# Modeling & Design of the Gilman Drive Overcrossing Foundations

## Presented by:


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# Gilman Drive Bridge

## Project Overview

# Gilman Drive Bridge

**Owner:** UCSD University of California, San Diego

**Engineer of Record:** Tony Sánchez, PhD, PE

**Geotechnical Engineer:** Eric Brown, GE Earth Mechanics, Inc. Geotechnical and Earthquake Engineering

**Bridge Structure:** 406-foot long concrete arch bridge with 3-spans and multi cell post-tensioned box section

**Total Width:** 62 feet (total width)

**Design and Construction schedule coordinated with:**

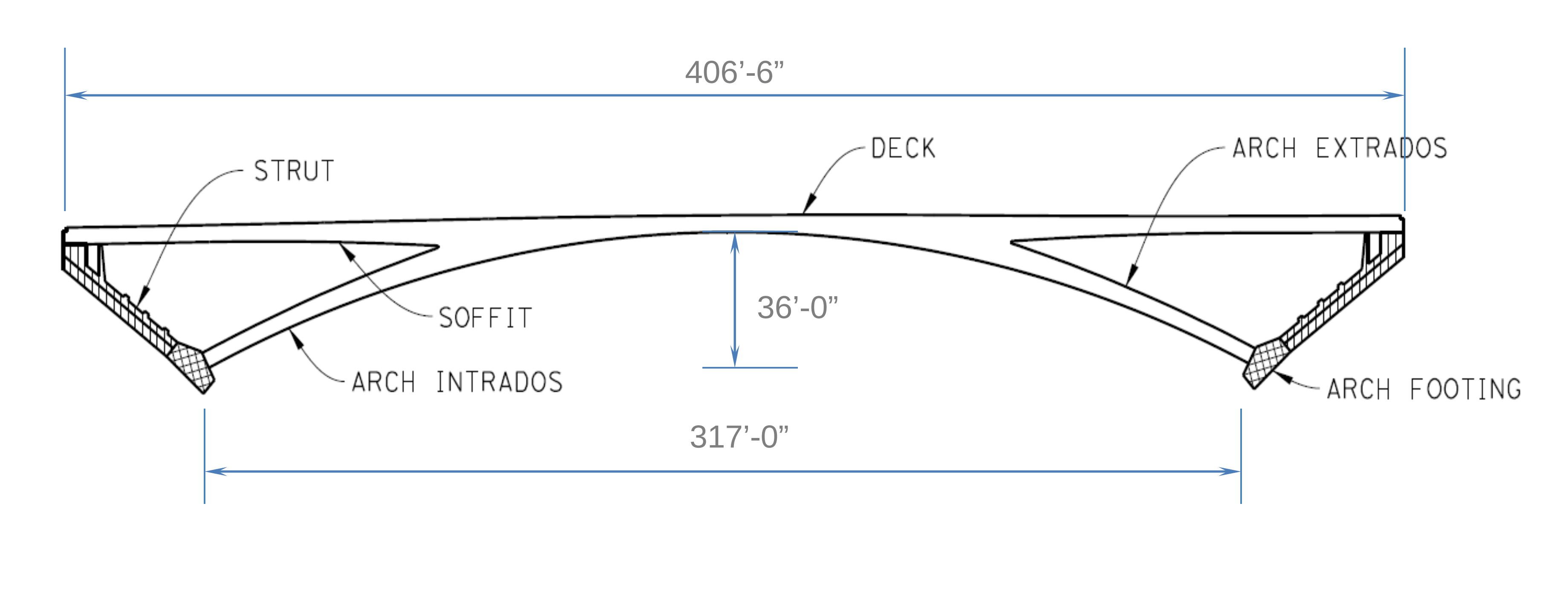
Caltrans for the I-5 Widening

SANDAG for the Mid Coast Trolley.

**Total Construction Value:** $20 Million (est.)

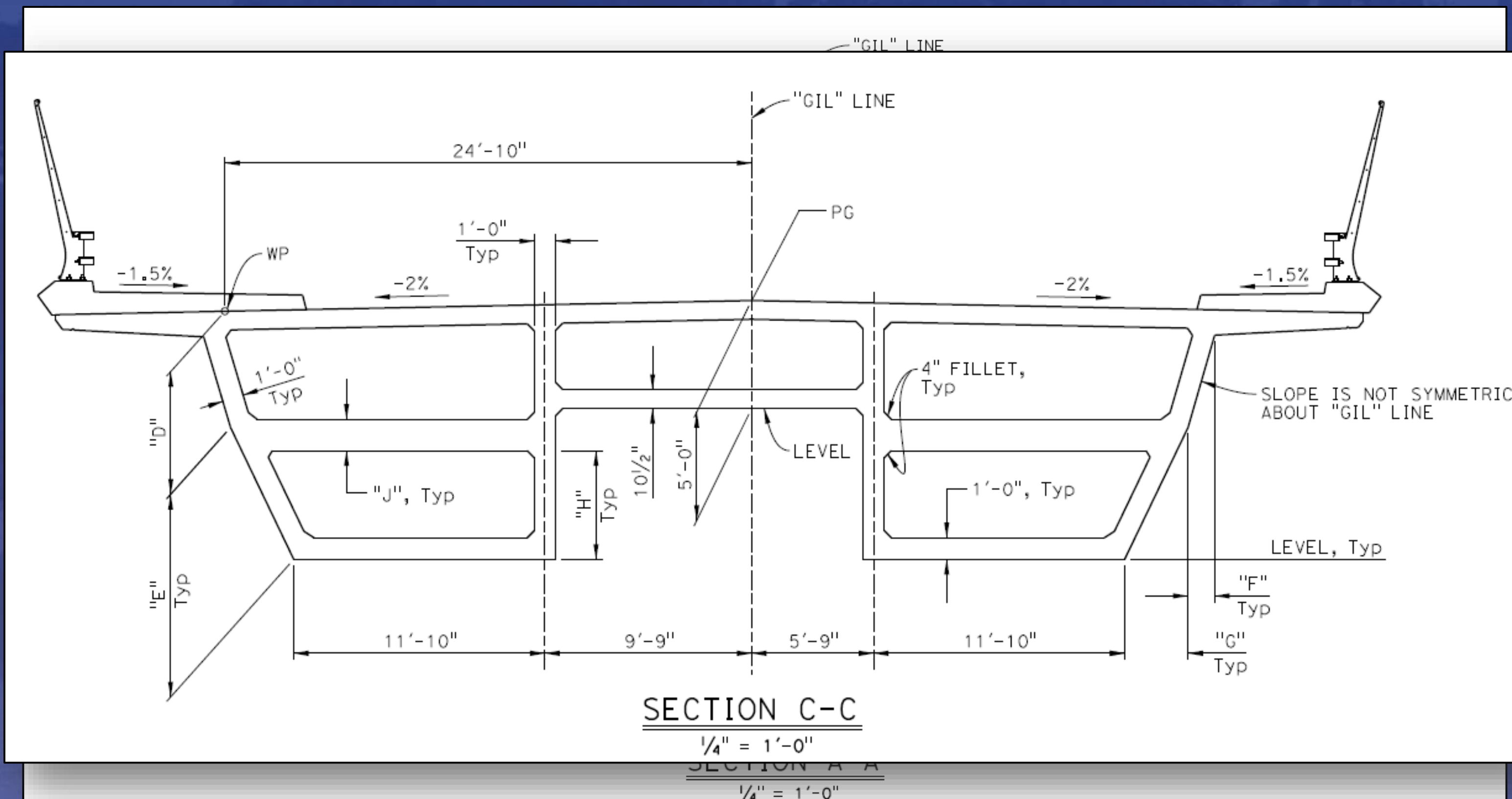
**Bridge Construction Value:** $10 Million (est.)

# Gilman Drive Bridge Layout



# Gilman Drive Bridge Geometry

- Superstructure

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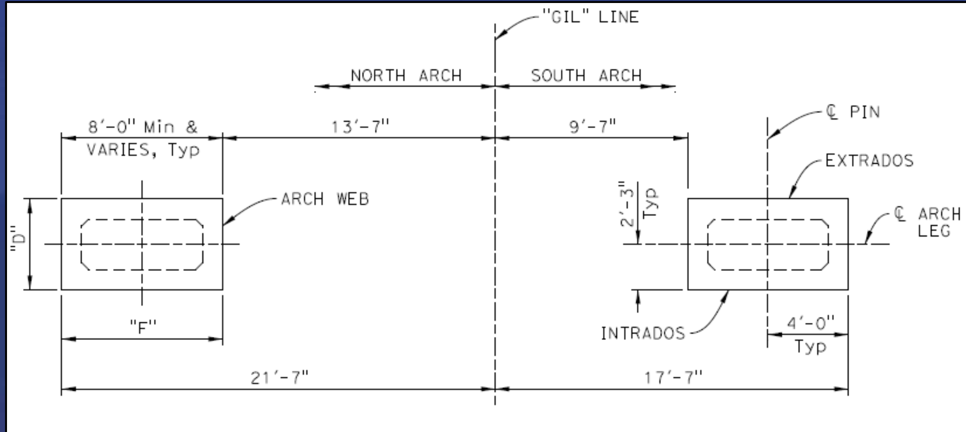
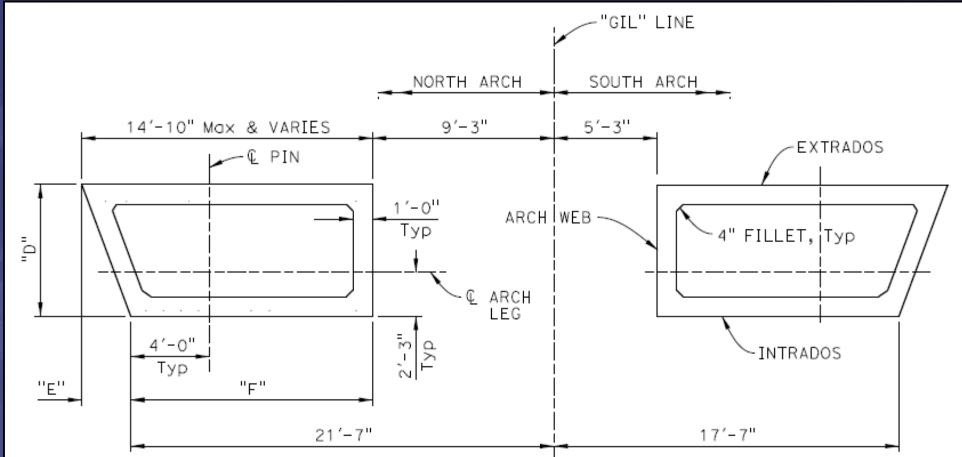
# Gilman Drive Bridge Geometry

- Arch Legs
  - Rectangular Cross Section at Arch Base
  - Arch Width and Depth Varies
  - Increasing slope of exterior face




SECTION @ ARCH BASE




SECTION @ SUPERSTRUCTURE

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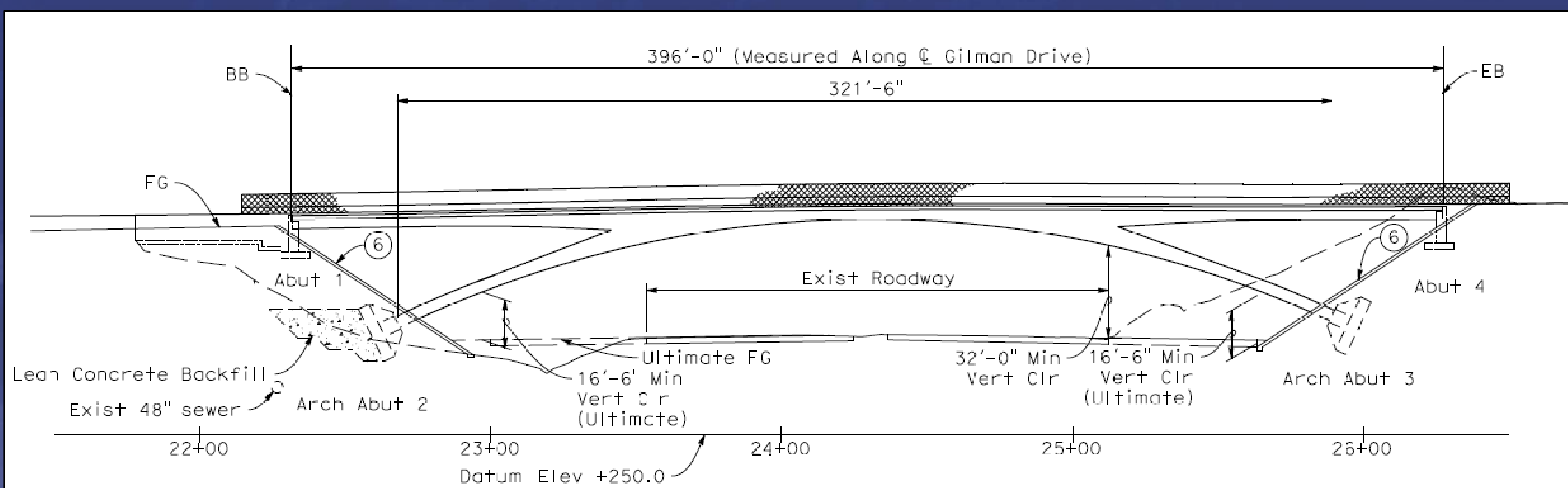
# Structure and Foundation Concepts

- Type Selection Concept: Found arch on spread footings
- Angle footings to the direction of arch thrust
- Supplement weak/soft rock on west of the freeway with lean concrete backfill
- Rock to the east of the freeway is adequate w/no improvements necessary

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# Geotechnical Considerations
# Geologic Conditions

- Weak/soft sedimentary rock
  - Scripps Formation – sandstone, siltstone, claystone, various levels of weathering
  - Ardath Shale – soft shale
  - Better than typical soil, but not nearly as good as granite or other hard rock
- Spread footing would likely work for a typical bridge, but the arch is more sensitive to settlement

# Geotechnical Considerations Field Investigation

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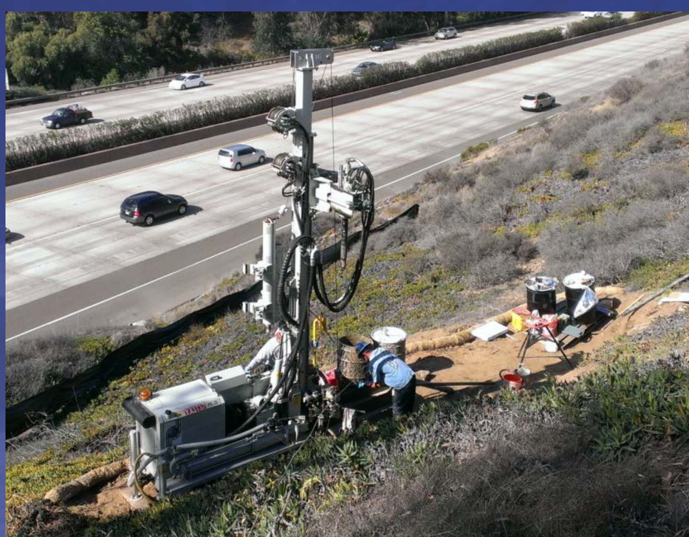
*Craning in the drill rig at Arch Abutment 3*

- 4 Borings
  - 2 End Abutments
  - 2 Arch Abutments
- Downhole P&S wave logging
- Pressuremeter testing



*Drill rig (Pacific Drilling) at Arch Abutment 3*

*Downhole logging at Arch Abutment 2*

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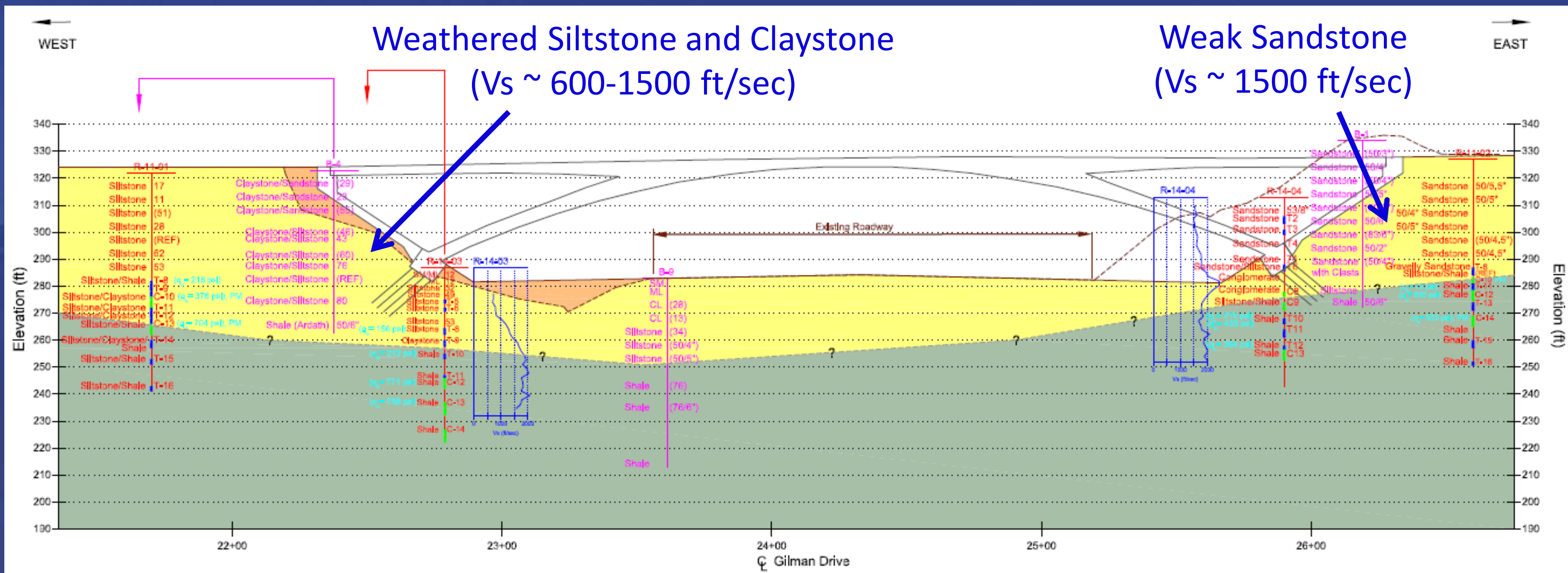
# Geotechnical Considerations Field Investigation

*Pitcher barrel and sample from Scripps Formation (sandstone)*

*Core barrel with Ardath Shale sample*

- Needed good samples for evaluating stiffness
- Sampling Methods
  - SPT – disturbed samples
  - Calmod – semi-disturbed samples
  - Pitcher barrel – undisturbed samples of weak sandstone/siltstone
  - Core barrel – undisturbed shale samples

# Geotechnical Considerations
# Subsurface Conditions




- Unconfined compression tests (UC)
  - Scripps Formation: about 70-400 psi
  - Ardath Shale: about 200-800 psi

***Reference Points for UC Strength:***
***Stiff Clay ~ 30 psi***
***Granite ~ 20,000 psi***

Proposed Fill
Scripps Formation
Ardath Shale

- Stiffness information: Pressuremeter, downhole wave velocities, UC tests
- Conditions within the Scripps Formation generally better on the east side of the freeway
- Ardath Shale was similar on both sides of the freeway

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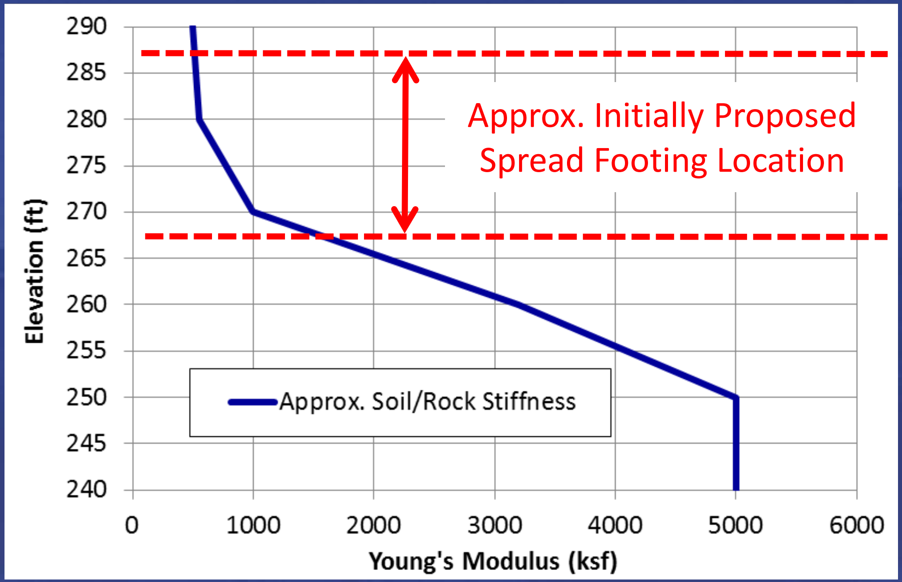
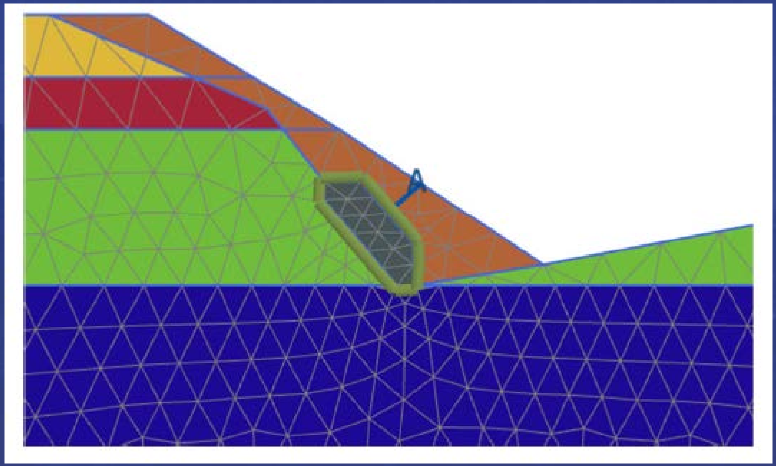
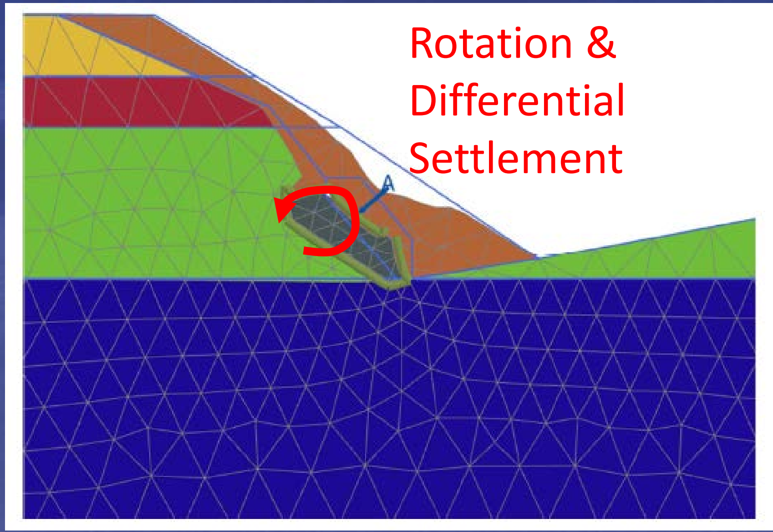
# Geotechnical Considerations Foundation Type




- Highly weathered soft weak rock near surface at west arch abutment
- Significant variation in ground stiffness along originally proposed footing location
- Leads to footing rotation and differential settlements
- Solution – Micropiles
  - Transmit bridge loads to deeper, stiffer Ardath Shale
  - Similar foundation stiffness at both footings



*FE model mesh*




*FE model deformed mesh*

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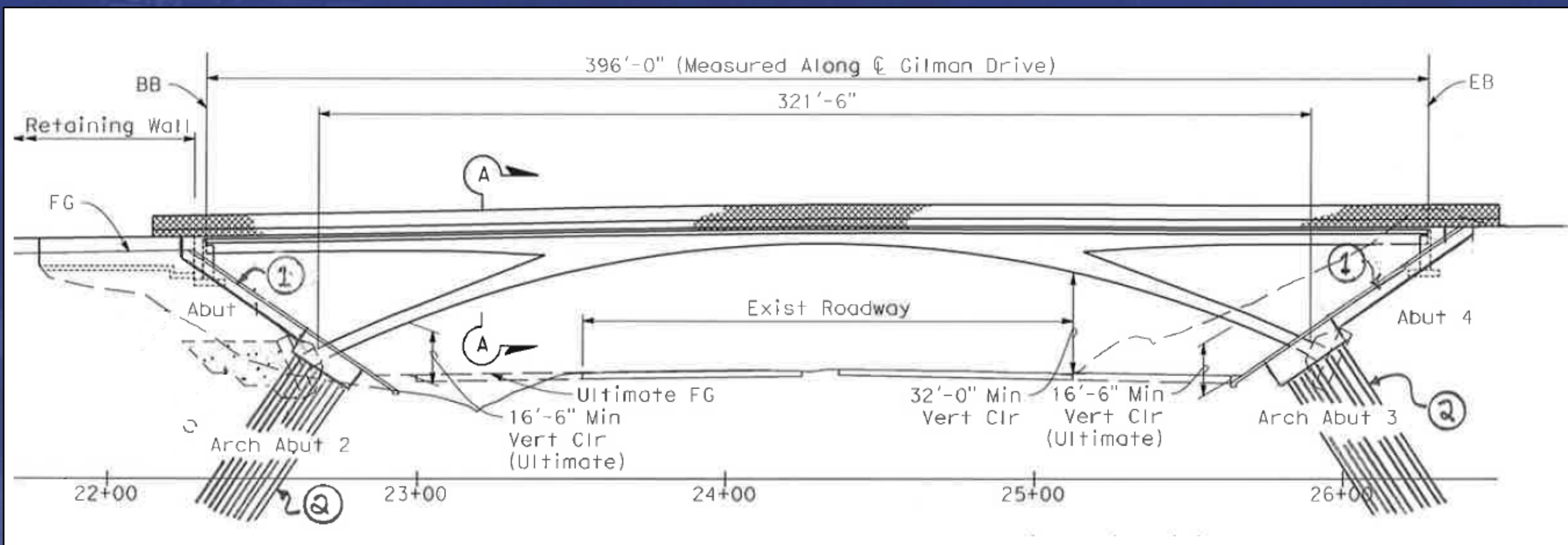
# Micropile Construction

- Micropiles
  - 10” Diameter, 65 ft long, 700 kip ultimate capacity
    - Contractor has option to redesign diameter and bonded length
  - Verification Testing: 2 tests per arch support
    - Tested to nominal resistance
  - Proof tests: 10% of production piles
    - Tested to maximum service load demand

# Structure and Foundation Concepts: Design Refinement

1. Connect abutment to arch foundation with inclined strut
2. Use micropiles in lieu of slurry backfill

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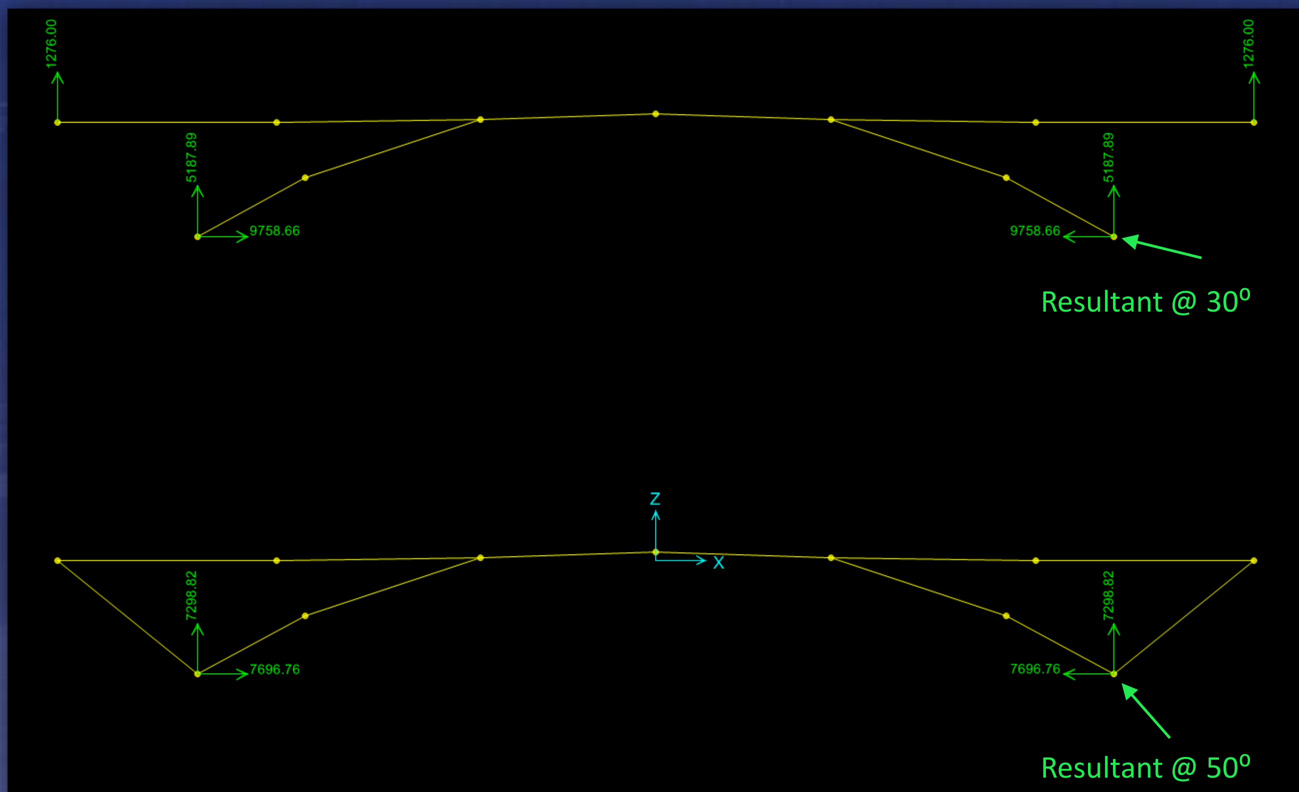
# Structure and Foundation Concepts: Design Refinement

- A strut was added between the superstructure and foundation to reduce arch thrust

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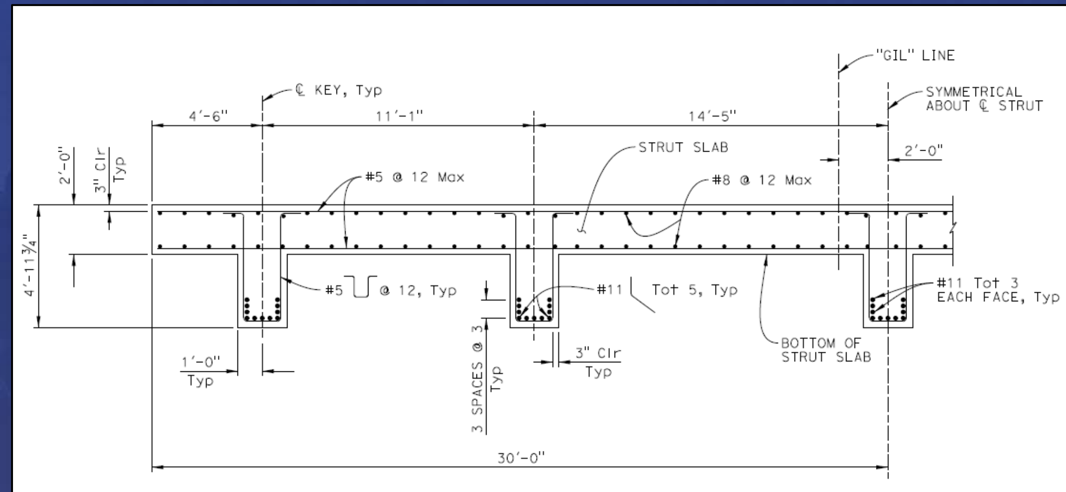
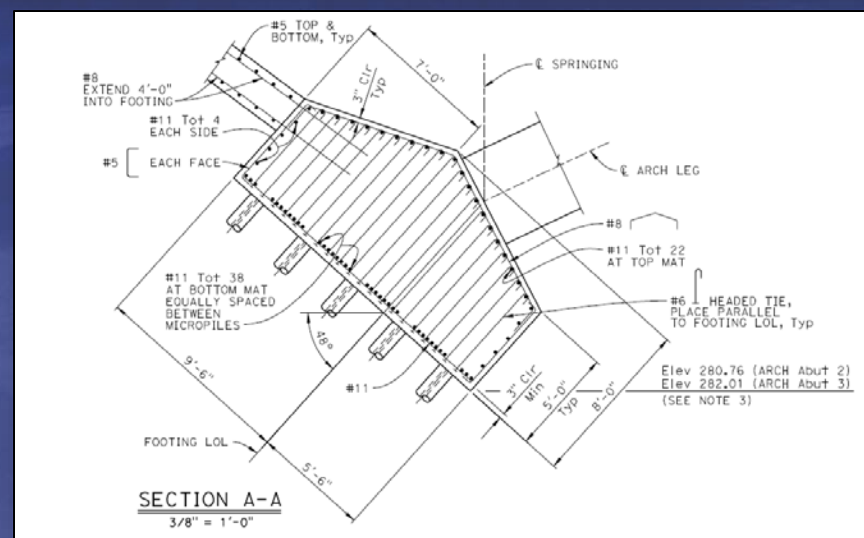
# Gilman Drive Bridge Geometry

- Strut
  - 60 ft Wide
  - 5 ft Deep
  - Five Keys
- Pile Cap
  - 60 ft Wide
  - 15 ft Long
  - Maximum 8 ft Deep

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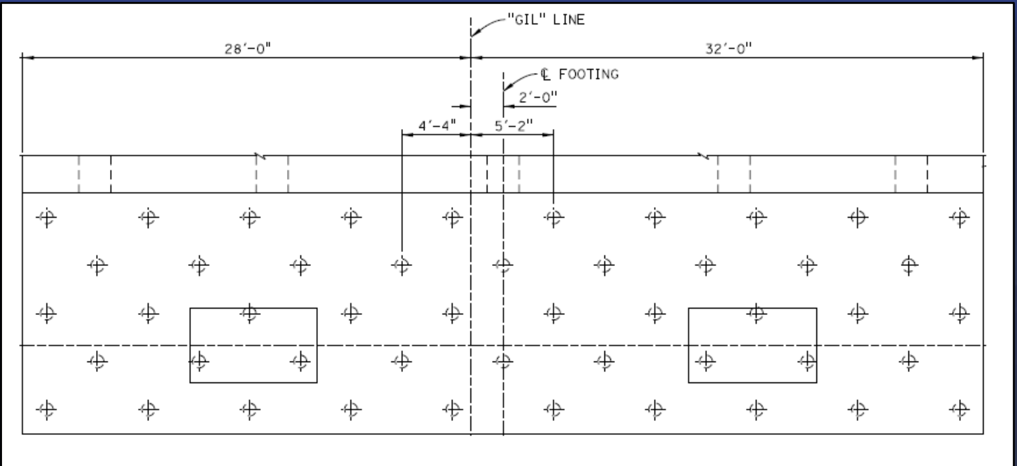
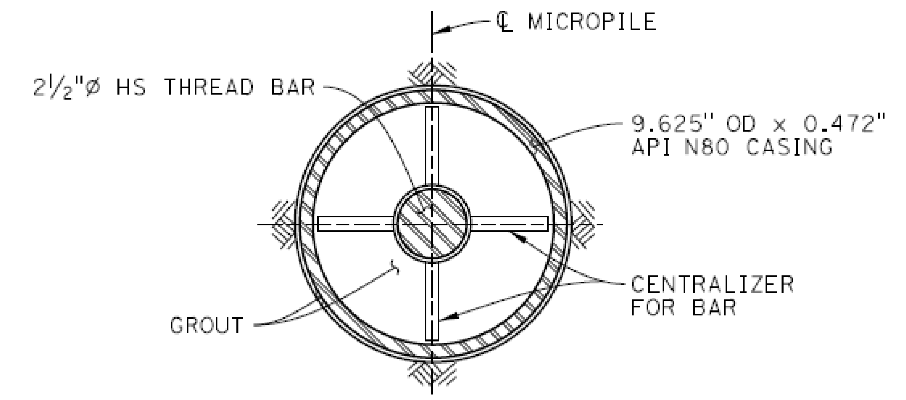
# Gilman Drive Bridge Geometry

- Micropiles
  - Spaced @ 5 x Dia
  - Inclined at 48° to the Horizontal
  - Design Length of Approximately 60 ft, Upper 20 ft Cased
  - 2½” Diameter High Strength Threaded Bar



ARCH FOOTING PLAN



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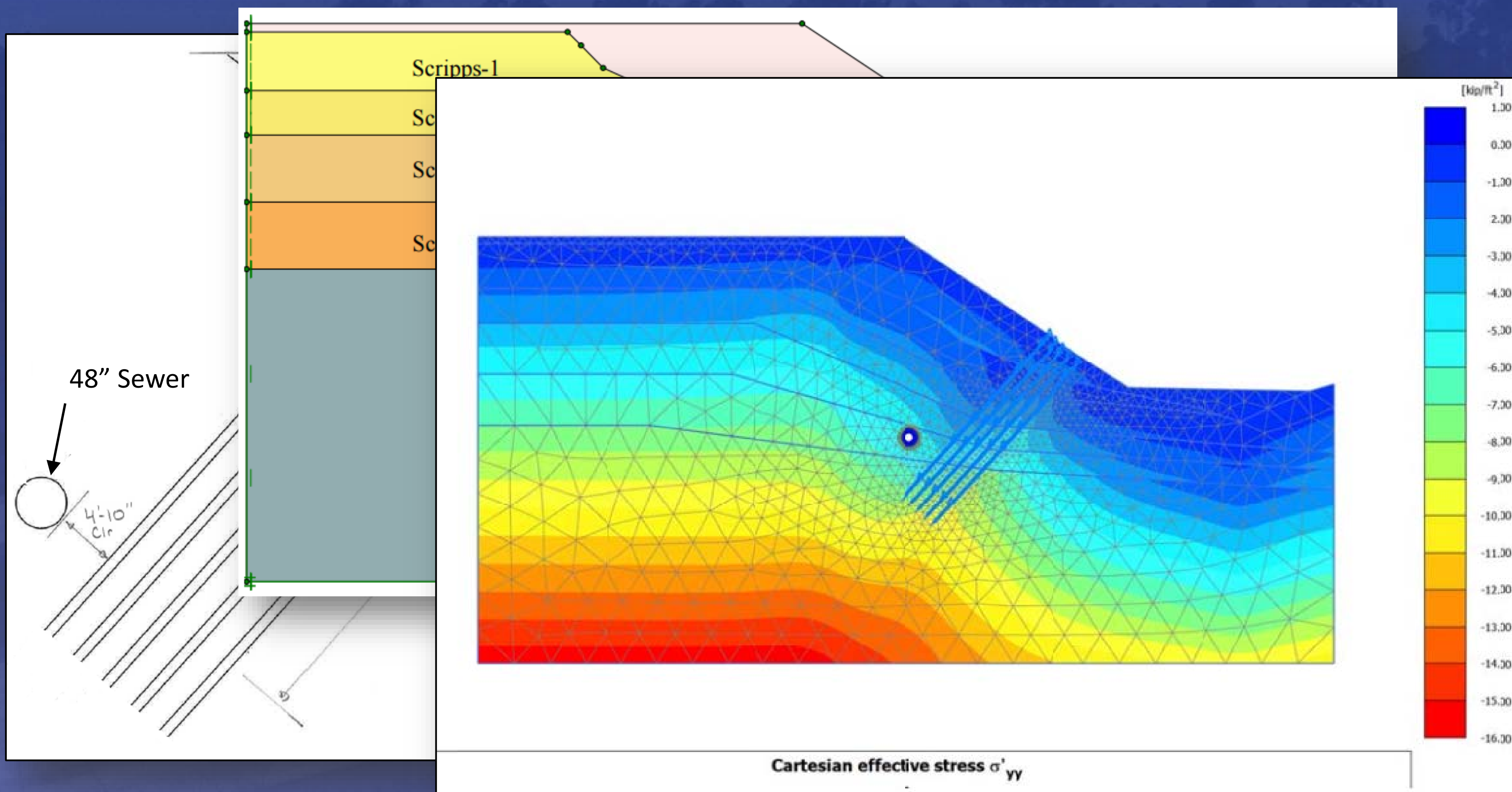
# Optimize Foundation

## Micropile Inclination

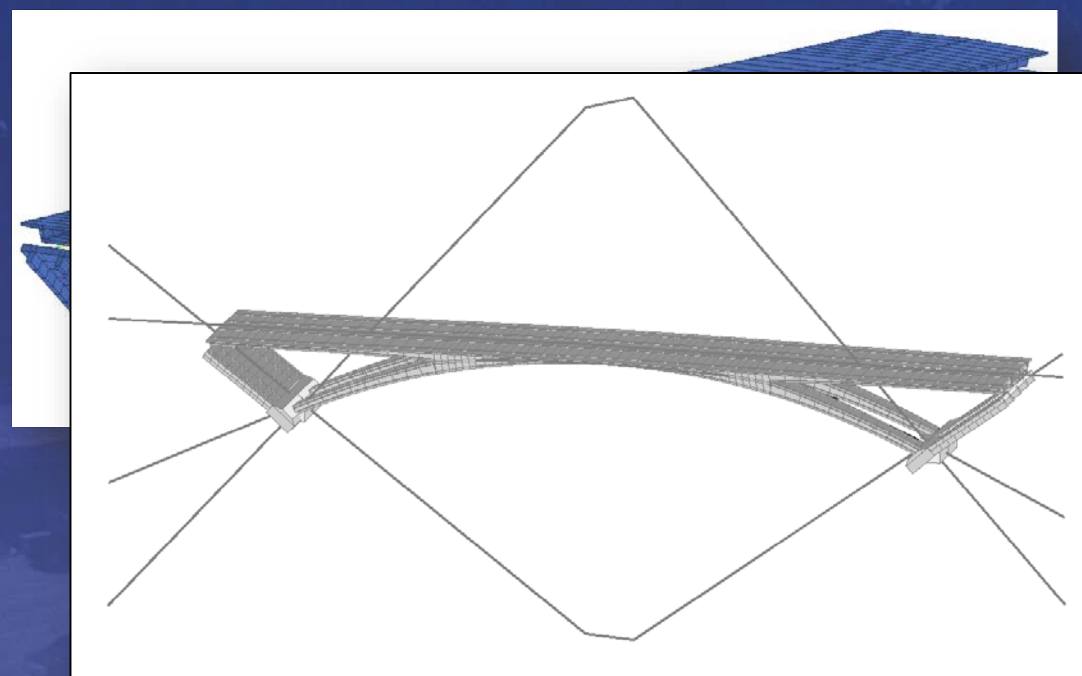
- A 48 inch sewer line below the west foundation limited Inclination and length of micropiles



# Foundation Modeling

## RM Bridge – Software Engine for Vertical Load Analysis

- Structure constructed as a spine model using Bentley's RM Bridge
- Bridge elements are connected through a series of longitudinal axes
- Arch legs, strut, pile cap and micropiles represent three separate axes



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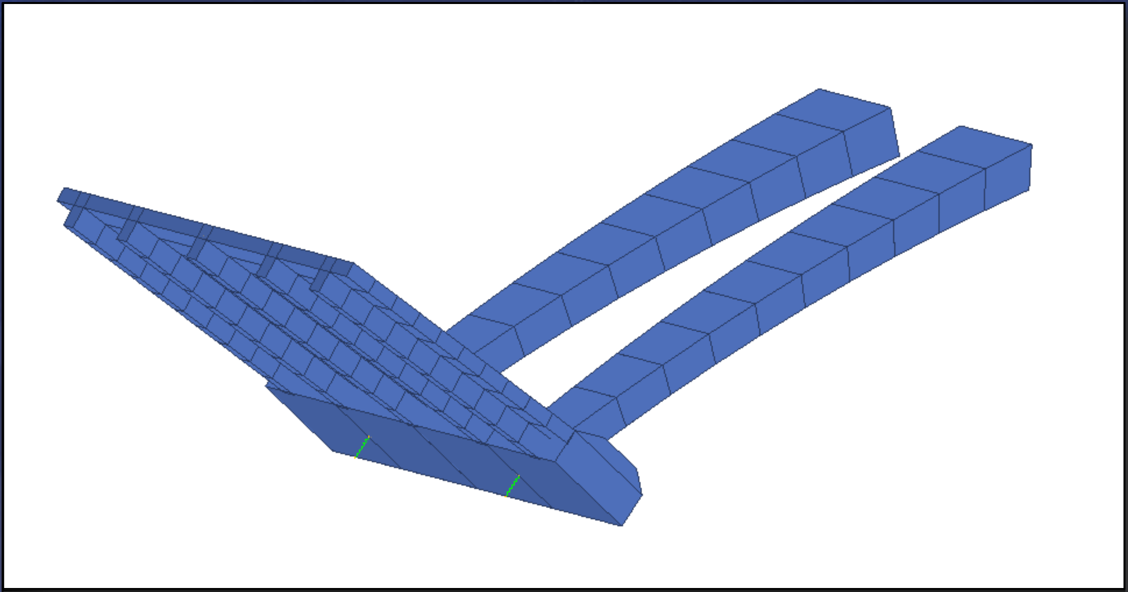
# Foundation Modeling

## RM Bridge – Software Engine for Vertical Load Analysis

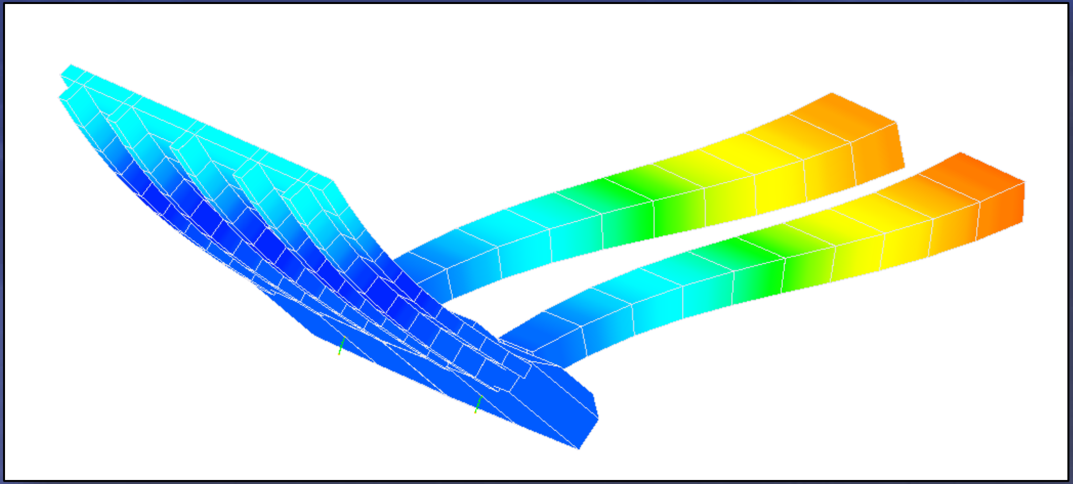
- Arches modeled as distinct elements
- Pile cap modeled in halves, connected by a massless transverse element with equivalent cap stiffness
- Pile cap is supported by springs with equivalent micropile stiffness
- Strut frames into edge of pile cap



# Foundation Modeling

## Foundation Design Philosophy:

- Only two springs modeled to represent 48 micropiles per arch abutment
  1. Model micropiles in RM Bridge to accurately capture global bridge behavior
  2. Micropiles springs are assigned axial, lateral and rotational stiffness based on geotechnical recommendations
  3. Export design forces from RM Bridge to a SAP2000 shell model to capture local behavior of pile cap and micropiles



# Foundation Modeling

## Micropile Stiffness:

- Axial micropile stiffness determined for a max allowable settlement of 0.5 inches

t-z springs from GE

**Arch Abutment 2 (West Side of I-5)**

| Micropile Length, ft | z, in | | | t, lbs/in |
|---|---|---|---|---|
| | LE | BE | UE | |
| 0 to 6 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 164 |
| | 3 | 3 | 3 | 164 |
| 6.1 to 26 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 654 |
| | 3 | 3 | 3 | 654 |
| 26.1 t0 41 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 1309 |
| | 3 | 3 | 3 | 1309 |
| > 41 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 1745 |
| | 3 | 3 | 3 | 1745 |

**Arch Abutment 3 (East Side of I-5)**

| Micropile Length, ft | z, in | | | t, lbs/in |
|---|---|---|---|---|
| | LE | BE | UE | |
| 0 to 14 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 873 |
| | 3 | 3 | 3 | 873 |
| 14.1 to 35 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 1309 |
| | 3 | 3 | 3 | 1309 |
| > 35 | 0 | 0 | 0 | 0 |
| | 0.2 | 0.1 | 0.06 | 1745 |
| | 3 | 3 | 3 | 1745 |

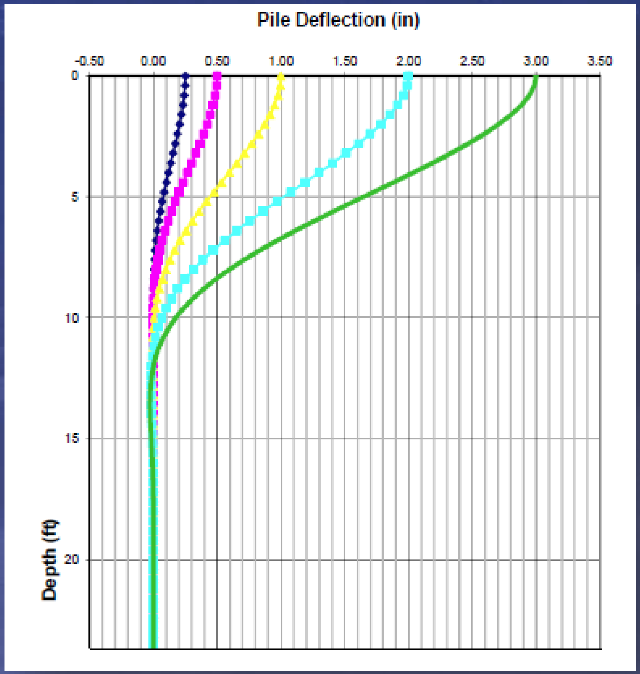
$$T = t * L_{trib}$$

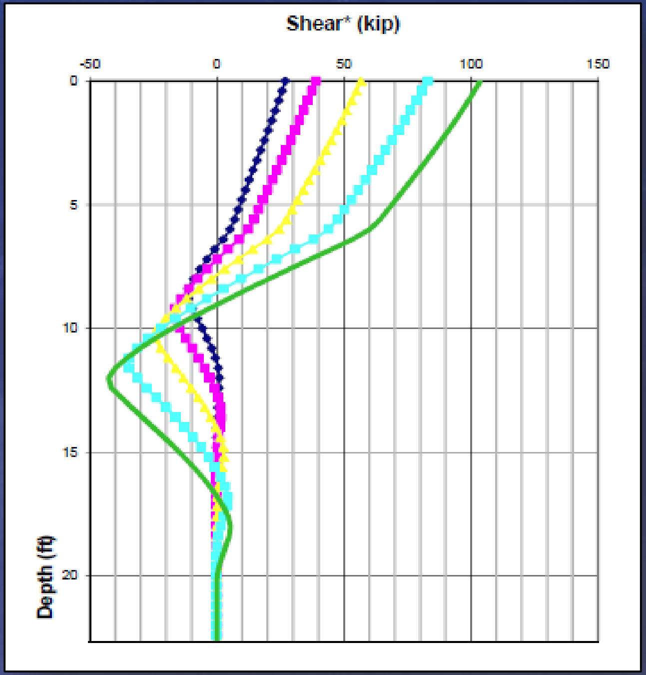
$$K = \frac{\Sigma T}{\Delta} \frac{12 \times n_{piles}}{1000}$$

# Foundation Modeling

## Micropile Stiffness:

- Lateral micropile stiffness determined from pile head deflections for a given shear force in LPile
- Iterate upon stiffness until output deflections converge with LPile runs

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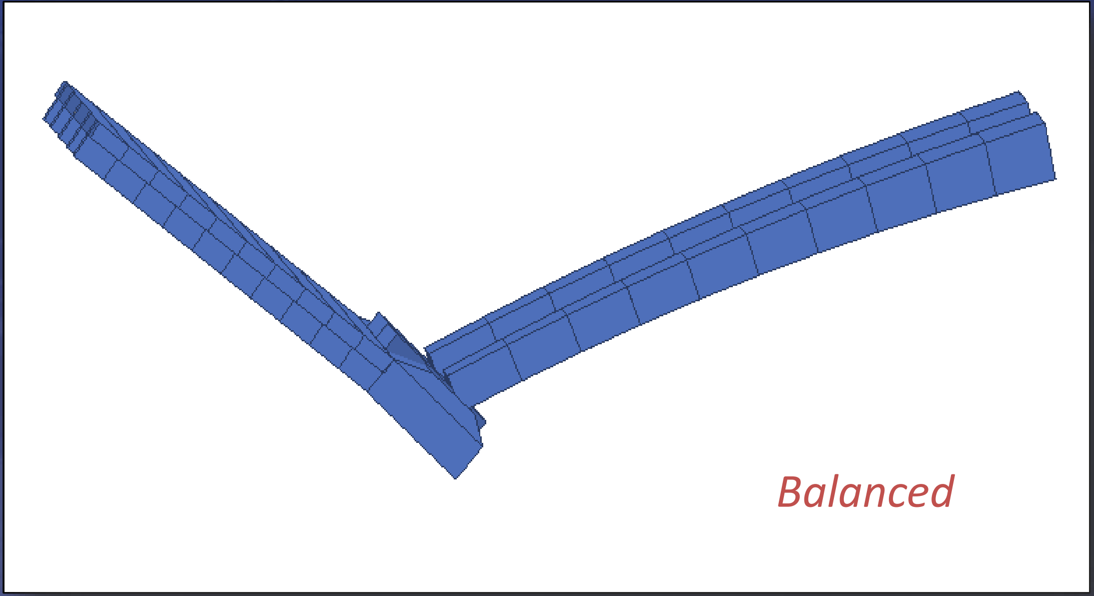
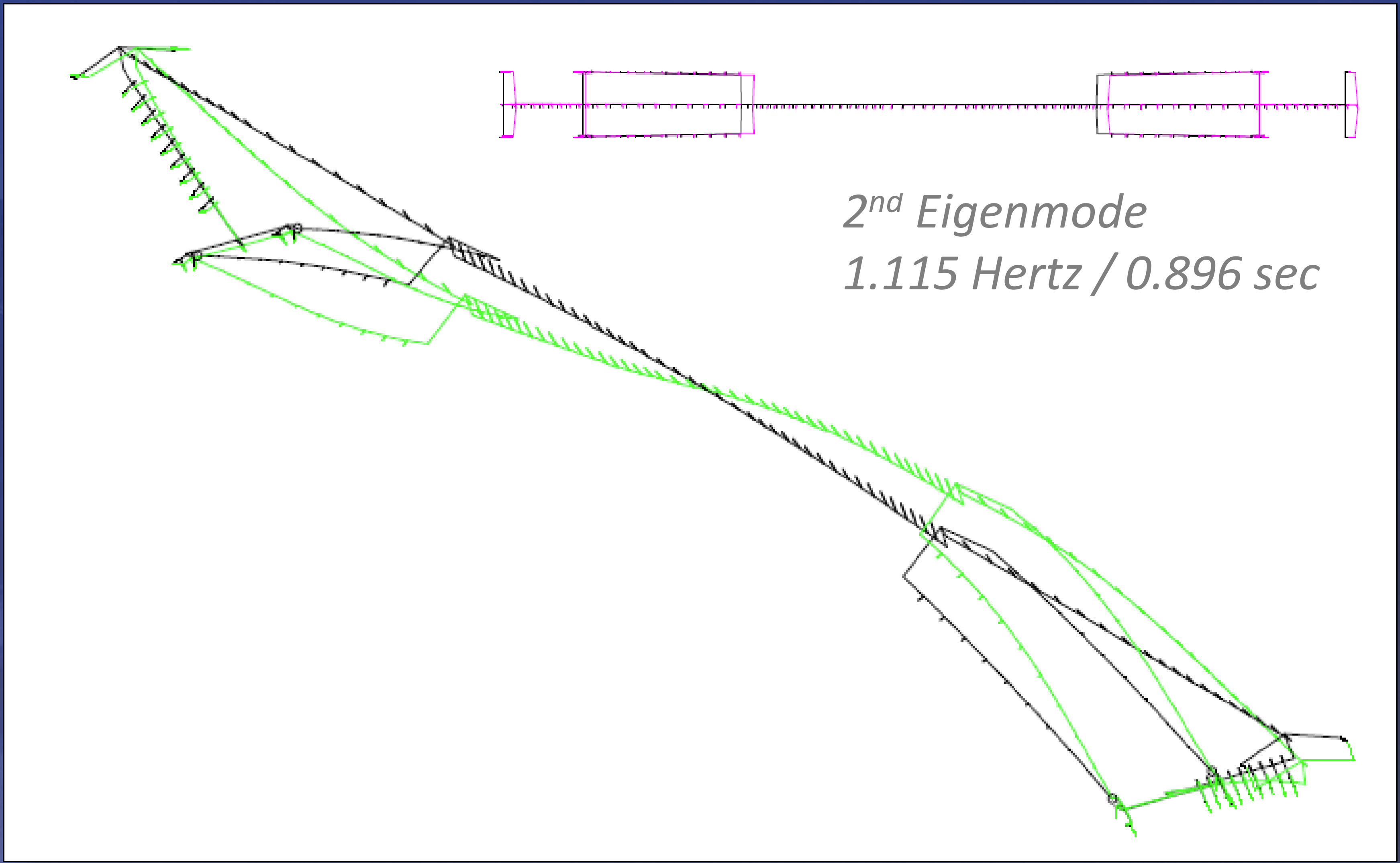
# Optimize Foundation

## Foundation Forces for Vertical Loads:

- Micropile inclination angle was choosen to minimize pile cap moment and shear under the service level load case
- High moments and shears indicate that the structure is not optimized



# RM Bridge Output

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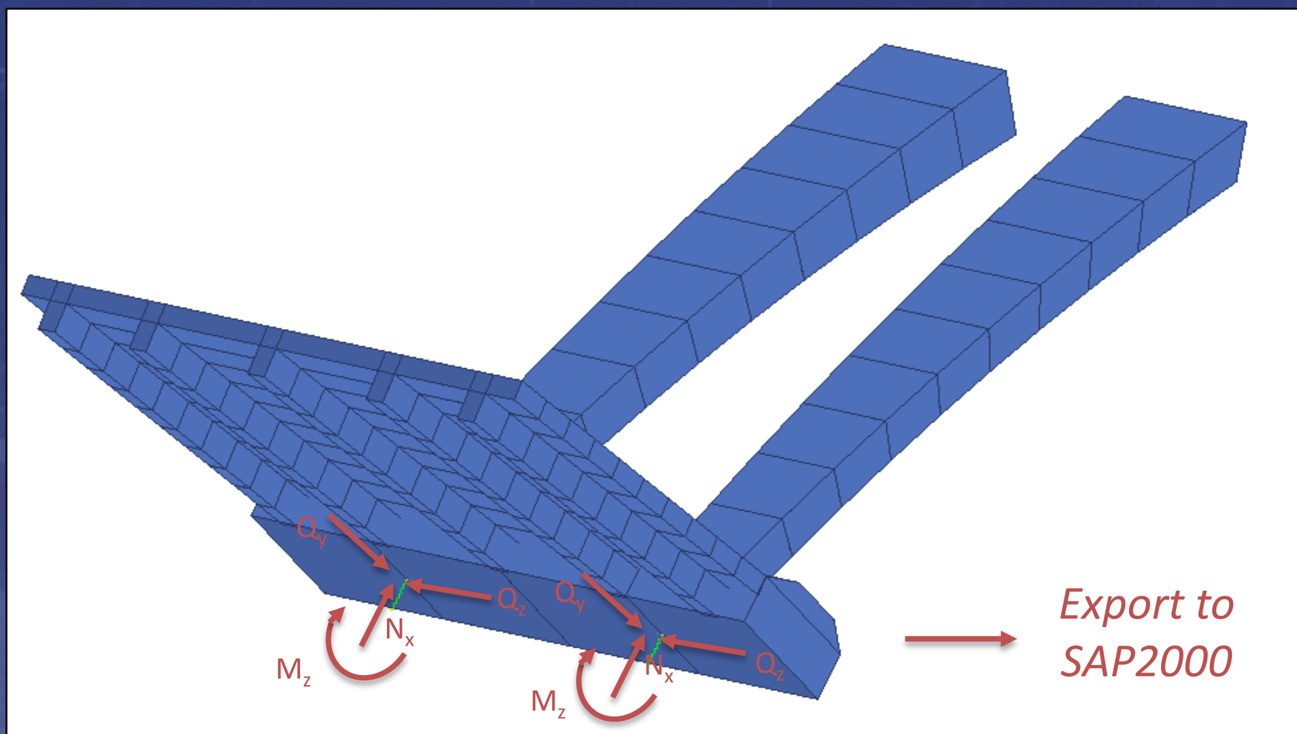
# RM Bridge Output

## Force Interaction:

- Micropile forces can be visualized acting on each foundation spring
- To capture the effect of these forces on the foundation we export to SAP2000

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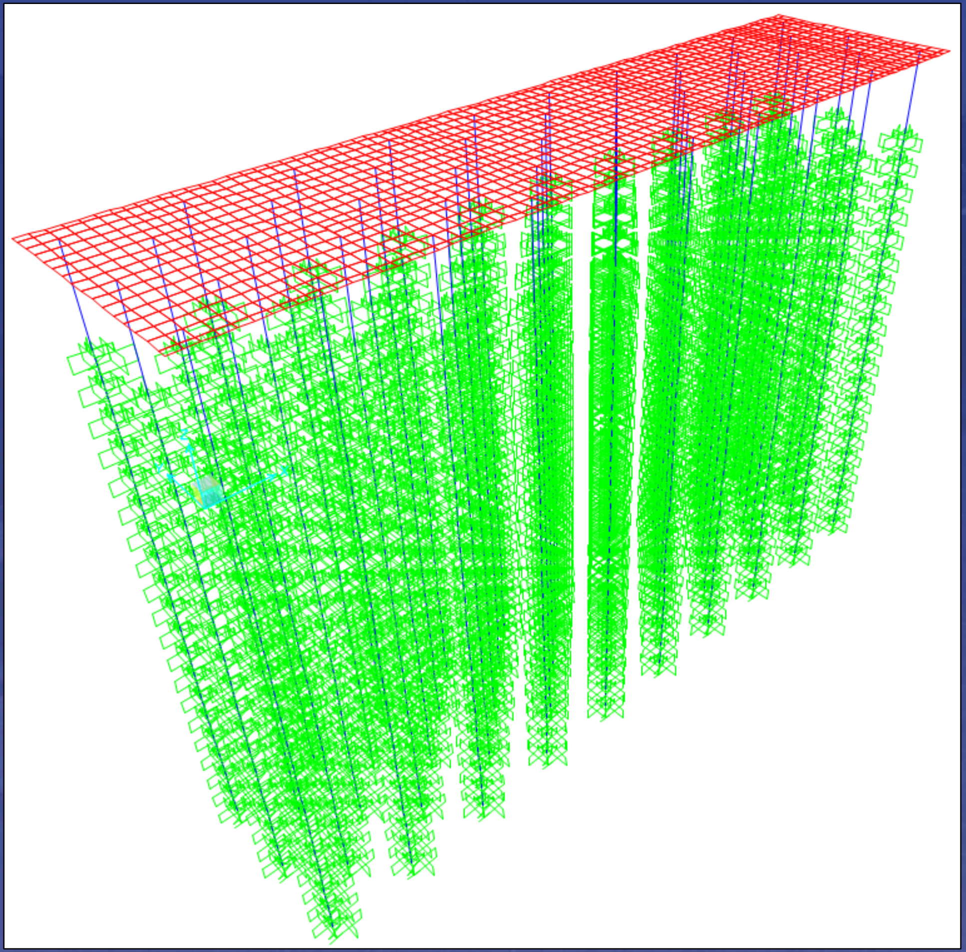
# Foundation Analysis

## SAP2000 Shell Model

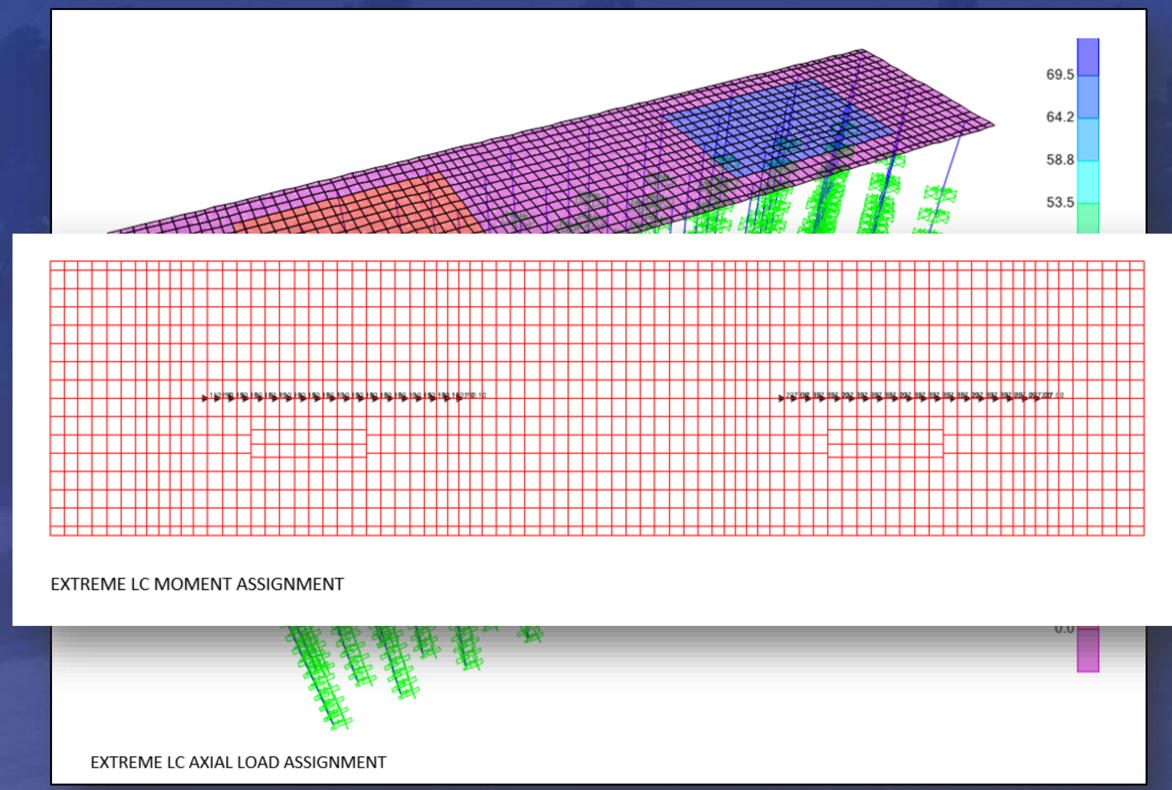
- Arch Abutments modeled as 6.5 ft. thick shell element with $f_c'$ = 3.6 ksi
- Micropiles modeled as frames with best estimate soil springs (p-y and t-z)
- Vertical & Extreme Event factored and service loads assigned from RM model
- Arch Abutment designed per AASHTO LRFD BDS w/ Caltrans amendments



# Foundation Analysis

## Load Application

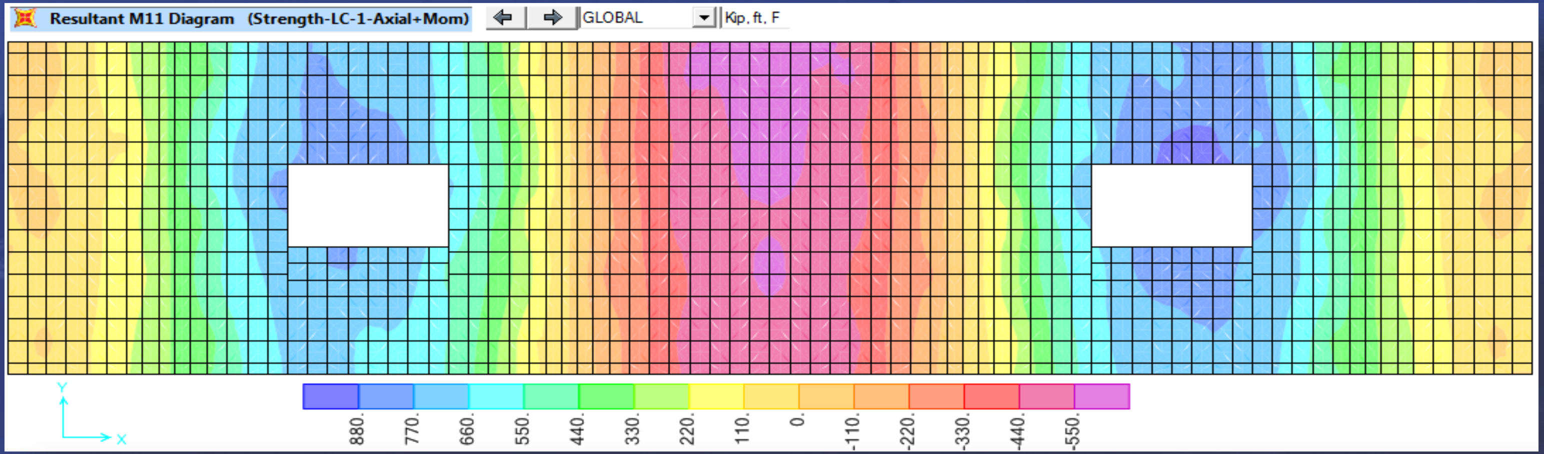
- Axial loads applied over an applied area
- Extreme case shown - one arch in tension, the other in compression
- Moments and shears modeled with a line load about the center of the arch rib

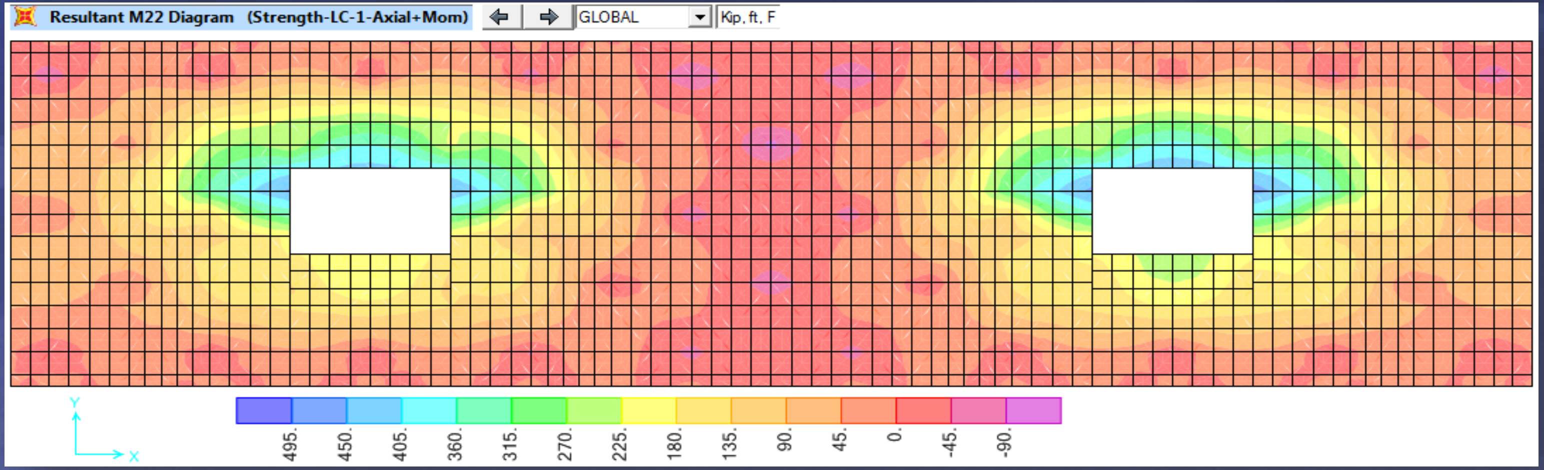


# Foundation Analysis

## Analysis Output of Arch Abutments (Strength Load)

*(East abutment shown, West similar)*

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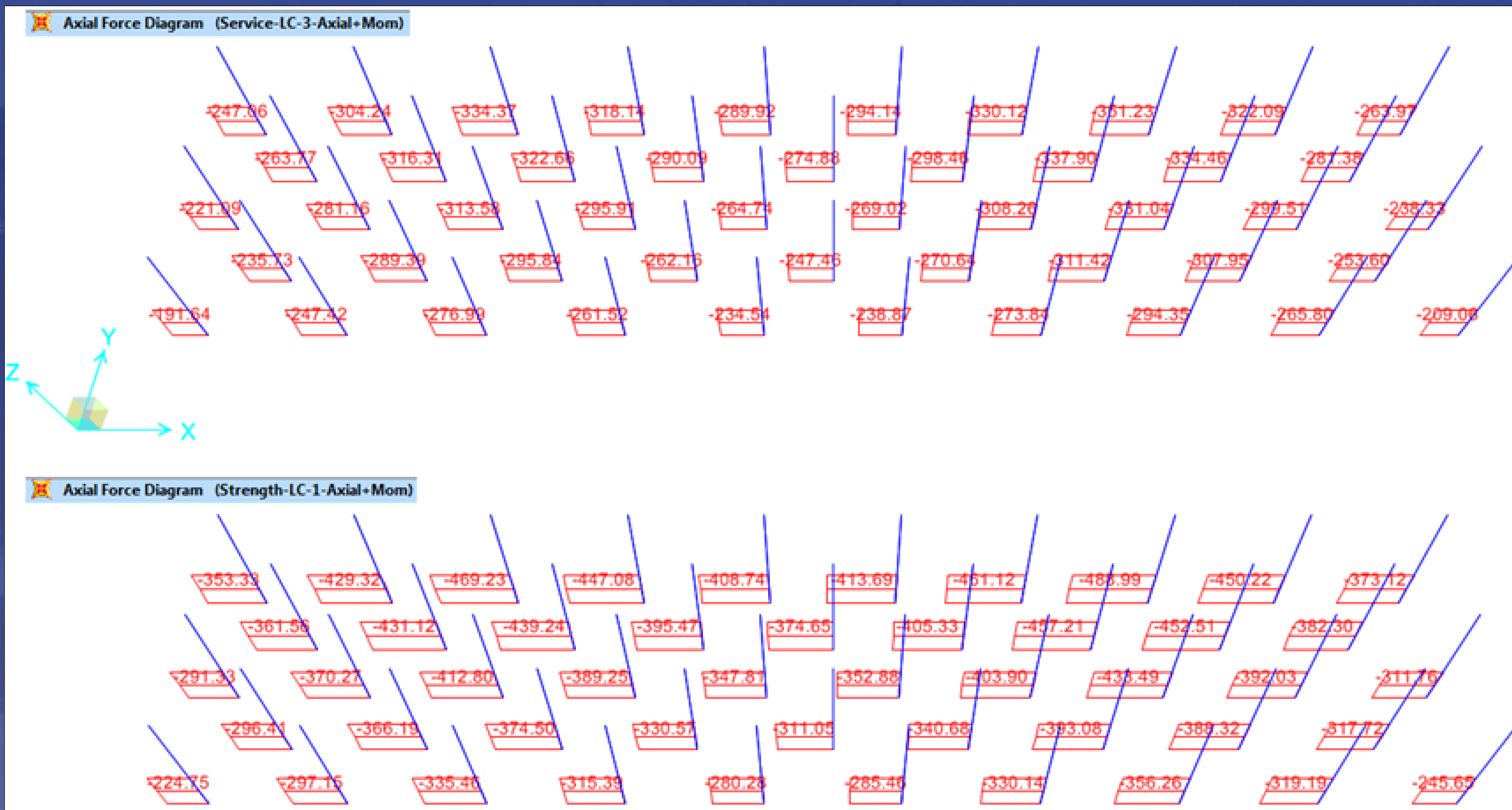
# Foundation Analysis

## Axial force distribution of Micropiles (Strength & Service Load)

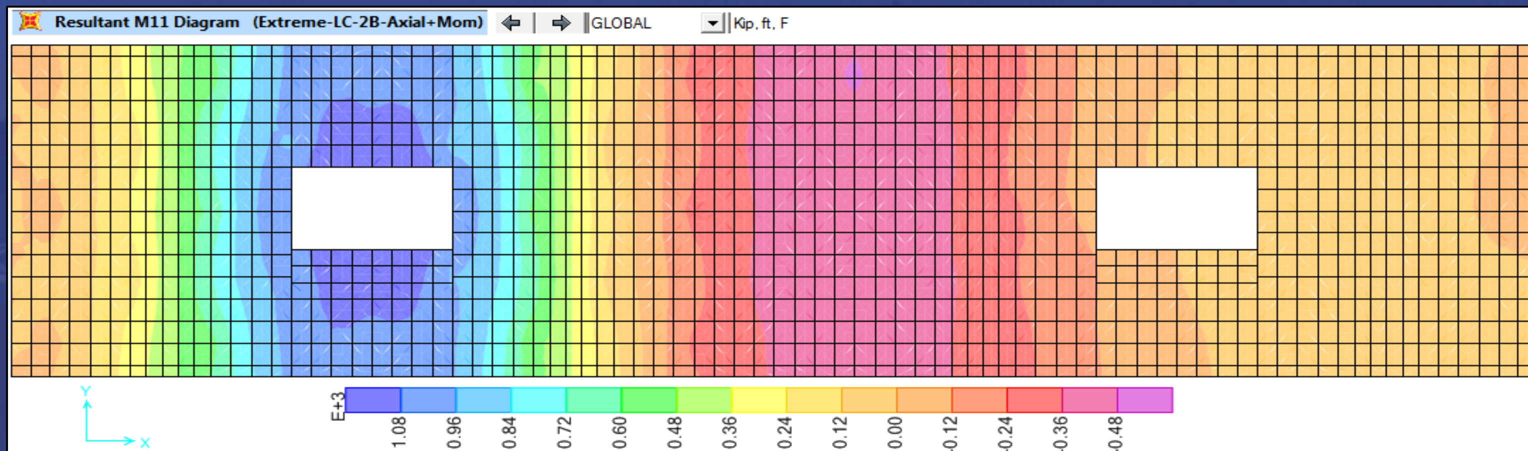
*(East abutment shown, West similar)*

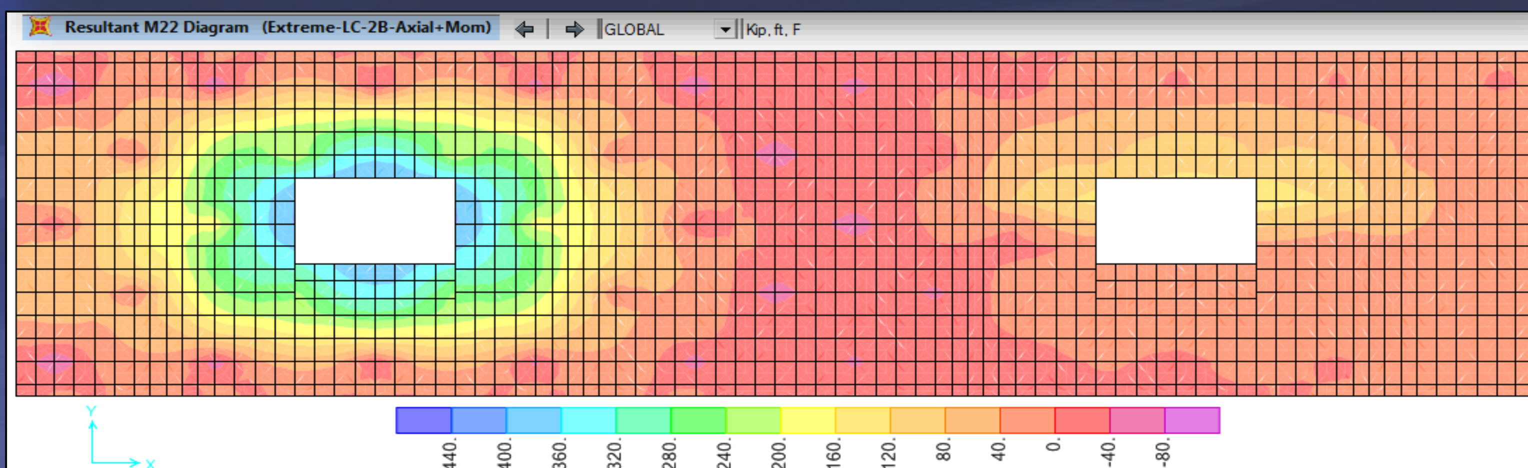


# Foundation Analysis

## Analysis Output of Arch Abutments (Extreme Load)

*(East abutment shown, West similar)*

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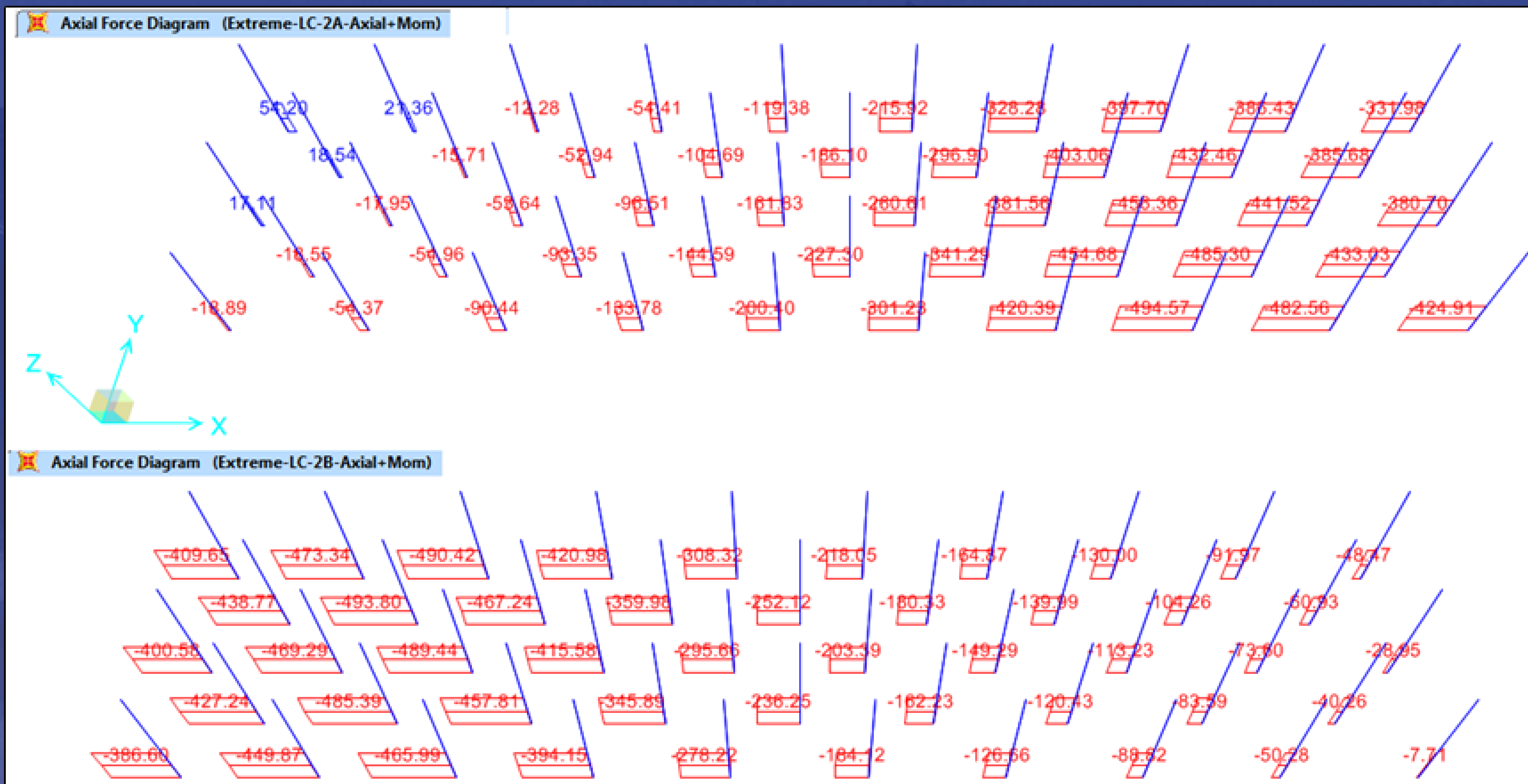
# Foundation Analysis

## Axial force distribution of Micropiles (Extreme Load)

*(East abutment shown, West similar)*

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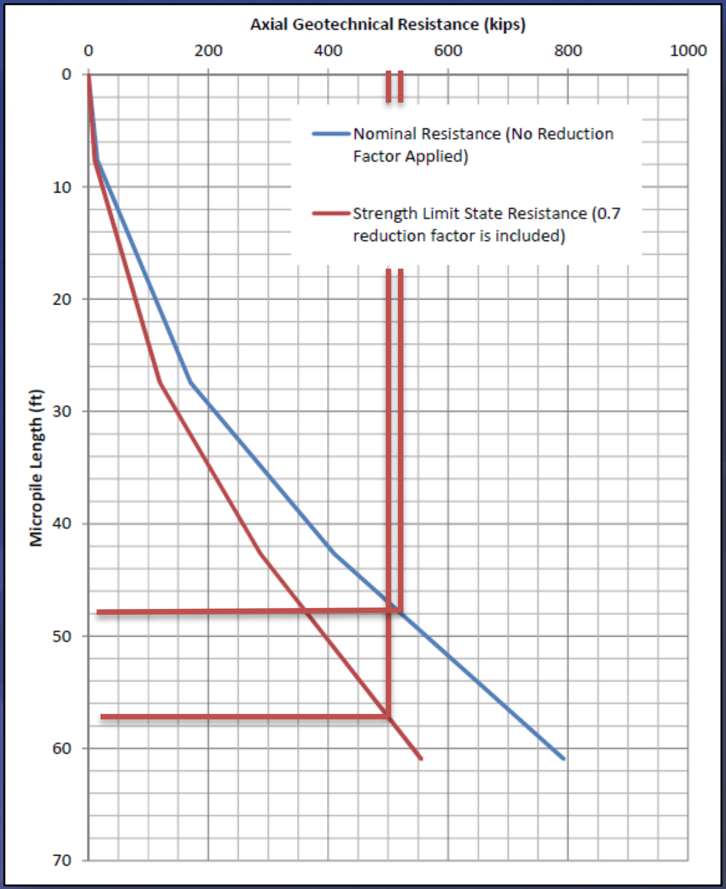
# Micropile Capacity

## Geotechnical Capacity (Axial Loads)

*Strength* (N = 489k)

*Extreme* (N = 535k)

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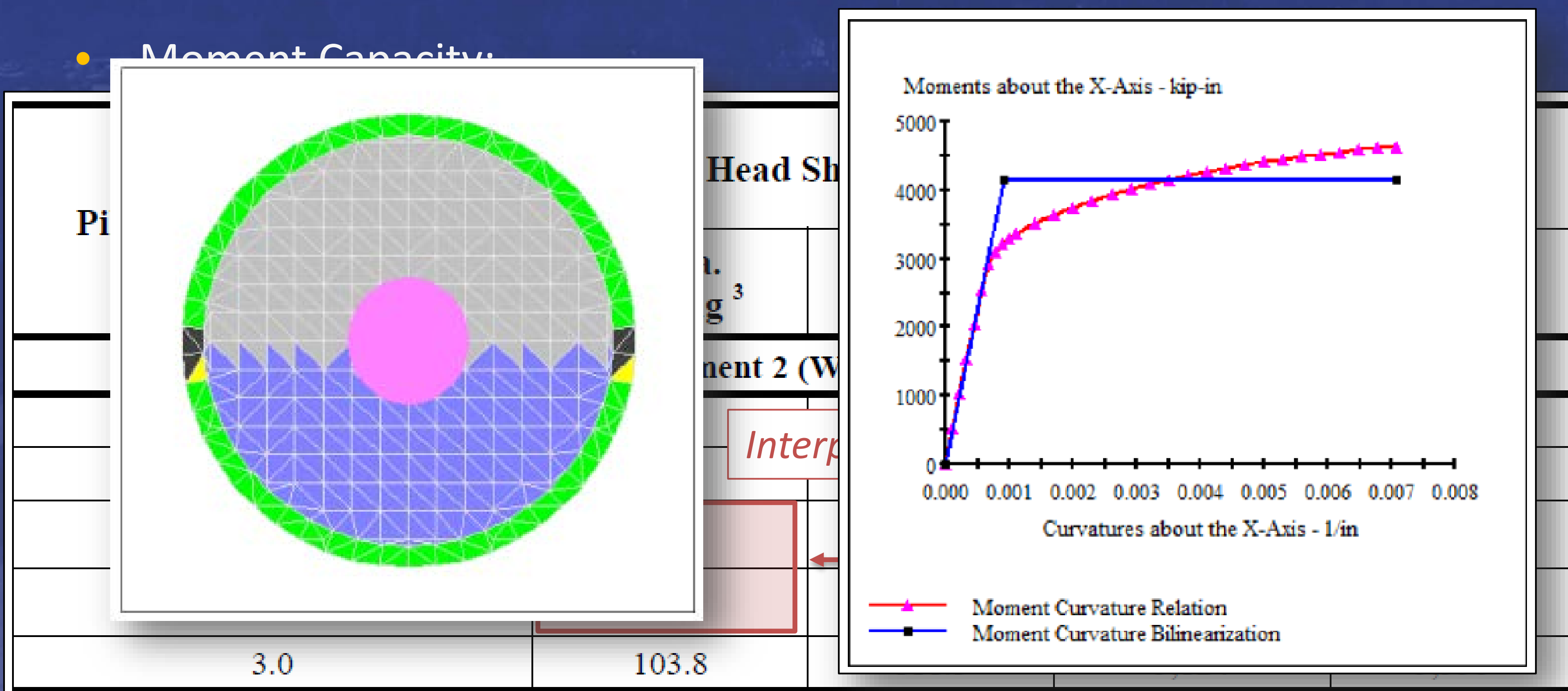
# Micropile Design

## Structural Capacity

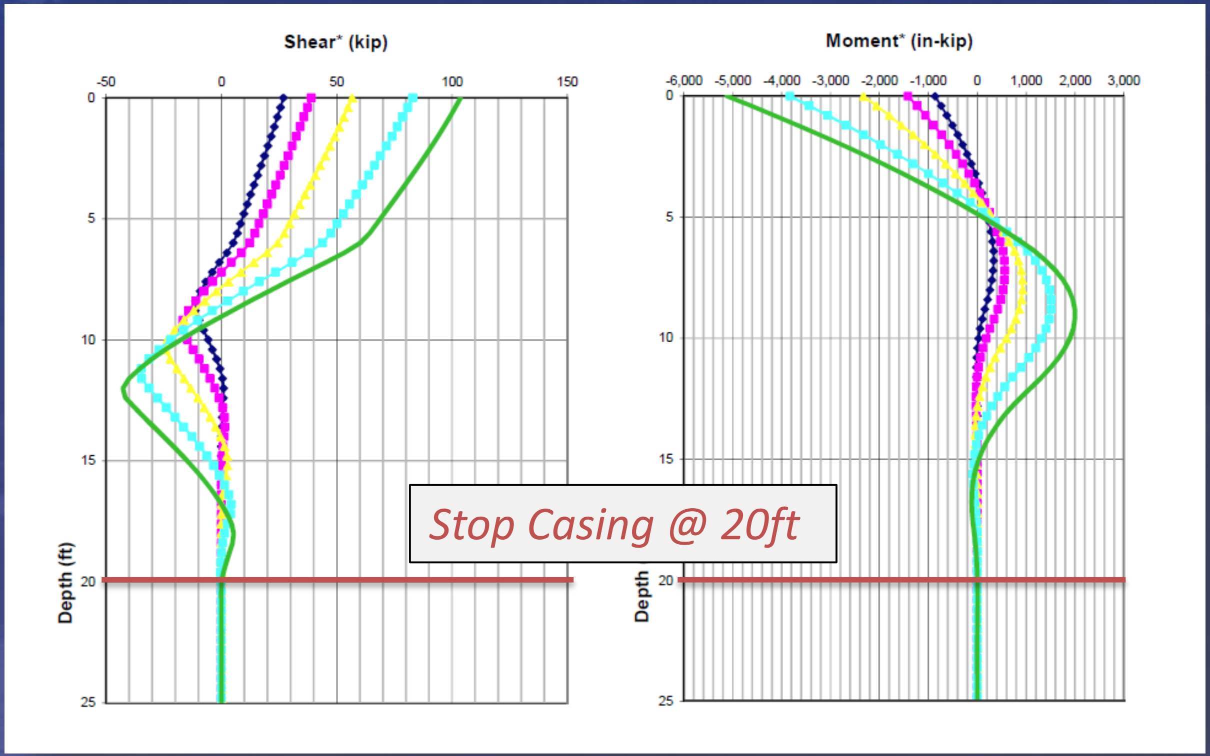
- Axial Capacity:
  - Consider Axial Capacity for Cased and Uncased Length
- Moment Capacity:



# Micropile Capacity

## Structural Capacity

- Drop structural casing when moments and shear disappear

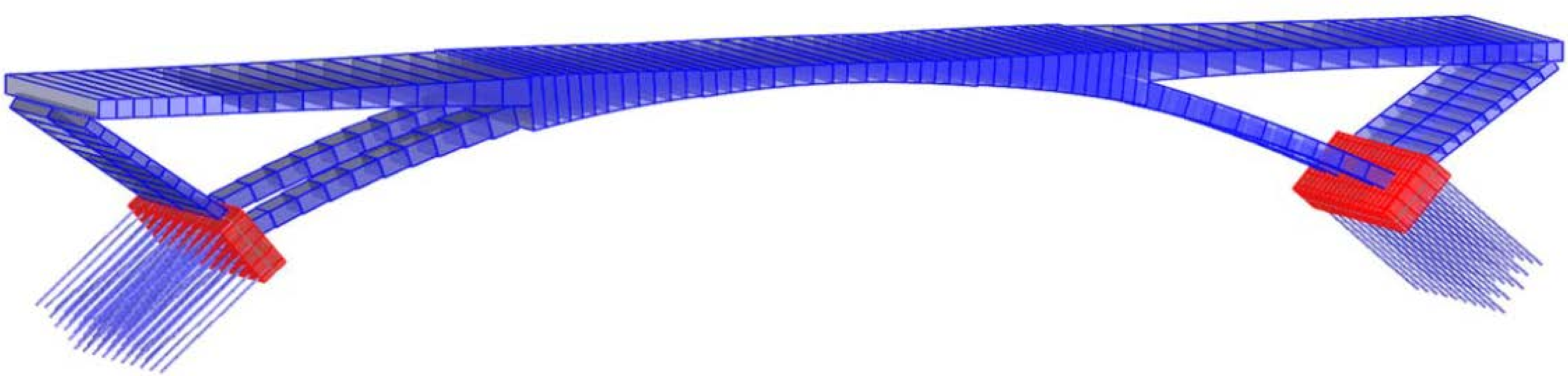


# Seismic Pushover Analysis

## SAP2000 Pushover Analysis – Micropiles Explicitly Modeled

- SAP2000 model incorporates each micropile into analysis – hinge properties based on XTRACT model
- Use SAP model to run longitudinal and transverse pushover

3D Iso View of Undeformed Model



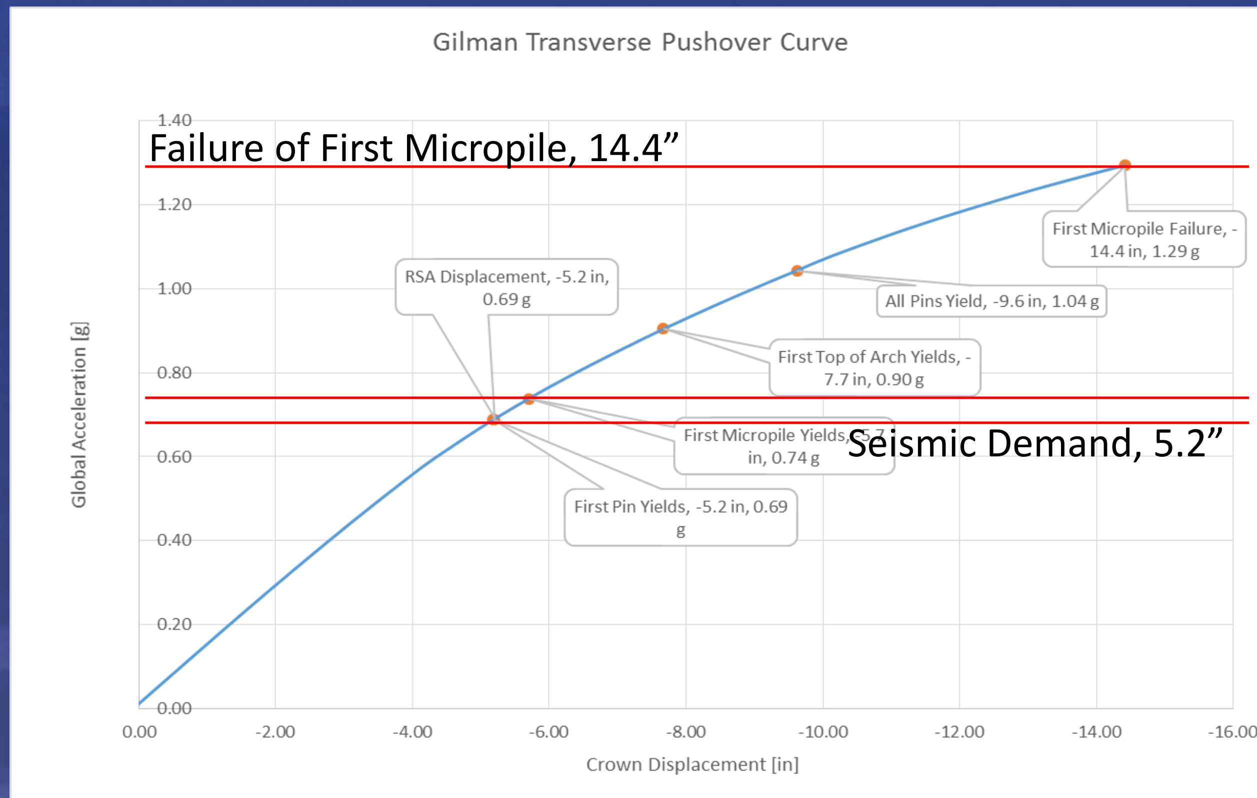
# SAP2000 Pushover Analysis

- Transverse pushover shown
- Corner piles yield first
- Twisting action of pile cap

# Seismic Pushover Analysis

## Transverse Pushover Results:

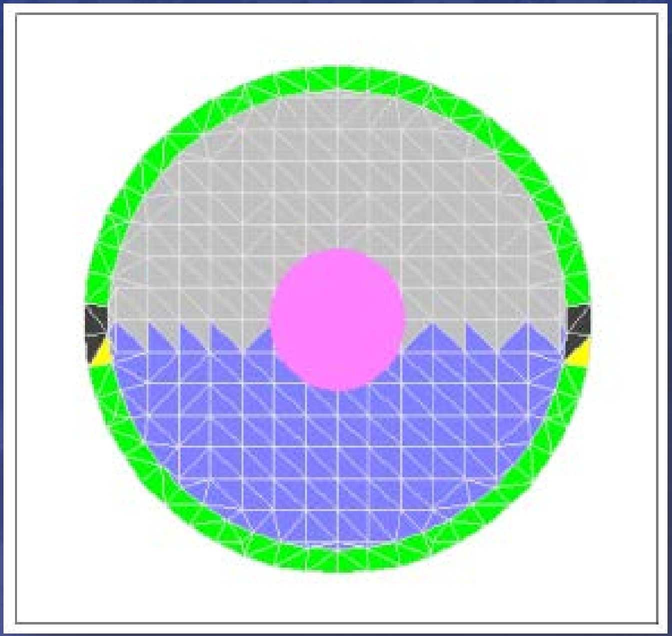
- Displacement Capacity vs. Demand = 14.4/5.2 = 2.8
- EQ would have to develop 2.8 times the intensity to fail one pile
- 96 piles
- Ductility Demand = 5.2/5.7 = 0.9 (Bridge stays elastic, no damage)
- SDC allows Ductility Demand of 5.0




# Structural Conclusions

## Advantages of Micropiles:

1. Stiffness
2. Axial Capacity
3. Strength in Numbers
4. Constructability
5. Versatility



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# Project Team

- UCSD - Project Management, Environmental
  Anka Fabian, Robin Tsuchida, Deborah Alto, Cathy Presmyk
- Caltrans – Design Oversight
  Arturo Jacobo, Kareem Scarlet, Shahbaz Alvi, Dave Stebbins, Norbert Gee
- Moffatt & Nichol – Civil, Roadway & Bridge Engineering
  Tony Sánchez, Perry Schacht, Victor Tirado, Mitch Duran, Debbie Ramirez, Arash Monsefan, Garrett Dekker, Elena Pleshchuk, Gernot Komar, Jason Hong, Bob Dameron, Al Ely, Patrick Chang, Amanda Del Bello
- Safdie Rabines Architects – Architecture
  Eric Lindebak, Brer Marsh, Ricardo Rabines
- Earth Mechanics – Geotechnical Engineering
  Eric Brown, Patrick Wilson

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*Thank You*

# *Questions?*

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