ENCE717 – Bridge Engineering
Introduction

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Introduction

1. **Role of Bridge Engineer**
2. Bridge Structure Selection
3. Load and Resistance Factor Design (1.2/1.3)
4. Various Bridge Structural Forms (2.2)
5. Approximate & Refined Analysis Methods (2.3 & 2.4)
6. Selected Mathematical Modeling (2.5)

Role of Bridge Engineer

- The bridge engineer is often involved with several or all aspects of bridge planning, design, and management
- The bridge engineer works closely with other civil engineers who are in charge of the roadway design and alignment.
- After the alignment is determined, the bridge engineer often controls the bridge type, aesthetics, and technical details
- The bridge engineer is often charged with reviewing shop drawing and often construction details
- The owner, who is often a department of transportation or other public agency, is charged with the management of the bridge, either doing the work in-house or hiring consultants

Role of Bridge Engineer (cont.)

- Bridge management includes routine inspections, repair, rehabilitation and retrofits or even replacement (4R) as necessary
- In summary, the bridge engineer has significant control over the design, construction, and maintenance processes. In return, bridge engineer has significant responsibility for public safety and resources
- In short, the bridge is (or interface closely with) the planner, architect, designer, constructor, and facility manager.

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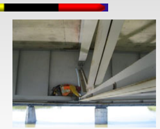
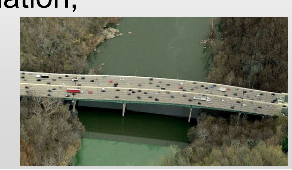
Bridge Structure Selection

- Environmental Assessment Consideration (Appendix A: FHWA Order)
  - Historic: consulting with the State Historic Preservation Officer
  - Construction Impact
  - Flood Plain (stream or river subject to overflow)
  - Wetlands
  - “Landmark”

Bridge Structure Selection (cont.)

- Design Philosophy
  - Safety
  - Serviceability (including durability of materials)
  - Inspectability
  - Maintainability
  - Rideability
  - Deformations (Deflections)
  - Constructability
  - Economy (Appendix B: Economic Evaluation; Appendix C: Caltran Estimate)
  - Bridge Aesthetics





Bridge Structure Selection (cont.)

- Life Costs vs. First Cost

  “Ideal” Life-Cycle Costs

  LCC = DC + BC + OC + LP + RC

where

DC = Design Costs

BC = Estimated Bid Costs

OC = Estimated Maintenance/Operating Costs

LP = Cost accrued by the traveling public due to delays and detours required for maintenance and/or rehabilitation

RC = Rehabilitation/Replacement Construction Costs

Bridge Structure Selection (cont.)

- Parameters in selecting the Type, Size and Location (TS&L)
  - Span Length (pier location, site constraints, best combination of super- and sub-structure costs)
  - Accessibility to the site (weight limit, on-site fabrication)
  - Estimated Costs
  - Beam Spacing
  - Material Availability (local supplier?)
  - Time available for design and construction (urban area time constraints)
  - Geometry – curved or straight?
- Deck Superstructures (Appendix D: Common Deck Superstructures)

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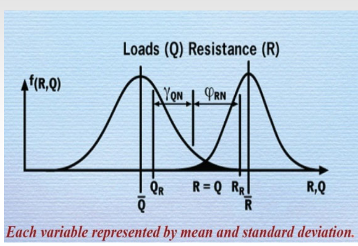
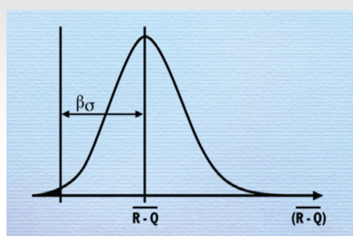
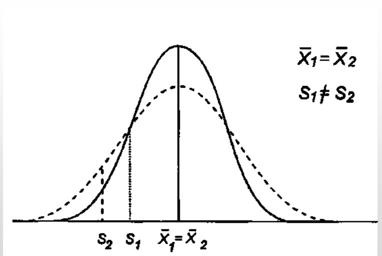
Concept of Load and Resistance Factor Design

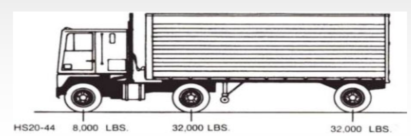




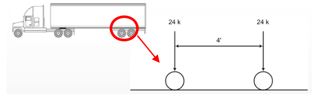


Live Loads considered in ASD and LRFD Methods

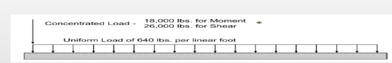
Vehicular load HS-20 used in ASD



HS-20 Truck

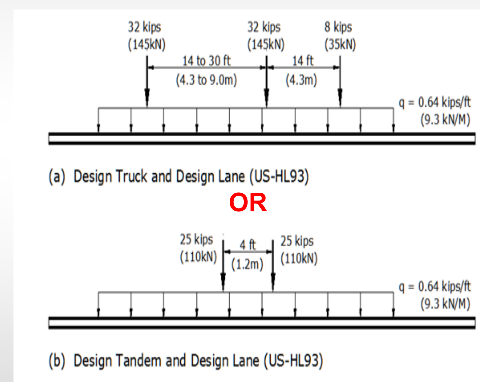


OR Tandem (Interstate or Military)

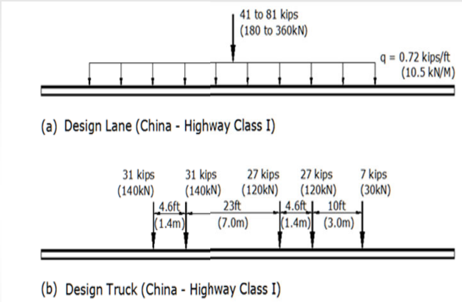


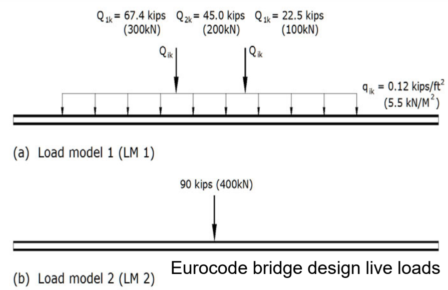
OR Concentrated Load plus Lane Load

Vehicular load HL-93 used in LRFD

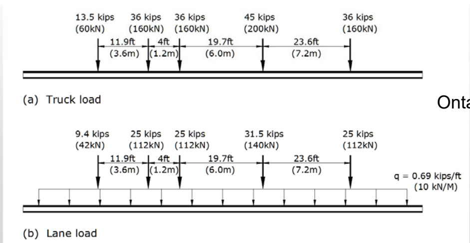


China, Eurocode and Ontario Bridge Design Live Loads





Eurocode bridge design live loads



Ontario bridge design live loads

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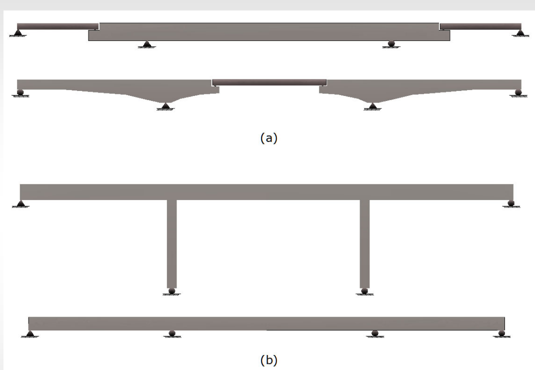
Bridge Structural Forms - Beam Deck



- (a) statically determinant structure

(determined solely from free-body diagrams and equations of equilibrium)

- (b) statically indeterminant structure

(To solve statically indeterminate systems, considering the material properties and compatibility in deformation)

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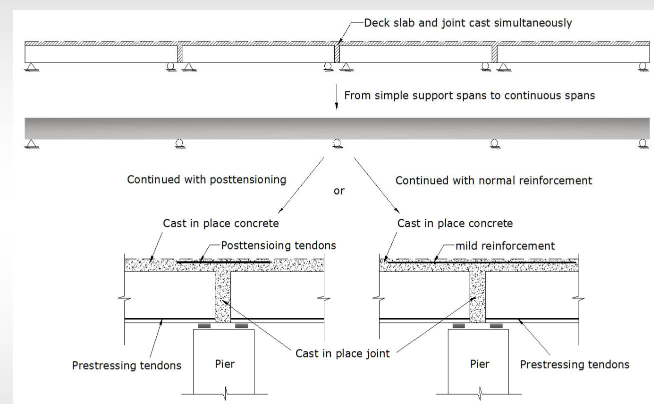
Bridge Structural Forms - Beam Deck



Two-stage construction and analysis – from simple support to continuous (SDCL)

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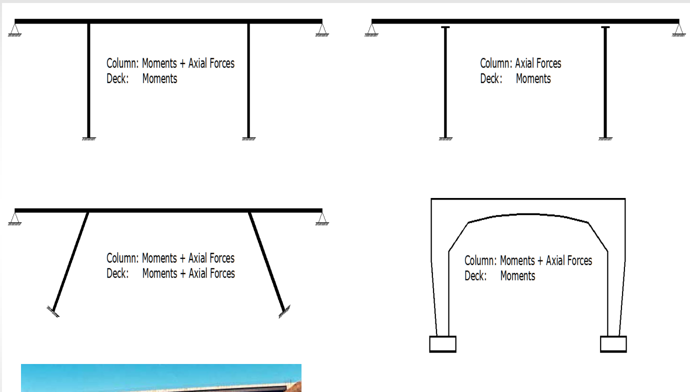
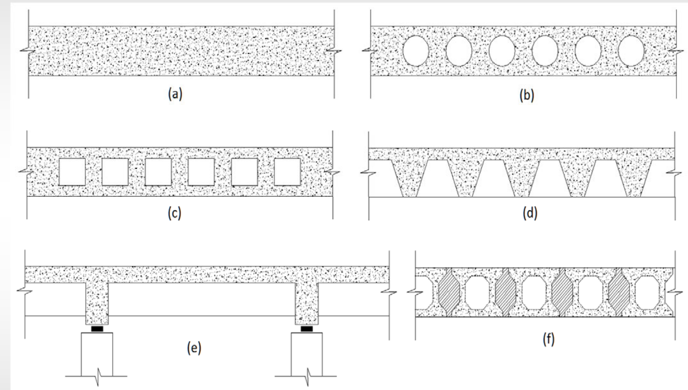
Bridge Structural Forms - Beam Deck

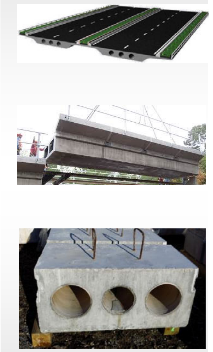


Blooming Rose Road over I-68, Garrett County, MD

Frame-type bridges and internal forces under main loads

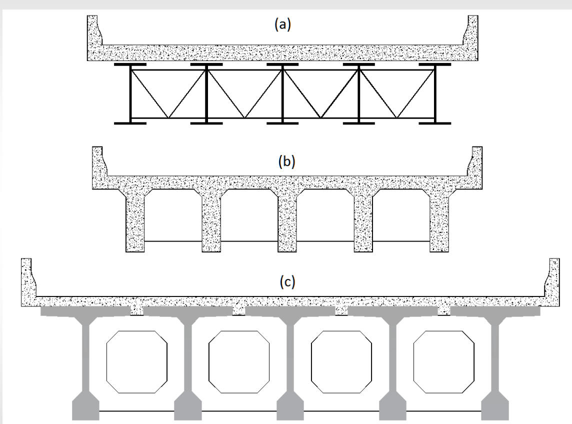
Bridge Structural Forms – Slab Deck





(a) solid slab; (b) circular void slab; (c) rectangular void slab; (d) corrugated slab; (e) precast beam slab; and (f) “shear key” slab

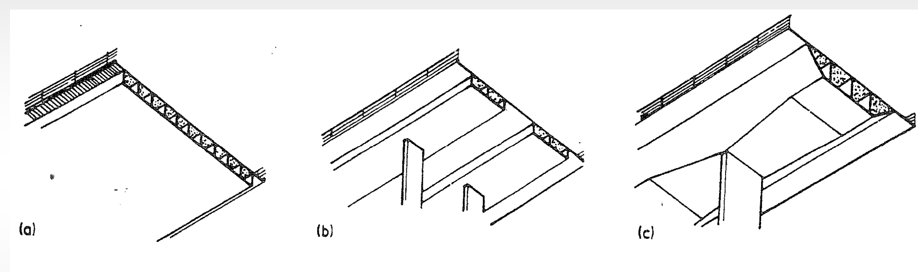
Bridge Structural Forms – Beam-Slab Deck



(a)steel composite, (b) cast-in-place concrete and

(c) precast concrete

Bridge Structural Forms – Cellular Deck



(a) rectangular attached multi-cell bridge; (b) detached multi-cell box-girder bridge; (c) trapezoidal attached multi-cell bridge

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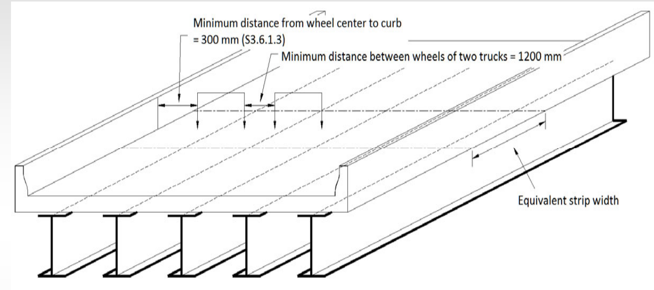
Approximate Analysis Methods – Plane Frame – Bridge Deck

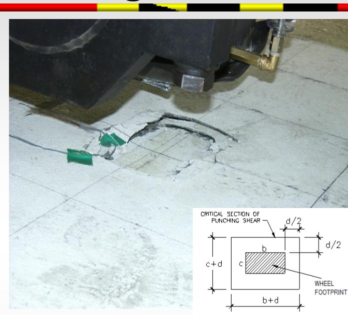


Equivalent strip width in AASHTO LRFD Specifications (modified Westergaard Equations in SI units) for calculating transverse flexural stresses between girders.

- +M: $E = 660 + 0.55S$ (2.1a)
- -M: $E = 1220 + 0.25S$ (2.1b)

where E is the equivalent strip width in mm, S is the stringer spacing, and +M is the positive moment region, -M is the negative moment region.

Approximate Analysis Methods – Plane Frame – Bridge Deck

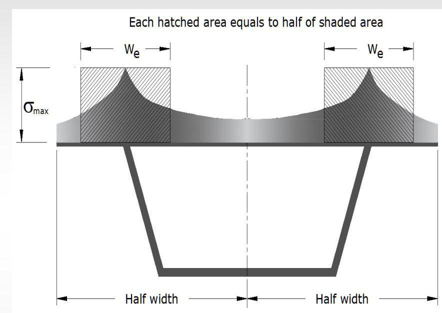


For punching shear without shear reinforcement, the shear strength of concrete V_n in equation 2.3 is governed by the AASHTO equation in metric form

- $V_n = \left(0.17 + \frac{0.33}{\beta_c}\right)\sqrt{f'_c}\, b_o d \le 0.33\sqrt{f'_c}\, b_o d$

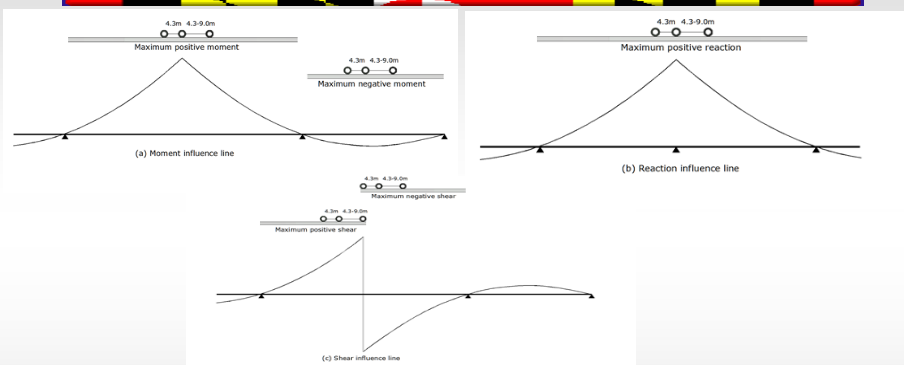
where β_c is the ratio of long side to short side of concentrated load or reaction area, and b_o is the perimeter (=2[(b+d)+(c+d)]

Approximate Analysis Methods – Plane Frame – Bridge Deck



- Live load distribution factor - portion of live loads carried by an individual girder
- Effective flange width (Shear Lag) - Since 2008, using the full tributary areas of the girder
- Live load influence line – moving load over a beam model

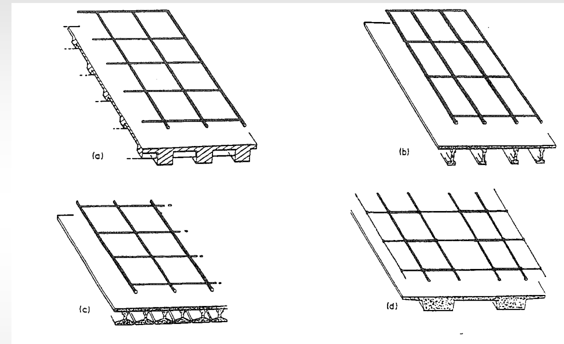
Approximate Analysis Methods – Plane Frame – Bridge Deck



AASHTO LRFD Specifications defines the following loading combinations:

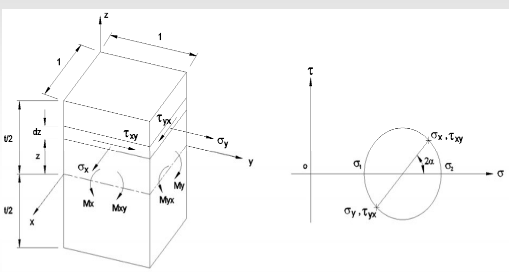
- design tandem with design lane load;
- one design truck with variable axle spacing with design lane load;
- 90% of two design trucks with axles from two trucks spaced minimum 15000 mm (two 145-kN axles spaced 4300 mm) with 90% of the design lane load.

Refine Analysis Methods – Grillage Analogy Method



(a) About equal stiffness
(b) More dominant longitudinal beams
(c) Closely spaced beams
(d) wider beams with two longitudinal members per beam

Refine Analysis Methods – Orthotropic Plate Method



(a) Moments and stresses in a unit area of an orthotropic plate (b) Principle stresses and Mohr's circle of stresses

$$D_x \frac{\delta^4 w}{\delta x^4} + (D_{xy} + D_{yx}) \frac{\delta^4 w}{\delta x^2 \delta y^2} + D_y \frac{\delta^4 w}{\delta y^4} = p(x,y)$$

Where $D_x = E_x t^3/[12(1 - \upsilon_x \upsilon_y)]$

$D_y = E_y t^3/[12(1 - \upsilon_x \upsilon_y)]$

$D_{xy} = \frac{1}{2}(1 - \nu_x \nu_y)\sqrt{D_x D_y}$

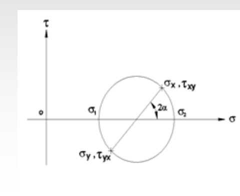
Refine Analysis Methods – Orthotropic Plate Method

(2.5b)

$$M_x = -D_x\left(\frac{\partial^2 w}{\partial x^2} + \upsilon_y \frac{\partial^2 w}{\partial y^2}\right) \qquad \sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left[\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2\right]}$$

$$M_y = -D_y\left(\frac{\partial^2 w}{\partial y^2} + \upsilon_x \frac{\partial^2 w}{\partial x^2}\right) \qquad \sigma_2 = \frac{\sigma_x - \sigma_y}{2} - \sqrt{\left[\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2\right]}$$

$$M_z = -2D_{xy}\left(\frac{\partial^2 w}{\partial x \partial y}\right) \qquad \tan 2\alpha = \frac{2\tau_{xy}}{\sigma_x - \sigma_y}$$

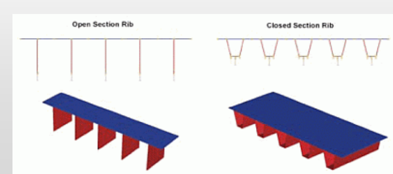


(b) Principle stresses and Mohr's circle of stresses

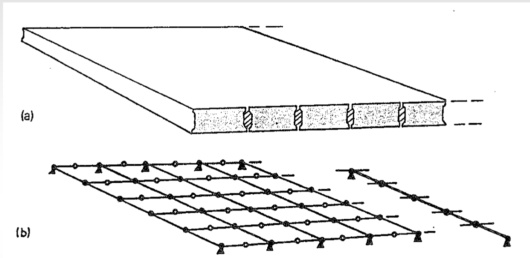
A simplified analysis is made by assuming:

For decks with closed ribs: $D_y \cong 0$

For decks with open ribs: $D_y \cong 0$, $D_{xy} \cong D_{yx} \cong 0$



Refine Analysis Methods – Articulated Plate Method



- Slab bridge with solid block – $D_x = \frac{E t^3}{12}$ $D_{xy} = \frac{G t^3}{3}$ if $S > t$ $D_{xy} = GS\frac{t}{3}$ if $S < t$
- Slab bridge with rectangular void block - $D_x = E t_1 \frac{H^2}{2}$ $D_{xy} = G\frac{J}{S}$ and $J = \frac{4A^2}{\oint \frac{ds}{t_1}}$
- Slab bridge with circular void block - $D_x = E\left(\frac{t^3}{12} - \frac{\pi t_\upsilon^4}{64 S}\right)$ $D_{xy} = G\frac{t^3}{3}\left[1 - 0.84\left(\frac{t_\upsilon}{t}\right)^4\right]$
- Box girder bridge - $D_x = \frac{E I_g}{S}$ $D_{xy} = G\frac{J}{S}$ and $J = \frac{4A^2}{\oint \frac{ds}{n_s t_1}}$

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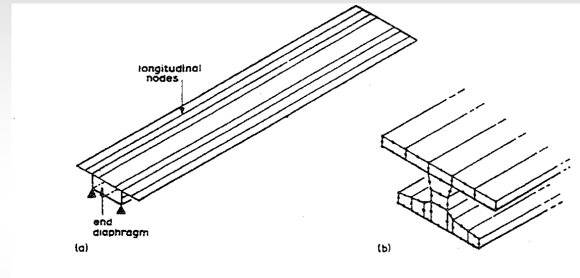
Refine Analysis Methods – Finite Strip Method



A simplified finite element with bridge deck modeled end-to-end is called finite strip . The displacement functions for in-plane and out-of-plane deformation of the strip are of the form

$$w, \theta, u \text{ or } v = \sum f(y) \sin\left(\frac{n\pi x}{L}\right)$$

- Since finite strip method involves fewer nodes and a smaller matrix to solve, it is sometimes more economical than other methods such as finite element.

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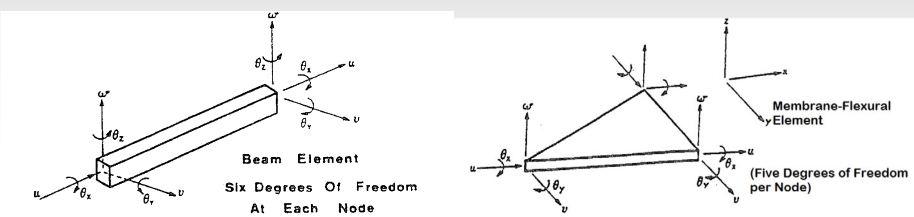
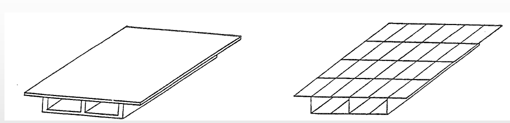
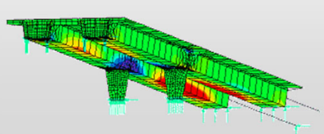
Refine Analysis Methods – Finite Element Method







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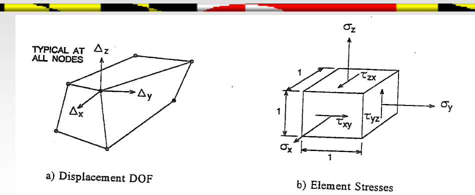
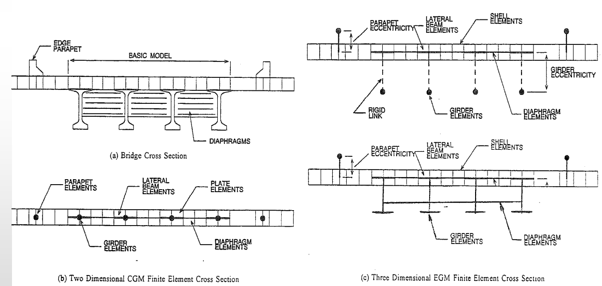
Refine Analysis Methods – Finite Element Method





Several different modeling techniques for a beam-slab bridge, which can be in 1D, 2D (b) or 3D (c) model.

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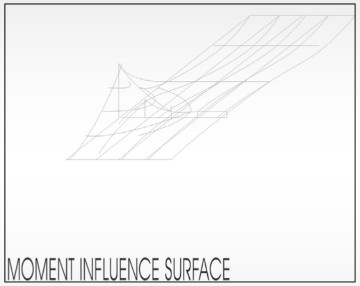
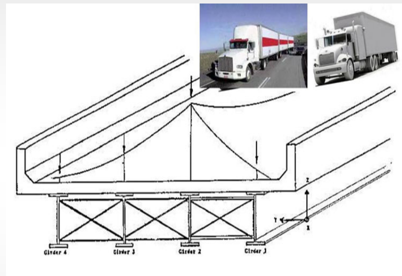
Refine Analysis Methods – Live Load Influence Surface





If a refined analysis method is used, influence surfaces are then generated, with x and y as the surface coordinates and z as the ordinate.

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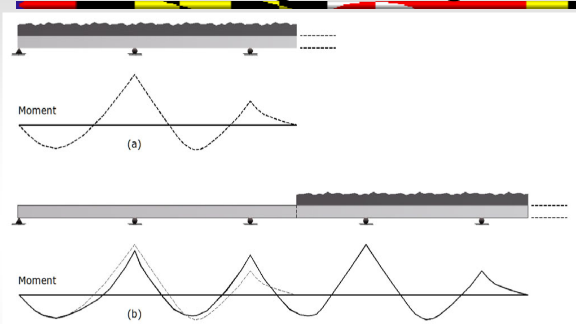
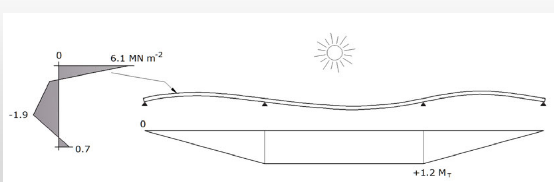
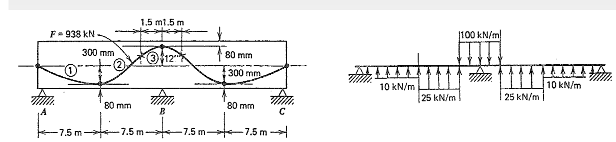
Selected Mathematical Modeling – Beam bridge and rigid frame bridge



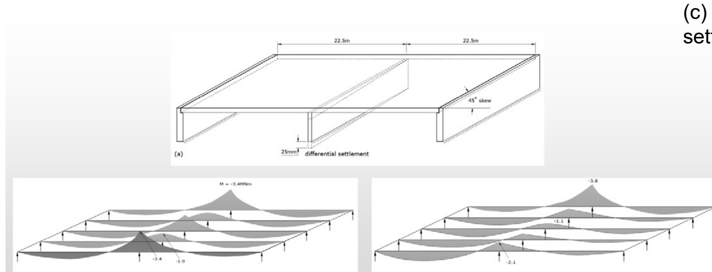
For simple model and quick turn-out, modeled by 2D beam elements and 2D frame elements:
- construction staging
- thermal loading due to differential temperature



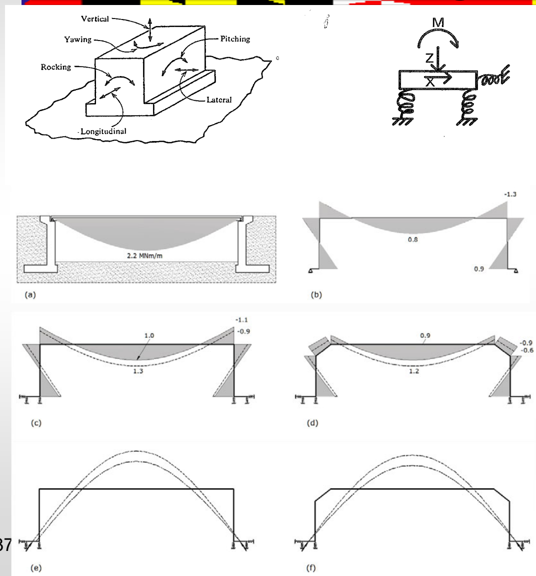
Selected Mathematical Modeling – Beam bridge and rigid frame bridge



- prestressing loading as equivalent applying forces
- loading due to support movement (moment redistribution in (b) for non-settlement case vs (c) for differential settlement case)



Selected Mathematical Modeling – Beam bridge and rigid frame bridge



- Three-spring foundation

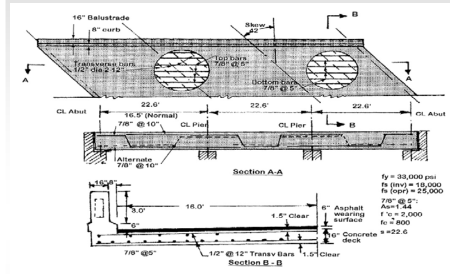
Vertical spring: $K_z = \frac{25GA^{0.5}}{(1-\nu)}$

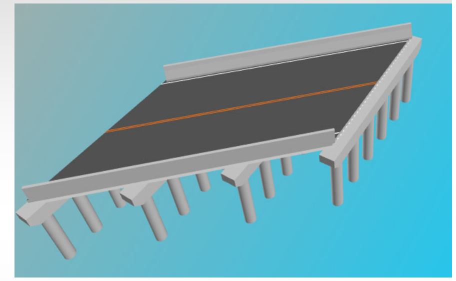
Horizontal spring: $K_x = 2G(1+\nu)A^{0.5}$

Rock spring: $K_{zr} = \frac{2.5GZ}{(1-\nu)}$

- 2D Frame structure modeled with soil springs

Selected Mathematical Modeling – Slab bridge





In the AASHTO LRFD Specifications, a beam model with equivalent strip width can be built for the slab bridge. With one lane loaded, the equivalent width of longitudinal strips is (AASHTO Eq. 4.6.2.3-1 & -2 in mm)

$$E = 250 + 0.42\sqrt{L_1 W_1}$$

and with multi-lane loaded,

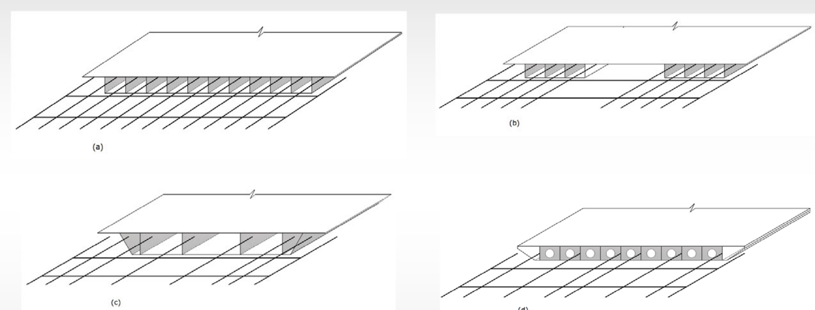
$$E = 2100 + 0.12\sqrt{L_1 W_1} \leq \frac{W}{N}$$

where E is the equivalent width (mm), L_1 is the modified span length taken equal to the lesser of the actual span or 18000 mm, W_1 is the modified edge-to-edge width of bridge taken equal to the lesser of the actual width or 18000 mm, W is the actual edge-to-edge width of bridge, L is the physical length of bridge, and N is the number of design lanes.

Selected Mathematical Modeling – Beam-Slab bridge

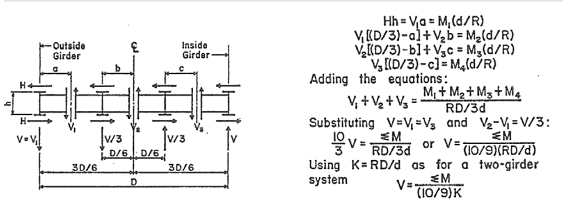
- Approximation of the beam model by using the effective width, live load distribution factor, and influence lines
- Several conditions to be met for a beam-slab bridge and they are defined in the AASHTO LRFD Specifications as:
  - width of the bridge is constant,
  - number of beams is not less than four,
  - beams are parallel and have approximately the same stiffness,
  - roadway part of the overhang does not exceed 1 m (3 ft),
  - curvature in plane is less than the limit specified in the AASHTO LRFD Specifications ,
  - cross-section is consistent with one of the cross-sections shown in the AASHTO LRFD Specifications.
- If the above conditions are violated, the refined methods, such as grillage analogy or finite element method, are recommended.
- When applying finite element, however, it has to be cautious that mesh size, coordinates, loading directions, and boundary conditions affect on getting good results.
- The most popular type which will be discussed in detail later

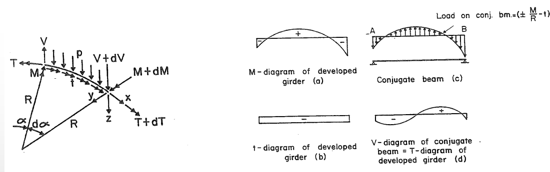
Selected Mathematical Modeling – Cellular/box girder bridge



- Types of cellular deck and their mesh definitions
- For a cellular deck, where the cells are either attached or detached, the principal modes of deformation are due to longitudinal bending, transverse bending, torsion, and distortion

Selected Mathematical Modeling – Curved girder bridge



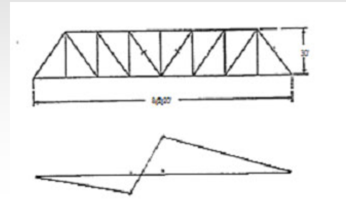


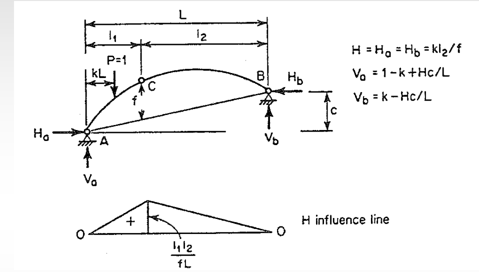
Two approximate methods which have been used to analyze curved girder bridges:

- V-Load Method used for curved I-girder bridges - radial force is converted to a shear force across the diaphragms
- M/R method used for curved box girder bridges

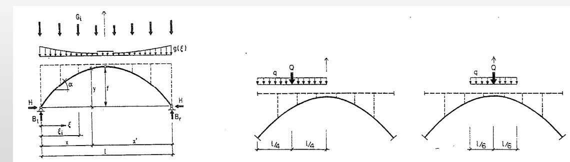
Currently, the most popular modeling method in applying finite element analysis is either 2D grillage analogy method, or generic 3D modeling.

Selected Mathematical Modeling – Truss and Arch bridge

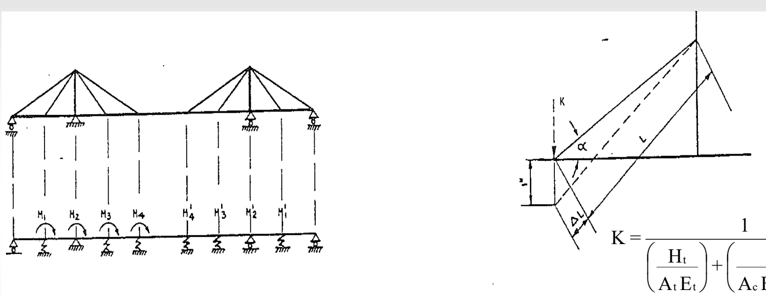




- Usually, trusses are designed assuming pin-jointed that the members carry direct axial stresses only, which are termed primary stresses
- If correctly designed, the self-weight of the arch structure induces mainly compressive forces (line of thrust).



Selected Mathematical Modeling – Cable-stayed bridge

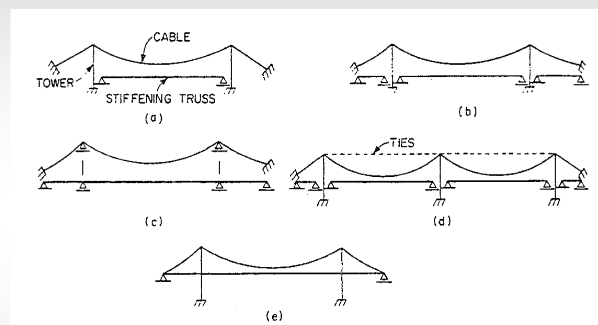


$$K = \frac{1}{\left(\frac{H_t}{A_t E_t}\right) + \left(\frac{L_c}{A_c E_c \sin^2 \alpha}\right)}$$

where A_t, E_t, and H_t are the area, Young's modulus and height of the tower. A_c, E_c, L_c and α are the area, Young's modulus, length, and inclined angle of the cable

Basic cable-stayed system
(a) assumption of continuous stiffening girder on elastic supports;
(b) moveable cable

Selected Mathematical Modeling – Suspension bridge



Suspension bridge model with different arrangements
(a) one suspended span with pinned stiffened truss,
(b) three suspended spans, with pin-ended stiffened trusses,
(c) three suspended spans with continuous stiffened trusses,
(d) multi-suspended spans with pin-ended stiffened trusses, and
(e) self-anchored suspension bridge