DESIGN OPTIMIZATION FOR SOUND TRANSIT'S LIGHT RAIL LYNNWOOD EXTENSION

Preliminary Structural Design

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WESTERN BRIDGE ENGINEERS' SEMINAR | SEPT 2015

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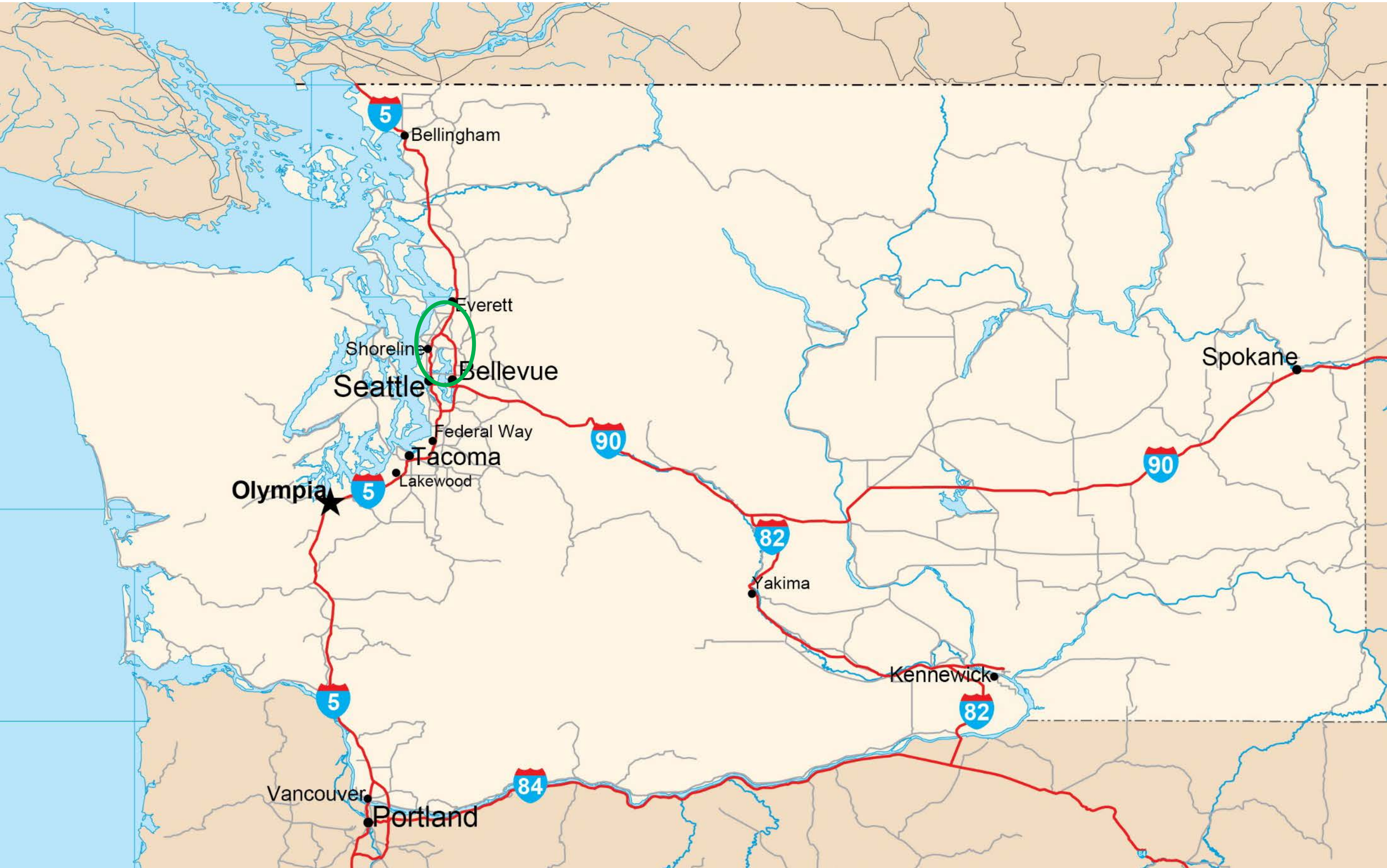
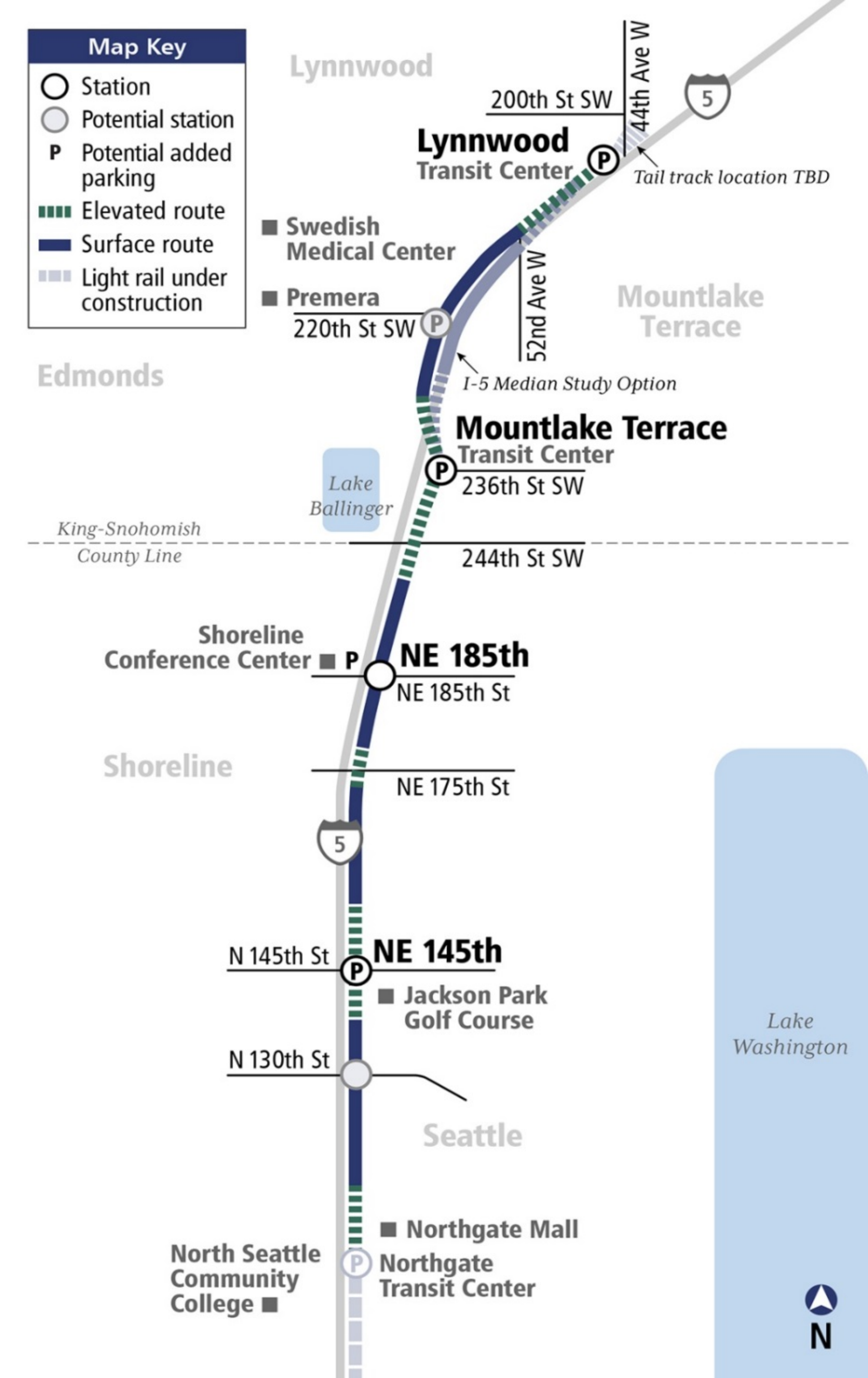
ENGINEERING . PLANNING . ENVIRONMENTAL SCIENCES

PROJECT LOCATION



SOUND TRANSIT LIGHT RAIL LYNNWOOD LINK EXTENSION

- 8.5 miles – Northgate Mall to Lynnwood
- 4.1 miles – Elevated guideway structure
- 4.4 miles – Retaining walls
- Noise walls
- 4 – Light rail stations (+2 future)
- 1 – New pedestrian bridge over I-5
- 1 – Bridge widening over I-5
- 1 – New road bridge over LRT



NORTH CORRIDOR TRANSIT PARTNERS (NCTP)

- A Joint Venture Consultant Team:

Parametrix	Parsons Brinckerhoff

- Sub-consultant firms:

Grijalva Engineering

GHL Consultants

Hewitt Architects

GeoEngineers

Paula Ito CADD Services

Bolima Drafting and Design

And more subconsultants

DESIGN OBJECTIVES

A. Meet Sound Transit's design requirements for safety and performance
B. Design optimization for cost-effectiveness and performance
C. Identify and minimize potential risks
D. Provide cost estimates that support budget and funding planning
E. Support the final EIS studies

EVALUATION CRITERIA FOR OPTIMIZATION

- Performance and Constraints
- Maintenance
- Durability
- Cost
- Speed of Construction
- Constructability
- Aesthetics
- Construction Impacts
- Sound Transit Practices
- Contract Packaging

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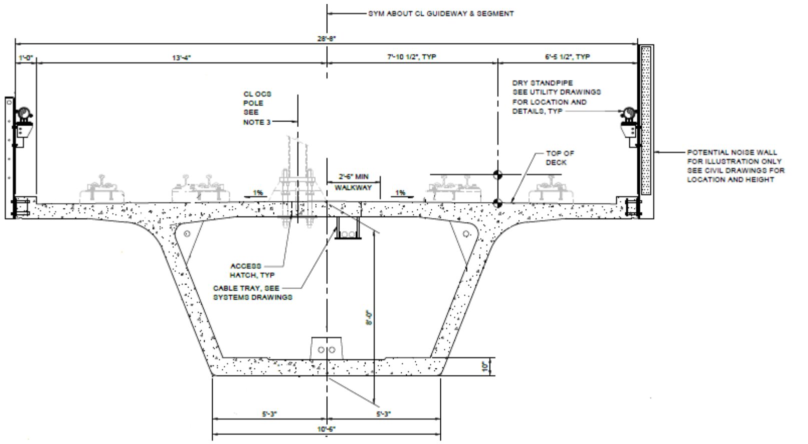
LIGHT RAIL AERIAL GUIDEWAY

- Types of superstructure/girders
- Typical girder sections
- Span lengths and layouts
- Pier shapes and sizes
- Foundations

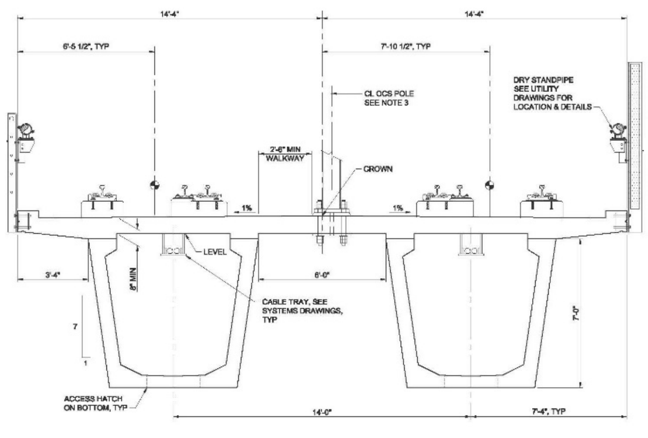
TYPES OF SUPERSTRUCTURE / GIRDER (4.1 MILES +/-)

Segmental Box Girders



TYPICAL CROSS SECTION
SCALE: 1/2" = 1'-0"

PT Precast Tub Girders



TYPICAL GUIDEWAY SECTION
SCALE: 1/2" = 1'-0"

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TYPICAL SEGMENTAL BOX GIRDER SECTIONS

- Girder depth
- Deck width
- Web slant ratio
- Interface with piers
- PT layout and diaphragms
- Super-elevation

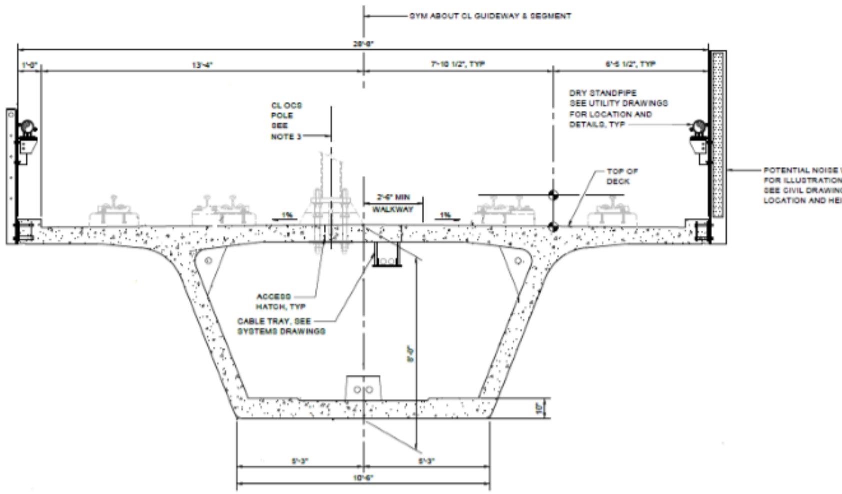
BOX GIRDER SECTION

Typical depth = 8 feet

- Convenient height for maintenance works
- Suitable for desired span length
- Proportional to the deck width (twin tracks)

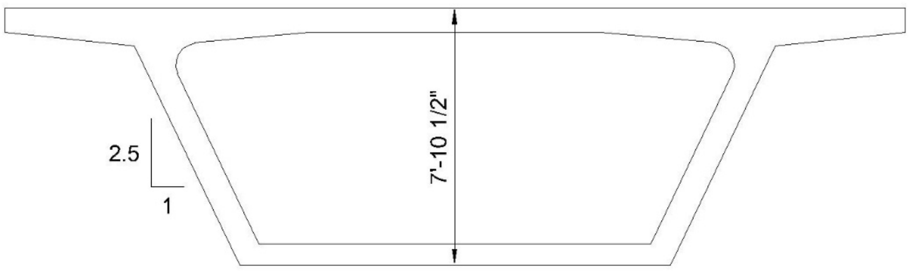
Deck width (Twin Tracks) = 28’- 8”

Soffit width = 10’ - 6”

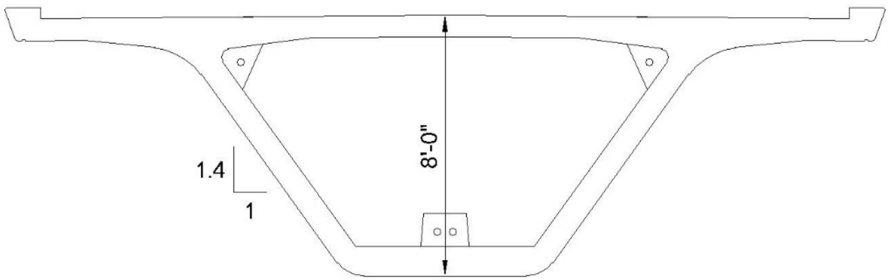


TYPICAL CROSS SECTION
SCALE: 1/2" = 1'-0"

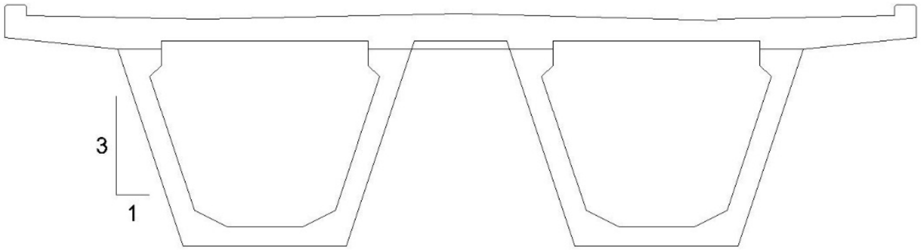
WEB SLANT RATIO (V/H)



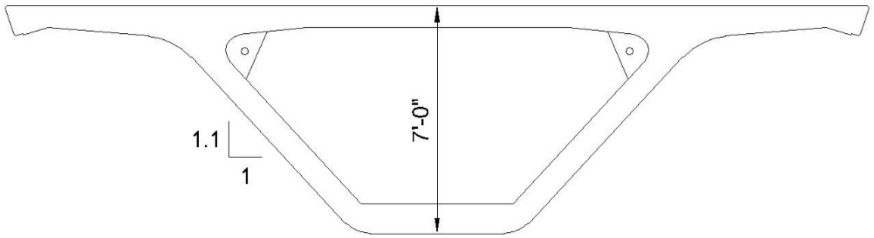
AASHTO Standard 2.5V/1.0H



S. 200th Link Extension 1.4V/1.0H



Northgate Link Extension 3.0V/1.0H



Central Link Light Rail 1.1V/1.0H

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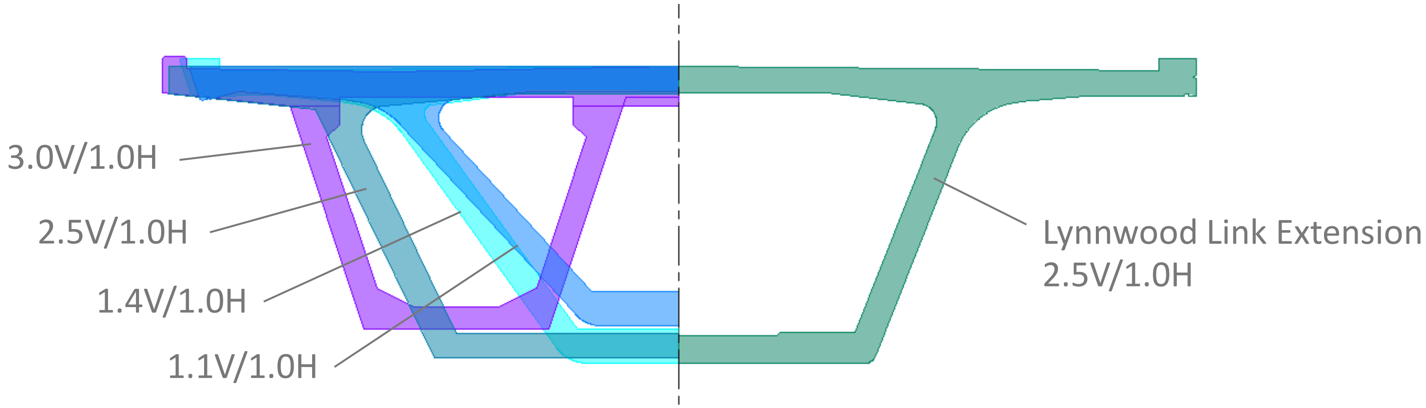
WEB SLANT RATIO (V/H)

Increase V/H Ratio (more vertical):

- Increase PT force vertical components (efficient)
- Increase box torsional capacity and section modulus
- More box interior space
- Less aerodynamic transversely

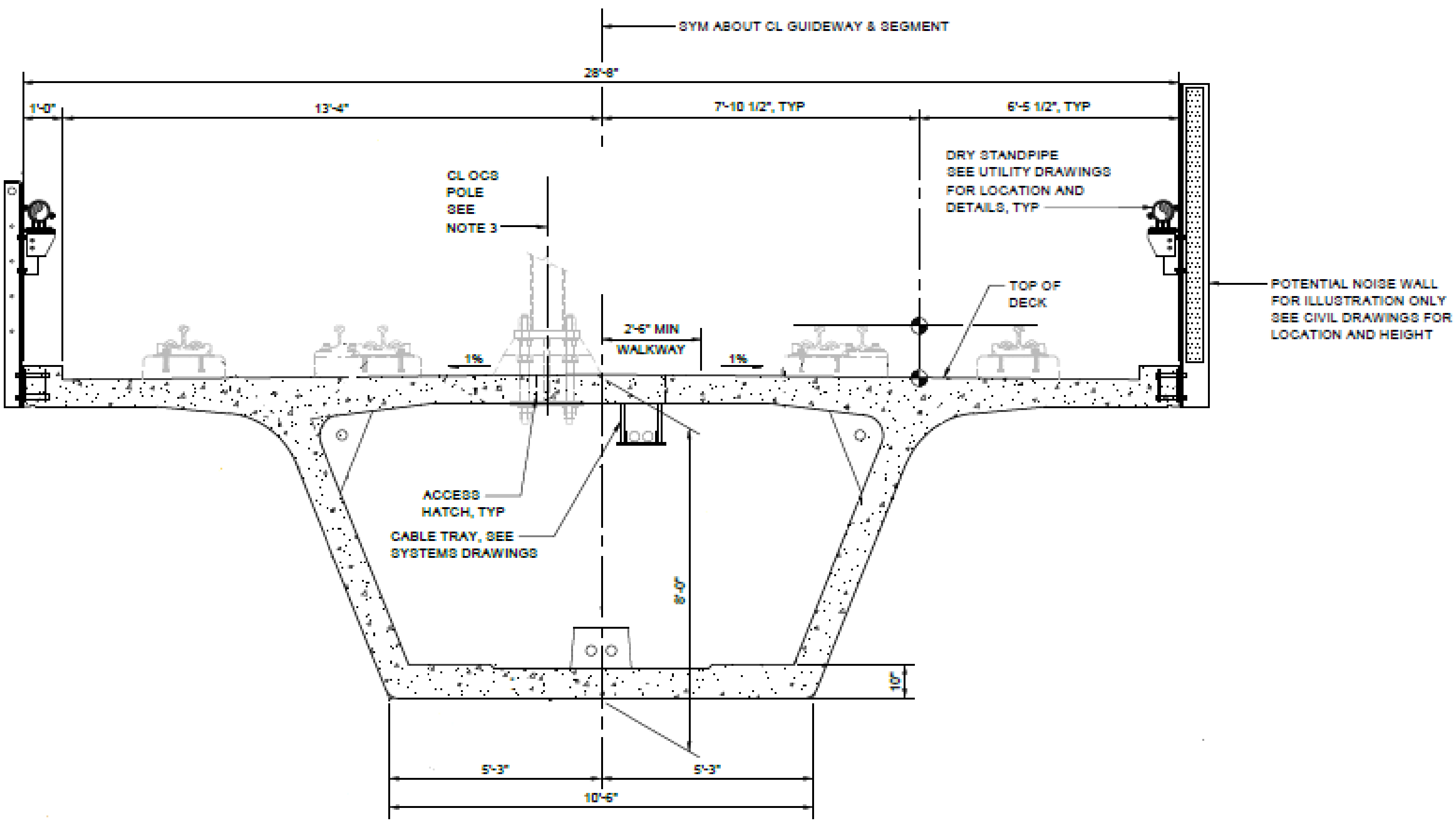


WEB SLANT RATIO (V/H): VISUAL EFFECTS

Integral with rectangular columns

Streamline and match tub girder

TYPICAL SECTION – TWIN TRACK



TYPICAL CROSS SECTION

SCALE: 1/2" = 1'-0"

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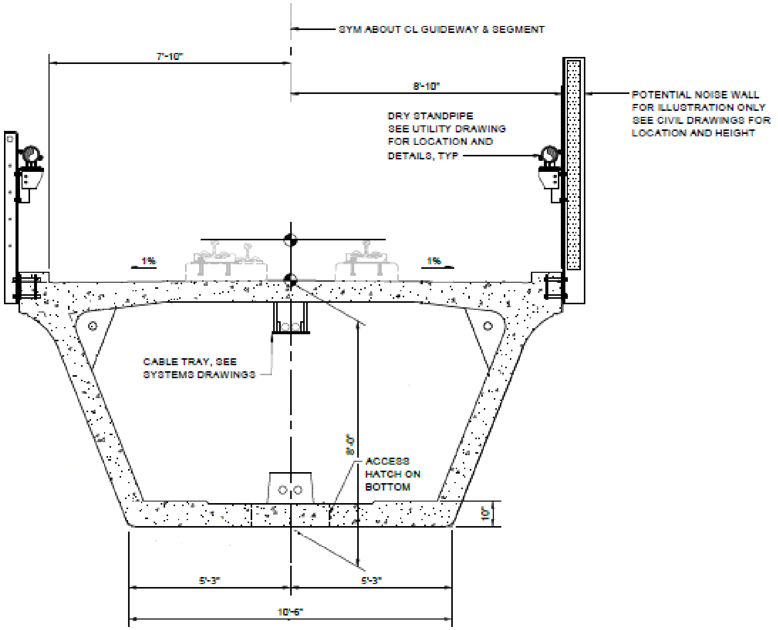
TYPICAL SECTION – SINGLE TRACK

- Box section same as the twin track box
- Same section geometry
- Without deck overhangs
- Same interface with the piers



TYPICAL CROSS SECTION
SCALE: 1/2" = 1'-0"

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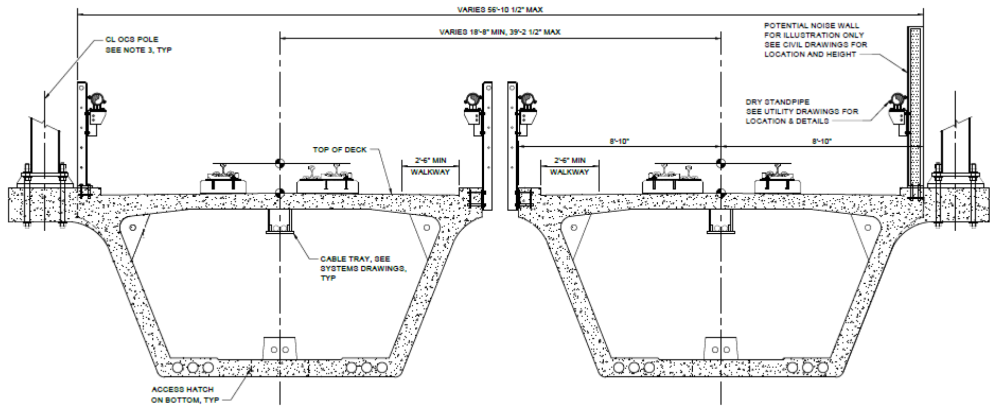
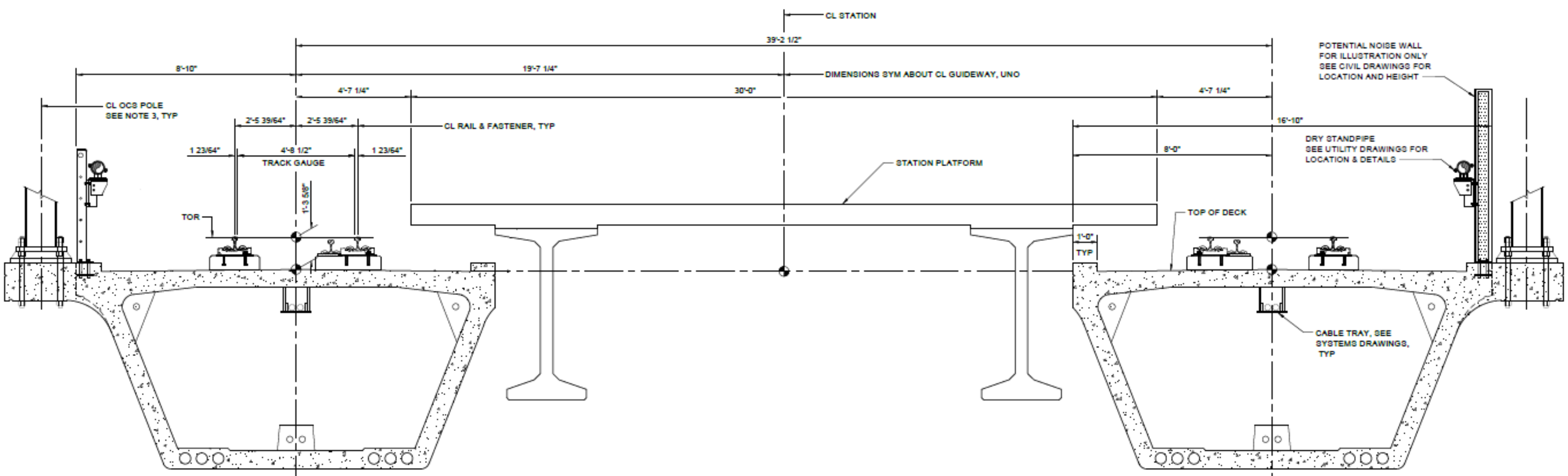
TYPICAL SECTION – SINGLE TRACK



TYPICAL SECTION - GUIDEWAY NEAR STATION

SCALE: 1/2" = 1'-0"



TYPICAL SECTION - GUIDEWAY AT STATION

SCALE: 1/2" = 1'-0"

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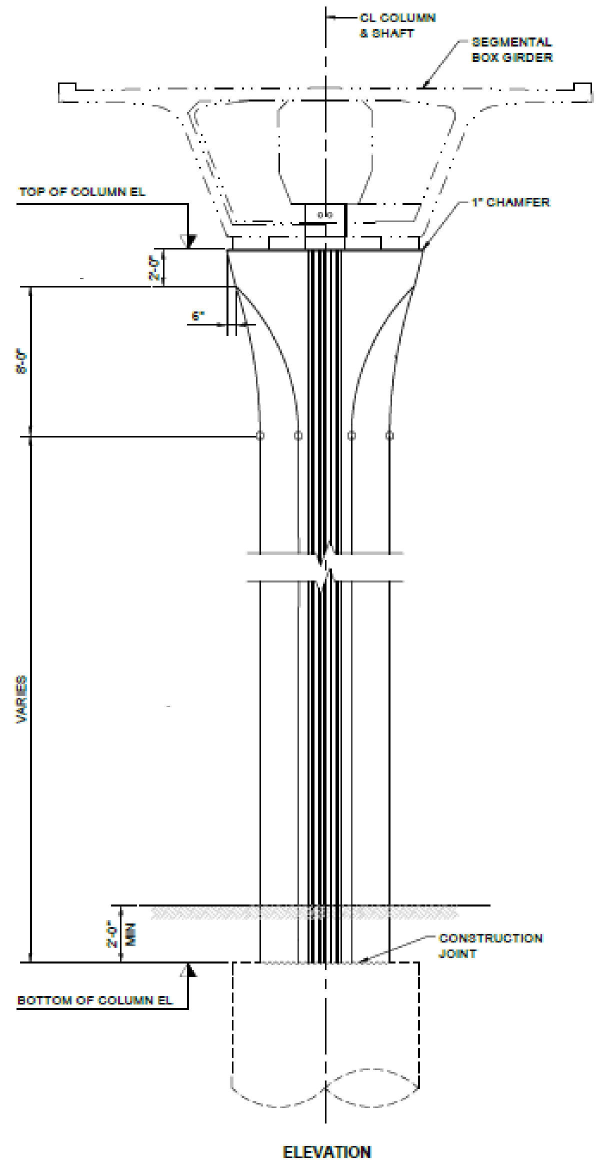
PIER INTERFACE

- No external diaphragm
- Integral
- Pin
- Movable



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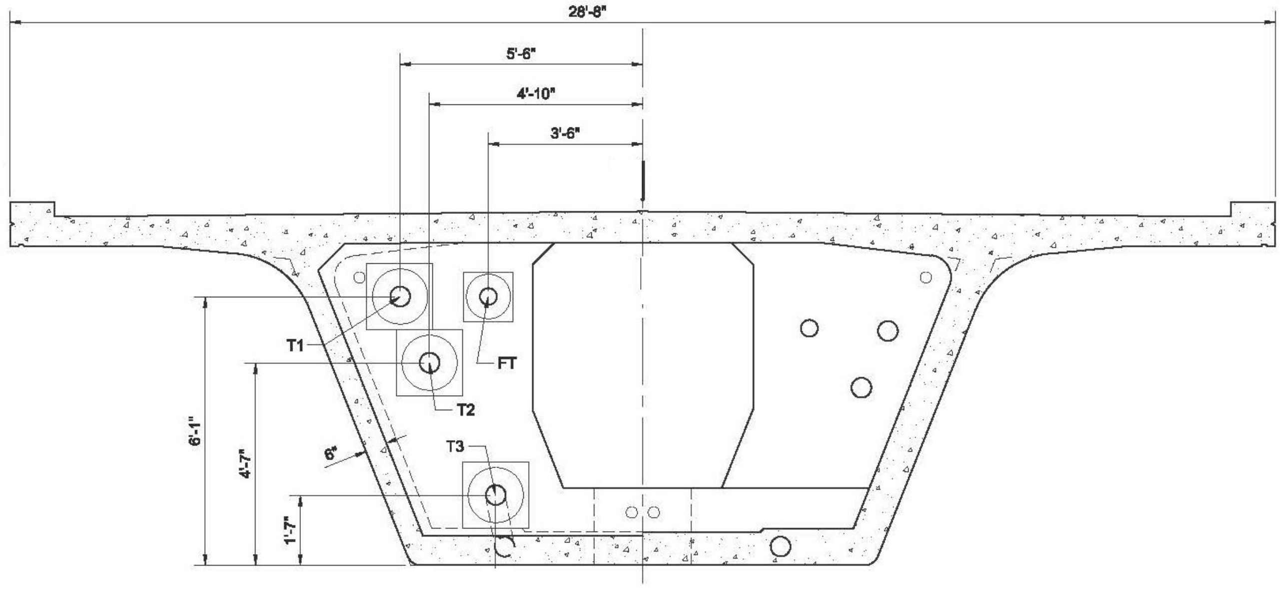
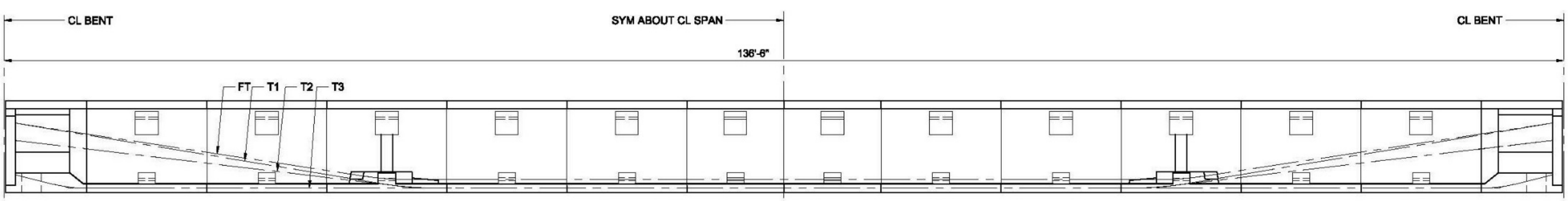
PT LAYOUT AND DIAPHRAGMS





VERTICAL SECTION AT CL GUIDEWAY

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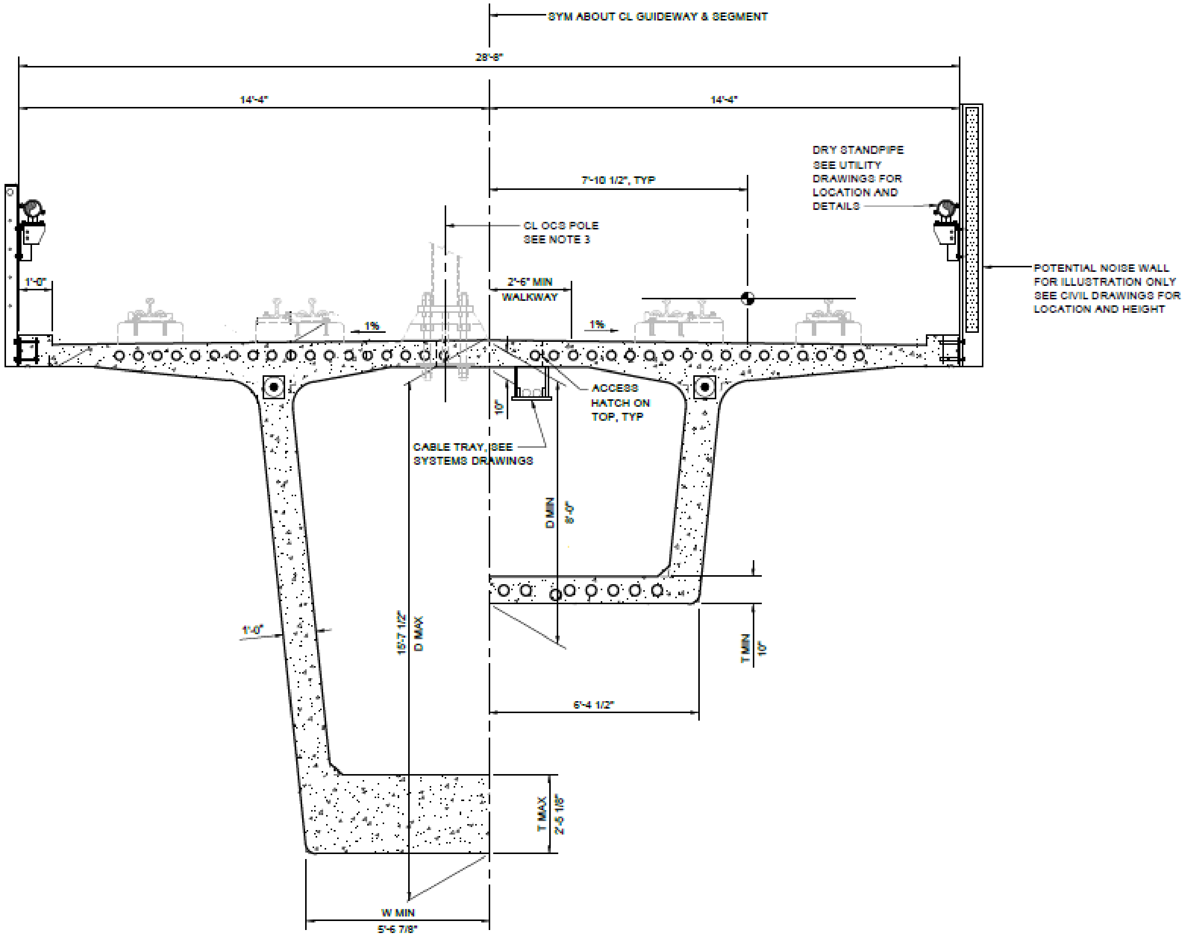
VARIABLE DEPTH SECTION – LONG SPANS



HALF SECTION
NEAR INTERIOR PIERS
SCALE: 1/2" = 1'-0"

HALF SECTION
MIDDLE SPAN PORTION
SCALE: 1/2" = 1'-0"

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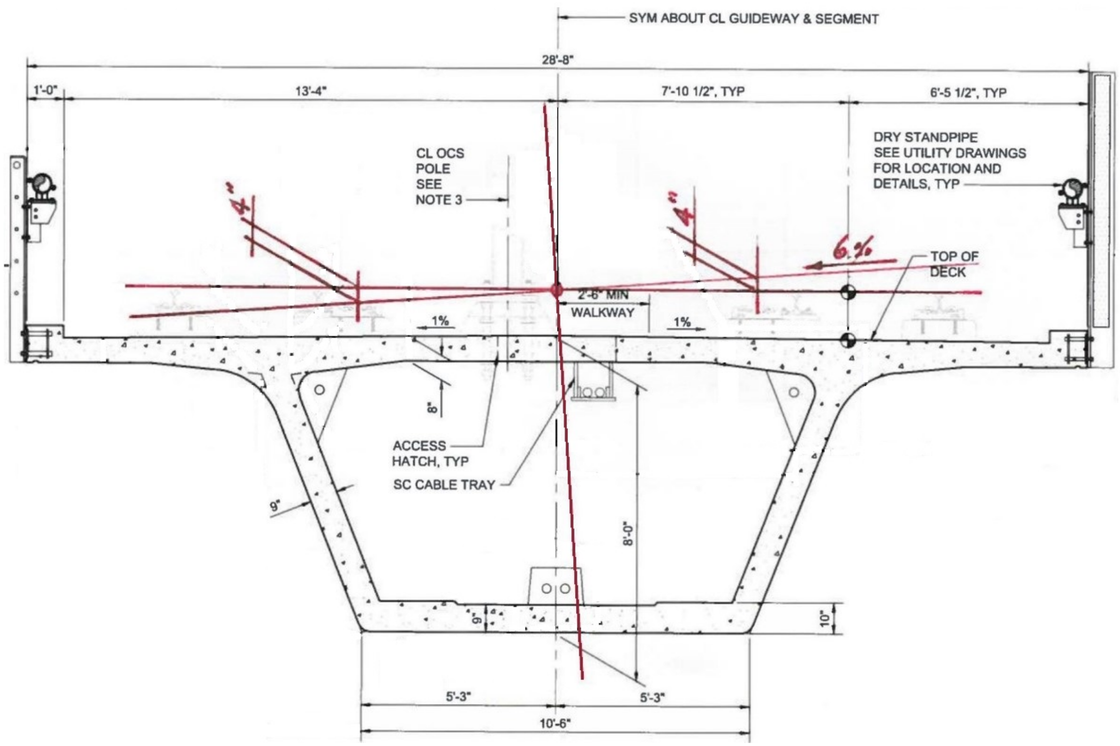
SUPER-ELEVATION: ADJUST PLINTH HEIGHTS

- Adjusting plinth heights instead of rotating the boxes
  - Reduce vertical ups and downs of the tracks
  - Reduce the length of vertical curves of the tracks



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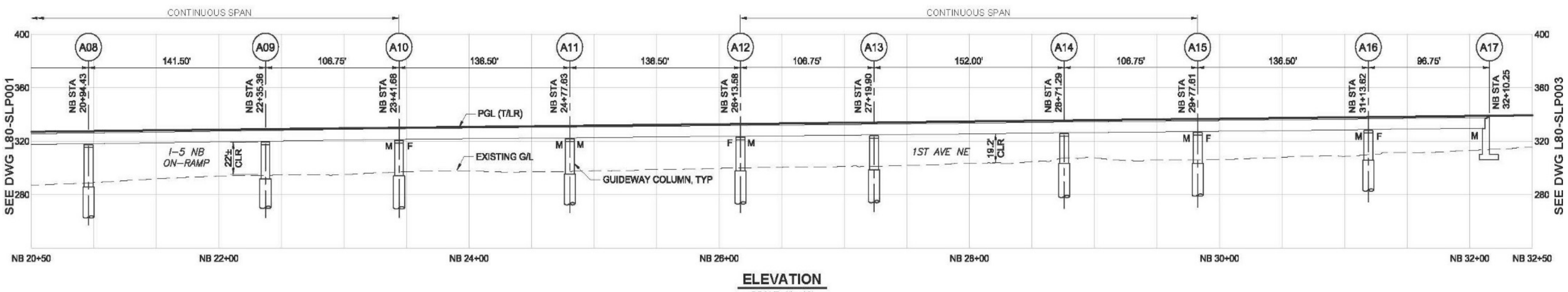
AERIAL GUIDEWAY STRUCTURE TYPICAL LAYOUT

Approximately 4.1 miles of elevated guideway structures, Construction efficiency is important.

- Maximize the use of simply supported girders
- Double cantilever construction for long spans



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MAXIMUM SPAN LENGTH

- Strength (load support capacity)
- Deflections/displacements
- Accelerations/vibrations
- Allowable rail gap length
- Construction methods

VIBRATION AND DEFLECTION

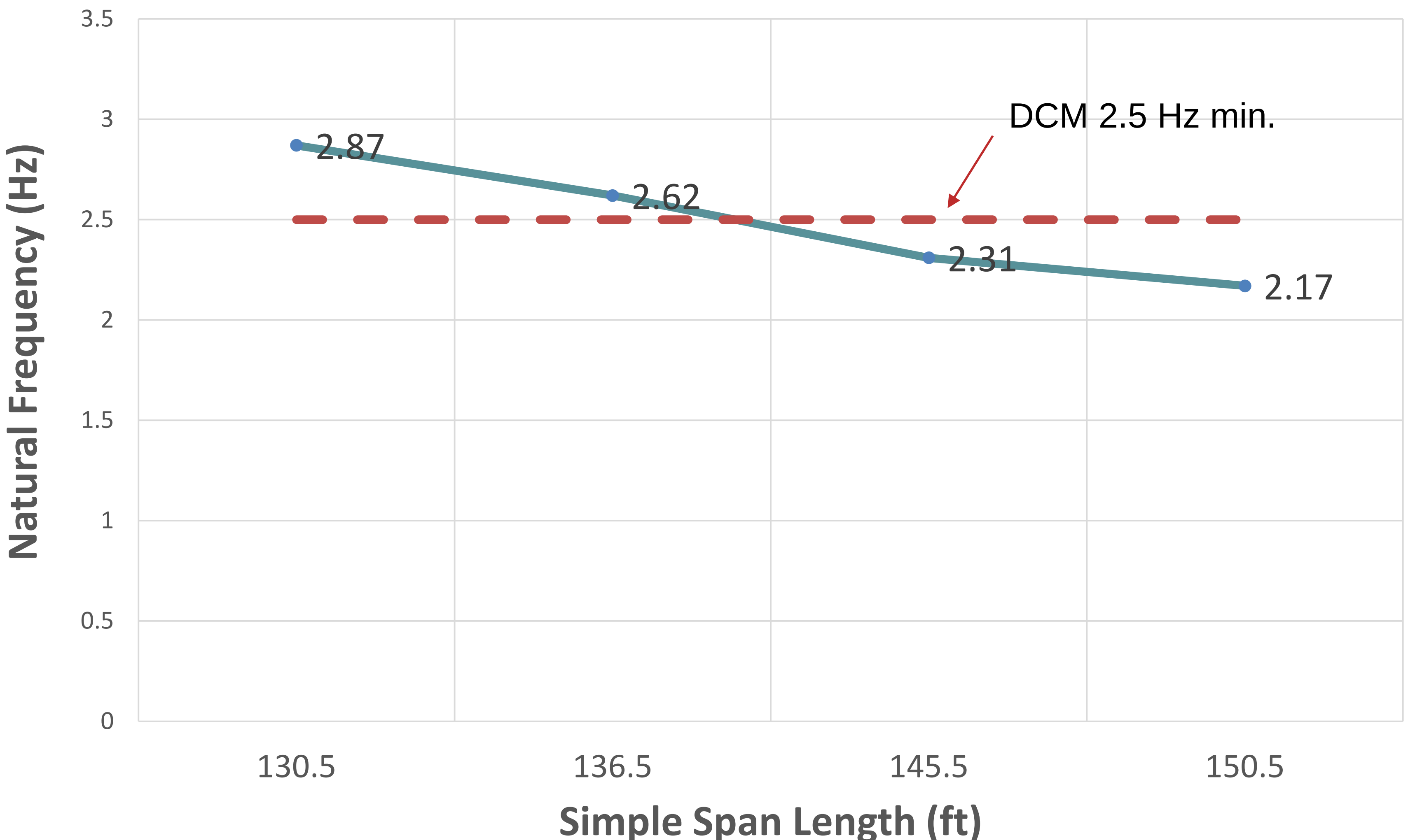
Vibration

- First mode of natural frequency
  - Simply Supported Span >= 2.5 Hz
  - Continuous Spans >= 3.0 Hz
- If frequency lower than above criteria, rail car and track interaction shall be evaluated

Deflection

- Deflections due to LL + Dynamic <= L/1,000

SIMPLE SPAN LENGTH (FT) VS. NATURAL FREQUENCY (Hz)



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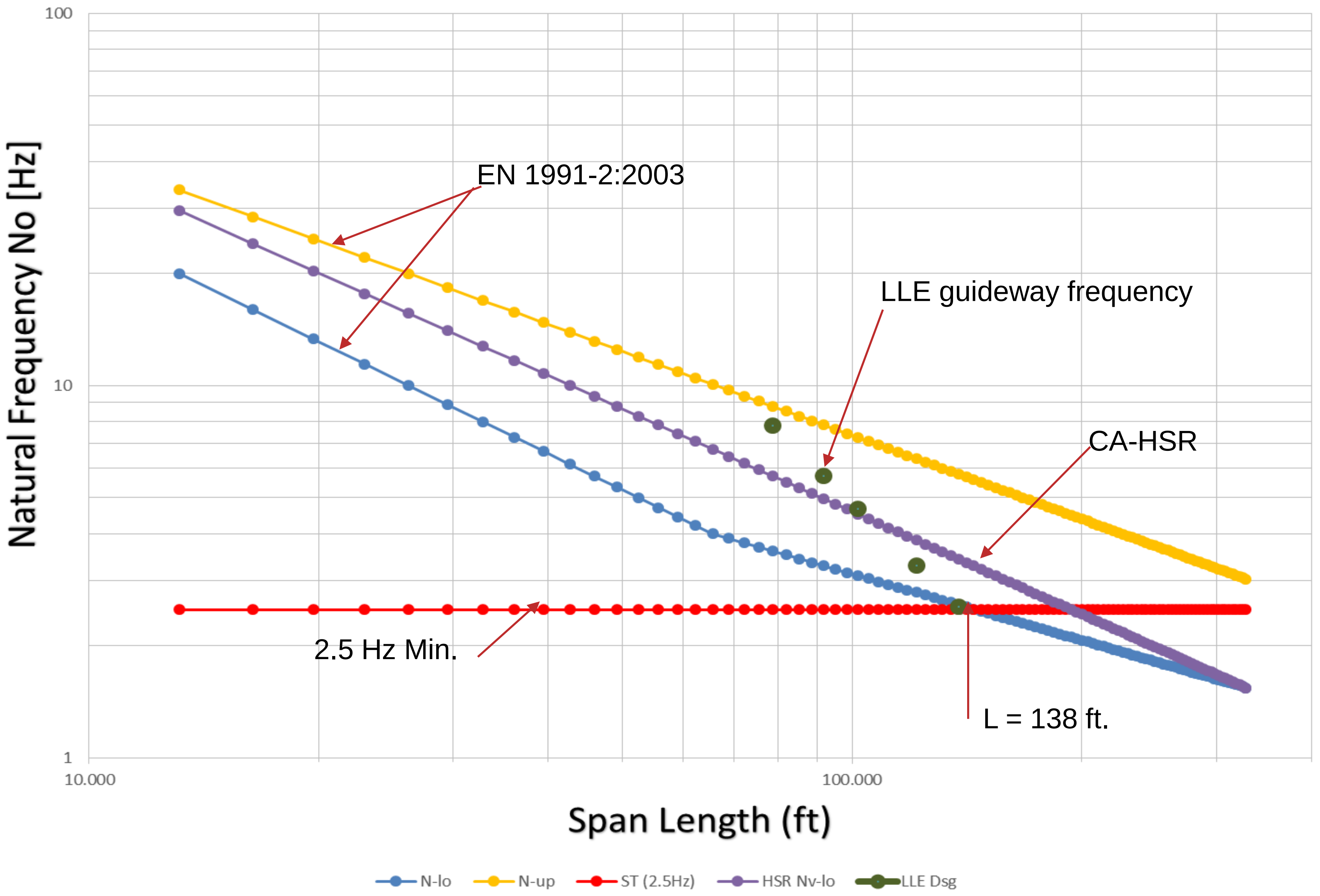
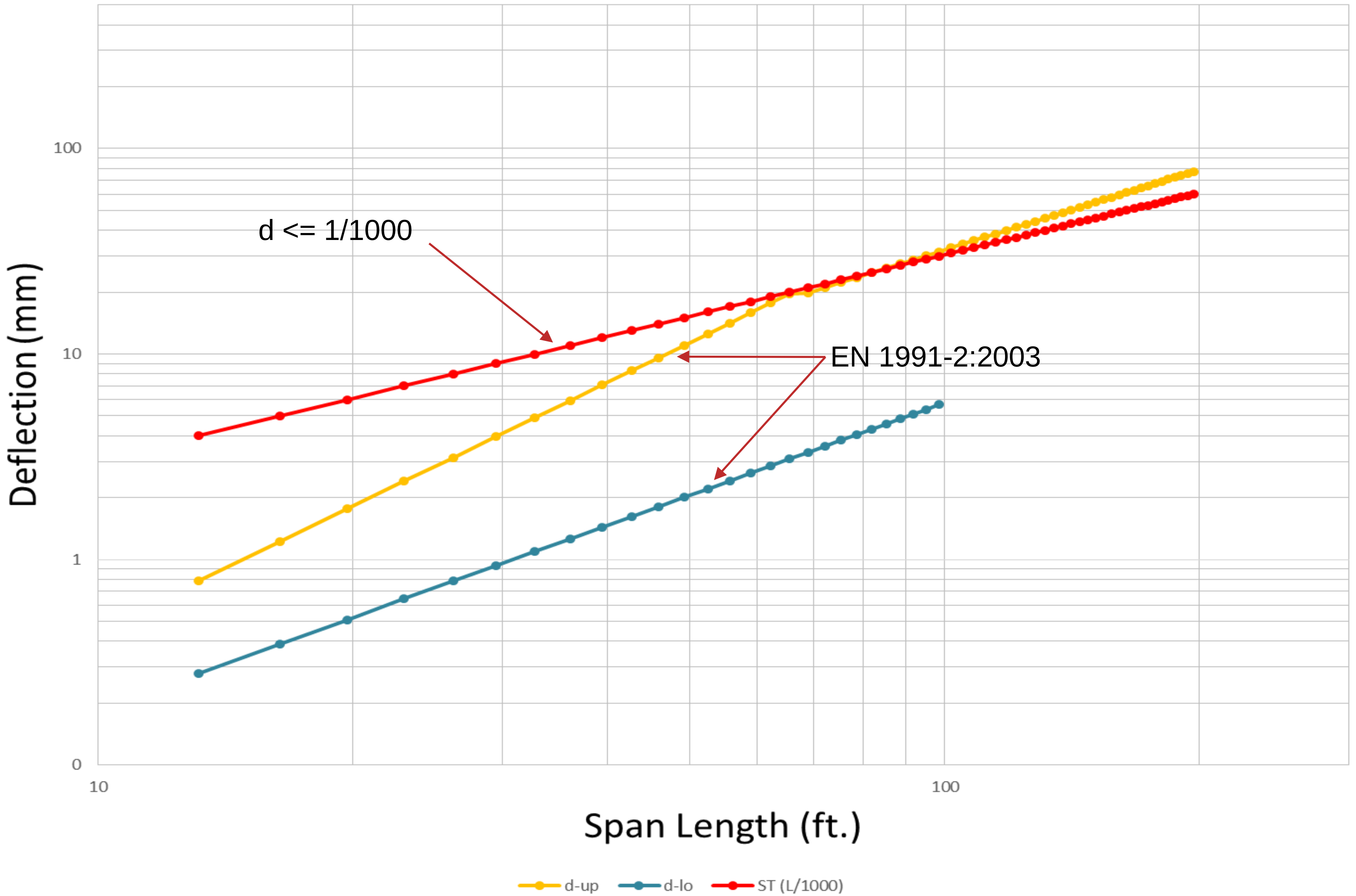
NATURAL FREQUENCY LIMITS VS. SPAN LENGTH

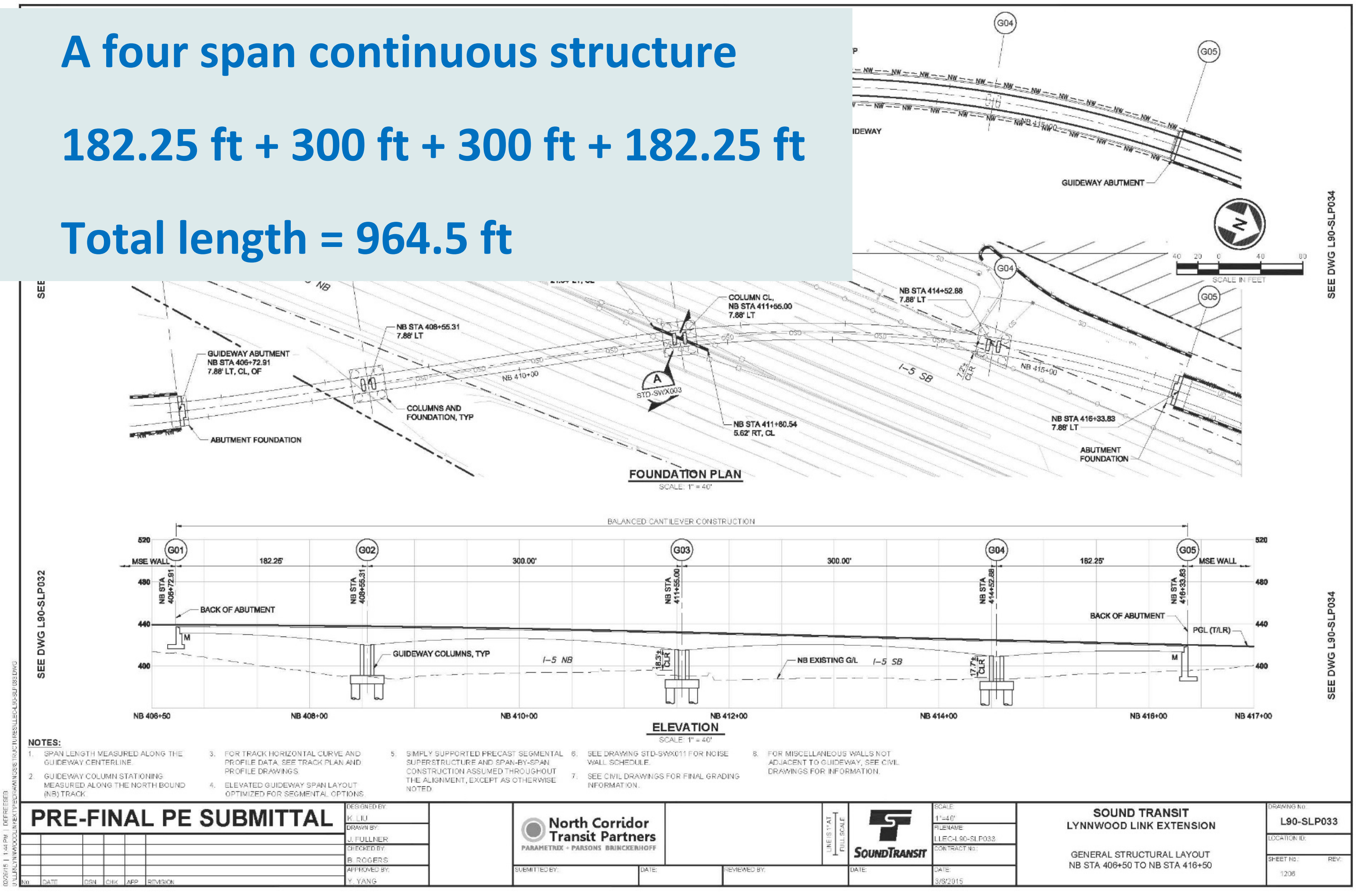


DEFLECTION LIMITS VS. SPAN LENGTH



RAIL GAP (Δ) CHALLENGE

- **A four span continuous structure**
- **182.25 ft + 300 ft + 300 ft + 182.25 ft**
- **Total length = 964.5 ft**



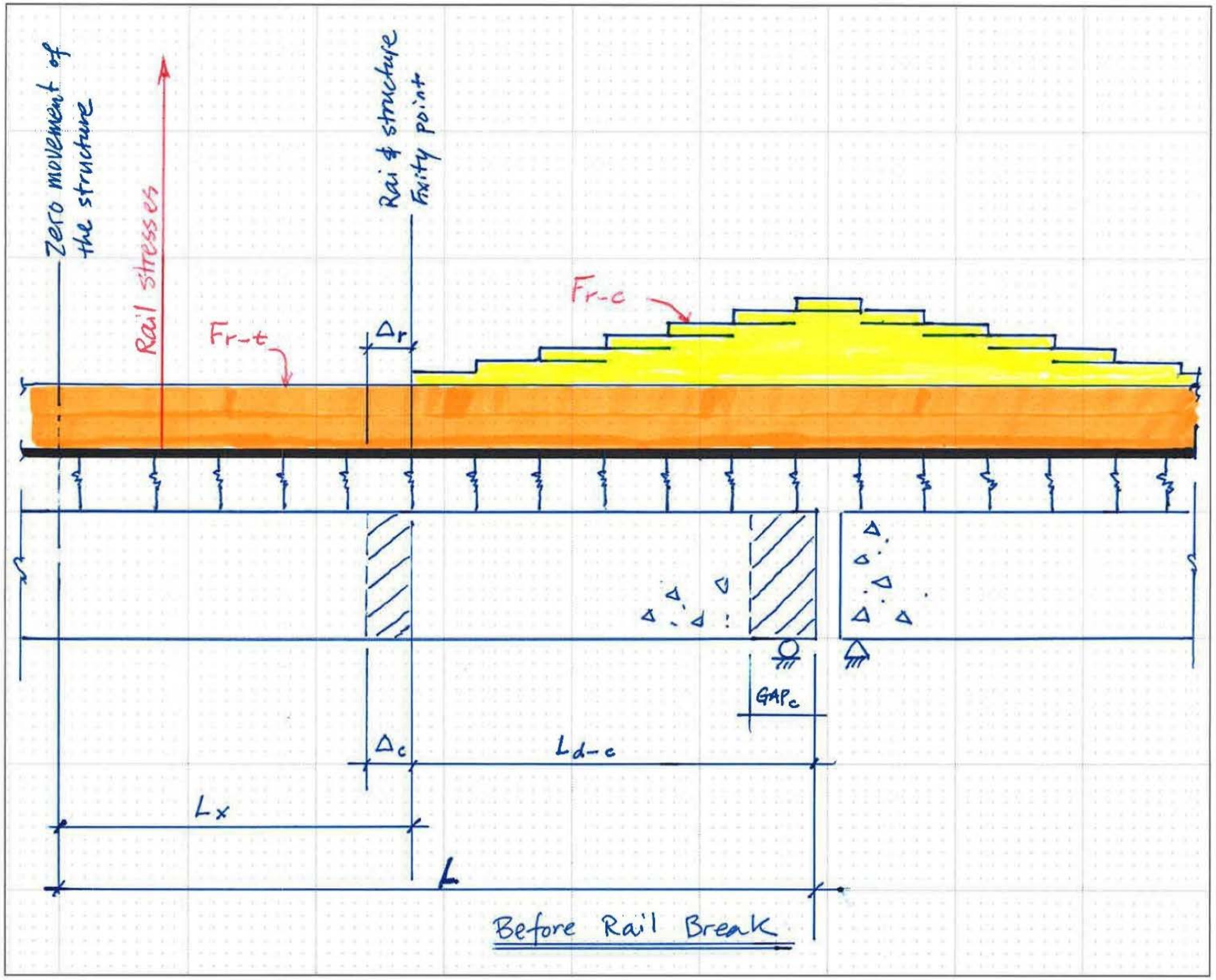
RAIL GAP Δ

- Sound Transit DCM: Broken rail gap <= 2 inches
- Sound Transit may approve slightly wider gaps under special conditions

MAJOR FACTORS THAT INFLUENCE RAIL GAP

- Concrete strength (f’c)
- Young’s modulus of concrete (Ec) and rail (Es)
- Temperature range (TU)
- Rail fastener friction (F**f**) & spacing (S**f**)
- Rail vehicle acceleration/deceleration
- Supporting structure movement (Δ)

RAIL INTERNAL STRESSES AND GAP



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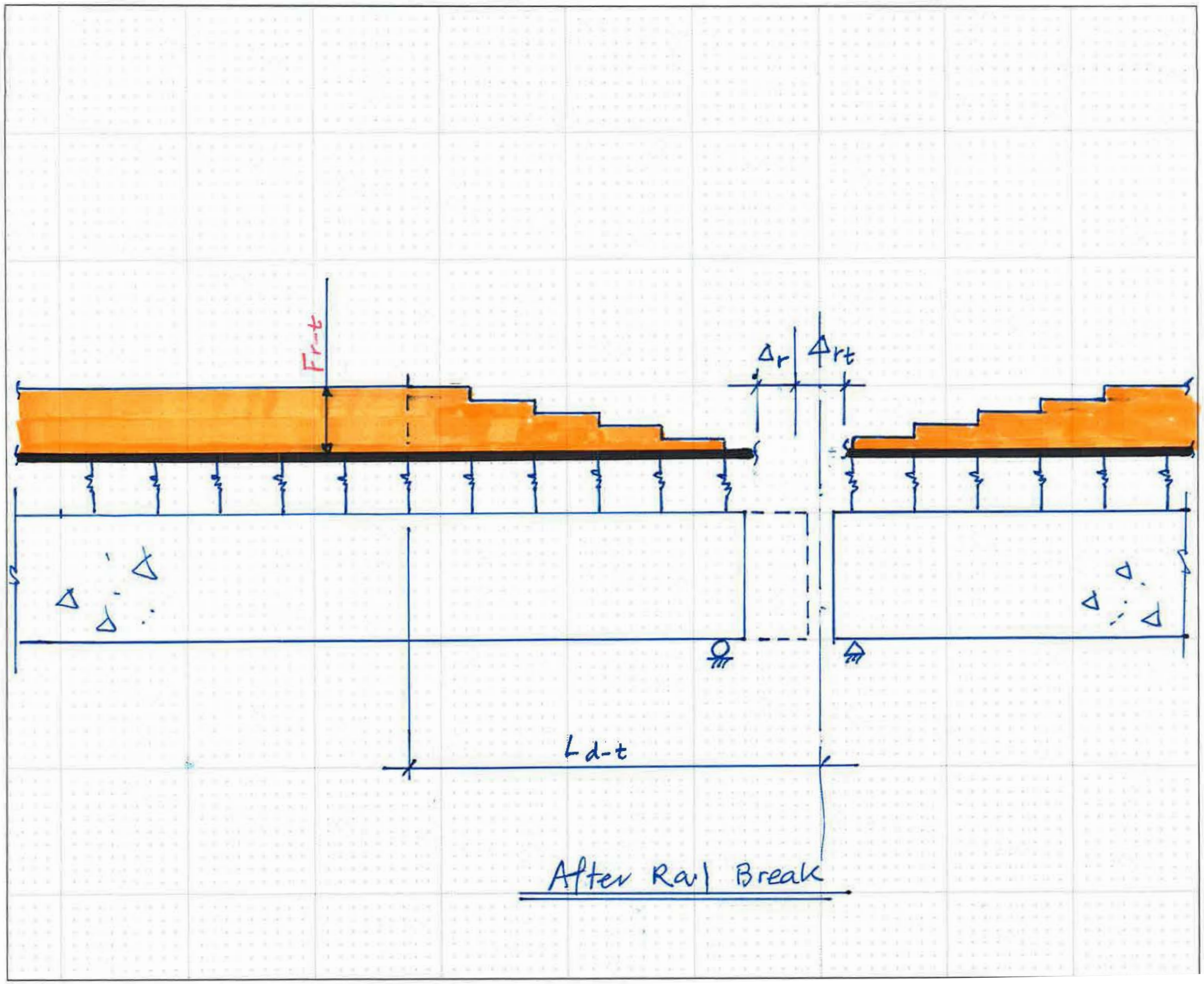
RAIL INTERNAL STRESSES AND GAP



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RAIL GAP Δ

- If rail breaks, at either abutment (expansion joint)

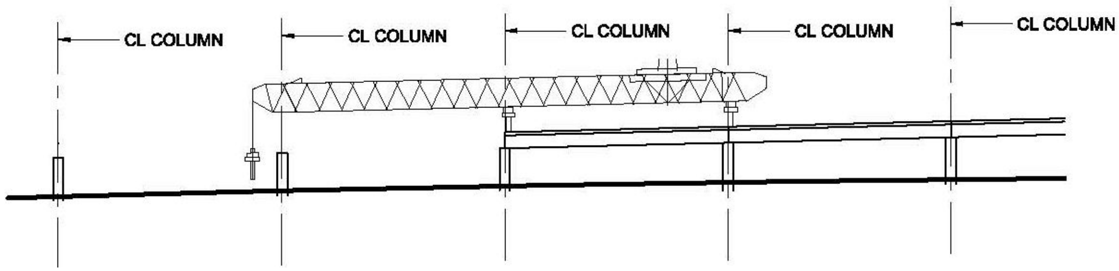
  Total **Δ** (rail stresses, temperature, structural move, etc.)

  = 2.3 inches

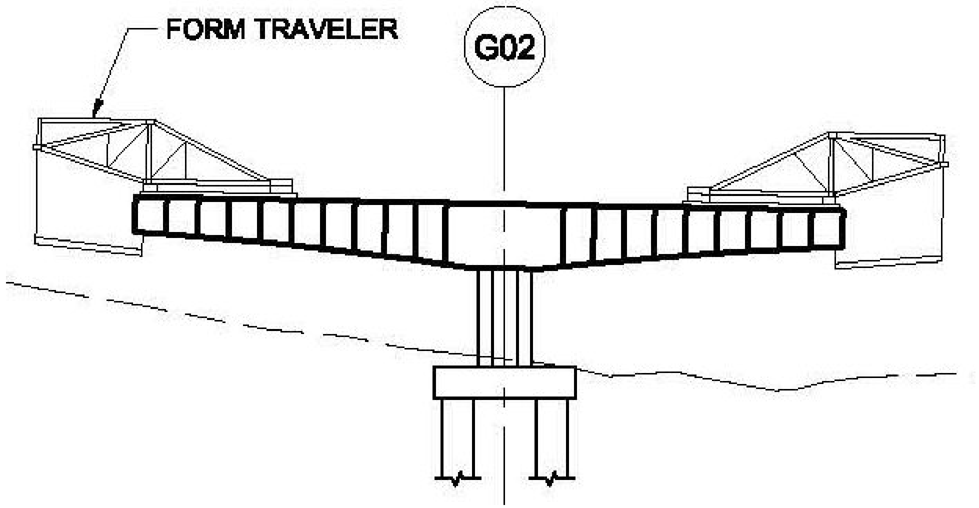
  Accepted for this special condition (Long Span)

CONSTRUCTION METHODS (SUGGESTED)

Span by span for constant depth girders

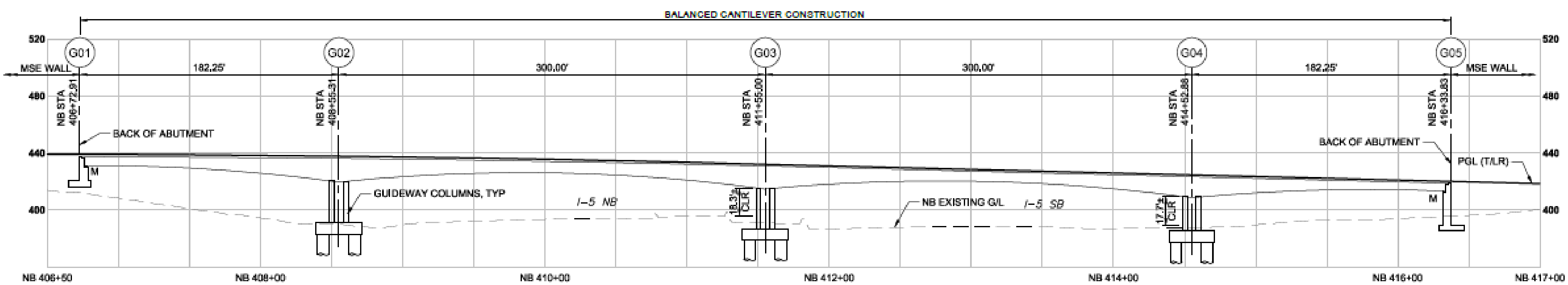


Double cantilever for variable depth long span girders



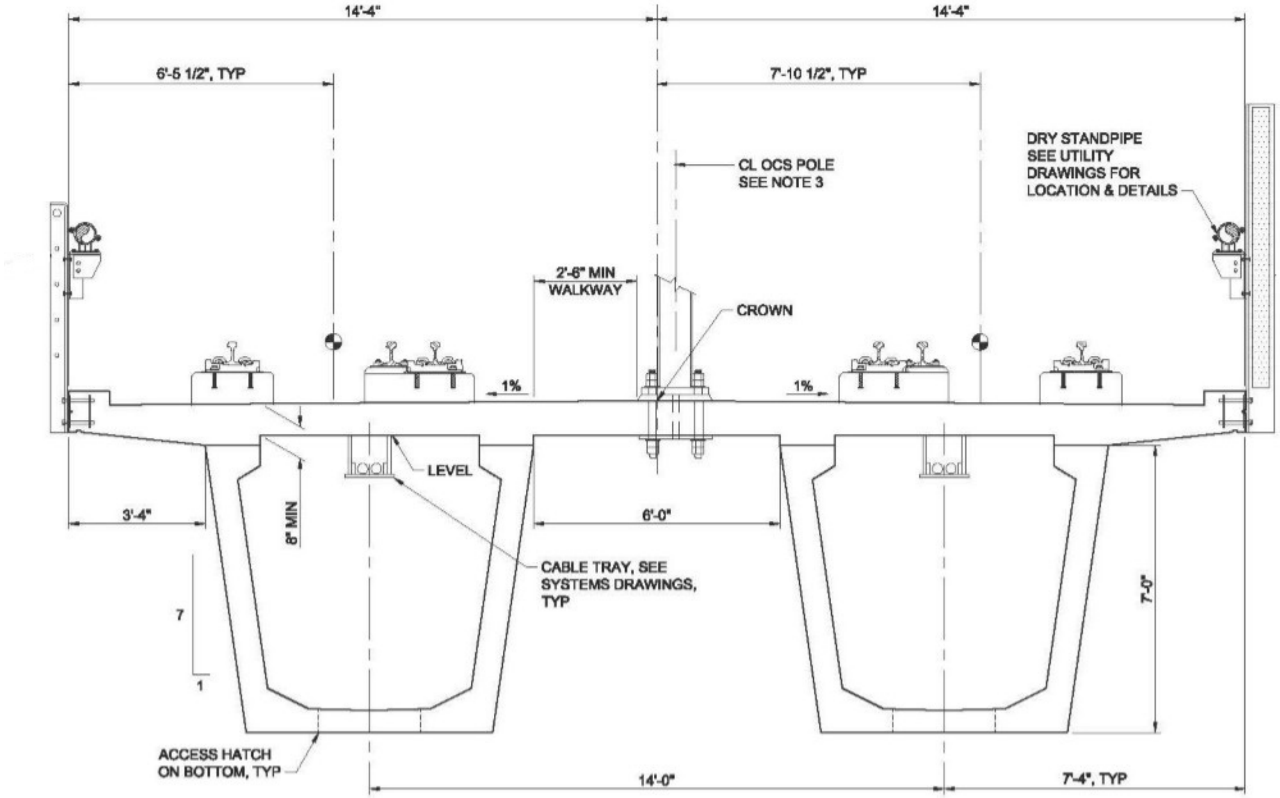
MAXIMUM SPAN LENGTHS (SEGMENTAL)

- Constant depth girder 8 feet typical:
  - Simply Supported Span, L max = 137 feet +/-
  - Continuous Interior Span, L max = 150 feet +/-
- Long spans with viable depth girders:
  - L max = 300 feet



ELEVATION
SCALE: 1" = 40'

PT TUB GIRDERS – STRUCTURAL ALTERNATIVE



TYPICAL GUIDEWAY SECTION

SCALE: 1/2" = 1'-0"

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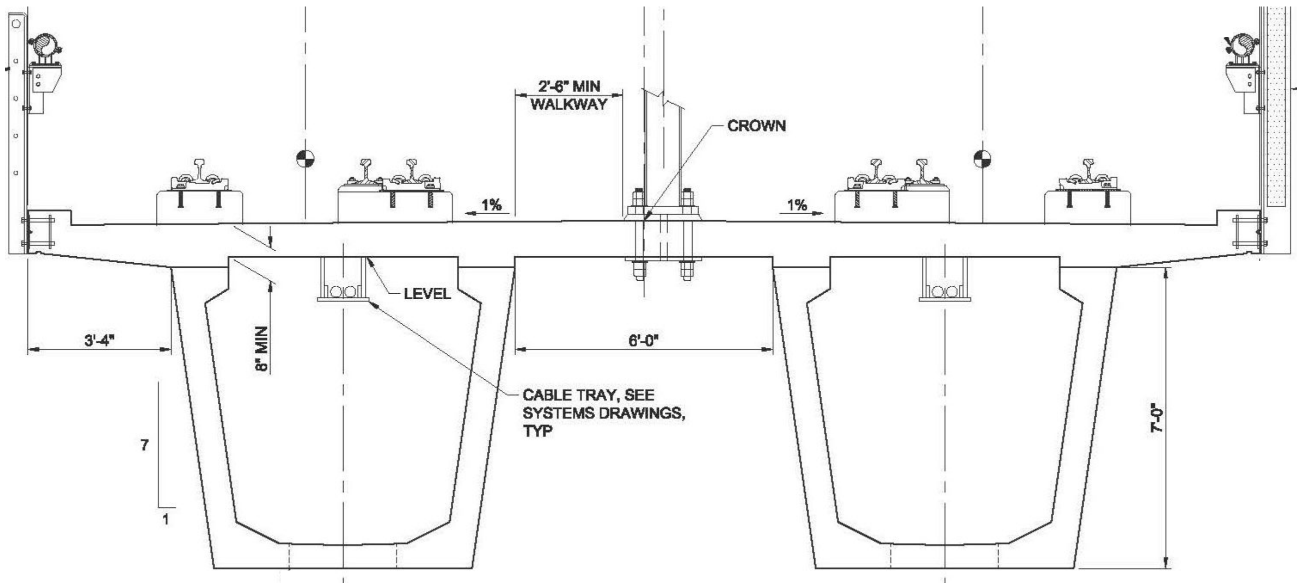
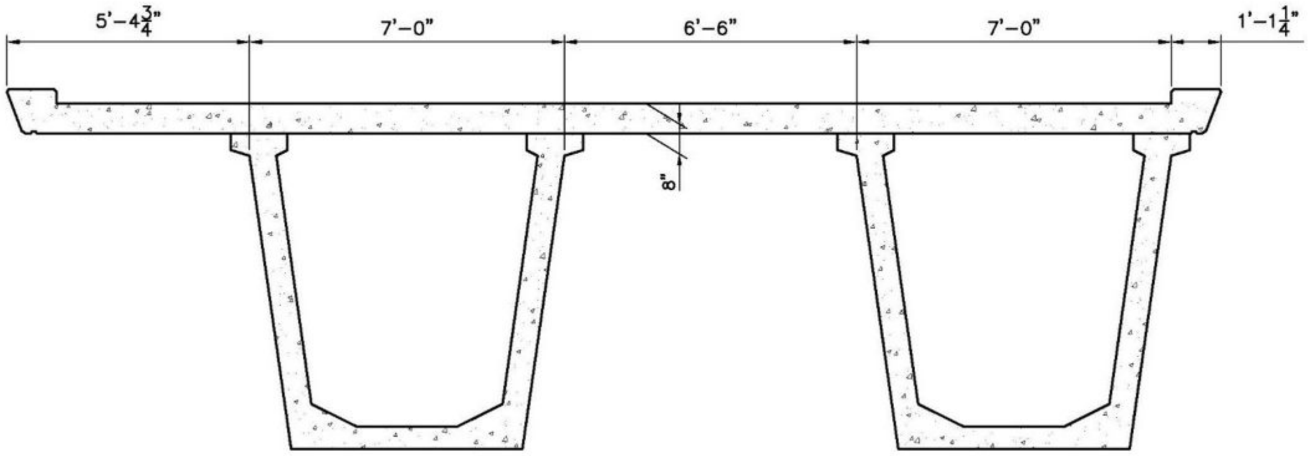
PT TUB GIRDERS – CURVE AFFECTS SPAN LENGTH





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PT TUB GIRDERS – SPAN LENGTH

Deck Eccentricity on Curved Alignment

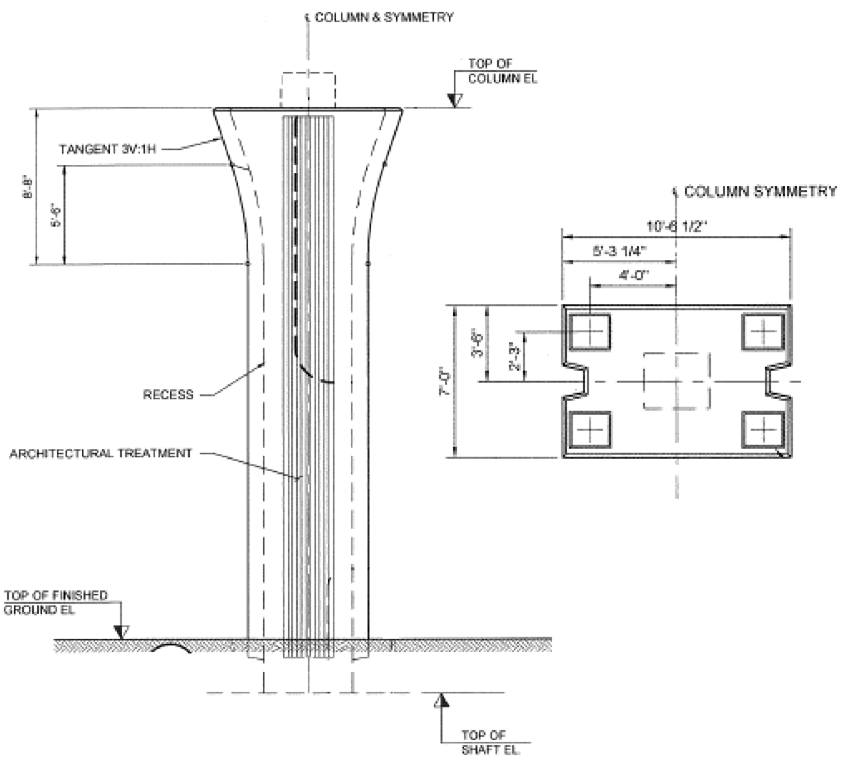
Span (ft.)	Radius (ft.)										
	500	600	700	800	900	1000	1085	1200	1500	1950	2500
	e (in.) - Eccentricity due to Curve										
60	10.80	9.00	7.71	6.75	6.00	5.40	4.98	4.50	3.60	2.77	2.16
70	14.69	12.25	10.50	9.19	8.17	7.35	6.77	6.12	4.90	3.77	2.94
80	19.19	15.99	13.71	12.00	10.66	9.60	8.85	8.00	6.40	4.92	3.84
90	24.28	20.24	17.35	15.18	13.50	12.15	11.20	10.12	8.10	6.23	4.86
100	29.98	24.99	21.42	18.74	16.66	15.00	13.82	12.50	10.00	7.69	6.00
110	36.26	30.23	25.92	22.68	20.16	18.15	16.72	15.12	12.10	9.31	7.26
120	43.15	35.97	30.84	26.99	23.99	21.59	19.90	18.00	14.40	11.08	8.64
130	50.63	42.21	36.19	31.67	28.15	25.34	23.36	21.12	16.90	13.00	10.14
136.5	55.81	46.53	39.89	34.91	31.04	27.94	25.75	23.28	18.63	14.33	11.18
140	58.70	48.94	41.97	36.73	32.65	29.39	27.09	24.49	19.60	15.08	11.76
145	62.96	52.50	45.01	39.39	35.02	31.52	29.06	26.27	21.02	16.17	12.61
150	67.37	56.18	48.17	42.16	37.48	33.73	31.09	28.12	22.50	17.31	13.50

LIGHT RAIL AERIAL GUIDEWAY

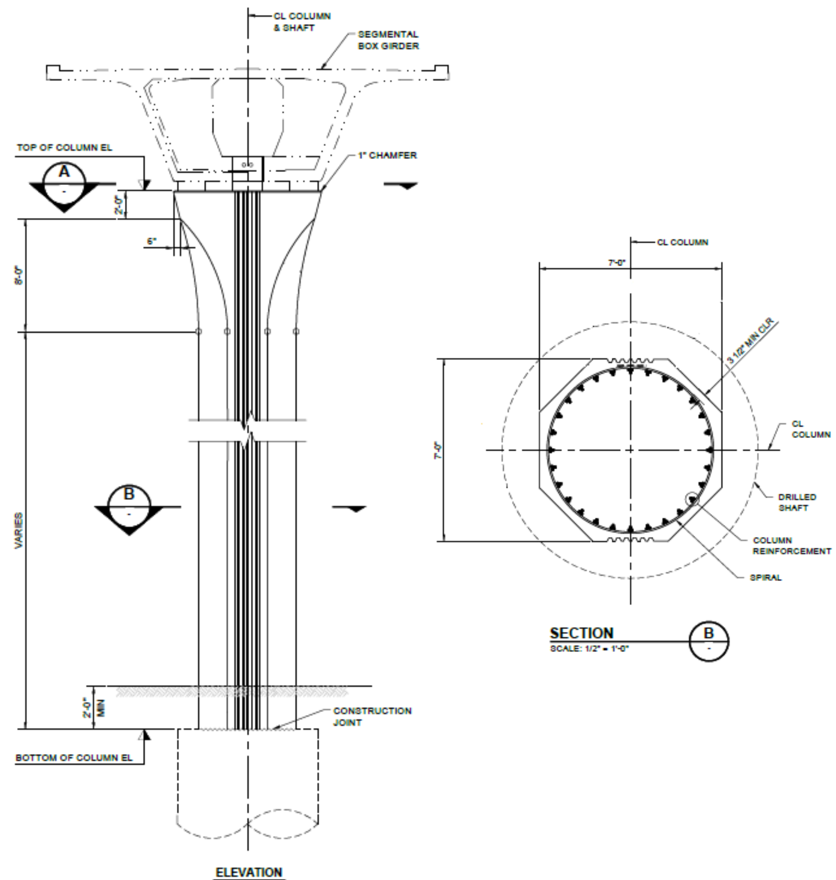
- Types of superstructure/girders
- Typical girder sections
- Span lengths and layouts
- Pier shapes and sizes
- Foundations

PIER SHAPES AND SIZES

Rectangular columns vs. Circular columns



TRANSVERSE ELEVATION
SCALE: 1/4" = 1'-0"



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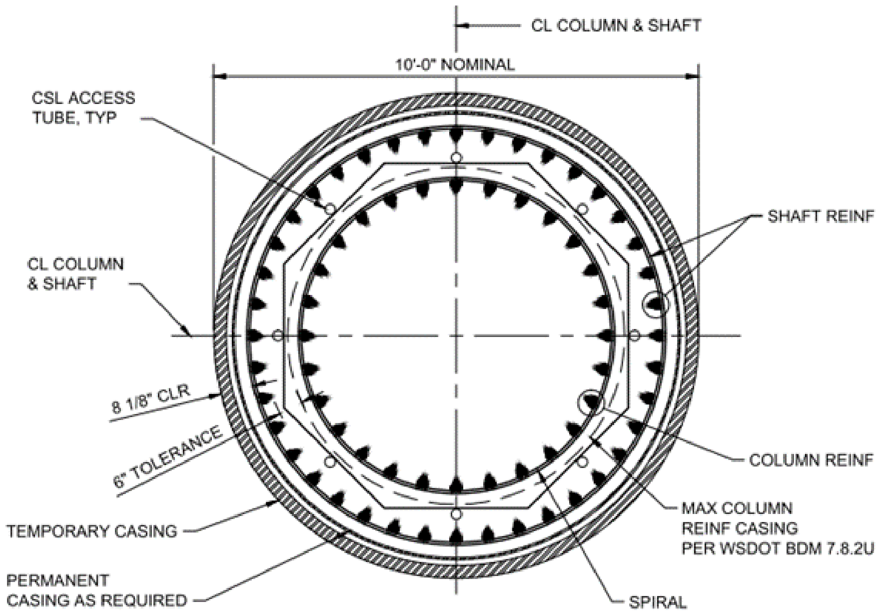
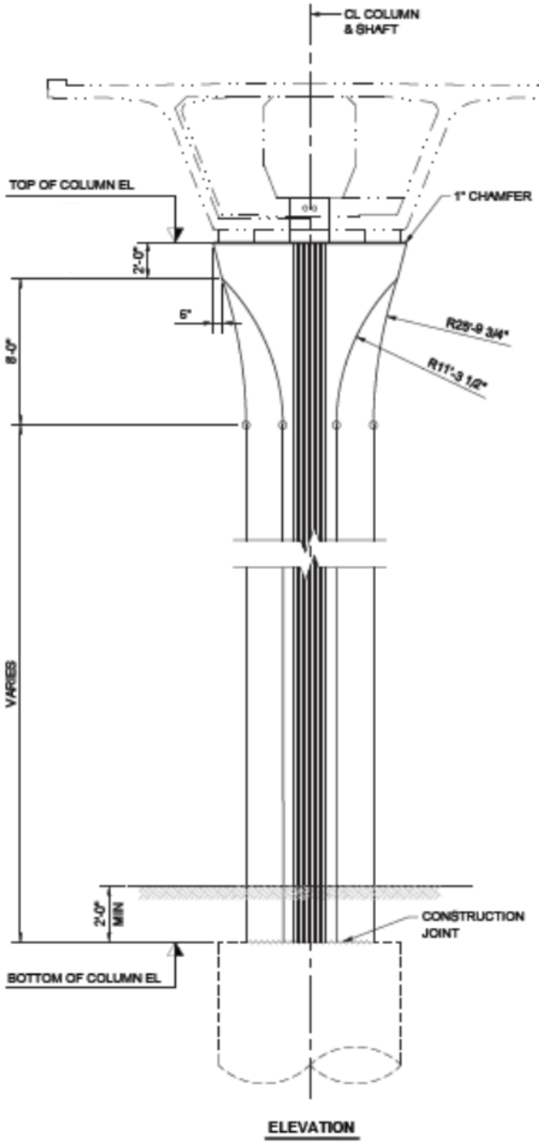
PIER SHAPES AND SIZES

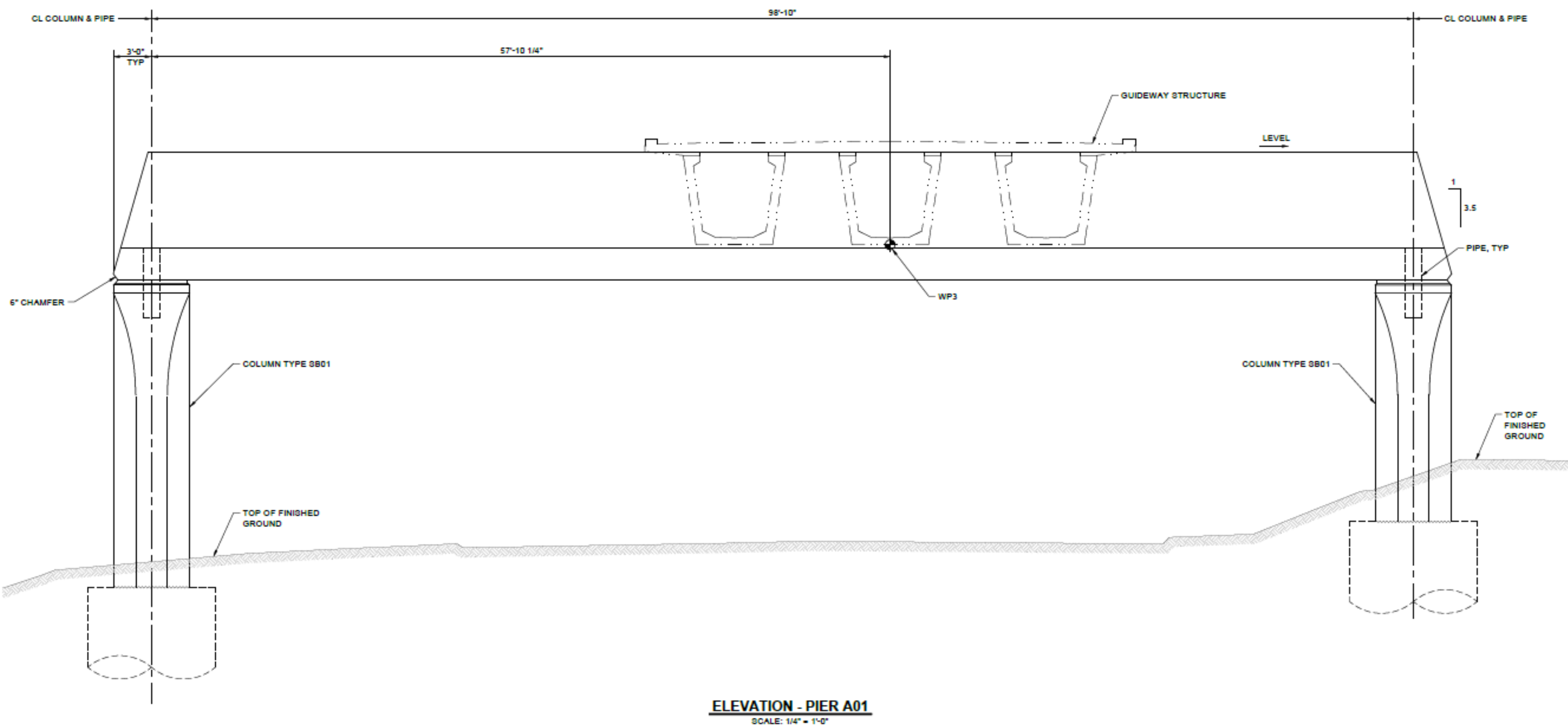
Single column





PIER SHAPES AND SIZES

Straddle bents



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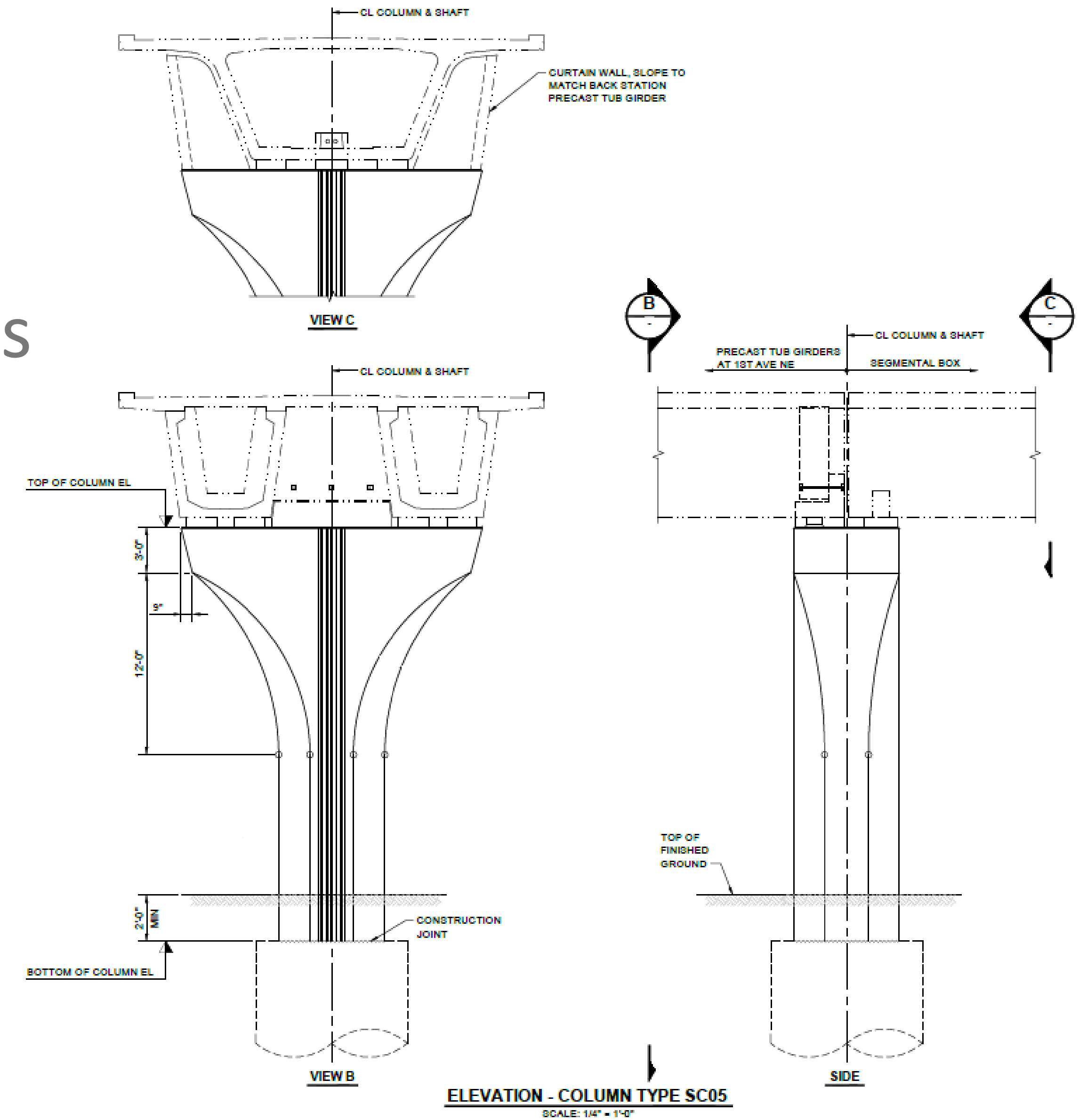
PIER SHAPES AND SIZES

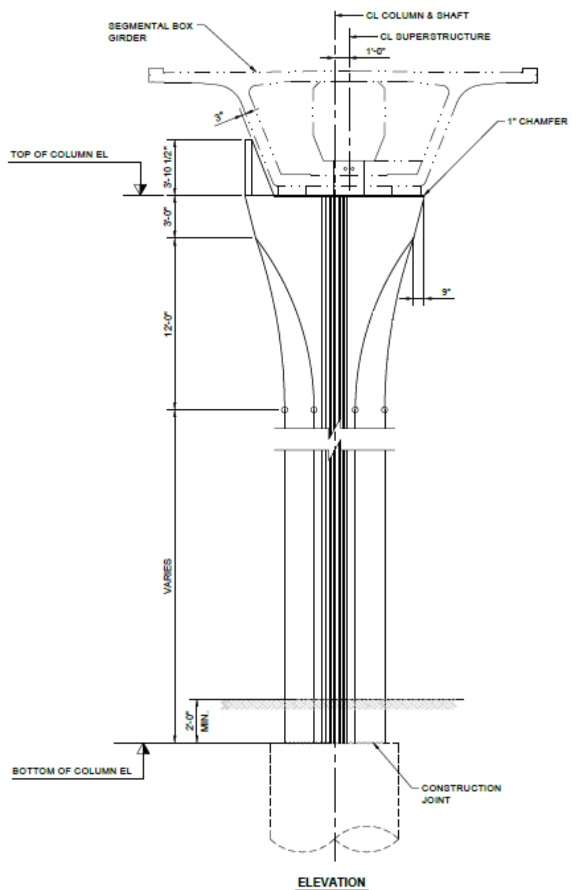
Support:

- CIP box girders
- Twin tub girders

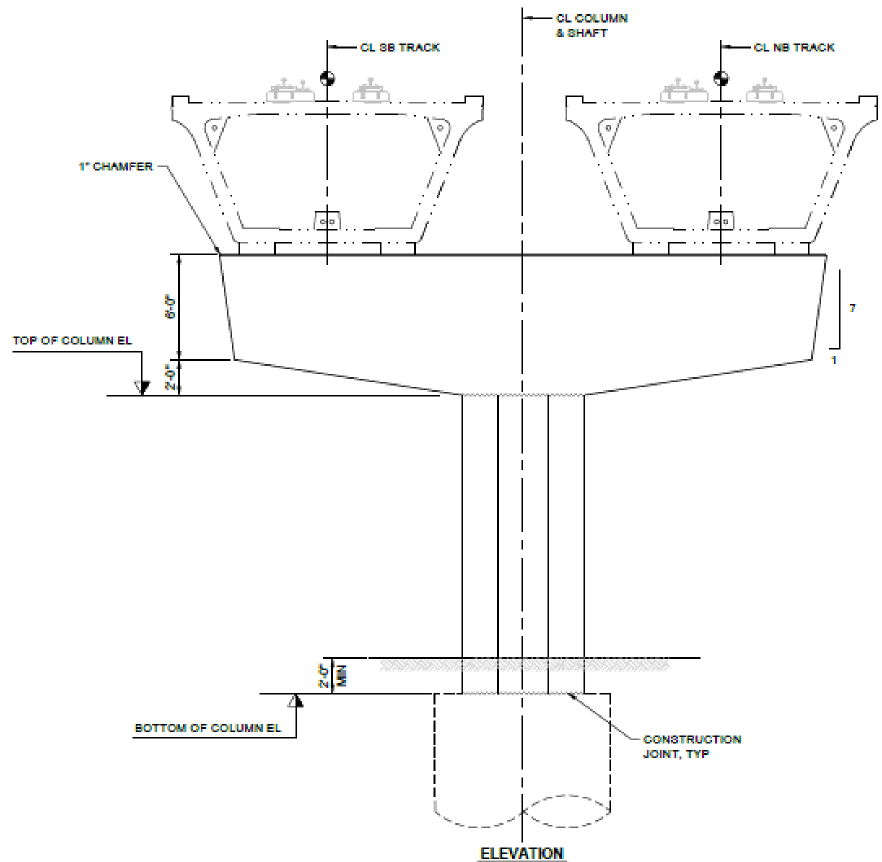


PIER SHAPES AND SIZES

Offset



Hammerhead



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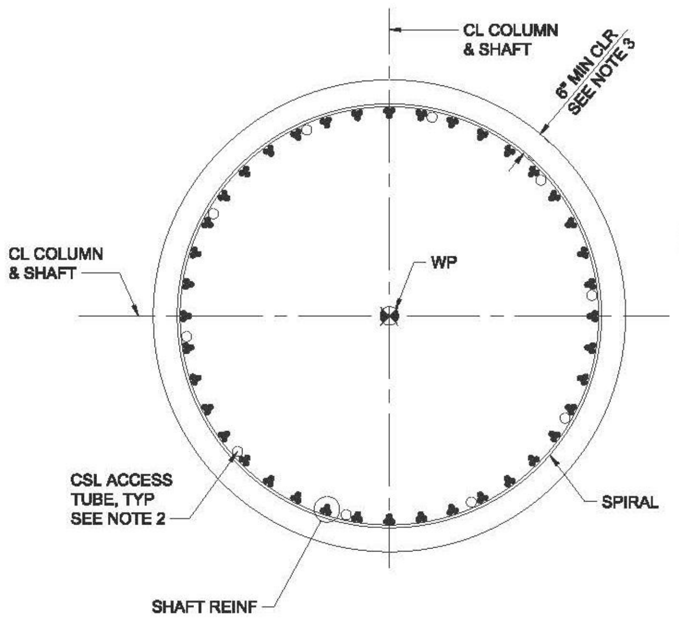
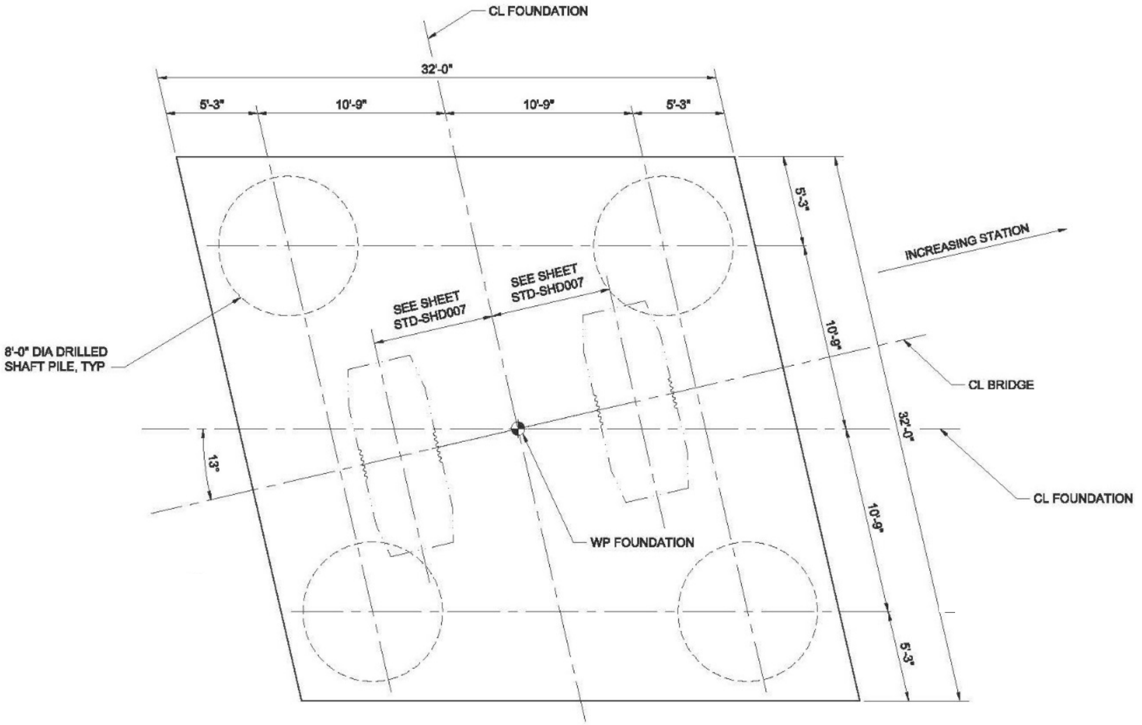
FOUNDATIONS

Single shaft



Pile/shaft group



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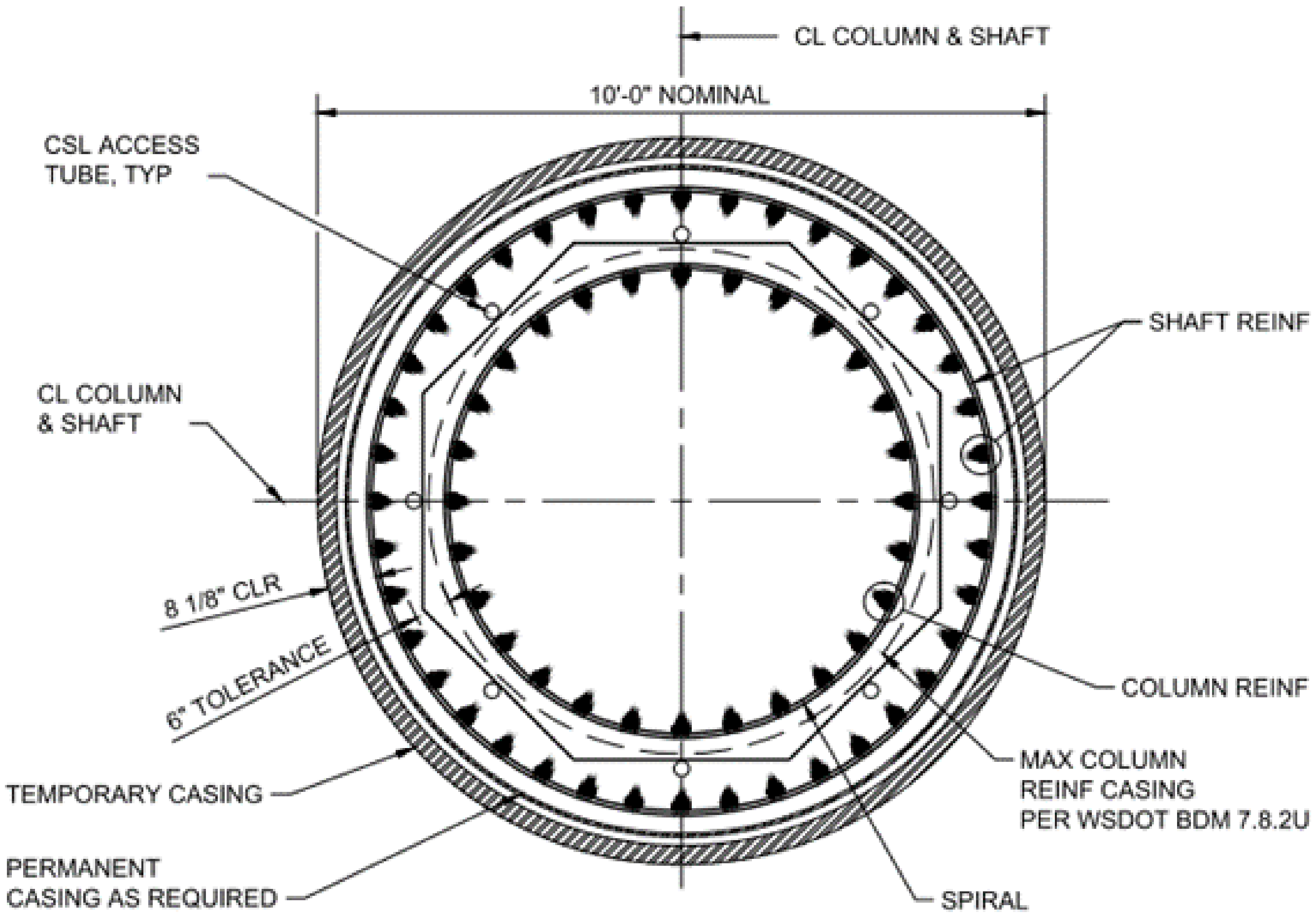
SHAFT VS. COLUMN SIZES



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SHAFT VS. COLUMN SIZES

- WSDOT BDM Section 7.8.2
- WSDOT Standard Specifications, Section 6-19

Column				Shaft					
Nominal Dia	Max. Dia.	Cover	Max. Cage Dia	Nominal Shaft Dia	Metric Casing Dia	Max (Outside) Reinf Dia	Tolera nce	Rebar	
ft.	ft.	in.	in.	ft.	ft.	in.	in.	in.	
4.00	4.05	2.0	44.58	6.0	6.560	64.02	6.0	3.72	
4.00	4.05	2.0	44.58	6.5	6.560	64.02	6.0	3.72	Note (1)
4.50	4.70	2.0	52.45	7.0	7.220	71.89	6.0	3.72	
5.50	5.59	2.0	63.10	8.0	8.200	83.70	6.0	4.30	
6.50	6.58	2.0	74.91	9.0	9.190	95.51	6.0	4.30	
7.00	7.10	2.0	81.208	10.0	9.840	101.81	6.0	4.30	Note (2)
8.00	8.51	2.0	98.11	11.0	11.250	118.71	6.0	4.30	
9.00	9.49	2.0	109.92	12.0	12.240	130.52	6.0	4.30	

Note (1) Assume up to three #11 mian reinforcing bar each bundle

Note (2) Assume up to three #14 mian reinforcing bar each bundle

SEISMIC DESIGN – TWO-LEVEL EARTHQUAKE HAZARD DESIGN

Design Life = 100 years

Operating Design Earthquake (**ODE**):

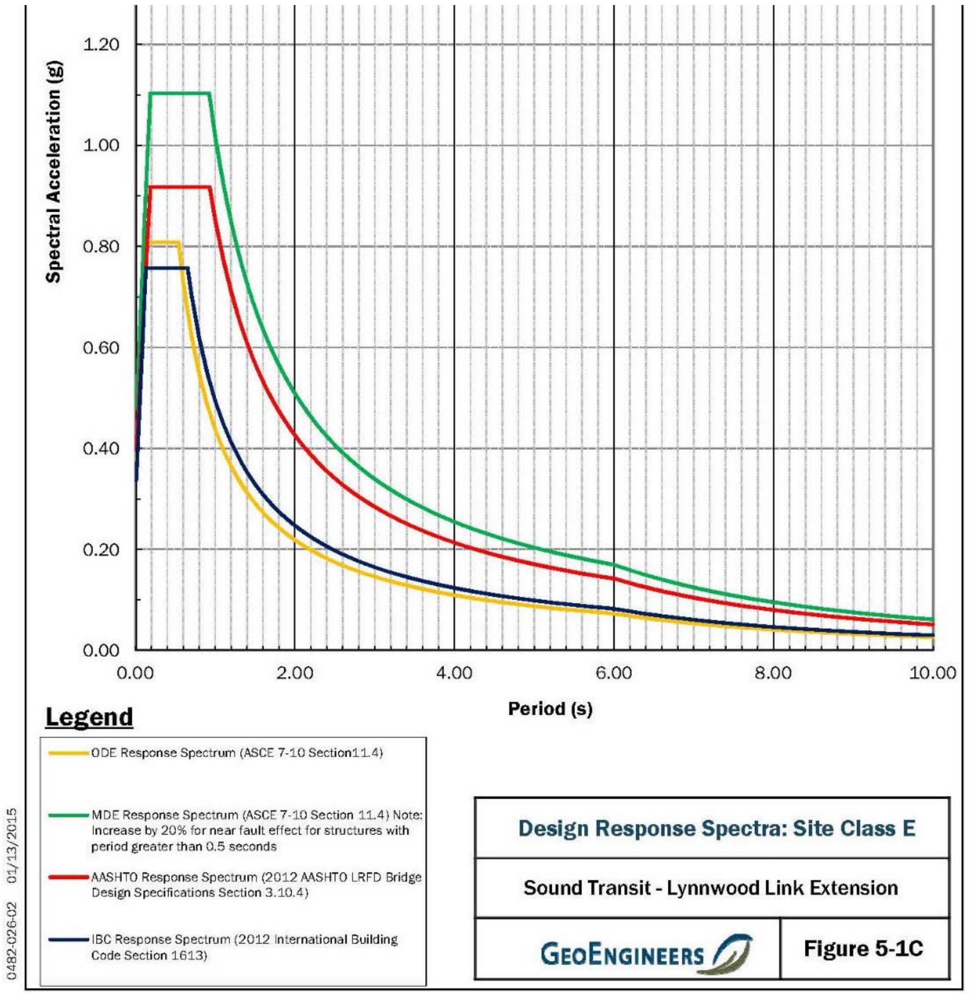
- Return period 150 years
- 50% probability of exceedance

Maximum Design Earthquake (**MDE**):

- Return period 2,500 years
- 4% probability of exceedance

Compare to **AASHTO** single level design:

- Return period 1,000 years
- 9.5% probability of exceedance



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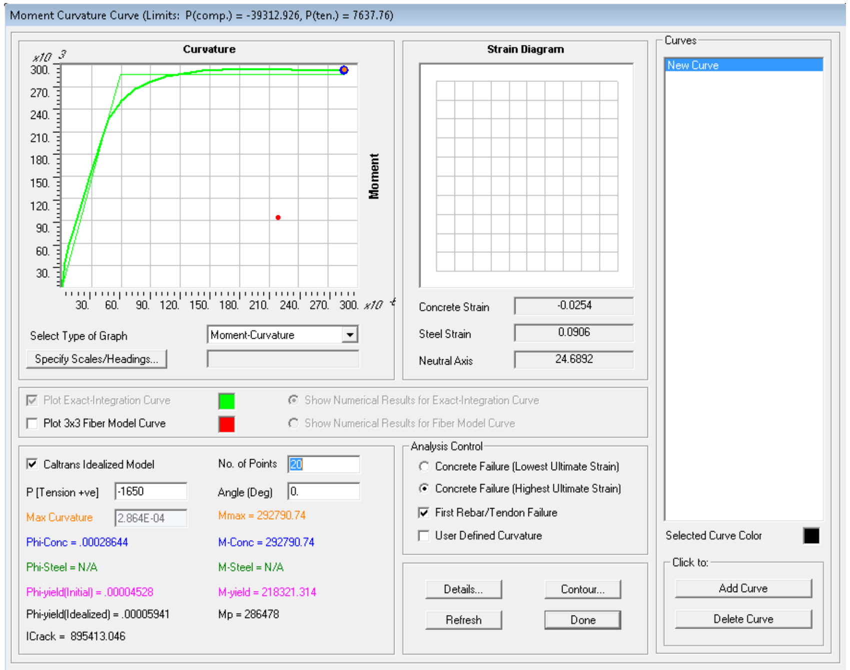
SEISMIC DESIGN – PERFORMANCE AND RISK ACCEPTANCE

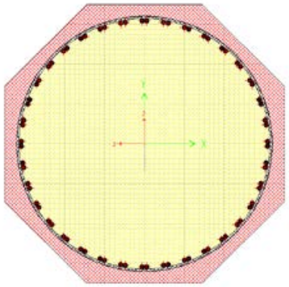
Operating Design Earthquake (ODE):

- Without significant structural damage
- Can be repaired during normal operating hours

Maximum Design Earthquake (MDE):

- To avoid major failure and prevent collapse
- To maintain life safety





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OPERATING DESIGN EARTHQUAKE

- Earthquake event with a 150 year return period
- Force based design per AASHTO LRFD Bridge Design Specifications
- Response modification factor = 1.0 per Sound Transit DCM

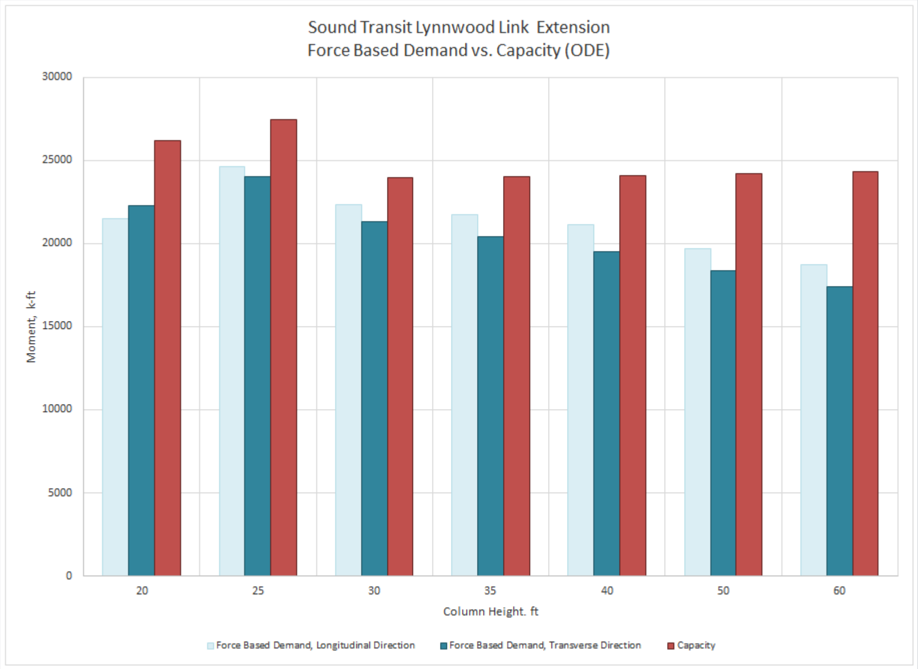

Table 8A-3 Response Modification Factors

Substructure	ODE[3] (150 year)
Wall-type pier [1]	1.0
Reinforced concrete pile bents	
a. Vertical piles only	1.0
b. One or more batter piles	1.0
Single Columns (reinforced concrete)	1.0
Steel or composite steel and concrete pile bents	
a. Vertical piles only	1.0
b. One or more batter piles	1.0
Multiple column bent (reinforced concrete)	1.0

Connections [2]	ODE (150 year)
Superstructure to Abutments [2]Expansion joints within a	1.0
span of the superstructure	1.0
Columns, piers or pile bents to cap-beam or	1.0
Superstructure Columns or piers to foundations [3]	1.0

[Sound Transit DCM]

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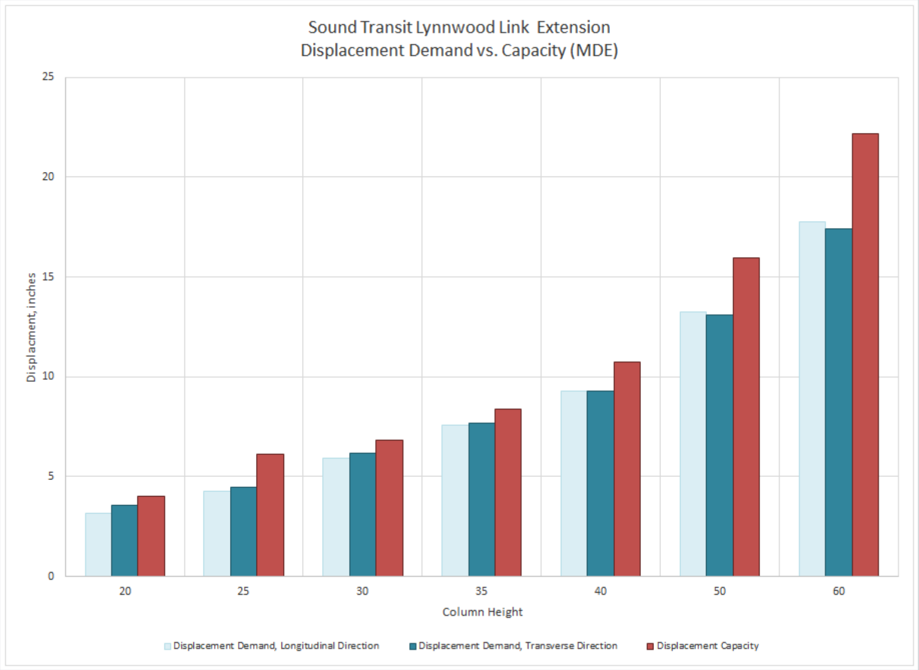
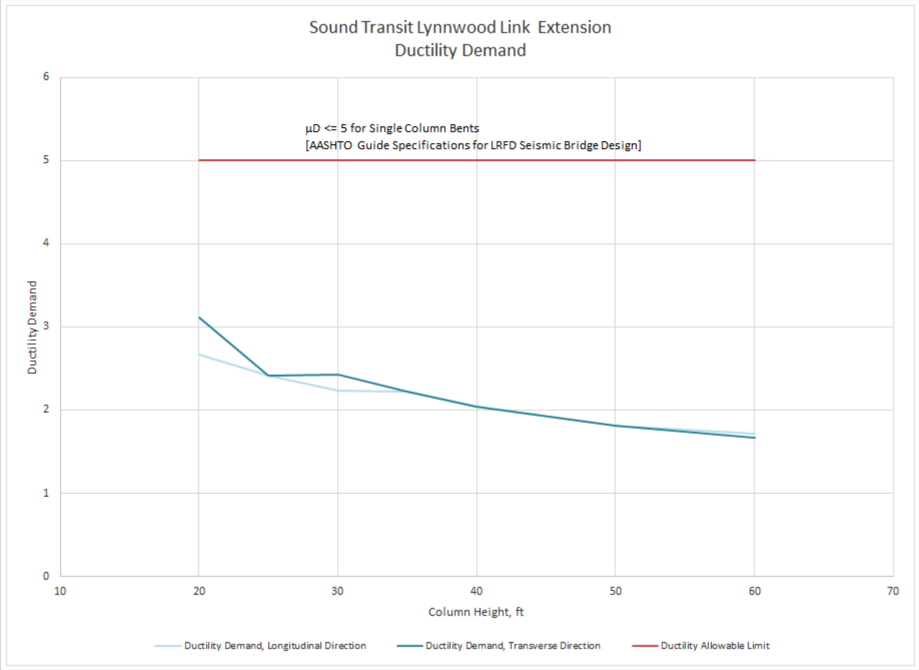
MAXIMUM DESIGN EARTHQUAKE

- Earthquake event with a 2,500 year return period
- Displacement based design per AASHTO Guide Specifications for LRFD Seismic Bridge Design
- P-Δ checked separately per Article 4.11.5 of the Guide Specifications





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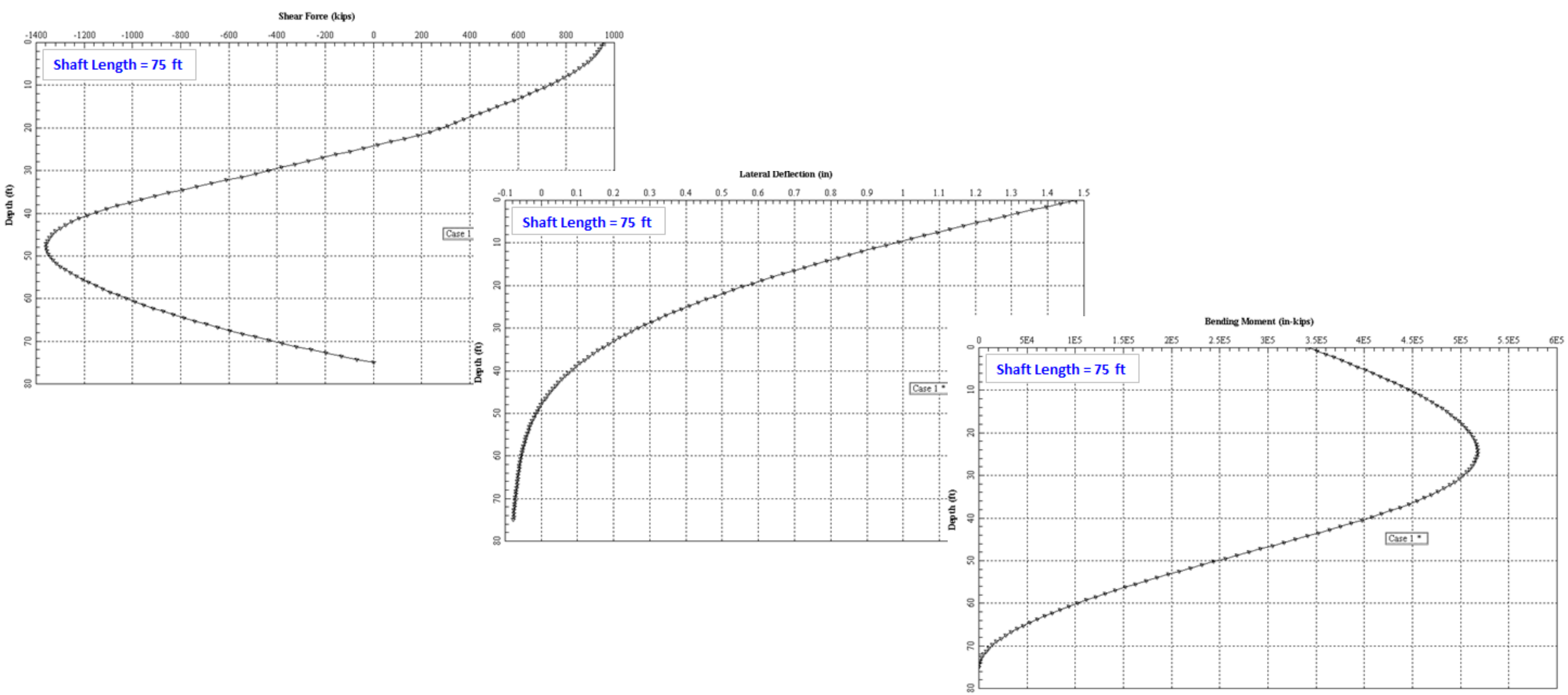
LATERAL DESIGN OF SHAFTS

- Typical shaft diameter = 10 feet
- Shaft length = 60-75 feet (avg.) / 100 feet (max.)
- Designed for over-strength plastic moment and shear at base of column



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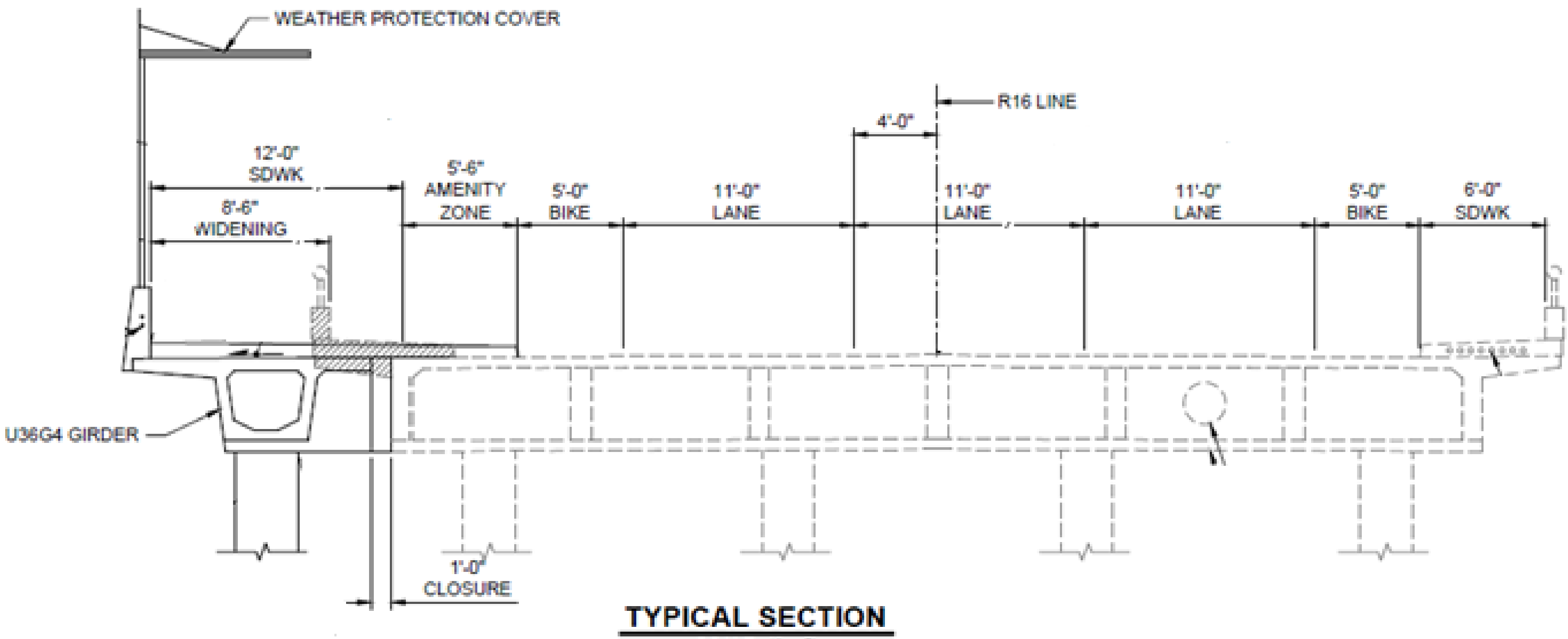
ROADWAY BRIDGES

- Widening NE 185th Street Bridge over I-5
- New NE 185th Street Bridge over light rail lines
- Replacing NE 195th Street Pedestrian Bridge over I-5

NE 185TH STREET BRIDGES

NE 185TH STREET WIDENING – CROSS SECTION



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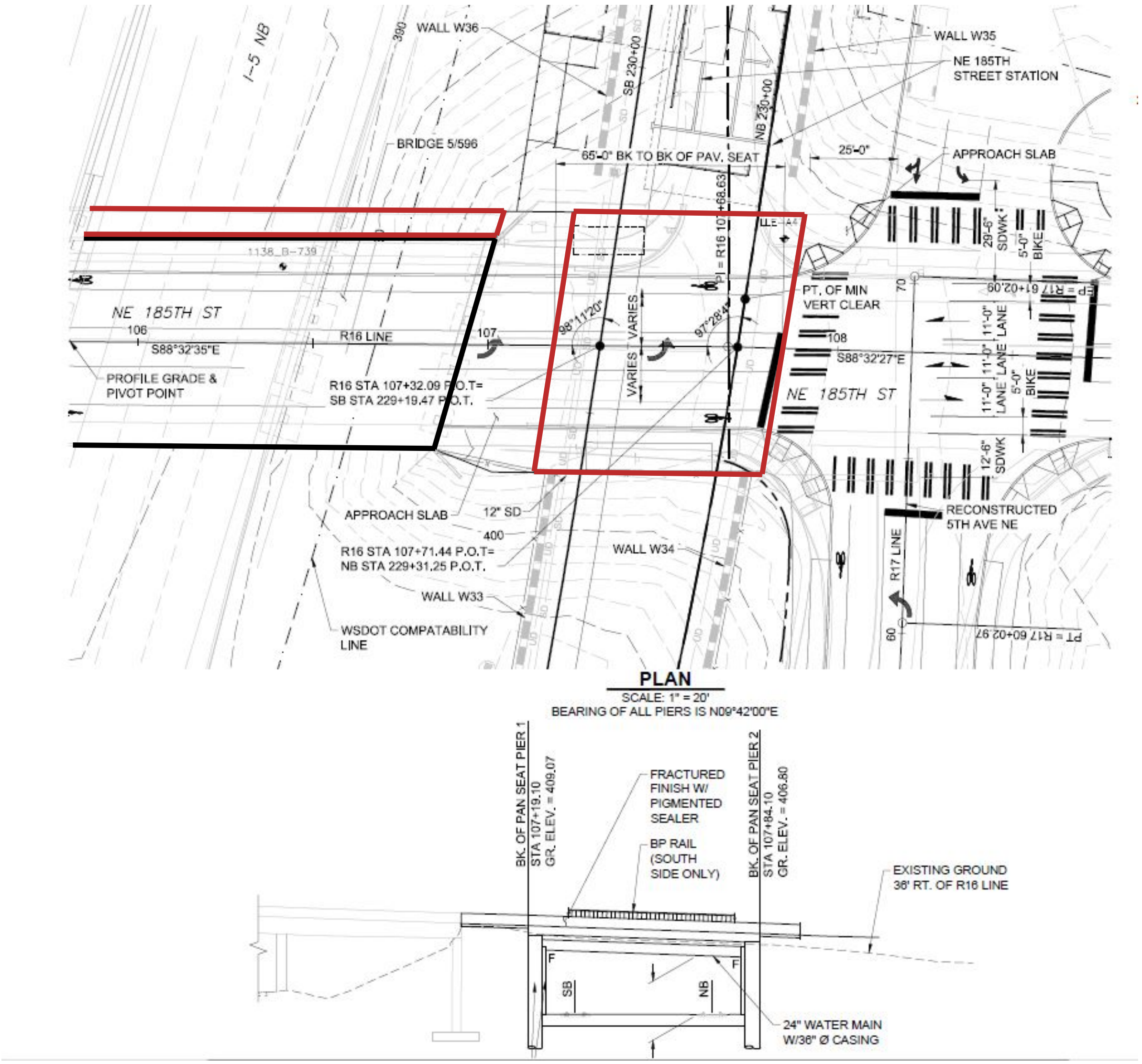
NE 185TH STREET LRT UNDERCROSSING



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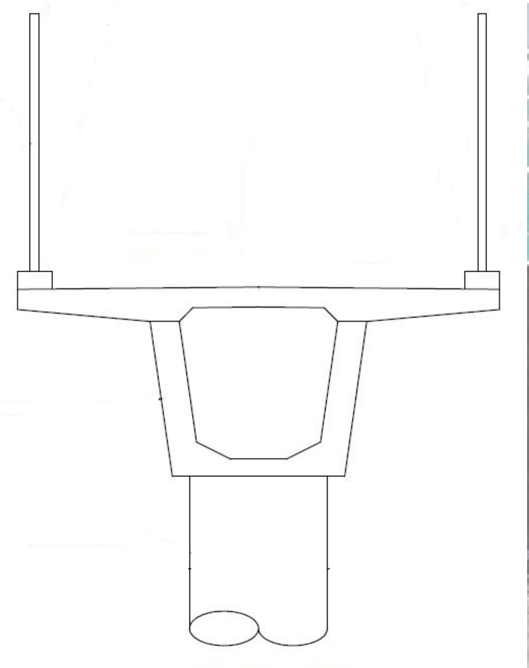
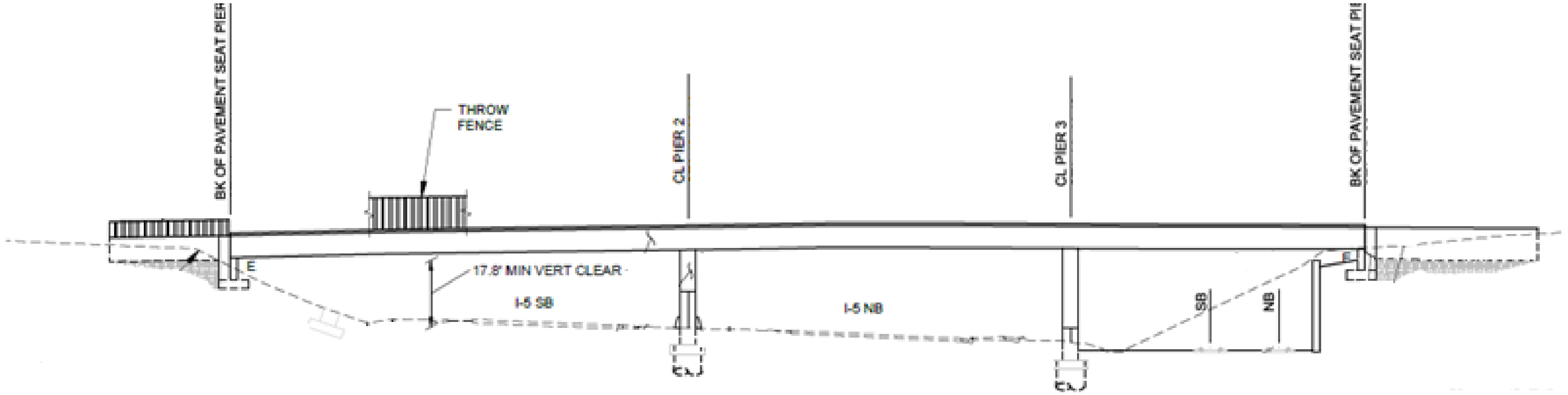
NE 195TH PEDESTRIAN BRIDGE – ELEVATION





SOUND TRANSIT
RIDE THE WAVE

Thank you for your time

QUESTIONS?

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