Design of a Modern Cable-Stayed Bridge in a High Seismic Zone

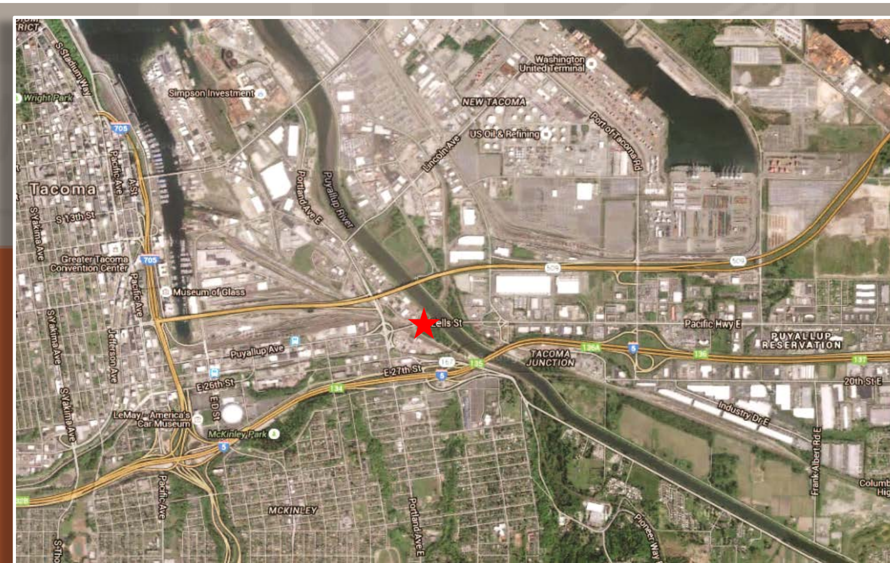
Presented by

Patrick D. Montemerlo, PE

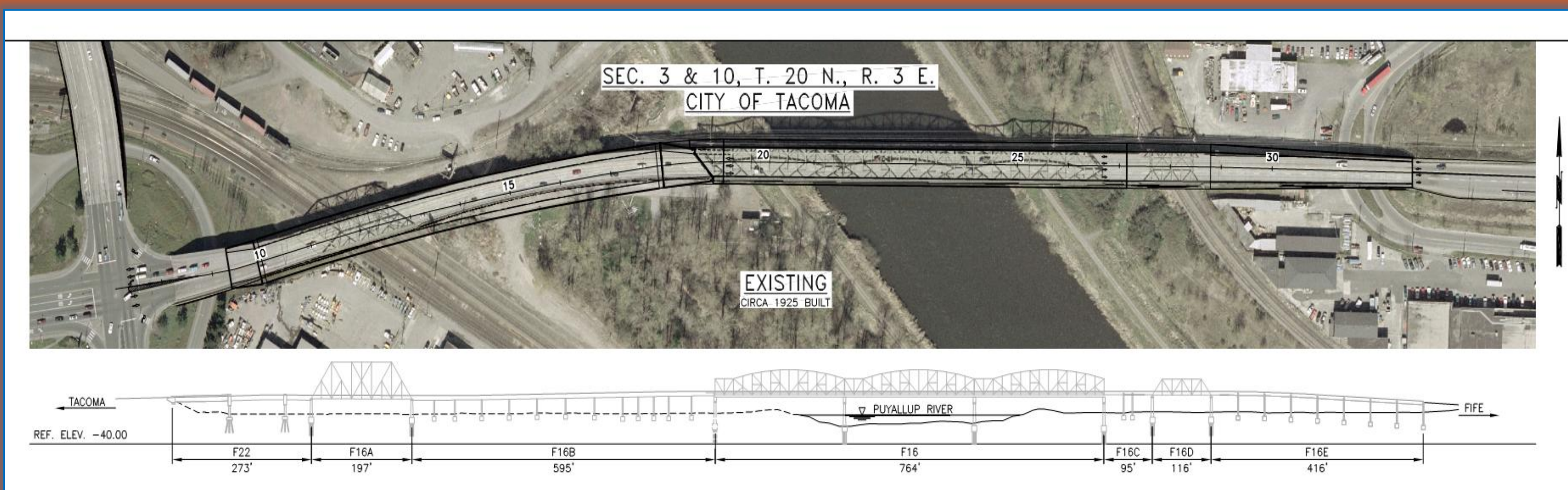
Overview

- Introduction
- Bridge Description
- Design Criteria
- Superstructure Design
- Tower Modeling
- Seismic Details
- Construction Specifications
- Conclusion

Introduction



- Project Site – Tacoma, WA
- 1925 Original Bridge Built
- Total Length = 2,456 feet
- 50 foot wide bridge; 3 Traffic Lanes and 2 Sidewalks
- 1972 West Approach Reconstructed



Existing Structure Condition Assessment

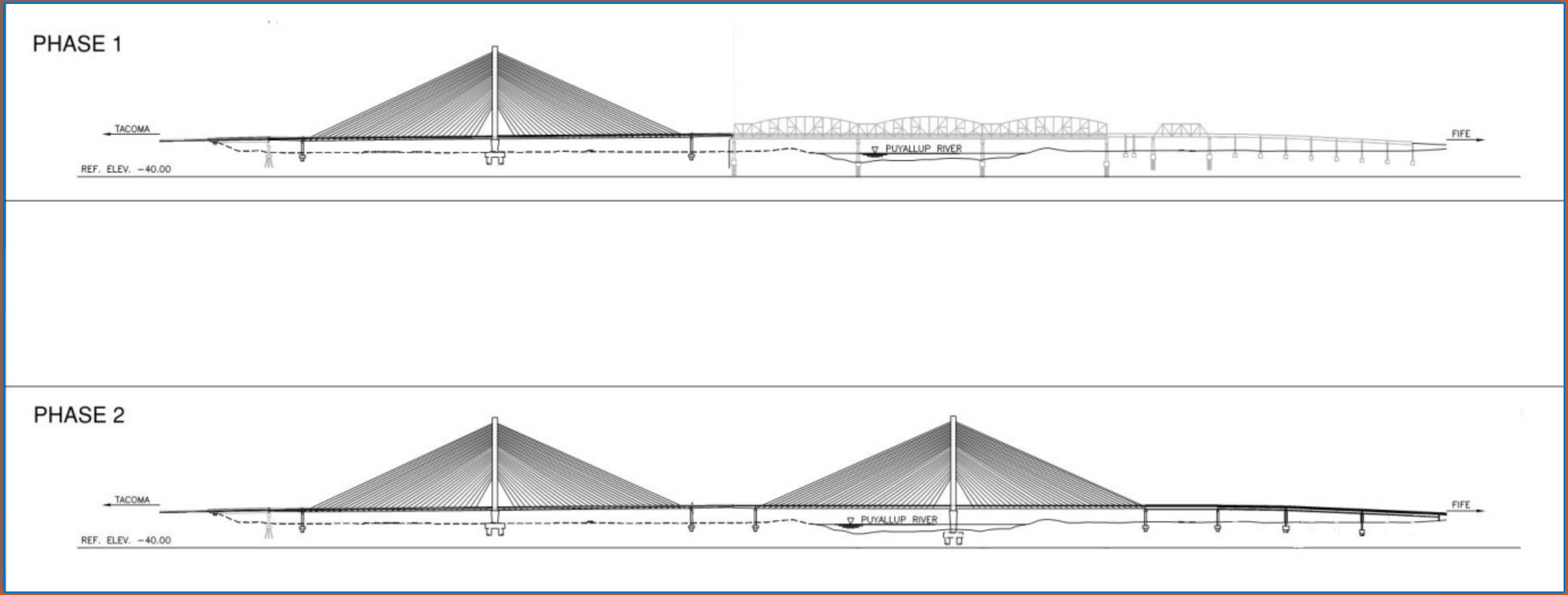
- NBI Structural Evaluation = 3
- Many critical WSDOT BMS Elements = Condition State 4
- Most recent load rating:
  - Bridge Sufficiency Rating = 4
  - Current load restriction = 10 tons

Bridge Replacement – Project Constraints

- Total replacement anticipated to cost over $100 million
- Bridge crosses eight (8) railroad tracks, the Puyallup River and future railroad tracks anticipated under the bridge
- Multiple government and private stakeholders

Existing Bridges - Phased Replacement

- Existing bridge re-inventoried into seven partitions
- Phase 1 = Replace 971 feet of western spans
- Phase 2 = Replace remaining spans (1,485 feet) in future

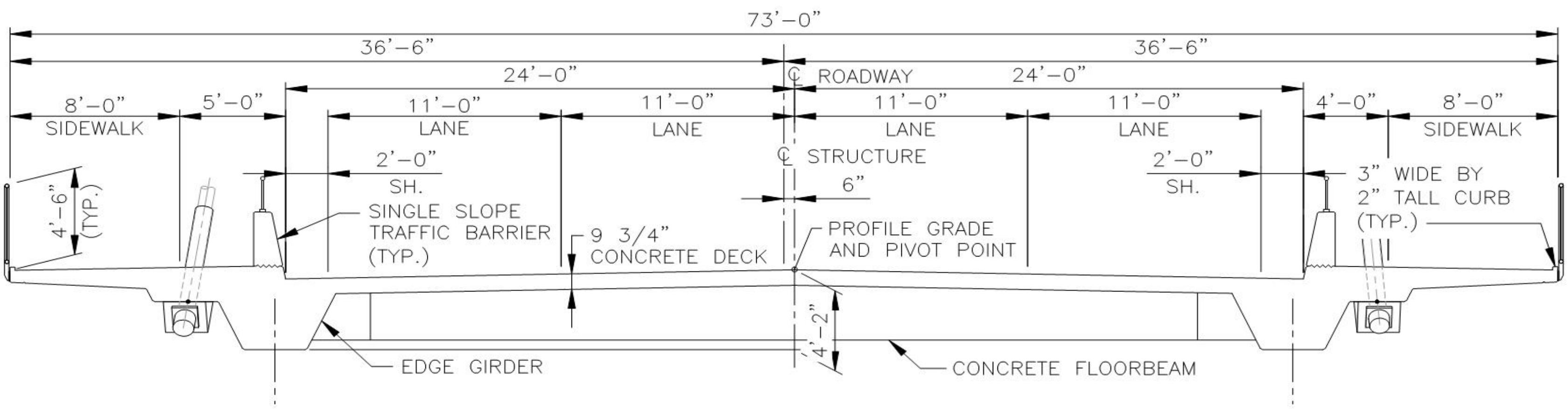


Phase 1 Replacement Structure Configuration

- Signature Cable-Stayed bridge unit:
  - Two 400 foot long precast/post-tensioned concrete main spans
  - 224 foot tall diamond shaped tower with steel box tower legs
  - CIP Concrete main tower base w/drilled shaft foundations
- Geometry:
  - Horizontal Alignment (R=5,200’)
  - Vertical Profile (105’ VC, 3% to -1%)
  - Two short transition spans

Superstructure Typical Section

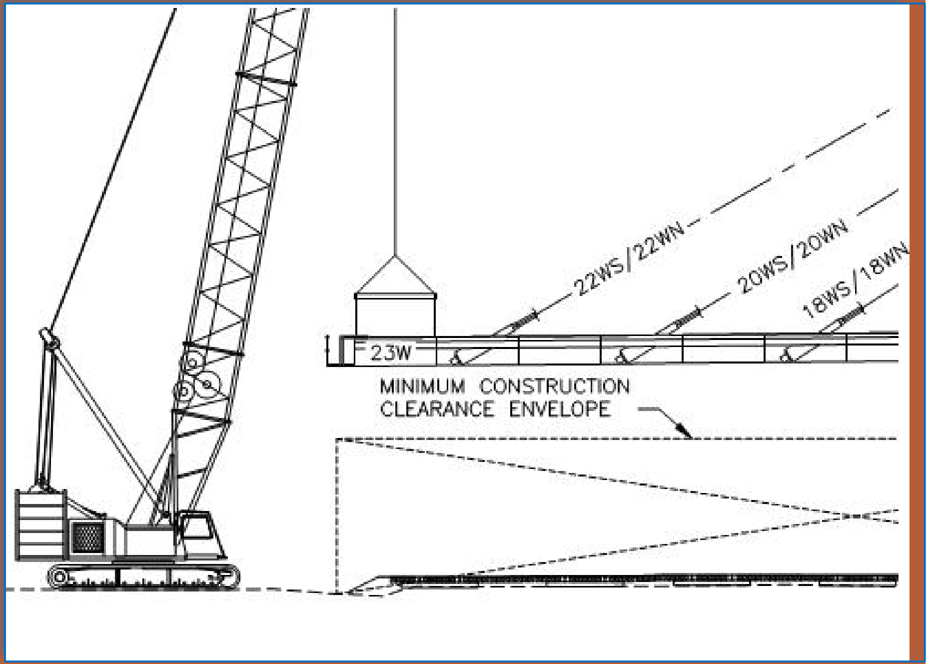
- Full Width Precast Segments
- Shallow Superstructure Precast Segments
- Offset stay cable shelf needed to meet permanent and temporary envelopes



TYPICAL DECK SEGMENT
(PRECAST CONCRETE DECK SEGMENT – LOOKING AHEAD ON STATION)

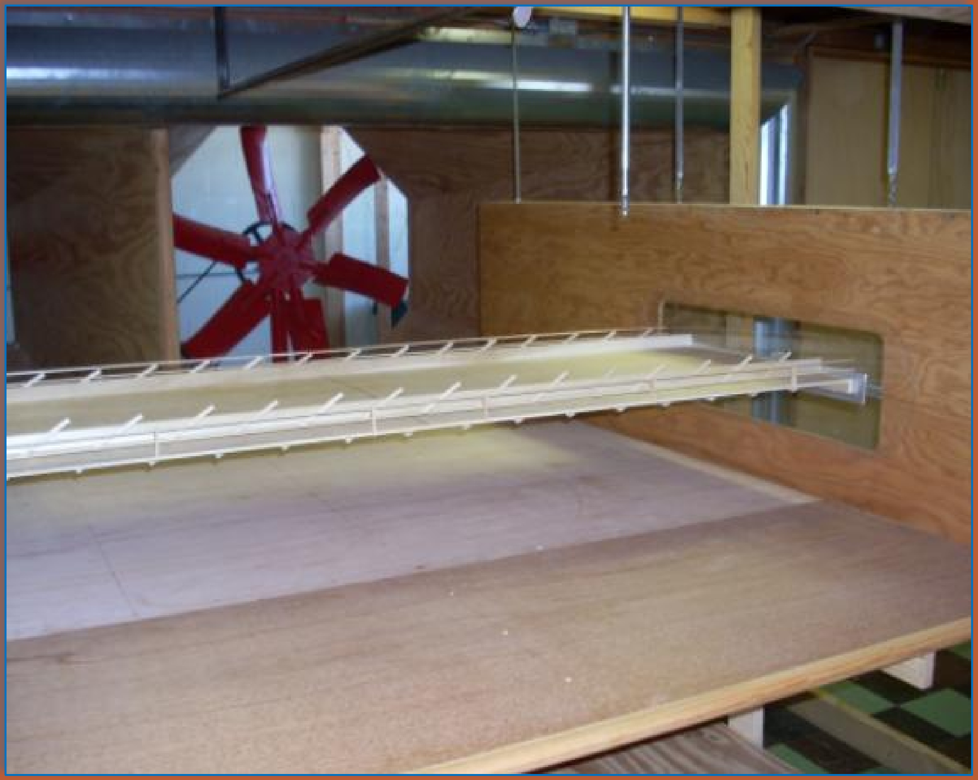
Superstructure Erection Sequence

- Balanced cantilever construction method
- Erection sequence timings driven by the active rail line owners/operators requirements
- Multi-stay stressing sequence in conjunction with cantilever ballast – designer's assumed construction method



Design Criteria

- Basic Design Requirements
- Wind Analysis/Design
- Thermal Analysis/Design
- Seismic Analysis/Design
- High Performance Concrete (HPC)
- Project Tensile Stress Limits

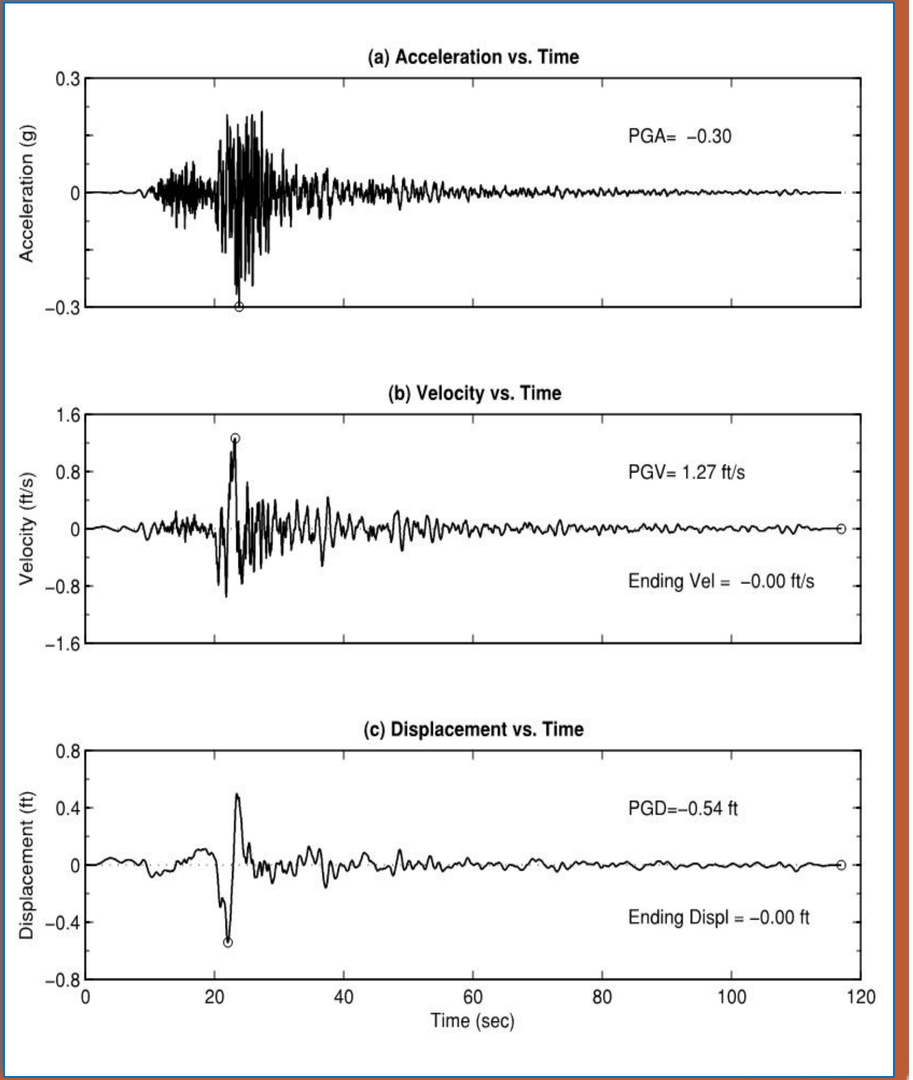


Design Criteria – Wind and Thermal

- WIND
  - Site specific wind load analysis required for cable stayed main span unit
  - Scale model wind tunnel testing
  - Dynamic analysis required for four different stages of cantilever construction
- THERMAL
  - AASHTO Nonlinear temperature gradient in the cable stayed main span unit superstructure
  - Linear temperature differential between the cables and bridge (deck, tower and end piers)
  - Linear temperature gradient between the opposite tower leg faces

Design Criteria – Seismic

- Cable-stayed main span - Time History Analyses
- Project specific response modification factors were developed
- Cable stayed main span unit ERS is a ductile substructure with near elastic superstructure

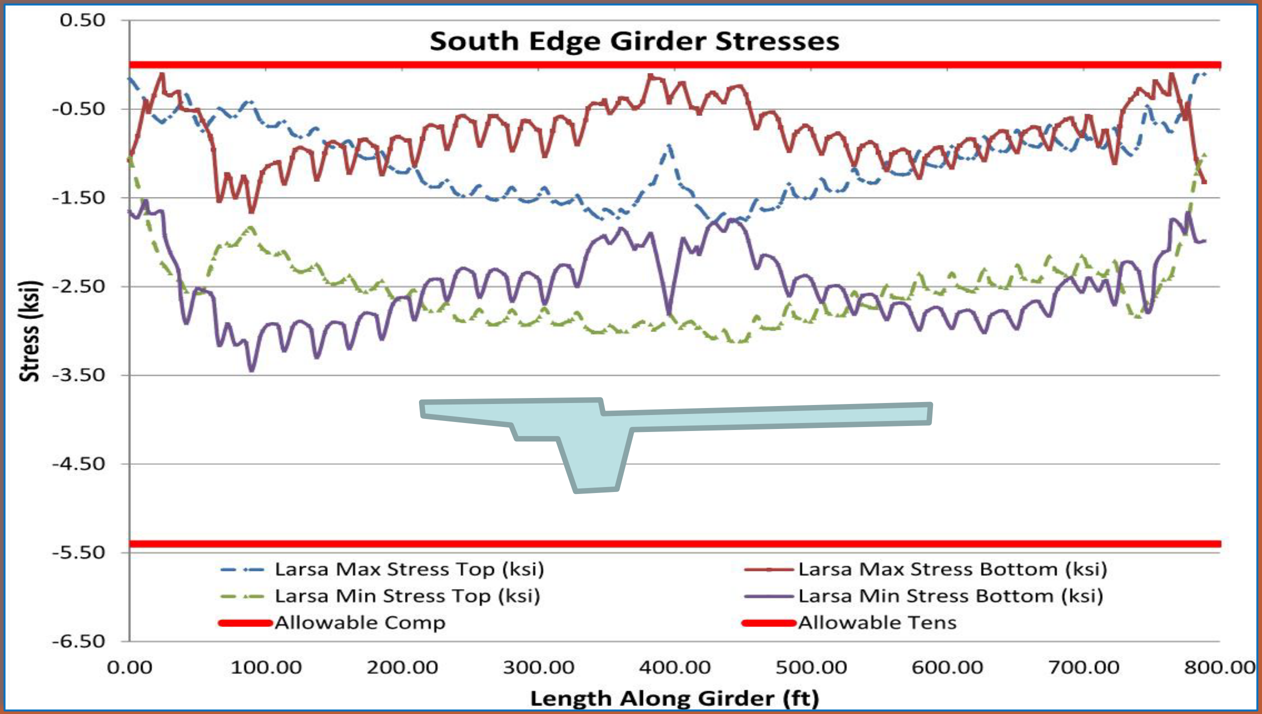


Design Criteria – HPC and Tensile Stress

- Necessary for shallow cable stayed main span superstructure
  - Superstructure depth of 4'-2"
- Precast concrete main span superstructure made up of match cast segments
- Project Specific Tensile Stress Limits
  - Epoxy joints also required
- Results in a very durable superstructure design

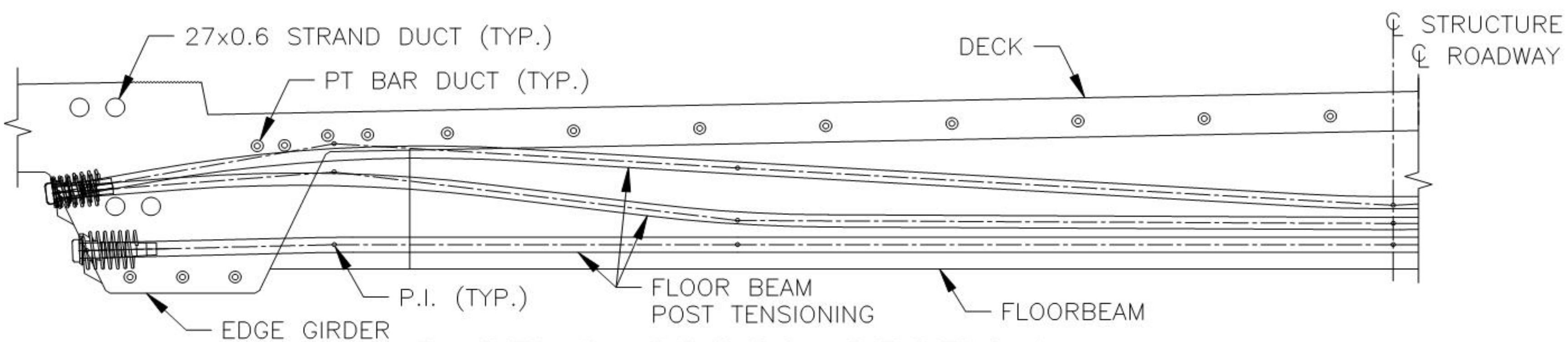
Superstructure Design – Edge Beam

- Per AASHTO LRFD Specifications
  - Construction tension stress limit = 0.22*sqrt(f'c)
  - Construction compression stress limit = 0.5*f'c
  - Service tensile stress limit = 0 ksi
  - Service compression stress limit = 0.6*f'c



Superstructure Design - Floorbeam

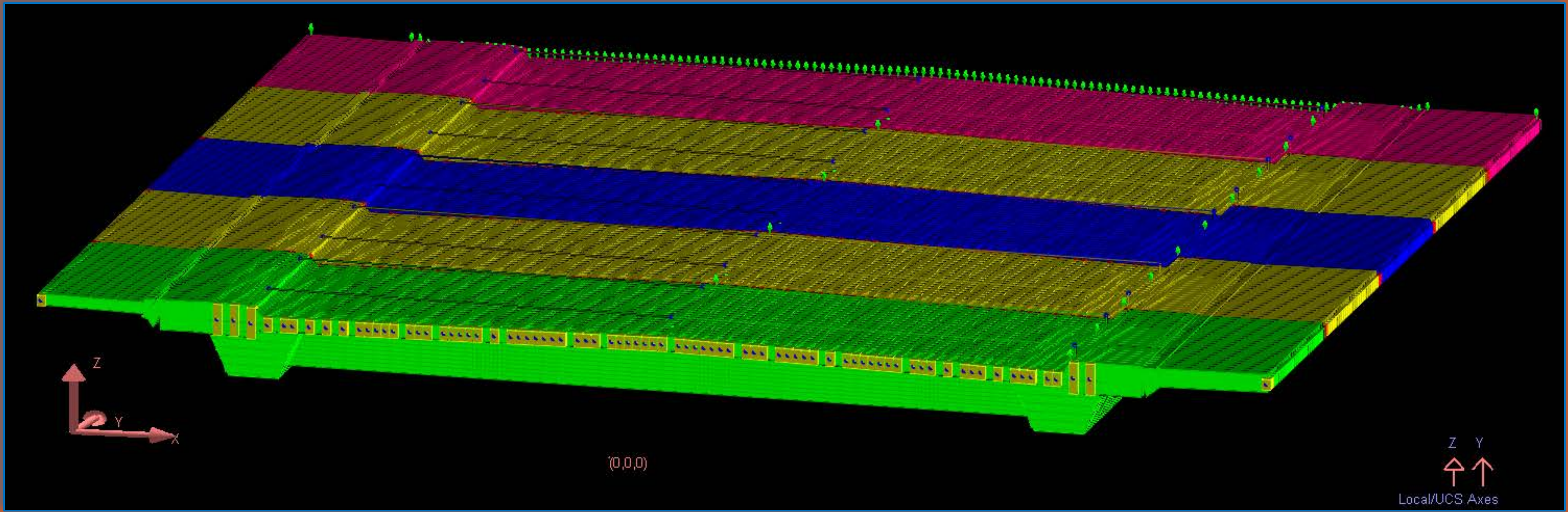
- Transverse post-tensioning required floorbeam elements
- 3 – 7 strand post-tensioning tendons utilizing 0.6 inch diameter ASTM A416, Grade 270, low relaxation strands
- Service tensile stress limits = 0.0948*sqrt(f'c)
- Mild reinforcing steel used for and contributes to nominal moment capacity



PARTIAL CROSS SECTION
(REINFORCEMENT NOT SHOWN FOR CLARITY)

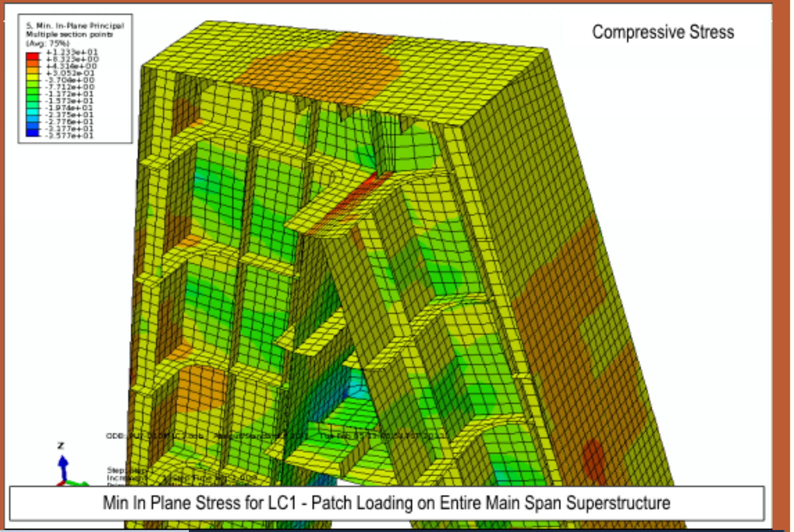
Superstructure Design – Segment FE

- Segment Finite Element Analysis used to evaluate:
  - Removal of formwork, segment transport and storage
  - Transverse post-tensioning stressing sequence
  - Cantilever construction and longitudinal PT stressing sequence
  - Temporary cantilever and final configuration loadings

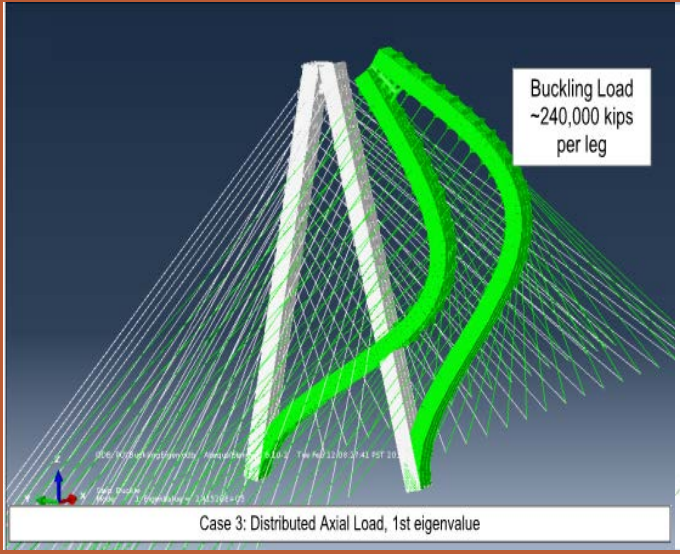


Tower Modeling – Global and Local

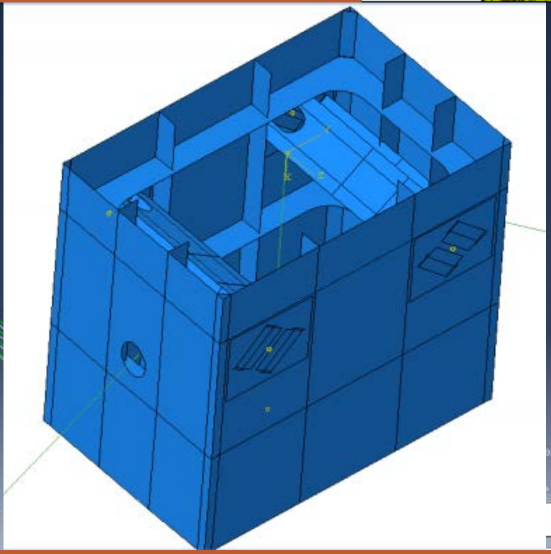
- Forces calculated from the Global Model and Hand Calculations were input into local ABAQUS Models to better verify plates and stiffeners and investigate the behavior of the tower at points of interest

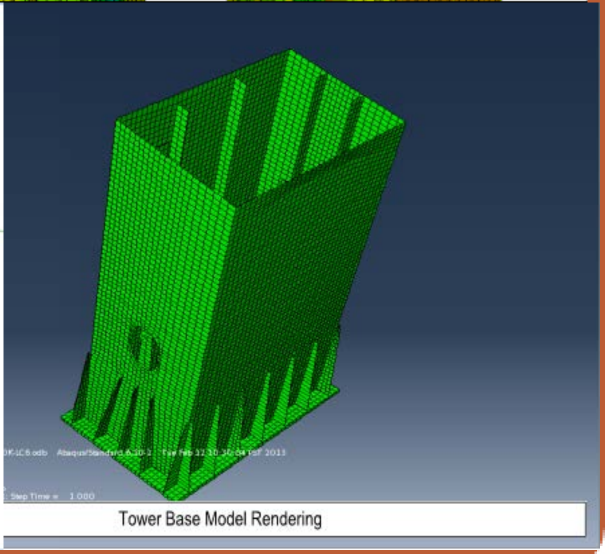


Min In Plane Stress for LC1 - Patch Loading on Entire Main Span Superstructure



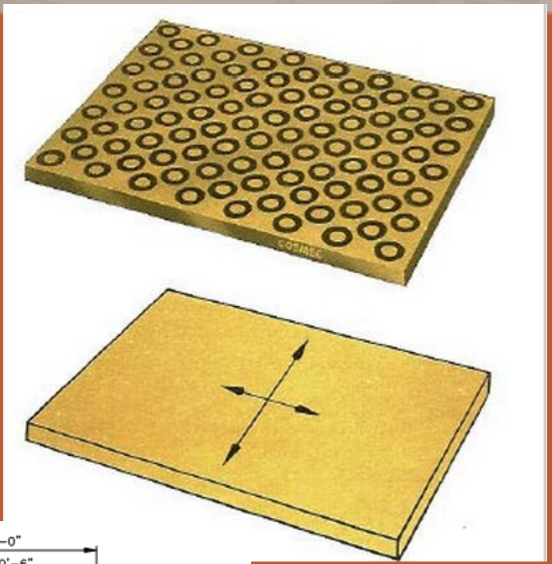
Case 3: Distributed Axial Load, 1st eigenvalue

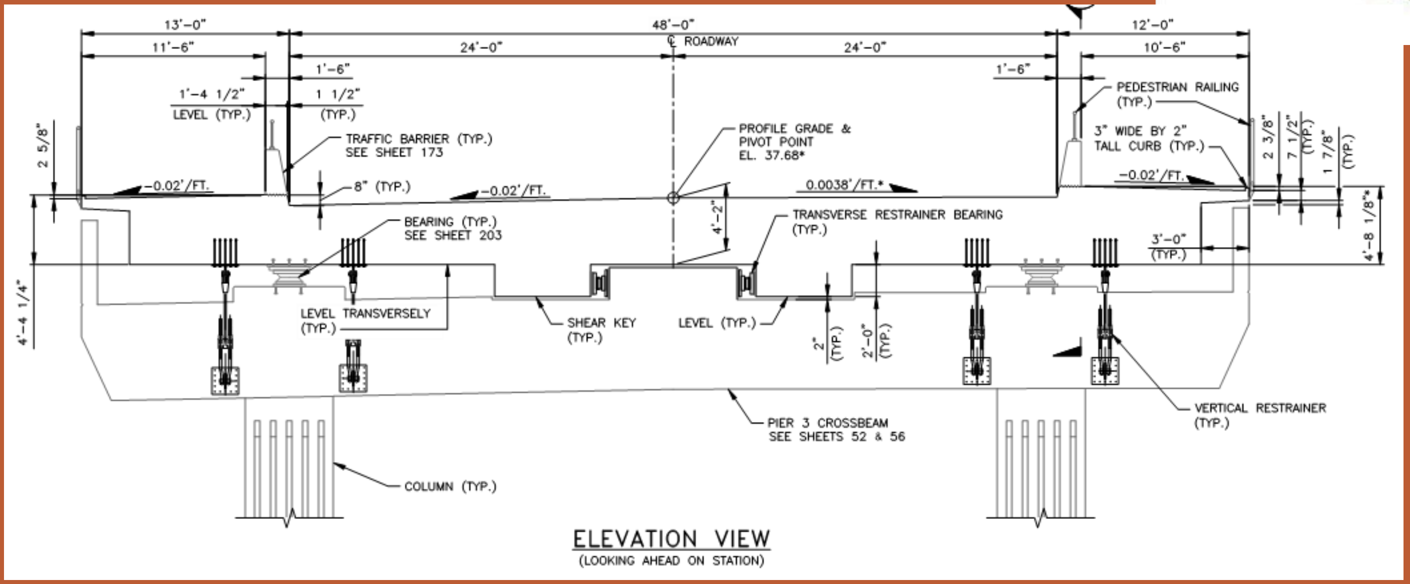



Tower Base Model Rendering

Lateral Forces and Longitudinal Movements at Ends of the Cable Stay

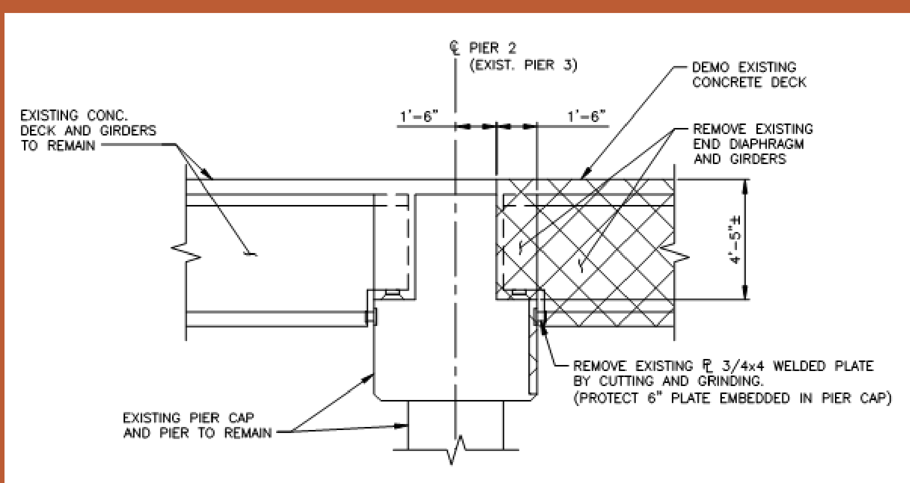
- Superstructure Fixed at the Tower/Pier Diaphragm for Movement and Rotation
- Longitudinal expansion and contraction were handled at the adjacent piers
- Large lateral forces from thermal and seismic were resisted by large brass bearings by Cosmec or similar

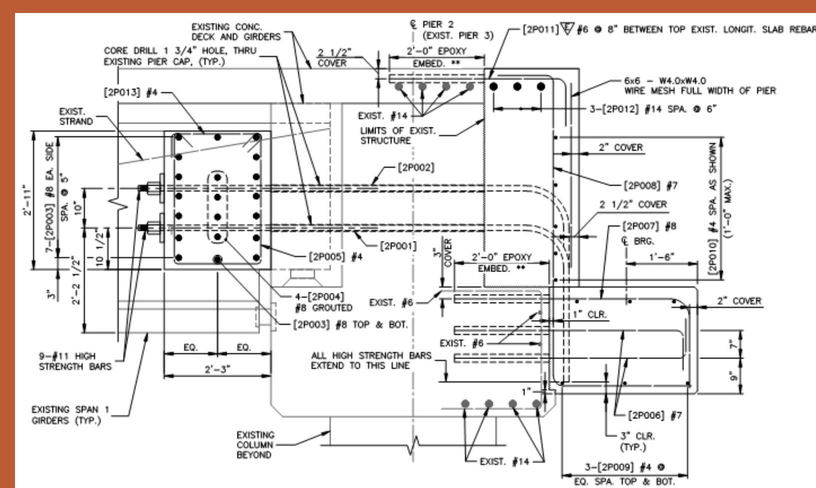




Substructure at Bridge Transitions - Pier 2

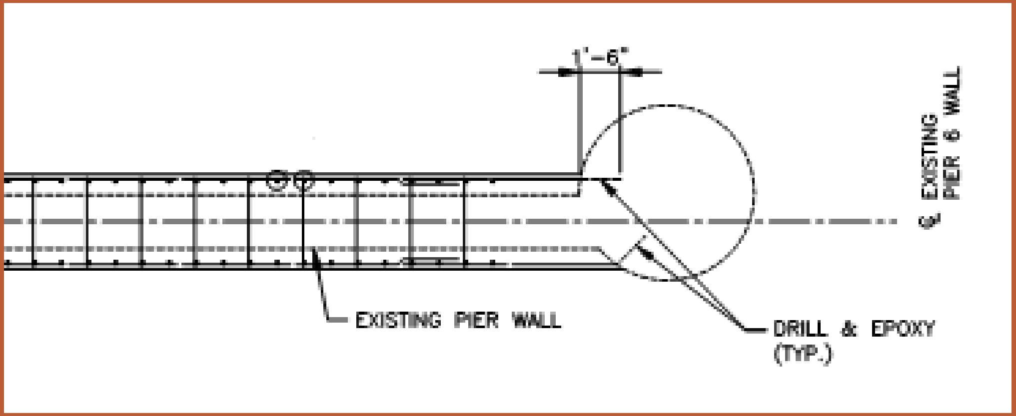
- Funding does not exist for the entire replacement of the 1970's approach.
- Large skew on the railroad span forced a need for bridge transition to occur within the 1970's west approach span
- Existing superstructure was continuous over the pier
- New transition span shorter and lighter than existing span
- Do No Harm Criteria was performed per WSDOT BDM

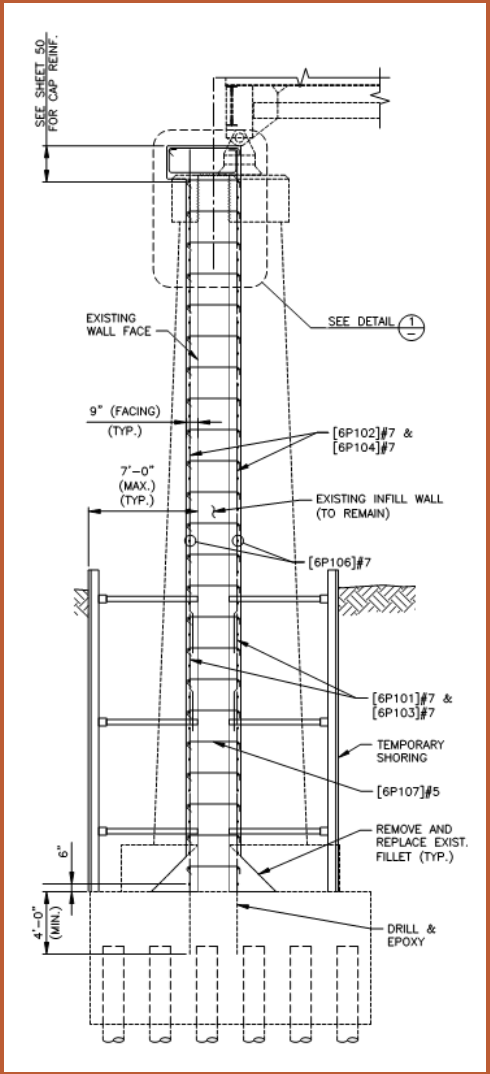




Substructure at Bridge Transitions - Pier 6

- Superstructure length supported by Pier 6 doubled
- Span 5 is temporary until Phase 2 is completed.
- Use of low friction sliding bearings reduced lateral forces to the pier from previously fixed state
- Infilling of existing hollow pier wall with lightweight concrete strengthened the existing wall for increased vertical loads
- Timber piles were checked for axial capacity





Construction Specifications

- High Performance Concrete (HPC) Requirements
- HPC defined as mass concrete will require to have a Mass Concrete Placement and Curing Plan
- Minimum segment age at time of erection = 60 days
- Superstructure erection geometry control
- A number of erection tolerances defined
  - Maximum differential between outside segment faces
  - Maximum transverse and longitudinal angular deviation between segments
  - Maximum accumulated permissible error

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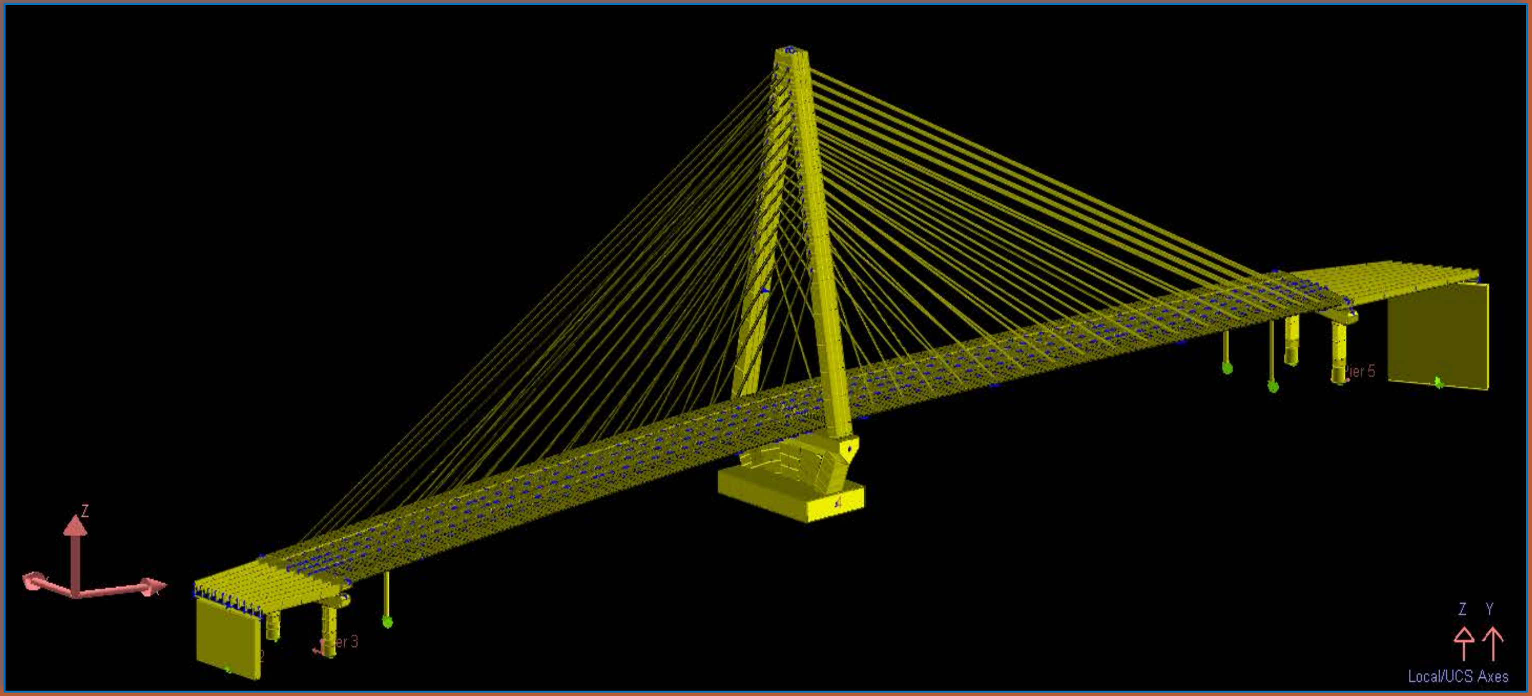

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QUESTIONS?

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