Introduction to Structural Design of Buried Bridges (Non-seismic)

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Chair, TRB AFF70 - Culverts and Hydraulic Structures

Webinar Outline

- Description of Buried Bridges and Design Input
- Design of Concrete Buried Bridges – Philip Creamer
- Design of Metal Buried Bridges – Joel Hahm
- Questions

What is a Buried Bridge?

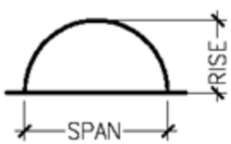
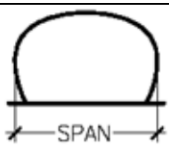
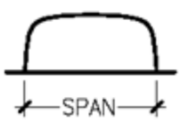
- Buried bridges are arch, three-sided, or box-shaped structures with unsupported spans (bridge lengths) greater than 20 ft that rely on soils for support.

- "Buried bridge" is distinguished from "bridge" to capture the need for design and analysis methods that consider soil-structure interaction.

- "Buried bridge" is distinguished from "culvert" to describe the importance of these large structures for highway safety.

- Addressed by Transportation Research Board (TRB)
  - Technical Committee *AFF70 Culverts and Hydraulic Structures*
  - Subcommittee *AFF70-1 Buried Bridges*

Buried Bridge Geometry

SHAPE	RANGE OF SIZES	COMMON USES
REINFORCED CONCRETE		
 RECTANGULAR (BOX)	**Span 8 ft to 48 ft**	**Culverts and Short-span bridges.**
 THREE-SIDED	**Span 8 ft to 48 ft**	**Culverts and Short-span bridges.**
 ARCH	**Span 15 ft to 102 ft**	**Culverts and Short-span bridges For low, wide waterway enclosures, aesthetic bridges**
CORRUGATED METAL		
 ARCH	Span x Rise 5 ft x 1 ft 9.5 in. to 82 ft x 42 ft	**Culverts and Short-span bridges, Low clearance waterway, aesthetic bridges**
 HIGH PROFILE ARCH	Span 20 ft To 83 ft	**Culverts and Short-span bridges, Grade separations, Ammunition magazines, earth covered storage**
 BOX	Span 10 ft To 53 ft	**Culverts and Short-span bridges**

Applications of Buried Bridges

- Bridge replacement or rehabilitation
- Limited site access and remote locations
- Staged construction
- Accelerated Bridge Construction (ABC) alternative to Cast-in-place (CIP) reinforced concrete bridge components
- Wildlife & aquatic crossings
- Environmentally sensitive crossings
- Canal / utility crossings
- Pedestrian access
- Emergency or temporary detours
- Single span alternative to daylight multi-cell culverts
- Extreme live loadings – Mines, runways, etc…
- …any bridge project!

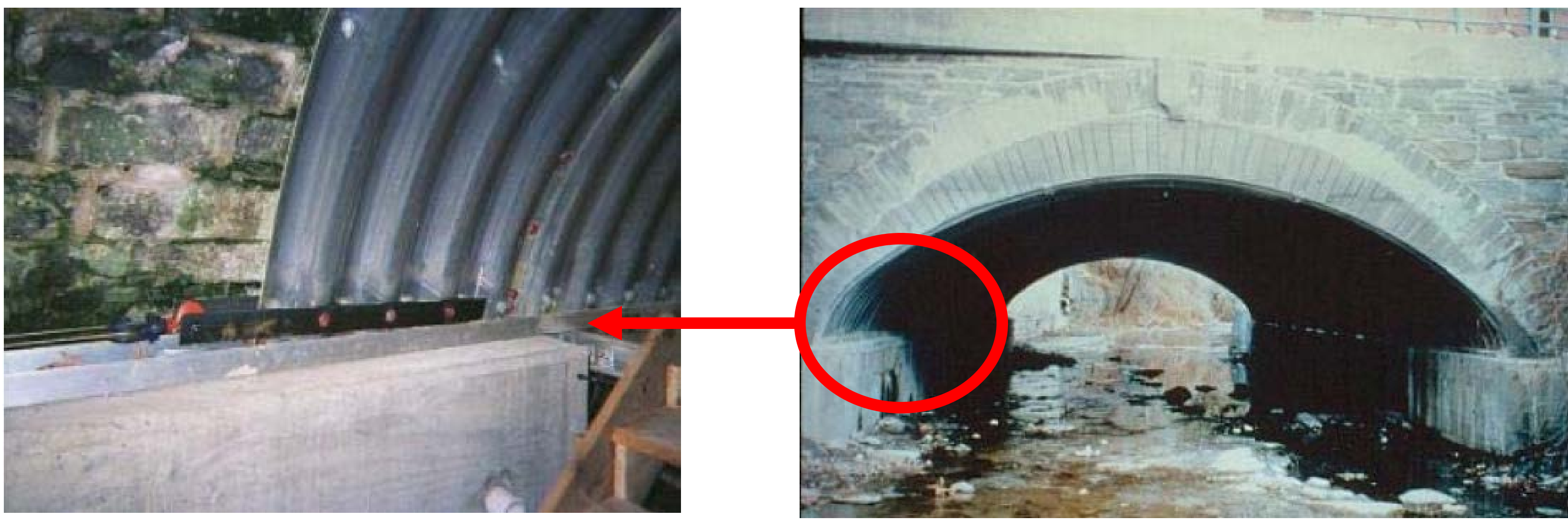
Double-cell Highway Stream Crossing

Railway Overpass with Cooper E-80 Loading

Airport Taxiway Grade Separation

Application: Preservation of Historical Stone Arch Bridge

- Conventional bridge replacement estimate
  - $600k bridge
  - $1.4M shoring for historical bldgs
- Custom fit metal buried bridge metal with grouted annular space
  - $260k



Application: Bridge Replacement

- Steel girder overpass scheduled for replacement
- Contractor proposed value engineering concrete buried bridge
  - Half construction time
  - Maintained 4 traffic lanes
  - No bridge deck maintenance
  - Est. $2.5M savings

Benefits of Buried Bridges – Design and Installation

- Reduced engineering design time
  - Simple/standard designs – less than 1 week.
  - Designs including soil-structure interaction – 2 to 3 weeks.

- Reduced fabrication and installation times (ABC)
  - Shop fabrication and relatively fast delivery.
  - Typical installation in 1-3 days reduces traffic impact.
  - Reduced manpower and equipment vs. conventional bridge installation.
  - Specialized labor skills are not required for installation.

- Sustainability benefits:
  - Reduced materials shipment needs.
  - Use of recycled materials for backfill and structure fabrication.

Other Benefits of Buried Bridges

- Reduced overall costs over conventional bridges.
- Reduced cost to add shoulders, bike lanes, etc. to width.
- Good seismic and blast performance due to soil embedment.
- Designs are adaptable to site-specific requirements such as curves, skews, and slopes.
- Aesthetics are easily adapted to fit local architecture or landscaping goals by using form liners, facades, and special end treatments.
- Significant increased load capacity relative to conventional girder bridges due to load sharing with soil embedment.
- No bridge deck or expansion joints significantly reduces common bridge maintenance needs.
- Reduced structural components simplifies routine inspection.
- Reduced cost to lengthen for future roadway widening.

Metal Buried Bridge Fabrication

Precast Concrete Buried Bridge Fabrication

Reduced Labor for Installation

Buried Utilities in Fill Over Bridge

Common End Treatments

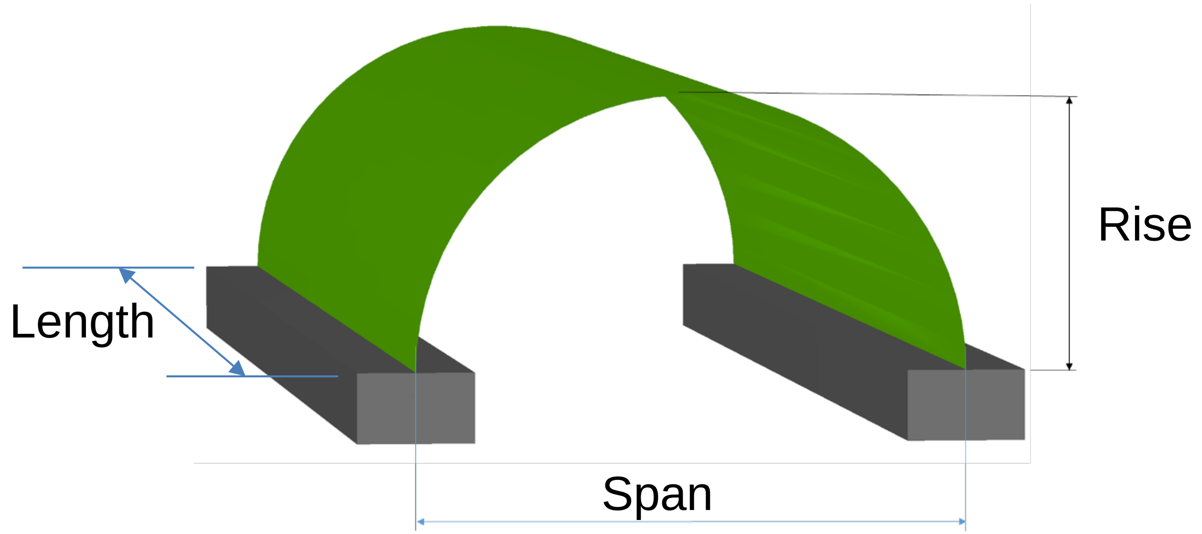
- MSE wire or block walls, geosynthetics
- Corrugated metal faced walls
- Vegetated or paved slopes
- Cast-in-Place or Precast Concrete Walls
- Stones or other architectural treatment

General Design Steps – Buried Bridges

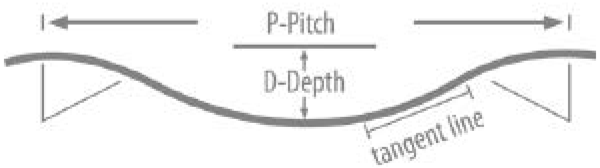
- Function
  - Determine buried bridge structure geometry
  - Hydraulics and special design (not discussed here)
- Serviceability
  - Evaluate durability (not discussed here)
- Safety
  - Structural design by soil-structure interaction (SSI)
  - Design foundation/bedding and backfill
- Design end treatments
- Specify product and installation requirements

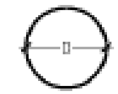
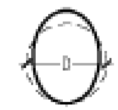
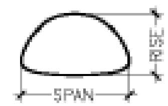
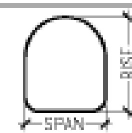
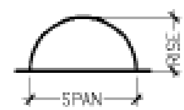
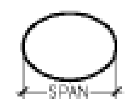
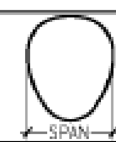
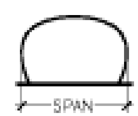
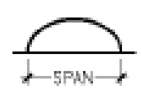
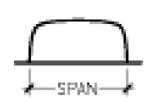
Buried Bridge Structure Geometry

- Span x rise determined by:
  - hydraulic opening based on design flood for stream crossing
  - roadway clearance envelope for grade separation
- Scour depth may influence rise and foundation depth.
- Bridge length determined by roadway geometry, embankment slopes, waterway channel alignment



Corrugated Metal Structure Shapes



SHAPE		RANGE OF SIZES	COMMON USES
Round		6 in. – 51 ft	Culverts, subdrains, sewers, service tunnels, etc. All plates same radius. For medium and high fills (or trenches).
Vertically–elongated (ellipse) 5% is common		4 – 21 ft nominal; before elongating	Culverts, sewers, service tunnels, recovery tunnels. Plates of varying radii; shop fabrication. For appearance and where backfill compaction is only moderate.
Pipe–arch		Span x Rise 17 in. x 13 in. to 20 ft 7 in. x 13 ft 2 in.	Where headroom is limited. Has hydraulic advantages at low flows. Corner plate radius, 18 inches or 31 inches for structural plate.
Underpass*		Span x Rise 5 ft 8 in. x 5 ft 9 in. to 20 ft 4 in. x 17 ft 9 in.	For pedestrians, livestock or vehicles (structural plate).
Arch		Span x Rise 5 ft x 1 ft 9½ in. to 82 ft x 42 ft	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse		Span 7 – 40 ft	Culverts, grade separations, storm sewers, tunnels.
Pear		Span 25 – 30 ft	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch		Span 20 – 83 ft	Culverts, grade separations, storm sewers, tunnels. Ammo ammunition magazines, earth covered storage.
Low Profile Arch		Span 20 – 83 ft	Low–wide waterway enclosures, culverts, storm sewers.
Box Culverts		Span 10 – 53 ft	Low–wide waterway enclosures, culverts, storm sewers.
Specials		Various	For lining old structures or other special purposes. Special fabrication.

Precast Concrete Shapes

SHAPE	RANGE OF SIZES	COMMON USES
CIRCULAR	12 to 144 in. reinforced 6 to 10 in. nonreinforced	Culverts, storm drains, and sewers.
PIPE ARCH	15 to 72 in. equivalent diameter	Culverts, storm drains, and sewers. Used where fill depth is limited.
HORIZONTAL ELLIPSE	Span x Rise 18 to 144 in. equivalent diameter	Culverts, storm drains, and sewers. Used where fill depth is limited.
VERTICAL ELLIPSE	Span x Rise 18 to 144 in. equivalent diameter	Culverts, storm drains, and sewers. Used where lateral clearance is limited.
RECTANGULAR (BOX)	Span 3 ft to 12 ft	Culverts, storm drains, and sewers. Used for wide openings with limited head.
ARCH	Span 15 ft to 102 ft	Culverts and storm drains. For low, wide waterway enclosures.

Hydraulic Design (not covered in this presentation)

- *AASHTO Drainage Guidelines*
- Considerations
  - Scour depth/limits
  - Alignment and end treatments
- Special Case Considerations
  - Design for Aquatic Organism Passage (AOP)

Durability (not covered in this presentation)

- AASHTO LRFD Sec 11.10 (from MSE Walls) to determine required steel protection based on soil corrosion potential.
- Manufacturer will offer coatings and linings for metal based on soil and water chemistry effects on the structure and foundation.
- Manufacturer will offer concrete mix designs for resistance to sulfates, if necessary.

AASHTO LRFD Structural Design

- AASHTO LRFD Bridge Design Specifications
  - 3.4 Load Factors and Combinations
  - 12.4 Soil and Material Properties
  - 12.5 Limit States and Resistance Factors
  - 12.6 General Design Considerations
  - 12.7, 12.8, 12.8.9, 12.9 Metal Arches & Boxes, Long-span, Deep corrugated, Structural Plate Box
  - 12.11, 12.14 Reinforced Concrete Boxes & Arches, Precast Reinforced Concrete Three-Sided Structures
- Design Live Loads:
  - AASHTO - HL-93
  - State-specific - HL-93 Mod; legal loads, overload trucks (load ratings)
  - Railroad - Cooper E-80
  - Runway - FAA Aircraft
  - Other - Owner specific special design loads

AASHTO Sec 3.4 Load Combinations & 12.5 Limit States

- 12.5 - Design for Service I, Strength I, and Strength II
- C12.5.3 – Do not design for fatigue, seismic due to burial

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n = R_r$$

Table 3.4.1-1—Load Combinations and Load Factors

Load Combination Limit State	*DC DD DW EH EV ES EL PS CR SH*	*LL IM CE BR PL LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	Use One of These at a Time *EQ*	*BL*	*IC*	*CT*	*CV*
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.4	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—

AASHTO Sec 12.4.1 - Foundations and Soils

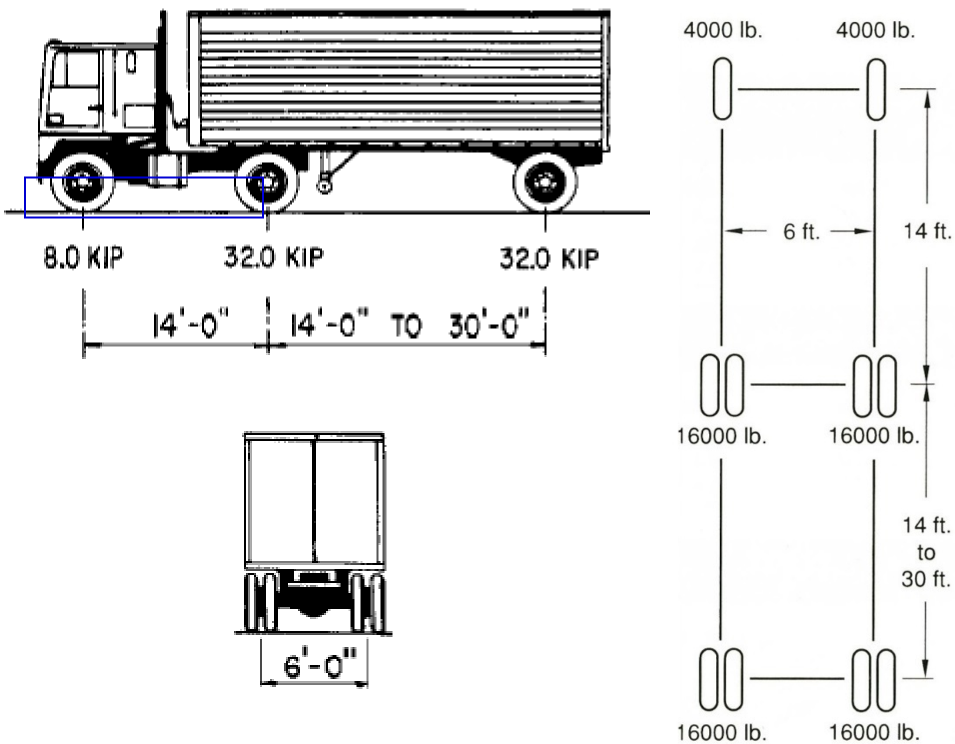
- Arches and Three-sided Structures
  - AASHTO LRFD Bridge Design Specifications Section 10 Foundations
  - Deep foundations (piles with pile cap)
  - Strip (spread) footings
- Closed shapes include design of bedding
- May require imported fill
- Re-use excavated site soils for backfill where quality, consistency, and economics allow
- Critical backfill around structure is engineered fill and includes specified material properties and specified compaction
- Roadway subgrade requirements dictate fill above critical backfill zone

AASHTO Design for Different Structure Types

- Sec 12.4.2 structure materials for buried bridges include:
  - Aluminum pipe and structural plate
  - Concrete, CIP and Precast
  - Steel pipe and structural plate
  - Deep corrugated structures

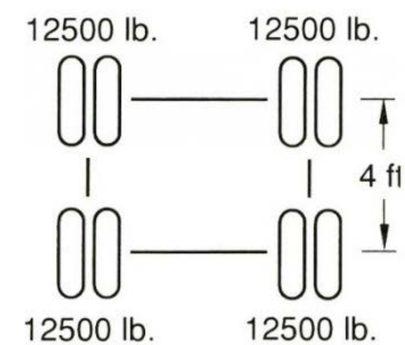
AASHTO Design Vehicular Live Load

- HL-93 live load is the design truck or design tandem with the design lane load.



Live Load Modifiers

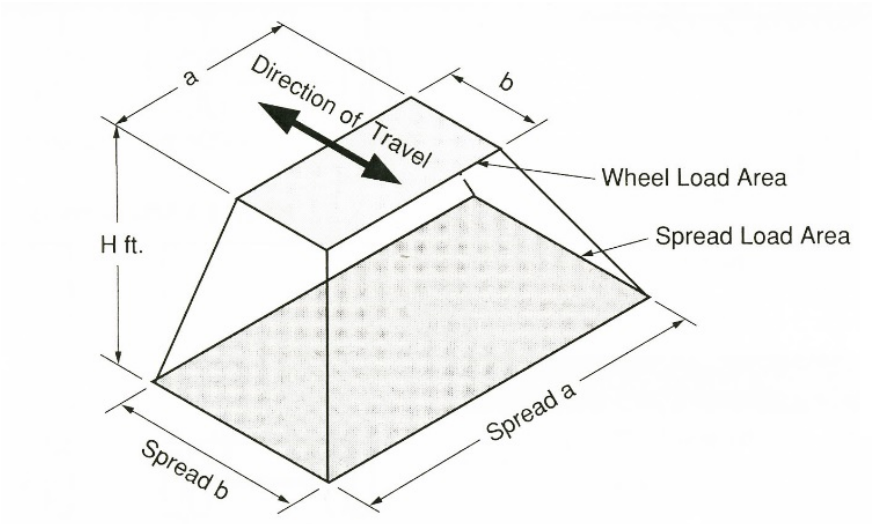
- Dynamic Load Allowance, IM
  - $IM = 33 * (1 - D_E/8) \geq 0\%$
  - D_E = Cover in ft
  - Apply to Load: $(1 + IM/100)$
- Multiple Presence Factor, m
  - For single lane, m = 1.2
  - For 2 lanes, m = 1.0

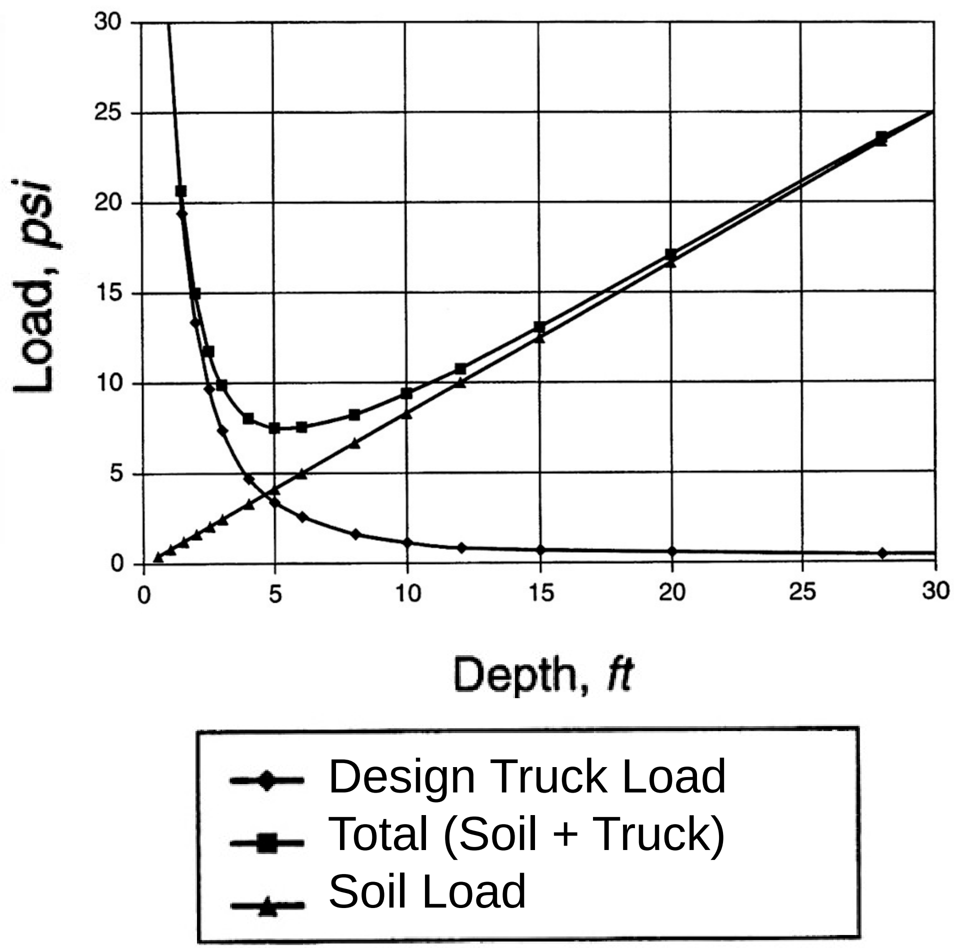


AASHTO Design Truck

AASHTO Design Tandem

Application of Live Load

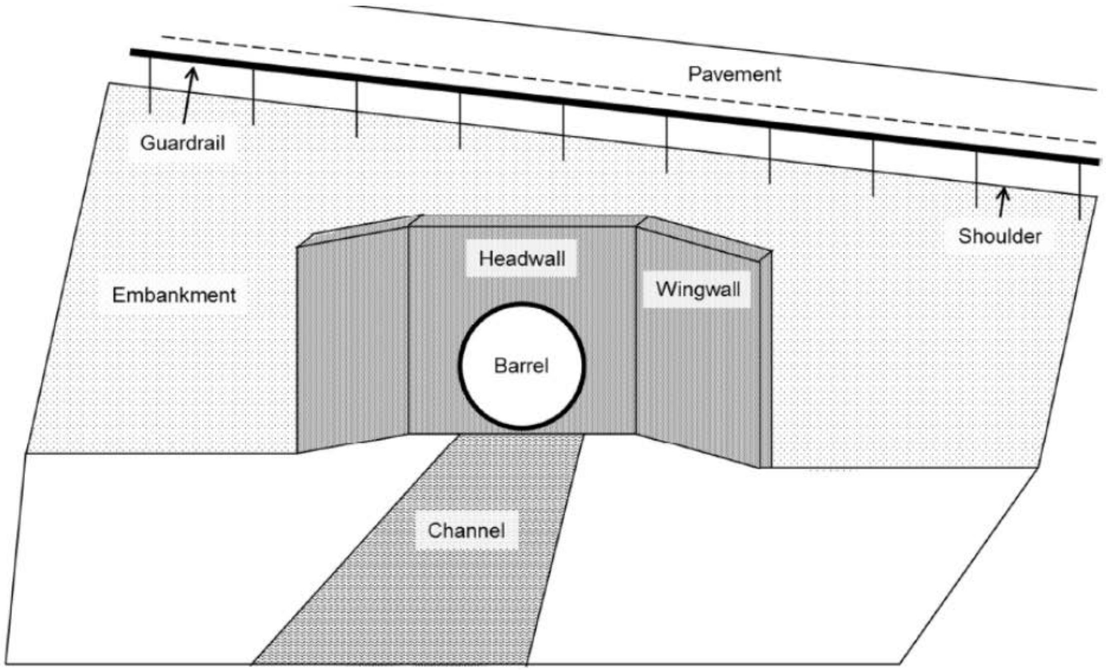




- Live Load Distribution
  - Wheel Area = a x b
  - Spread a = a + 1.15H
  - Spread b = b + 1.15H
  - Area at depth = Spread a x Spread b

End Treatments

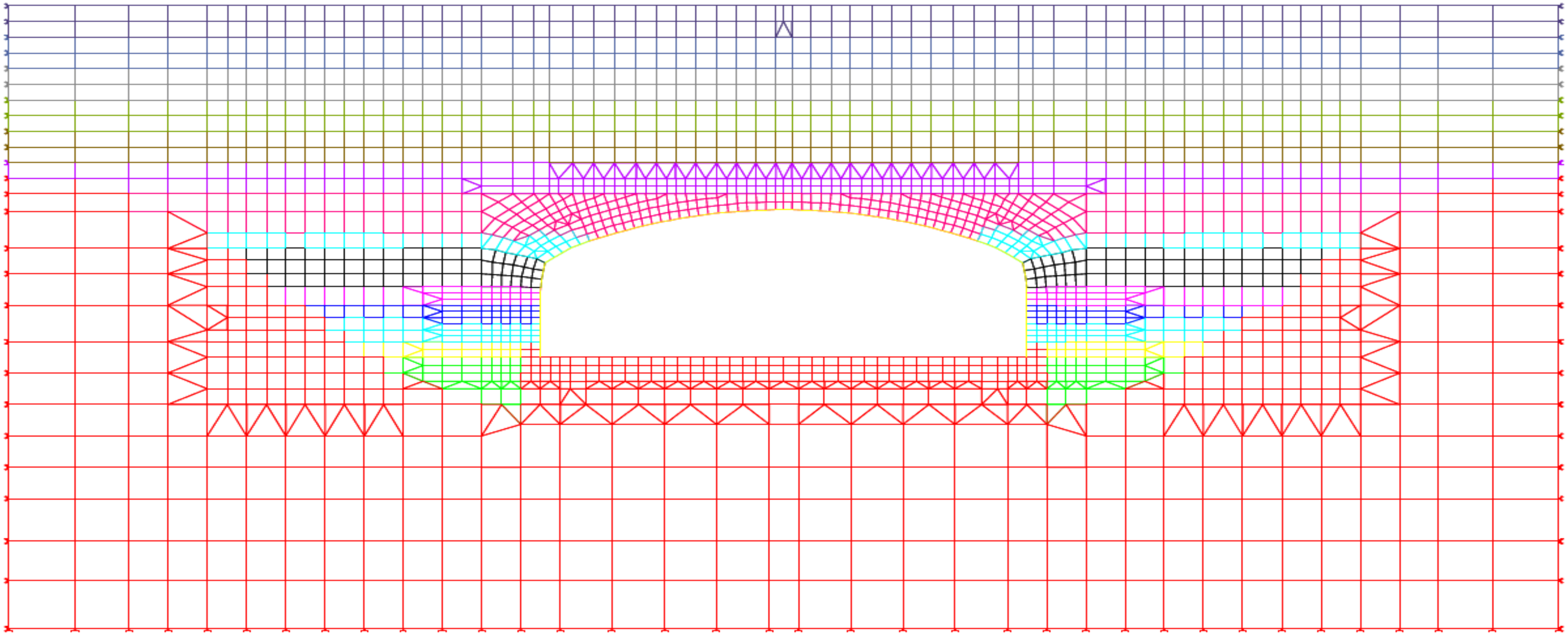
- Site conditions influence end treatments (headwall, wingwall, spandrel wall)
  - Waterway hydraulic design and alignment
  - Roadway and embankment support
  - Economy
  - Aesthetics



Design of Concrete Buried Bridges
Philip Creamer
Contech Engineered Solutions LLC

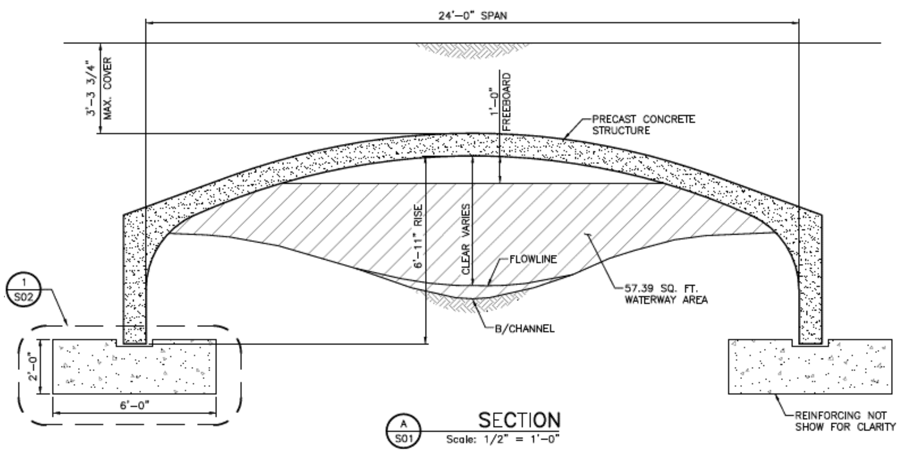
Design of Metal Buried Bridges
Joel Hahm
Big R Bridge

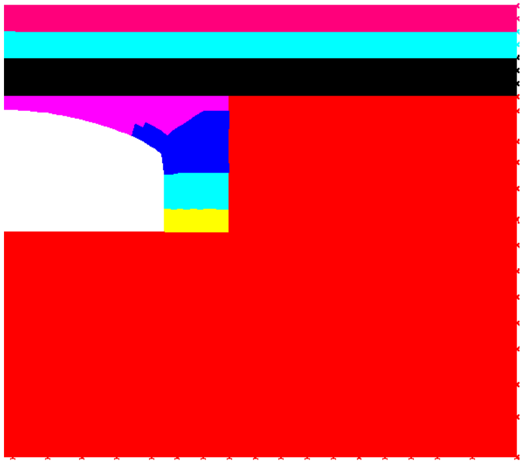
Advanced Analysis of Buried Bridges



Two-Dimensional (2D) Finite Element Analysis (FEA)

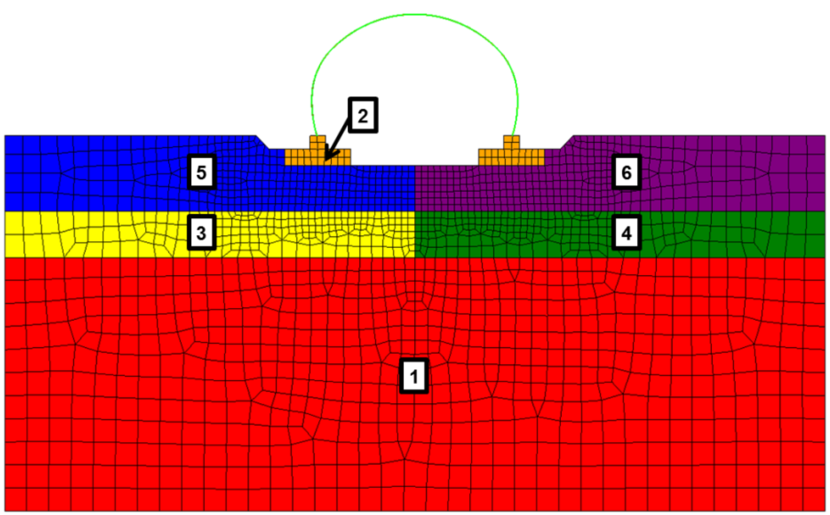
- Many tools available for buried pipe structural design
- FHWA Culvert ANalysis and DEsign (CANDE)
  - Free download - http://www.candeforculverts.com/home.html
  - Analysis of buried bridges using soil-structure interaction (SSI).
  - Non-linear structure and material models.
  - Advanced soil model capabilities.
  - Ability to model backfill construction increments.
  - Can model single or multi-cell structures.

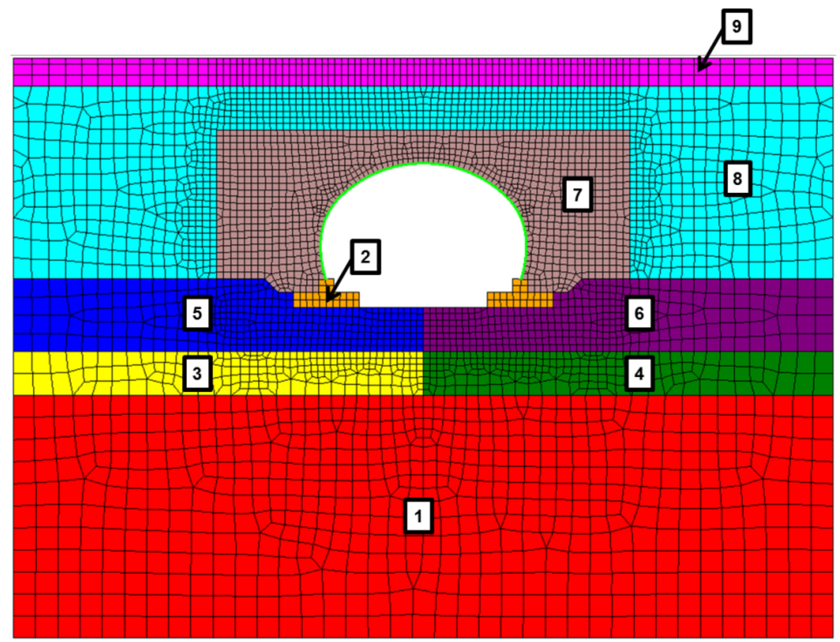




Sample 2D FEA Model

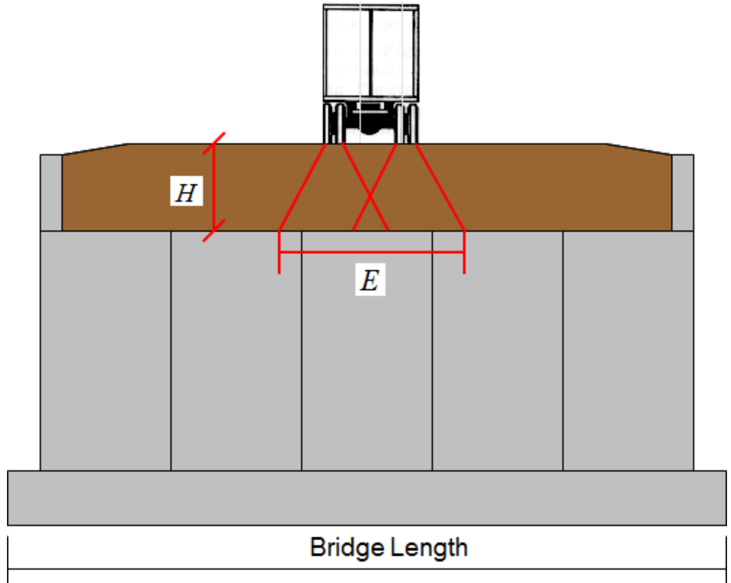
- Native (in situ) soil – Zones 1,3,4,5, and 6.
- Concrete footings in Zone 2.
- Backfill soil in Zones 7, 8, 9.
  - Placed in 12 in. lifts at specified compaction and unit weight.
  - Can simulate construction compaction loading.





CANDE 2D FEA SSI Limitations

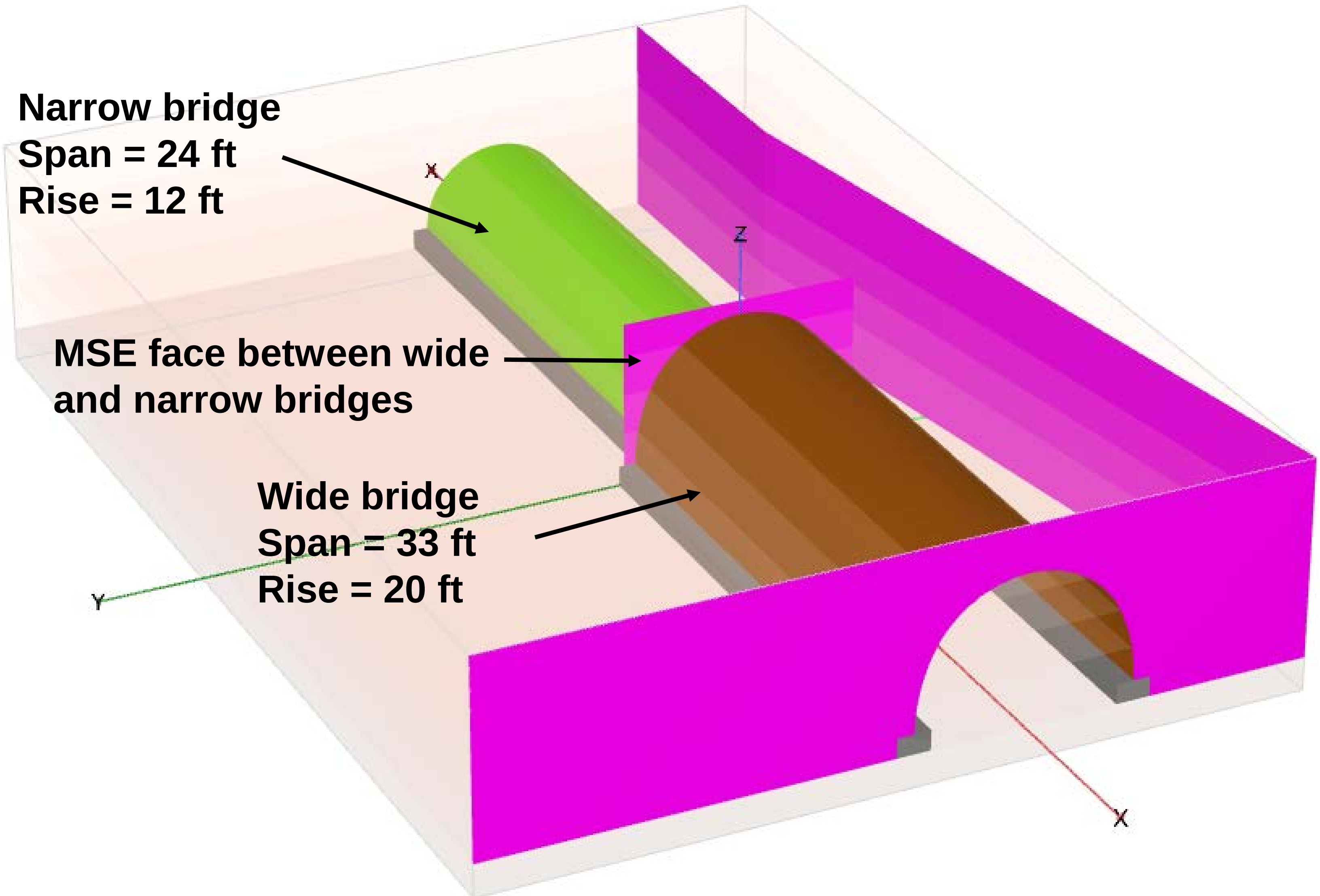
- Requires knowledge of soil-structure interaction and finite element analysis methods.
- Does not include dynamic loads.
- Requires preprocessor to create input file (no automeshing) and has limited ability for error checking.
- 2D, so must approximate 3D live load effects or nonuniform soil cover loadings.



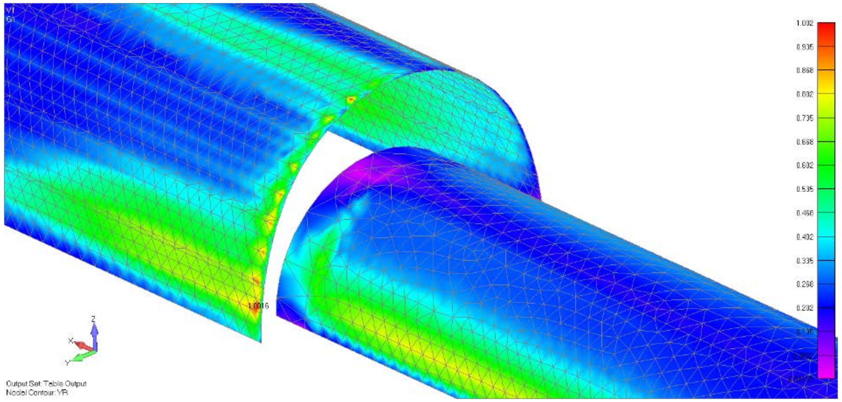
Three-Dimensional (3D) FEA

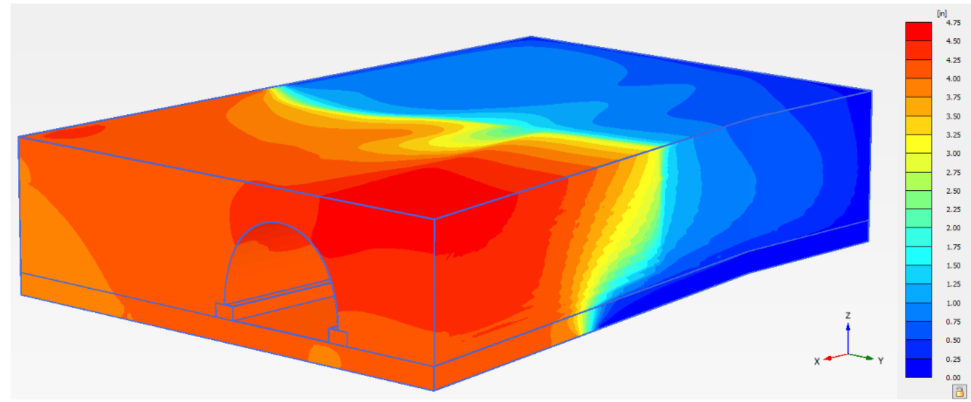
- Many tools available; common tools include Plaxis, Flac, Ansys, Abaqus, etc.
- Additional information required for:
  - Material models for bridge structure.
  - Material models for native soil(s).
  - Backfill material properties and compaction levels.
  - Structure variation along length (bridge width).
- Live load application and load spread using SSI.
- Allows variable foundation support along bridge length.
- Change structure geometry along bridge length.
- Allows evaluation of sloped or otherwise nonuniform soil cover.
- Computationally more expensive that 2D

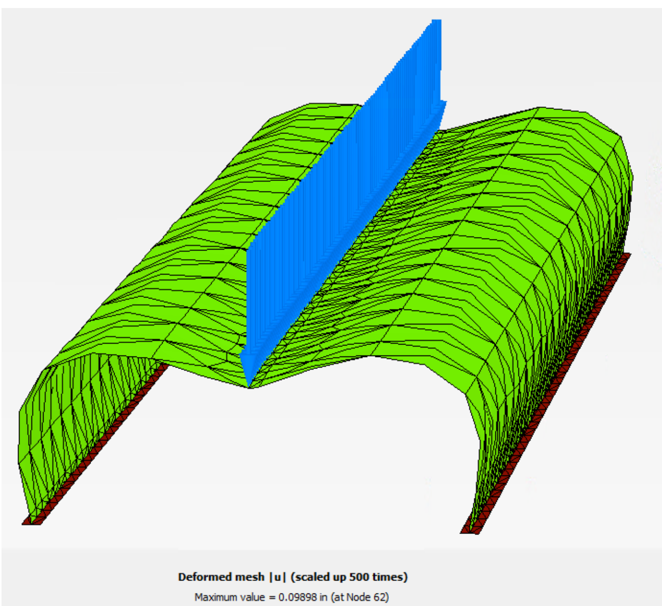
Sample 3D FEA Model

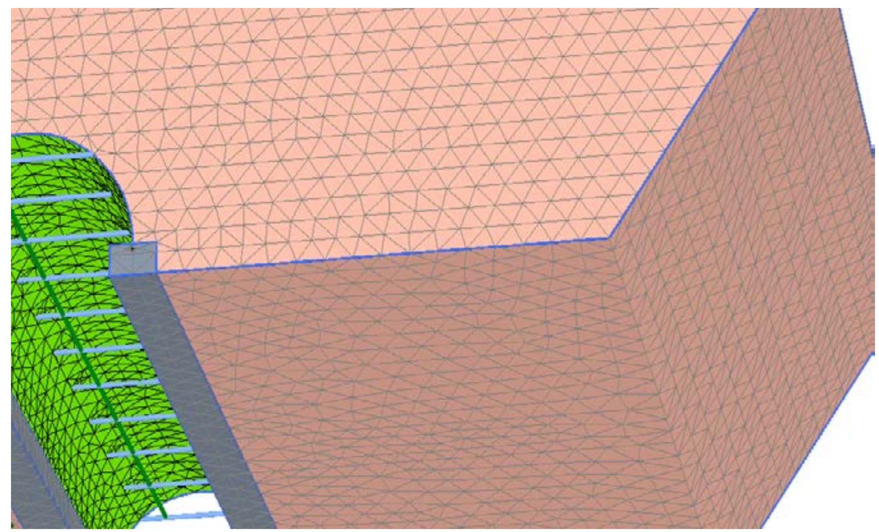


Sample 3D FEA Results









Questions?

Introduction to Structural Design of Buried Bridges (Non-seismic)

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TRB Webinars - http://www.trb.org/ElectronicSessions/ConferenceRecordings.aspx

Design of Concrete Buried Bridges

Philip Creamer, P.E. – Contech Engineered Solutions

June 2016

Concrete Buried Bridges

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Concrete Buried Bridges

Material Components

- Concrete
  - Typical Compressive Strengths 4 ksi to 6 ksi
  - Higher if Necessary
- Reinforcing
  - Welded Wire Reinforcing – 65 ksi
  - Conventional Reinforcing Bars – 60 ksi
  - Higher Strength Steel is becoming more common

Design Considerations

- Strength Limit State
  - Flexure / Axial Effects
  - Shear Effects
- Service Limit State
  - Crack Control
  - Deflections
  - Fatigue

Table 3.4.1-1—Load Combinations and Load Factors

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										EQ	BL	IC	CT	CV
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event I	γ_p	γEQ	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0	—	—	—	—	—
Fatigue I—*LL, IM & CE* only	—	1.50	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II—*LL, IM & CE* only	—	0.75	—	—	—	—	—	—	—	—	—	—	—	—

Table 3.4.1-2—Load Factors for Permanent Loads, γ_p

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		Load Factor	
		Maximum	Minimum
DC: Component and Attachments		1.25	0.90
DC: Strength IV only		1.50	0.90
DD: Downdrag	Piles, α Tomlinson Method	1.4	0.25
	Piles, λ Method	1.05	0.30
	Drilled shafts, O'Neill and Reese (1999) Method	1.25	0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• *AEP* for anchored walls		1.35	N/A
EL: Locked-in Construction Stresses		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structure		1.30	0.90
• Rigid Frames		1.35	0.90
• Flexible Buried Structures			
○ Metal Box Culverts and Structural Plate Culverts with Deep Corrugations		1.5	0.9
○ Thermoplastic culverts		1.3	0.9
○ All others		1.95	0.9
ES: Earth Surcharge		1.50	0.75

➢ Resistance Factors for Buried Structures – 12.5.5

Reinforced Concrete Cast-in-Place Box Structures • Flexure • Shear	 0.90 0.85
Reinforced Concrete Precast Box Structures • Flexure • Shear	 1.00 0.90
Reinforced Concrete Precast Three-Sided Structures • Flexure • Shear	 0.95 0.90

Design Considerations

- Live Load Distribution – 12.14.5.2 and 12.11.2
  - Cover 2’-0” or Greater – 3.6.1.2.6 (All Buried Structures)
    - Distribution of Wheel Loads through Earth Fills
    - Live Load Distribution Factor (LLDF) = 1.15
  - Cover Less than 2’-0” – 4.6.2.10 (Concrete Specific)
    - Equivalent Strip Widths

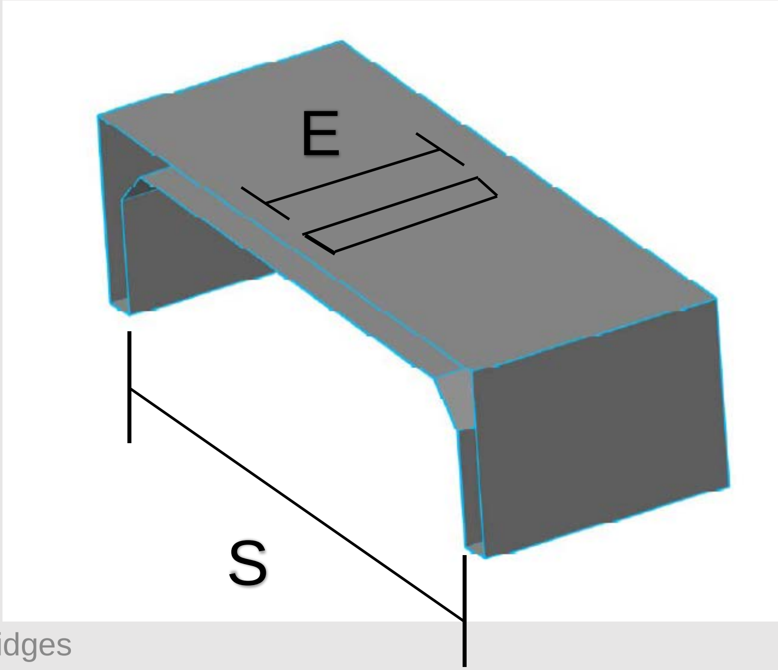
Design Considerations

- ➢Equivalent Strip Widths
  - ➢ Traffic Travels Parallel to Span
    - ➢ *Distribution Perpendicular to Span*

$E = 96 + 1.44\,(S)$

E = Equivalent Distribution Width for Axle Load, in.

S = Clear Span, ft



Design Considerations

- Equivalent Strip Widths
  - Traffic Travels Parallel to Span
    - *Distribution Parallel to the Span*

$$E_{span} = L_t + LLDF\ (H)$$

L_t = Tire Contact Length, in.

H = Depth of fill from top of structure to top of pavement, ft

LLDF = Distribution Factor (1.15 or 1)

Design Considerations

Soil Structure Interaction Factor, F_e and F_t

- Box Culverts
- Small Buried Bridges/Culverts
- Not Typically used for Larger Structures

12.11.2.2—Modification of Earth Loads for Soil-Structure Interaction

12.11.2.2.1—Embankment and Trench Conditions

In lieu of a more refined analysis, the total unfactored earth load, W_E, acting on the culvert may be taken as:

- For embankment installations:

$$W_E = F_e \gamma_s B_c H \qquad (12.11.2.2.1\text{-}1)$$

in which:

$$F_e = 1 + 0.20\frac{H}{B_c} \qquad (12.11.2.2.1\text{-}2)$$

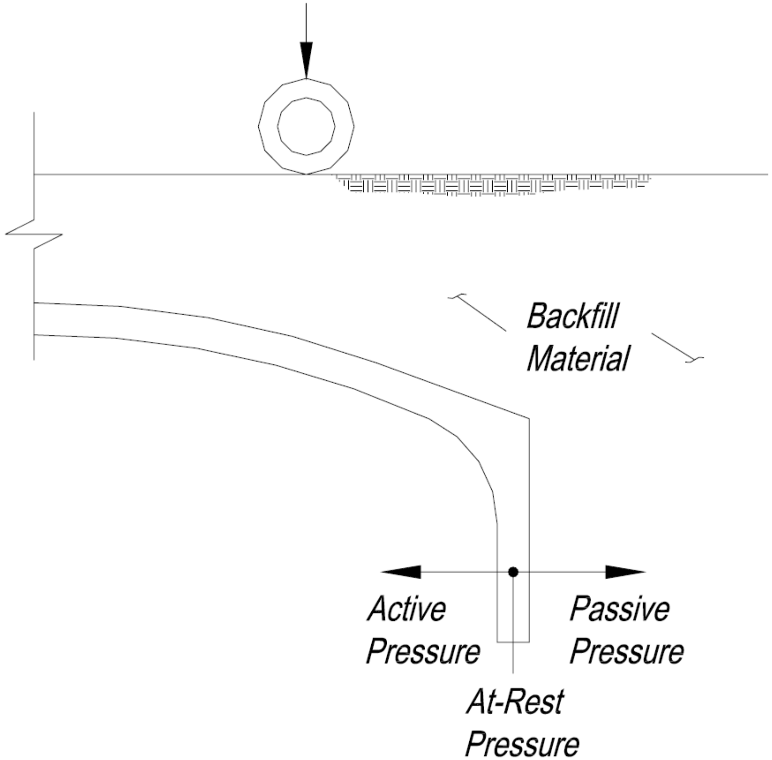
- For trench installations:

$$W_E = F_t \gamma_s B_c H \qquad (12.11.2.2.1\text{-}3)$$

in which:

$$F_t = \frac{C_d B_d^{\,2}}{HB_c} \le F_e \qquad (12.11.2.2.1\text{-}4)$$

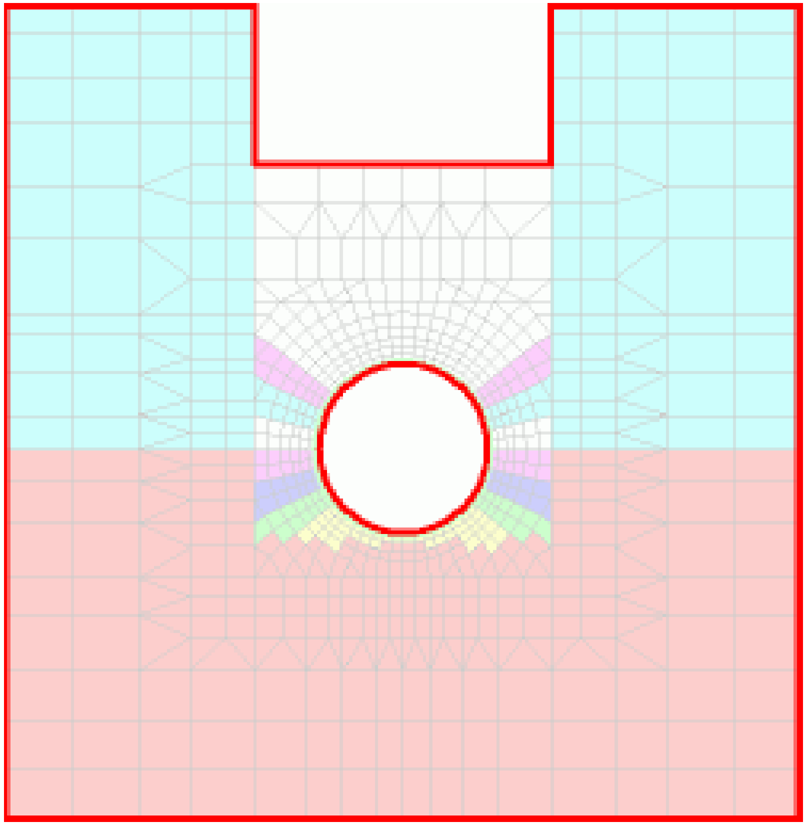
Design Considerations



Lateral Earth Pressure Conditions

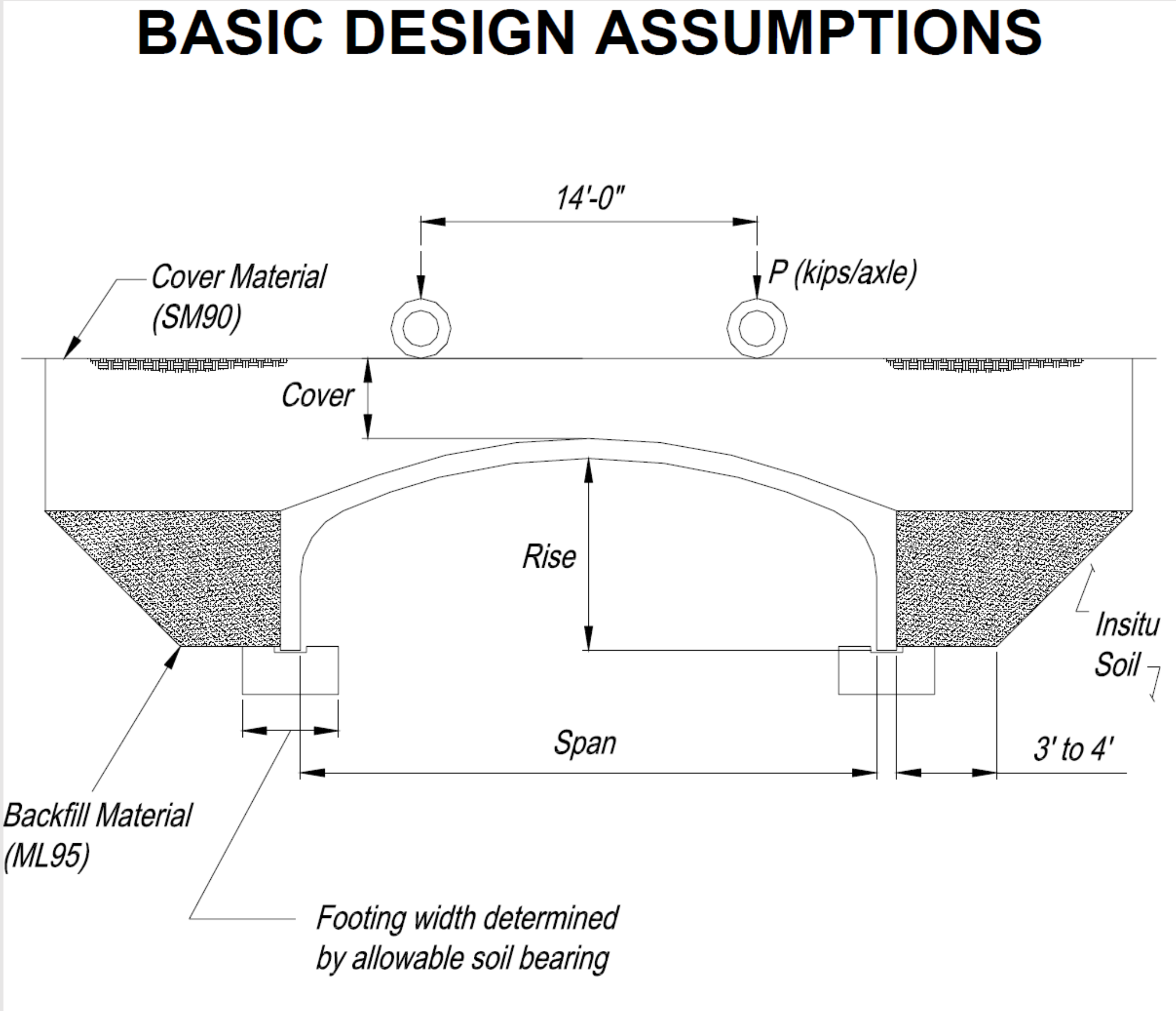
- **At-Rest Earth Pressure:** No wall movement relative to backfill.
- **Active Earth Pressure:** Wall moves slightly away from backfill material.
- **Passive Earth Pressure:** Wall moves slightly toward backfill material.

CANDE-2007
Culvert Analysis and Design
User Manual and Guideline



Developed under National Cooperative Highway Research Project NCHRP 15-28

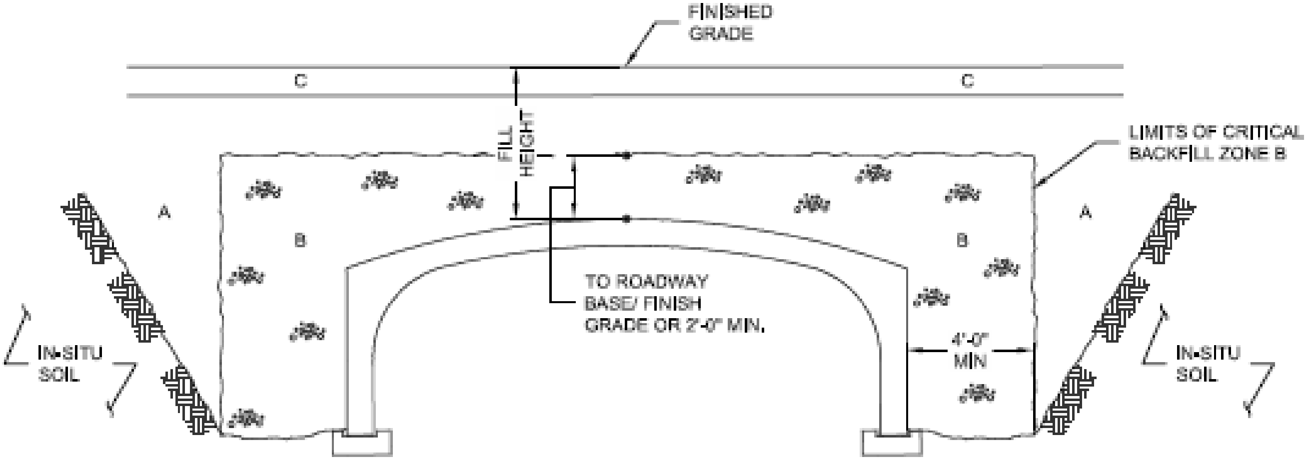
Design Example



Backfill Envelope

ACCEPTABLE SOILS FOR USE IN ZONE B BACKFILL

TYPICAL USCS MATERIALS	AASHTO GROUP	AASHTO SUBGROUP	PERCENT PASSING US SIEVE NO.			CHARACTER OF FRACTION PASSING NO. 40 SIEVE		SOIL DESRIPTION
			#10	#40	#200	LIQUID LIMIT	PLASTICITY INDEX	
GW, GP, SP	A1	A-1a	50 MAX	30 MAX	15 MAX		6 MAX	LARGELY GRAVEL BUT CAN INCLUDE SAND AND FINES
GM, SW, SP, SM		A-1b		50 MAX	25 MAX		6 MAX	GRAVELLY SAND OR GRADED SAND, MAY INCLUDE FINES
GM, SM, ML, SP, GP	A2	A-2-4			35 MAX	40 MAX	10 MAX	SANDS, GRAVELS WITH LOW-PLASTICITY SILT FINES
SC, GC, GM		A-2-5			35 MAX	41 MIN	10 MAX	SANDS, GRAVELS WITH PLASTIC SILT FINES
SP, SM, SW	A3			51 MIN	10 MAX		NON-PLASTIC	FINE SANDS
ML, SM, SC	A4				36 MIN	40 MAX	10 MAX	LOW-COMPRESSIBILTY SILTS



SPAN	FILL HEIGHT	ACCEPTABLE MATERIAL INSIDE ZONE B
≤ 24'-0"	≥ 12'-0"	A1, A3
≤ 24'-0"	< 12'-0"	A1, A2, A3, A4
> 24'-0"	ALL	A1, A3

BACKFILL REQUIREMENTS

CANDE Soil Models

Table 5.6-4 – Material names (MATNAM) and values for Duncan model (IBULK=0)

MATNAM	Young's Tangent Modulus Parameters						Bulk Parameters		Density reference
	K	n	C	φ_0	$\Delta\varphi$	R_f	K_b	m	
(word)*	(--)	(--)	(psi)	(deg)	(deg)	(--)	(--)	(--)	(lb/ft^3)
CA105	600	0.40	0.0	42	9	0.7	175	0.2	150
CA95	300	0.40	0.0	36	5	0.7	75	0.2	140
CA90	200	0.40	0.0	33	3	0.7	50	0.2	135
SM100	600	0.25	0.0	36	8	0.7	450	0.0	135
SM90	300	0.25	0.0	32	4	0.7	250	0.0	125
SM85	150	0.25	0.0	30	2	0.7	150	0.0	120
SC100	400	0.60	0.5	33	0	0.7	200	0.5	135
SC90	150	0.60	0.3	33	0	0.7	75	0.5	125
SC85	100	0.60	0.2	33	0	0.7	50	0.5	120
CL100	150	0.45	0.4	30	0	0.7	140	0.2	135
CL90	90	0.45	0.2	30	0	0.7	80	0.2	125
CL85	60	0.45	0.1	30	0	0.7	50	0.2	120

*MATNAM is composed of two letters and a number defined as follows:
CA = Course Aggregates, SM = Silty Sand, SC = Silty-Clayey Sand and CL = Silty Clay
Number = percent relative compaction, per AASHTO T-99

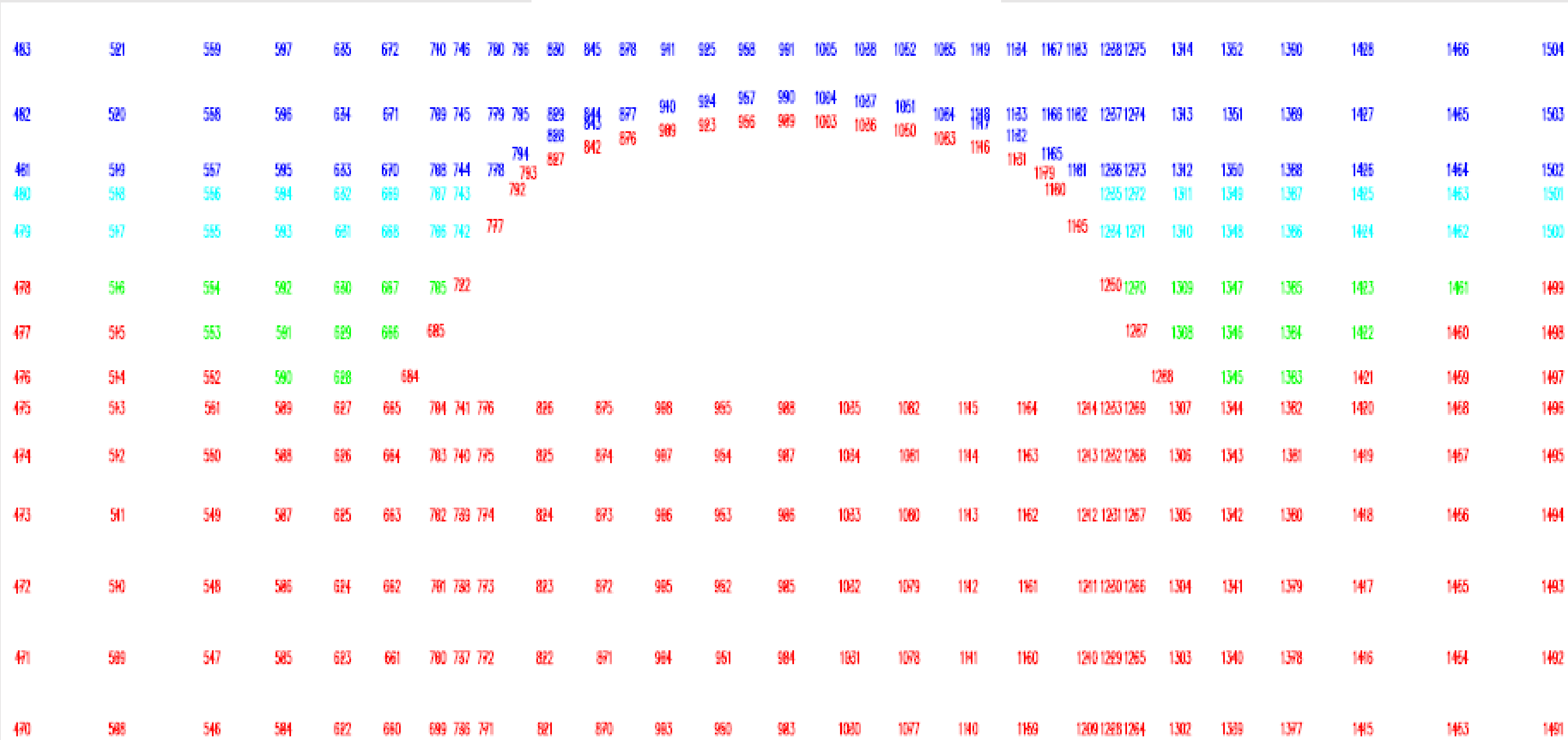
Table 5.6-5 – Material names (MATNAM) and values for Duncan/Selig model (IBULK=1)

MATNAM	Young's Tangent Modulus Parameters						Bulk Parameters***		Density reference
	K	n	C	φ_0	$\Delta\varphi$	R_f	B_i/P_a	ε_u	
(word)**	(--)	(--)	(psi)	(deg)	(deg)	(--)	(--)	(--)	(lb/ft^3)
SW100	1300	0.90	0.0	54	15	0.65	108.8	0.01	148
SW95	950	0.60	0.0	48	8.0	0.70	74.8	0.02	145
SW90	640	0.43	0.0	42	4.0	0.75	40.8	0.05	140
SW85	450	0.35	0.0	38	2.0	0.80	12.7	0.08	130
SW80	320	0.35	0.0	36	1.0	0.90	6.1	0.11	120
ML95	440	0.40	4.0	34	0.0	0.95	48.3	0.06	135
ML90	200	0.26	3.5	32	0.0	0.89	18.4	0.10	130
ML85	110	0.25	3.0	30	0.0	0.85	9.5	0.14	122
ML80	75	0.25	2.5	28	0.0	0.80	5.1	0.19	115
ML50	16	0.95	0.0	23	0.0	0.55	1.3	0.43	66
CL95	120	0.45	9.0	15	4.0	1.00	21.2	0.13	130
CL90	75	0.54	7.0	17	7.0	0.94	10.2	0.17	125
CL85	50	0.60	6.0	18	8.0	0.90	5.2	0.21	120
CL80	35	0.66	5.0	19	8.5	0.87	3.5	0.25	112

**MATNAM is composed of two letters and a number defined as follows:
SW = Gravelly Sand, ML = Sandy Silt, and CL = Silty Clay
Number = percent relative compaction, per AASHTO T-99

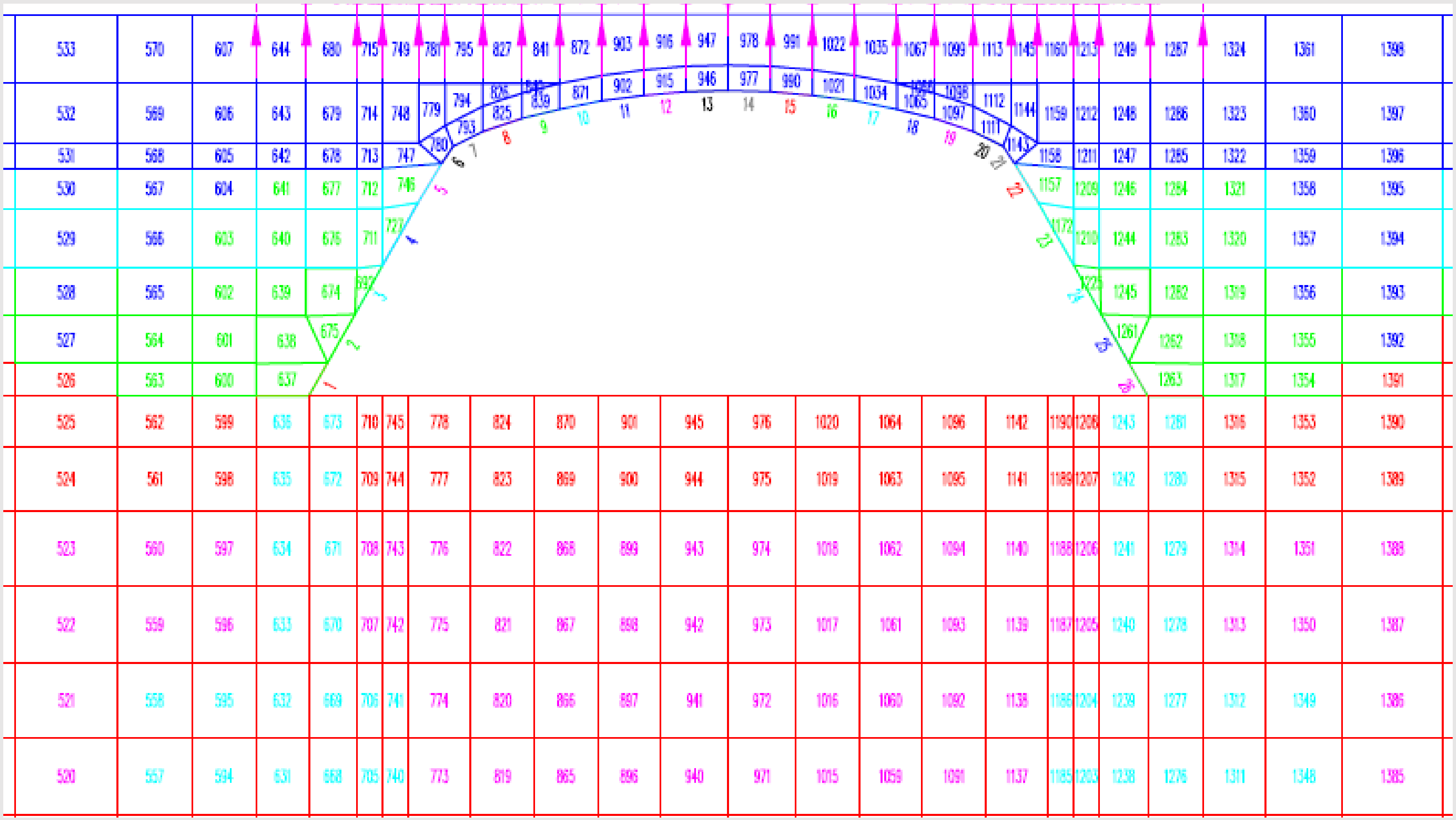
CANDE Model

Node Numbers



CANDE Model

ELEMENTS



CANDE Model

Parameter (columns) (format) (units)	Input Options	Description
Concrete wall thickness at node N. PT(N) (01-10) (F10.0) (inches)	Concrete wall thickness at node N for current node sequence. (Default = none)	The specified concrete wall thickness may differ from node sequence to node sequence along element group as desired. The current node sequence is defined by the local node numbers NSEQ1 through NSEQ2. See comments below (*See Note).
Area of steel, cage 1 (ASI(N)) (11-20) (F10.0) (in^2/in)	Steel area of cage # 1 for node sequence. This is a smeared average area per unit pipe length. (Default = 0.0 in^2/in)	Cage # 1 is associated with the inner pipe wall. Steel areas may vary from node sequence to node sequence as desired, including the case of no steel ASI(N) = 0.0.
Area of steel, Cage 2 (ASO(N)) (21-30) (F10.0) (in^2/in)	Steel area of cage # 2 for node sequence. This is a smeared average area per unit pipe length. (Default = 0.0 in^2/in)	Cage # 2 is associated with the outer pipe wall. Steel areas may vary from node sequence to node sequence as desired, including the case of no steel ASO(N) = 0.0.
Concrete cover, cage 1 (TBI(N)) (31-40) (F10.0) (inches)	Concrete cover thickness to centerline of cage # 1 for node sequence (Default = 1.25 in)	Concrete cover thickness for cage # 1 is relative to the inner wall surface. Cover thickness may vary from node sequence to node sequence as desired.
Concrete cover, cage 2 (TBO(N)) (41-50) (F10.0) (inches)	Concrete cover thickness to centerline of cage # 2 for node sequence (outer cage) (Default = 1.25 in)	Concrete cover thickness for cage # 2 is relative to the outer wall surface. Cover thickness may vary from node sequence to node sequence as desired

Thickness	As (I)	As (O)	Cover (I)	Covert (O)
12	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2
12.2	0.03	0.08	1.7	2.2
14.06	0.03	0.08	1.7	2.2
17.17	0.03	0.08	1.7	2.2
21.34	0.03	0.08	1.7	2.2
27.96	0.03	0.08	1.7	2.2
19.2	0.03	0.08	1.7	2.2
14.41	0.03	0.08	1.7	2.2
12.17	0.06	0.08	1.7	2.2
12	0.06	0.08	1.7	2.2
12	0.06	0.08	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.03	1.7	2.2
12	0.06	0.08	1.7	2.2
12	0.06	0.08	1.7	2.2
12.17	0.06	0.08	1.7	2.2
14.41	0.03	0.08	1.7	2.2
19.2	0.03	0.08	1.7	2.2
27.96	0.03	0.08	1.7	2.2
21.34	0.03	0.08	1.7	2.2
17.17	0.03	0.08	1.7	2.2
14.06	0.03	0.08	1.7	2.2
12.2	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2
12	0.03	0.08	1.7	2.2

Design Example

CONFIGURATION

Span: 16'-0"
Rise: 5'-10"
Cover: 1'-0" min. to 3'-6" max.

DESIGN LOADING

HL-93 & 60 PSF FUTURE WEARING SURFACE

DESIGN SPECIFICATIONS

AASHTO LRFD SPECIFICATIONS
CURRENT EDITION

MATERIALS

Concrete: f'c = 4,000 psi
WWF Reinforcing: fy= 65,000 psi

SOILS

In Situ:
Youngs Modulus*= 3000-8000 psi
Unit Weight

Backfill
Selig ML95
Unit Weight = 125 pcf

Cover
Duncan SM90
Unit Weight = 120 pcf

*In situ modulus varies with depth to model confined soil behavior. Soil modulus increases with increasing depth of fill.

IMPACT

Per AASHTO Section 3.6.2.2
Impact = 33 (1.0 - 0.125 De) > 0%
De = Cover (feet)

LOAD FACTORS (γ)

Dead Load = 1.3
Live Load = 1.75
Redundancy (Dead Load Only) = 1.05

LFRD DISTRIBUTION OF WHEEL LOADS

For cover less than 2'-0", live load shall be distributed per 4.6.2.10
EL = 96 + 1.44 (S) < 2 Times Unit Width
S = Span (feet)
For covers greater than 2'-0", loads are distributed per 3.6.1.2.6
ED = tire area + 1.15H

Whereas such areas overlap, the total load shall be uniformly distributed over the area.
For Cover > 8'-0" & Cover Height > Span, Live Load not applied per AASHTO Section 3.6.1.2.6

A Multiple Presence Factor (MPF) shall be included on axle loads per Section 3.6.1.1.2

NOMENCLATURE

EL = length of lateral distribution ≤ 2'-0" Cover
ED = length of lateral distribution > 2'-0" Cover
W = line load per unit length
P = axle or wheel loads
H = height of cover (feet)

Design Example

CONTROLLING CASES

Case 1

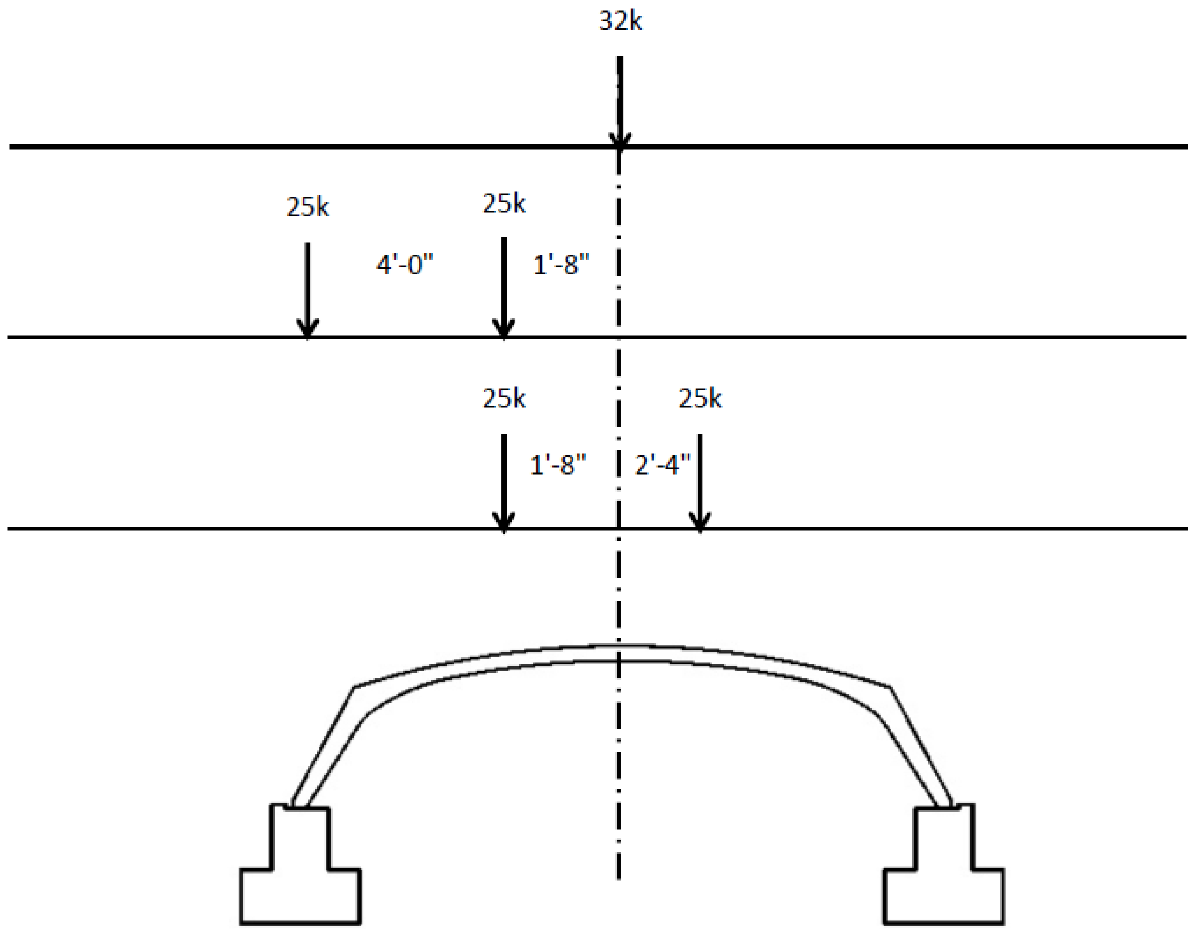
Maximum Positive Moment
HL-93, 1'-0" Cover

Case 2

Maximum Negative Moment
HL-93, 1'-0" Cover

Case 3

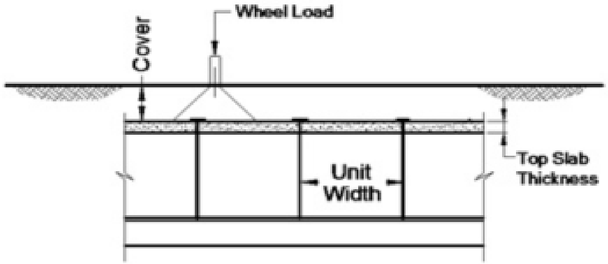
Maximum Shear
HL-93, 1'-0" Cover



BRIDGE ELEVATION

NOTE: The load cases shown above are the controlling cases for maximum moments and shears determined by varying the load locations across the span and/or rise.

Design Example



BRIDGE PROFILE

LRFD DISTRIBUTION WIDTH

The calculation shown below is for HL-93 live load and 1'-0" cover at the centerline of the structure.

EL = 96 + 1.44 Span < 2 x Unit Width

EL = 96 + 1.44 * (16) < 2 * 7.98

EL= 9.92' < 15.96'

ELcontrolling = 9.92'

LIVE LOAD CALCULATION

IM= 0.33(1.0-0.125(1')) = 0.29

PL = γ (axle load)*(1+IM)*(MPF)

PL = (1.75)*32*(1 + 0.29)*(1.2)

PL = 86.6 kips

WL = PL/EL = 8.73 k/ft

LANE LOAD CALCULATION

Lane Width = 10 ft

Lane Load = 64 psf (10 ft) = 640 lbs/ft

Pult = (1.75)(0.640 k/ft)

Pult = 1.12 k/ft

Wult = 1.12/10 k/ft^2

Wult = 0.112 k/ft^2

MINIMUM REINFORCEMENT

Flexural Reinforcement: Asmin = 0.002(Agross)

(AASHTO Section 12.14.5.8)

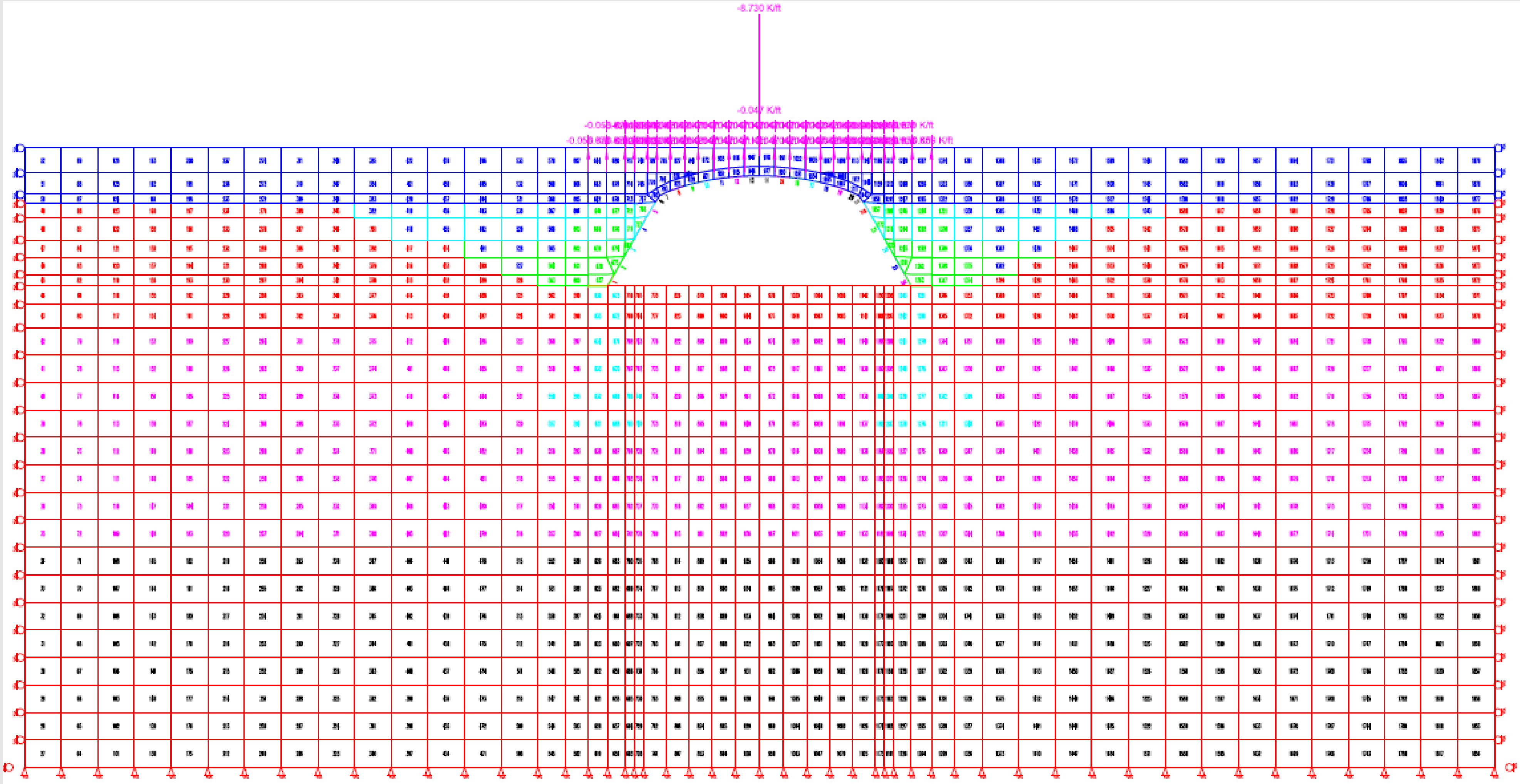
Asmin = 0.002(12)(8) in^2/ft

Asmin =0.192 in^2/ft

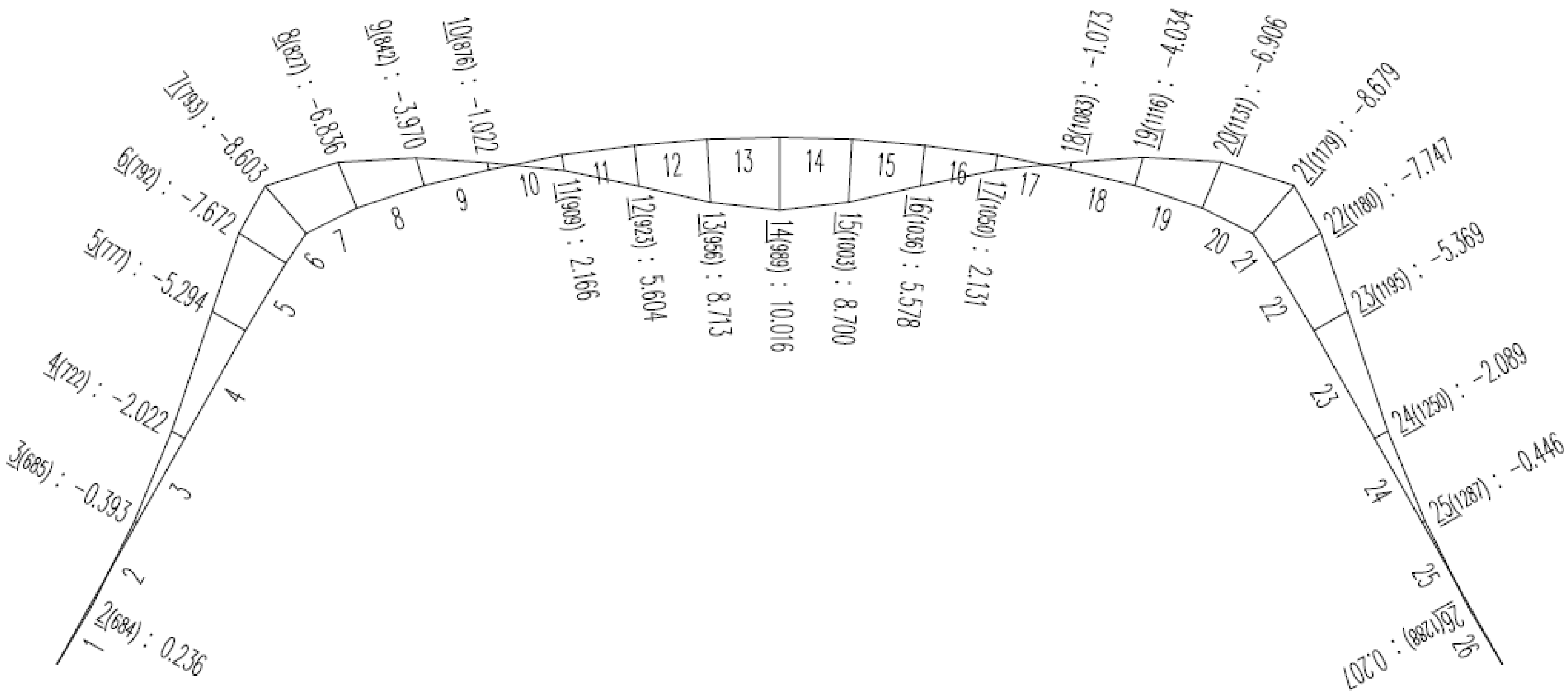
Temperature & Shrinkage:

Asmin = 0.125 in^2/ft each face

Design Example

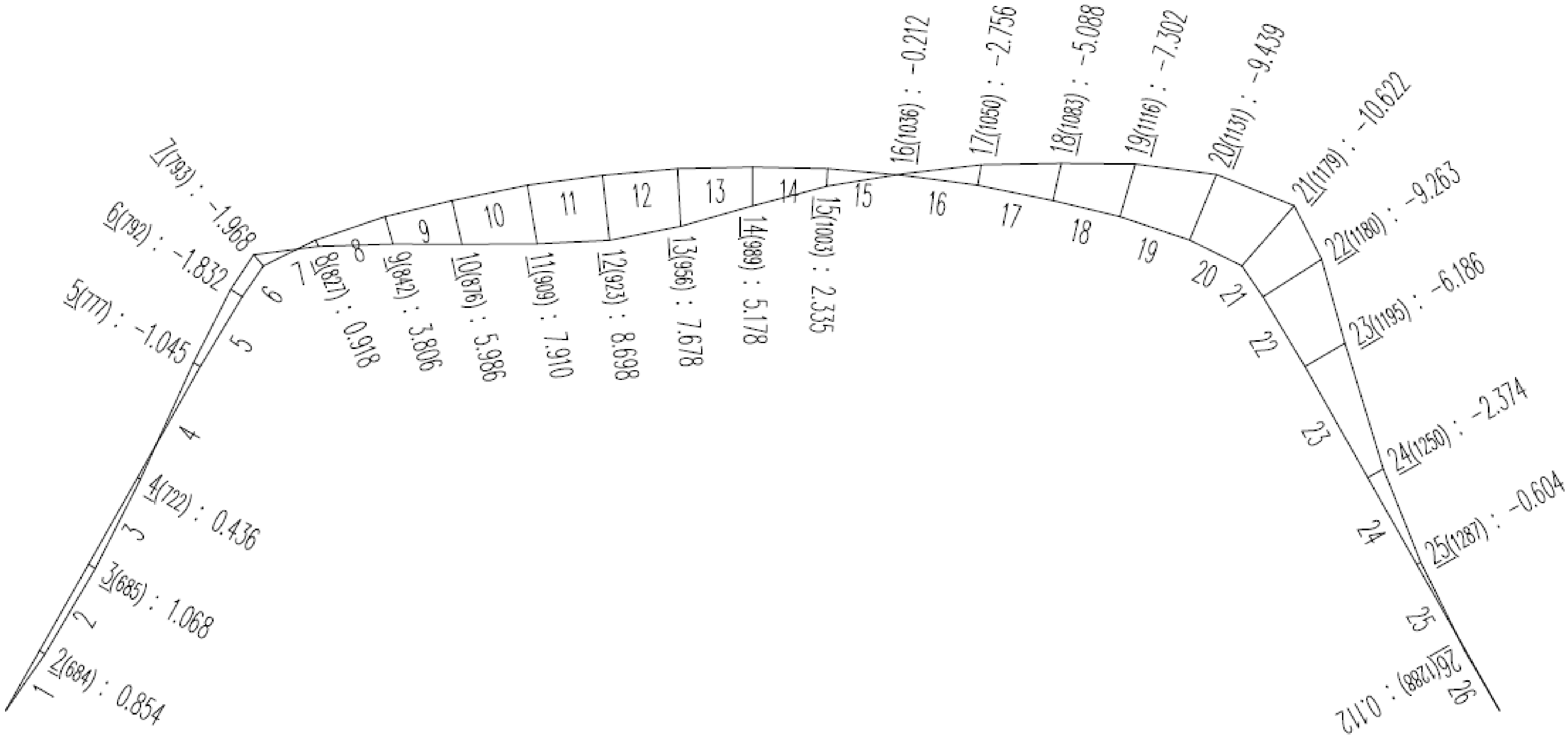


Design Example



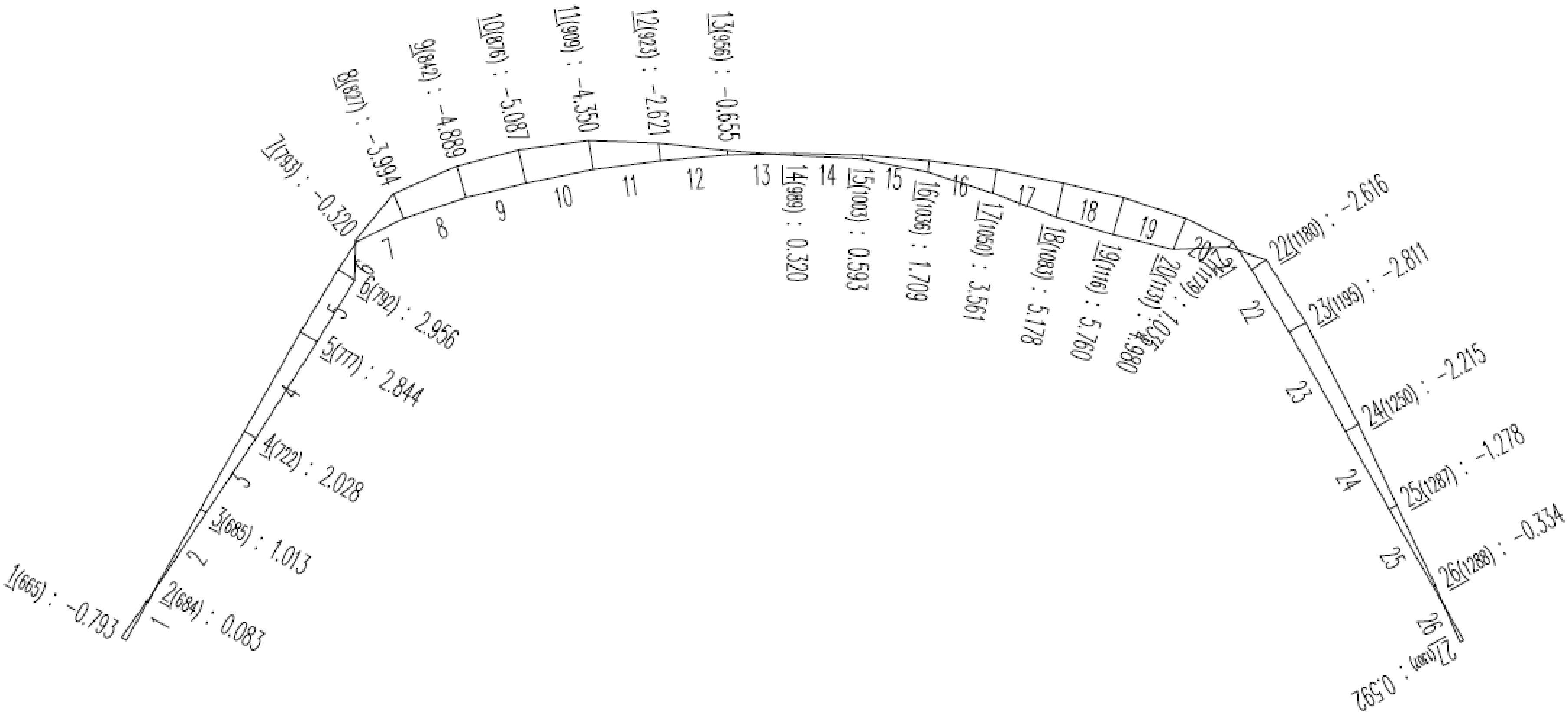
Controlling Case: Maximum Positive Moment

Design Example



Controlling Case: Maximum Negative Moment

Design Example



Controlling Case: Maximum Shear

Design Example

C3 LOAD INCREMENT 5: APPLIED LIVE LOAD

C3.1 STRUCTURAL RESPONSE OF BRIDGE

```
Displacements and Crack depth are in in, Forces are in K/ft, MOMENT are in ft*K/ft

                              BN(N) = Beam node number (N=Corresponding Node number)
                           X-D, Y-D = Node displacements
                             NP, SP = Normal and Shear pressures at the node
              MOMENT, SHEAR, THRUST = Values at the node
                                 CD = Crack depth
                           V@C, T@C = Shear and Thrust values at the center of the element between
node BN and node BN+1
```

BN(N)	X-D	Y-D	NP	SP	MOMENT	THRUST	SHEAR	CD	V@C	T@C
1(665)	-.11	-.27	-7.97	3.25	0.0	-14.89	-.79	0.0	-6.94	-12.98
2(684)	-.11	-.26	-6.53	2.65	0.27	-14.53	0.08	0.0	-7.52	-12.23
3(685)	-.12	-.26	-6.12	2.49	-.3	-14.15	1.01	0.0	-8.18	-11.41
4(722)	-.13	-.25	-5.79	2.56	-1.97	-13.72	2.03	0.0	-8.86	-10.49
5(777)	-.14	-.25	-5.51	2.97	-5.59	-13.28	2.84	5.46	-9.41	-9.6
6(792)	-.13	-.26	-4.29	4.09	-8.42	-12.97	2.96	6.33	-9.55	-9.05
7(793)	-.11	-.27	-5.32	3.25	-9.57	-12.64	-.32	7.39	-9.6	-8.58
8(827)	-.1	-.3	-4.58	2.52	-7.36	-12.01	-3.99	5.92	-9.54	-8.03
9(842)	-.08	-.35	-3.09	2.89	-3.64	-11.22	-4.89	4.43	-9.32	-7.6
10(876)	-.07	-.41	-5.16	8.64	0.35	-10.25	-5.09	0.0	-8.47	-6.79
11(909)	-.05	-.48	-15.33	8.52	4.57	-8.98	-4.35	0.0	-7.75	-4.78
12(923)	-.04	-.55	-21.28	4.12	7.71	-8.0	-2.62	5.4	-7.54	-2.18
13(956)	-.04	-.6	-18.33	-3.55	8.97	-7.89	-.65	5.51	-8.09	0.0
14(989)	-.04	-.62	-5.54	-9.49	8.81	-8.66	0.32	5.48	-9.23	0.67
15(1003)	-.04	-.61	-7.06	10.08	8.44	-8.65	0.59	5.45	-7.97	1.45
16(1036)	-.04	-.58	-18.84	1.39	7.82	-8.02	1.71	5.41	-7.55	3.69
17(1050)	-.03	-.52	-19.43	-5.08	5.57	-8.41	3.56	0.0	-7.77	6.12
18(1083)	-.02	-.47	-15.39	-8.38	1.79	-9.42	5.18	0.0	-8.34	8.08
19(1116)	-.01	-.42	-5.72	-9.1	-2.74	-10.77	5.76	0.0	-9.15	9.0
20(1131)	0.01	-.37	-3.66	-3.85	-7.3	-12.09	4.98	5.91	-9.38	9.51
21(1179)	0.02	-.34	-3.13	-5.32	-10.13	-13.12	1.04	0.0	-9.56	9.94
22(1180)	0.04	-.32	-1.44	-4.4	-9.18	-13.74	-2.62	6.39	-9.67	10.37
23(1195)	0.07	-.3	-3.86	-3.82	-6.51	-14.15	-2.81	5.63	-9.43	11.25
24(1250)	0.09	-.29	-5.03	-3.26	-2.73	-14.73	-2.21	0.0	-8.92	12.21
25(1287)	0.1	-.29	-5.99	-3.03	-.78	-15.27	-1.28	0.0	-8.33	13.1
26(1288)	0.11	-.28	-6.9	-3.2	0.1	-15.72	-.33	0.0	-7.74	13.93
27(1307)	0.12	-.28	-8.42	-3.91	0.0	-16.15	0.59	0.0		

Design Example

C3.2 STRESSES IN BRIDGE WALL

Stresses are in psi

BN = Beam node number
FSI, FSO = Stresses in the Inner and Outer steel cages
FC = Concrete compression
FV = Shear stress

BN	FSI	FSO	FC	FV
1	-1331.0	-1330.9	-155.04	-11.52
2	-1152.1	-1382.3	-175.44	1.19
3	-1353.8	-1103.0	-169.13	13.89
4	-2017.0	-447.44	-302.8	26.81
5	-3934.2	23523.0	-1569.6	35.88
6	-5019.4	34591.0	-1970.6	33.53
7	-5470.9	30845.0	-1607.6	-2.95
8	-4261.8	33040.0	-1953.7	-49.12
9	-3281.1	12986.0	-1116.9	-66.63
10	-708.3	-993.18	-132.41	-69.32
11	1286.6	-2417.6	-498.9	-59.29
12	34054.0	397.31	-1927.9	-35.71
13	40683.0	712.03	-2096.5	-8.93
14	39681.0	505.9	-2088.1	4.37
15	37717.0	429.06	-2050.6	8.09
16	34574.0	425.56	-1953.5	23.29
17	1780.2	-2729.8	-582.53	48.53
18	3.39	-1443.9	-253.1	70.57
19	-2170.9	73.25	-354.25	78.5
20	-4250.7	32713.0	-1939.3	61.25
21	-3763.5	1719.5	-584.91	9.55
22	-5511.8	38345.0	-2065.1	-29.68
23	-4343.0	28414.0	-1831.7	-35.47
24	-2436.1	-262.7	-377.72	-29.27
25	-1667.7	-1025.2	-223.57	-17.53
26	-1339.5	-1423.0	-171.0	-4.76
27	-1444.0	-1443.8	-168.22	8.6

LRFD CHECK CRACK CONTROL

fs = 700γe/βs(S+2dc) < 0.6(fy) AASHTO (5.7.3.4)

βs = 1 + dc / 0.7(h-dc)

Notations:

γe = exposure factor

dc = thickness of concrete cover measured from extreme tension fiber to center of closest bar or wire. (in.)

h = overall thickness or depth (in.)

s = spacing of reinforcement (in.)

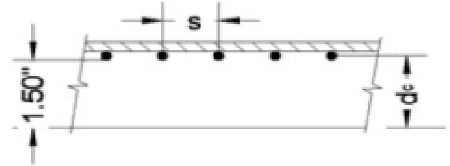
AT MIDSPAN

dc = 1.64 in.

h = 8.00 in.

s = 2

βs = 1.37



POSITIVE MOMENT REINFORCEMENT

fs = 700*0.75/1.37(2+2(1.64)) < 0.6(65 ksi)

fs = 72.75 ksi > 39 ksi (39 ksi Controls)

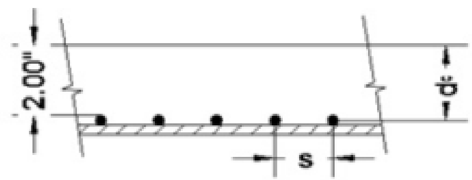
AT HAUNCH

dc = 2.13 in.

h = 7.00 in.

s = 2

βs = 1.62



NEGATIVE MOMENT REINFORCEMENT

fs = 700*0.75/1.62(2+2(2.13)) < 0.6(fy)

fs = 51.74 ksi > 39 ksi (39 ksi Controls)

FROM NON-FACTORED ANALYSIS (SERVICE LOADS)

fs,midspan = 27.6 ksi	OK
fs,haunch = 2.3 ksi	OK

LRFD FACTORED LOAD CHECK

Strength Reduction Factors (AASHTO Section 12.5.5)

φ = .95 for Combined Flexure & Thrust

φ = .90 for Shear

MAXIMUM POSITIVE MOMENT STEEL STRESS UNDER FACTORED LOADS:

$fs(+) = 51.5$ ksi

$fs(+) < \varphi Fy = 0.95(65 \text{ ksi}) = 61.75$ ksi

OK

MAXIMUM NEGATIVE MOMENT STEEL STRESS UNDER FACTORED LOADS:

$fs(-) = 53.6$ ksi

$fs(-) < \varphi Fy = 0.95(65 \text{ ksi}) = 61.75$ ksi

OK

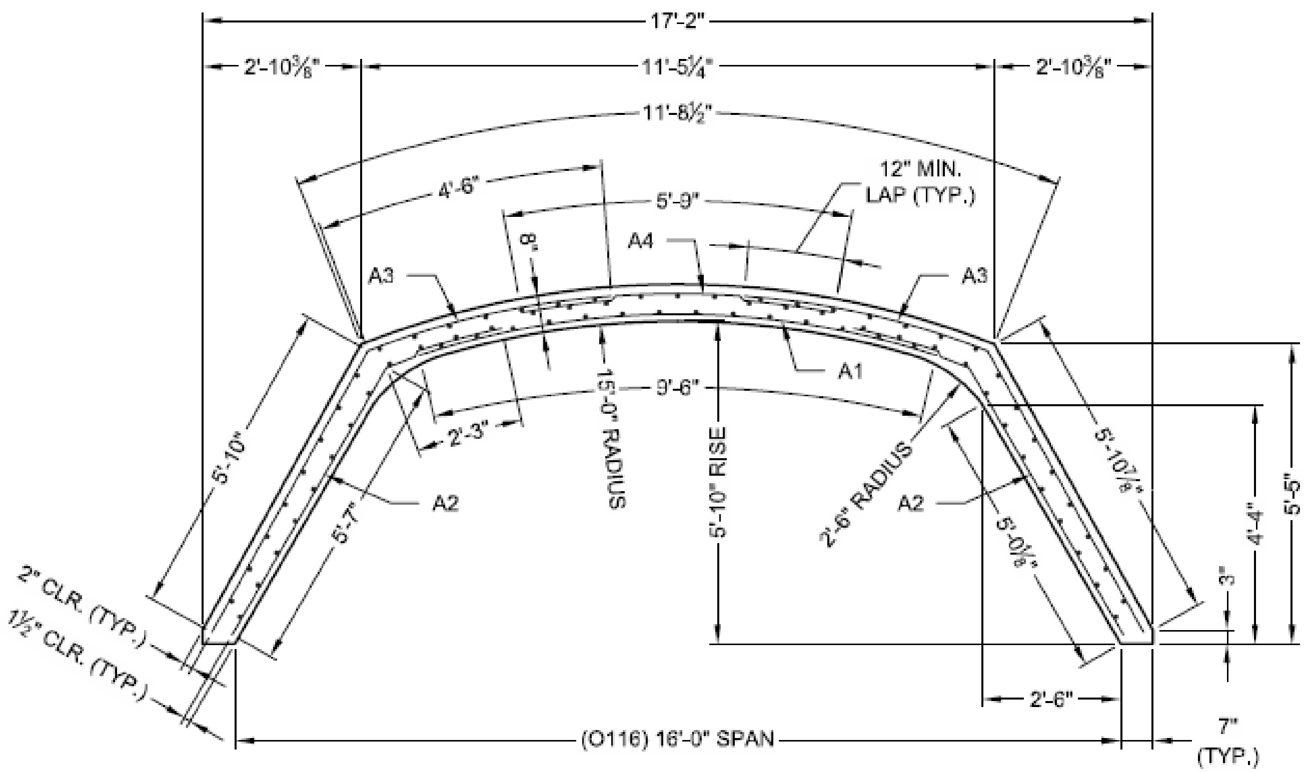
MAXIMUM SHEAR STRESS UNDER FACTORED LOADS:

$v = 78.5$ psi

$v < \varphi Vc = 0.9(0.0316)(2)\sqrt{f'c}$

$v < \varphi Vc = 113.8$ psi

OK



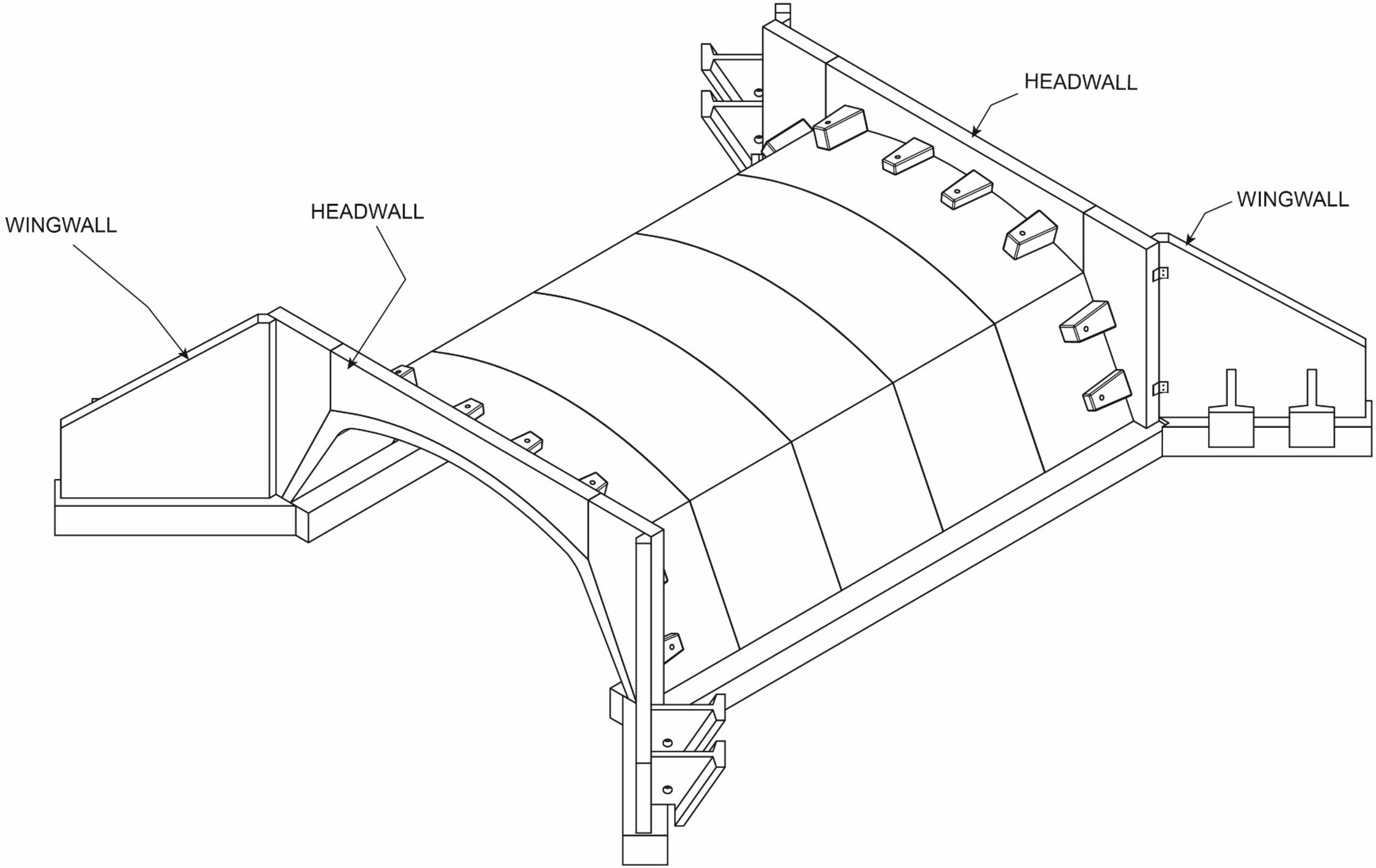
PRECAST UNIT REINFORCEMENT

SHEET NO.	CIRCUMFERENTIAL AREA REQ'D (IN²/FT)	LONGITUDINAL AREA REQ'D (IN²/FT)	MESH SIZE	LENGTH (FT)	CIRCUMFERENTIAL AREA SUPL'D (IN²/FT)	LONGITUDINAL AREA SUPL'D (IN²/FT)
1	A1 = 0.36	0.13		9'-6"		
2	A2 = 0.24	0.13		7'-10"		
3	A3 = 0.30	0.13		10'-4"		
4	A4 = 0.24	0.13		5'-9"		
5						
DESIGN LOADING: HL-93 & 60 PSF FUTURE WEARING SURFACE				COVER = 1'-0" MIN. \ 3'-6" MAX.		

Buried Bridge Foundations

- Types
  - Spread Foundations
  - Driven Piles
  - Drilled Shafts
  - Micropiles
  - Concrete Slab
  - Rammed Aggregate Piers, Helical Piles etc…

End Treatments



TRB Webinar – Introduction to Design of Buried Bridges (non-seismic)

Flexible Buried Bridges

June 23, 2016

Joel Hahm, P.E.
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Chair of TRB AFF70-1

Outline

- AASHTO LRFD Design Checks
- Design Inputs & Considerations
- Sample Design
- End Treatments / Installation

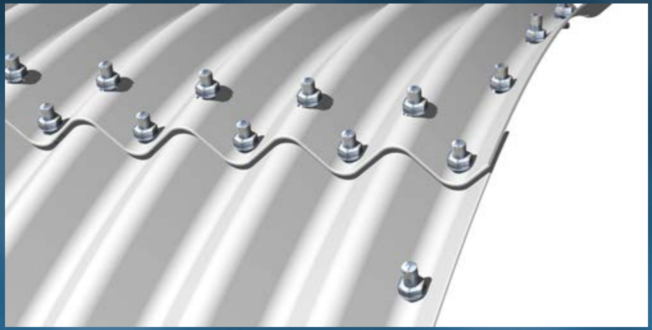
Material & Design Properties

- Material properties provided in AASHTO M167 / ASTM A761
- Design properties provided in AASHTO LRFD Section 12 (Appendix A12)
- Thicknesses up to 0.380” thick.
- Hot dipped galvanized with 3.0 oz/ft^2 coating weight (50% more than CSP)
- ¾” or ⅞” diameter high strength bolts (ASTM A449) depending on design
- 24, 33, or 44 ksi design yield strength depending on material
- Granular backfill with same electrochemical requirements as those in AASHTO LRFD Design Section 11.10.6.4.2 for MSE walls. Considers pH, resistivity, chlorides, sulfates, organics.

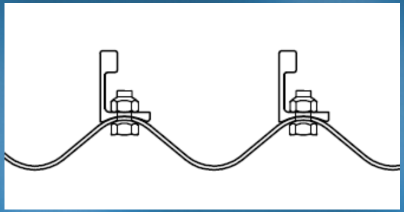
Property	Aluminum (ALSP)	Shallow Corrugated Steel	Deep Corrugated Steel
Geometry Types	Small arch, box, closed shapes	Arches, closed shapes	Arch, box, pipe, multi-radius arches
Corrugation Profile	9” x 2.5”	6” x 2”	15” x 5.5”
Design Yield Strength	24 ksi	33 ksi	44 ksi
Relative Stiffness	~1.5 x shallow	1 (baseline)	~9 x shallow ~6.25 x ALSP

AASHTO LRFD Design Checks

- Shallow Corrugated Arches – Design Based on Thrust Loads (Section 12.7)
  - Wall Area (12.7.2.3)
  - Buckling (12.7.2.4)
  - Seam Strength (12.7.2.5)
  - Flexibility for Installation (12.7.2.6)



- Shallow Corrugated Boxes – Design Based on Flexure (Section 12.9)
  - Moment Capacity (12.9.4.2, 12.9.4.3)
  - Typically Includes Circumferential Reinforcing (Ribs)

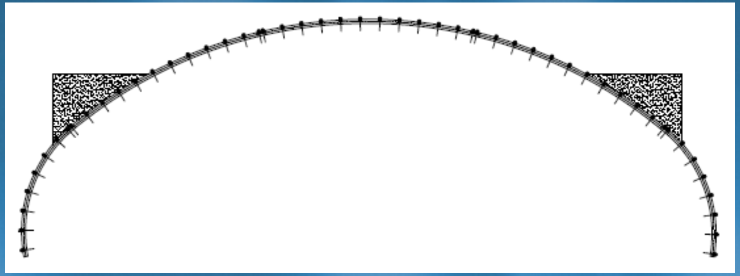


AASHTO LRFD Design Checks

- Traditional Long Span Structures – Design Based on Thrust (Section 12.8)
  - Wall Area, Buckling, Seam Strength, Flexibility Same as Above
  - Additional Requirements Based on Geometric Limits (Table 12.8.3.1.1-1)
  - Requires Special Features (typically longitudinal stiffeners or ribs)

Table 12.8.3.1.1-1—Minimum Requirements for Long-Span Structures with Acceptable Special Features

Top Arc Minimum Thickness (in.)					
Top Radius (ft)	≤15.0	15.0–17.0	17.0–20.0	20.0–23.0	23.0–25.0
6" × 2" Corrugated Steel Plate—Top Arc Minimum Thickness (in.)	0.111	0.140	0.170	0.218	0.249
Geometric Limits					
The following geometric limits shall apply: • Maximum plate radius—25.0 ft • Maximum central angle of top arc—80.0° • Minimum ratio, top arc radius to side arc radius—2 • Maximum ratio, top arc radius to side arc radius—5					
Minimum Cover (ft)					
Top Radius (ft)	≤ 15.0	15.0–17.0	17.0–20.0	20.0–23.0	23.0–25.0
Steel thickness without ribs (in.)					
0.111	2.5	—	—	—	—
0.140	2.5	3.0	—	—	—
0.170	2.5	3.0	3.0	—	—
0.188	2.5	3.0	3.0	—	—
0.218	2.0	2.5	2.5	3.0	—
0.249	2.0	2.0	2.5	3.0	4.0
0.280	2.0	2.0	2.5	3.0	4.0

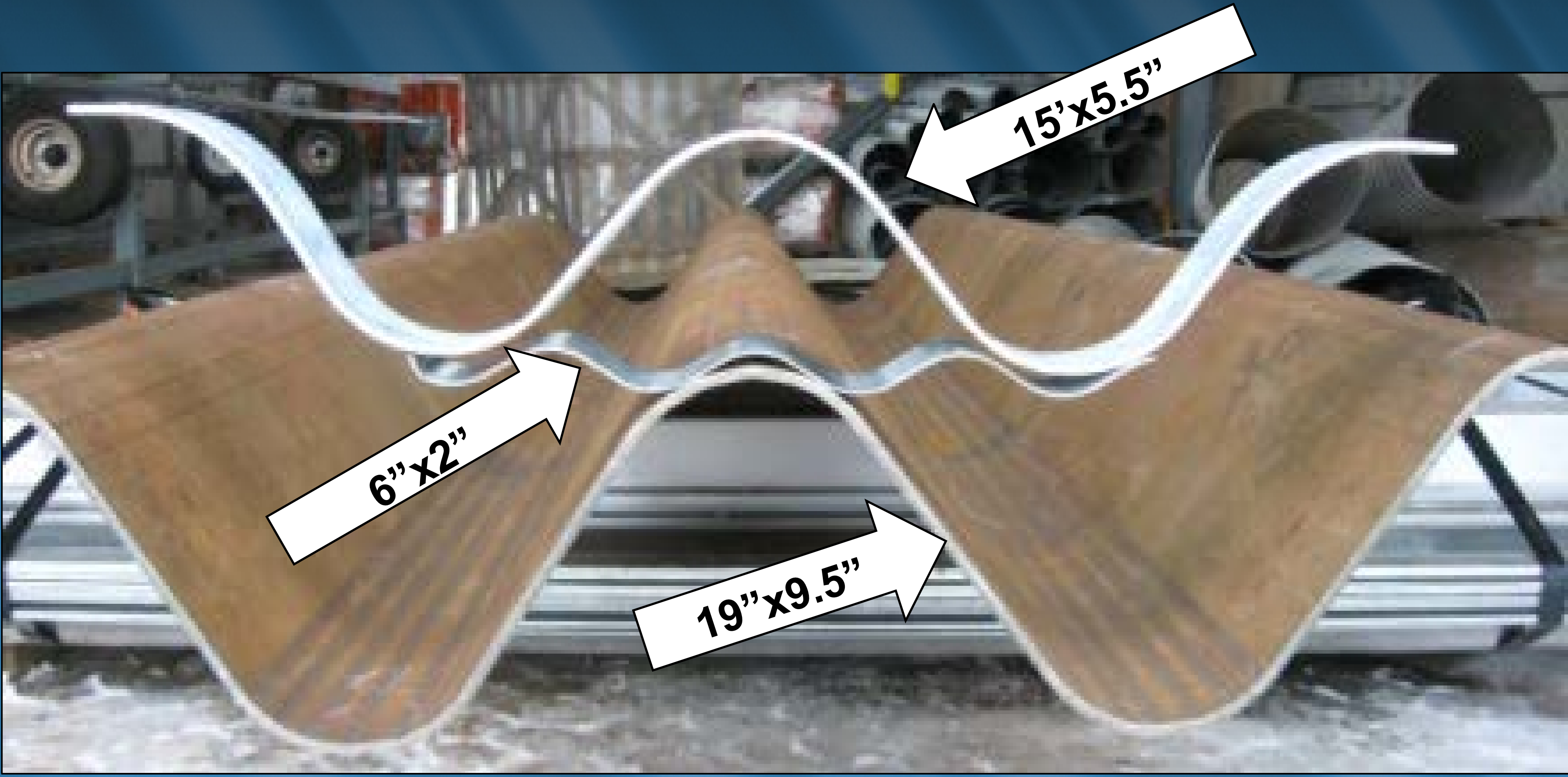


AASHTO LRFD Design Checks

- Deep Corrugated Structures – Design Based on Thrust and Flexure (Section 12.8.9)
  - Requires Rigorous Analysis (typically FEA)
  - Wall Area, Seam Strength Same as for Long Span Structures
  - Check Flexure (includes reduction for connections)
  - Moment-Thrust Interaction Check (Eq. 12.8.9.5-1)
  - Global Buckling Check (Eq. 12.8.9.6-1)
  - Flexibility, Special Features, Shape Requirements for Long Span do not Apply (12.8.9.1)
  - Includes Requirements for minimum cover and backfill zone width (12.8.9.2 & 12.8.9.4)

$$\left(\frac{T_f}{R_t}\right)^2 + \frac{|M_u|}{|M_n|} \leq 1.00$$

Steel Corrugation Profiles



General Design Inputs

- Inputs for Shallow Corrugated Structures:
  - Span
  - Soil Cover
  - Wheel Loads (based on LL design vehicle)
  - Plate Radii (for categorizing as arch, long span and box shapes)
  - Structure Section Properties – from Appendix A12
- Inputs for Deep Corrugated Structures:
  - Structure Geometry (dimensions, shape, radii, etc.)
  - Soil Cover & Backfill Zone Width
  - Wheel Loads (based on LL design vehicle)
  - Structure Section Properties – from Appendix A12
  - Soil Properties – foundation soils, backfill zone soils, site soils
  - Foundation Type & Approximate Dimensions

Site Geometry Inputs

- Inside clearance / end area
- Hydraulic / environmental considerations – maximize span to eliminate multi-cell crossings / get out of water, outside limits of disturbance, etc.
- Available distance from bottom of structure to top of road
- Flexibility (raise road grade, lower foundations, encroach on clearance box, etc.)
- ***Custom geometries are most cost effective – Don’t limit yourselves to what is in the brochure!***

Geometry Type (arch vs. box)

- Determined by site limitations & end area / clearance requirements
- 2 ft min cover for box (1.5 ft for spans ≤ 25 ft 5 in), 3 ft min cover for arch
- Arch geometries are lighter / more efficient / lower structure cost
- *No need to specify geometry type – can be determined by manufacturer based on project requirements & site limitations*

Site Soil Conditions & Backfill

- Boring logs & historical site data
- Local geology & experience
- Classification & electrochemical tests of representative materials
- Scour depth & other hydraulic concerns
- Some geometries sensitive to FEA soil inputs

Loading Requirements

- HL-93 is AASHTO LRFD standard
- U-80, mining vehicles, E-80 Cooper, heavy trucks (heavier than legal loads)
- Special design loads require axle loads & spacing, tire size, vehicle specs (if available)
- Design capacity is driven by axle loading rather than GVW – less impact on design than a traditional or rigid bridge. As a result, buried bridges can generally carry higher loads.

Other Considerations

•Foundation types – design foundations based on settlement tolerance, consider foundation soil improvement to save on costs & improve quality. Biggest project cost / time savings vs. traditional & RCBC/Precast bridges can come from foundations.

•Modest investment in geotechnical engineering can pay off – have geotech consult with designer to make sure appropriate recommendations are provided. FEA designs can be customized and optimized to site.

•Look at project costs rather than only comparative structure costs. Construction time & labor, foundations, grading, site access, equipment, maintenance, inspection, and other costs can be very different between flexible buried bridge & rigid / traditional bridge options.

Box Shapes

Simple Arches

HP Arches

LP Arches



Design Example

Load & Resistance Factors

Table 3.4.1-2—Load Factors for Permanent Loads, γ_p

Type of Load, Foundation Type, and Method Used to Calculate Downdrag		Load Factor Maximum	Load Factor Minimum
DC: Component and Attachments		1.25	0.90
DC: Strength IV only		1.50	0.90
DD: Downdrag	Piles, α Tomlinson Method	1.4	0.25
	Piles, λ Method	1.05	0.30
	Drilled shafts, O'Neill and Reese (1999) Method	1.25	0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• *AEP* for anchored walls		1.35	N/A
EL: Locked-in Construction Stresses		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structure		1.30	0.90
• Rigid Frames		1.35	0.90
• Flexible Buried Structures			
○ Metal Box Culverts, Structural Plate Culverts with Deep Corrugations, and		1.5	0.9
Fiberglass Culverts		1.3	0.9
○ Thermoplastic Culverts		1.95	0.9
○ All others			
ES: Earth Surcharge		1.50	0.75

Table 3.4.1-1—Load Combinations and Load Factors

Load Combination Limit State	*DC DD DW EH EV ES EL PS CR SH*	*LL IM CE BR PL LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	Use One of These at a Time *EQ*	*BL*	*IC*	*CT*	*CV*
Strength I (unless noted)	γ_p	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_p	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_p	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength IV	γ_p	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	γ_p	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event I	γ_p	γEQ	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	γ_p	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0.30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0	—	—	—	—	—
Fatigue I—*LL, IM & CE* only	—	1.50	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II—*LL, IM & CE* only	—	0.75	—	—	—	—	—	—	—	—	—	—	—	—

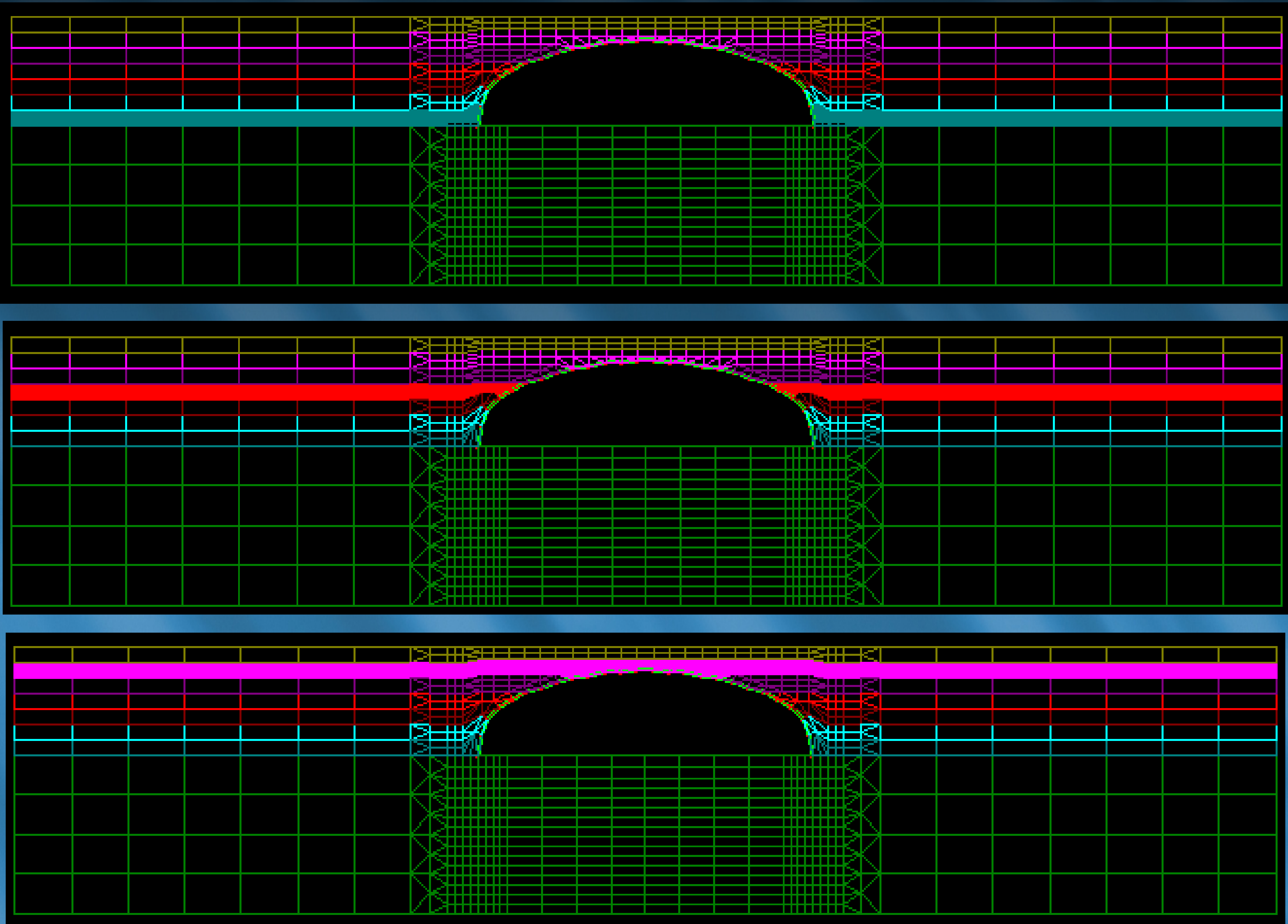
Table 12.5.5-1—Resistance Factors for Buried Structures

Structure Type	Resistance Factor
Metal Pipe, Arch, and Pipe Arch Structures	
Helical pipe with lock seam or fully welded seam:	
• Minimum wall area and buckling	1.00
Annular pipe with spot-welded, riveted, or bolted seam:	
• Minimum wall area and buckling	1.00
• Minimum longitudinal seam strength	0.67
• Bearing resistance to pipe arch foundations	Refer to Section 10
Structural plate pipe:	
• Minimum wall area and buckling	1.00
• Minimum longitudinal seam strength	0.67
• Bearing resistance to pipe arch foundations	Refer to Section 10
Long-Span Structural Plate and Tunnel Liner Plate Structures	
• Minimum wall area	0.67
• Minimum seam strength	0.67
• Bearing resistance of pipe arch foundations	Refer to Section 10
Structural Plate Box Structures	
• Plastic moment strength	1.00
• Bearing resistance of pipe arch foundations	Refer to Section 10
Deep Corrugated Structural Plate Structures	
• Minimum wall area and general buckling, ϕ_b	0.70
• Plastic hinge, φ_h	0.90
• Soil, ϕ_s	0.90

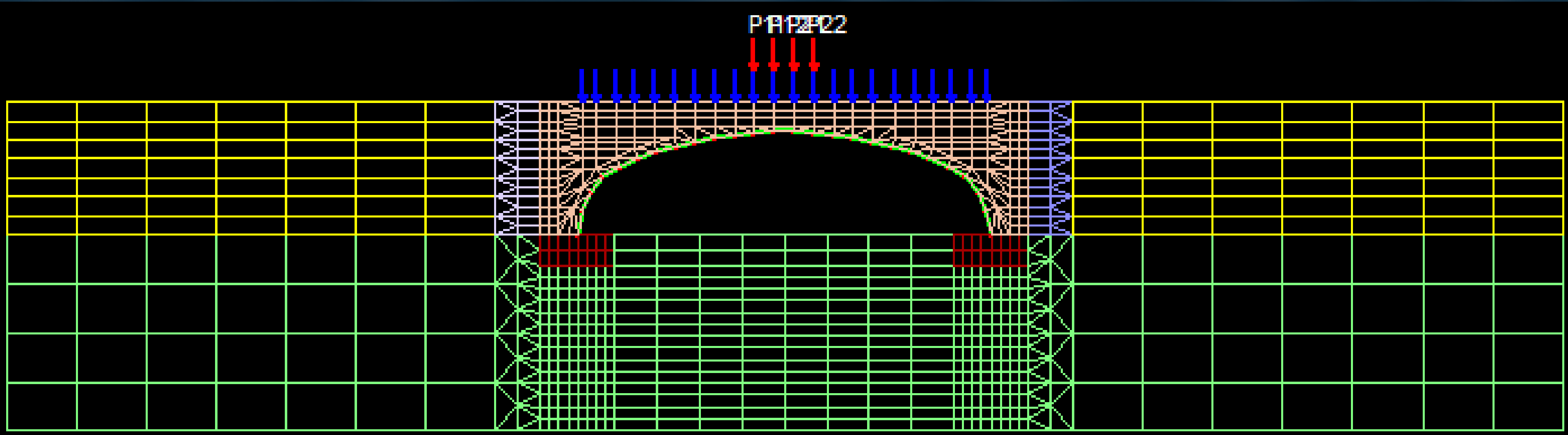
Design Example – Small Span Box

27’3”span, medium dense granular foundation soils, A-1 backfill, silty/sandy site soils, HL93 loading, 2’ cover, span/5 backfill zone, spread footings, 15x5.5 profile, 1 gauge

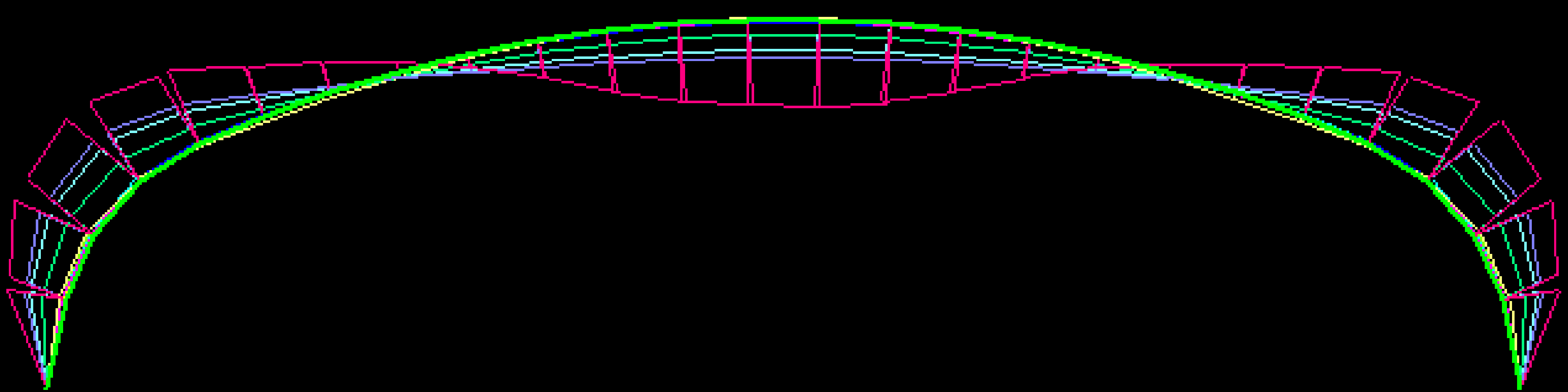
Loads are applied incrementally…



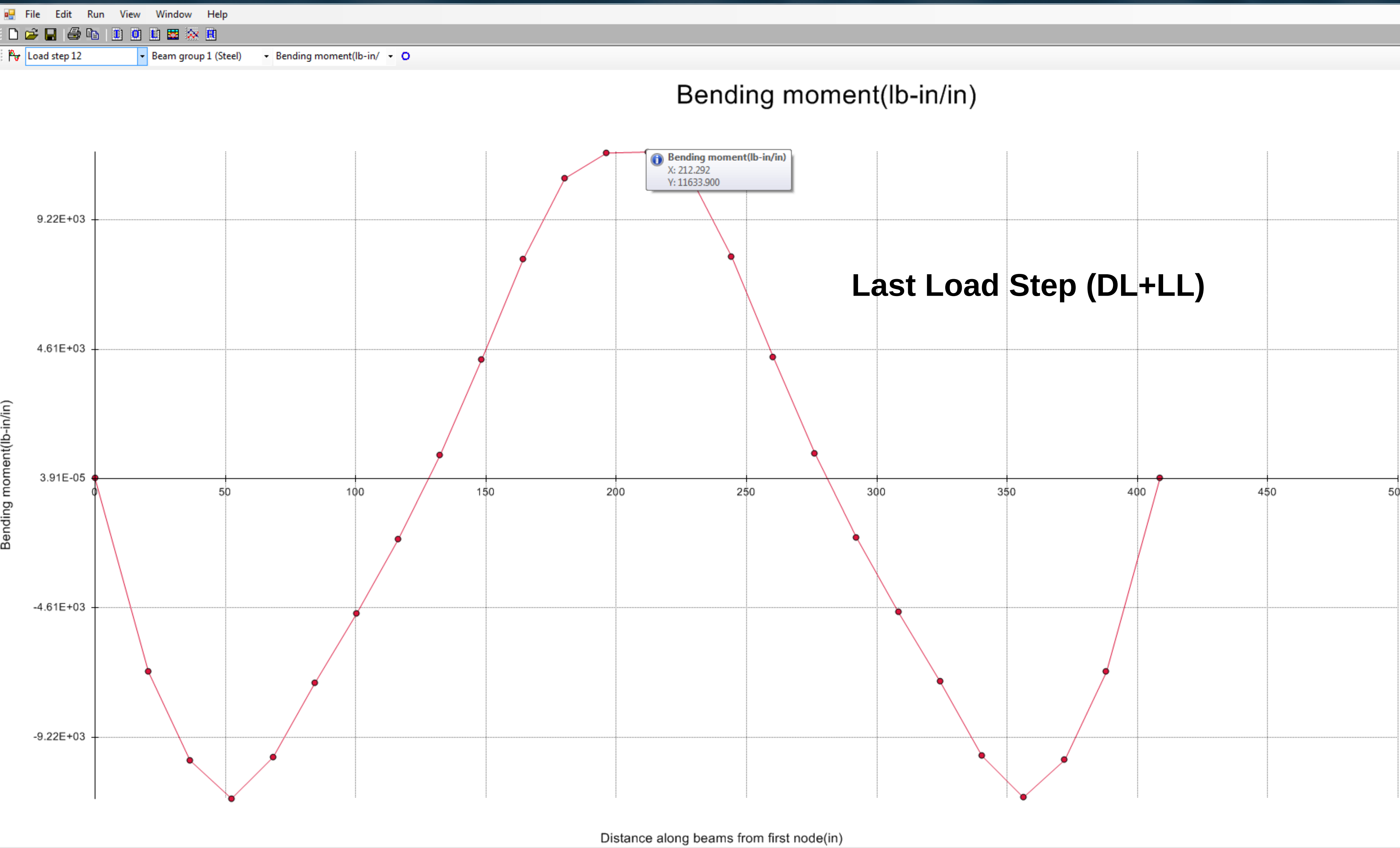
Live load applied at last step – design governed by HL93 Tandem



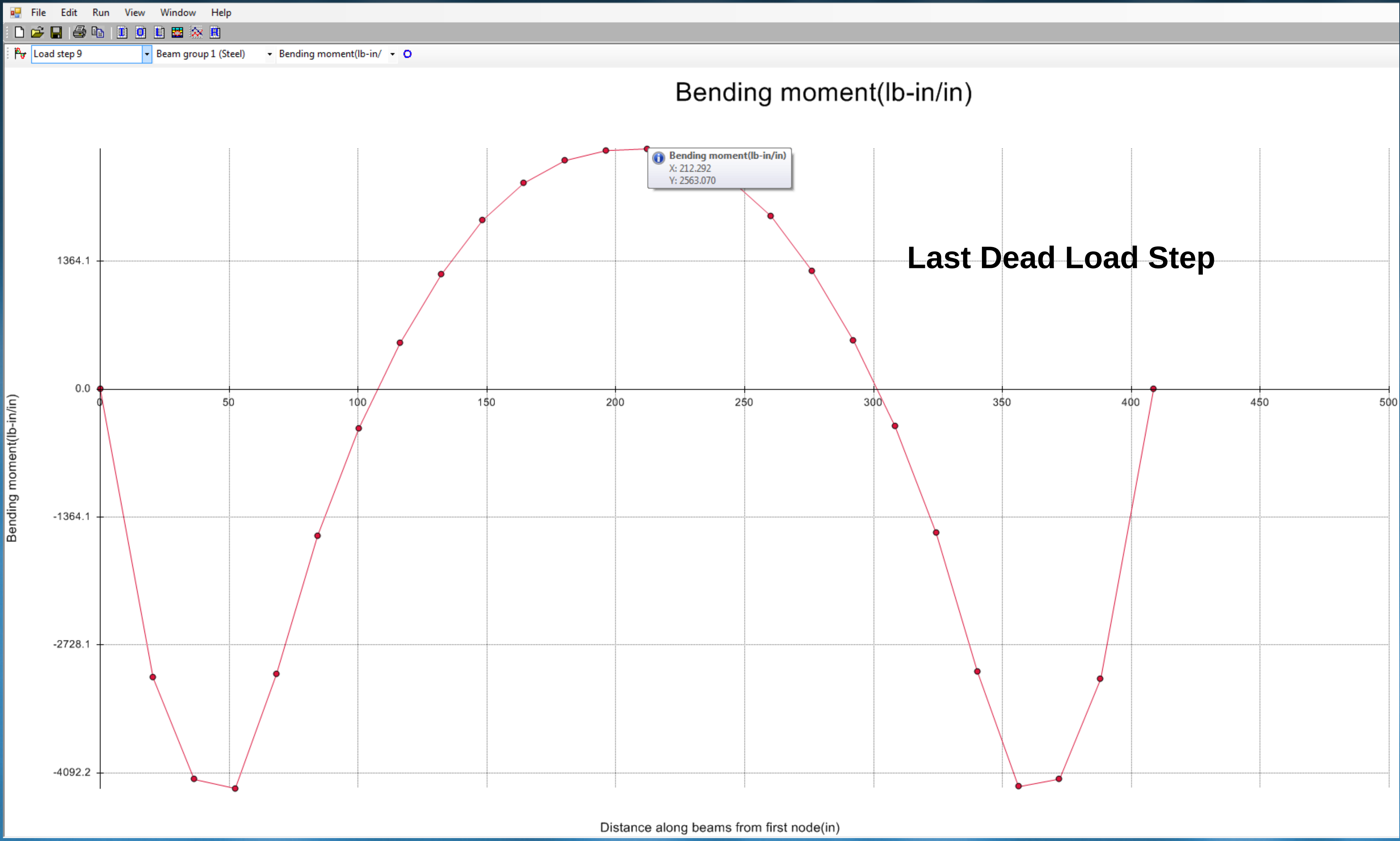
Moment diagram of all load steps (LL in pink)



Obtain loads from FEA output



Obtain loads from FEA output



Design loads obtained using FEA based on SSI & load factors applied

FEA Analysis:

Total Factored Thrust:	**25.9 k/ft.**
Total Factored Applied Moment:	**23.0 k-ft./ft.**

Structure capacities calculated based on AASHTO LRFD Equations

Calculated Capacity

Nominal Buckling Resistance			Eq. 12.8.9.6-1
	R_b = 78.3 k/ft.	**OK**	
Factored Wall Resistance			12.7.2.3
	R_n = 142.8 k/ft.	**OK**	
Nominal Seam Resistance			12.7.2.5
	SS = 96.5 k/ft.	**OK**	
Factored Moment Resistance			12.8.9.7
	M_r = 26.9 k-ft./ft.	**OK**	
Factored Moment Resistance across seam (10% reduction in member moment capacity)			12.8.9.7
	$M_{r10\%}$ = 24.7 k-ft./ft.	**OK**	

Check moment-thrust interaction:

$$\left(\frac{T_f}{R_t}\right)^2 + \frac{|M_u|}{|M_n|} \leq 1.00$$

$$\left(\frac{25.9}{142.8}\right)^2 + \frac{|23.0|}{|26.9|} = 0.89 \leq 1.00$$


TEREX





Peabody
18 FT 8 IN


5,4m


갈마치고개 생태이동통로


STOP

Thank You!

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