Regardless of Number of Loaded Lanes: &lt;br&gt; [ 0.05 \cdot 0.85 \cdot \frac{N_I}{N_o} = 0.425 ]</td>
</tr>
</tbody>
</table>
Table 4.6.2.2.2d-1 - Distribution of Live Loads Per Lane for Moment in Exterior Longitudinal Beams

<table>
<thead>
<tr>
<th>Type of Superstructure</th>
<th>Applicable Cross-Section from Table 4.6.2.2.1-1</th>
<th>One Design Lane Loaded</th>
<th>Two or More Design Lanes Loaded</th>
<th>Range of Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>a, l</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>l</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid, or Partially Filled Grid on Steel or Concrete Beams; Concrete T-Beams, T and Double T Sections</td>
<td>a, e, k and also i, j if sufficiently connected to act as a unit</td>
<td>Lever Rule</td>
<td>[ g = e g_{\text{interior}} ] [ e = 0.77 + \frac{d_e}{2800} ] ( -300 \leq d_e \leq 1700 )</td>
<td>( N_b = 3 ) use lesser of the values obtained from the equation above with ( N_b = 3 ) or the lever rule</td>
</tr>
<tr>
<td>Multicell Concrete Box Beams, Box Sections</td>
<td>d</td>
<td>[ g = \frac{W_e}{4300} ]</td>
<td>[ g = \frac{W_e}{4300} ]</td>
<td>( W_e \leq S )</td>
</tr>
<tr>
<td>Concrete Deck on Concrete Spread Box Beams</td>
<td>b, c</td>
<td>Lever Rule</td>
<td>[ g = e g_{\text{interior}} ] [ e = 0.97 + \frac{d_e}{8700} ] ( 0 \leq d_e \leq 1400 ) ( 1800 &lt; S \leq 3500 )</td>
<td>Use Lever Rule ( S &gt; 3500 )</td>
</tr>
<tr>
<td>Concrete Box Beams Used in Multibeam Decks</td>
<td>f, g</td>
<td>Lever Rule</td>
<td>[ g = e g_{\text{interior}} ] [ e = 1.04 + \frac{d_e}{7600} ] ( 300 \leq d_e \leq 600 )</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Beams Other than Box Beams Used in Multibeam Decks</td>
<td>h</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Steel Grid Deck on Steel Beams</td>
<td>a</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Girders</td>
<td>b, c</td>
<td>As specified in Table b-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Superstructure</td>
<td>Applicable Cross-Section from Table 4.6.2.2.1-1</td>
<td>One Design Lane Loaded</td>
<td>Two or More Design Lanes Loaded</td>
<td>Range of Applicability</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------------------------------</td>
<td>------------------------</td>
<td>-------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>See Table 4.6.2.2.2a-1</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>a, e, k and also i, j if sufficiently connected to act as a unit</td>
<td>[ \frac{0.36}{7600} \times S ]</td>
<td>[ \frac{0.2}{3600} \left( \frac{S}{10700} \right)^2 ]</td>
<td>1100 ≤ S ≤ 4900 6000 ≤ L ≤ 73 000 110 ≤ t_1 ≤ 300 4×10^9 ≤ K_0 ≤ 3×10^{10} N_c &gt; 4</td>
</tr>
<tr>
<td>Concrete Deck, Filled Grid, or Partially Filled Grid on Steel or Concrete Beams, Concrete T-Beams, T- and Double T-Sections</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multicell Concrete Box Beam, Box Sections</td>
<td>d</td>
<td>[ \left( \frac{S}{2900} \right)^{0.04} \left( \frac{d}{L} \right)^{0.1} ]</td>
<td>[ \left( \frac{S}{2200} \right)^{0.08} \left( \frac{d}{L} \right)^{0.1} ]</td>
<td>1800 ≤ S ≤ 4000 6000 ≤ L ≤ 73 000 890 ≤ d ≤ 2800 N_c ≥ 3</td>
</tr>
<tr>
<td>Concrete Deck on Concrete Spread Box Beams</td>
<td>b, c</td>
<td>[ \left( \frac{S}{3050} \right)^{0.04} \left( \frac{d}{L} \right)^{0.1} ]</td>
<td>[ \left( \frac{S}{2250} \right)^{0.08} \left( \frac{d}{L} \right)^{0.1} ]</td>
<td>1800 ≤ S ≤ 3500 6000 ≤ L ≤ 43 000 450 ≤ d ≤ 1700 N_c ≥ 3</td>
</tr>
<tr>
<td>Concrete Box Beams Used in Multibeam Decks</td>
<td>f, g</td>
<td>[ 0.70 \left( \frac{b}{L} \right)^{0.15} \left( \frac{J}{J_0} \right)^{0.05} ]</td>
<td>[ 0.70 \left( \frac{b}{4000} \right)^{0.14} \left( \frac{J}{J_0} \right)^{0.05} ]</td>
<td>900 ≤ b ≤ 1500 6000 ≤ L ≤ 37 000 5 ≤ N_c ≤ 20 1.0×10^{10} ≤ J ≤ 2.5×10^{11} 1.7×10^{10} ≤ J ≤ 2.5×10^{11}</td>
</tr>
<tr>
<td>Concrete Beams Other Than Box Beams Used in Multibeam Decks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Grid Deck on Steel Beams</td>
<td>a</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck on Multiple Steel Box Beams</td>
<td>b, c</td>
<td>As specified in Table 4.6.2.2.2b-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Superstructure</td>
<td>Applicable Cross-Section from Table 4.6.2.2.1-1</td>
<td>One Design Lane Loaded</td>
<td>Two or More Design Lanes Loaded</td>
<td>Range of Applicability</td>
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<td>-----------------------------------------------</td>
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<tr>
<td>Wood Deck on Wood or Steel Beams</td>
<td>a, l</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
<tr>
<td>Concrete Deck on Wood Beams</td>
<td>l</td>
<td>Lever Rule</td>
<td>Lever Rule</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| Concrete Deck, Filled Grid, or Partially Filled Grid on Steel or Concrete Beams; Concrete T-Beams, T- and Double T-Beams | a, e, k and also i, j if sufficiently connected to act as a unit | Lever Rule | $g = e g_{\text{interior}}$  
$e = 0.6 + \frac{d_e}{3000}$ | $-300 \leq d_e \leq 1700$ | |
| Multicell Concrete Box Beams, Box Sections   | d                                             | Lever Rule             | $g = e g_{\text{interior}}$  
$e = 0.64 + \frac{d_e}{3800}$ | $-600 \leq d_e \leq 1500$ | $N_b = 3$ |
| Concrete Deck on Concrete Spread Box Beams   | b, c                                          | Lever Rule             | $g = e g_{\text{interior}}$  
$e = 0.8 + \frac{d_e}{3050}$ | $0 \leq d_e \leq 1400$ | $S > 3500$ |
| Concrete Box Beams Used in Multibeam Decks   | f, g                                          | Lever Rule             | $g = e g_{\text{interior}}$  
$e = 1.02 + \frac{d_e}{15 \, 000}$ | $-300 \leq d_e \leq 800$ | |
| Concrete Beams Other Than Box Beams Used in Multibeam Decks | h, i, j if connected only enough to prevent relative vertical displacement at the interface | Lever Rule             | Lever Rule                      | N/A                    |
| Steel Grid Deck on Steel Beams               | a                                             | Lever Rule             | Lever Rule                      | N/A                    |
| Concrete Deck on Multiple Steel Box Beams    | b, c                                          | As specified in Table 4.6.2.2.2b-1 | | |