Design Complexities of CIP/PS Slab Bridges

Presidio Parkway Project

Western Bridge Engineering Conference

September 4-6, 2013

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Presidio Parkway

- Project Overview:
  - History and Phases
  - Architecture
  - Environmental

- Main Structural Elements
  - Tunnels (cut & cover)
  - Bridges (CIP/PS Slab, CIP/PS Box Girder)

- Structural Design Considerations
  - Accommodation of Architectural Requirements
  - Balanced Stiffness & P-Delta Effect
  - Liquefaction Mitigation (Use of CDSM)
  - Scour Analysis
  - Construction Sequencing

PRESIDIO PARKWAY

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History & Phases

- Seismically and structurally deficient structures needed replacement
- Improving safety evacuation routes
- Providing direct access to the water front
- Restore greenbelt for transportation safety on Hwy 1 and local streets (use of local plants, national park preservation)
- Complying with regulations and requirements of Presidio Trust of SF

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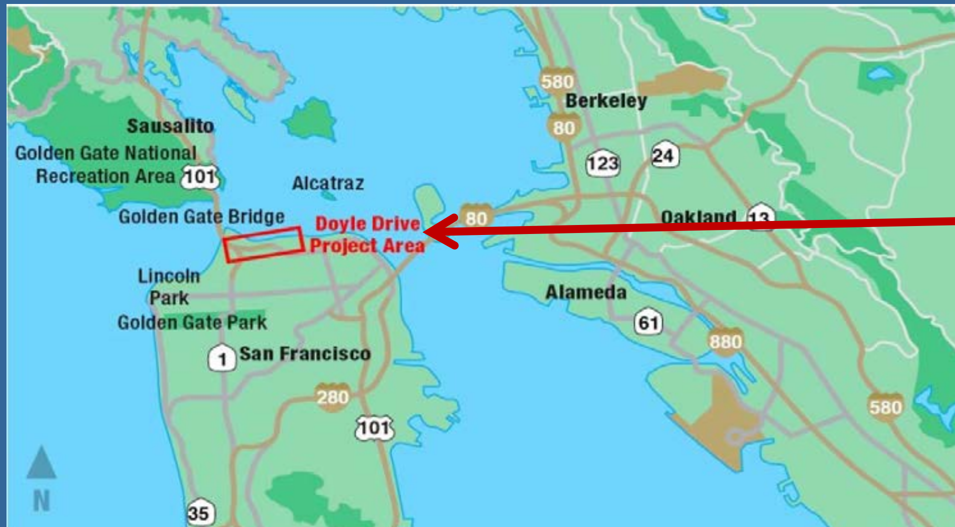
History & Phases (Cont.)

- Partnership

Project Overview and Limits



South Approach to Golden Gate –
About 1.6 miles long

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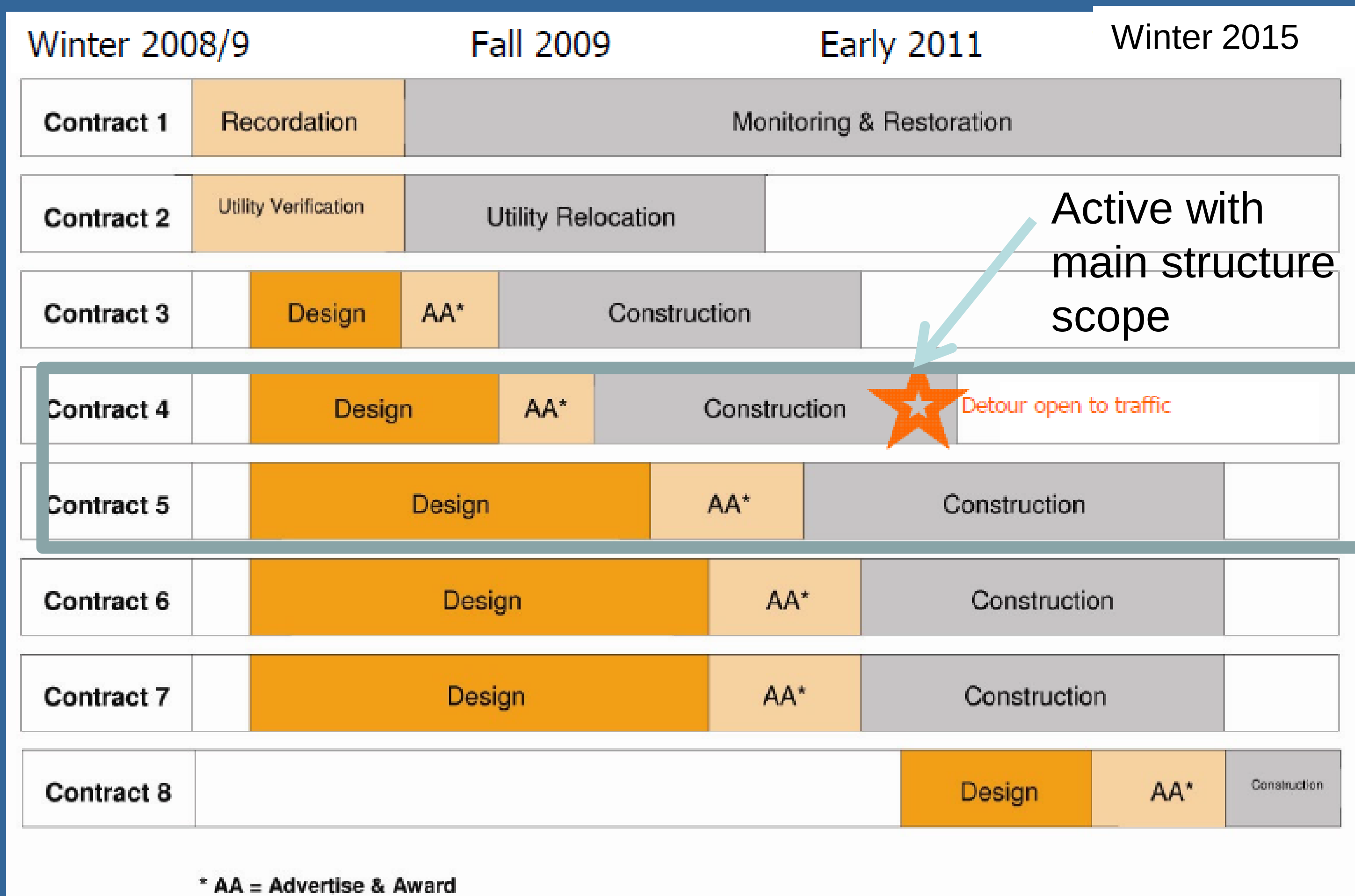
History & Phases (Cont.)

- Project performed in 8 contracts



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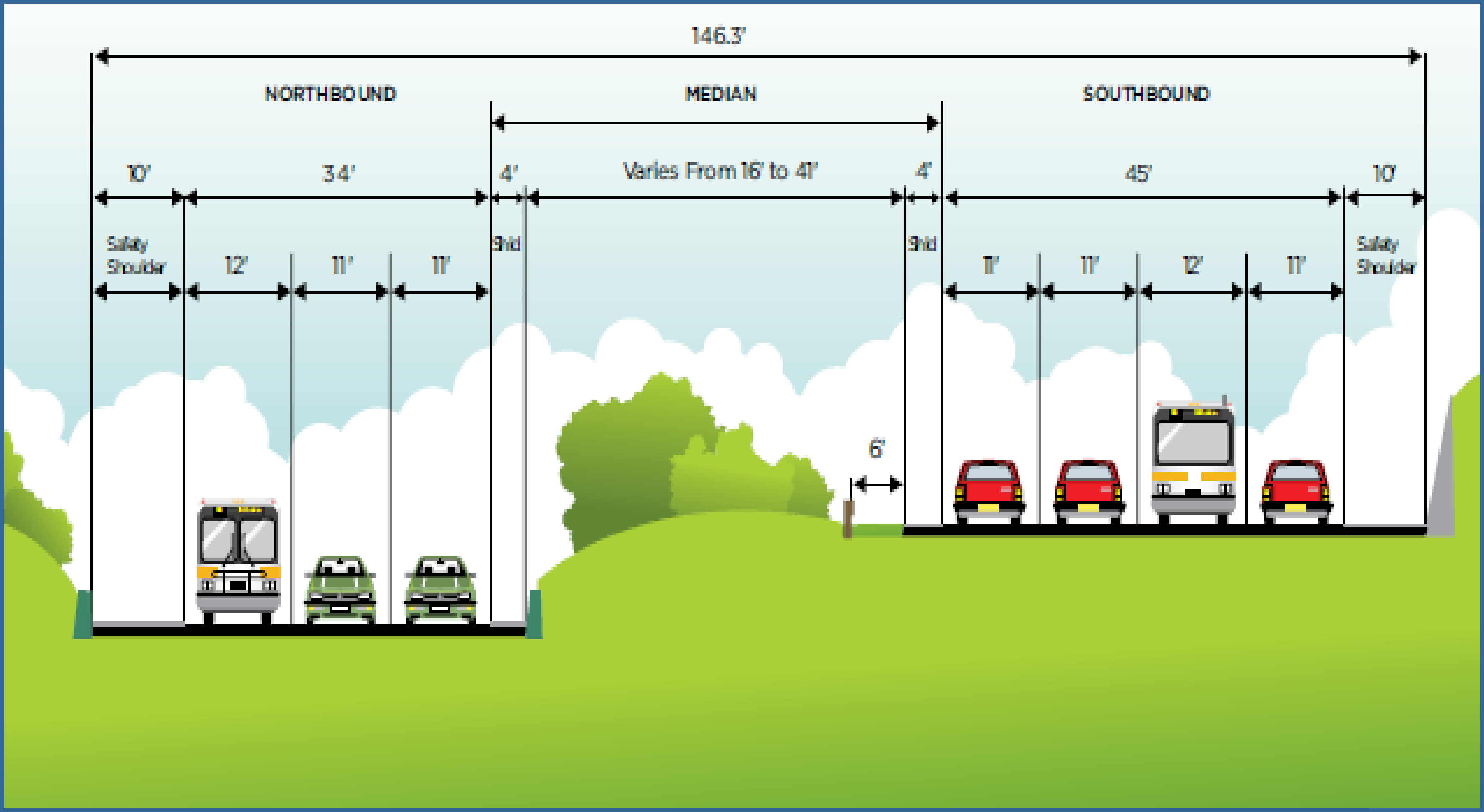
History & Phases (Cont.)

- Contract 4 awarded to Flatiron-Kiewit-HNTB team in Sept. 2011
- Over $1.2 billion total construction cost
- First P3 contract in California
- To be completed in 2015
- Multiple stakeholders
- Challenging site (liquefaction, tsunami, …)
- Environmentally and aesthetically sensitive
- Historically and socially sensitive
- Strict construction sequencing

At Grade Section



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Architecture

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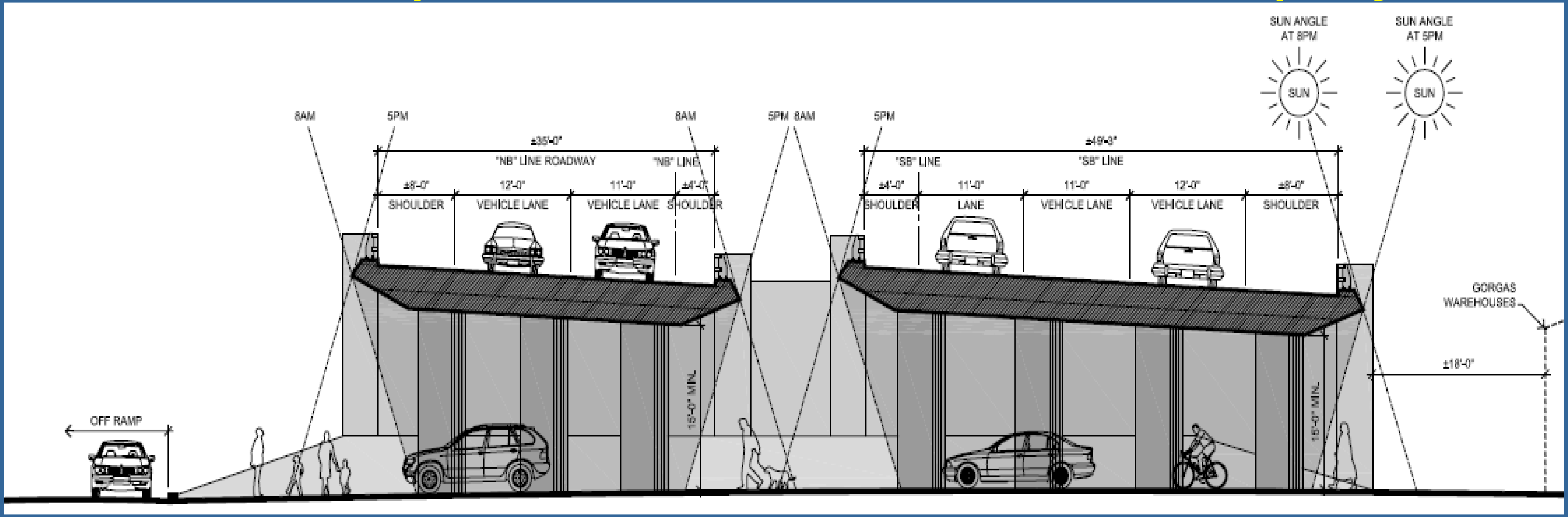
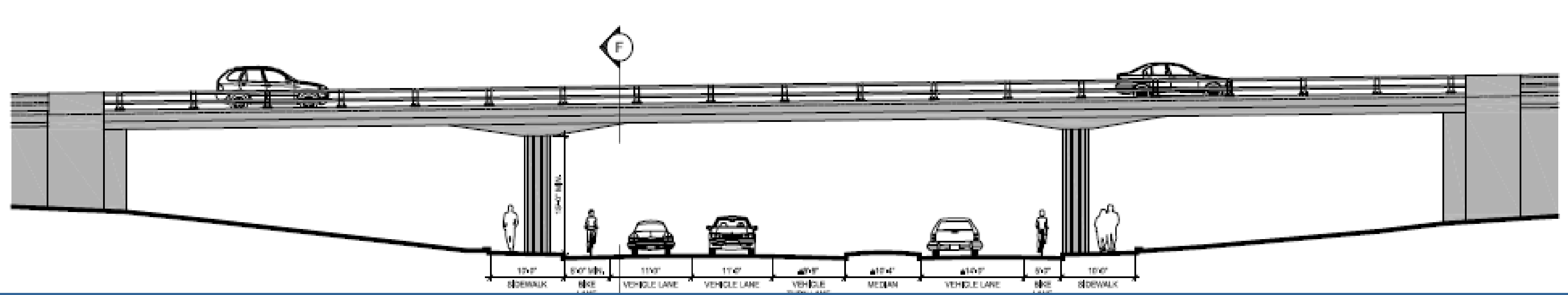
Architecture

- Landscape and Architecture driven project





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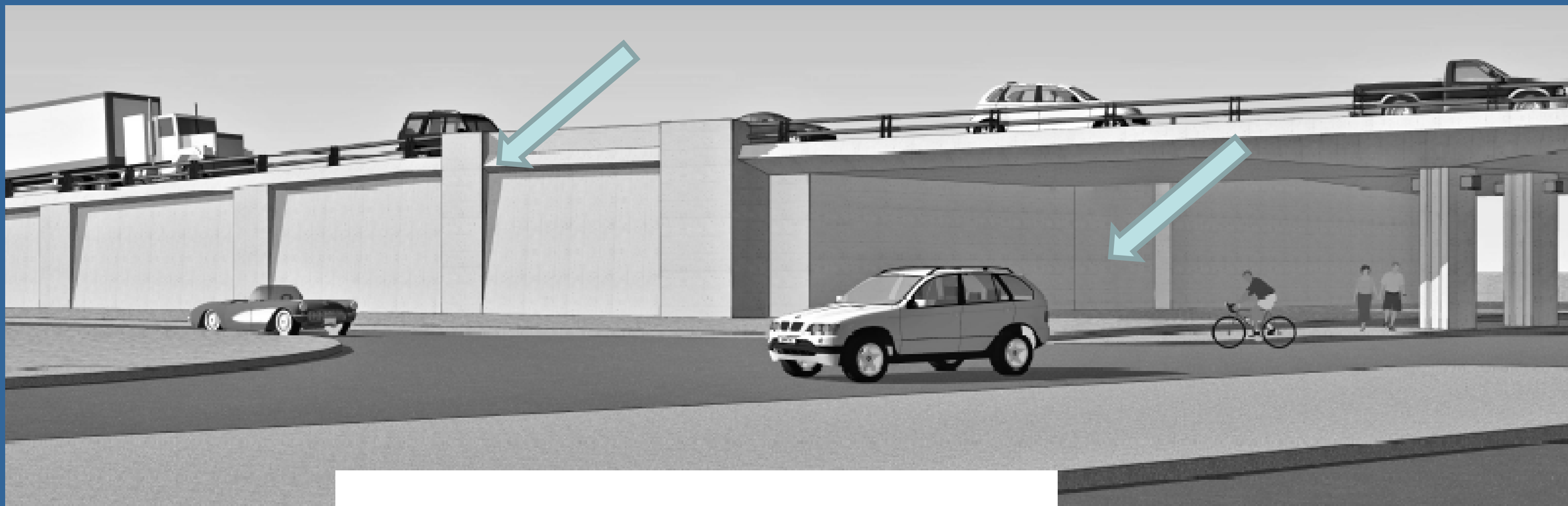
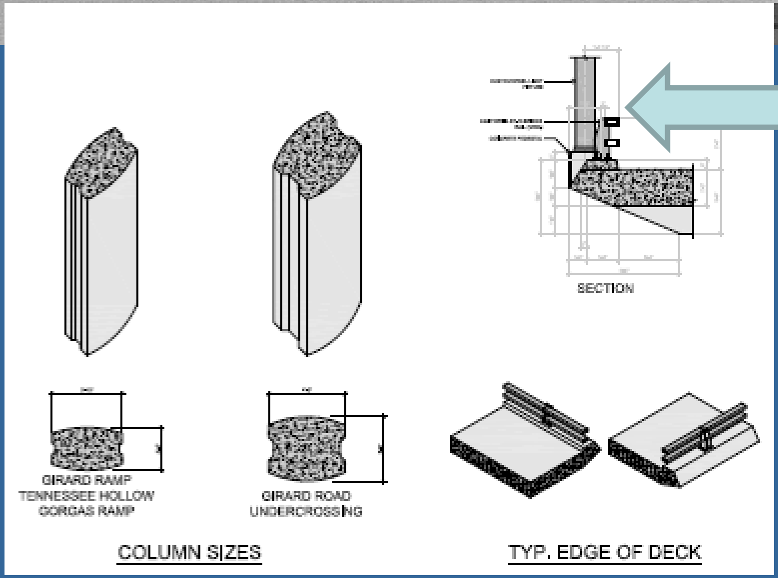
Architecture (Cont'd)





Use of international orange color to match Golden Gate

Architecture (Cont'd)

- Historic Preservation of Existing Bldgs.

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Demolition

Photo from Caltrans

Environment

- Close to a major body of water
- High water table
- Sensitive environment (native plants, migratory birds)
- In the heart of Presidio National Park and National Cemetery
- Sensitive Natural aquifers that should not be punctured under bridge structure piles

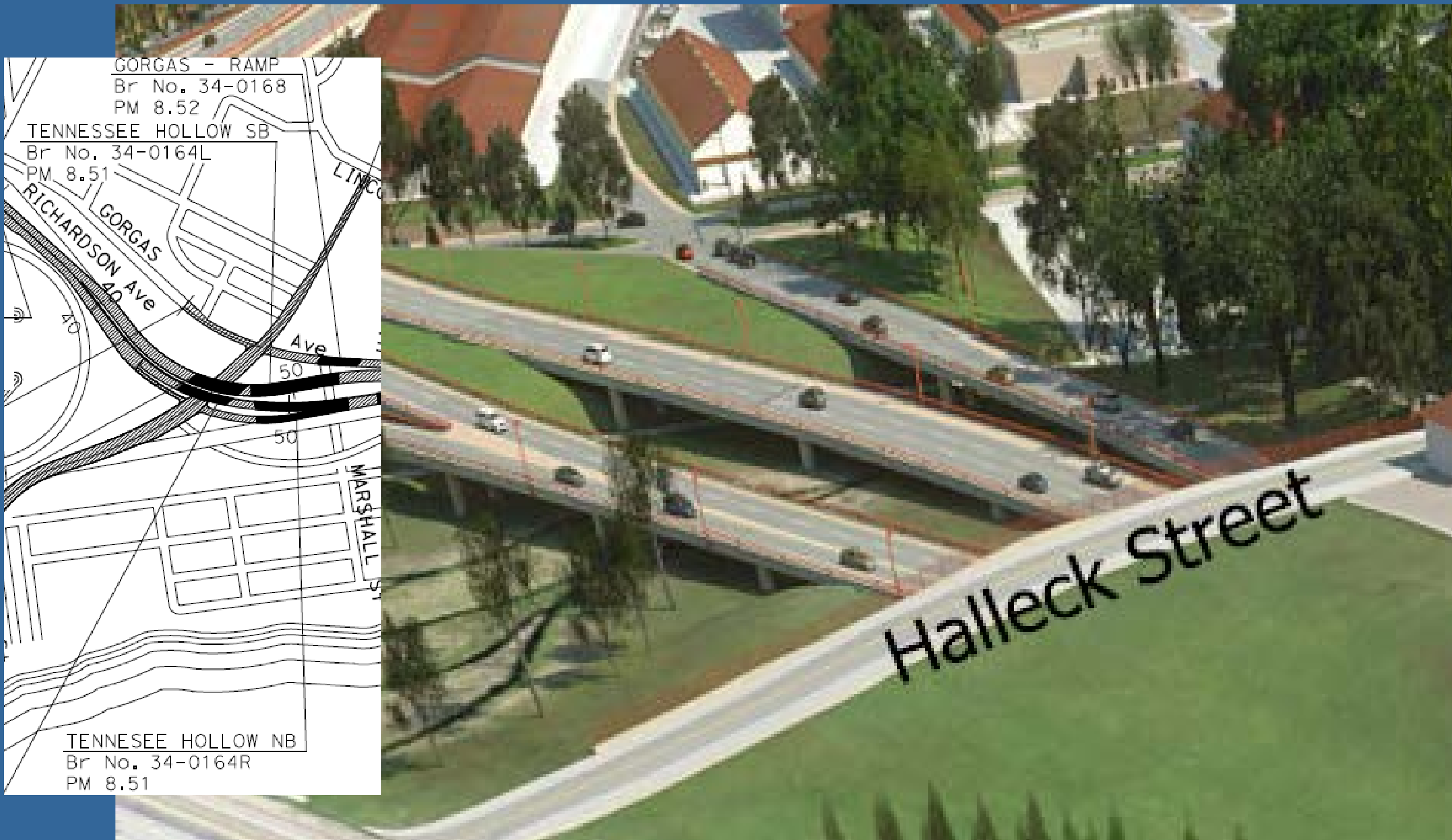
Main Structural Elements

- Bridges
  - High Viaduct (CIP/PS Box Girder)
  - Veteran Off-Ramp (CIP/PS Box Girder)
  - Tennessee Hollow Bridges (CIP/PS Solid Slabs) – 3 bridges
  - Girard UC (CIP/PS Solid Slabs) – 2 bridges
- Tunnels
  - Main Post Tunnels (cut & cover) – 2 tunnels
  - Northbound Battery Tunnel (cut & cover)

Total of 7 bridges and 3 tunnels

Main Structural Elements (Cont'd)

- Tennessee Hollow Bridges



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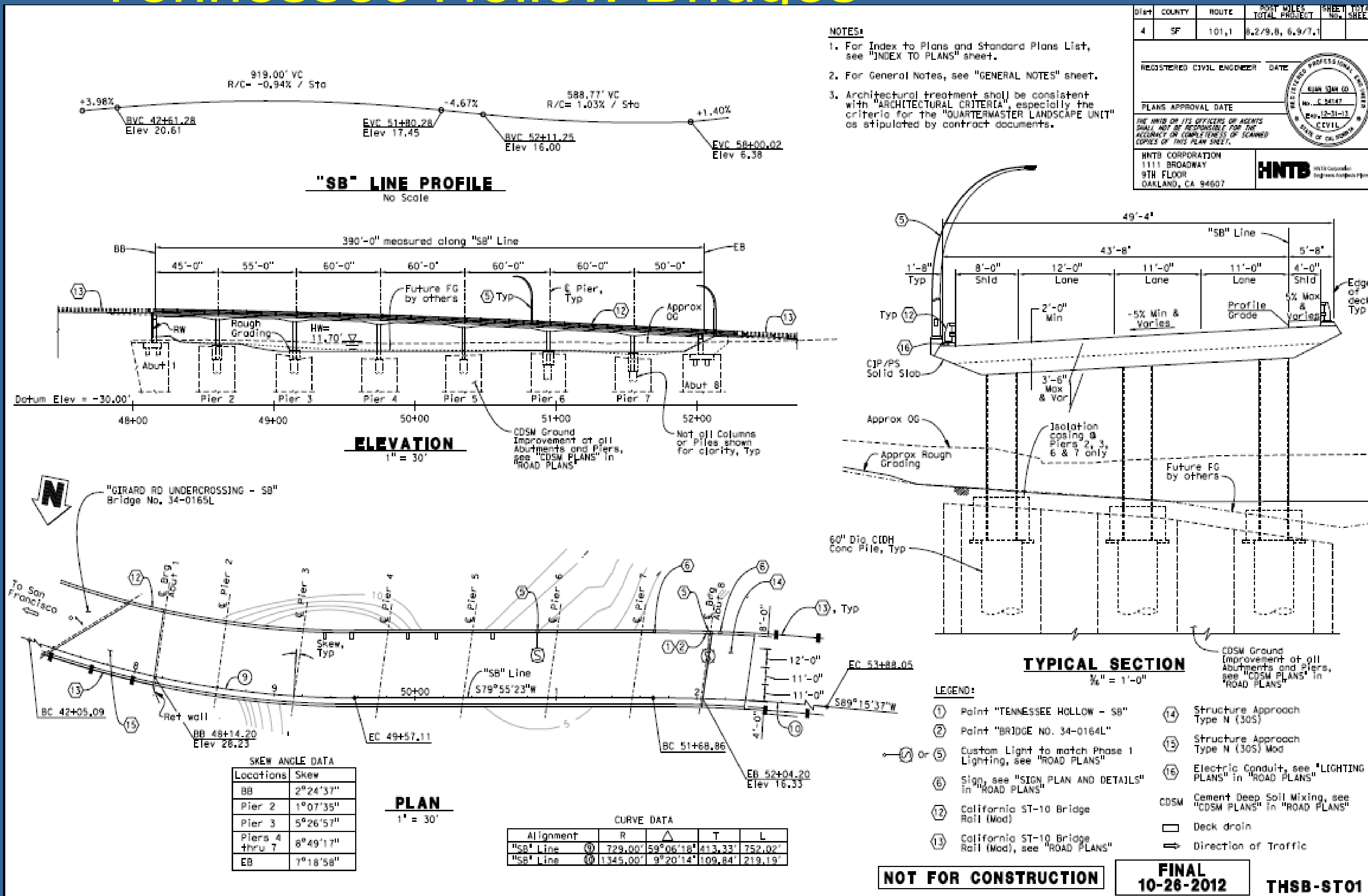
Main Structural Elements (Cont'd)

- Tennessee Hollow Bridges



Seismic Design Criteria

PROJECT SPECIFIC SEISMIC DESIGN CRITERIA

PERFORMANCE MEASURES

Design Earthquake	Performance Level
Functionality Evaluation Earthquake (FEE)	Functionality performance level Repairable-to-serviceable damage, with or without traffic restrictions Immediate access to emergency vehicles following inspection
Safety Evaluation Earthquake (SEE)	Safety performance level Significant damage/No-Collapse: life safety assured Limited service

Safety Evaluation Earthquake (SEE)

Envelope of the median (50th percentile) deterministic Maximum Credible Earthquake (MCE) ARS and a probabilistic hazard ARS for an event with a mean return period of 1,000 years (i.e., 7.5% probability of exceedance in 75 years).

Functionality Evaluation Earthquake (FEE)

A probabilistic hazard ARS for an event with a mean return period of 108 years (i.e., 50% probability of exceedance in 75 years).

Seismic Analysis and Evaluations

Displacement Demand:

Response Spectrum Analysis

Displacement Capacity:

Inelastic Static Analysis

ALLOWABLE CONCRETE STRAIN

Performance Goal	Allowable Concrete Strain
Functional performance	0.005
Safety/No-Collapse performance	67% ϵ_{cu}^{+}

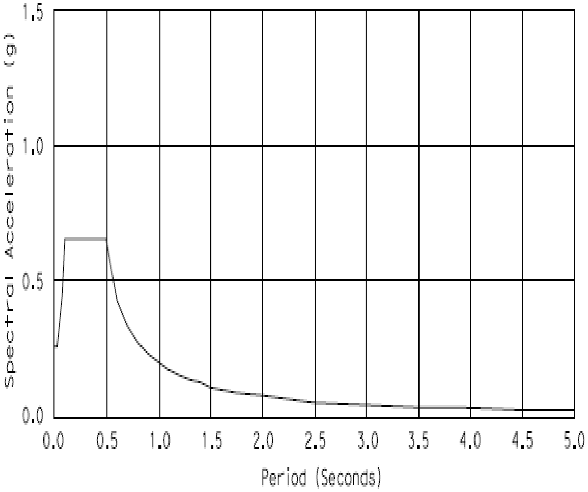
+ Ultimate Concrete Strain (ϵ_{cu}) considering confinement of the concrete core

ALLOWABLE STEEL STRAIN

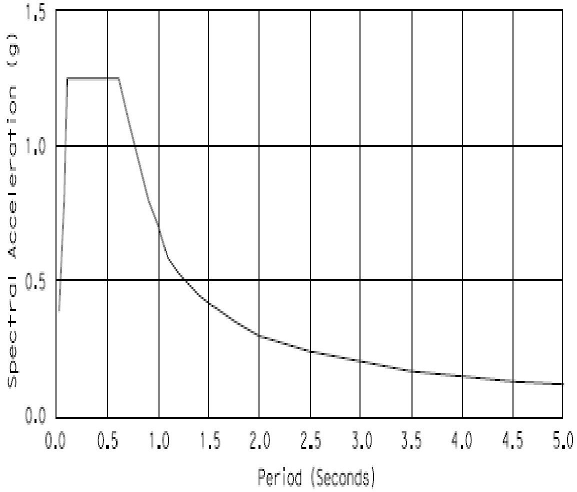
Performance Goal	Reinforcement Size	Allowable Steel Strain#
Functional performance	#10 Bars and Smaller	50% ϵ_{su}
	Bars Larger Than #10	50% ϵ_{su}
Safety/No-Collapse performance	#10 Bars and Smaller	67% ϵ_{su}
	Bars Larger Than #10	67% ϵ_{su}

Maximum Steel Strain #10 Bars and Smaller ϵ_{su} = 0.12

Maximum Steel Strain Bars Larger Than #10 ϵ_{su} = 0.09

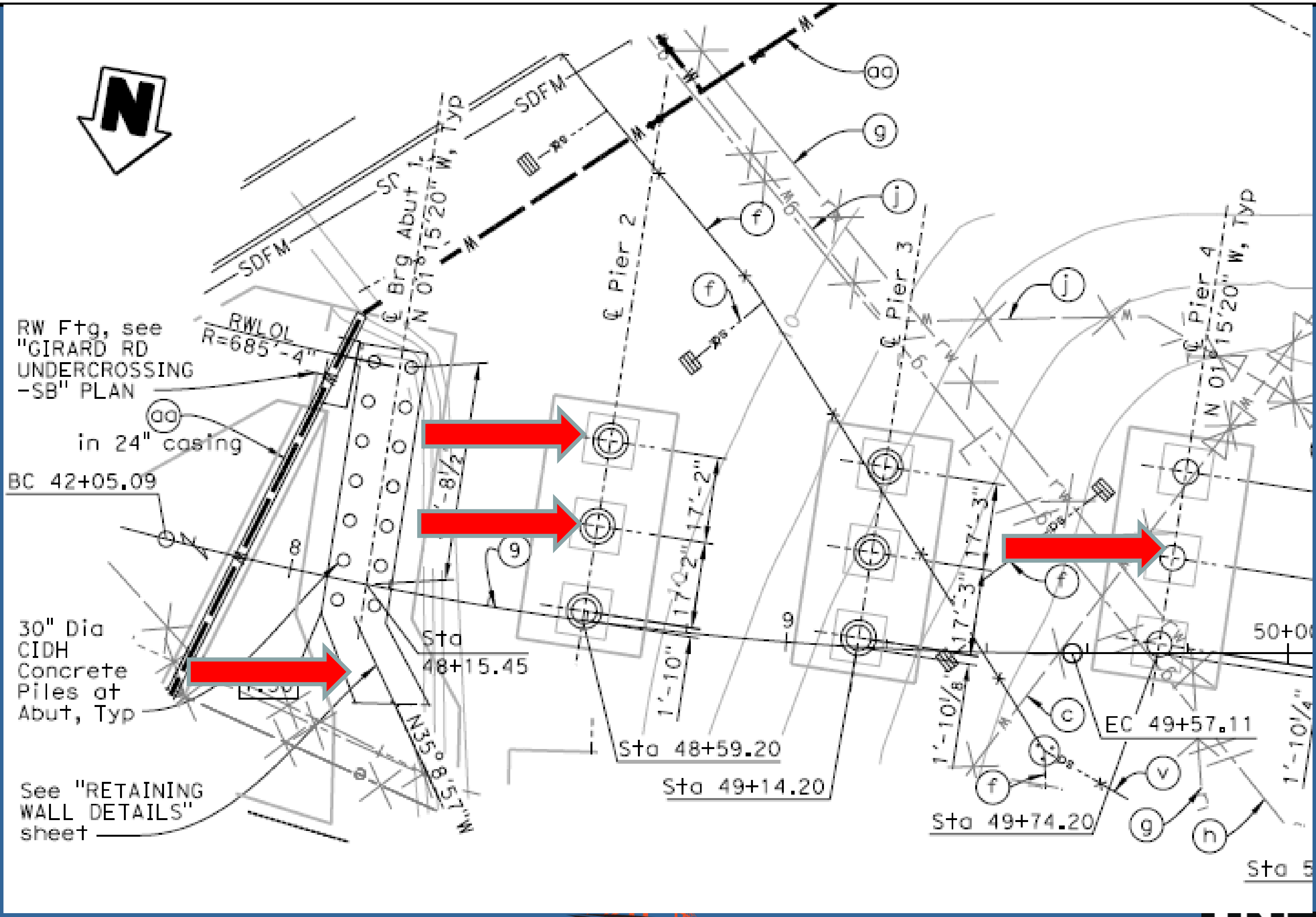


FEE ARS CURVE



SEE ARS CURVE

Abut. Connectivity & Casings



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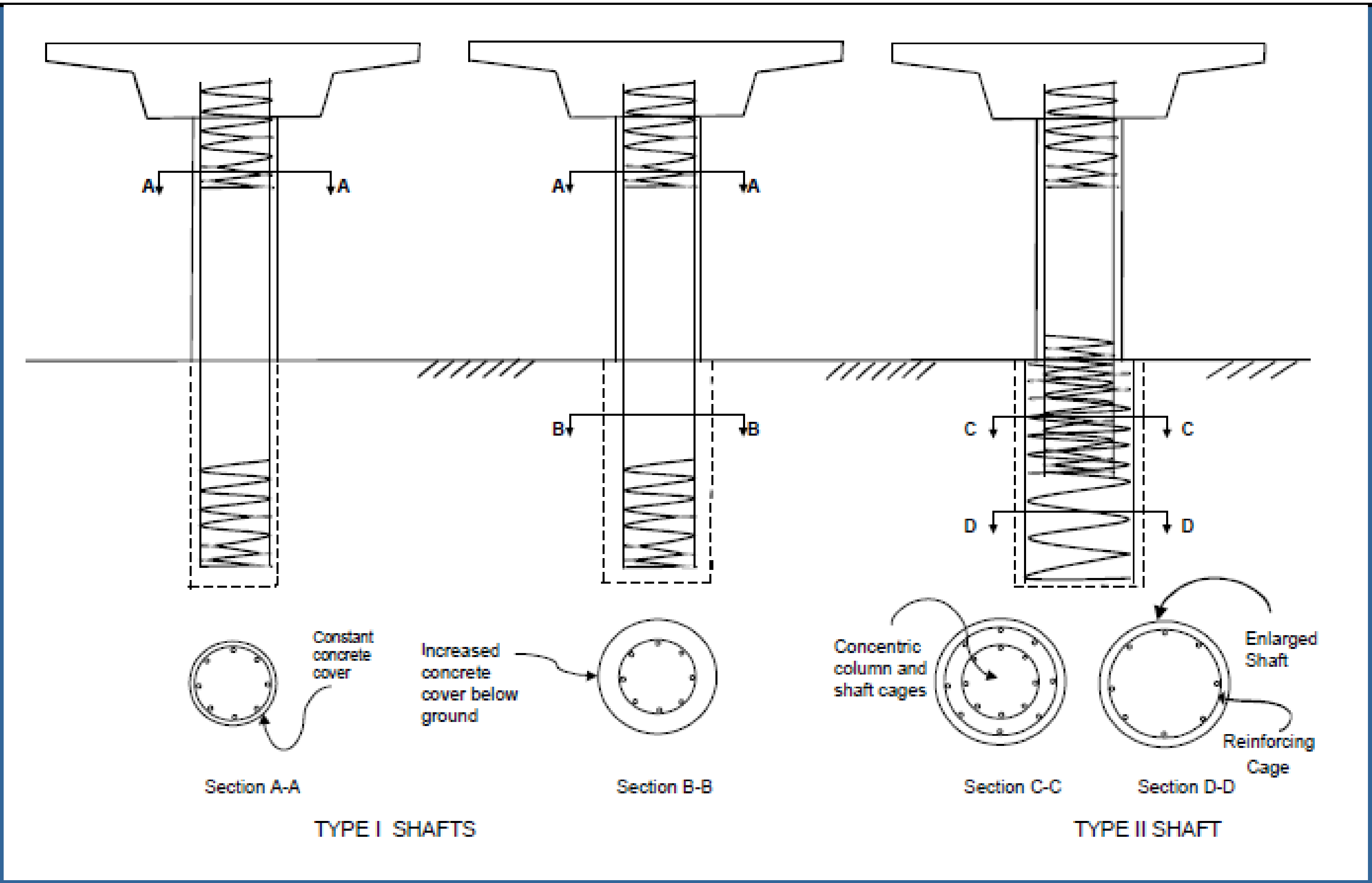
Ductility (Type II Shaft)



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Ductility (cont'd)

Local displacement ductility capacity for a particular member is defined in Equations 3.6.

$$\mu_c = \frac{\Delta_c}{\Delta_Y^{col}} \quad \text{for Cantilever columns,}$$

$$\mu_{c1} = \frac{\Delta_{c1}}{\Delta_{Y1}^{col}} \quad \& \quad \mu_{c2} = \frac{\Delta_{c2}}{\Delta_{Y2}^{col}} \quad \text{for fixed-fixed columns} \qquad (3.6)$$

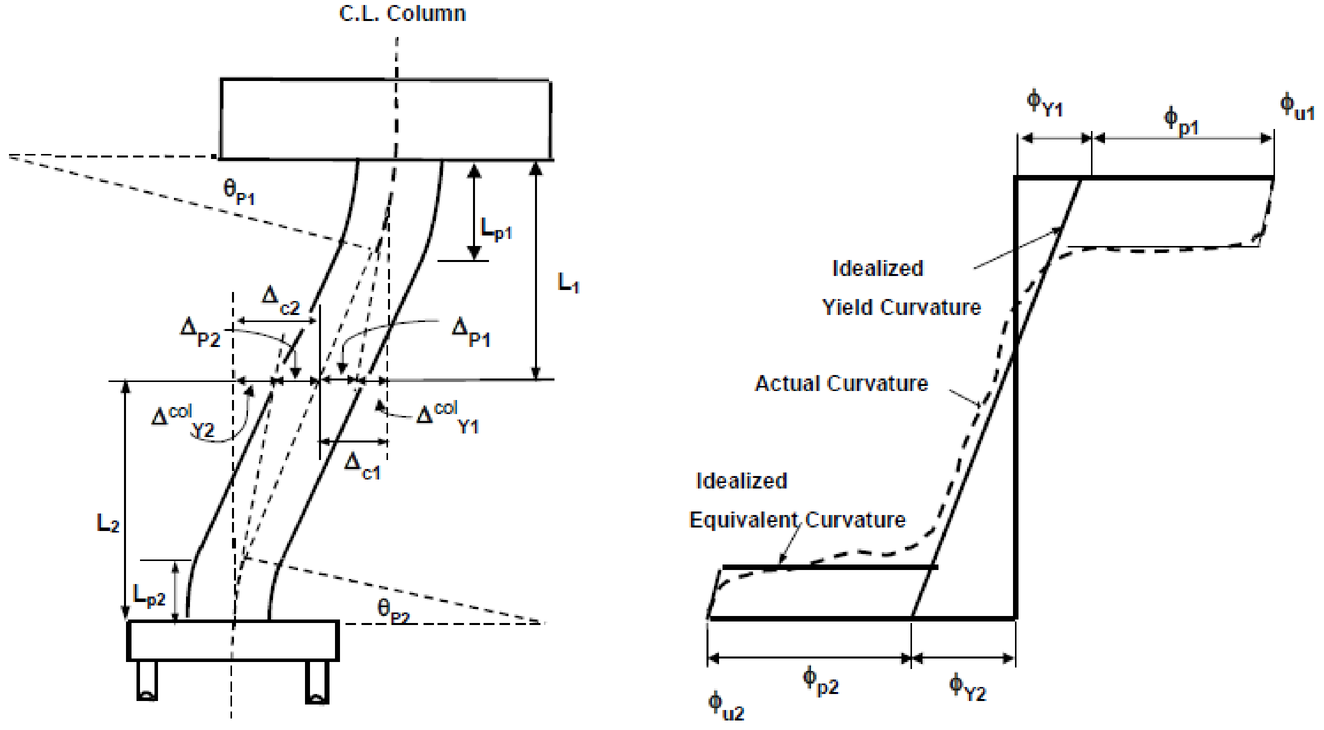
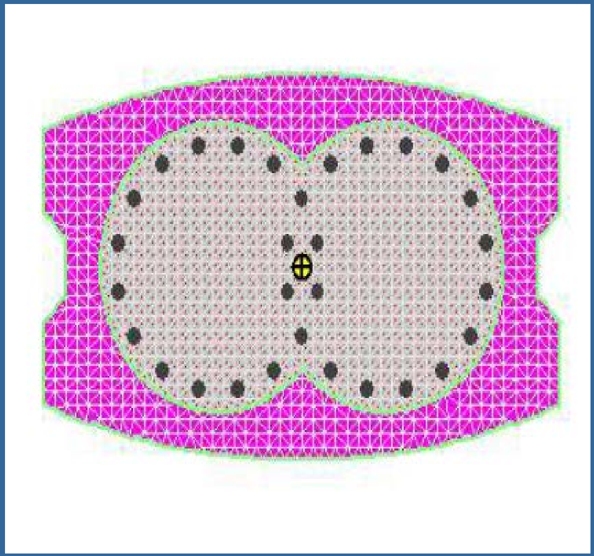
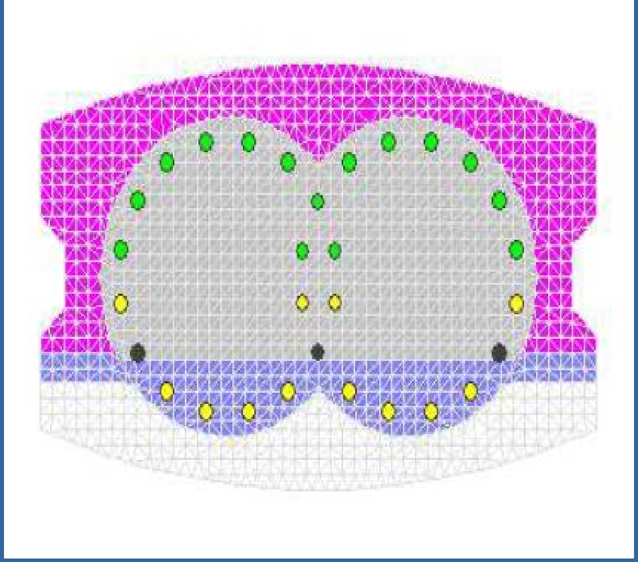


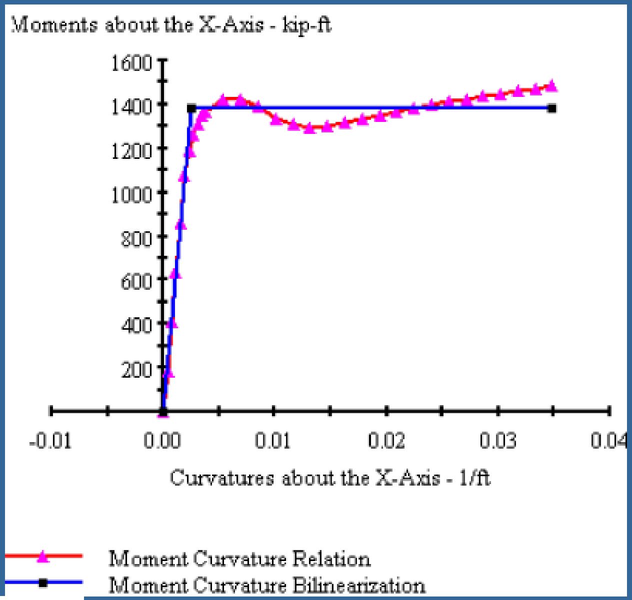
Figure 3.2 Local Displacement Capacity – Framed Column, assumed as fixed-fixed

Ductility (cont'd)

- Mp Calculation (longitudinal)







Material Types and Names:

Unconfined Concrete:	Unconfined1
Confined Concrete:	Confined1
Strain Hardening Steel:	Steel1

Analysis Results:

Failing Material:	Confined1
Failure Strain:	14.28E-3 Compression
Curvature at Initial Load:	-.3657E-20 1/ft
Curvature at First Yield:	1.921E-3 1/ft

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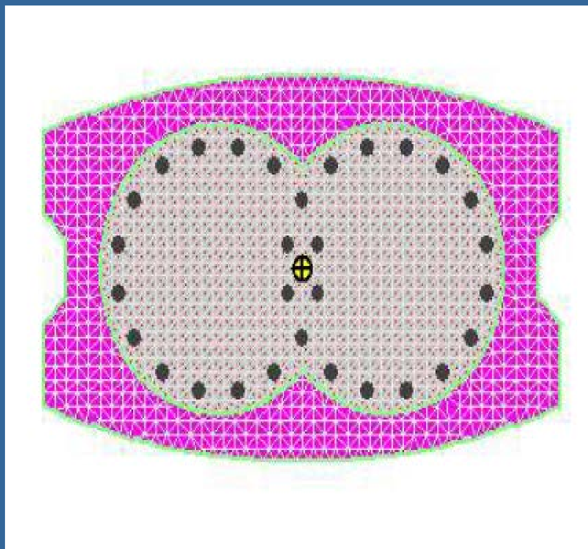
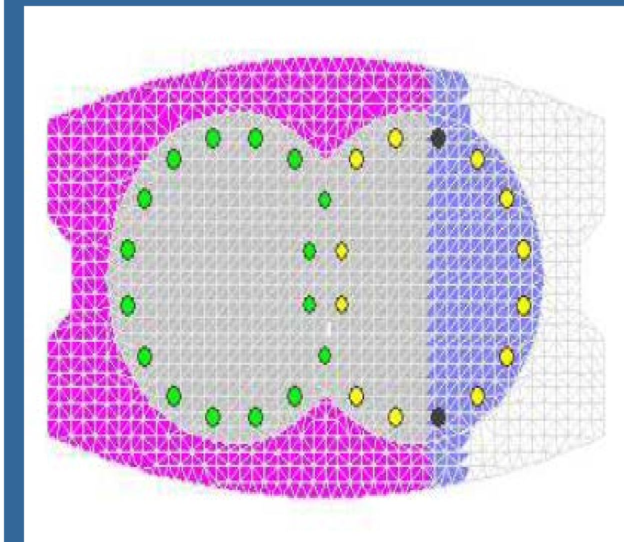
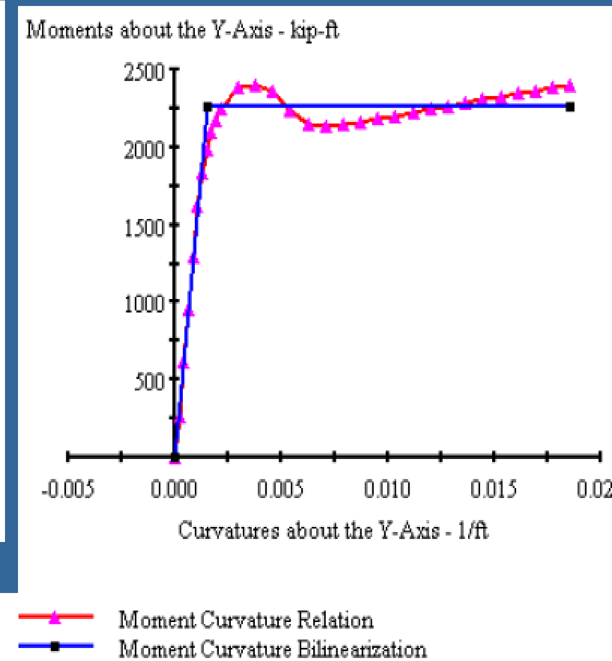
Ductility (cont'd)

- Mp Calculation (transverse)







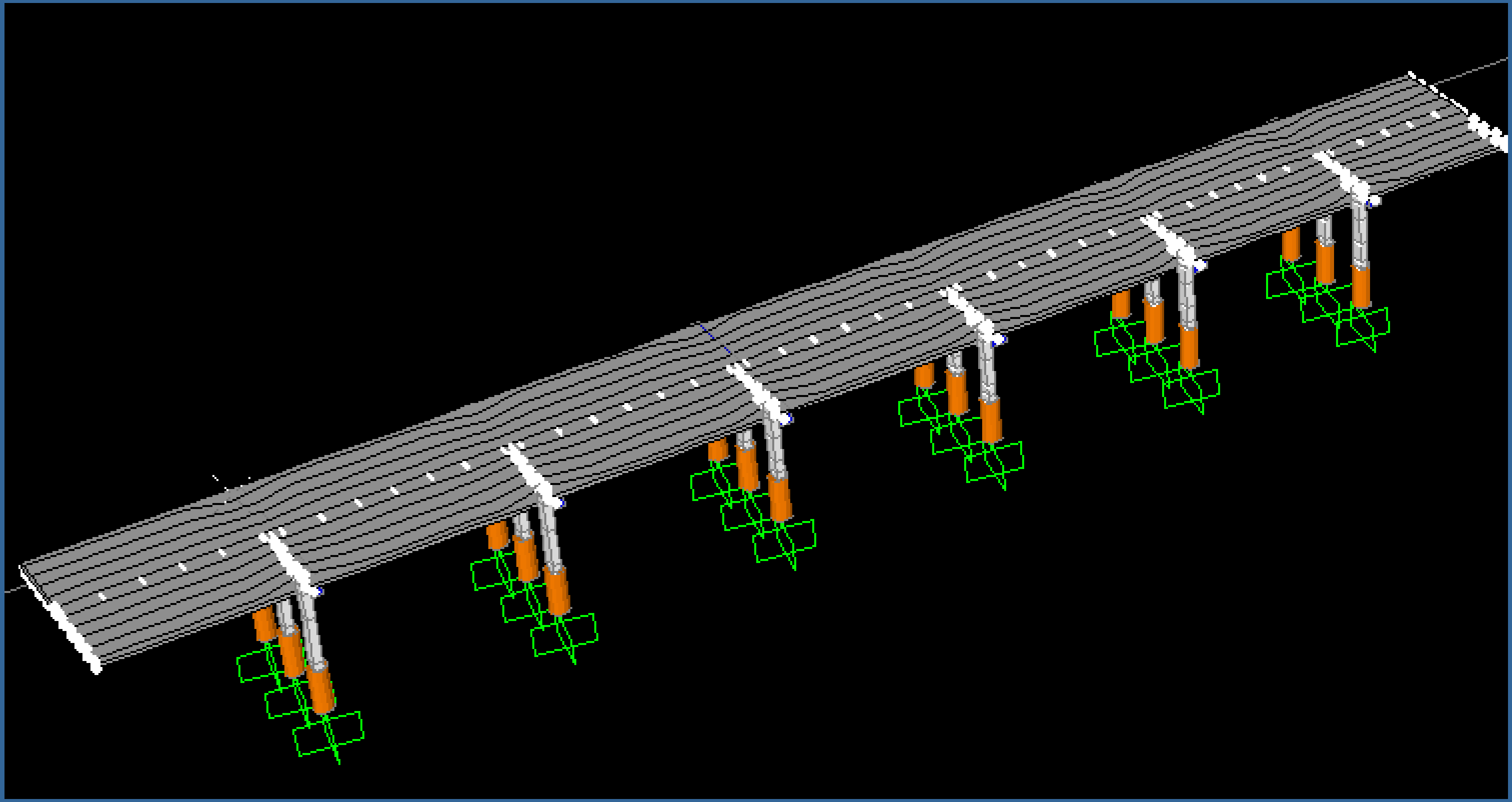
Material Types and Names:

Unconfined Concrete:	Unconfined1
Confined Concrete:	Confined1
Strain Hardening Steel:	Steel1

Analysis Results:

Failing Material:	Confined1
Failure Strain:	14.28E-3 Compression
Curvature at Initial Load:	-10.85E-9 1/ft
Curvature at First Yield:	1.079E-3 1/ft

Spectral Analysis (SAP model)



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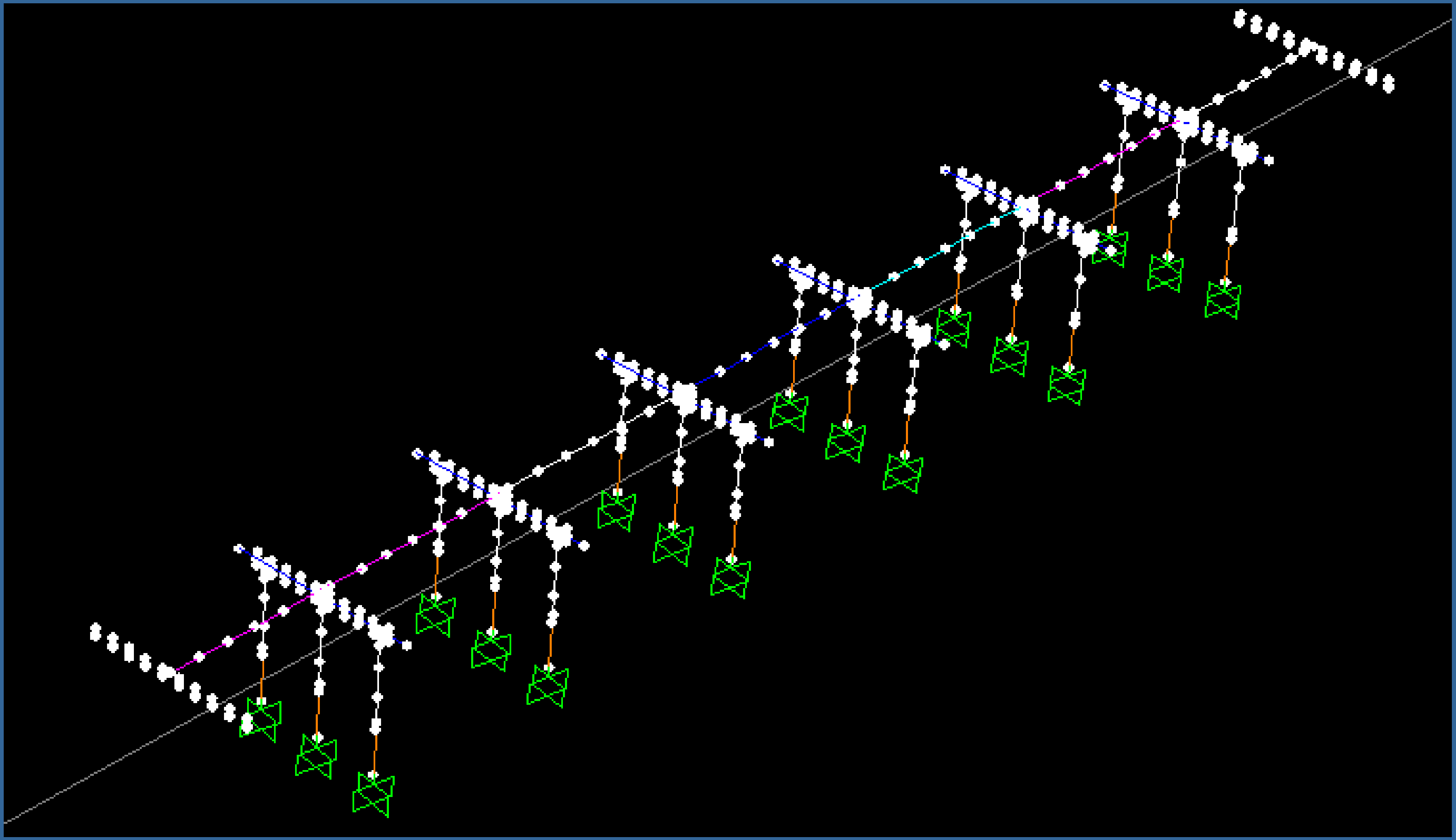
Spectral Analysis (SAP model)



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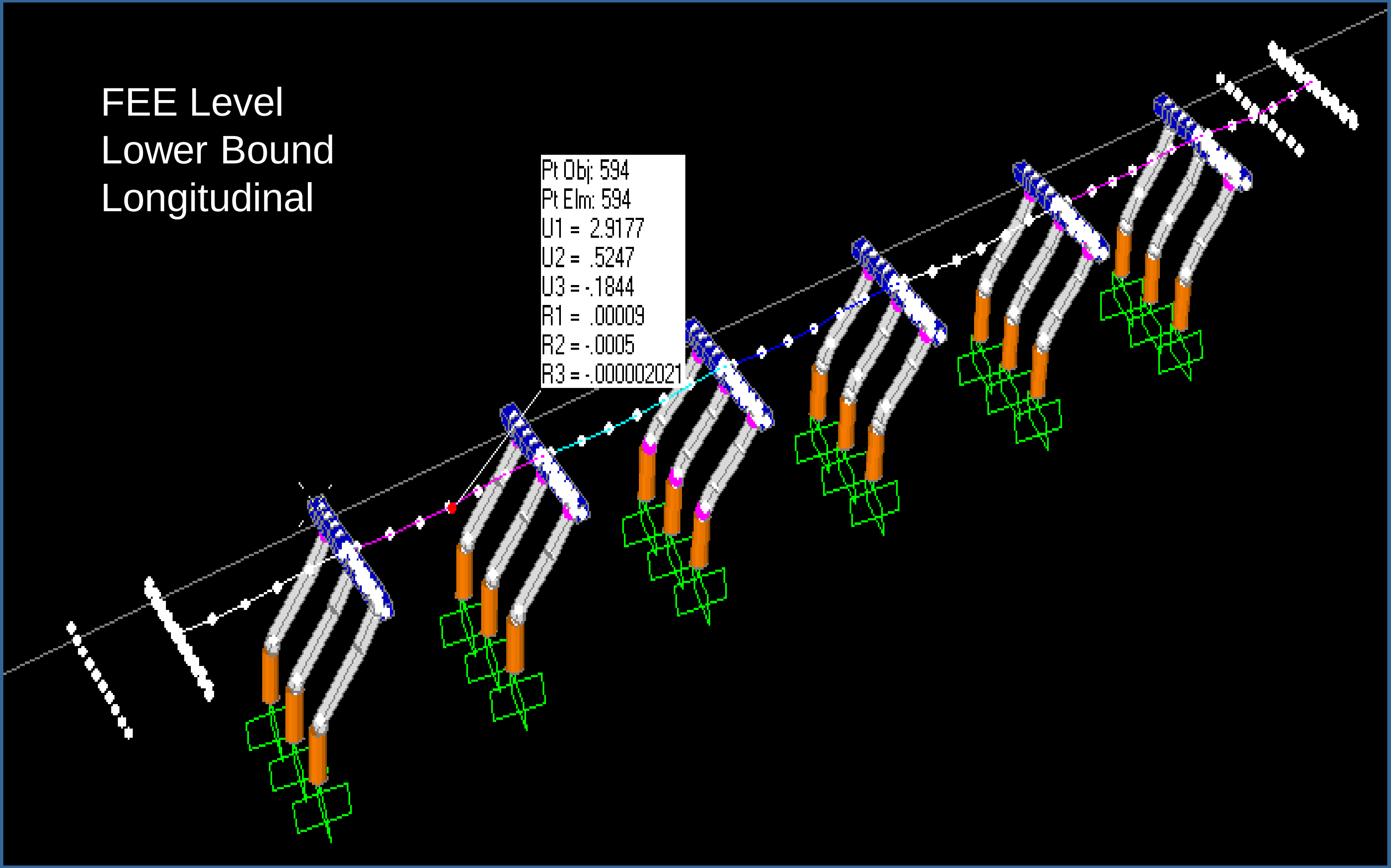
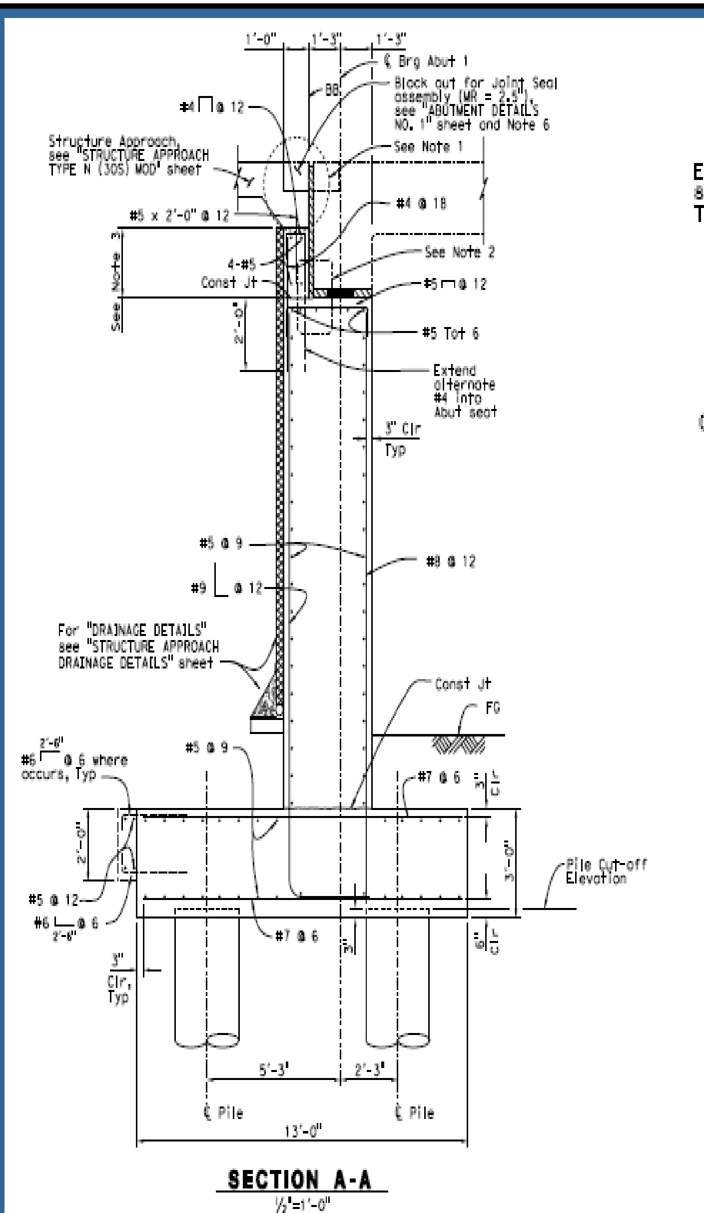
Deformed Shape (3D)

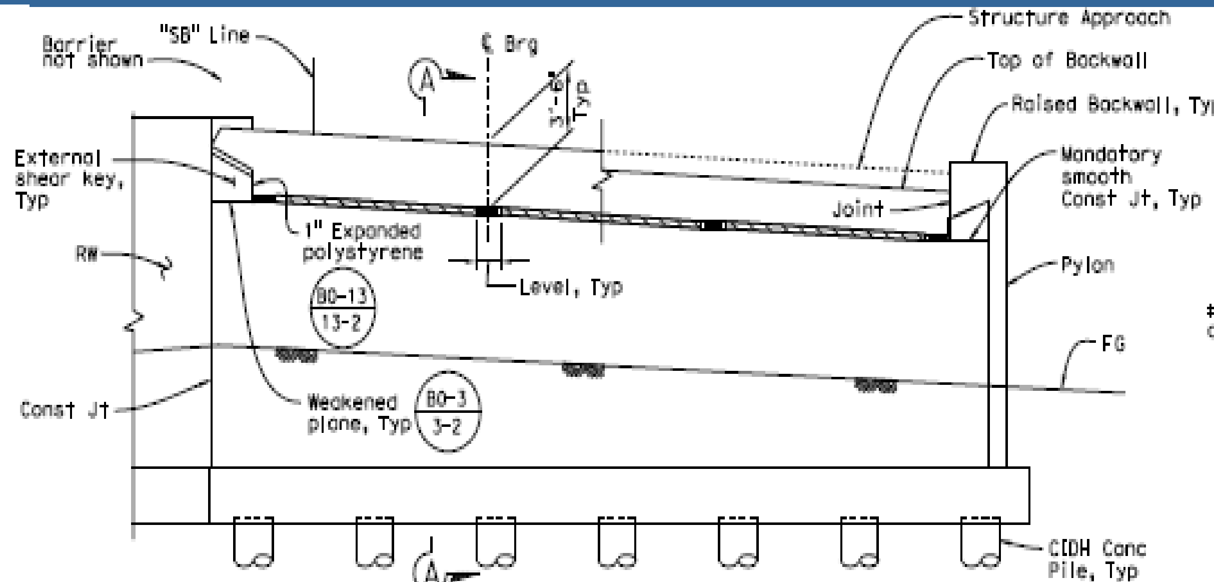
FEE Level
Lower Bound
Longitudinal



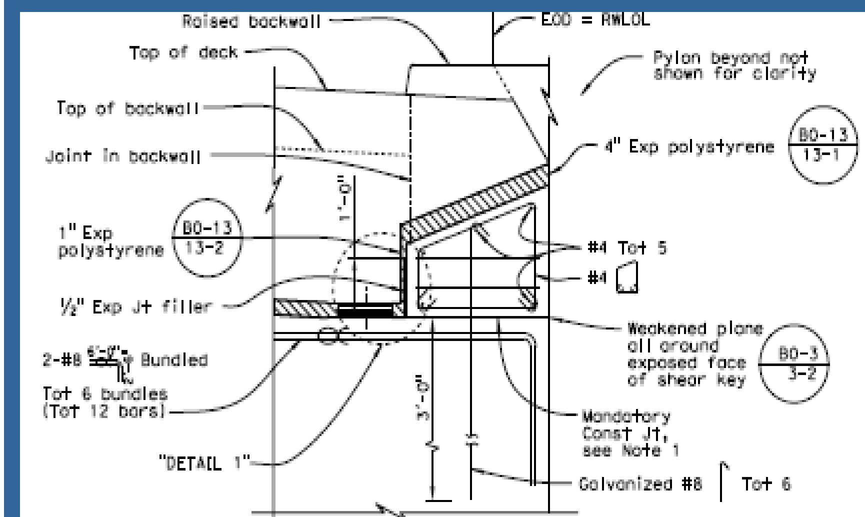
Long. Response & Abut Design



SECTION A-A
½"=1'-0"



ELEVATION



ELEVATION

ABUTMENT SHEAR KEY DETAIL

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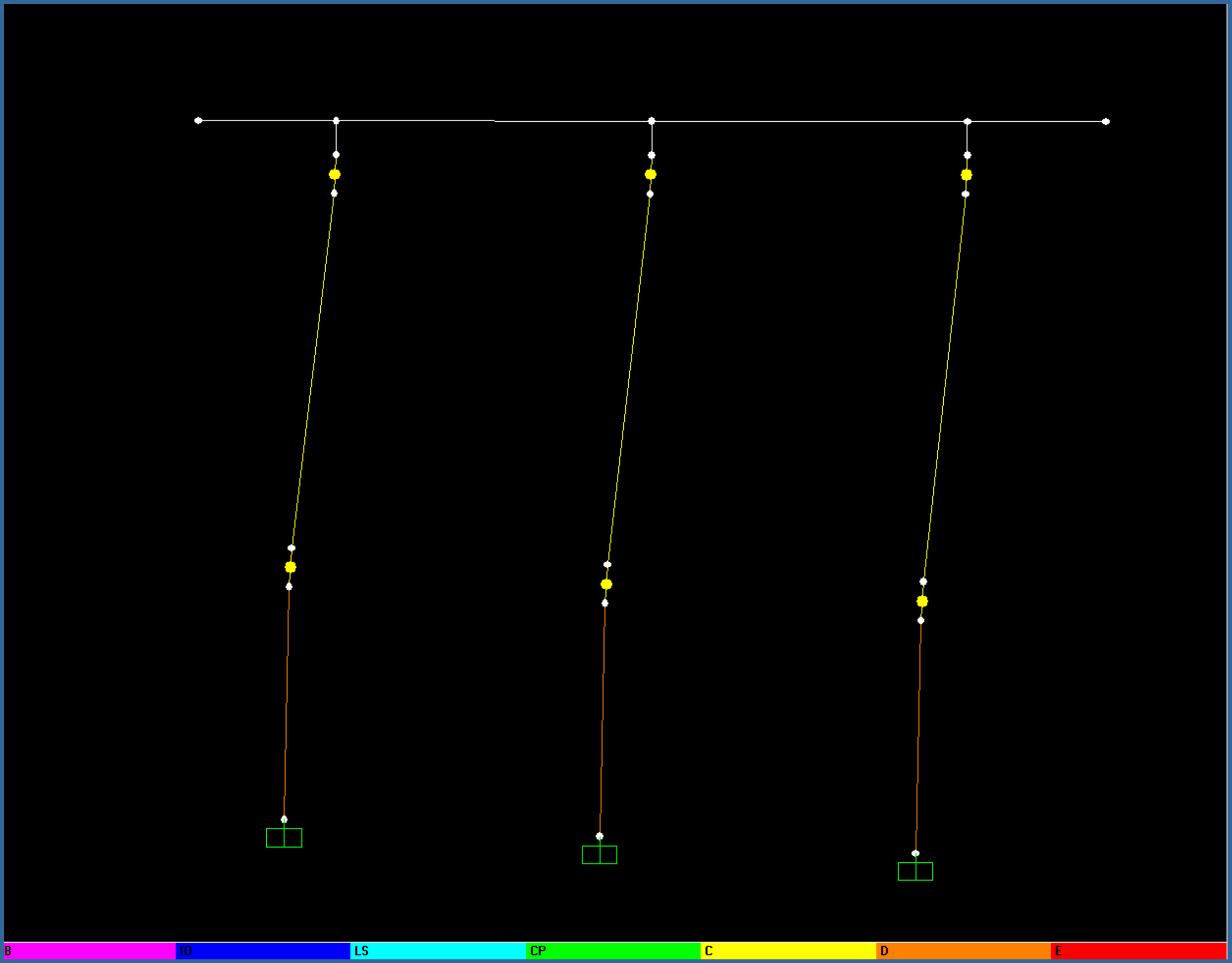
Push Over Analysis (2D & 3D)



Typically performed at each bent or at least at governing bents

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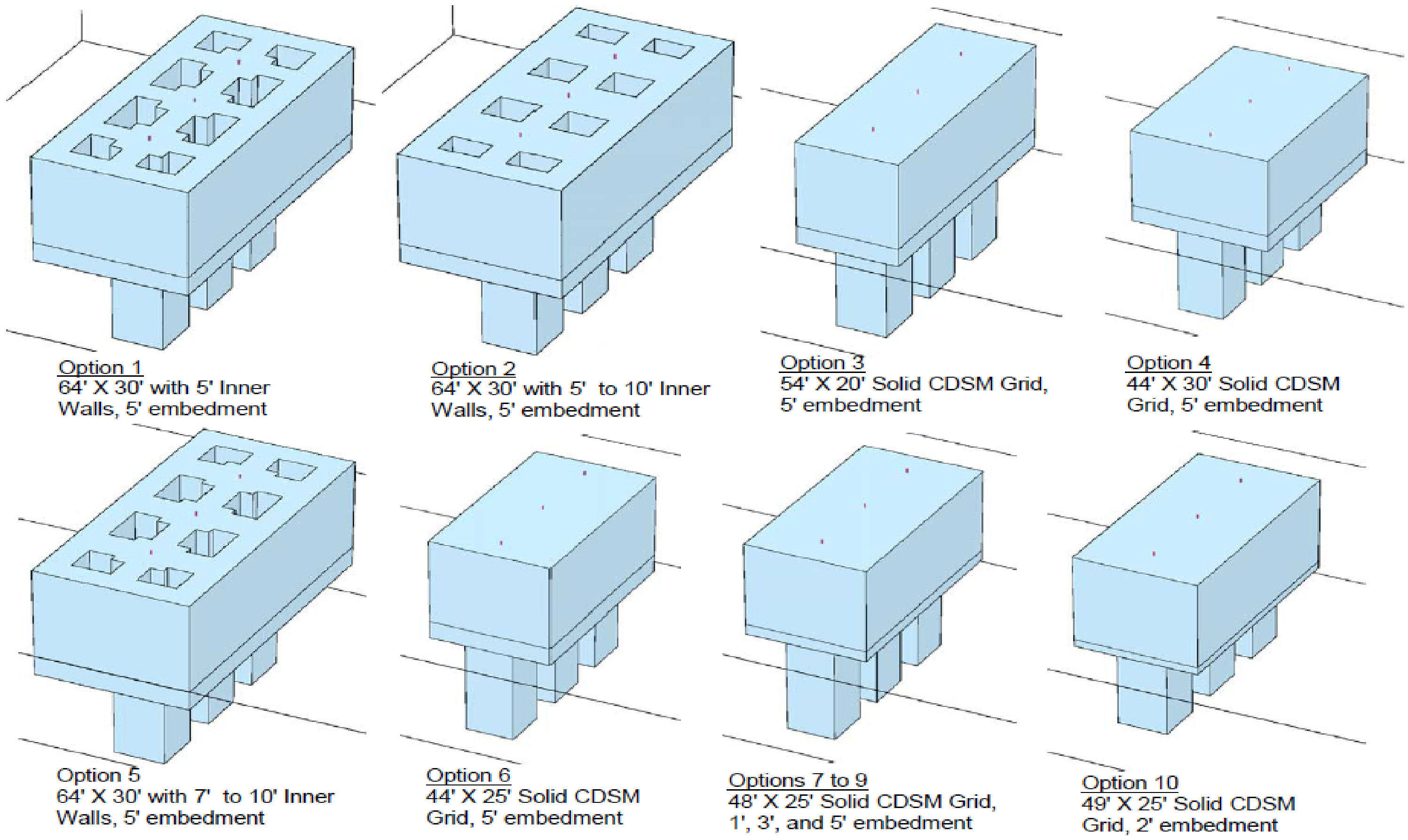
Pile & Column Design Iteration



CDSM GRID LAYOUTS CONSIDERED FOR A TYPICAL 3-PILE PIER
Presidio Parkway Project
San Francisco, California

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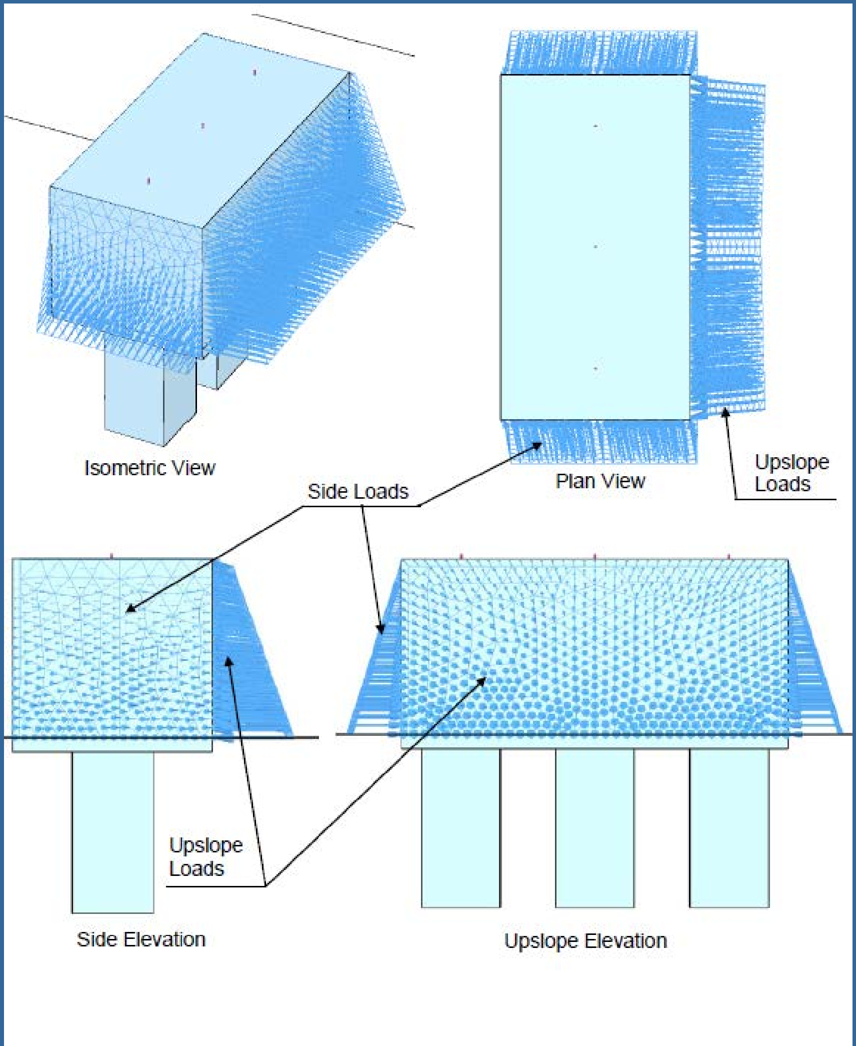
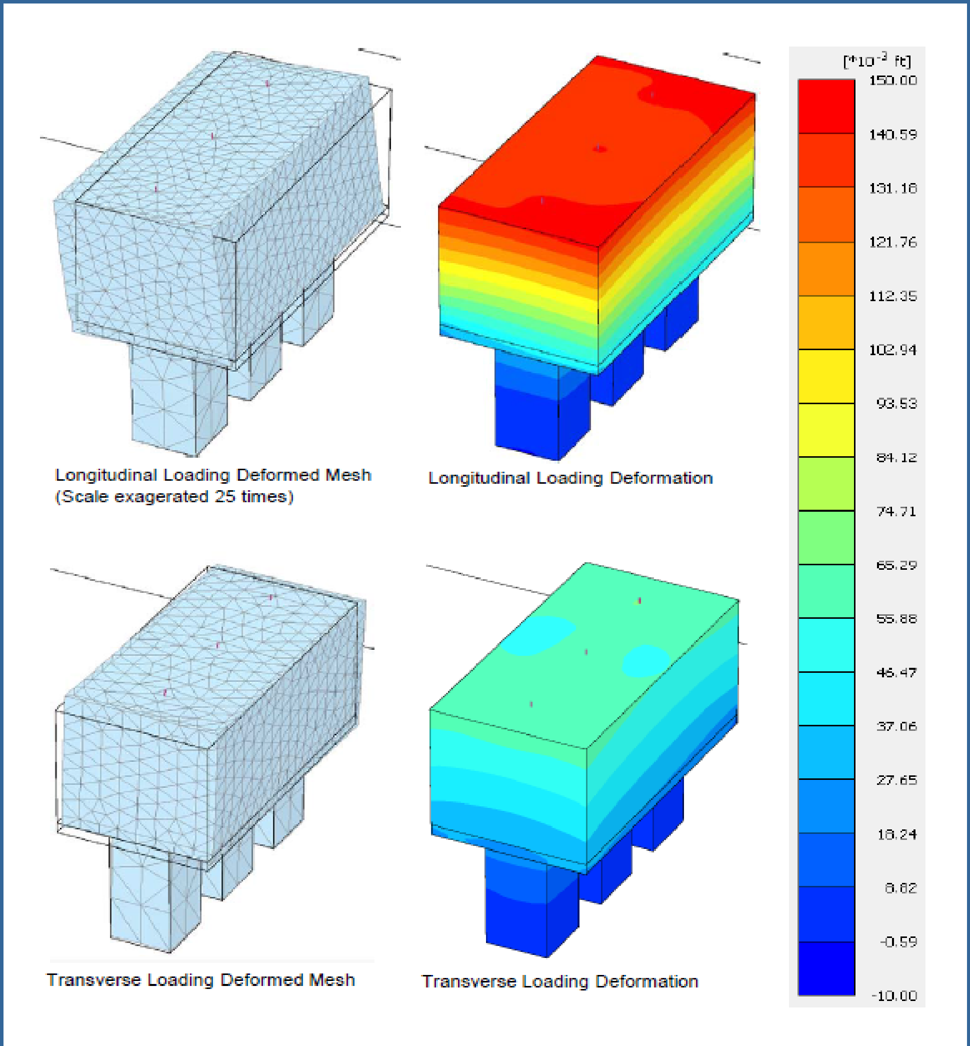
Pile & Column Design Iter. (Cont'd)



TYPICAL LATERAL SPREADING LOAD DISTRIBUTION FOR PIER CDSM



CDSM DEFORMATION AND TENSION CRACKING PATTERNS FOR THE CRITICAL 3-PILE PIER

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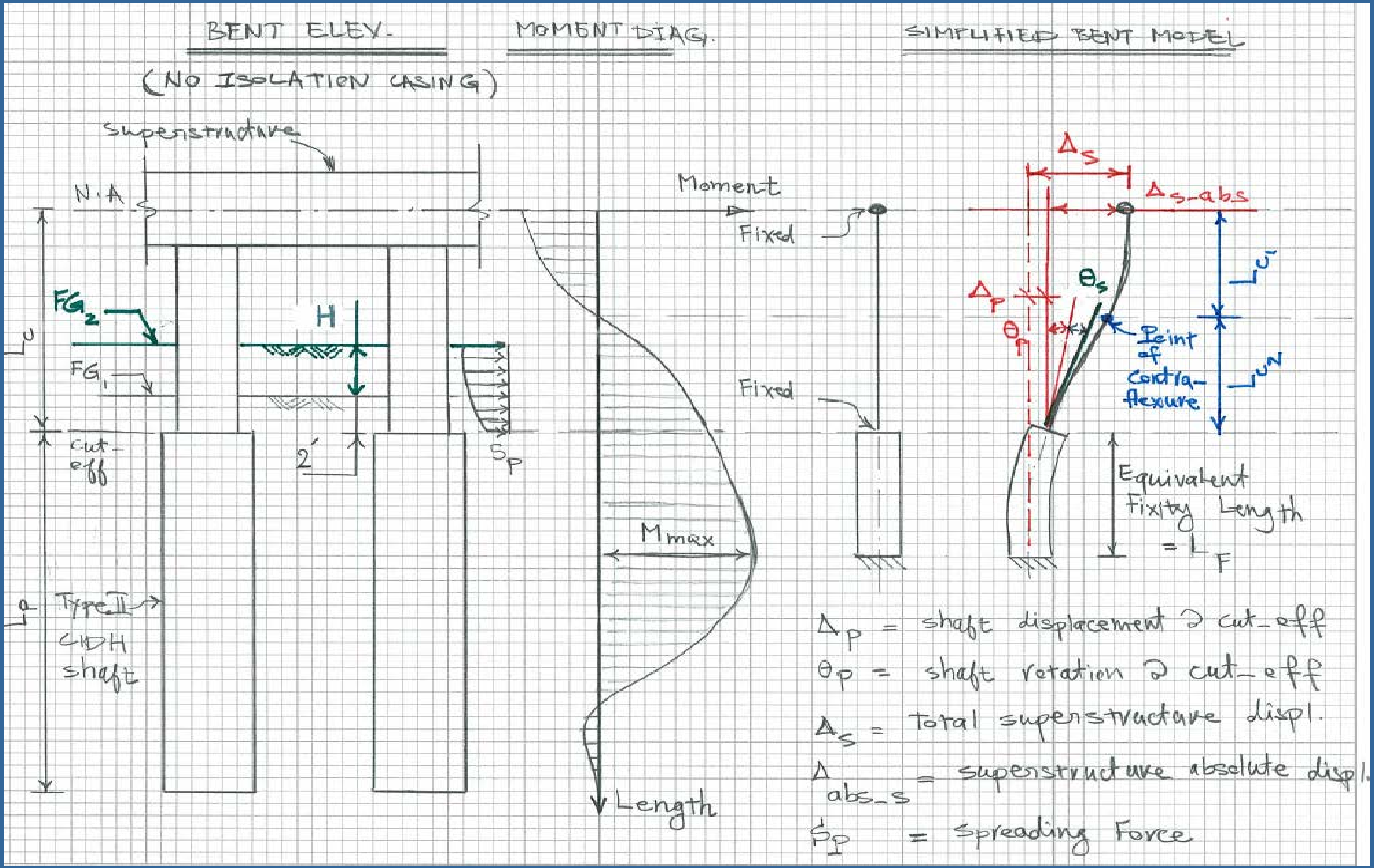
Pile & Column Design Iter. (Cont'd)



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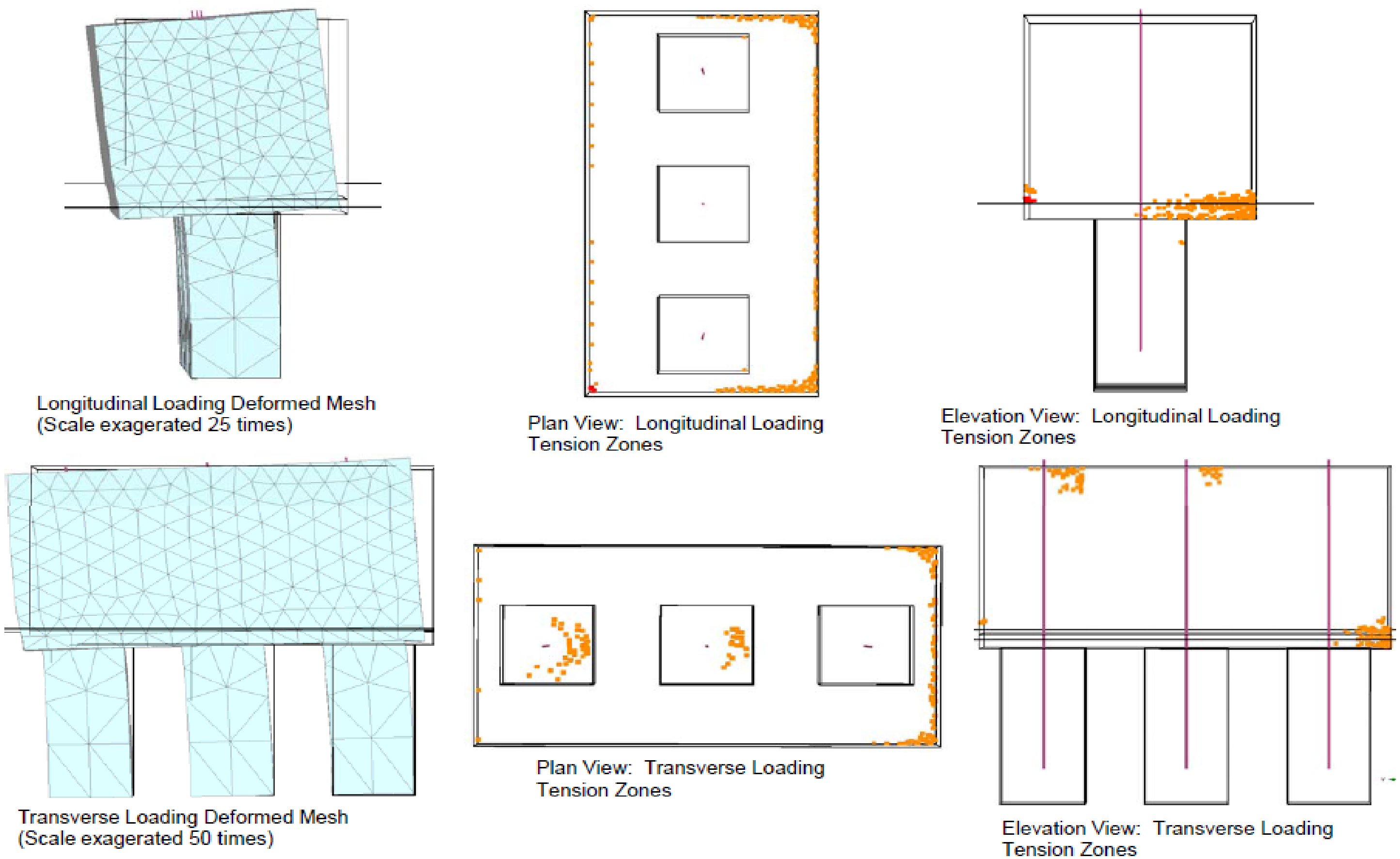
Pile & Column Design Iter. (Cont'd)



Note: Orange colored markings denote tension cracking zones; red markings denote shear cracking

CDSM DEFORMATION AND TENSION CRACKING PATTERNS FOR THE CRITICAL 3-PILE PIER

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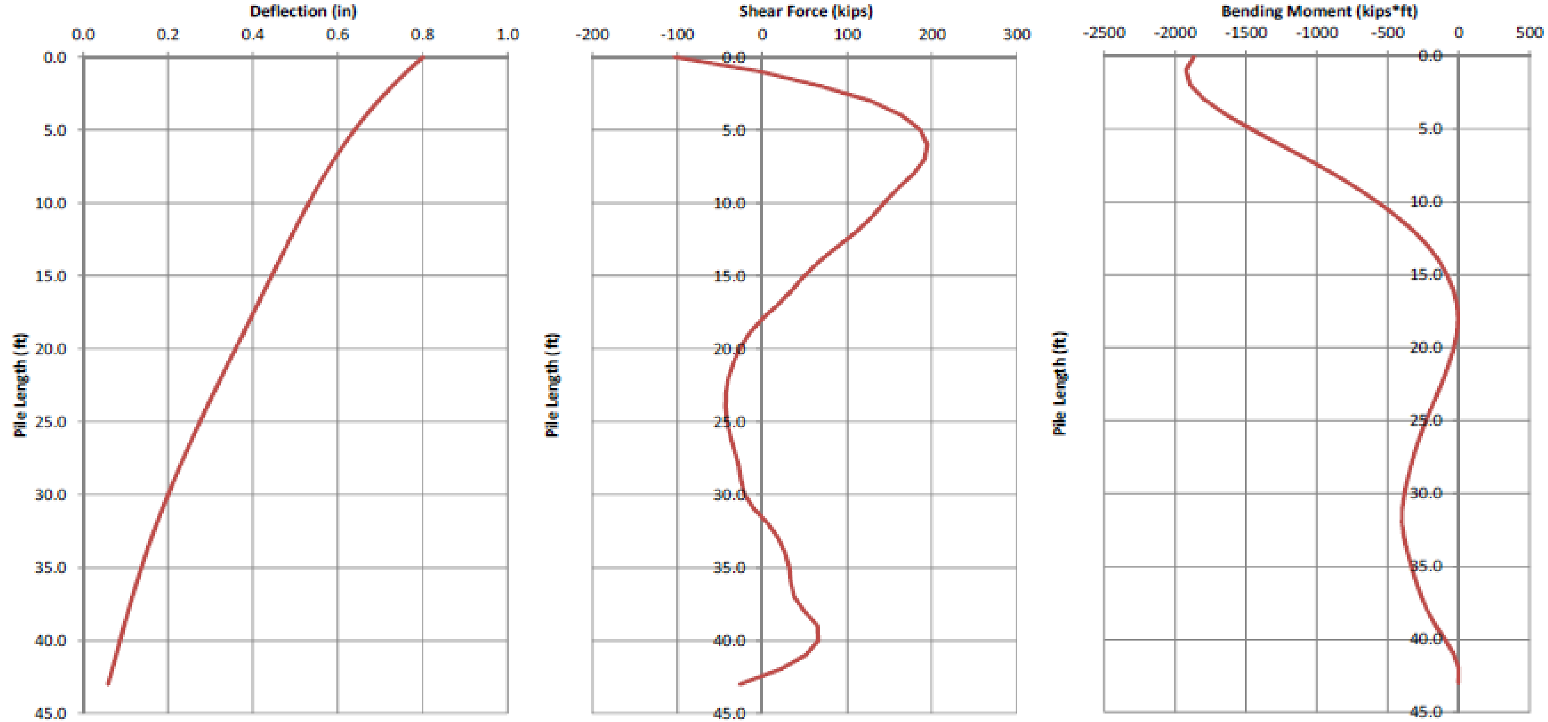
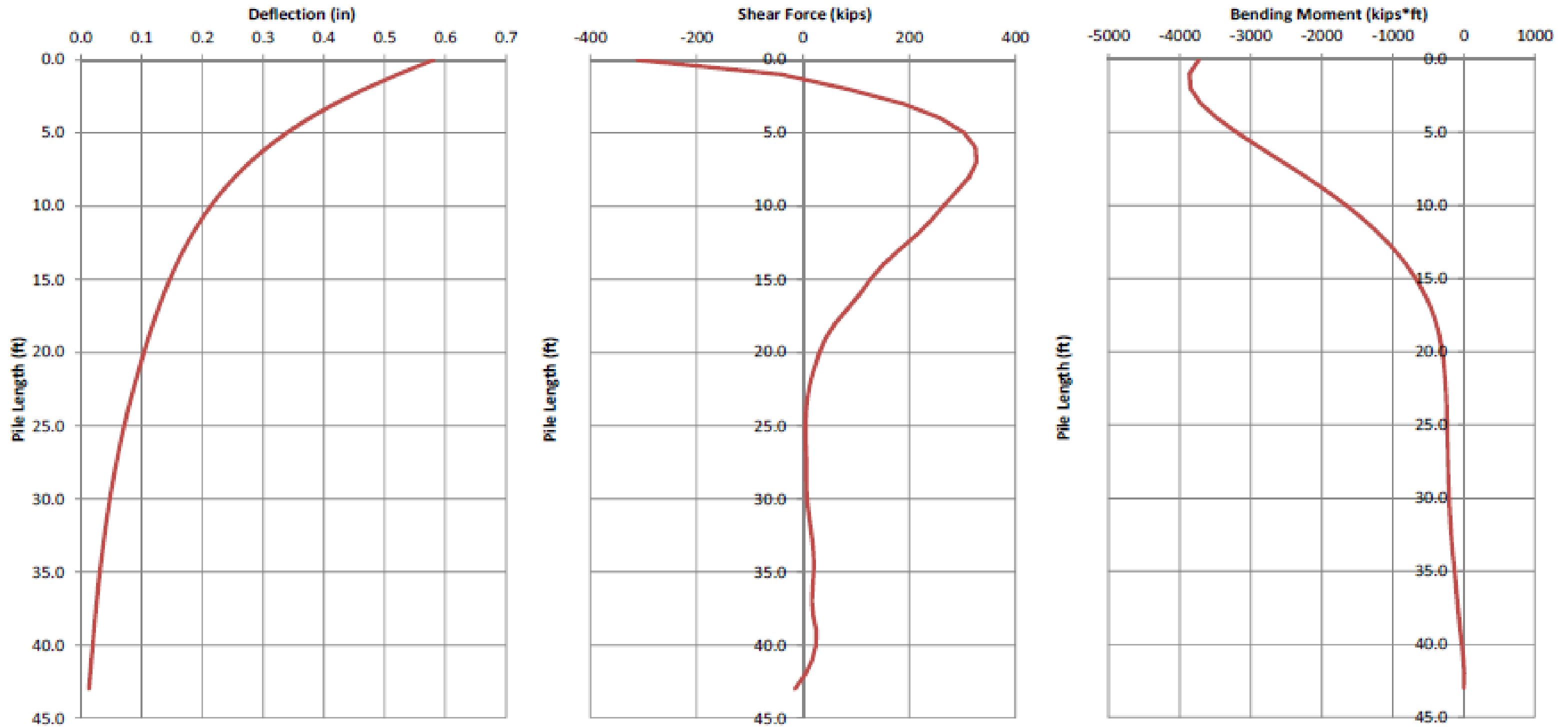
Pile & Column Design Iter. (Cont'd)



PILE DEFLECTION, SHEAR FORCE, AND BENDING MOMENT PROFILES
CRITICAL 3-PILE PIER, TRANSVERSE LOADING, 100% KINEMATIC + 50% INERTIA LOADING

Pile & Column Design Iter. (Cont'd)



PILE DEFLECTION, SHEAR FORCE, AND BENDING MOMENT PROFILES
CRITICAL 3-PILE PIER, TRANSVERSE LOADING, 100% INERTIA LOADING

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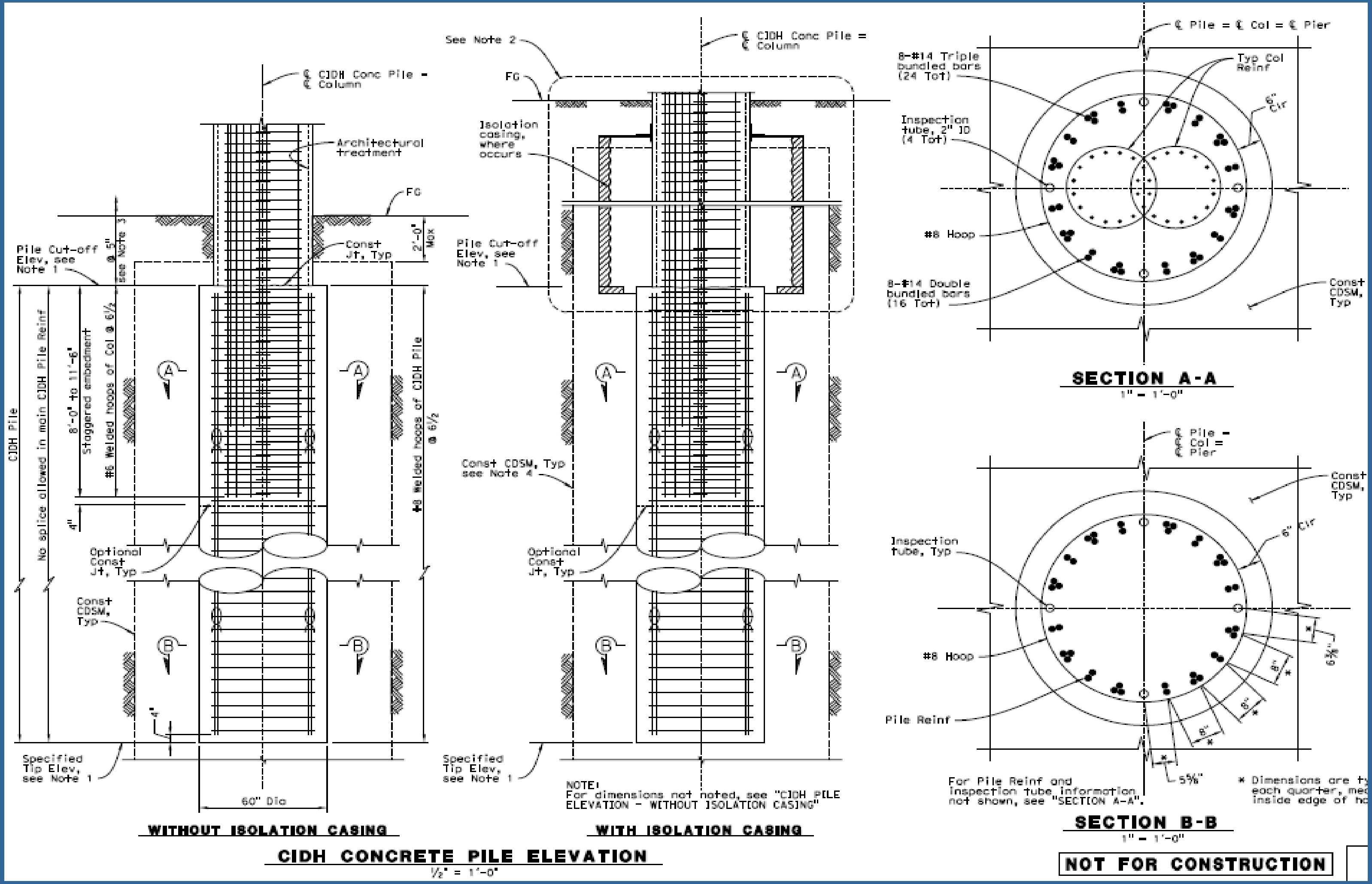
Pile & Column Design Iter. (Cont'd)



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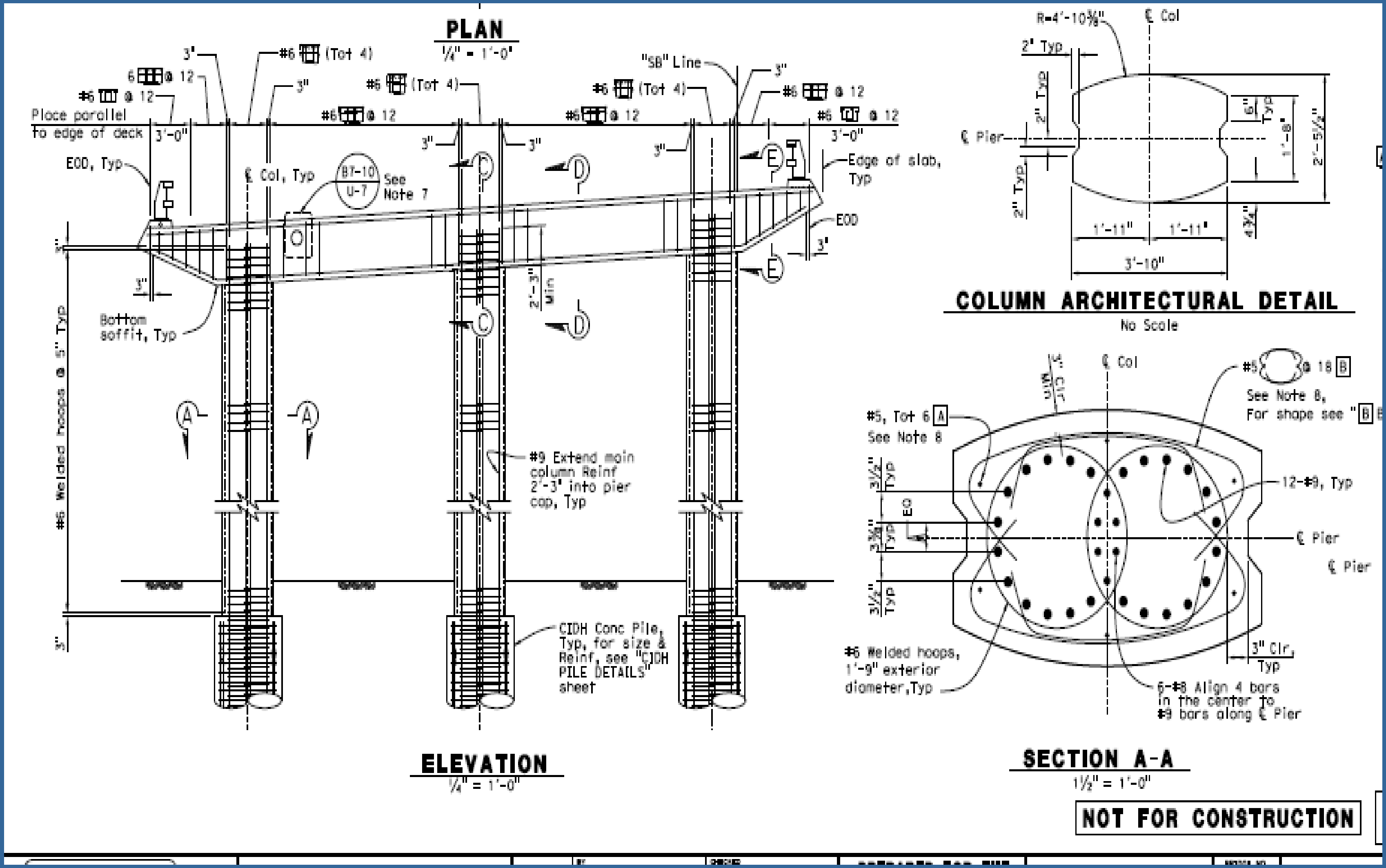
Pile & Column Design Iter. (Cont'd)



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Balanced Stiffness

	Constant Width Frames	Variable Width Frames
For any 2 Bents in a frame **or** any 2 Columns in a Bent	$k_i^e / k_j^e \geq 0.5$ (7.1a)	$2 \geq \dfrac{k_i^e / m_i}{k_j^e / m_j} \geq 0.5$ (7.1b)
For adjacent bents in a frame **or** adjacent Columns in a Bent	$k_i^e / k_j^e \geq 0.75$ (7.2a)	$1.33 \geq \dfrac{k_i^e / m_i}{k_j^e / m_j} \geq 0.75$ (7.2b)

P-Delta Effect

$$P_{dl} \times \Delta_r \leq 0.20 \times M_p^{col} \qquad (4.3)$$

Where: Δ_r = The relative lateral offset between the point of contra-flexure and the base of the plastic hinge. For Type I shafts $\Delta_r = \Delta_D - \Delta_s$

Δ_s = The shaft displacement at the point of maximum moment

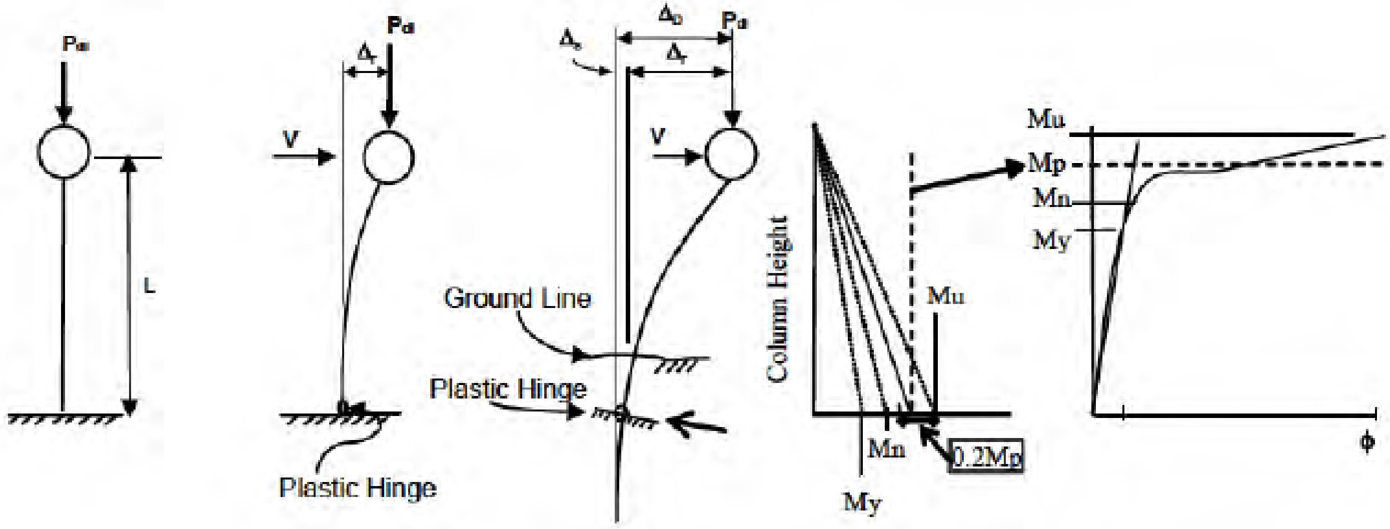

Figure 4.2 P-Δ Effects on Bridge Columns

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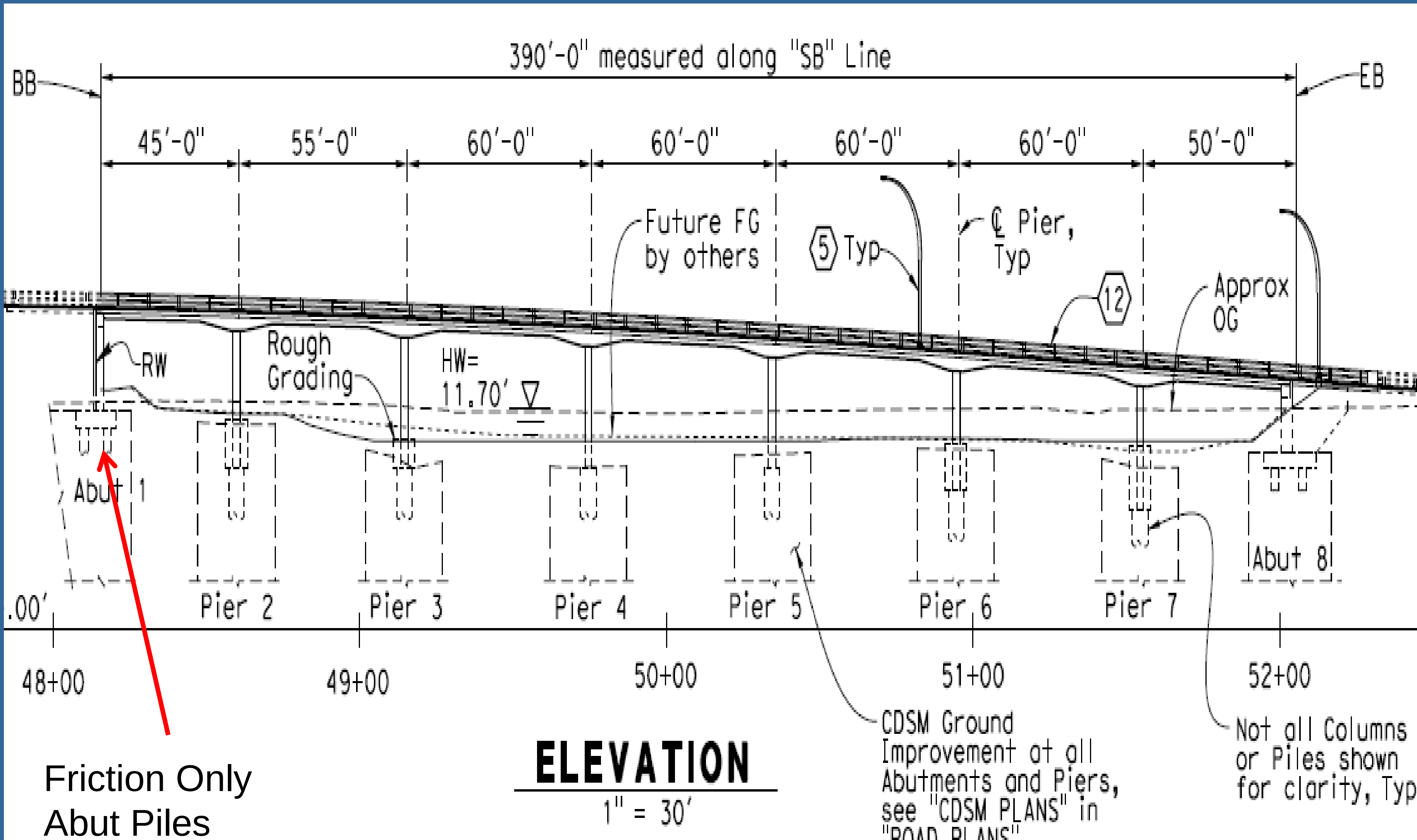
Balanced Stiffness (Cont'd)



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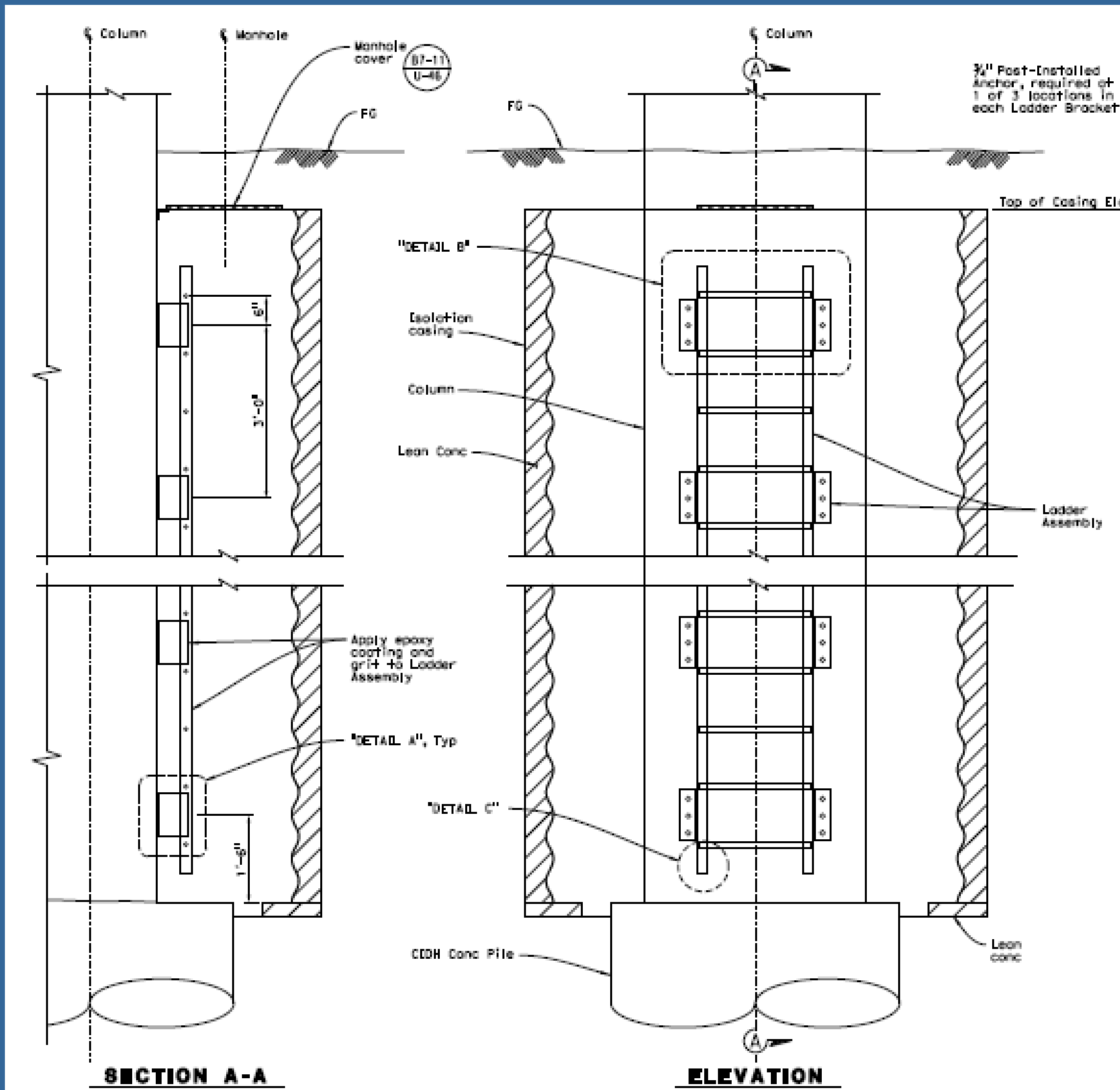
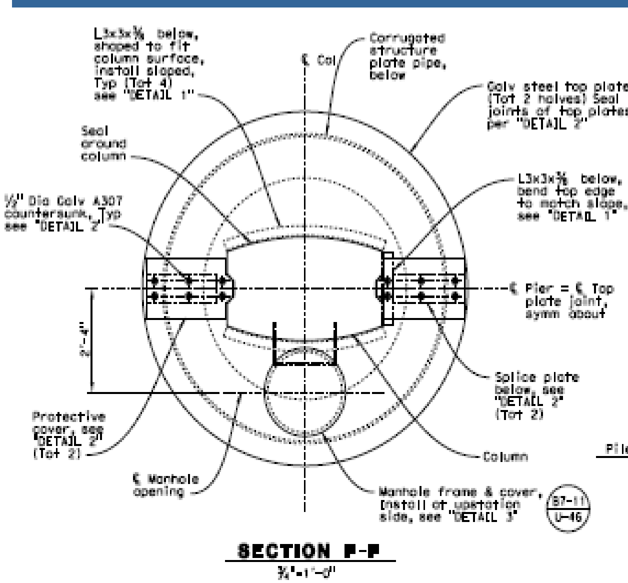
Balanced Stiffness (Cont'd)





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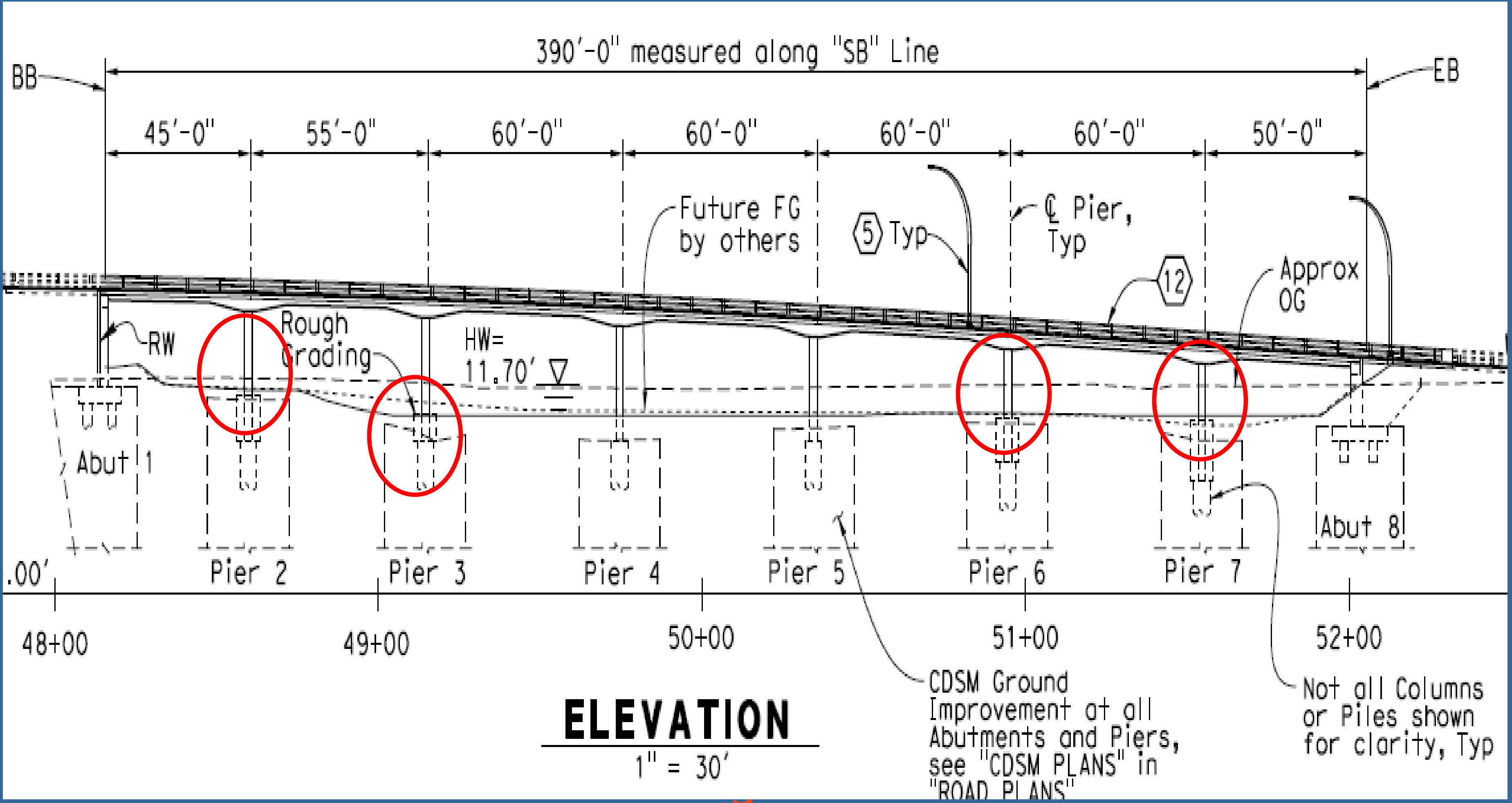
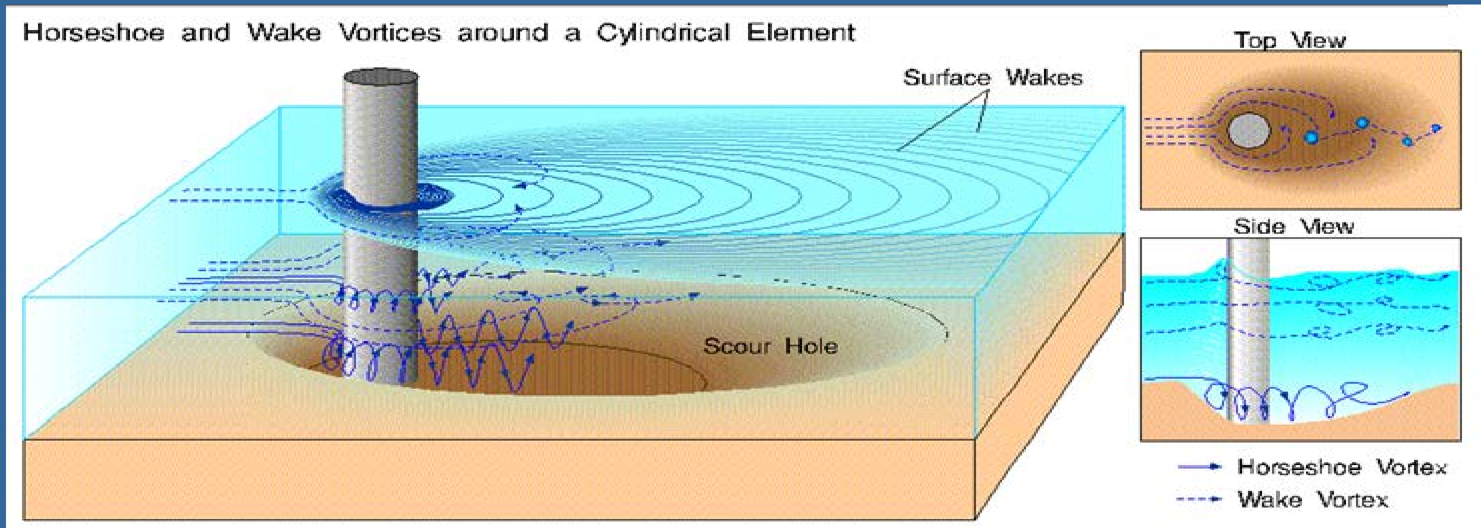
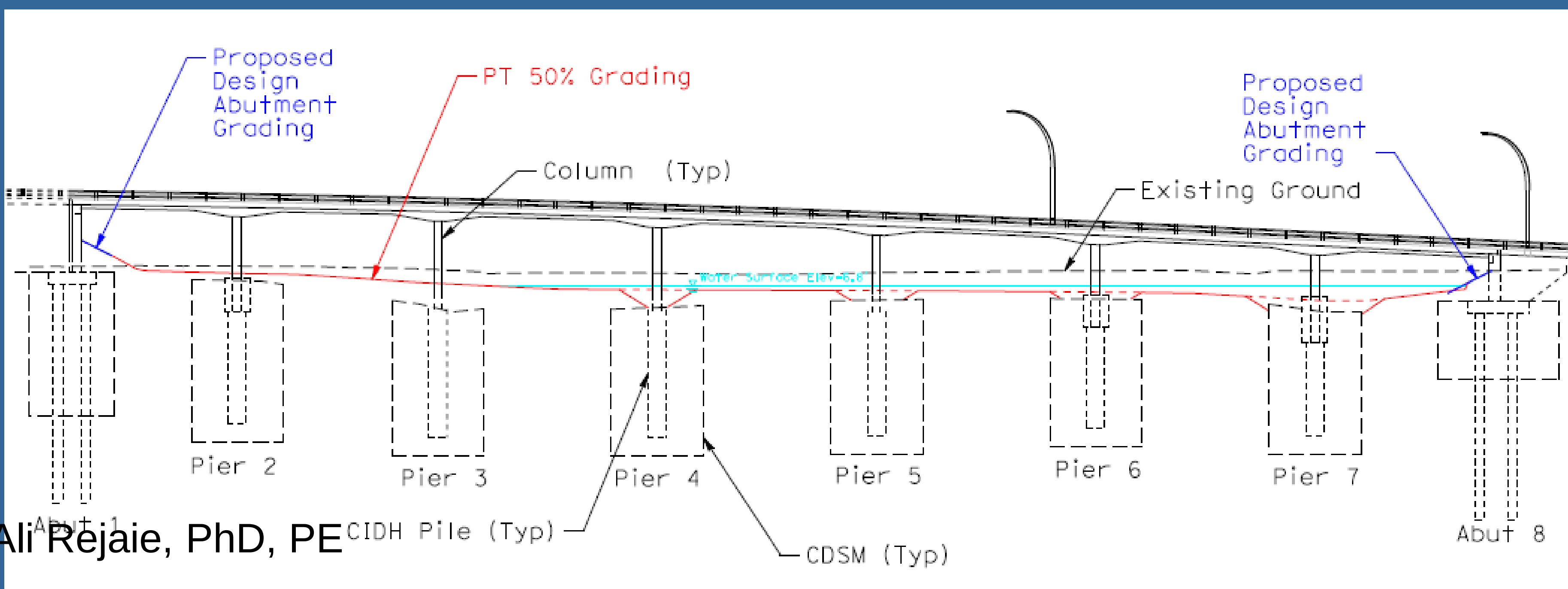


390'-0" measured along "SB" Line
BB
EB
45'-0"
55'-0"
60'-0"
60'-0"
60'-0"
60'-0"
50'-0"
Future FG by others
5 Typ
℄ Pier, Typ
12
Approx OG
RW
Rough Grading
HW= 11.70'
Abut 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Pier 7
Abut 8
.00'
48+00
49+00
50+00
51+00
52+00
CDSM Ground Improvement at all Abutments and Piers, see "CDSM PLANS" in "ROAD PLANS"
Not all Columns or Piles shown for clarity, Typ
ELEVATION
1" = 30'

Scour





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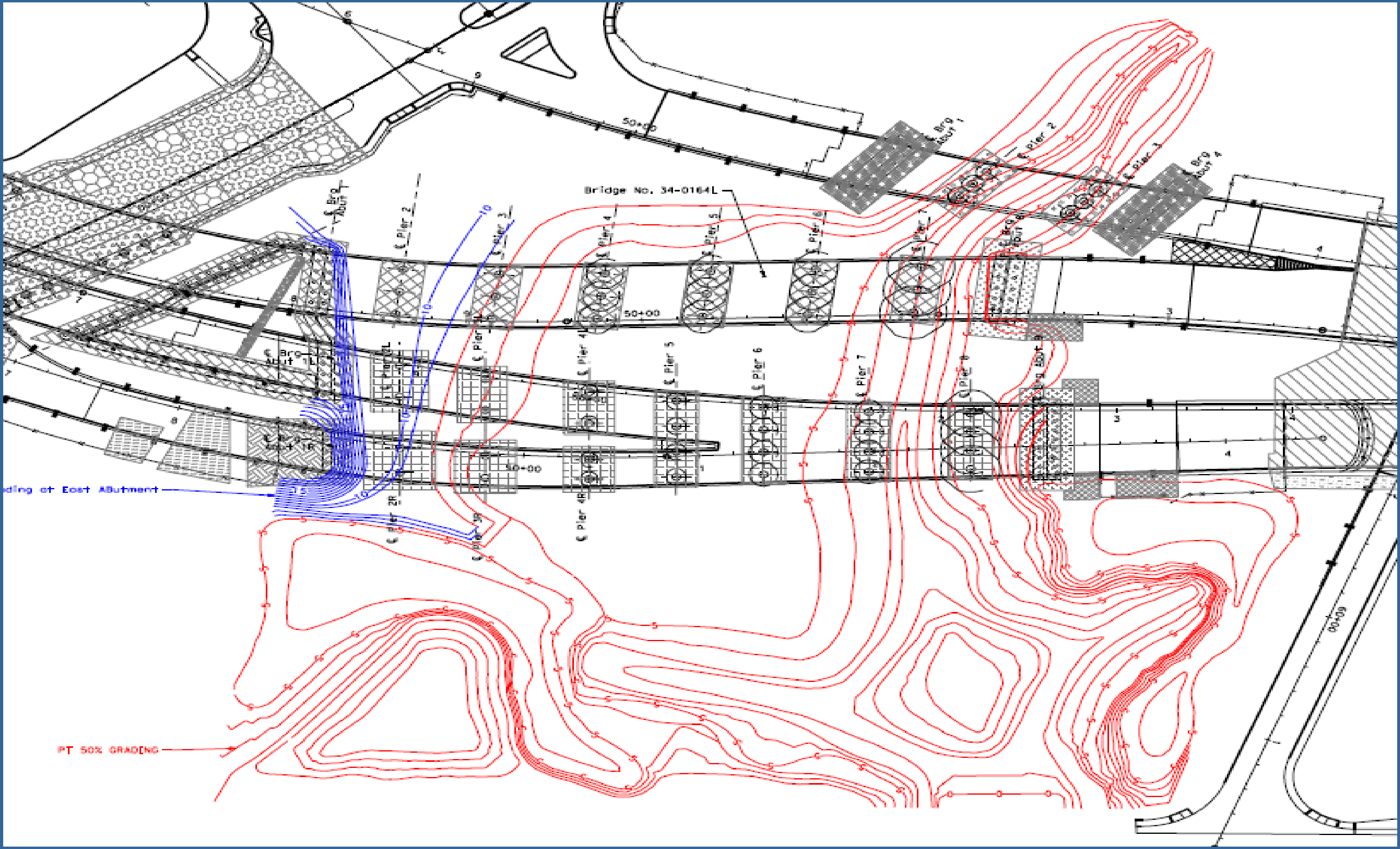
Scour (Cont'd)



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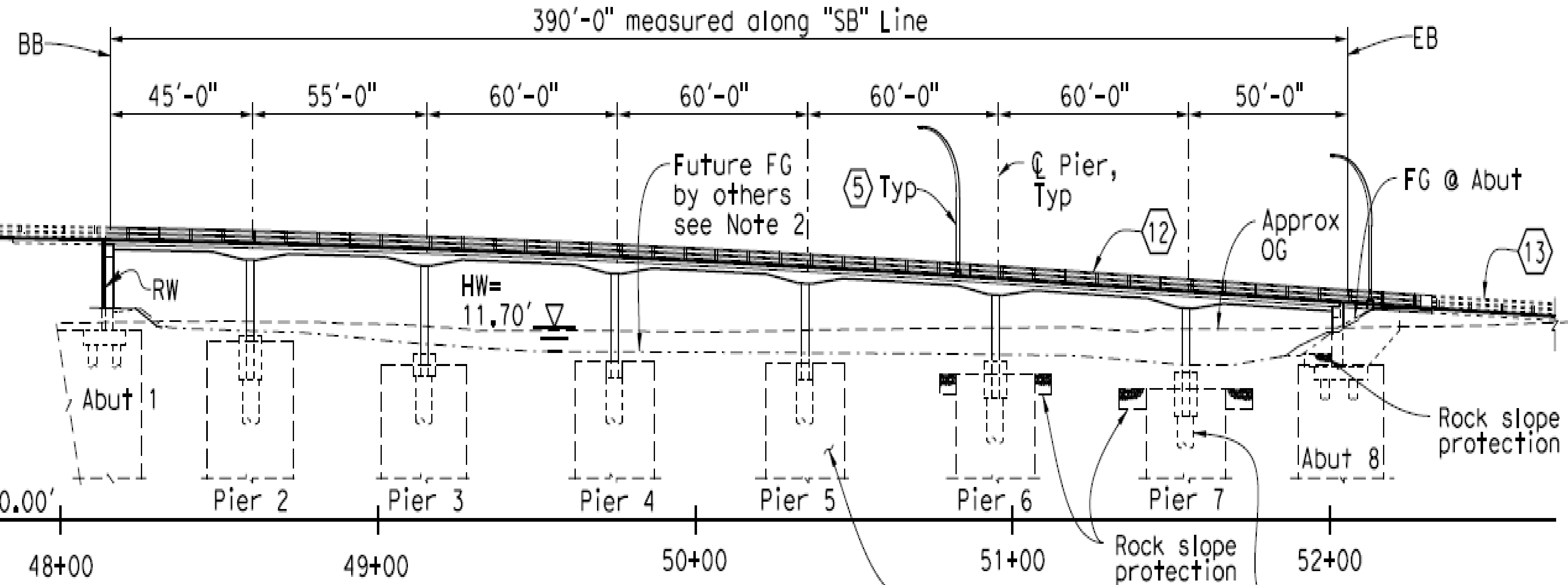
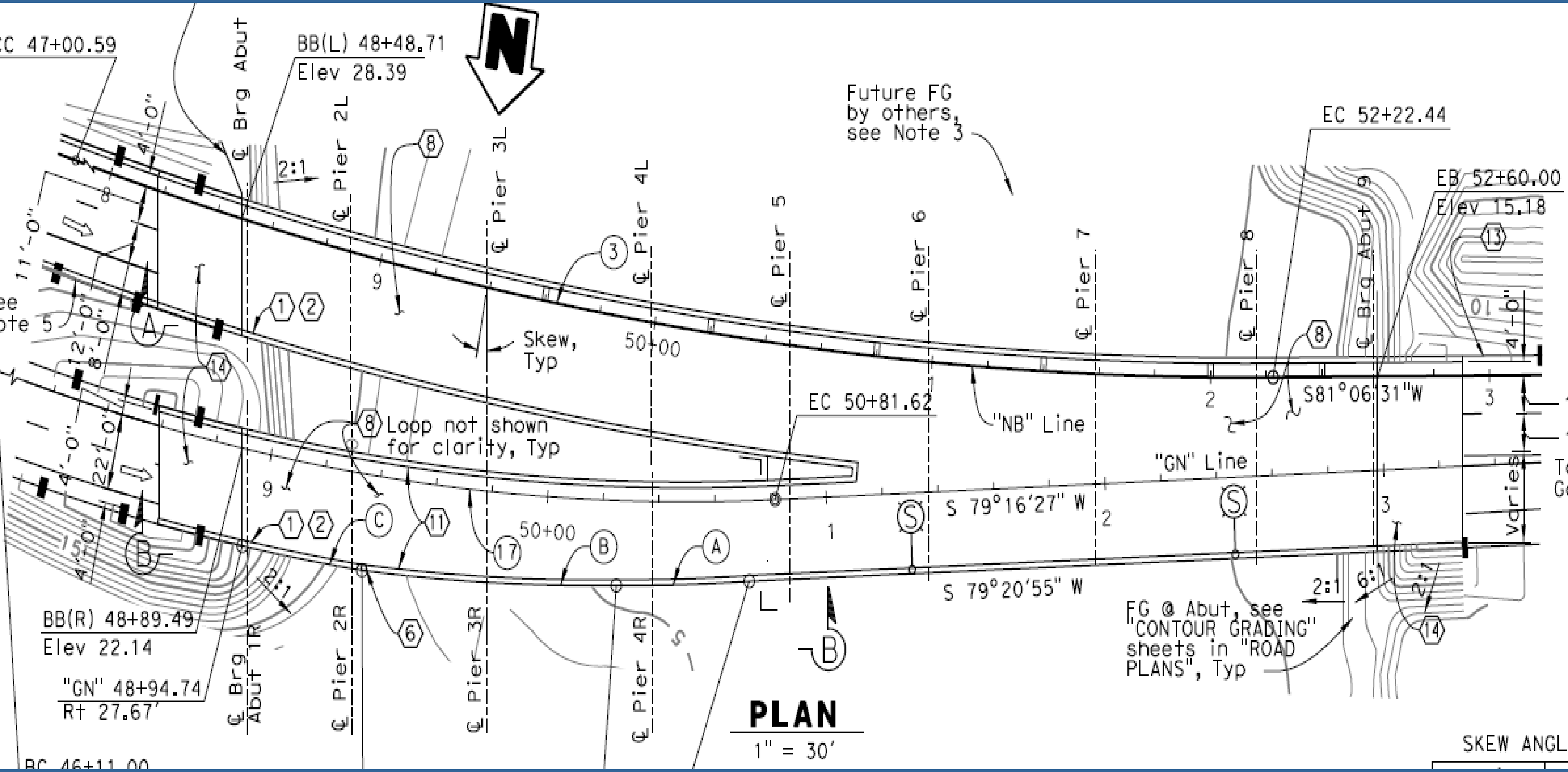
Addition of Rock Slope Protection



ELEVATION
1" = 30'

Elimination of Deck Expansion Joint



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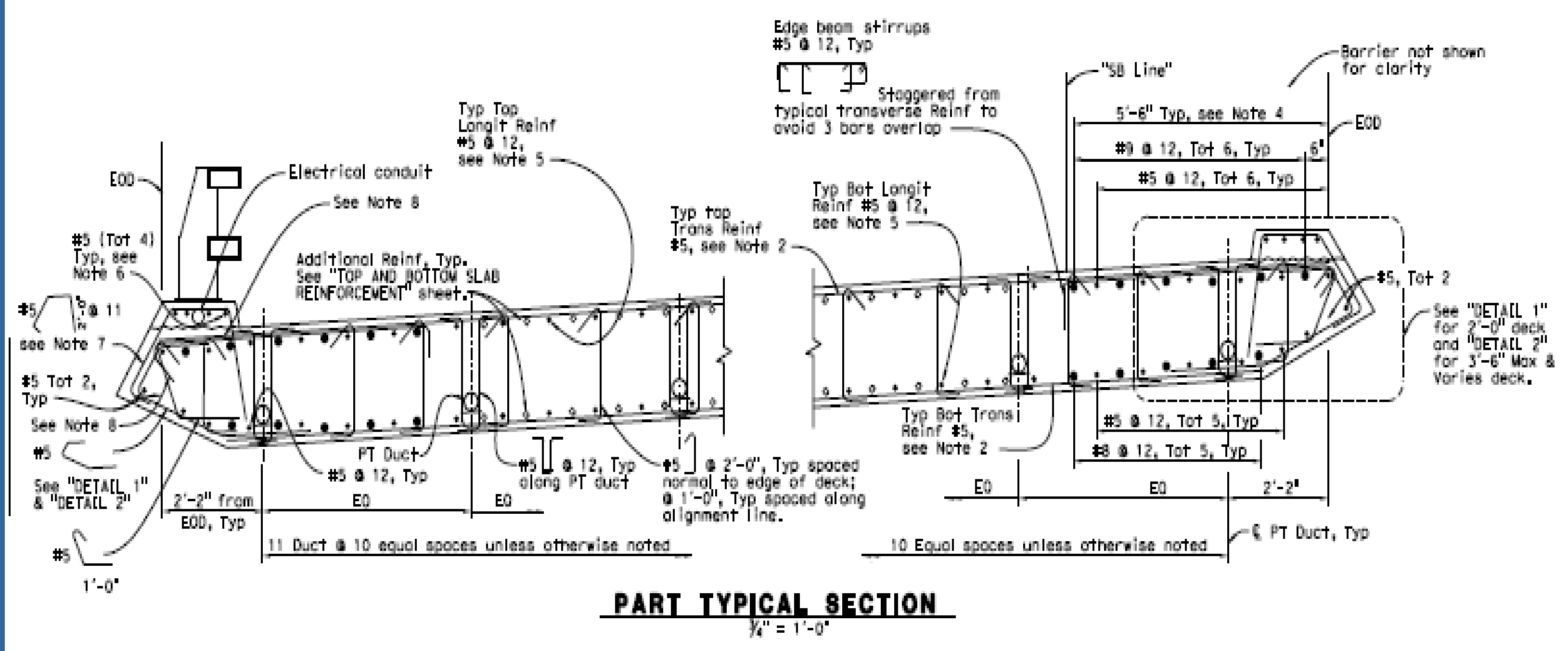
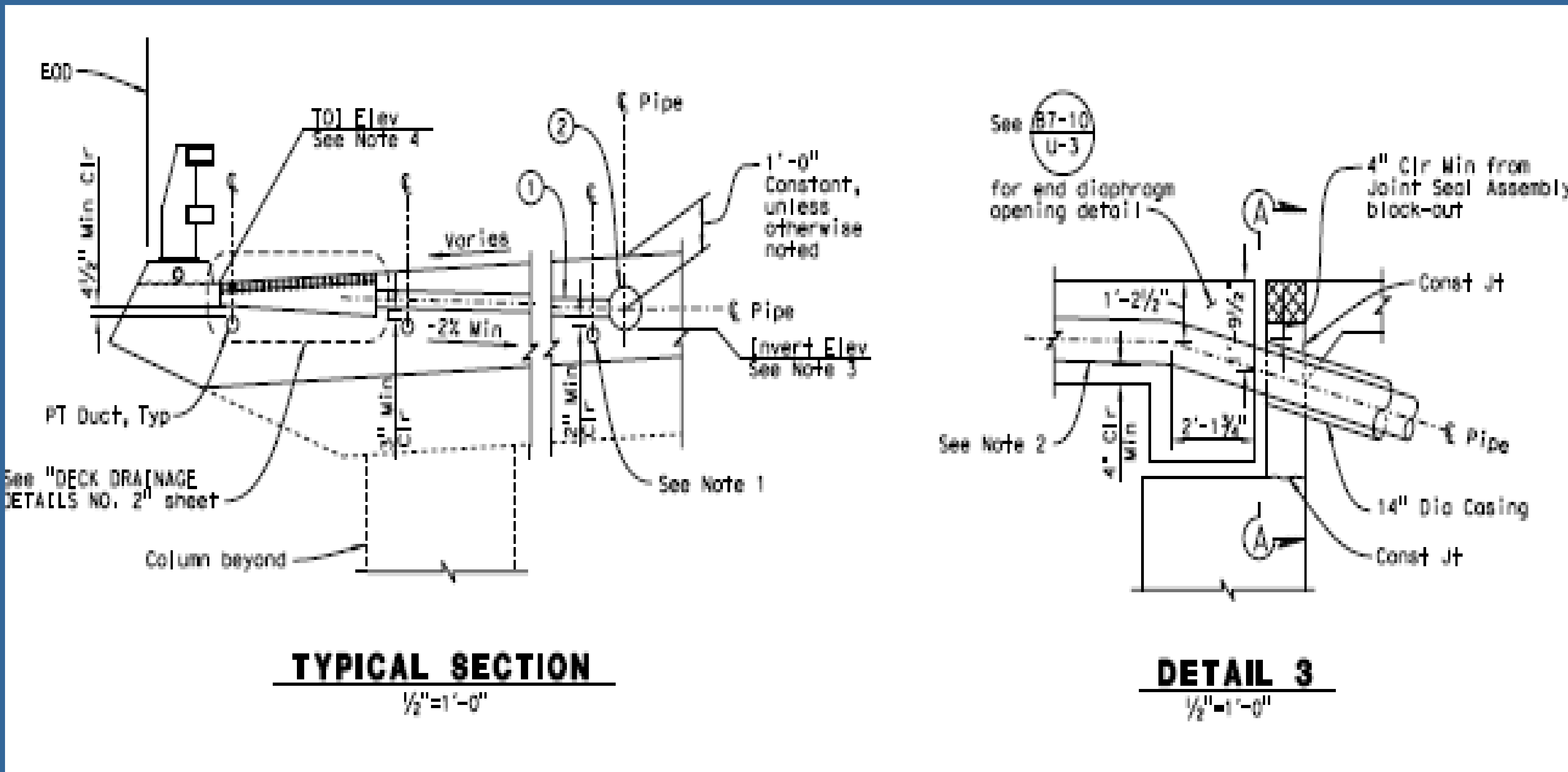
Low Congestion in Deck Reinf.

- Designed for relative settlement of 1” & vertical acceleration



Addition of Deck Drainage



Conclusions

- Architectural driven project posed design challenges.
- Iterative process was required to address several design parameters.
- Challenging site required additional design iterations.
- All complexities were resolved.

Thanks

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