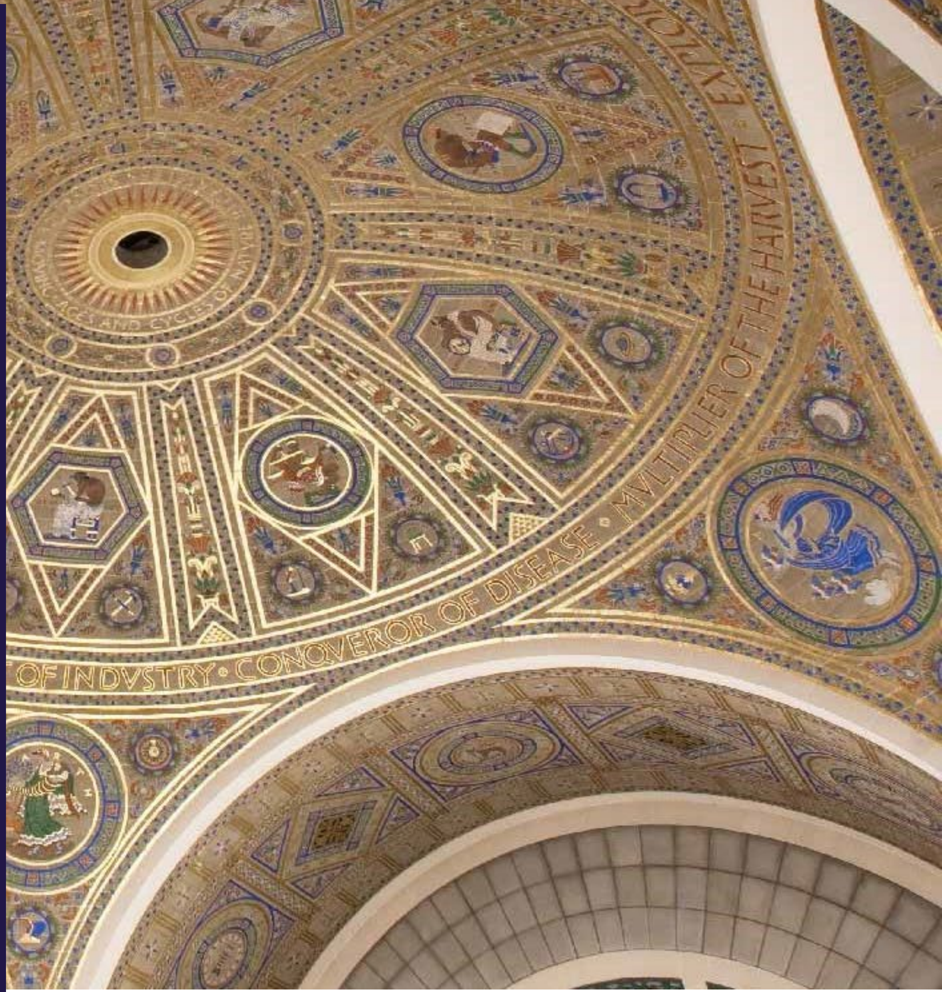
NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Demonstrated Performance of Buried Bridges

October 31, 2023

11:00 AM – 12:30 PM



PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

AICP Credit Information

1.5 American Institute of Certified Planners Certification Maintenance Credits

You must attend the entire webinar

Log into the American Planning Association website to claim your credits

Contact AICP, not TRB, with questions

Purpose Statement

This webinar will explore successful case studies showcasing the exceptional performance of concrete and steel buried bridges, supported by multi-year measurements.

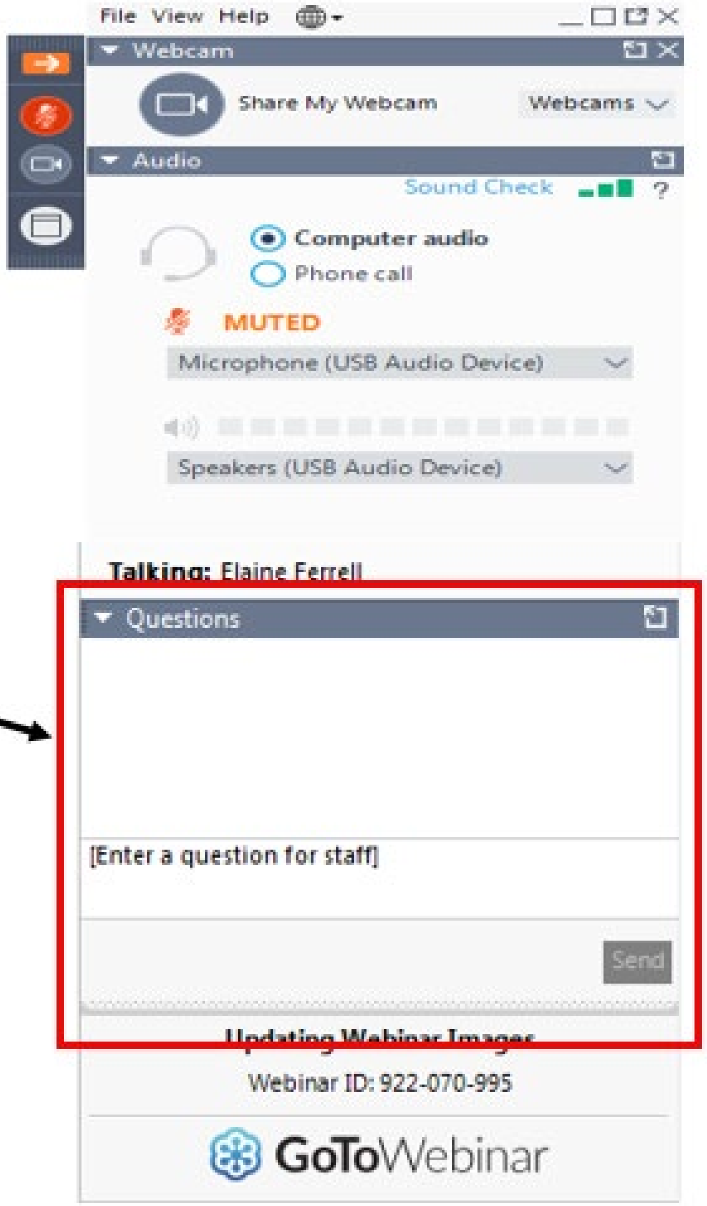
Learning Objectives

At the end of this webinar, you will be able to:

- Evaluate long term performance of buried bridges based on field measurements
- Identify conditions where buried bridges may be a preferred option over traditional beam bridges

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

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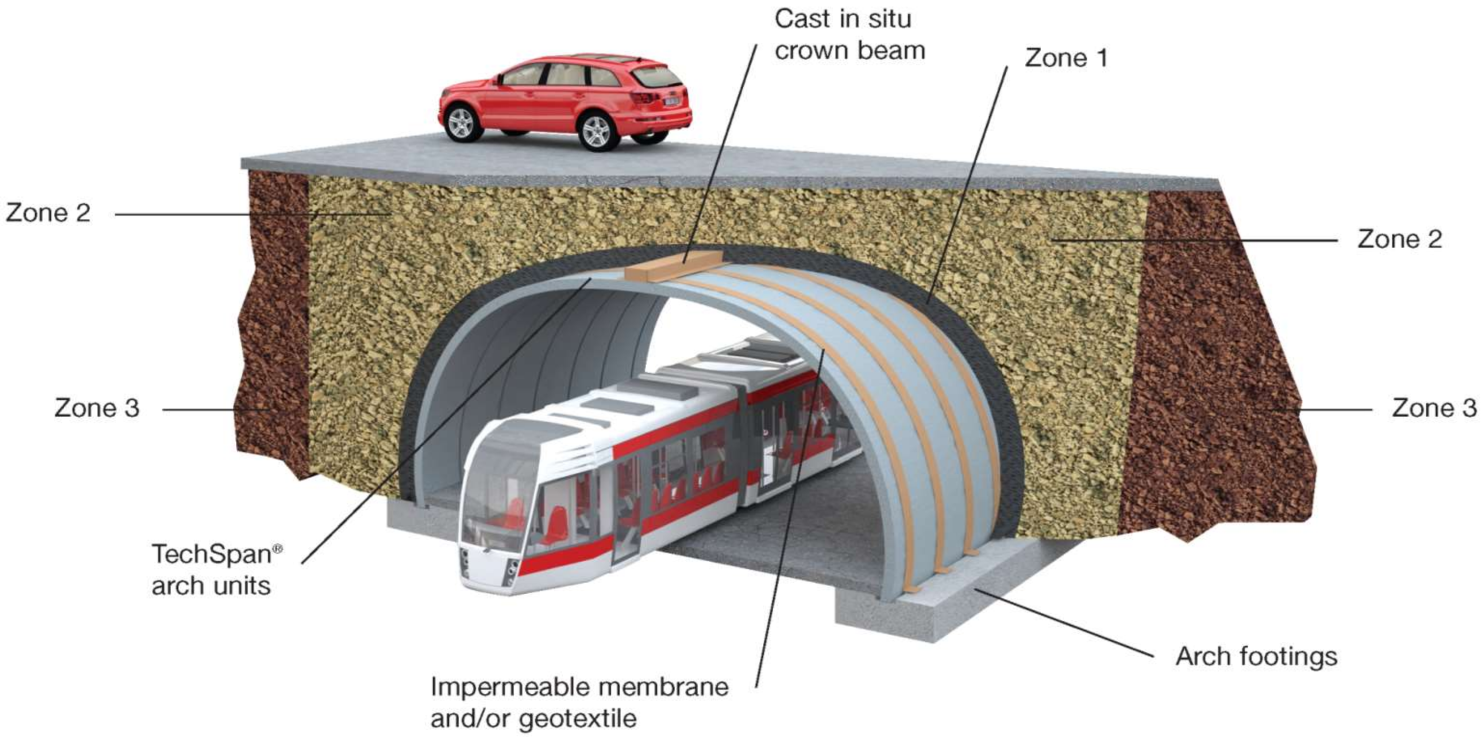
TRB Webinar
"Demonstrated Performance of Buried Bridges"

TechSpan®: The precast concrete arch system

2023 October 31st

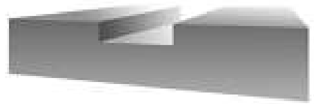
PIACENTINO Roberto

The Precast Arch System: Components

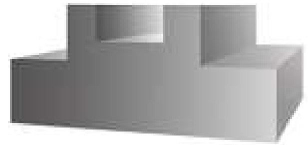


FOUNDATIONS

Based on site specific conditions, foundations can be one of the following options



Spread footing



Spread footing with pedestal

Raft foundation

Pile cap on deep foundation

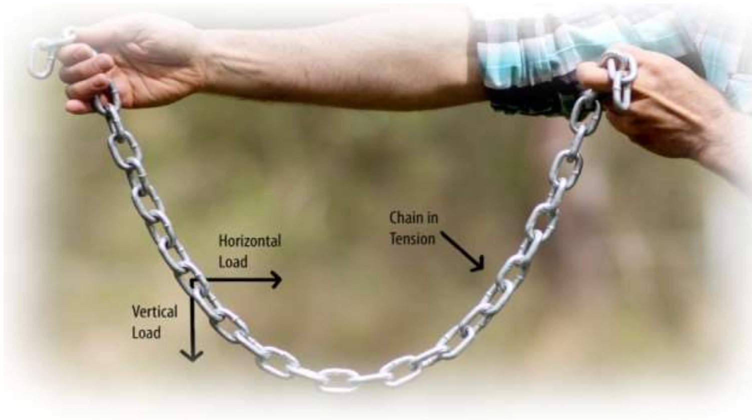
TYPICAL DIMENSIONS

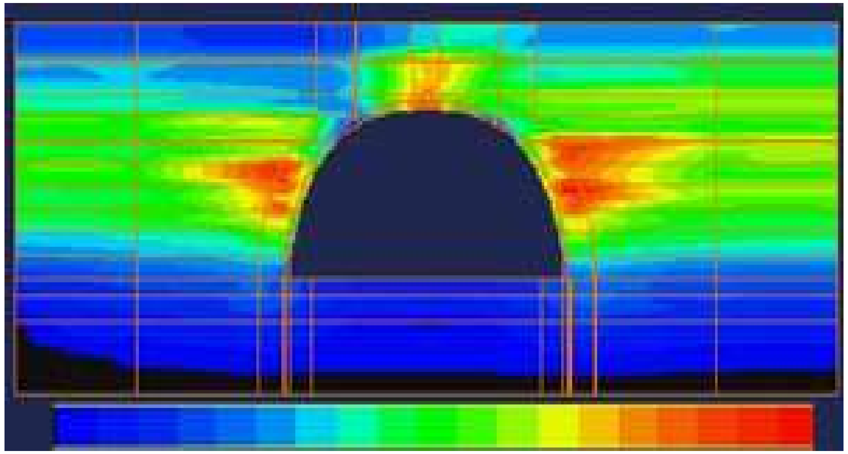
- **Typical Span** of the arches ranges from about **10 ft to 98 ft** (3 to 30 m)
- **Height** of the arch ranges from about **30% to 70%** of the span
- Arch **thickness** is in range of **8 in to 20 in** (200mm to 500mm)

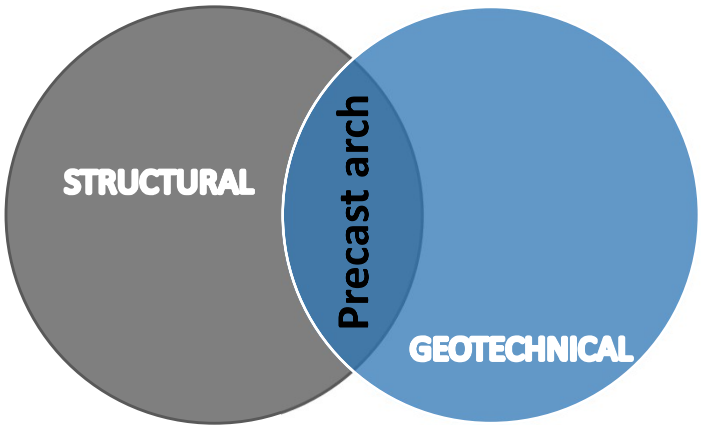
The Precast Arch System: Design Method

F.E.M. model

- Concept of **FUNICULAR CURVE** to achieve an economical design (customized shapes are also possible).
- **STAGED** analysis incorporates **Duncan-Chang** or **Mohr-Coulomb** soil models in an attempt to obtain the best possible simulation of the real behaviour of the soil-structure interaction.
- **CONSTRUCTION PHASE** loads can govern the design of the arch element.

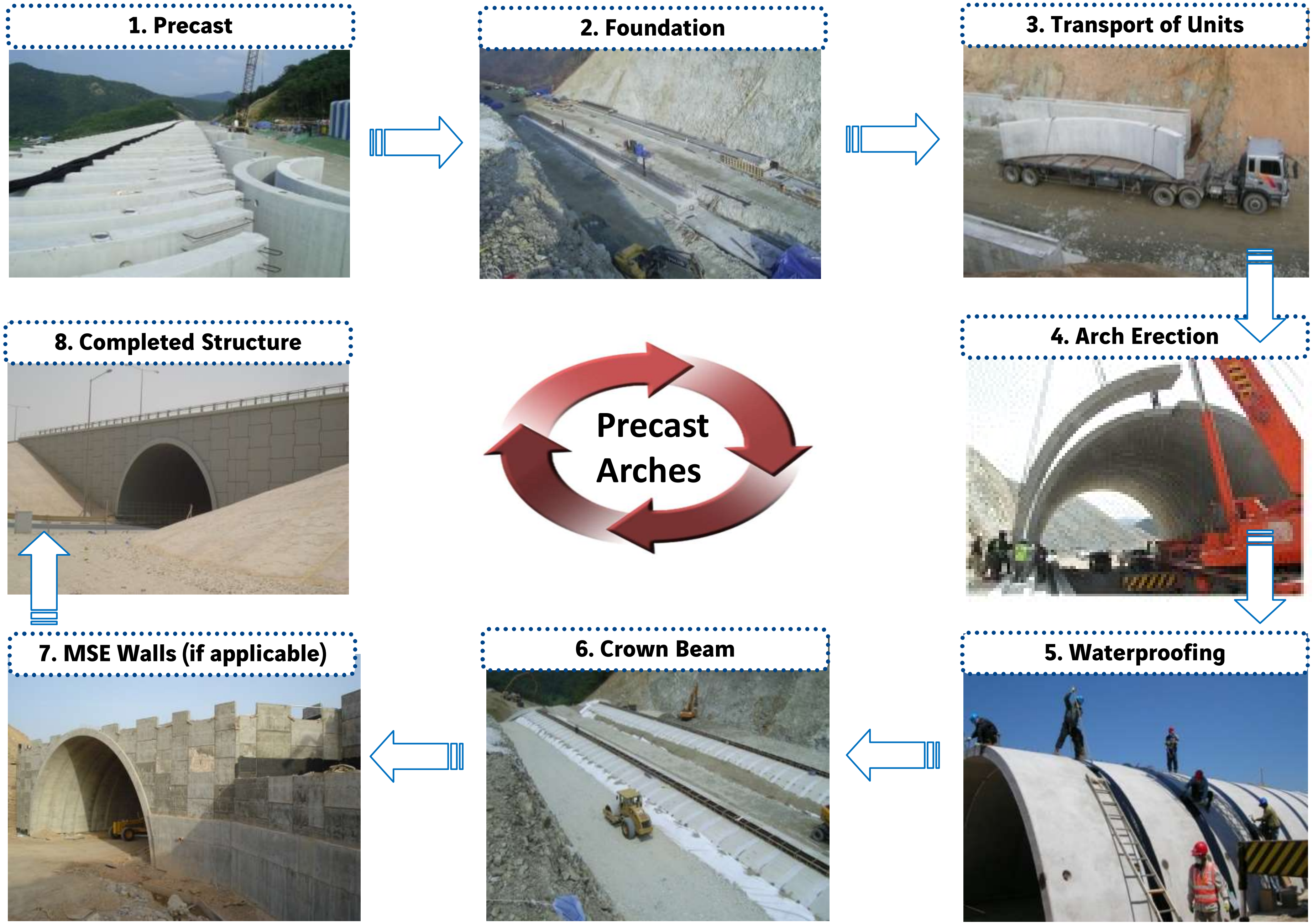






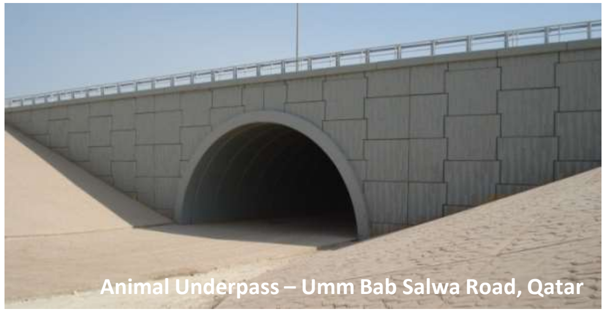
SOIL is not only a load, **IT'S PART OF THE STRUCTURE**

The Precast Arch System: Construction



The Precast Arch System: Applications

Not only application for Roadways and Railways bridges & underpasses …



… but also Cut & Cover tunnels, Hydraulic, Risk Mitigation, Oil & Gas, Mining & Industrial…

The Precast Arch System: Performance Benefits

PRECAST

- Better **QUALITY CONTROL** comparing to CIP structures
- Extended **DURABILITY**

BURIED

- The soil **INTERACTS** with the structure, supporting the loads
- Buried structures benefits from **EARTH SHELTER**, reducing from concern many loads which can deteriorate the structures during its service life (temperature & shrinkage, dynamic loads, vibrations, earthquakes, blast...)
- Concentrated loads are **DISSIPATED** through the soil

ARCH

- **ARCH** has proven its extraordinary durability characteristics throughout history
- The **FUNICULAR** shape minimizes the tensile stresses

Ras Al Khaimah arch bridge – construction year 2000 – UAE

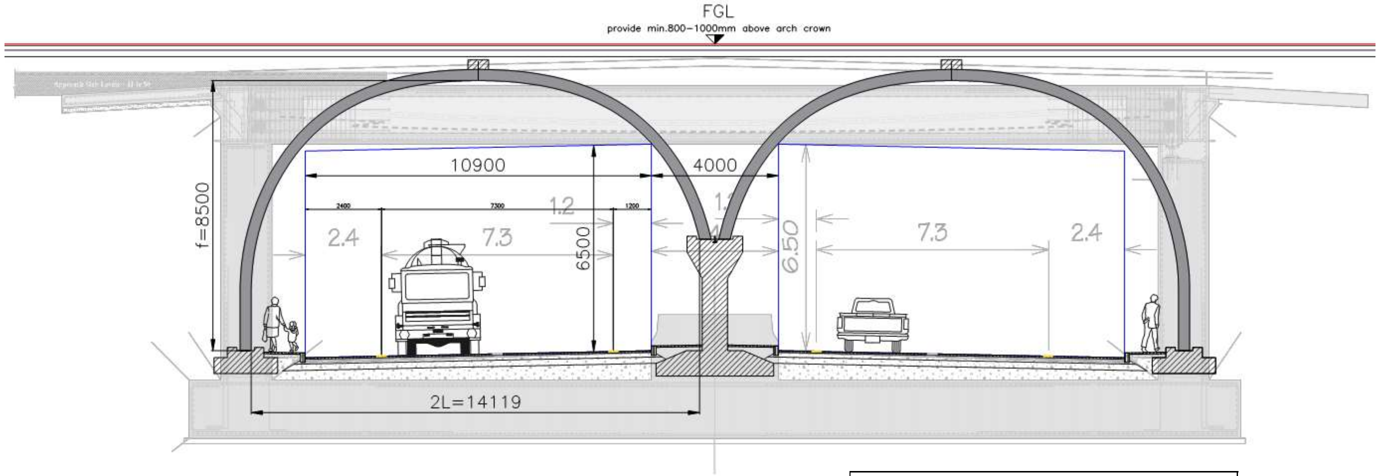
Roman aqueduct – The Pont du Gard - Built about 2000 years ago – France

The Precast Arch System: Life-Cycle cost Benefits

Construction costs are in range of 30% to 70% compared to standard bridges

PRECAST ARCH

- Concrete & steel savings
- No abutments
- No expansion joints
- No bearings
- No post tensioning



CONCRETE CONSUMPTION TAKEOFF				
ITEM	TechSpan [m^3/m]	BOX UNDERPAS [m^3/m]	SAVING [m^3/m]	[%]
CONCRETE	26	153	127	83%

Minimal maintenance works during the service life of the structure!

Performance of Precast Buried Arches

Ras Al Khaimah arch bridge (UAE, 2000)

Excellent comparison example of performance between Precast buried arches and traditional bridges in **extreme environment conditions**

Environment conditions

- **Aggressive** Backfill (high content of chlorides and sulfates)
- **Marine** Environment
- **Dry/wet exposure** to sea water

Traditional Bridge

- Cast in place piers with pre-stressed concrete beams
- Several maintenance works (Concrete spalling, corrosion, expansion joints and bearings)

Structure abandoned after a relatively short service life

Precast Buried Arch

- 3 hinges precast arches Span= 43ft (13 m), rise= 18 ft (5,50m), thickness= 13,8 in (350 mm)
- Specific mix design, curing control, painted coating, concrete cover 3 in (75mm)

No maintenance works or issues reported since the construction (>23years)

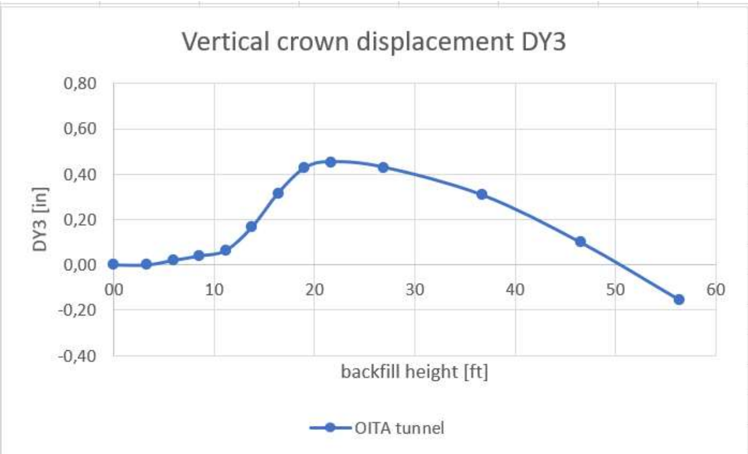
Case Study 1 - Analysis of buried arch: Performance vs prediction

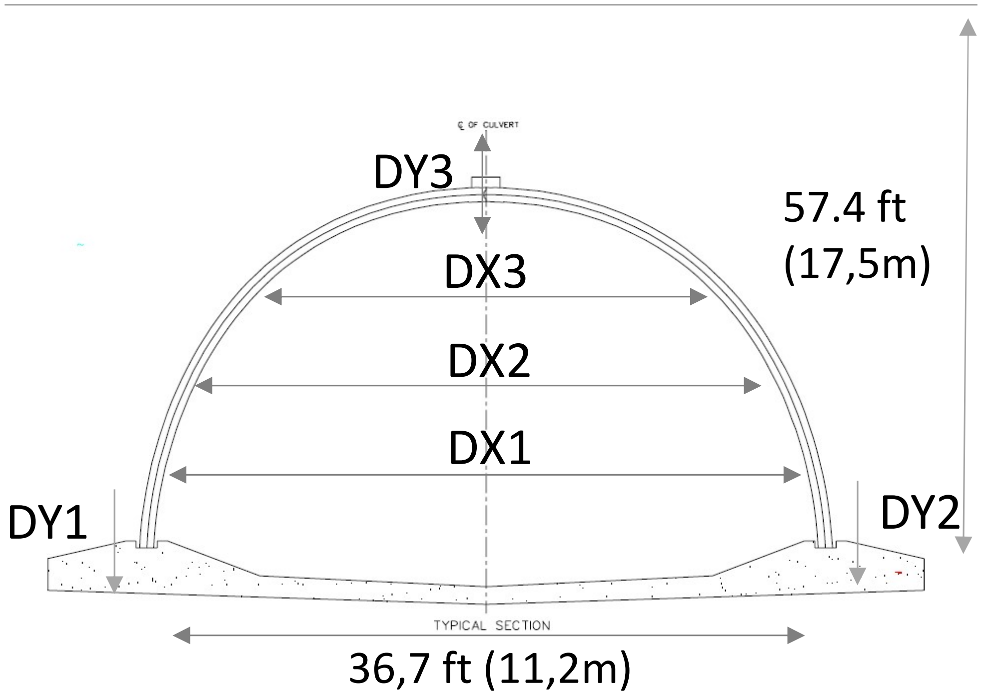
Comparison between site measurements and results of **FEM analysis**

OITA TechSpan tunnel (Japan, 1995)

Site measurements

- Vertical **crown deflection**
- Horizontal **width variation** of the arch
- **Reinforcement strain**
- **7 sections** monitored





Bending Moment estimation

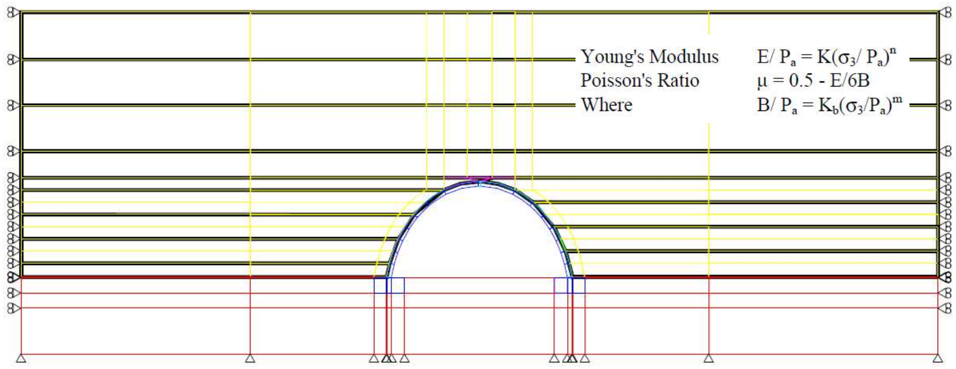
- Hyp. 1: Cracked concrete **Mmax= 266 kip.in** (30kNm)
- Hyp. 2: Uncracked concrete **Mmax= 974 kip.in** (110kNm) (tensile bending stress carried also by concrete)

Case Study 1 - Analysis of buried arch: Performance vs prediction

OITA TechSpan tunnel (Japan, 1995)

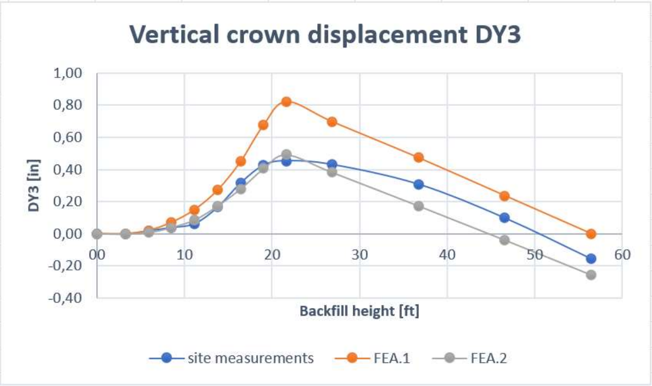
FEM MODEL

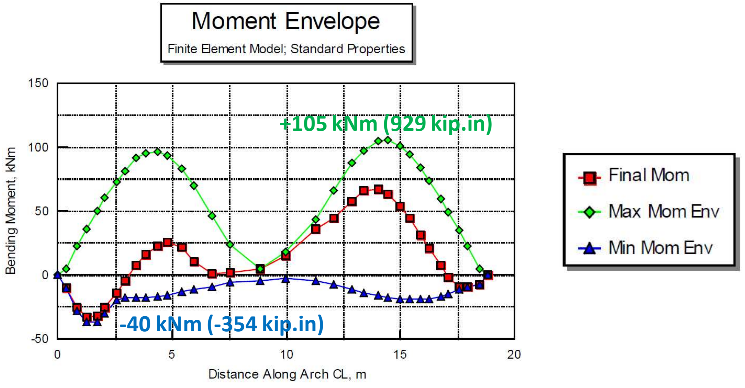
- **Duncan & Chang** elasto-plastic soil model
- **Step** loading (real backfilling sequence)
- **Friction layer** around the arch (soil-structure interaction)
- **Concrete** linear elastic

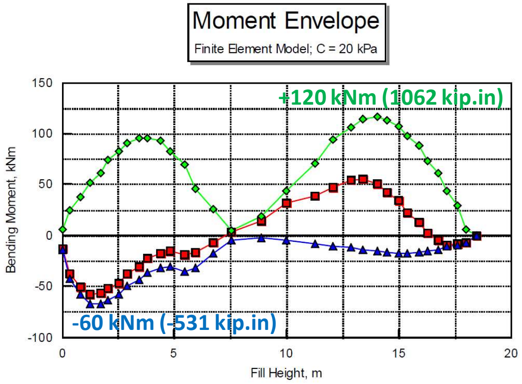


FEA.1: phi=30°; c=0; Ec= 2900 kip/in² (20GPa) (standard)

FEA.2: phi=30°; c=20 KPa; Ec= 5075 kip/in² (35GPa)







- Higher **deflections** for FEA.1; good results for modified model FEA.2
- **Bending moments** in good agreement for both models (small variation with Ec)
- Ec= 2900 kip/in² (20GPa) is however **conservative** for the design

GOOD RESULTS FOR THE DESIGN OF THE CONCRETE SECTION

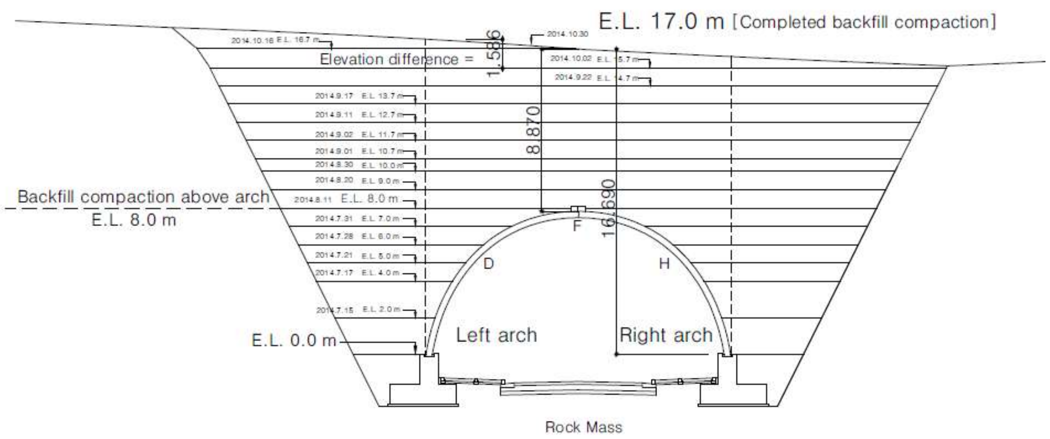
Case Study 2 - Analysis of buried arch: Performance vs prediction

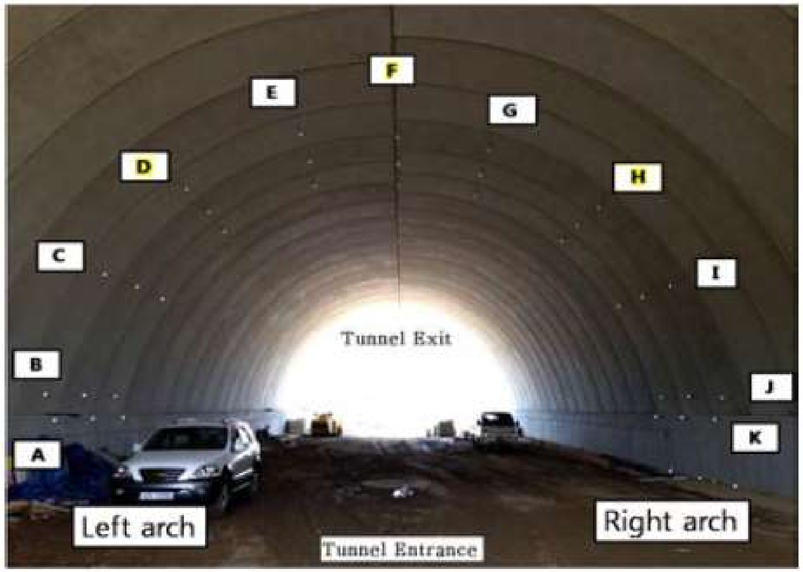
Investigation on deformations of precast arch structures

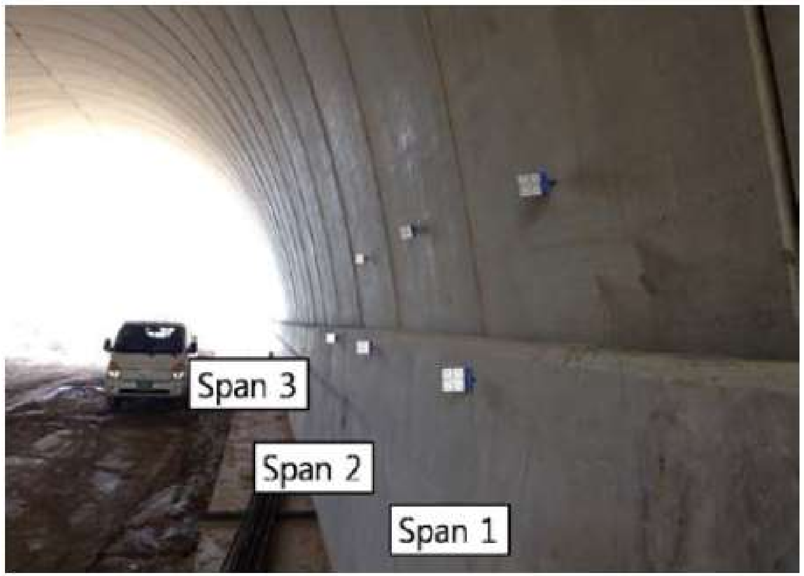
Gosan-gun TechSpan tunnel (Korea, 2014)

Site geometry & measurements

- Span= 52,5ft (16m), rise= 25ft (7,6m), th.= 13,8in (350mm)
- L= 230ft (70m), $H_{max.soil}$= 29ft (8,87m)
- **Displacements** measurement on site (A→H)
- **3 sections** monitored





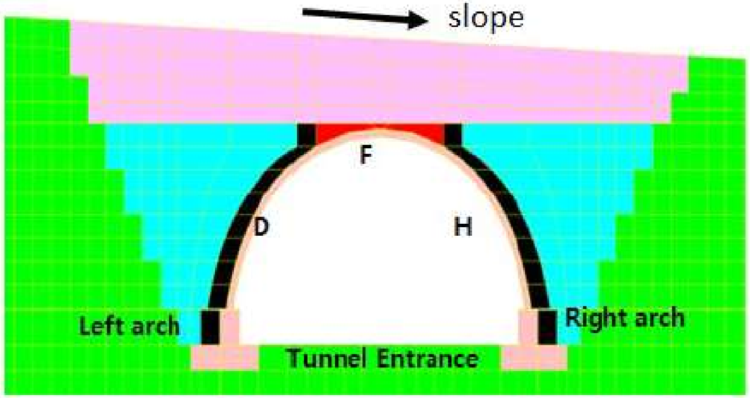


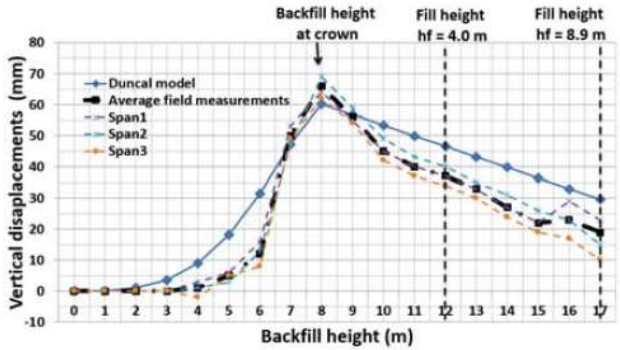
Case Study 2 - *Analysis of buried arch: Performance vs prediction*

Gosan-gun TechSpan tunnel (Korea, 2014)

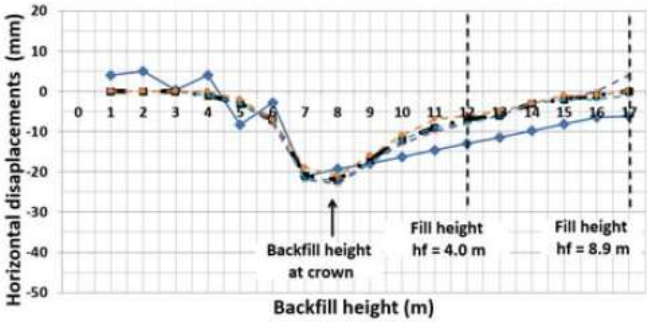
Numerical analysis

- **FEM model** with Aztech software
- **Duncan-Chang** soil model
- **Backfill properties:** γ= 0,125kcf (20kN/m3), φ=32°, c'=0KPa
- **Concrete ELASTIC** (fck= 5,8 kip/in^2 (40MPa), Ec= 4350 kip/in^2 (30GPa)

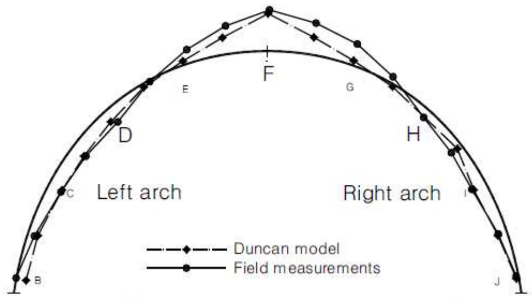




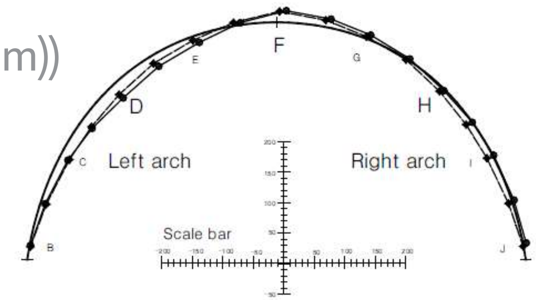
(a) Point F (crown)



(b) Point H (right arch)



(a) Backfill compaction up to arch height (backfill level = 8.0 m)



(b) After backfill compaction completed (backfill level = 17.0 m)

- Max Vertical uplift displacement of the crown close to reality (H= 26,2ft (8m))
- The variation of displacements with backfill height is more **gradual** in the fem analysis
- **Deformed shape** from FEM model is **similar** to field measurements
- The fem model globally well represent the trend of the displacements

Conclusions

- Buried precast arches demonstrate **extended durability** compared to standard bridges (quality control, funicular shape, compression stresses…).
- **Applications** for such type of structures cover a wide range of sectors (cut & cover tunnels, hydraulic, mining & industrial, rock protection, oil & gas…)
- The **backfill** around the arch, which is a structural component of the system, behaves as a **shelter** dissipating the loads.
- **Cost savings** in construction and for maintenance during the service life of the structure (no abutments, no expansion joints, no bearings, no PTs).
- **FEM models** well represent the behavior of the structure, simulating the **interaction soil-structure** and the **flexibility** of the arch.

Thank you for listening!

References:

- *Analysis of buried arch structures; performance versus prediction (D.A.Jenkins)*
- *Investigation for the deformation behavior of the precast structure in the open-cut tunnel (Hak Joon Kim, Gyu-Phil Lee, Chul Won Lim)*

TRB Webinar:

Demonstrated Performance of Buried Bridges

Atlantic Industries Limited

We Support You.

October 31st, 2023

Meckkey El-Sharnouby, Ph.D. P.Eng
Garrett Smith, MASc. P.Eng

CANADA BEST MANAGED COMPANIES

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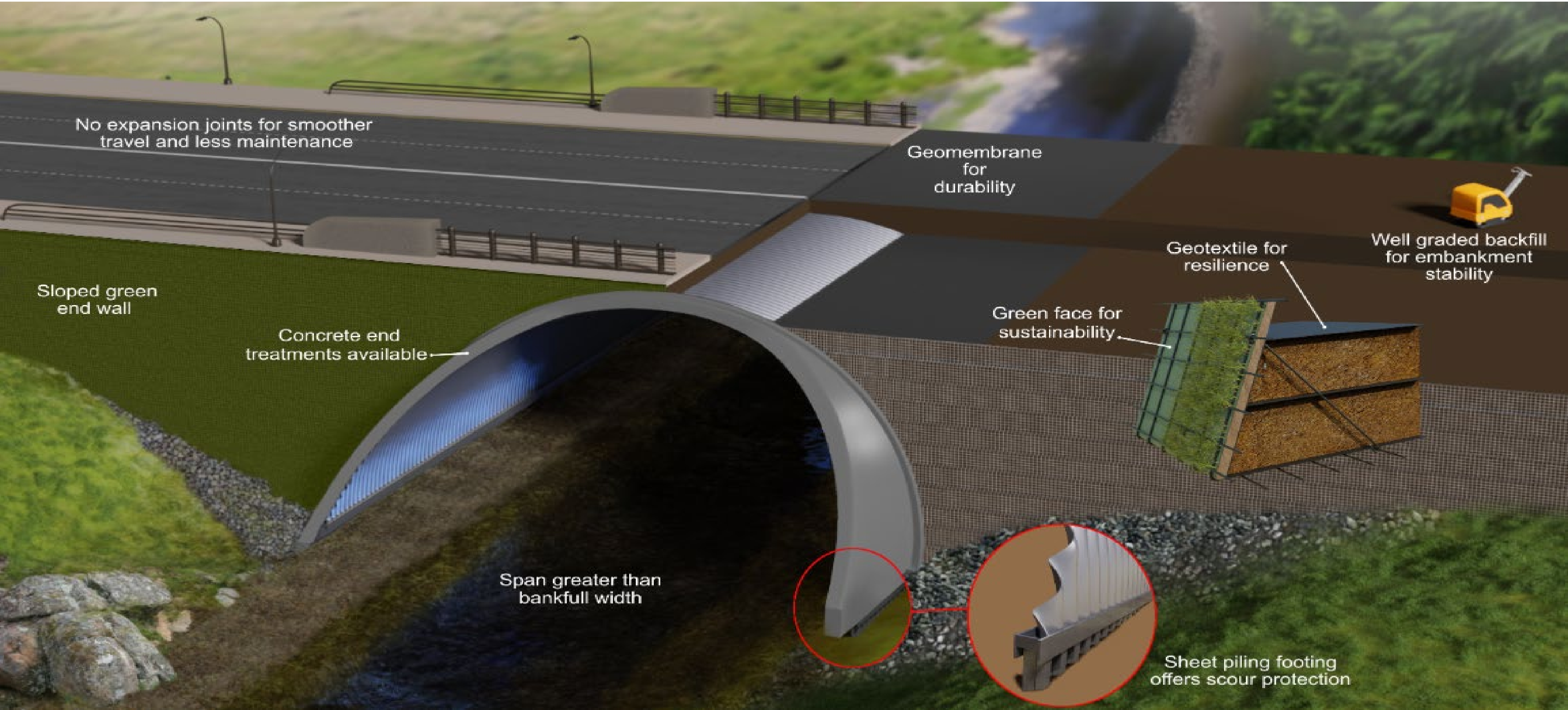
Buried Bridges Background

- What is a soil-steel Bridge?

A bridge that utilizes the composite behaviour of a steel structure and engineered backfill built using embankment or trench methods

- Designs governed by AASHTO LRFD section 12, CHBDC section 7, AS/NZ2041
- Soil-steel interaction, load distribution
- Used primarily in transportation, mining and forestry sectors for road crossings and stream crossings
- Single spans range from 10’ to 115’

Buried Bridges Background



Structural Plate

- Defined in AASHTO M167
- Properties in ASTM A796
- 1960's Shallow Corrugation
  - 2" by 6" (51mm by 152mm)
  - Thickness: 0.11" to 0.38" (3mm to 7mm)
- 1990's Deep Corrugation
  - 5.5" by 15" (140mm by 381mm)
  - Thickness: 0.14" to 0.38" (3.6mm to 8mm)
- 2010's Deeper Corrugation
  - 9.5" by 19" (237mm by 500mm)
  - Thickness: 0.28" to 0.38" (7mm to 9.5mm)

Structure Design

- Bridges are considered using a limit states design philosophy
- Includes serviceability, strength and fatigue limit states

12.8.9.5—Combined Thrust and Moment

The combined effects of moment and thrust at all stages of construction shall meet the following requirement:

$$\left(\frac{T_f}{R_t}\right)^2 + \left|\frac{M_u}{M_n}\right| \leq 1.00 \qquad (12.8.9.5\text{-}1)$$

where:

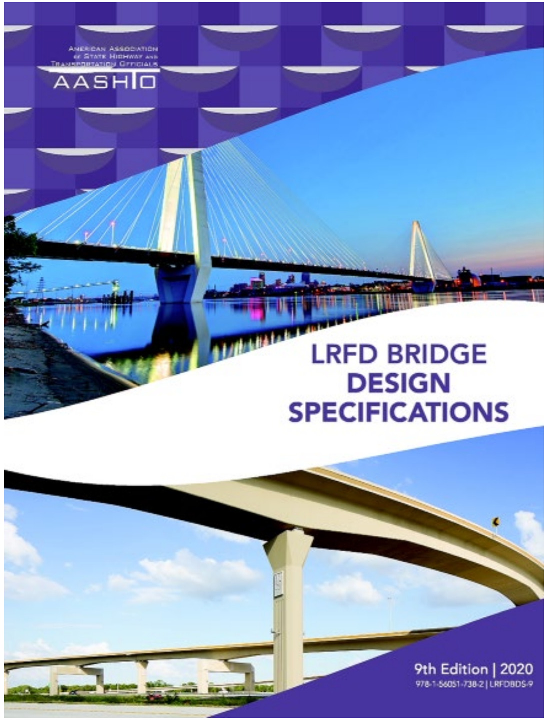
T_f = factored thrust
R_t = factored thrust resistance = $\phi_h F_y A$
M_u = factored applied moment
M_n = factored moment resistance = $\phi_h M_p$
M_p = plastic moment capacity of section

12.8.9.7—Connections

The factored moment resistance of longitudinal connections shall be at least equal to the factored applied moment but not less than the greater of:

- 75 percent of the factored moment resistance of the member or
- the average of the factored applied moment and the factored moment resistance of the member.

Moment resistance of connections may be obtained from qualified tests or published standards.



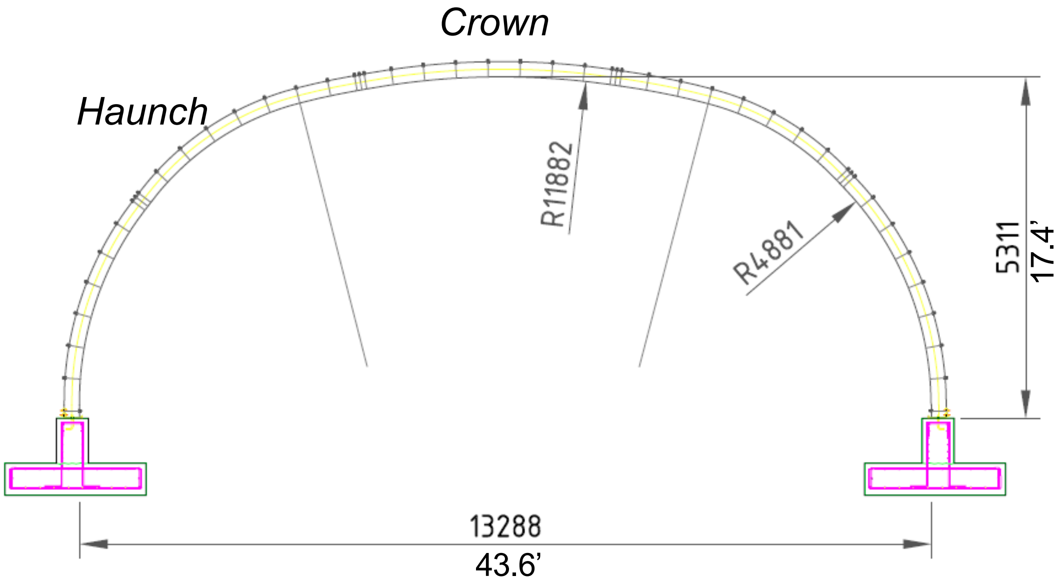
Case Study: Corner Brook, NL

- Trans-Canada highway twining project
- Local road to water treatment plant
- Constructed in 2012
- First deeper corrugation structure in North America
- Bridge designed and manufactured by Atlantic Industries Ltd.

Case Study: Corner Brook, NL

Structure Details

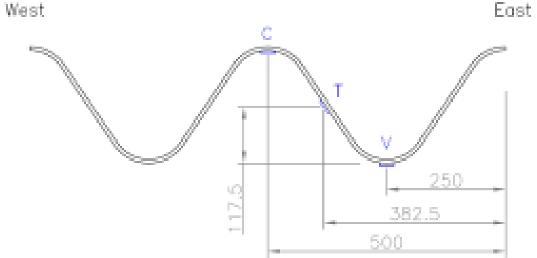
- Rise = 17.4’ (5.3 m)
- Clear Span = 43.6’ (13.3 m)
- Engineered Backfill Envelop = 88.6’ (27 m)
- Structure Length = 180.4’ (55 m)
- Haunch Radius = 16’ (4.9 m)
- Crown Radius = 40’ (11.9 m)
- Design Live Loading = 140 kips

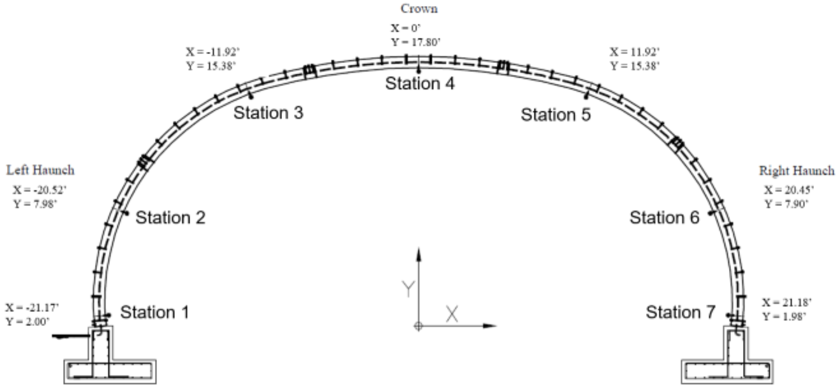


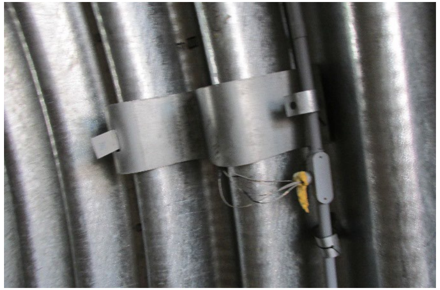
Case Study: Corner Brook, NL

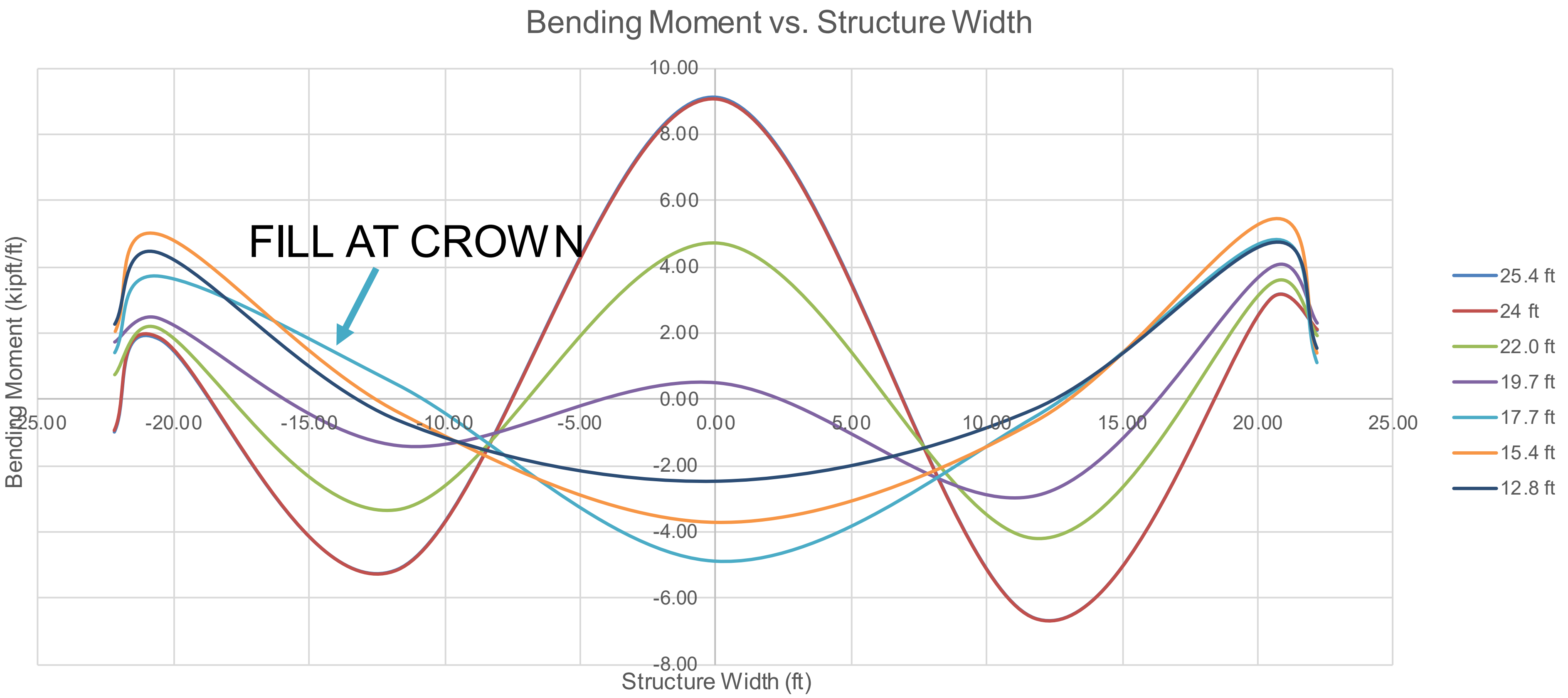
Instrumentation

- Monitoring date: April 2012 – July 2013
- 1 ring monitored with strain gauges
  - 7 Strain gauge stations
  - 3 thermo-couples
- 3 rings monitored for deflection

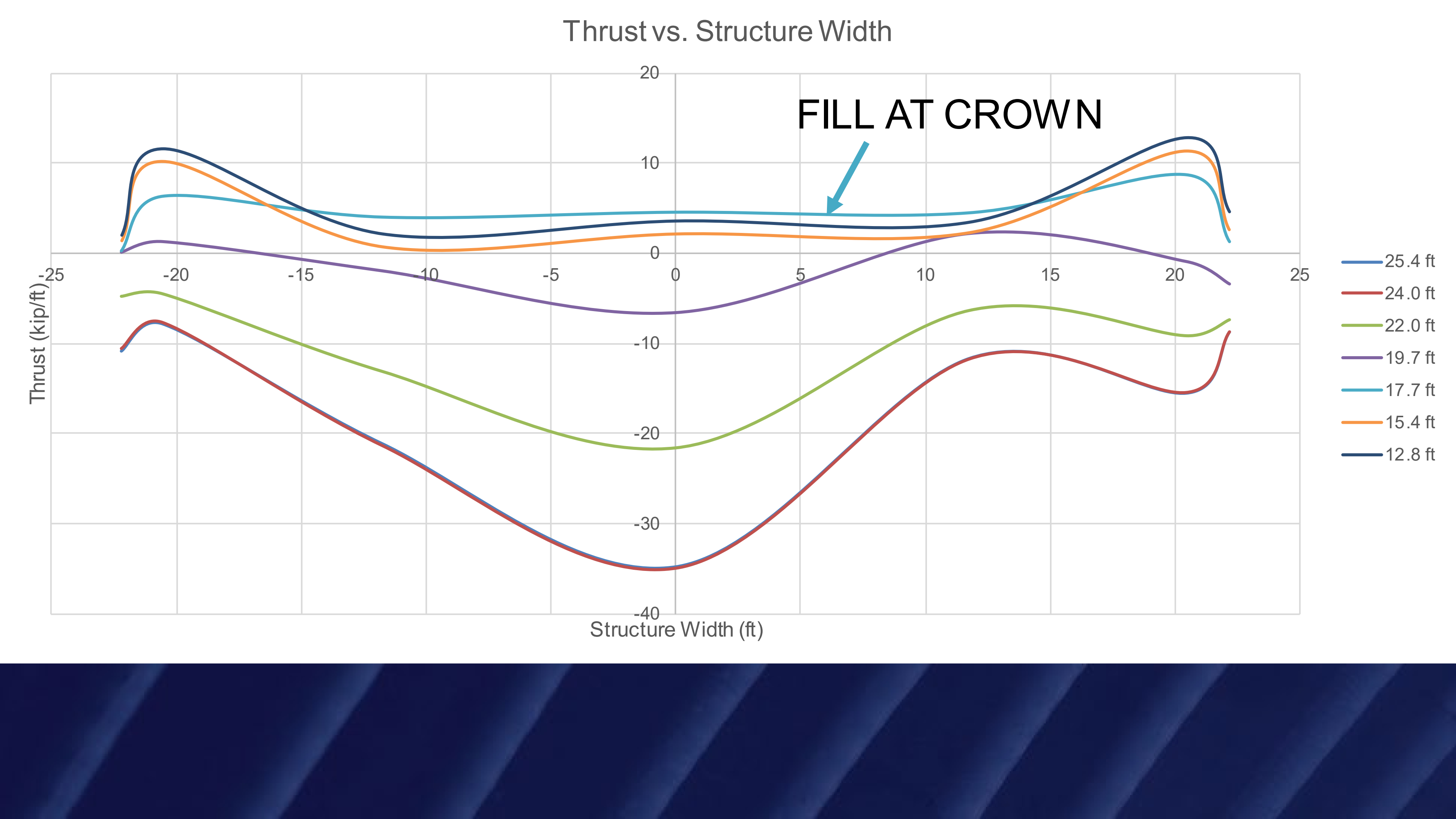




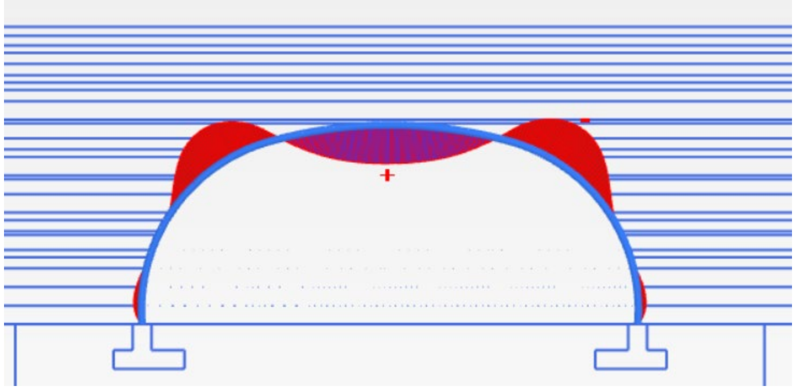


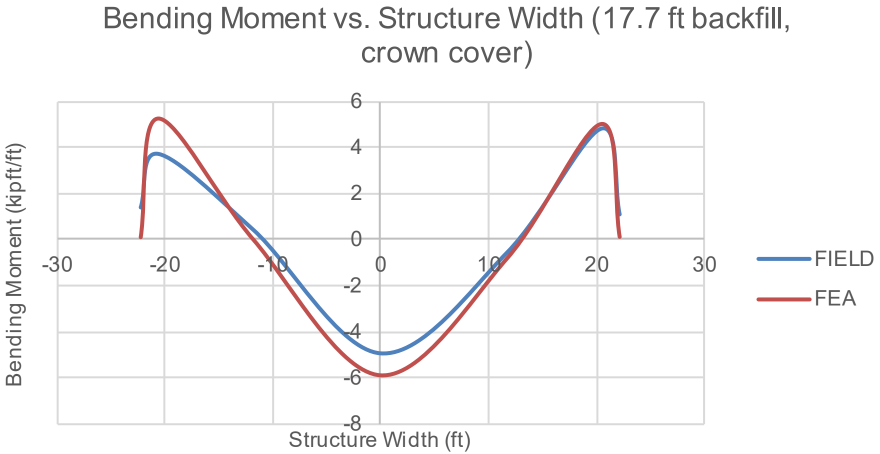


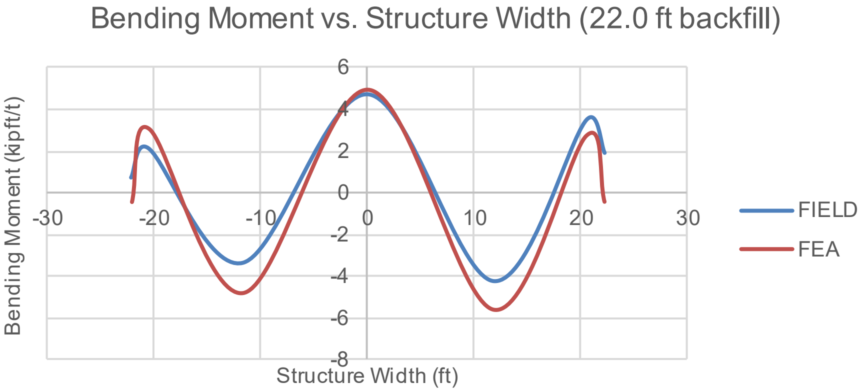
Bending Moment vs. Structure Width
FILL AT CROWN
Bending Moment (kipft/ft)
Structure Width (ft)
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-25.00
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.00
25.00
25.4 ft
24 ft
22.0 ft
19.7 ft
17.7 ft
15.4 ft
12.8 ft

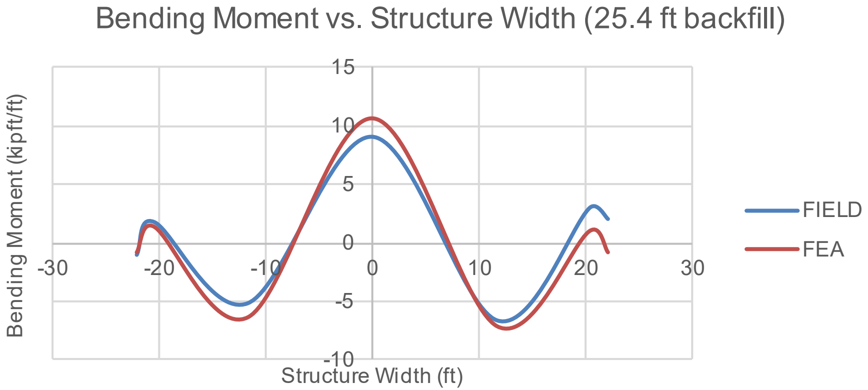


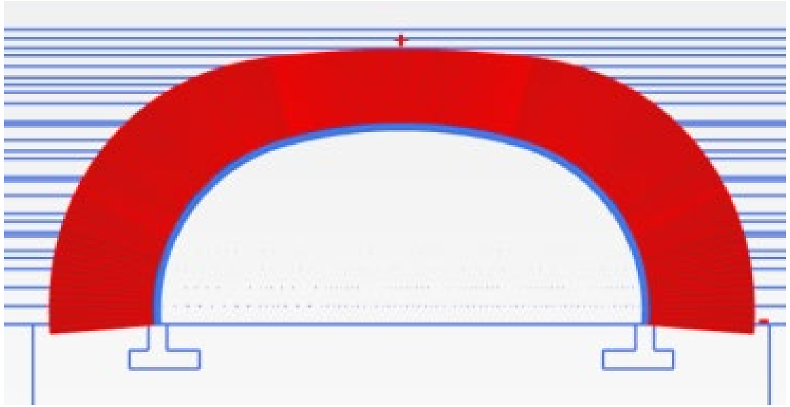
Thrust vs. Structure Width
FILL AT CROWN
Thrust (kip/ft)
Structure Width (ft)
20
10
0
-10
-20
-30
-40
-25
-20
-15
-10
-5
0
5
10
15
20
25
25.4 ft
24.0 ft
22.0 ft
19.7 ft
17.7 ft
15.4 ft
12.8 ft

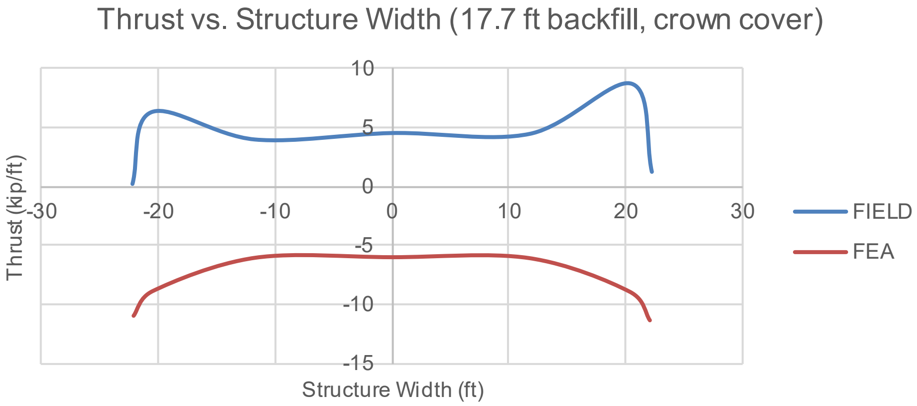


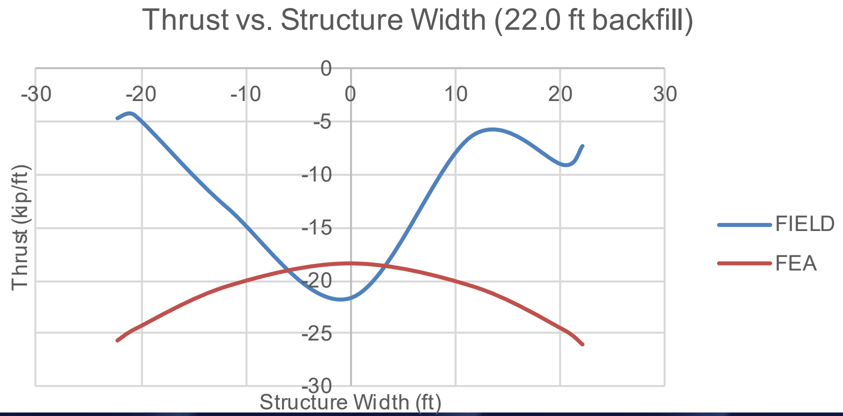

Bending Moment vs. Structure Width (17.7 ft backfill, crown cover)
Bending Moment (kipft/ft)
Structure Width (ft)
6
4
2
0
-2
-4
-6
-8
-30
-20
-10
0
10
20
30
FIELD
FEA

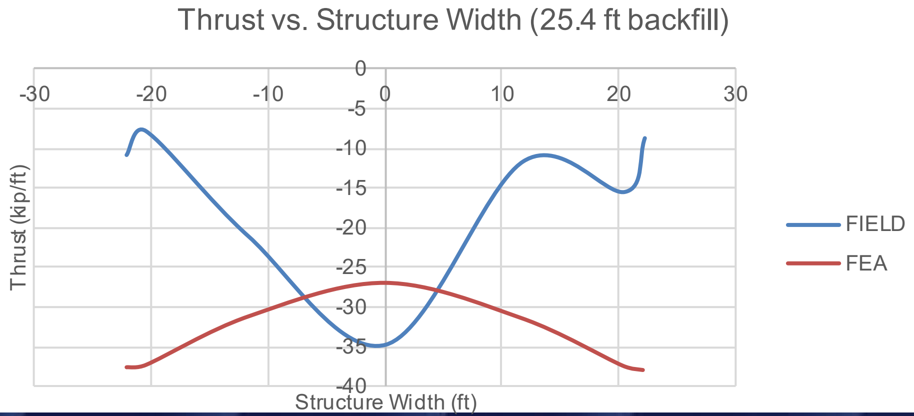

Bending Moment vs. Structure Width (22.0 ft backfill)
Bending Moment (kipft/t)
Structure Width (ft)
6
4
2
0
-2
-4
-6
-8
-30
-20
-10
0
10
20
30
FIELD
FEA


Bending Moment vs. Structure Width (25.4 ft backfill)
Bending Moment (kipft/ft)
Structure Width (ft)
15
10
5
0
-5
-10
-30
-20
-10
0
10
20
30
FIELD
FEA




Thrust vs. Structure Width (17.7 ft backfill, crown cover)
Thrust (kip/ft)
Structure Width (ft)
FIELD
FEA
10
5
0
-5
-10
-15
-30
-20
-10
0
10
20
30


Thrust vs. Structure Width (22.0 ft backfill)
Thrust (kip/ft)
Structure Width (ft)
FIELD
FEA
0
-5
-10
-15
-20
-25
-30
-30
-20
-10
0
10
20
30


Thrust vs. Structure Width (25.4 ft backfill)
Thrust (kip/ft)
Structure Width (ft)
FIELD
FEA
0
-5
-10
-15
-20
-25
-30
-35
-40
-30
-20
-10
0
10
20
30

Case Study: central Chile

- Forestry road river crossing
- Constructed in early 2022
- Span: 75.5’ (23.0 m)
- Rise: 16.3’ (5.0 m)
- Designed for heavy vehicle loads
- Designed to AASHTO LRFD

Case Study: Gagetown, NB

- Highway stream crossing
- Constructed in late 2022
- Span: 64.3’ (19.6 m)
- Rise: 20.7’ (6.3 m)
- Designed for heavy vehicle loads
- Made use of two different corrosion protection system on the steel plate

To help protect your privacy, PowerPoint has blocked automatic download of this picture.

Case Study: Ladysmith, BC

- Main stream crossing with two smaller trail conduits
- Local road to new subdivision
- Constructed in early 2023
- Span: 62.7’ (19.1 m)
- Rise: 24.3’ (7.4 m)
- Design with substantial soil sloping
- Complex layout

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Case Study: Saint John’s, NL

- Trans-Canada highway interchange
- Currently under construction
- Span: 83.3’ (25.4 m)
- Rise: 21.0’ (6.4 m)

Case Study: Canmore, AB

- Twin structures over the Trans-Canada highway
- Currently under construction
- Span: 78.7' (24.0 m)
- Rise: 25.3' (7.7 m)
- Steeply beveled structure ends
- Irregular backfill envelope
- Wildlife crossing

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Case Study: Canmore, AB

- Safe passage for animal migration and movement
- Reduce likelihood of vehicle-animal collisions
- Bevel ends: more sustainable solution
- Flared bridge geometry improves wildlife adaptation and usage of the crossing
- Less disruptive to the local ecologic system
- Improved sightlines for motorists


Live traffic proceeding throughout bridge construction

Demonstrated Performance of Buried Bridges

Case Study of Instrumented Steel Buried Bridges in US

TRB Webinar – October 31, 2023

Joel Hahm, P.E.
Senior Engineer
Contech Engineered Solutions
joel.hahm@conteches.com

Outline

- NCHRP 15-54 Research Project Summary
- Case study on deep corrugated steel buried bridge
- General results & conclusions from test data

NCHRP Project 15-54

- Main purpose was to develop and propose load rating procedures for culverts & buried structures in the MBE.
- Generally involved analysis and field testing of buried bridges to determine behavior under live loads.
- Full scale testing of four concrete structures and 3 metal structures with spans ranging from 14 ft to 56.5 ft.
- Structures selected based on available design data and cooperation of local agencies.
- Structures were analyzed using 3D FEM and 2D CANDE FEA to obtain predicted live load responses.
- Structures were instrumented with strain gauges to obtain full scale responses under loading.
- Test vehicles were selected to provide vehicular loading as close to HL93 as possible to develop direct correlations with AASHTO LRFD design – actual wheel weights were recorded.
- One structure was under construction and data was obtained before & after paving.

https://nap.nationalacademies.org/catalog/25673/proposed-modifications-to-aashto-culvert-load-rating-specifications

NCHRP

Web-Only Document 268:

Proposed Modifications to AASHTO Culvert Load Rating Specifications

Mark Mlynarski
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Contractor's Final Report for NCHRP Project 15-54
Submitted July 2019

ACKNOWEDGMENT

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The National Academies of
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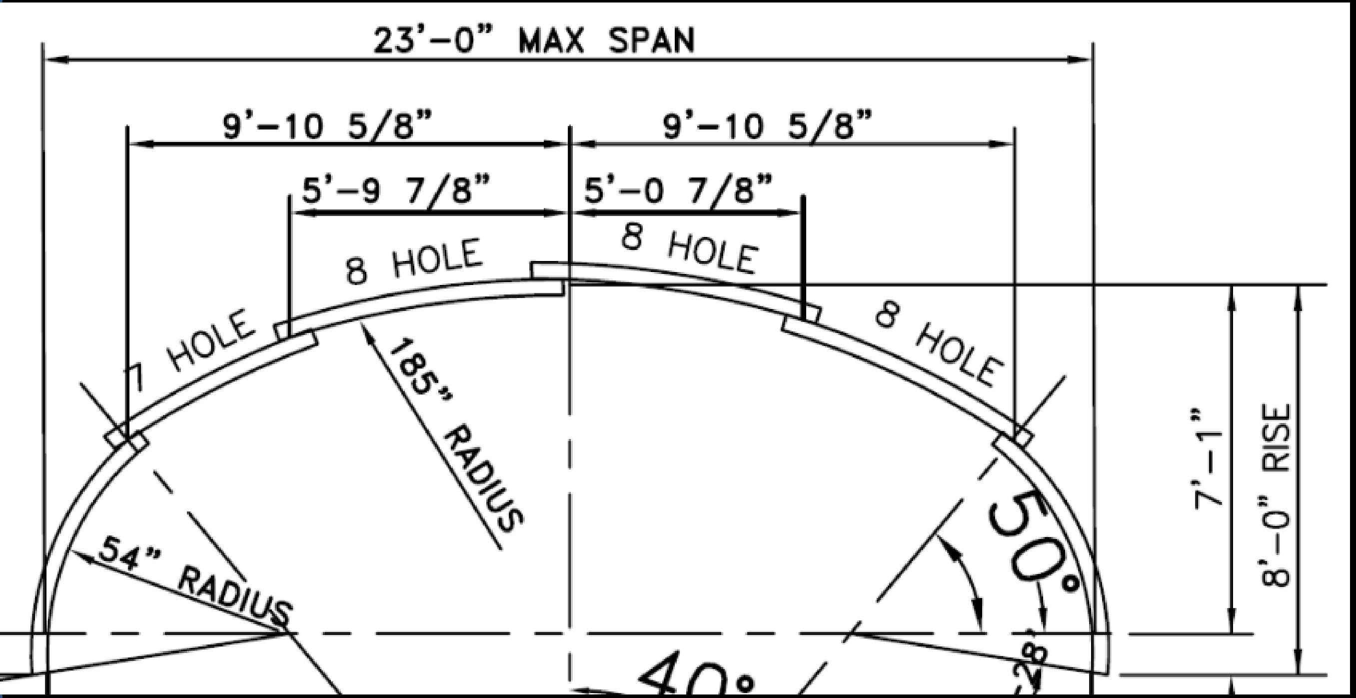
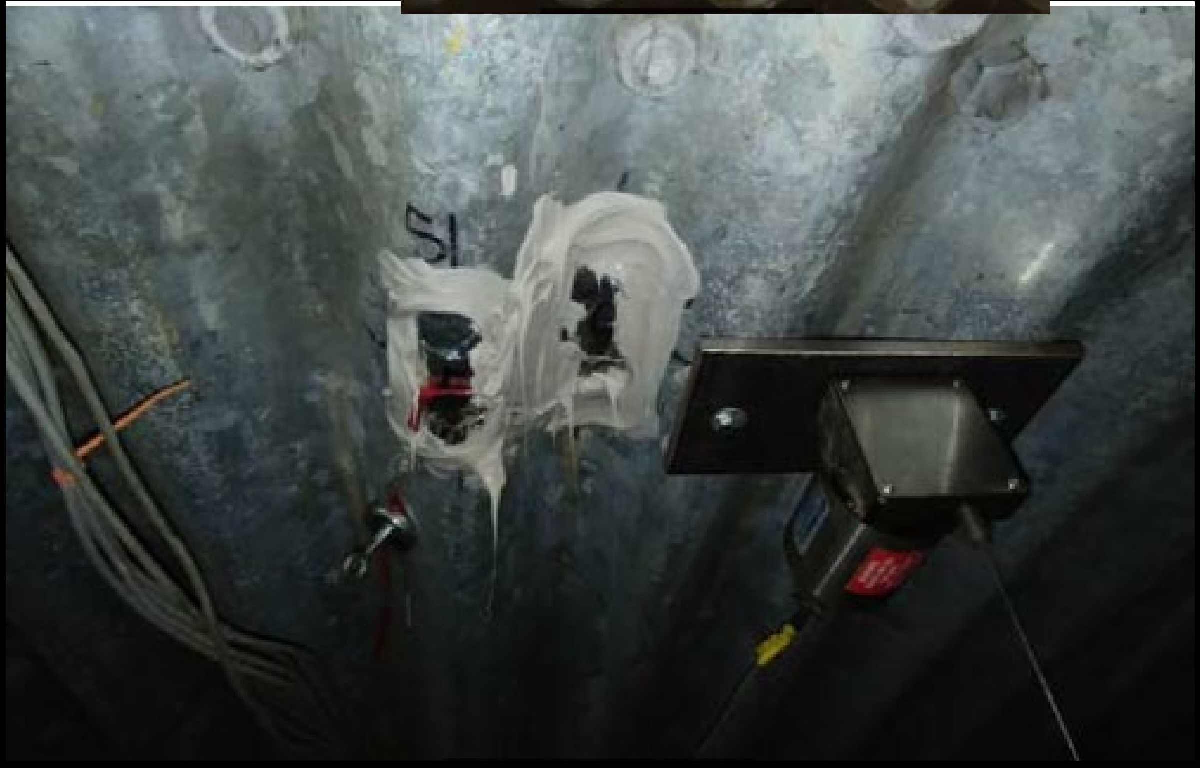
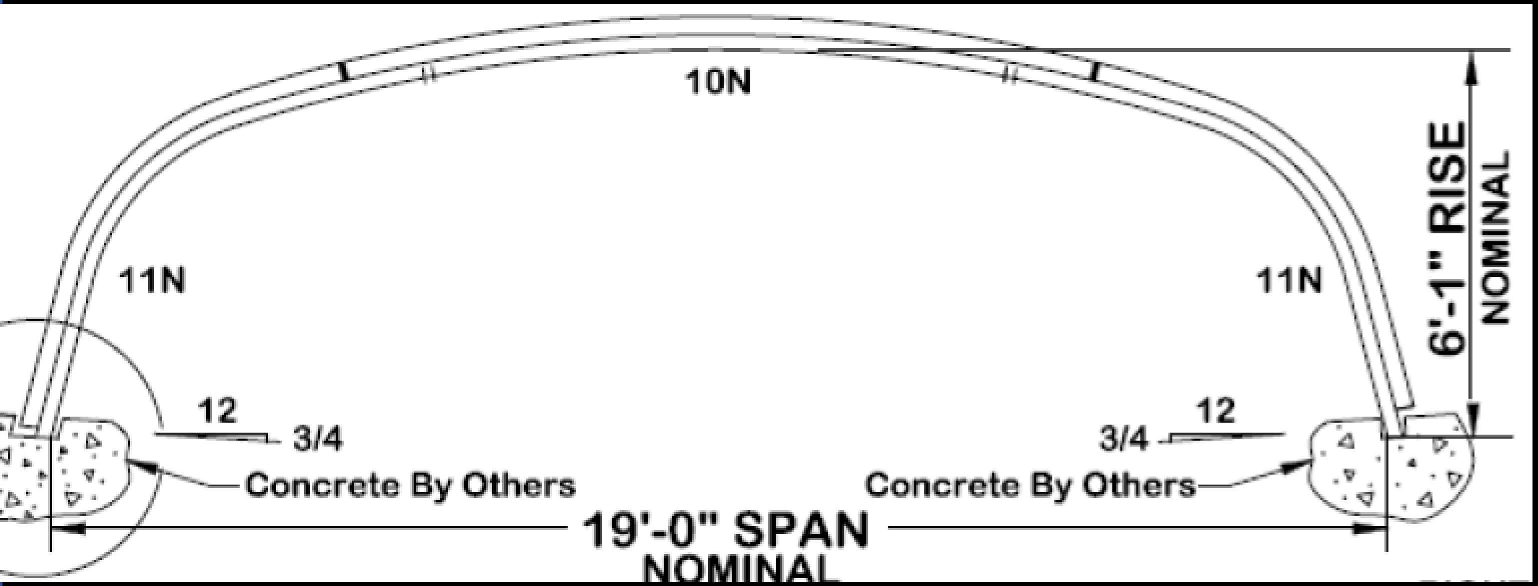
NCHRP Project 15-54 - 23' x 8' Low Profile Arch





NCHRP Project 15-54 – 19’ x 6’1” Aluminum Box



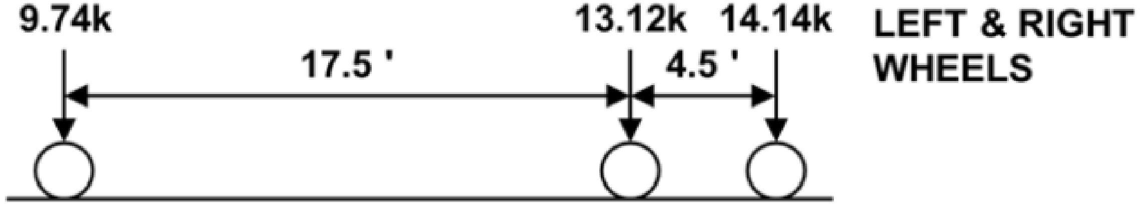
I-95 Temporary Bridge over North Ave Attleboro, Massachusetts

- Carrying I-95 traffic during replacement of twin bridges
- VE alternative to Bailey Bridge
- Saved 4mo & over $1 million on project & won job for contractor
- 100 plates assembled in one 16hr day by first time contractor
- Incorporated MSE Wire Headwalls to avoid interference with new bridge abutments.

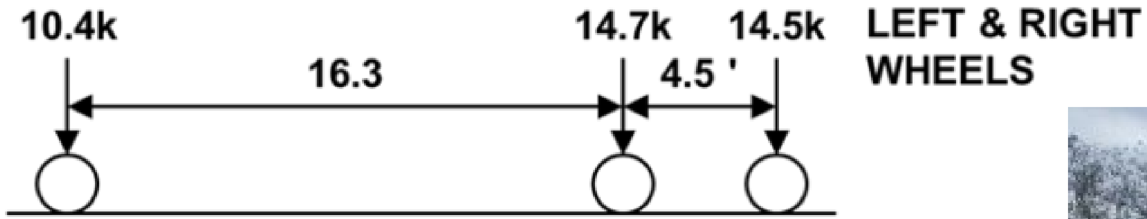
56’6” span x 17’9” rise Box Structure

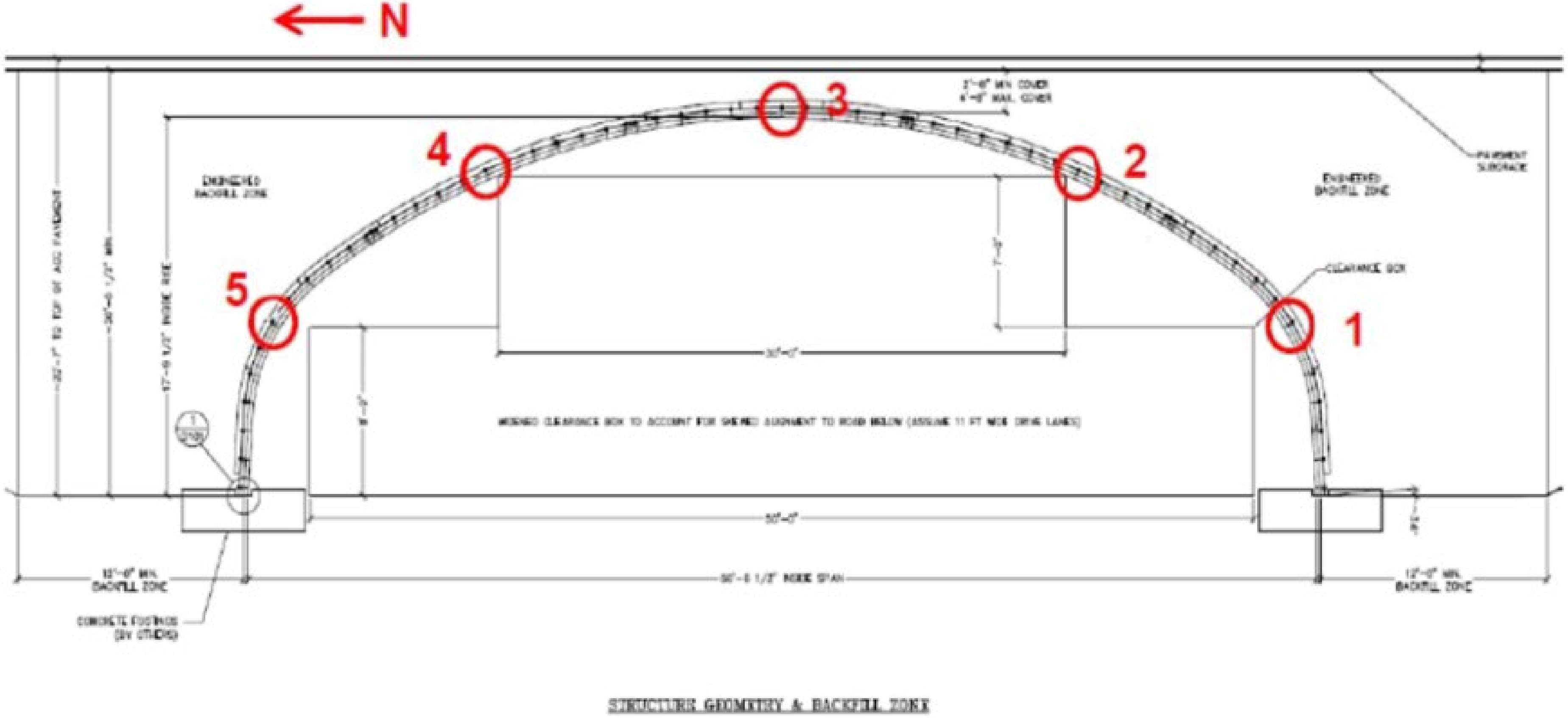

DEERE
220D
W
United Rentals


DEERE



M7C1 Test Truck
(Without Pavement)





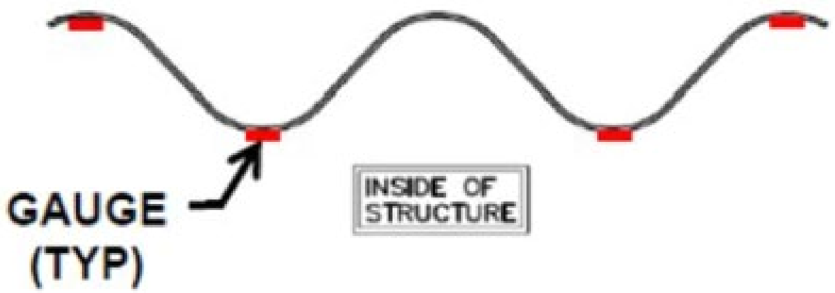


Figure 51 - Instrumentation Locations

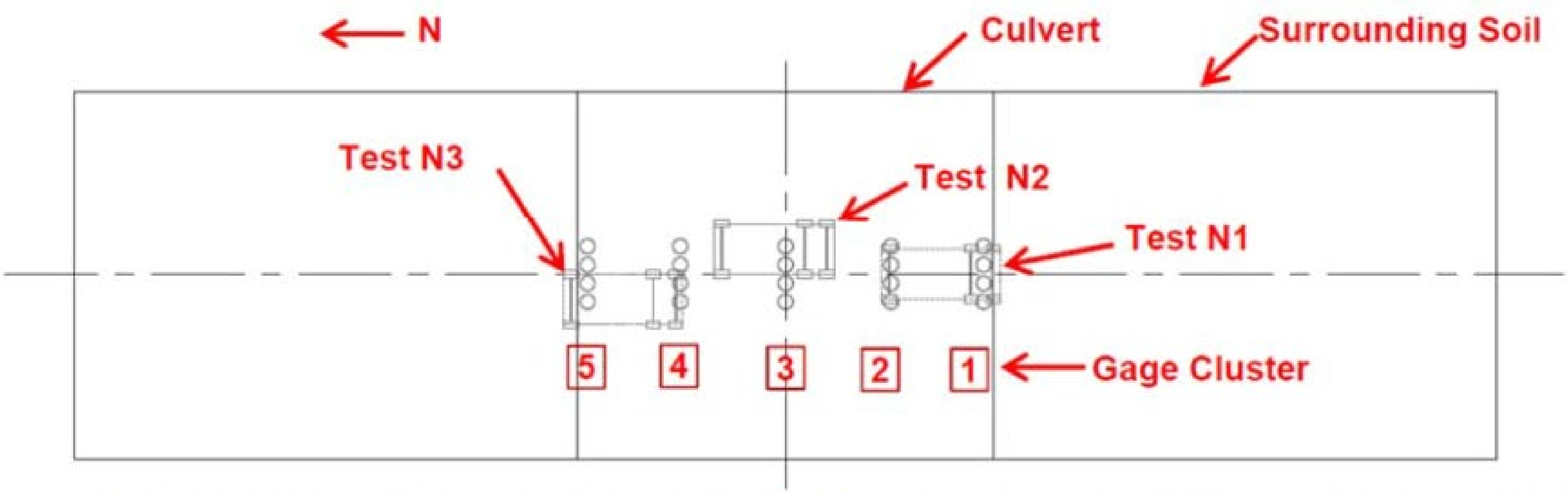


Figure 49 M7C1 Plan View: Showing Location of Gages and Truck Positioning for Each Set of Test

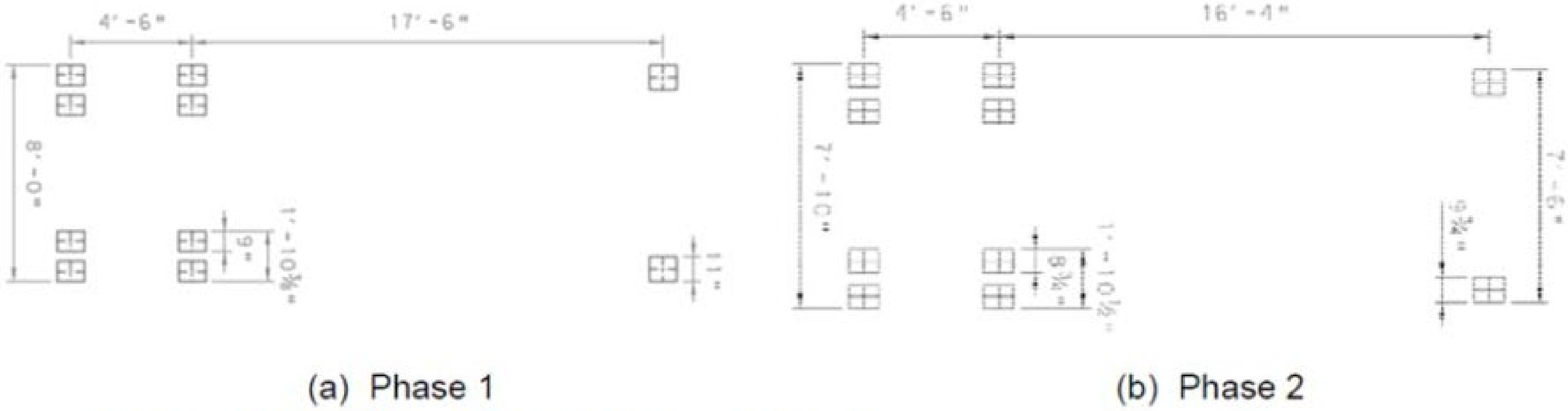


Figure 50 - Truck Dimensions for Each Phase of Testing

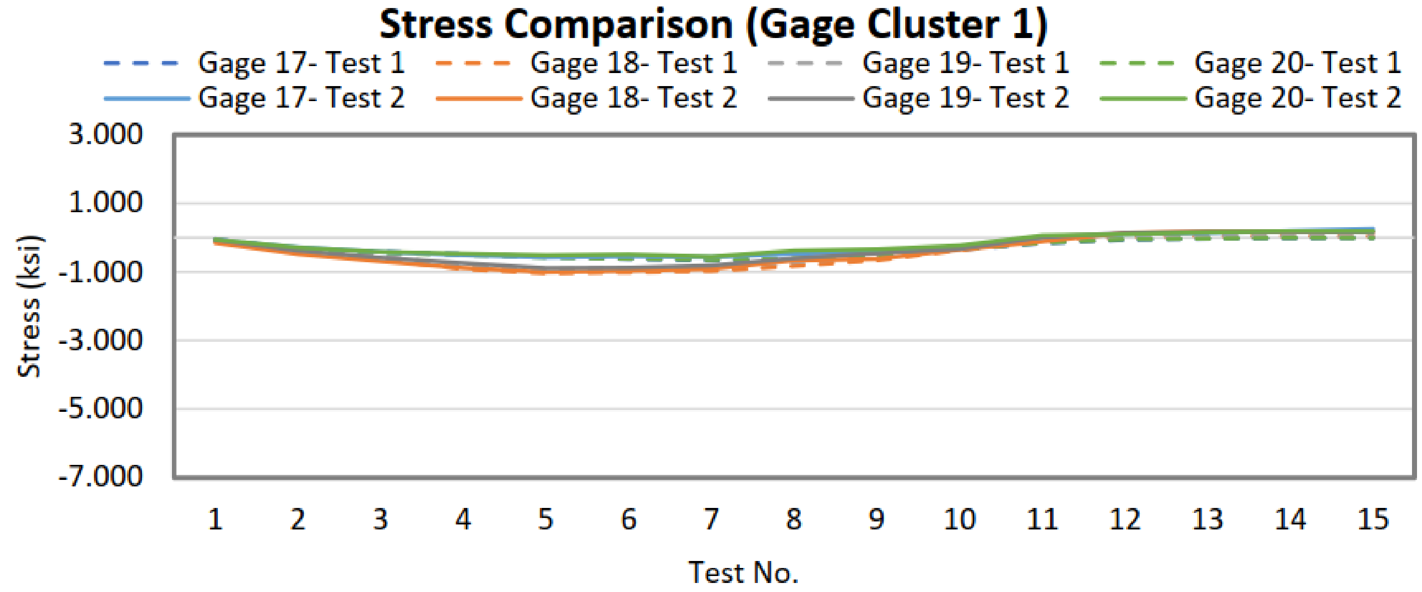


Figure 57 - Model 7 Before and After Paving: Test N1, Gauges 17-20 (Cluster 1)

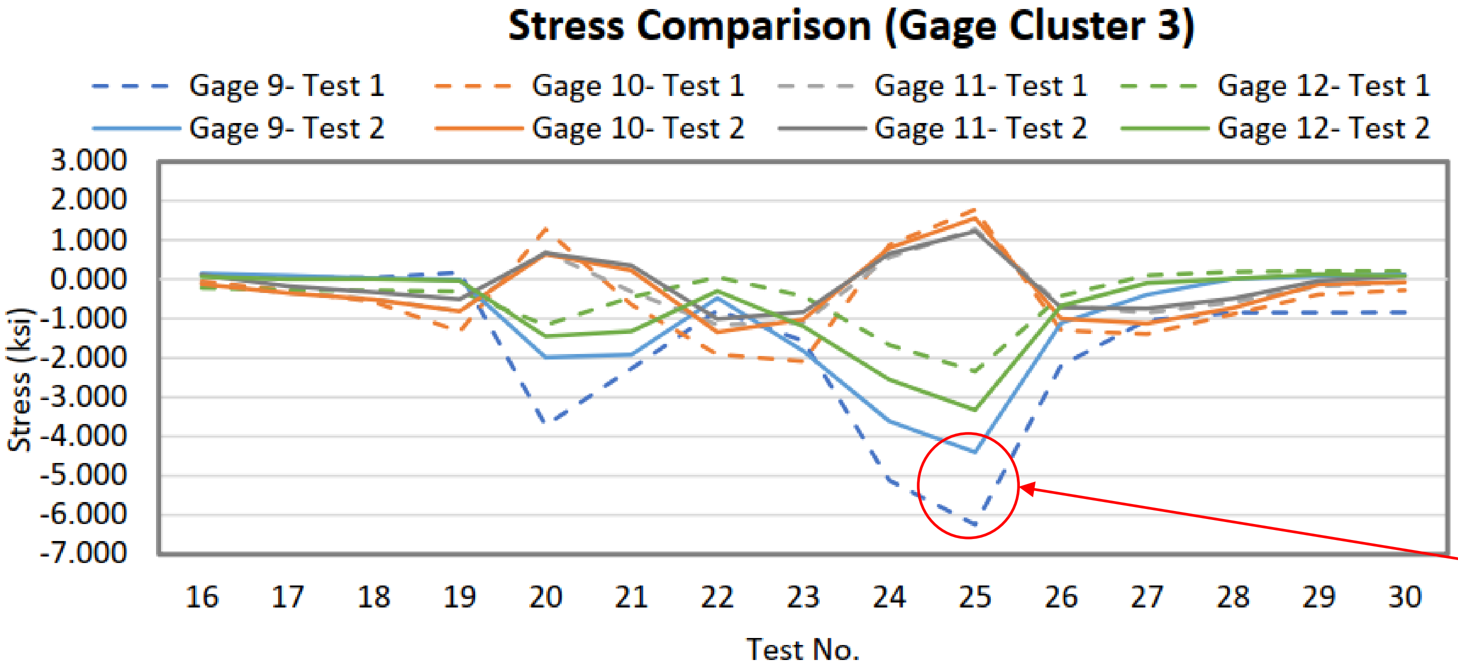


Figure 60 - Model 7 Before and After Paving: Test N2, Gauges 9-2 (Cluster 3)

CANDE FEA Results

Table 14 – M7C1 Rating Results

Rating	No pavement	E = 200,000 psi ν = 0.33 Pavement (6")
1.5 ft fill		
Material Thrust	14.64 (Node 16)	15.61 (Node 14)
Buckling Thrust	8.56 (Node 16)	4.57 (Node 9)
Seam Thrust	14.64 (Node 16)	15.61 (Node 14)
Plastic-Penatrate	10000 (Node 1)	10000 (Node 1)
Combined T&M Ratio	2.13 (Node 23)	3.75 (Node 23)

~33% improvement
with pavement

Thank You!

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January 7 - 11

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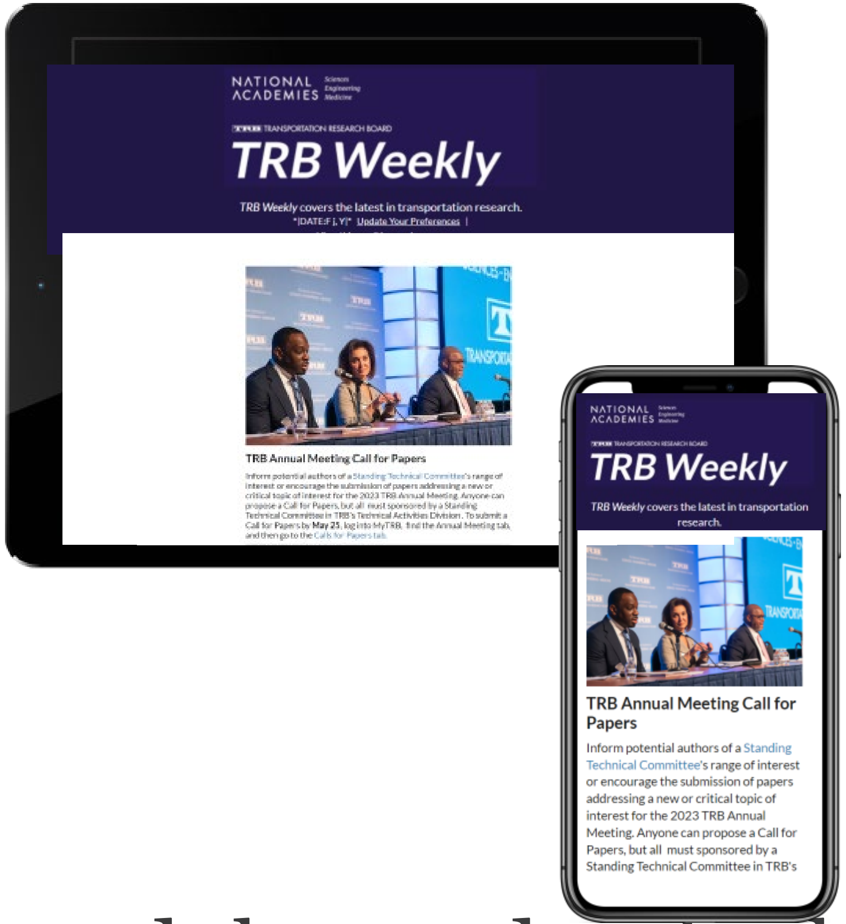

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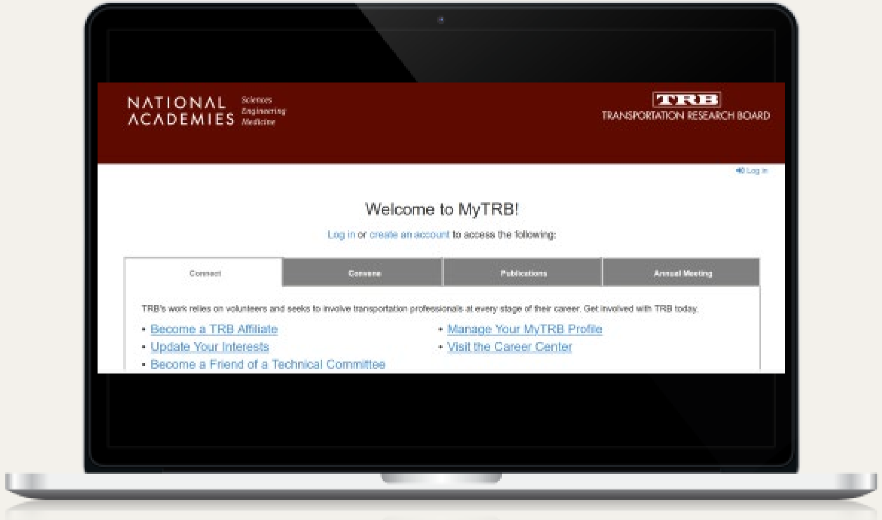

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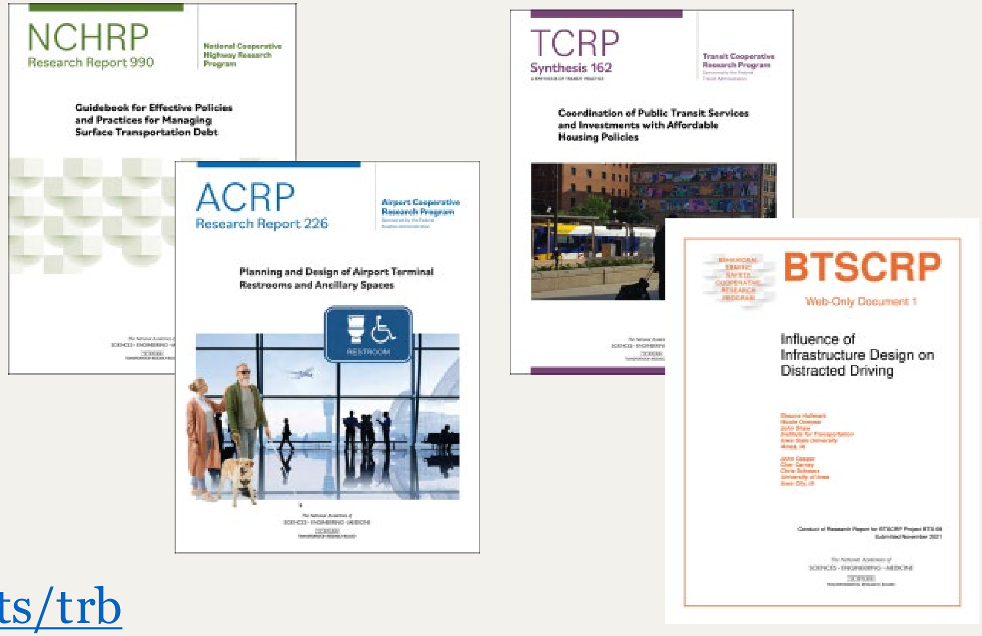

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