The Joy of being a Structural Engineer

Alok A. Deshpande

Presented at IIIT-Hyderabad
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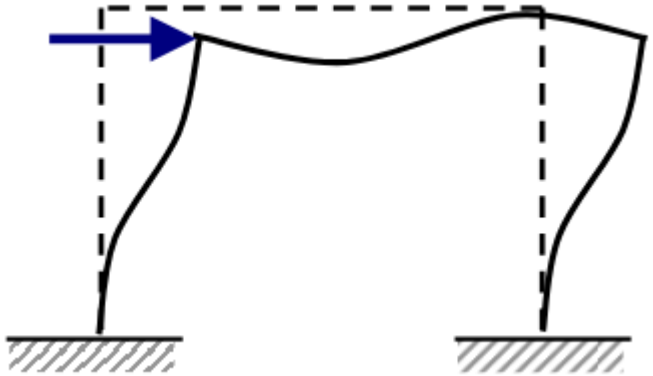


Education

2010 – B.Tech. (College of Engineering, Pune)

2011 – M.S. (University of Illinois at Urbana-Champaign)

2019 – Ph.D. (University at Buffalo)

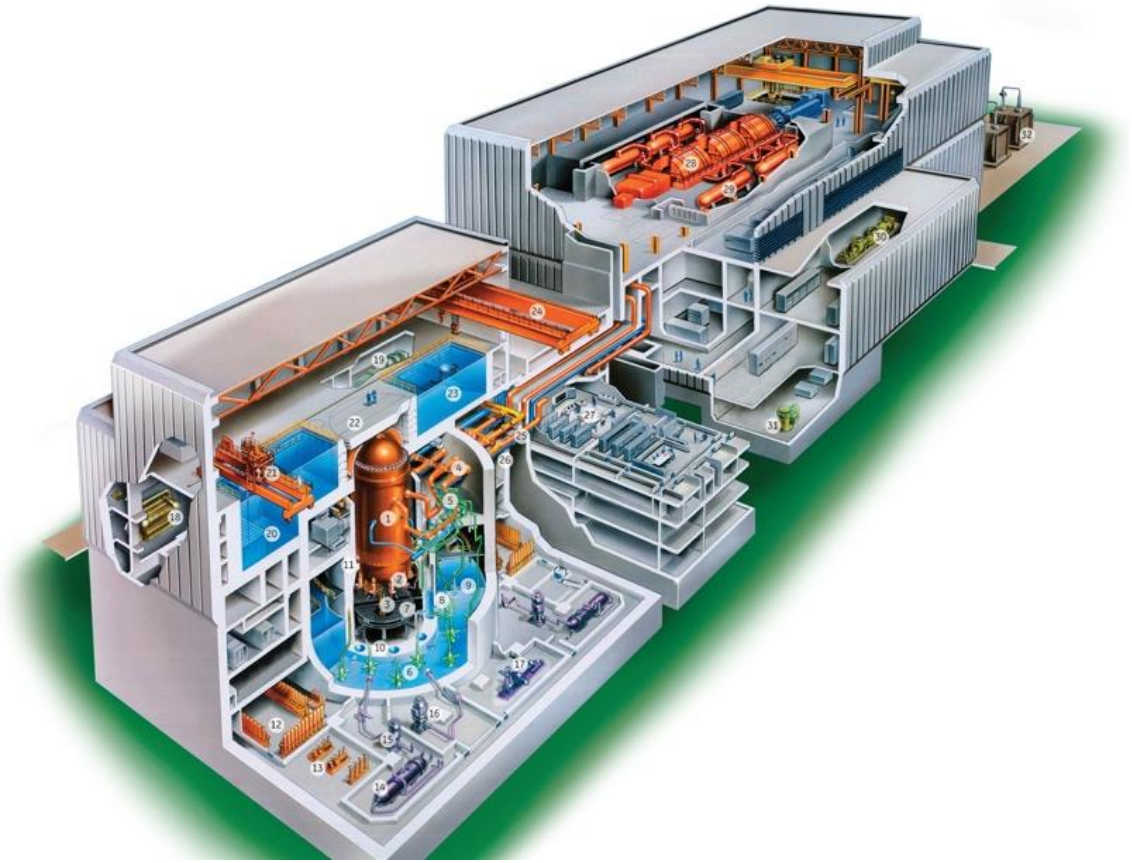
Effects of high temperatures on concrete and reinforced concrete walls

Outline

- Background
- Analysis of a buried bridge
- Food for thought
- Questions

Background

Loss of coolant accidents (LOCA)



"*… those postulated accidents that result in a loss of reactor coolant at a rate in excess of the capability of the reactor makeup system from breaks in the reactor coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system*" (NRC, 2018)

Possible causes of LOCA (steam pipe-break):

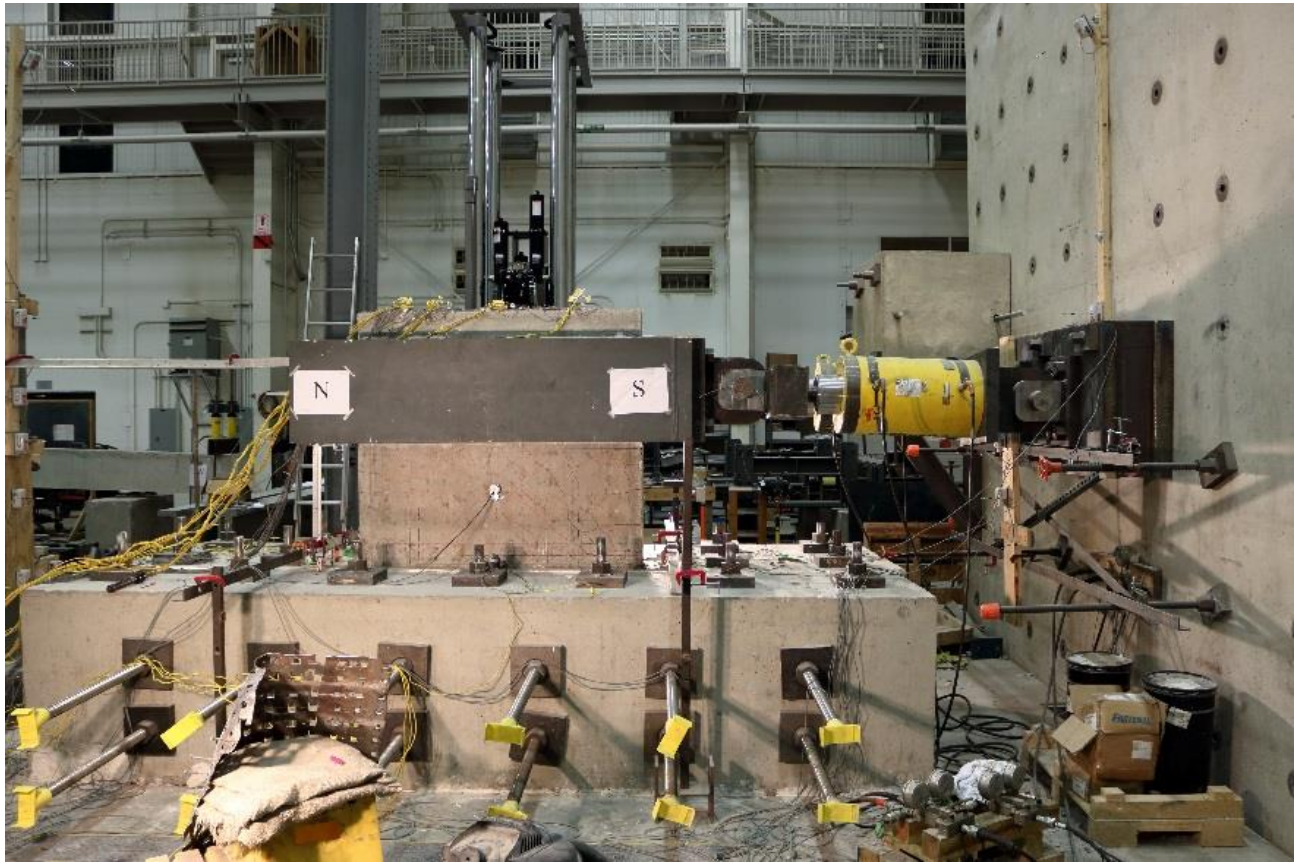
- Fatigue
- Thermal aging
- Beyond design basis earthquake shaking

Integrity of structural components?

Image: ABWR DCD (GENE, 1997)

Wall test program

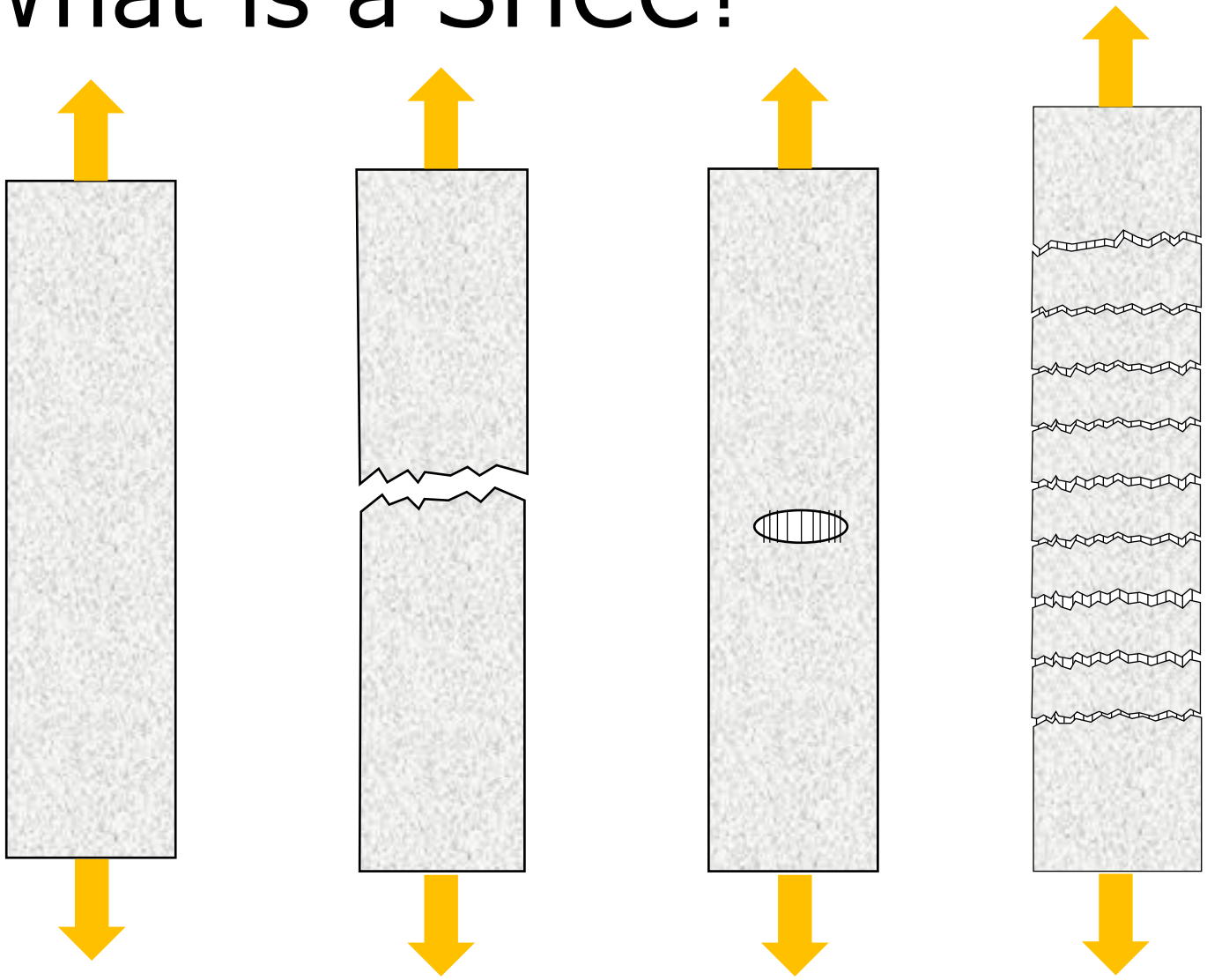
- Concrete
  - 6 ksi [41 MPa] (conventional)
- Reinforcement
  - Two walls: 0.93%
  - Two walls: 2%
- Testing conditions
  - Ambient
  - Heated
  - Residual



Key takeaways from wall tests

- Initial stiffness
  - 30% of theoretical uncracked value
  - Similar to observations of Sozen and Moehle (1993) and Luna (2016)
- Effects of temperature on stiffness
  - Low levels of force : max reduction of 30%
  - Greater levels of force : masked by mechanical damage
- No significant effect of temperature on strength

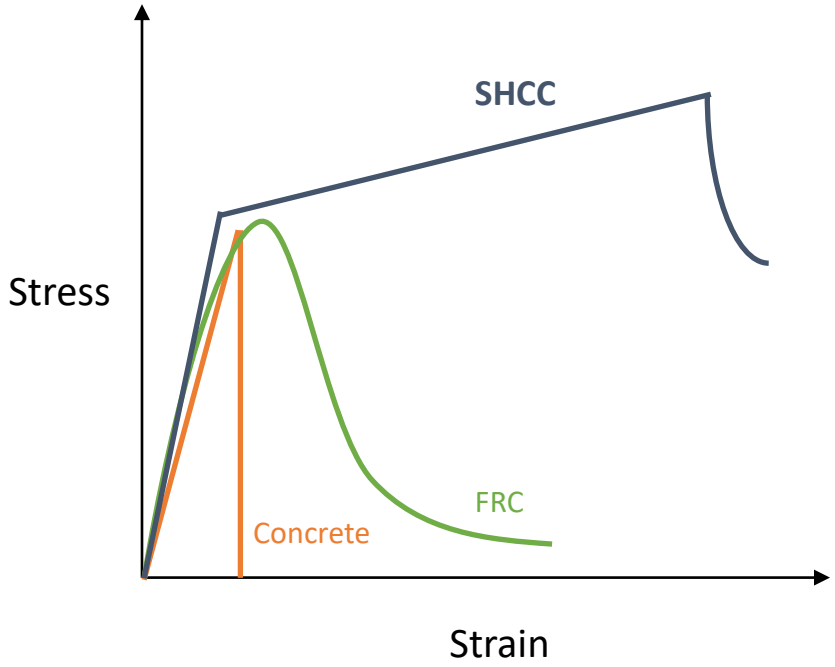
What is a SHCC?



Conventional concrete

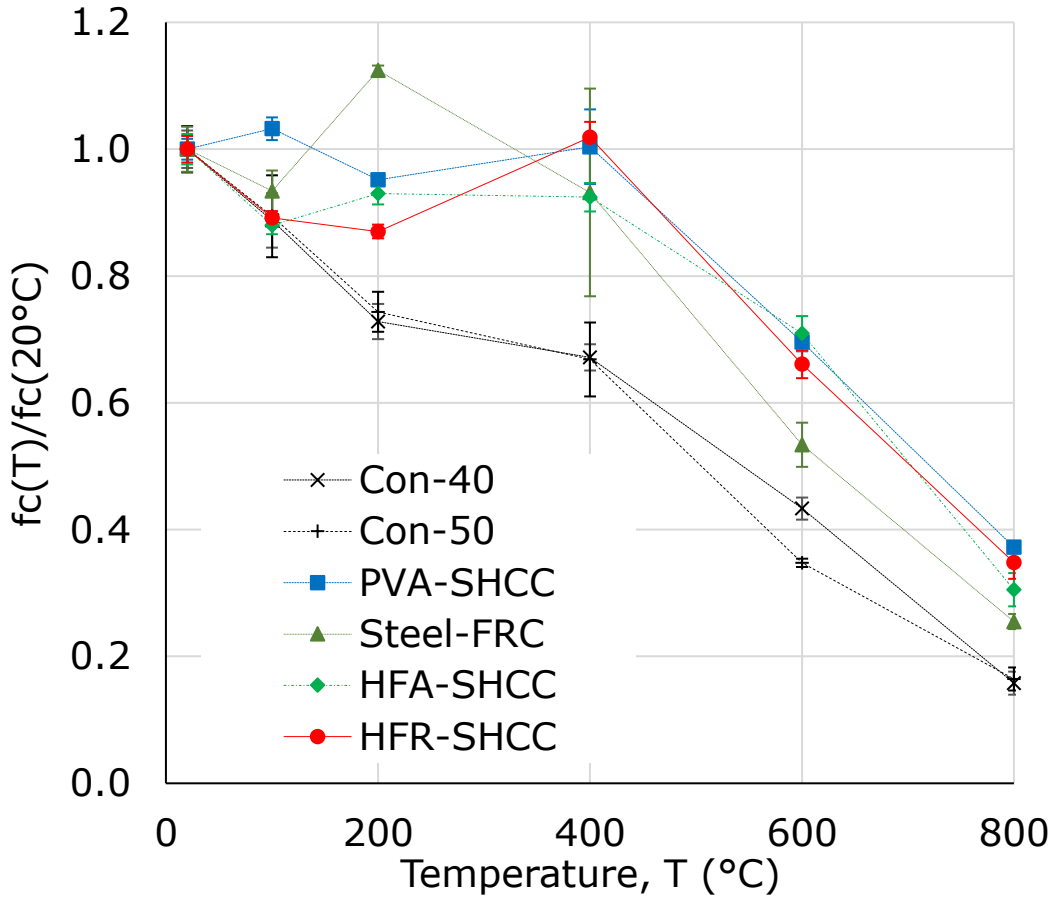
Conventional FRC

SHCC



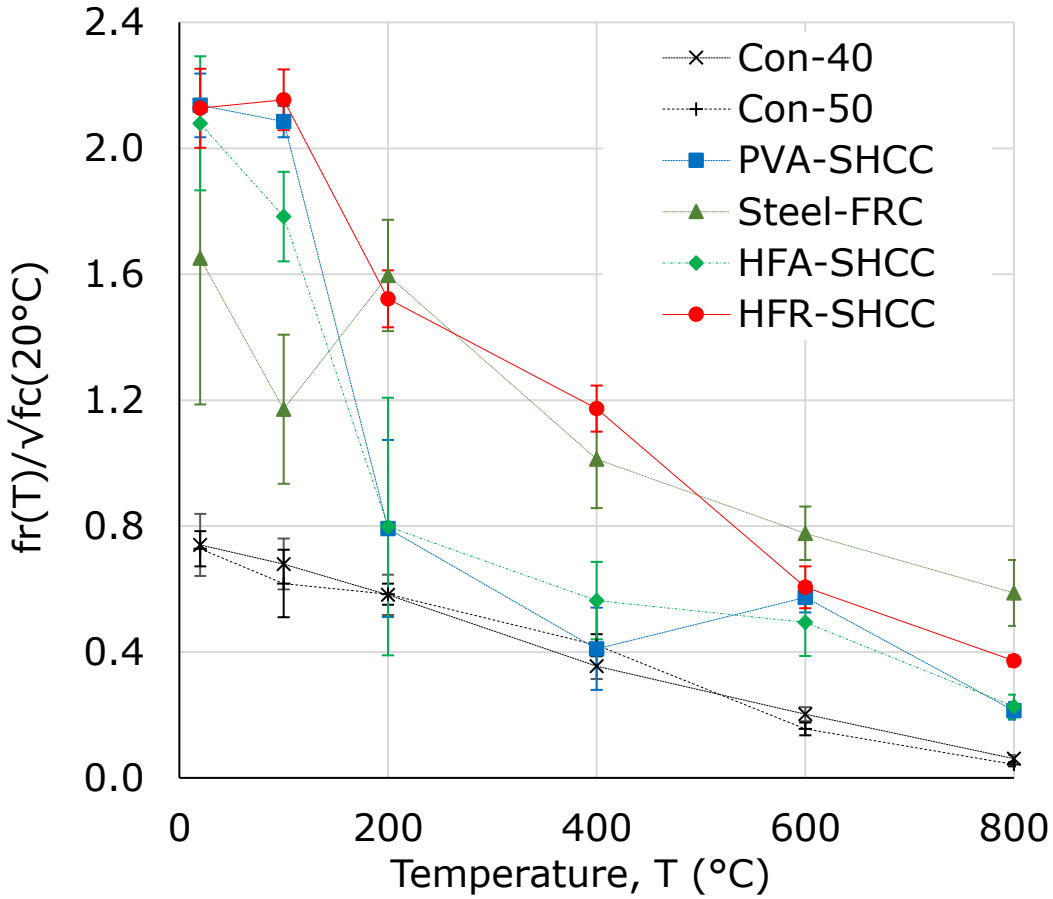
Mechanical behavior

- Normalized with fc at room temp.
- Concrete – monotonic reduction
- SHCCs - ~90% retention to 400°C
- Linear beyond 400°C



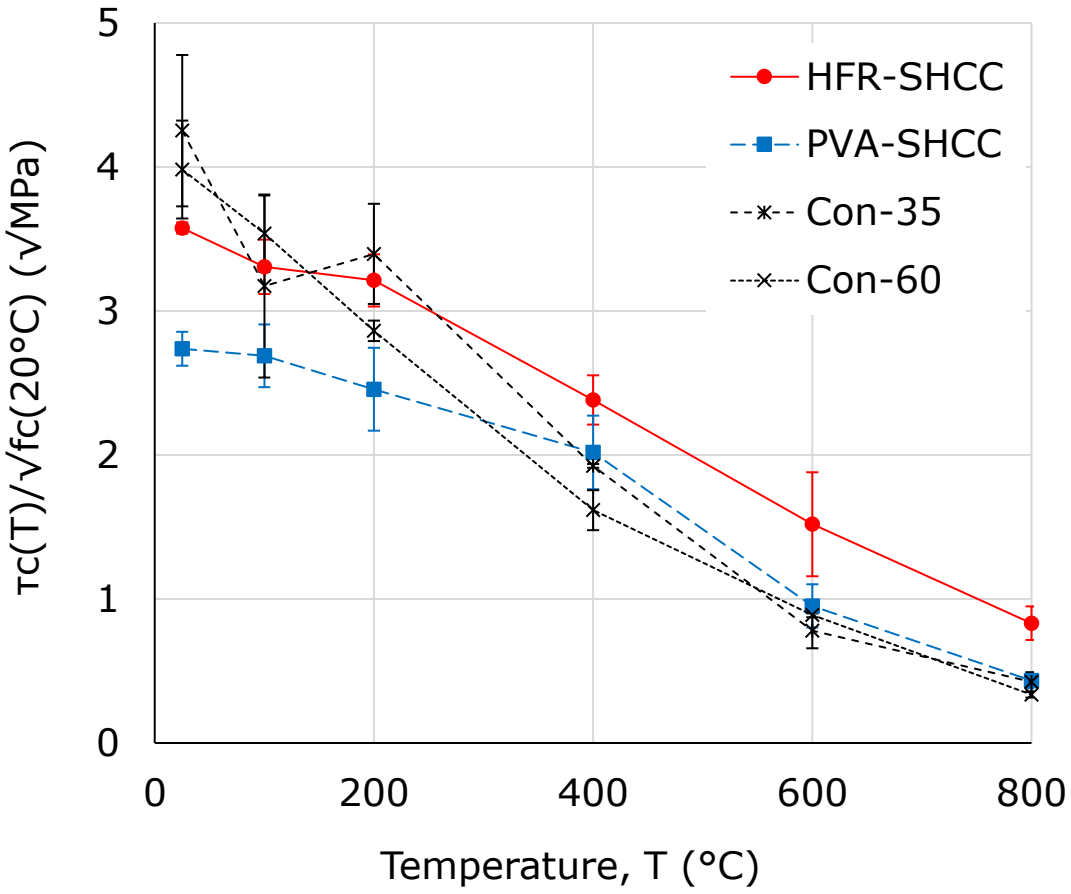
Mechanical behavior

- Normalized with √fc(20 °C)
- Concrete – linear
- Sharp drop for PVA-SHCC at 200°C
- Improvement for HFR-SHCC



Bond with rebar

Anchorage bond strength



Current

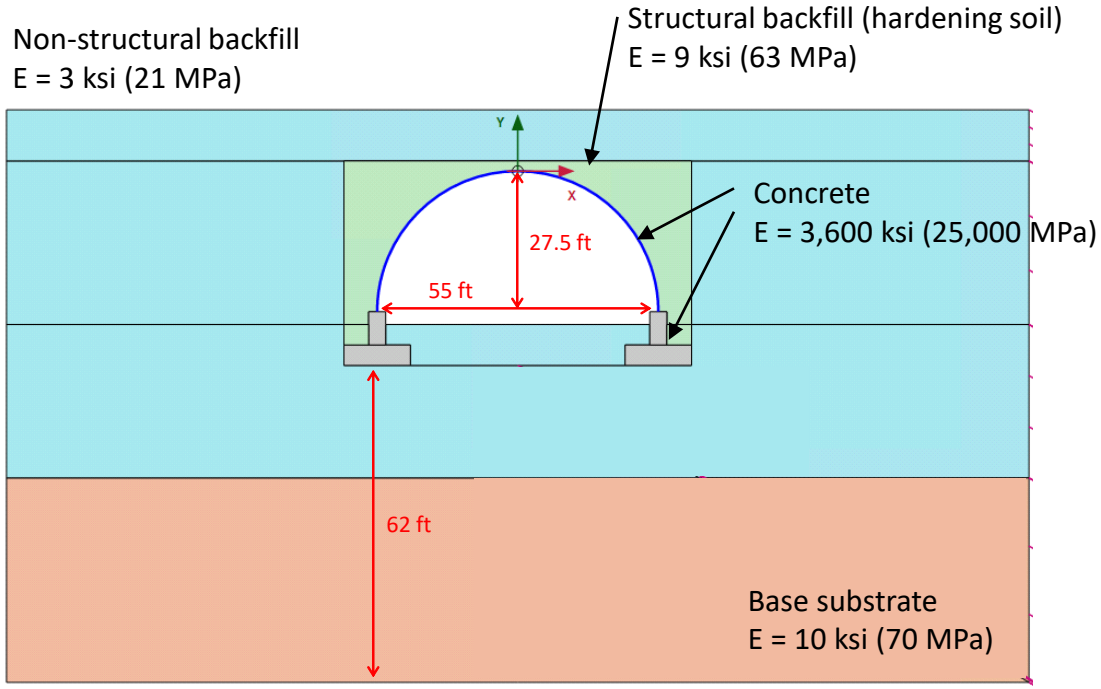
- Consulting Engineer

  Simpson, Gumpertz and Heger (SGH), Waltham, MA

- Projects
  - Buried infrastructure (tunnels, pipes, tanks)
  - Nuclear structures
  - Concrete inspections and repairs

Analysis of a buried bridge

What is a buried bridge?



- Arching action
- Different stiffnesses
- SSI

Construction sequence

- Design
  - 2D
  - SSI (CANDE)
- Arch
  - Rigid (RC)
  - Flexible (Steel, Plastics)
- RC segments
  - Using welded wire
  - Transport to site

Construction sequence

- Foundation and stem wall
  - Cast in-place
  - RC
  - Placement of arches
  - Arch key (?)
  - Grout the base

Construction sequence

- Backfill
  - Structural
  - Layers

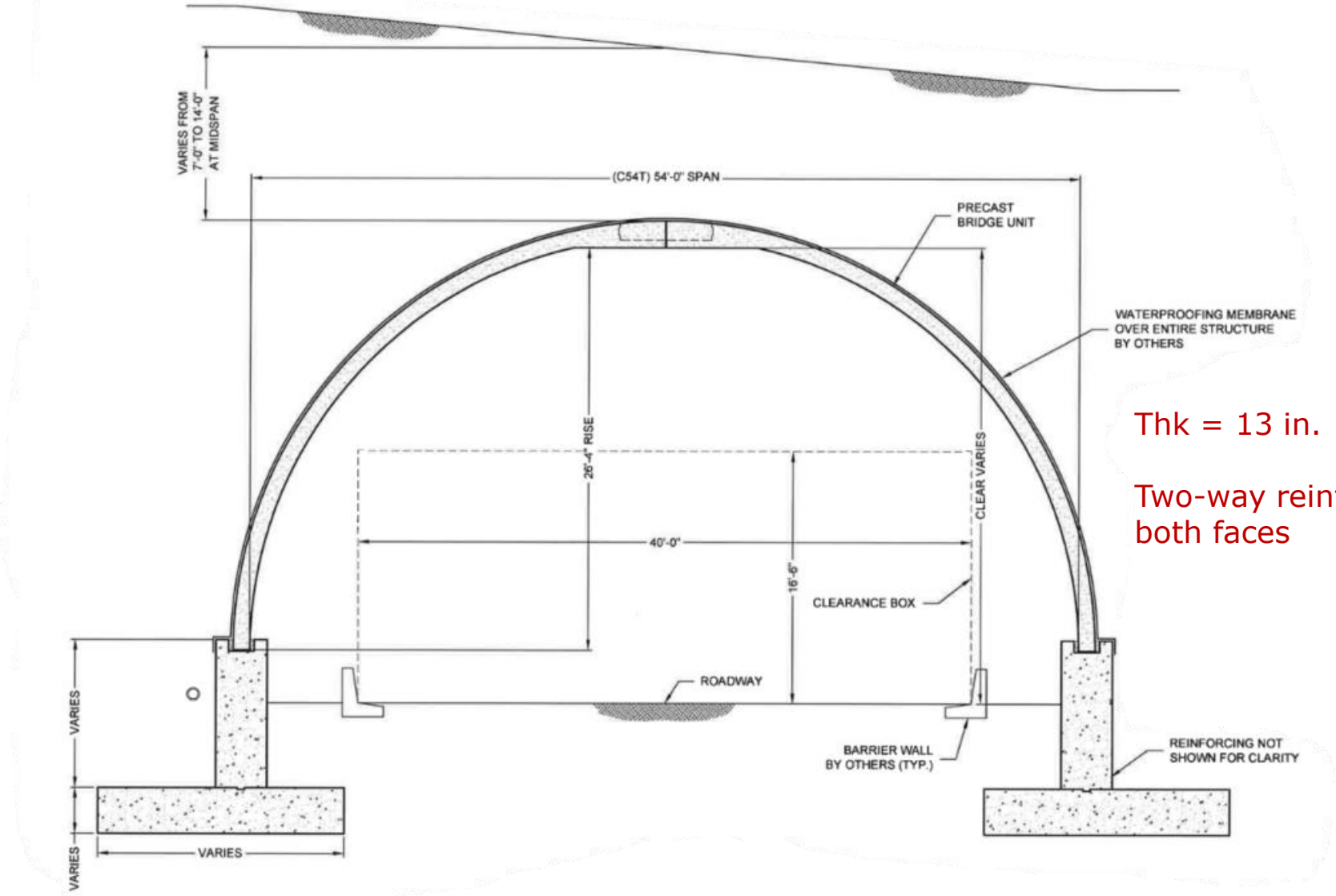
Background

Structure built in 2018

Public access highway below the arch

Payload = 226,000 kg
Total weight (loaded) = 390,000 kg

Elevation

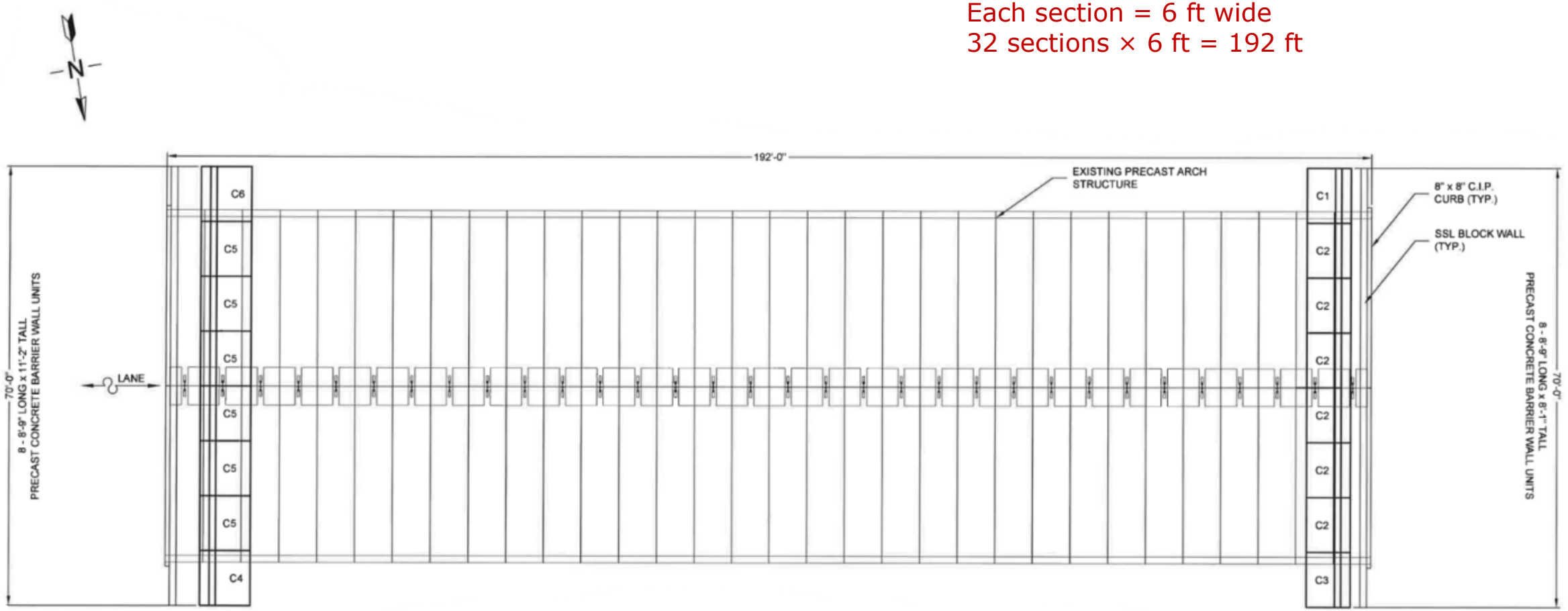


Thk = 13 in.

Two-way reinforcement on both faces

Plan

Each section = 6 ft wide
32 sections × 6 ft = 192 ft



Issue

Stem wall

Vertical cracking

Two questions

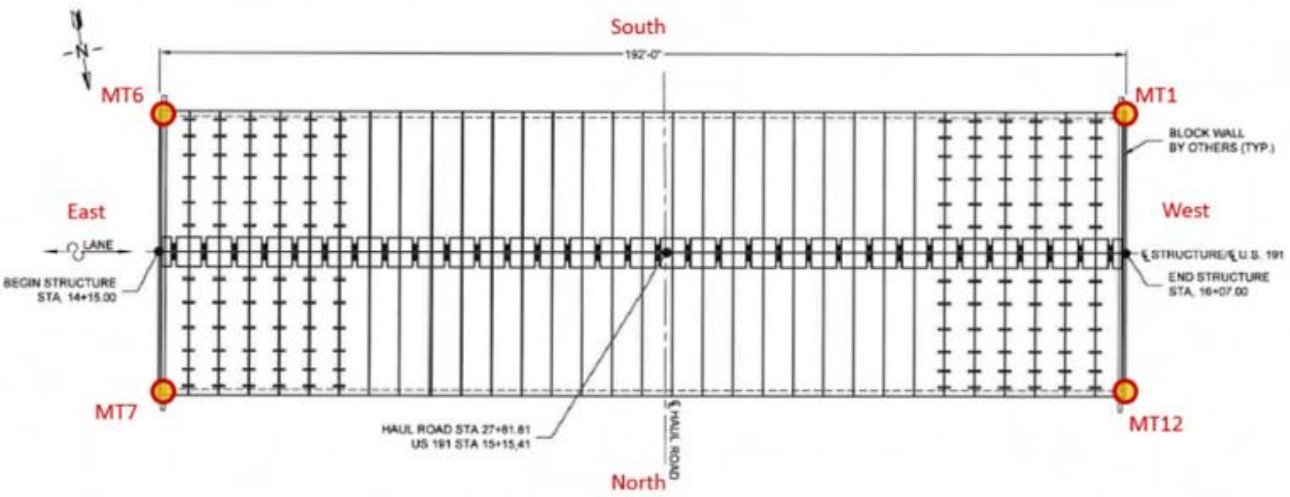
1. Does the bridge need to shut down for highway traffic below the arch?

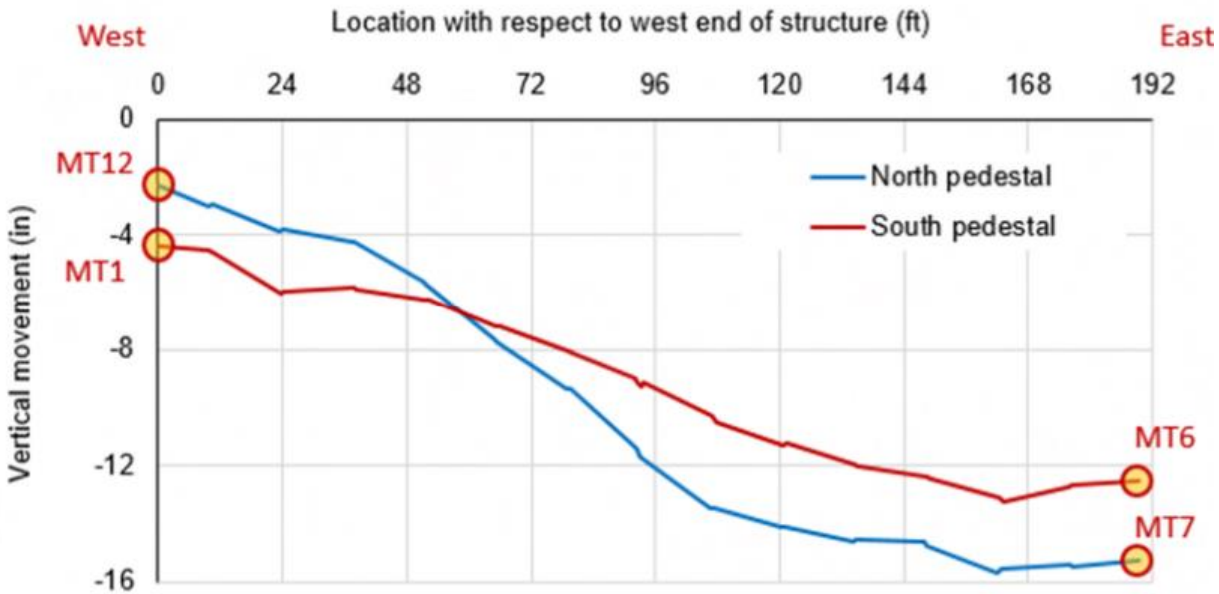
2. Does the bridge need to shut down for mine traffic above the arch?

Scope – Evaluate the structural health of the precast bridge units

Request additional information

- Hypothesis:
  Orientation of cracks → settlement
- Recommendation
  Survey the top of pedestals
- Compare to an as-built survey?

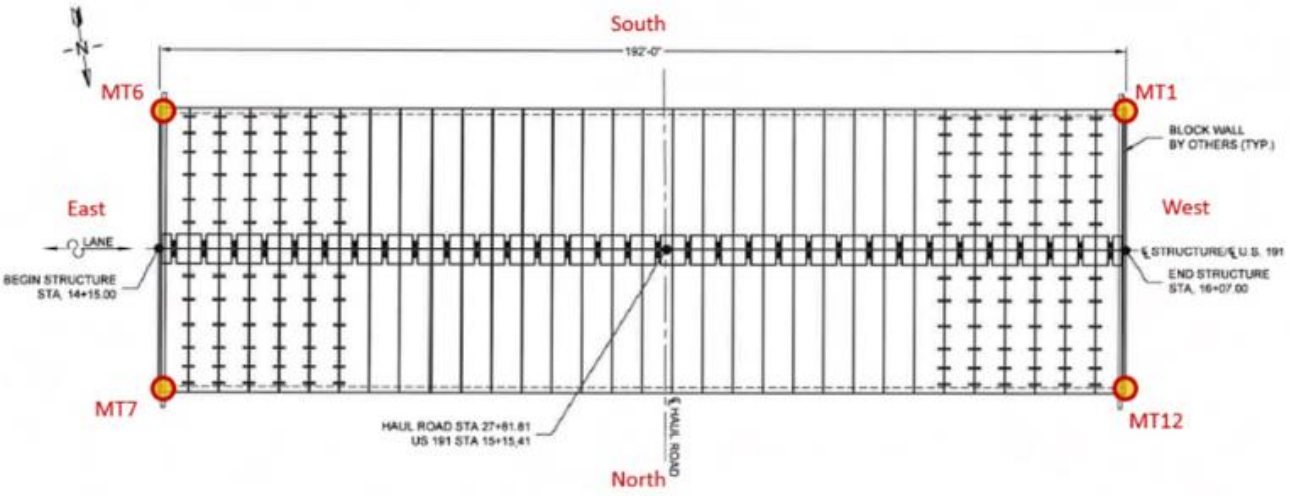


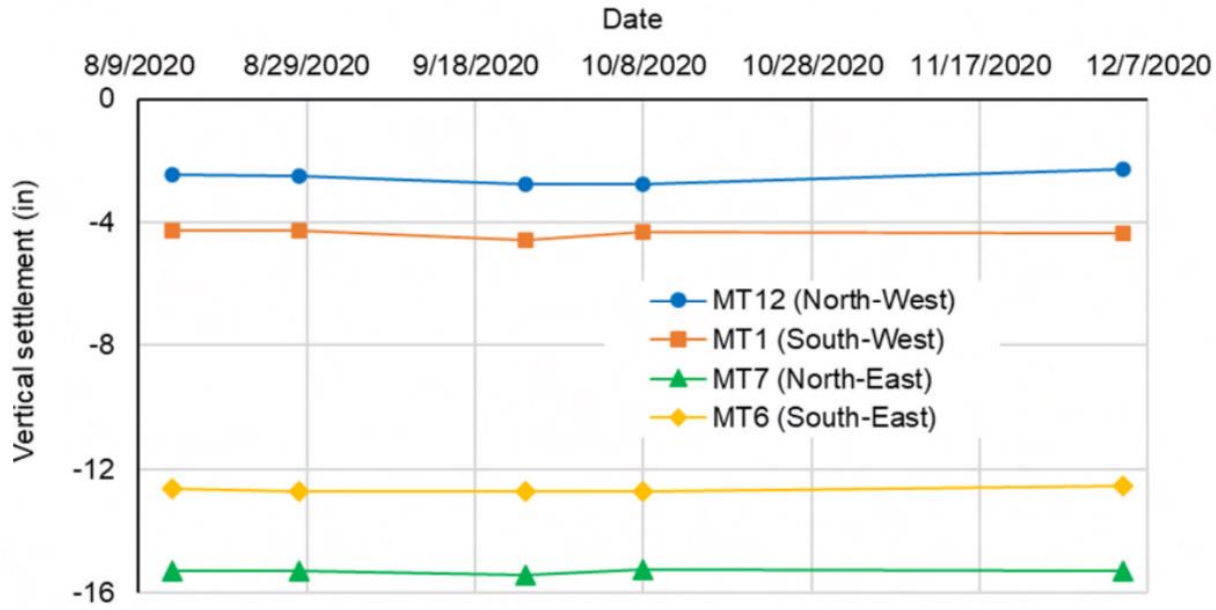


Settlements

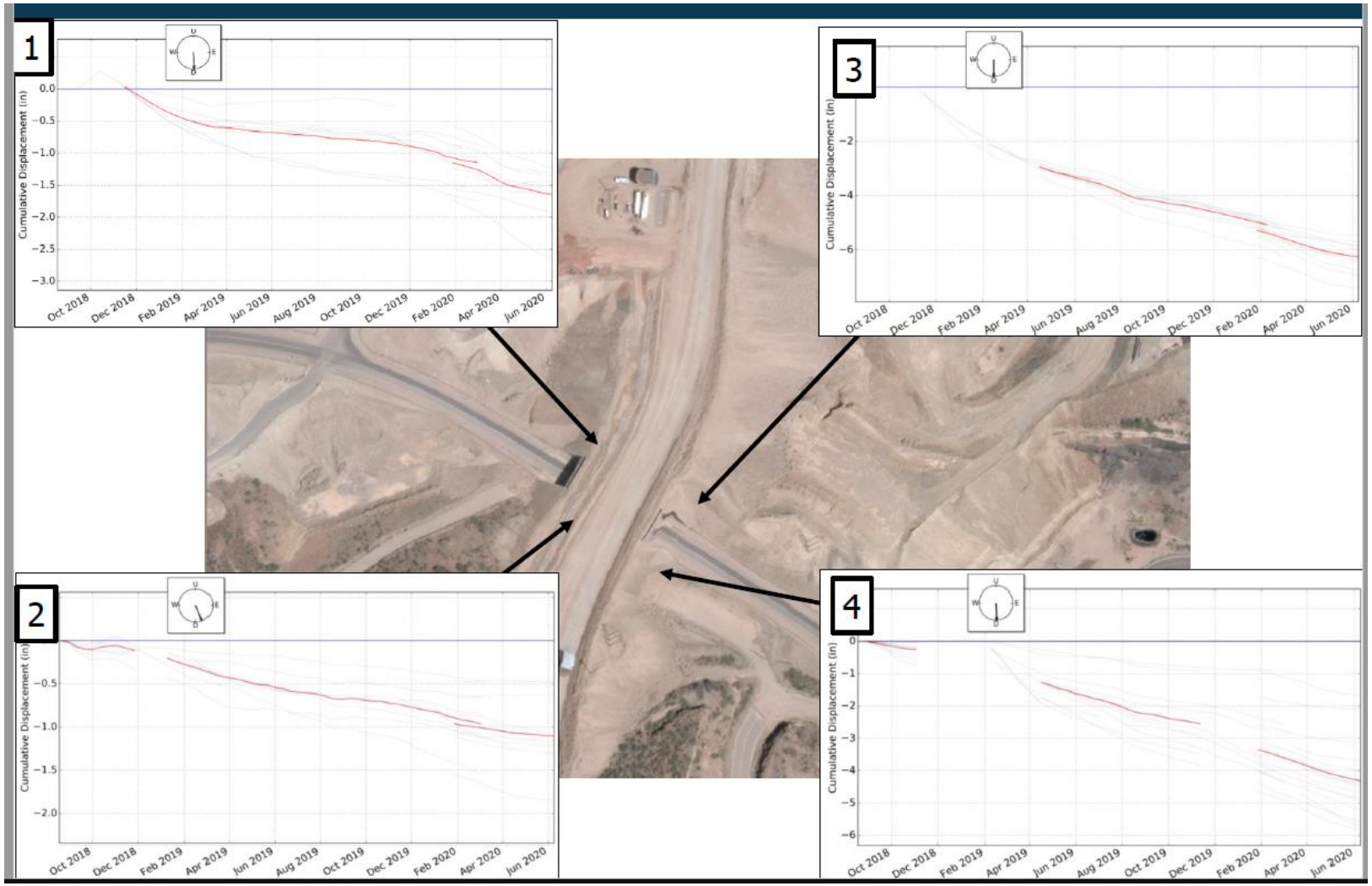
Are the settlements ongoing?

Or have they happened some time ago and someone noticed them recently?



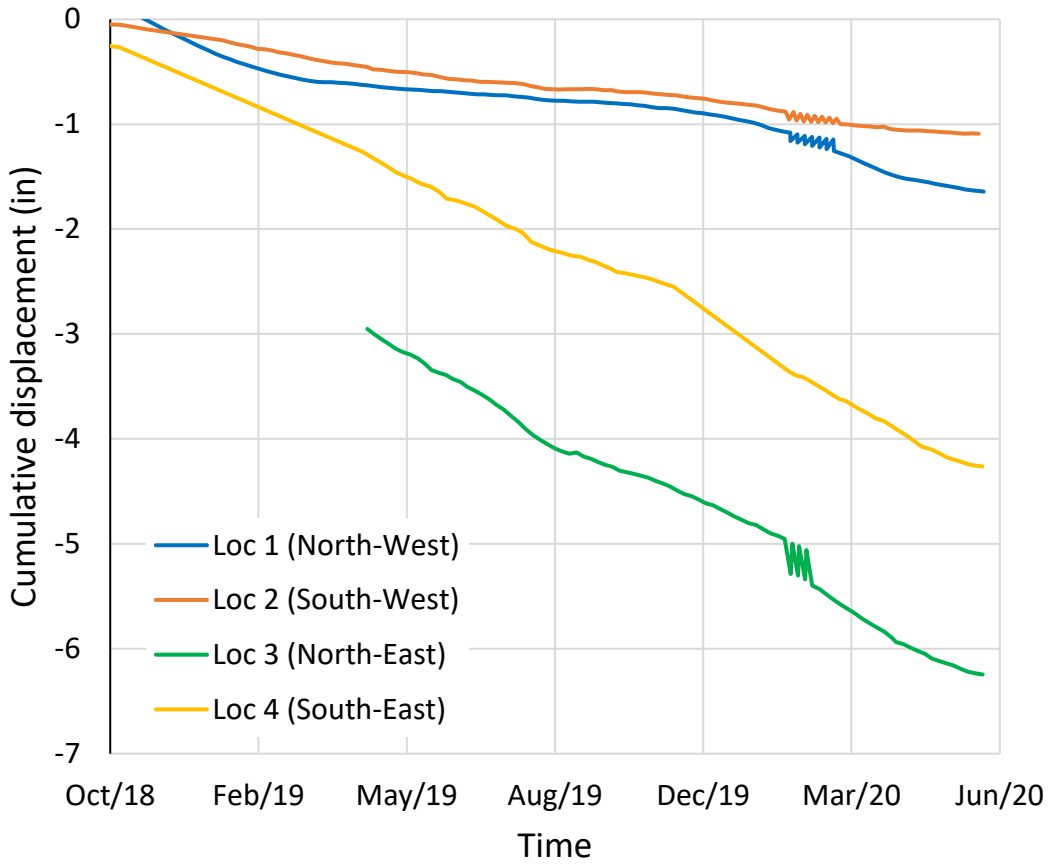


InSAR



* Interferometric Synthetic Aperture Radar

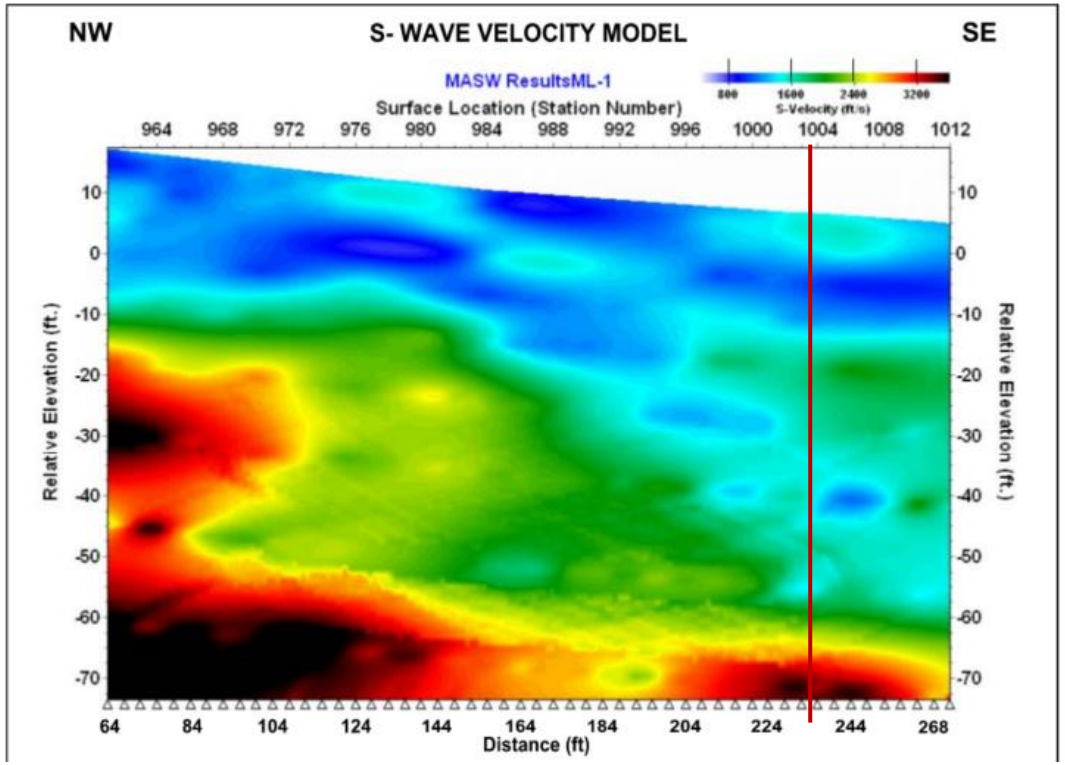
InSAR



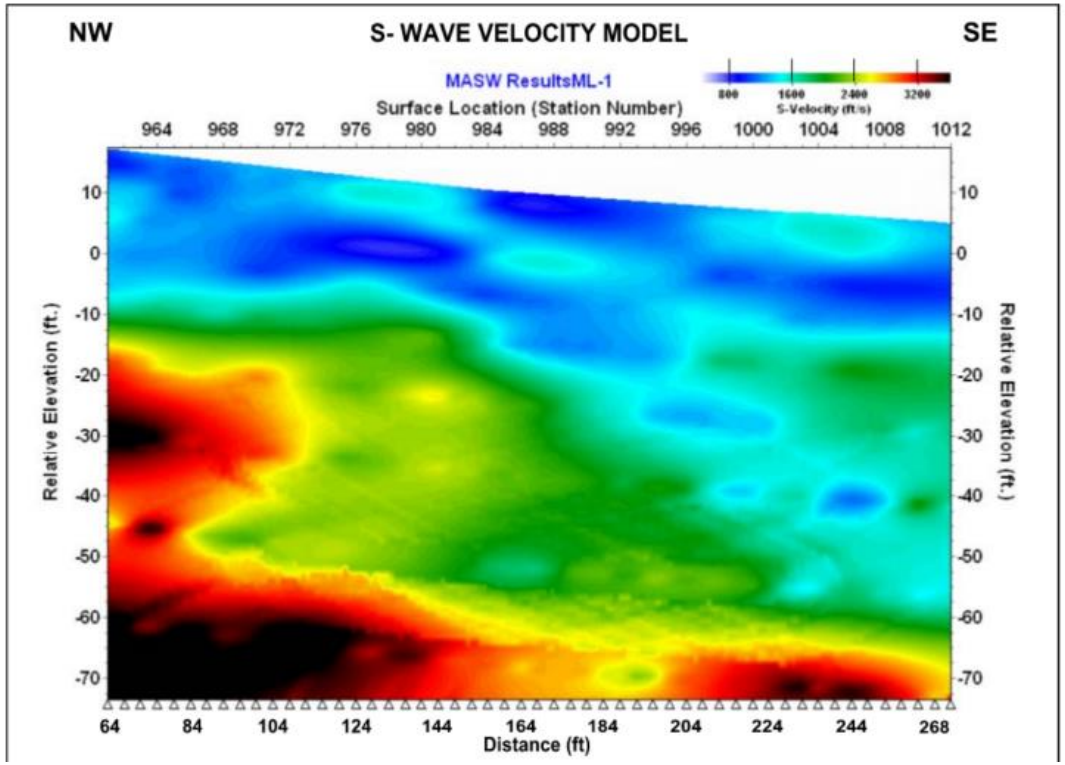
- Active mine site - large quantities of earth moved around

Causes of settlement

Geotechnical report
(2018; before construction)

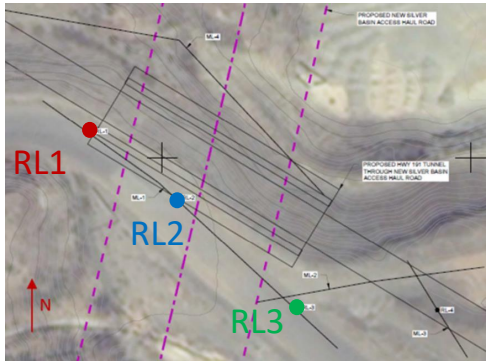


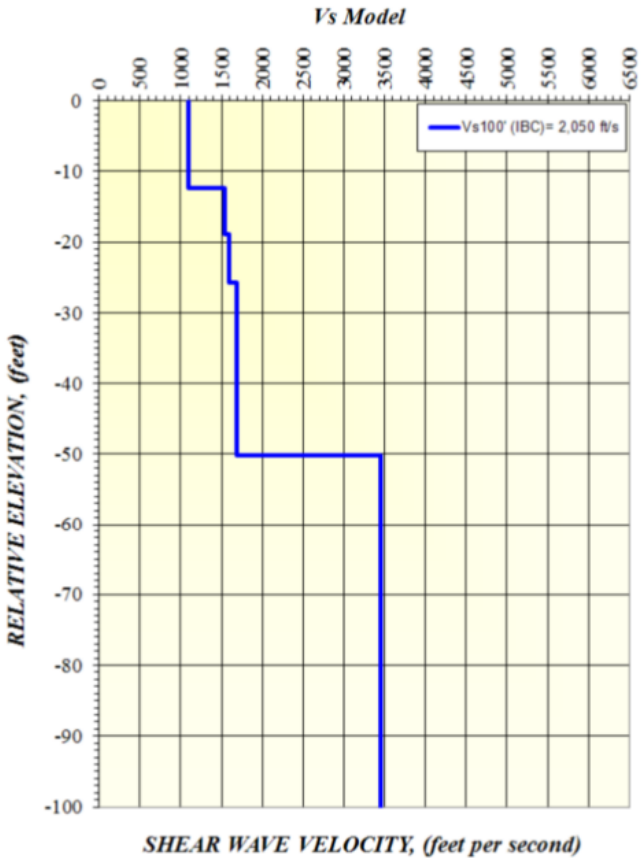
Comparison



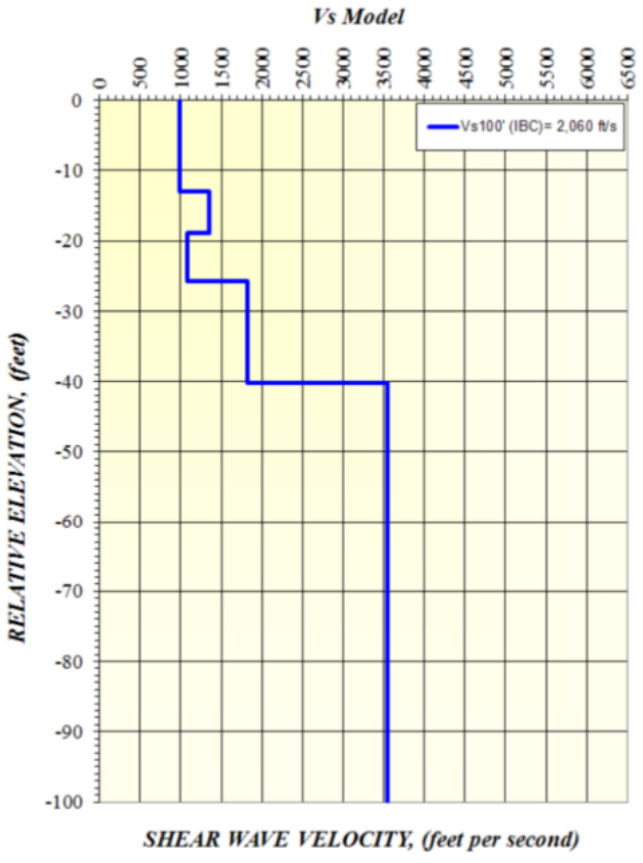
Material	Approximate depth (ft)	Shear wave velocity (ft/s)	Settlement modulus (ksf)
Run-of-mine fill	13 to 26	300 to 1,000	800
Old rock fill	26 to 40	1,300 to 1,800	3,000
Bedrock	40 and deeper	> 3,500	6,000

Causes of settlement

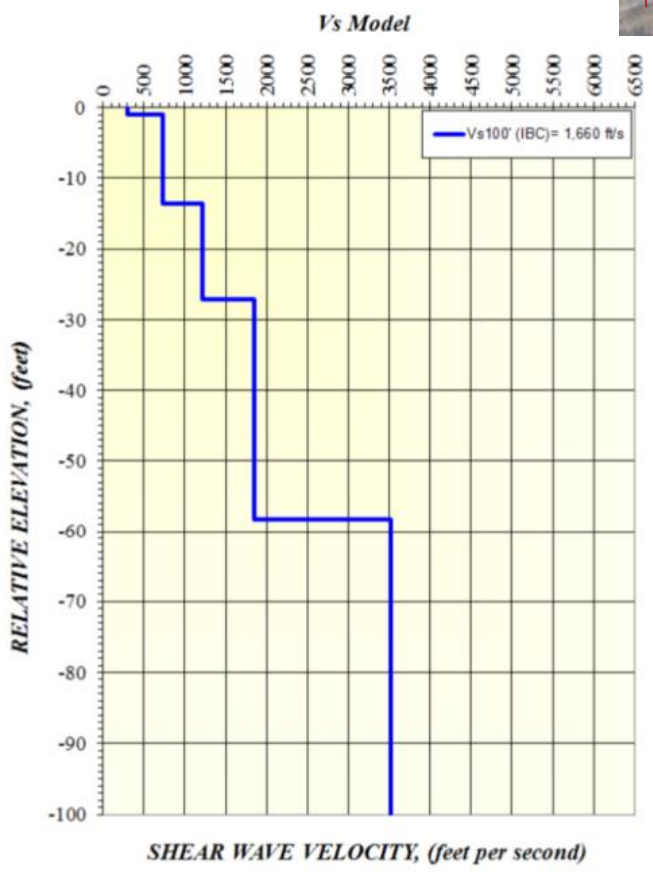




RL1



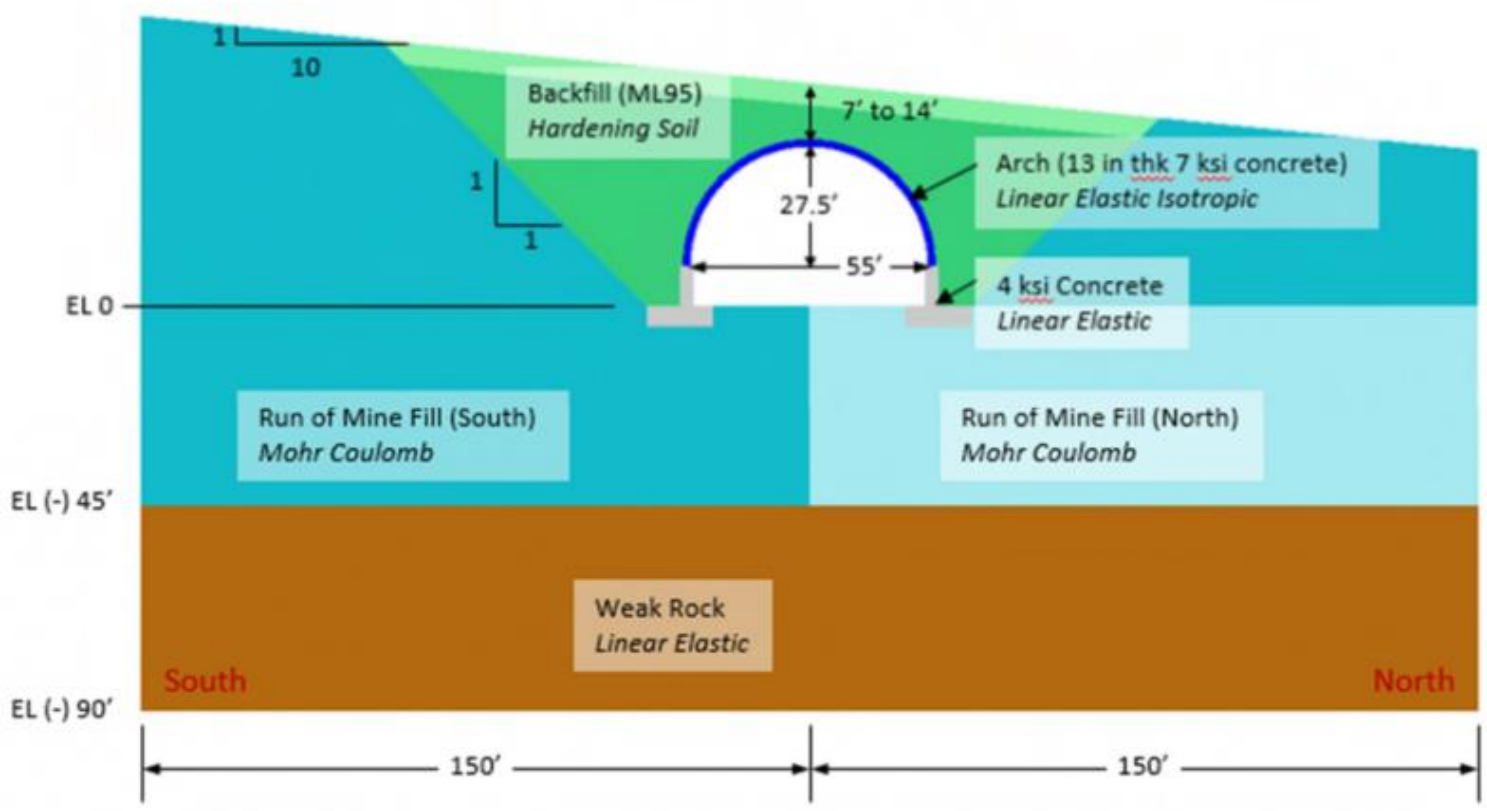
RL2



RL3

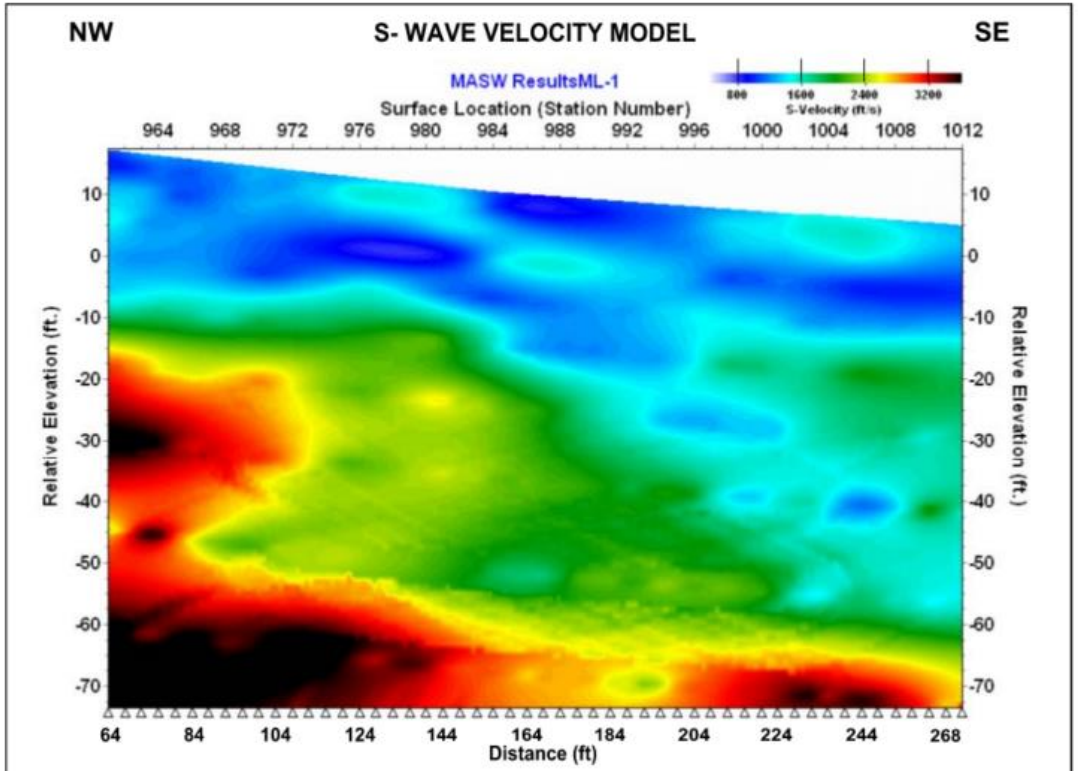
Analysis model

Plaxis-2D



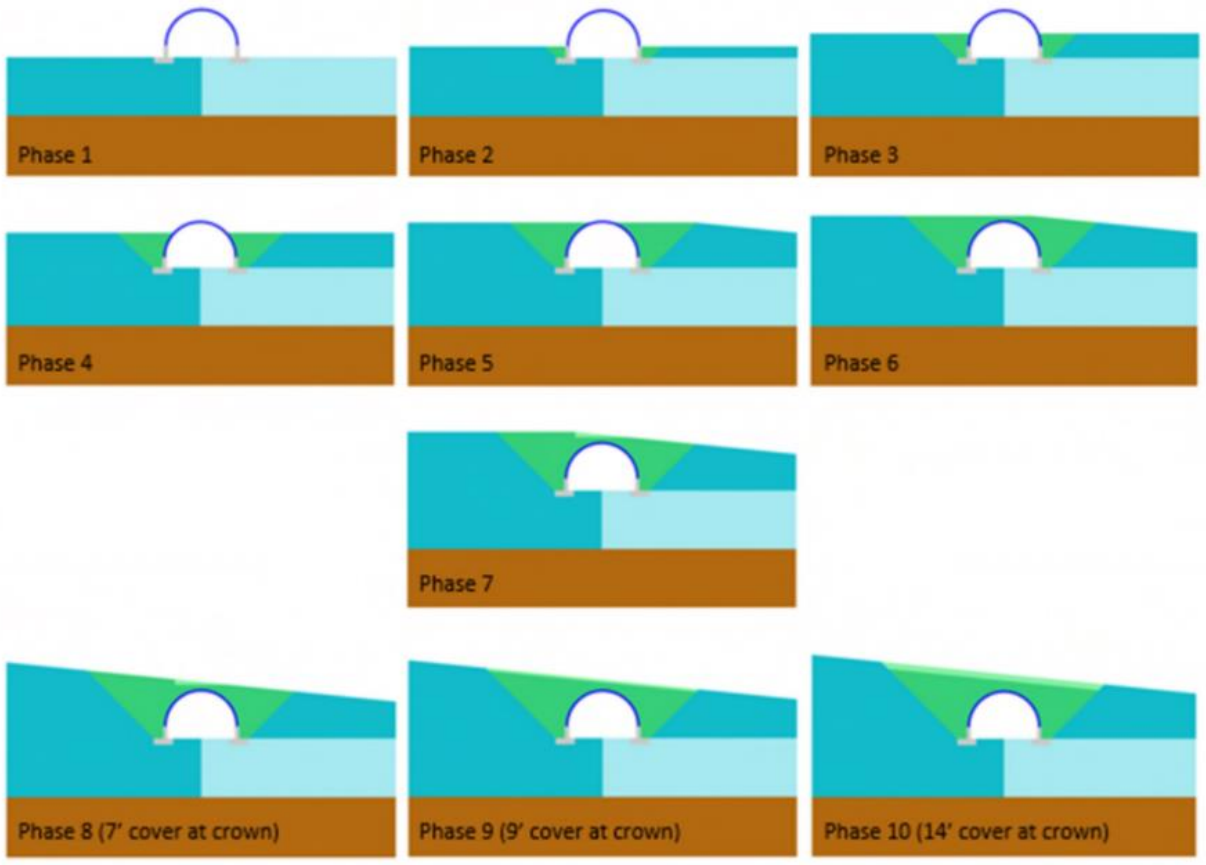
Material	Stiffness (E)
Arch concrete fc = 7 ksi (48 MPa)	4,700 ksi (33,000 MPa)
Foundation concrete Fc = 4 ksi (28 MPa)	3,600 ksi (25,000 MPa)
Backfill (ML95)	500 ksf (hardening soil)
Run-of-mine fill (South)	320 ksf
Run-of-mine fill (North)	180 ksf
Weak rock	6,000 ksf

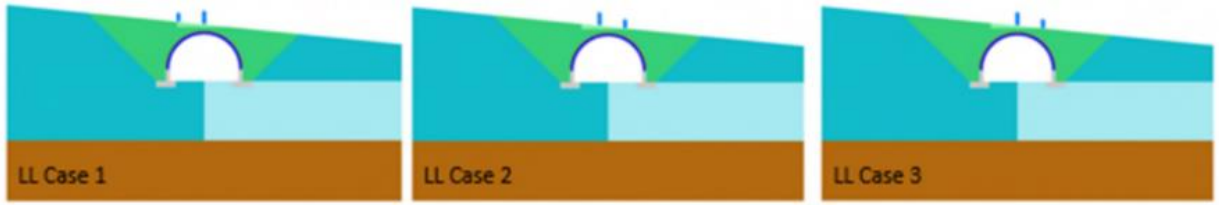
Discussion on subgrade moduli



- Goetech report suggested 800 ksf for run-of-mine fill
- Model (iterations to match total and differential settlements):
  North = 180 ksf
  South = 320 ksf
- Back-calculate shear wave velocity:
  North = 330 ft/s
  South = 440 ft/s
- Report range: 300 to 1000!

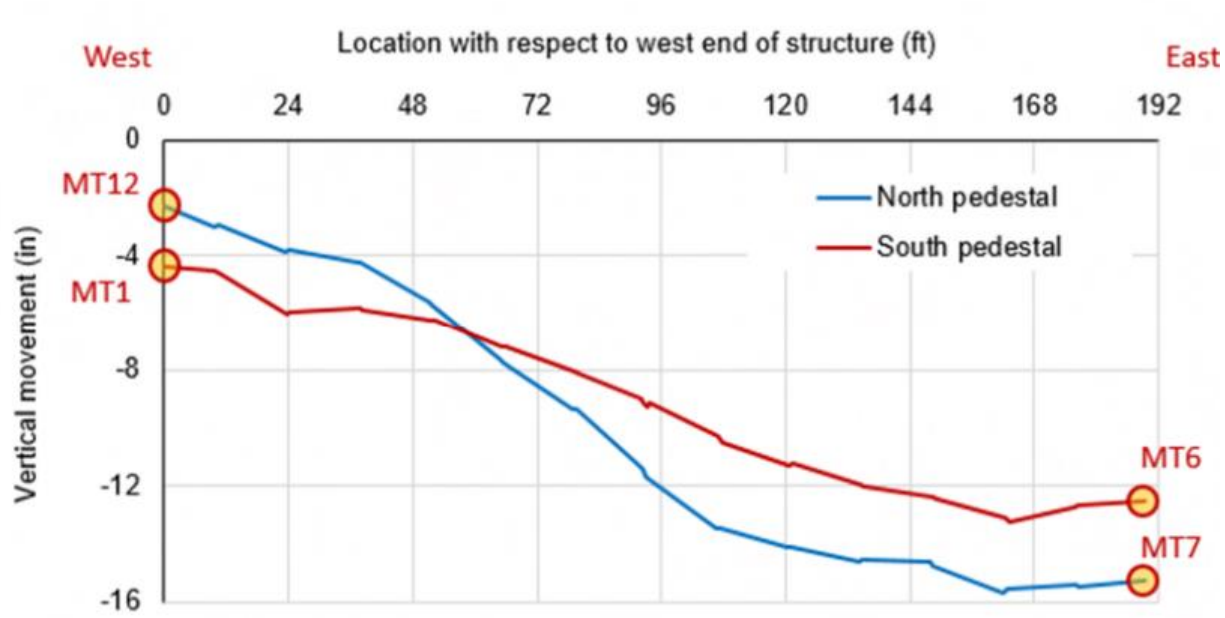
Construction sequence





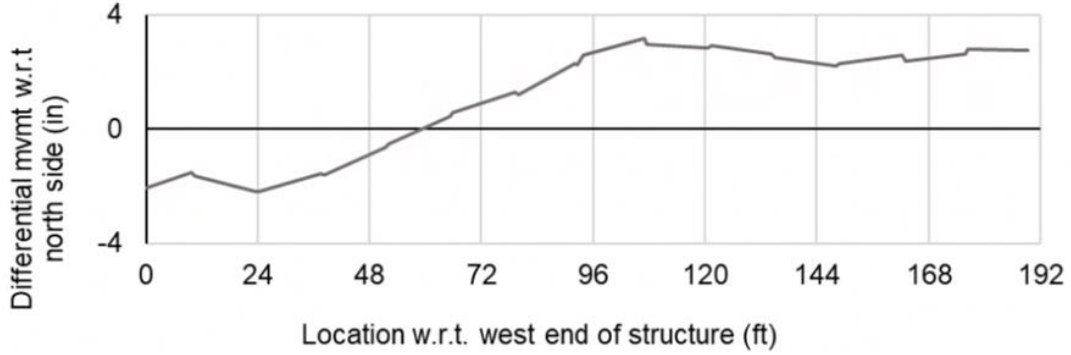
Effects on the arch

- Structures are designed to act in 2D



Span change

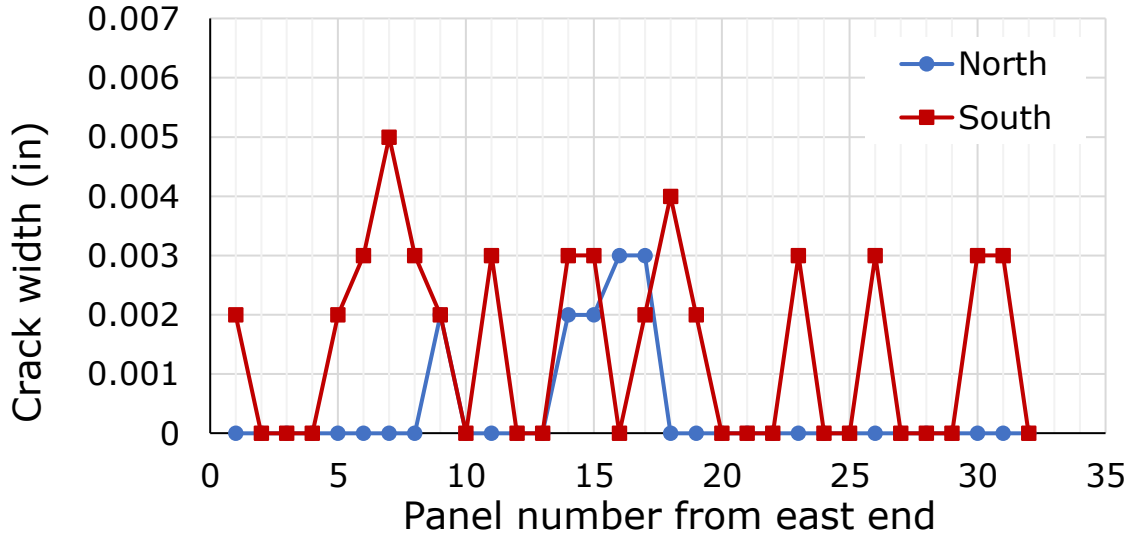
Differential settlement

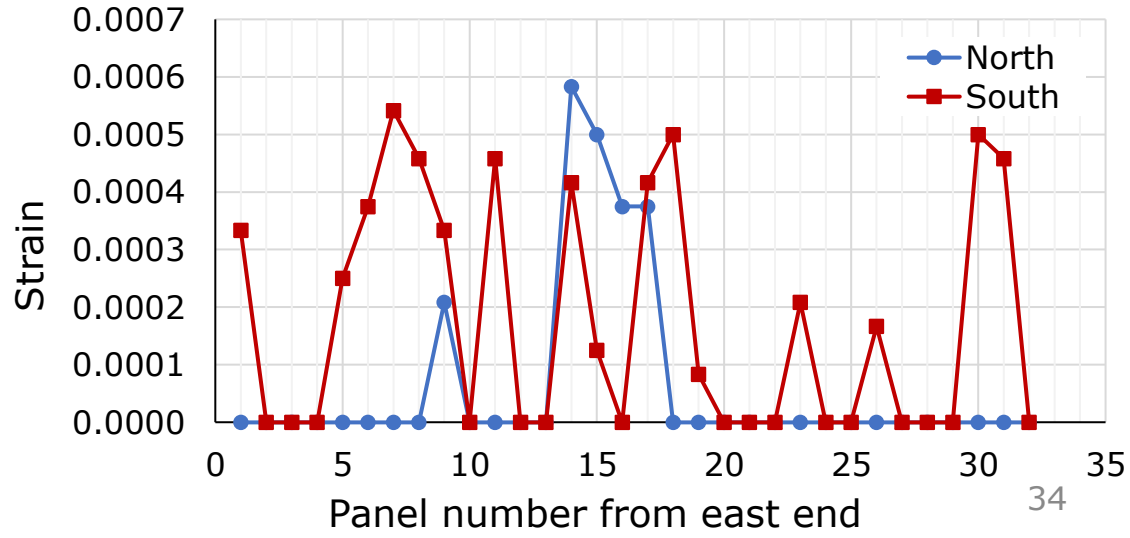


Effects on the arch

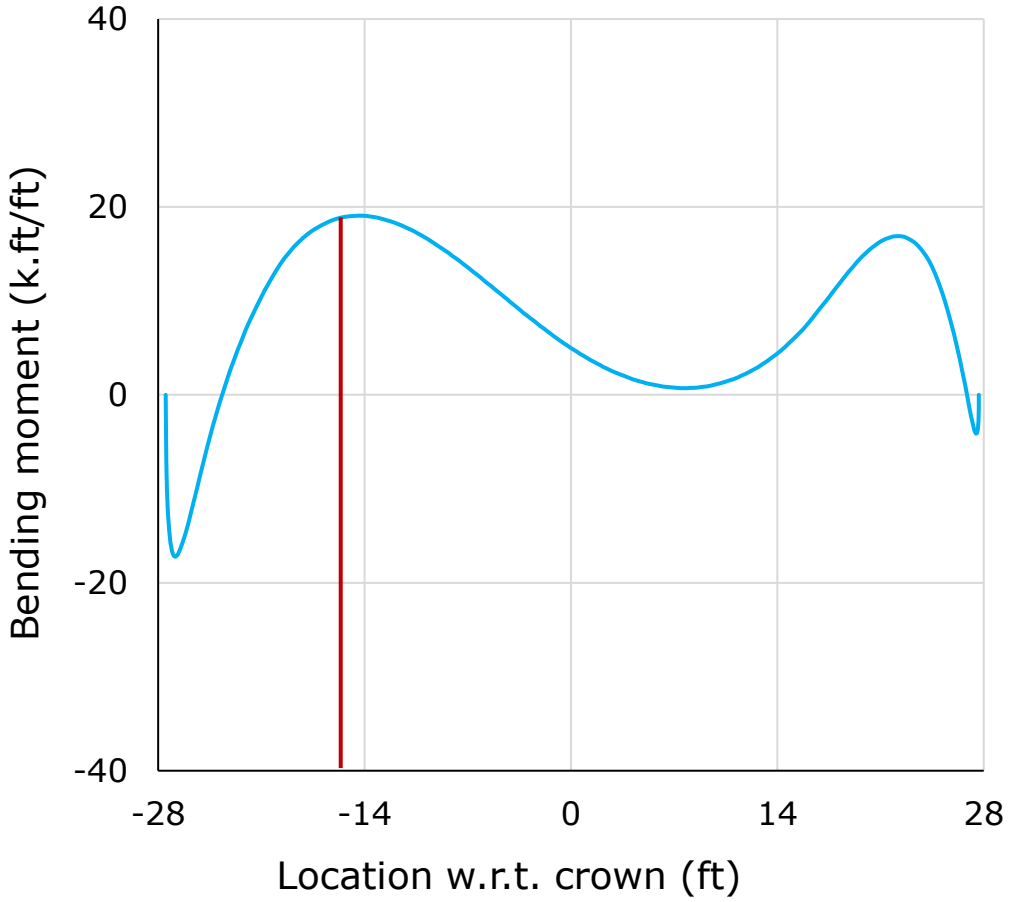
- Visual survey of the arch
- Any obvious signs of distress
  - Spalls ×
  - Cracks √
- Map cracks on the inside surface
  - Width
  - Spacing
- Estimate the tensile strain

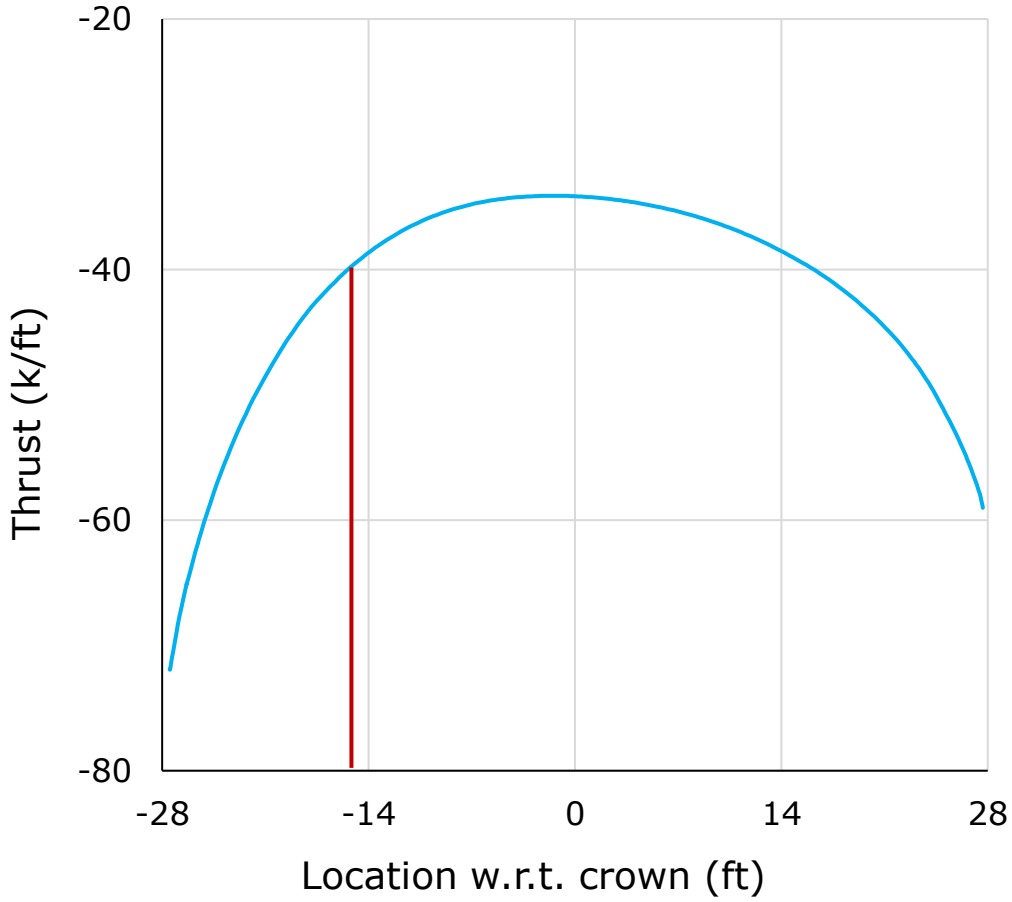
$$\text{Strain} \approx \frac{\sum \text{crack width over length L}}{\text{L}}$$



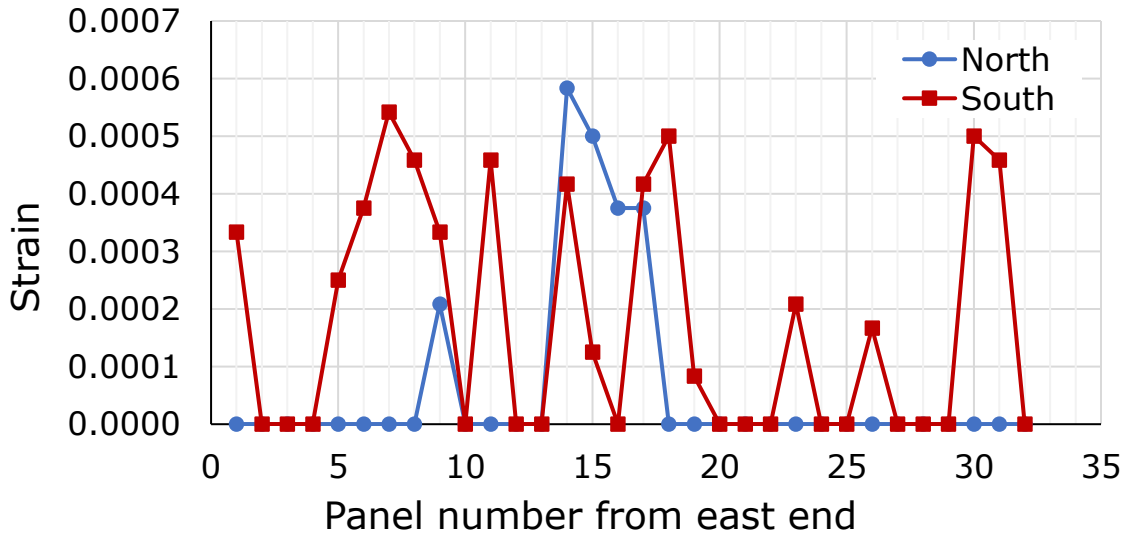


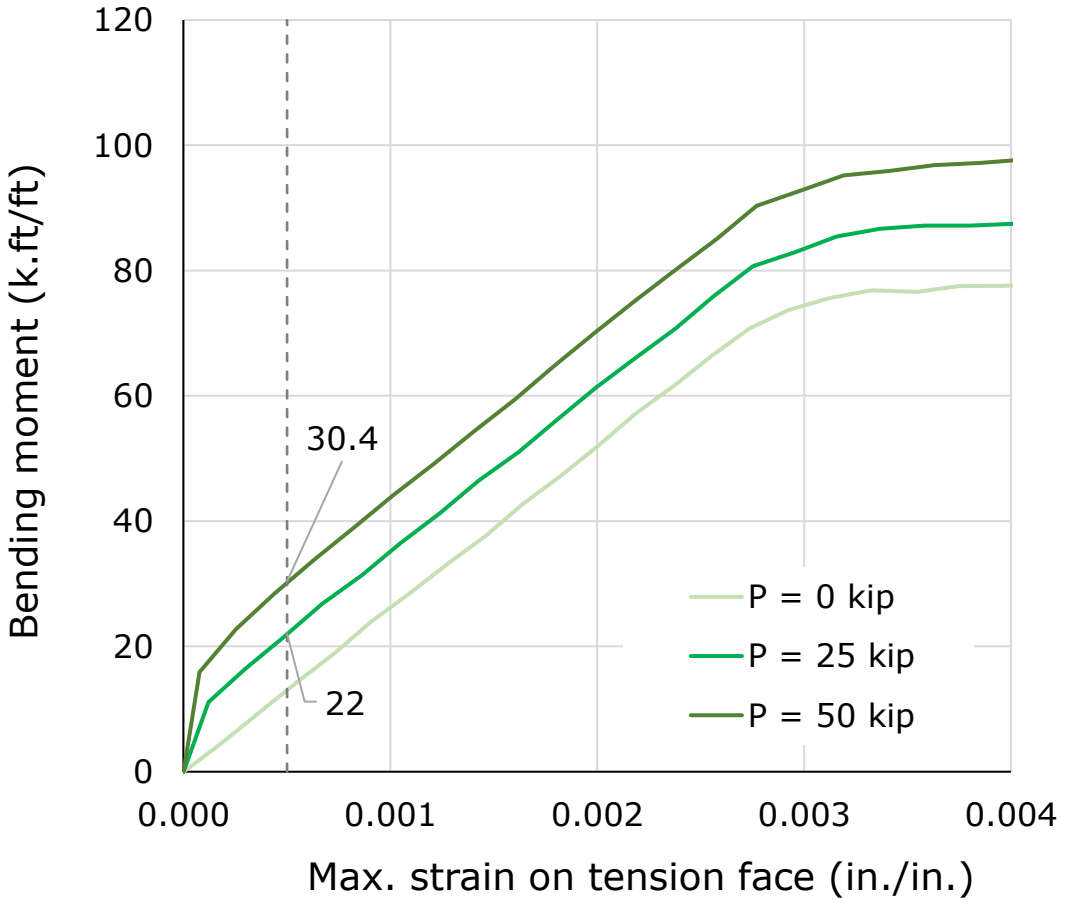
Results


40
20
0
-20
-40
Bending moment (k.ft/ft)
-28
-14
0
14
28
Location w.r.t. crown (ft)


-20
-40
-60
-80
Thrust (k/ft)
-28
-14
0
14
28
Location w.r.t. crown (ft)

Validation


0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
Strain
0
5
10
15
20
25
30
35
Panel number from east end
North
South


120
100
80
60
40
20
0
Bending moment (k.ft/ft)
30.4
22
P = 0 kip
P = 25 kip
P = 50 kip
0.000
0.001
0.002
0.003
0.004
Max. strain on tension face (in./in.)

Summary and conclusions

- Subgrade movement after construction resulted in a differential settlement of the arch (~ 3 inches)
- Likely cause of the settlements was the variation in subgrade modulus
- 2D analysis was in good agreement with observed structural behavior
- Max DCRs:

  Thrust-bending (PM) = 0.8

  Shear = 0.6

Recommendations

- Allow use of highway below and mine traffic above
- Continue monitoring displacements on the pedestals
- Reanalyze if displacements exceed 10% or if the structure shows any signs of distress

Food for thought …

Education and professional experiences

2006 to 2010 – B.Tech. (College of Engineering, Pune)

2010 to 2011 – M.S. (University of Illinois at Urbana-Champaign)

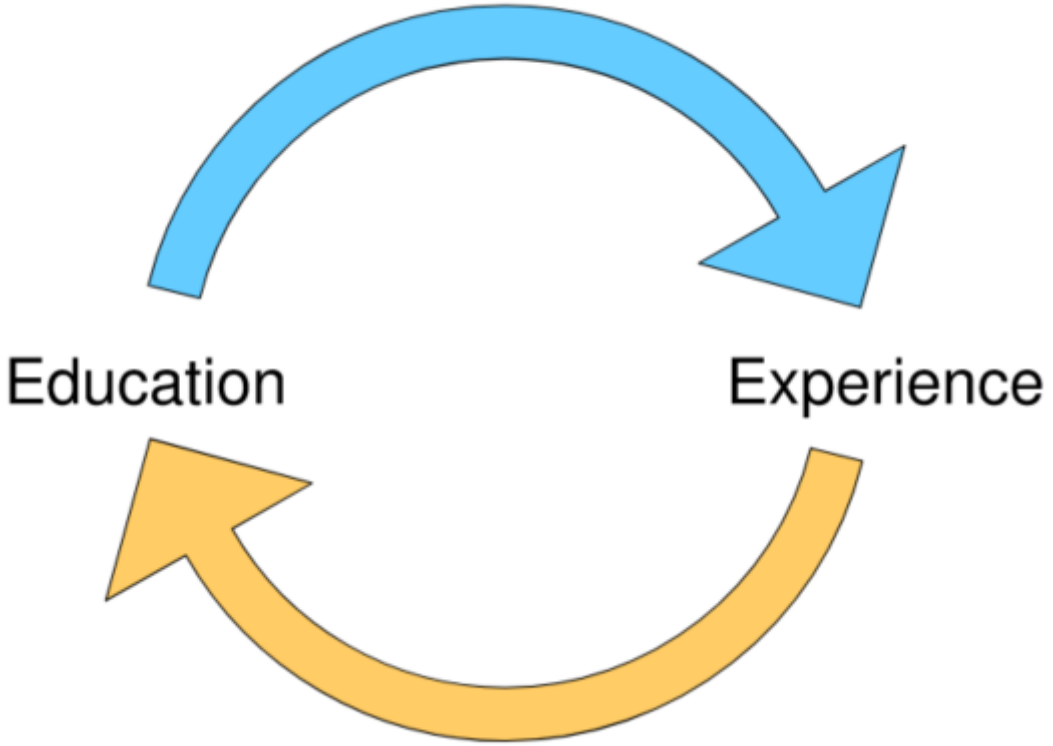
2012 to 2014 – Design Engineer (LERA Consultants)

2014 to 2015 – Project Officer (IIT Madras)

2015 to 2019 – Ph.D. (University at Buffalo)

2019 to today – Consulting Engineer (SGH)

Continuing education



The 3 I’s of success*

Imitate

* Professor Rupen Goswami (IIT Madras); Professor Maria Garlock (Felix Candela: Strength and Elegance in Structural Engineering)

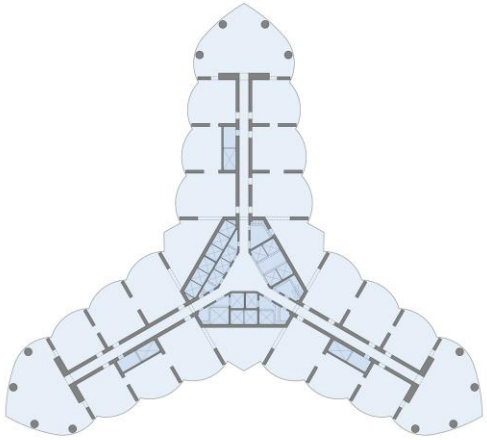
The 3 I’s of success

Imitate → Innovate

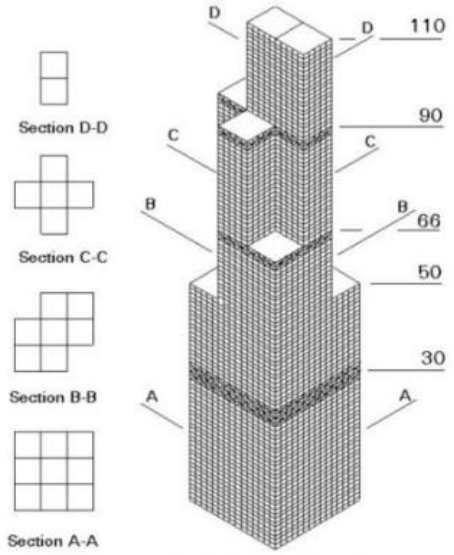
The 3 I’s of success

Imitate → Innovate → Inspire

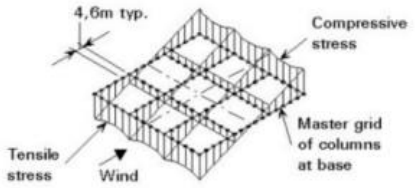
Bill Baker



Fazlur Khan



(a) Modular floor configurations

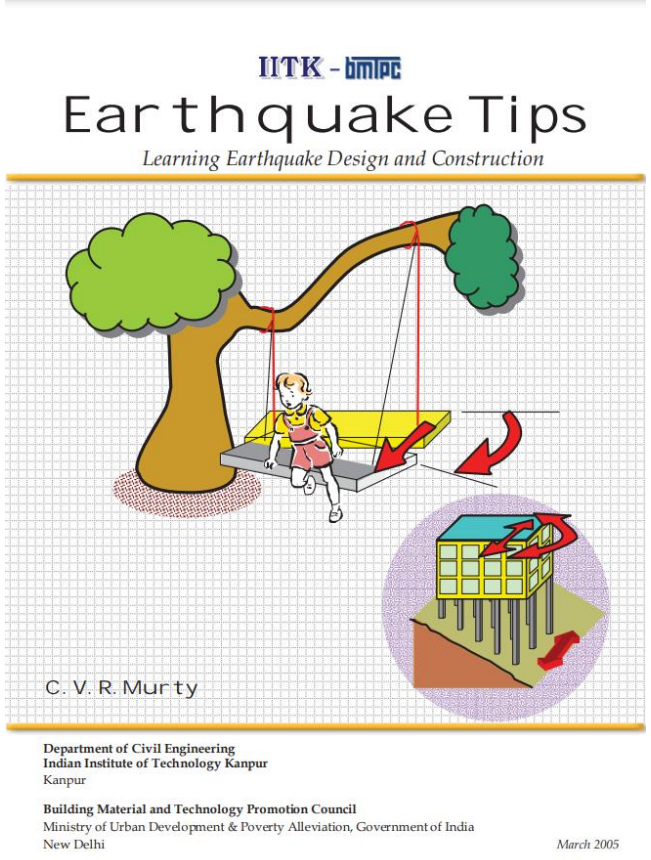


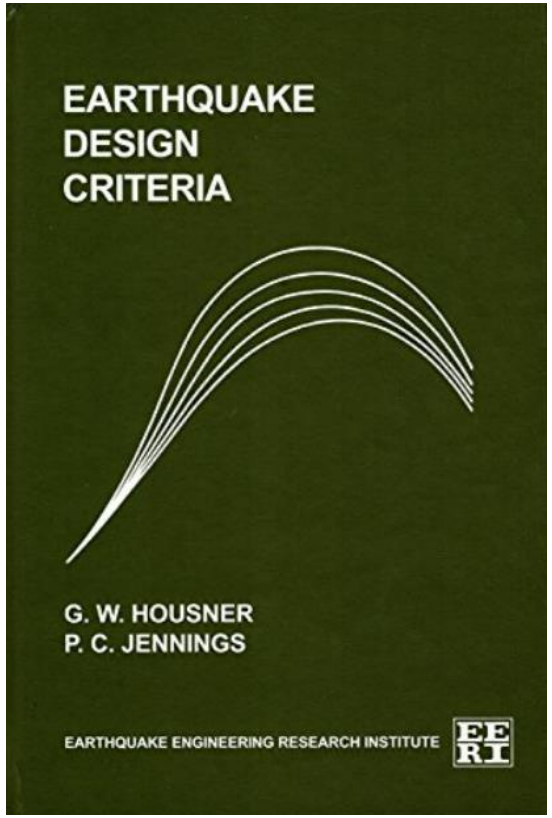
(b) Shear lag behaviour

Figure 10 Sears Tower, Chicago, Illinois

Reading recommendations

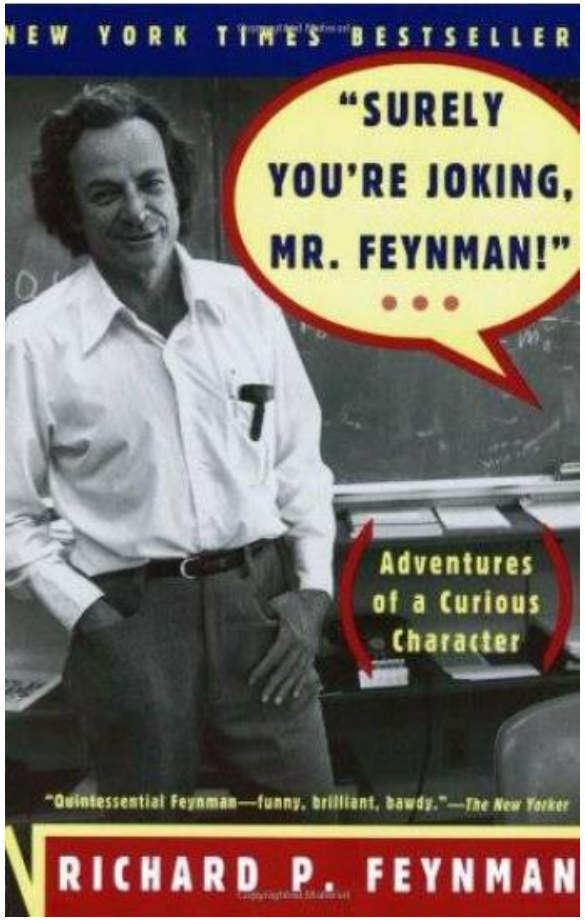
Technical

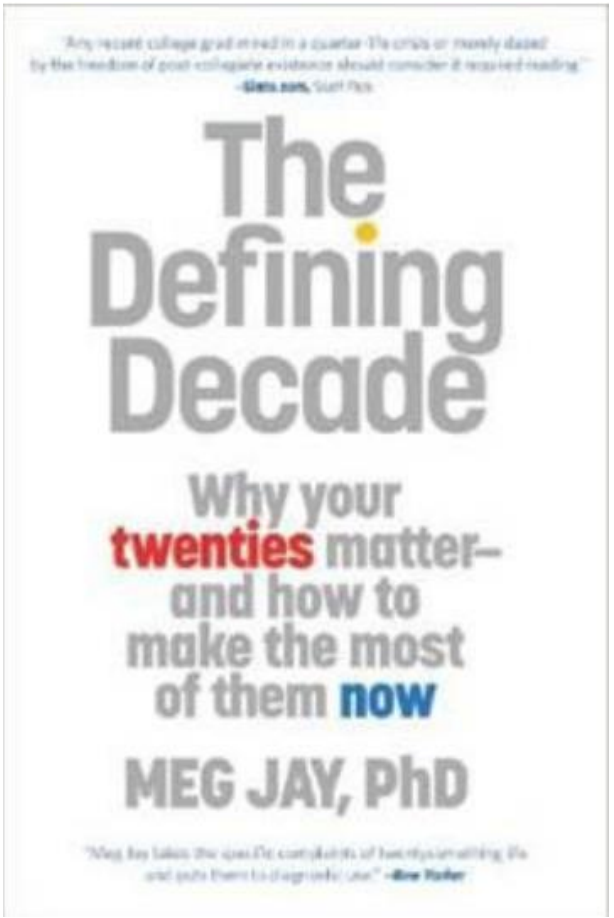


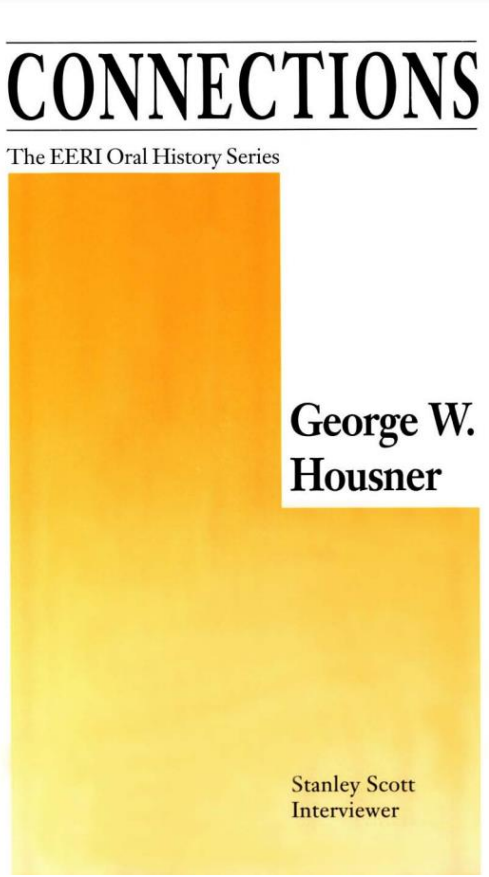


Reading recommendations

Non-technical







In closing …

Make your teachers and parents proud!

… Always remember the enormous sacrifices they have made for us to be where we are

Thank you!

Questions

1. What are some of the challenges one may face at the beginning of one's consultancy career?

- Where to start and what area to focus
- Well-rounded experience
- Talk to seniors in the field (people in the industry, professors)

Questions

2. If someone wants to open their own consultancy, what should be the plan to go forward for the next five years?

- Gain experience
- Create a niche – establish yourself as the expert
- Publish papers, attend conferences, contribute to codes

Questions

3. What is the expected financial growth trajectory of the career given the current market situation?

- Current market situation – will happily defer to other experts!
- Trajectory for Civil Engineers is slower
- Pay is proportional to responsibility
- Responsibility comes with experience and expertise
- Takes time and effort to gain both
- Safety of hundreds to millions riding on your shoulders

Questions

4. How to explore opportunities abroad?

- Easier to pursue educational opportunities
- More funded opportunities for Ph.D. students

Questions

5. Any company in India where diverse work (prestressed concrete, RC, steel, prefabricated) happens?

- Not an expert here
- L&T is an excellent firm with a diverse project portfolio

Questions

6. If someone wants to pursue a Ph.D. and a career as a consultant, what are some recommended research areas which can help their consultancy career?

- Follow your passion
- Ph.D. is a difficult journey – especially if you don’t like your advisor or area of research
- Research evolves – good to focus on advisor and school
- Explore current funding opportunities

Questions

7. In what direction is Civil Engineering headed? What are some necessary skills to flourish in it?

- No one knows :-)

- Clear fundamentals – should be able to work from first principles
- Coding – essential to operate (Python, Mathcad, Excel)
- Communication – written and oral

Questions

8. What are some necessary domain and non-domain knowledge and skills required to start your own consultancy? Any tips on financial management to run a company?

- Experience and expertise
- Clear communication
- Basic finance
- Resource management
  - Human – engineers, technicians, admin
  - Time