Modeling & Design of the Gilman Drive Overcrossing Foundations

Presented by:

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Gilman Drive Bridge

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

Engineer of Record: Tony Sánchez, PhD, PE

Geotechnical Engineer: Eric Brown, GE

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
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
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
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

- 4 Borings
  - 2 End Abutments
  - 2 Arch Abutments
- Downhole P&S wave logging
- Pressuremeter testing
Geotechnical Considerations
Field Investigation

• 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

- 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

Reference Points for UC Strength:
- Stiff Clay ~ 30 psi
- Granite ~ 20,000 psi
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
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
1. Connect abutment to arch foundation with inclined strut

2. Use micropiles in lieu of slurry backfill
A strut was added between the superstructure and foundation to reduce arch thrust.
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
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
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
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

\[
T = t \times L_{trib}
\]

\[
K = \frac{\sum T \times 12 \times n_{piles}}{\Delta \times 1000}
\]
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

![Plot of Pile Deflection vs Depth and Shear vs Depth](image-url)
Optimize Foundation

Foundation Forces for Vertical Loads:

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

Balanced
Inclusion of struts stiffen the structure transversely and longitudinally.

The structure is expected to remain elastic during the seismic event.

Foundation Design:
1. Run response spectrum analysis (RM Bridge) in the longitudinal and transverse and combined directions – record pile forces
2. Run pushover (SAP2000) to push the bridge beyond elastic limit to ensure ductile behavior of structure

1st Eigenmode
1.013 Hertz / 0.987 sec

2nd Eigenmode
1.115 Hertz / 0.896 sec
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

Export to SAP2000
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)
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)
Foundation Analysis

Axial force distribution of Micropiles (Extreme Load)
(East abutment shown, West similar)
Micropile Capacity

Geotechnical Capacity (Axial Loads)

**Strength** \((N = 489k)\)

**Extreme** \((N = 535k)\)
Micropile Design

Structural Capacity

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

- **Moment Capacity:**
  - Ensure the piles remain elastic – $\phi M_n$ determined from XTRACT
  - Interpolate Moment
Micropile Capacity

Structural Capacity

- Drop structural casing when moments and shear disappear

Stop Casing @ 20ft
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 Undefomed Model
Seismic Pushover Analysis

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
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
Thank You

Questions?