Design and Construction of the Fort Edmonton Footbridge Over the North Saskatchewan River

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Western Bridge Conference

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Introduction

- The City of Edmonton's Fort Edmonton Footbridge completes a link within the City's extensive riverfront park system.
- The bridge site is located upstream of one of Canada's largest living history museums
- Aesthetics and environmental considerations were paramount, an extensive public communication program was utilized
- The North Saskatchewan River is a major river in the Province of Alberta, construction within the river banks must address seasonal flow variations, large temperature swings, and the dynamic of river ice effects.

Design and Construction Team

- Owner: City of Edmonton
- Prime Consultant and Designer : CH2M HILL
  - Dynamic Analysis: Boundary Layer Wind Tunnel Laboratory
  - Geotechnical: Thurber Engineering
  - Trails: EDA Collaborative
  - Hydrotechnical: NHC
  - Environmental: AMEC & CH2M HILL
  - Specialist Consultant: Jiri Strasky
- Construction: Alberco Construction Ltd.
  - Precast: Lafarge
  - Cable: Bridon
  - Post-Tensioning: DSI

Project Site

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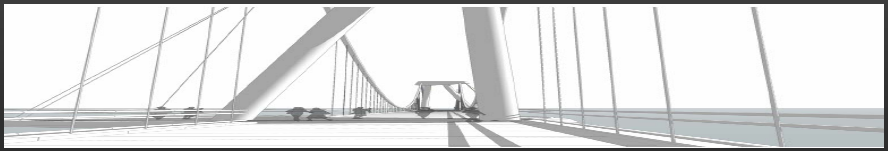
Contextual Design Issues

- Minimize impact on View
  - views of Edmonton from top of bluffs
  - views along river corridor
- Appropriately scaled icon structure
  - unique architectural identity
- Sustainable facility
  - Life Cycle Costs
  - compatibility with special natural environment (Greenfield site)
- Encourage interaction with river environment
  - park setting
  - gathering place



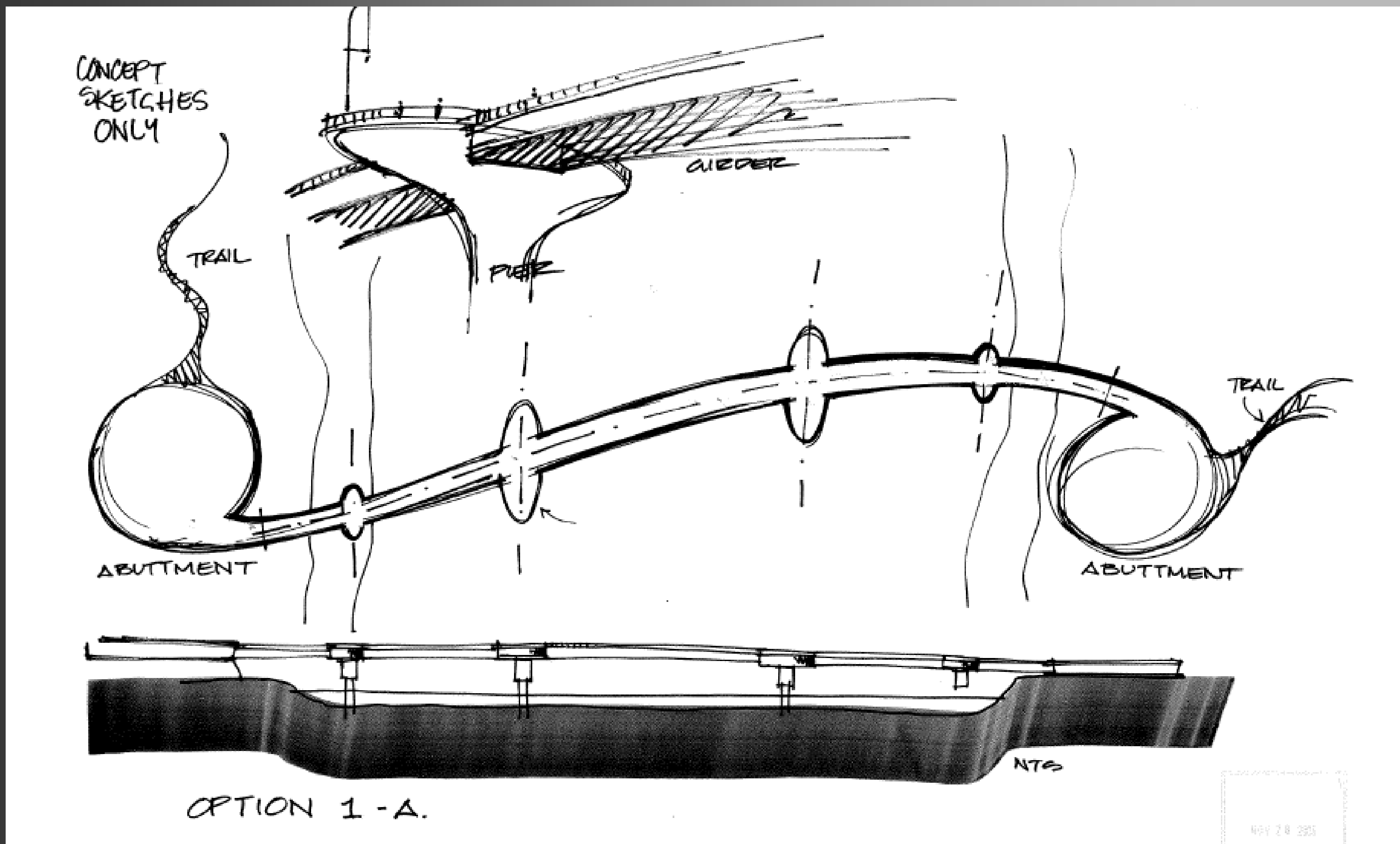
Site Context – North Saskatchewan River Valley

Site Context – City of Edmonton Parks

Site Context

- Linear park with river valley
  - park is major urban amenity
  - summer months with long days
- Adjacent to Fort Edmonton Heritage Park
- Neighborhoods on top of bluffs
  - valley is 30 meters (100 feet) deep
  - View concerns from property owners
- North Saskatchewan River Valley

Early Concepts



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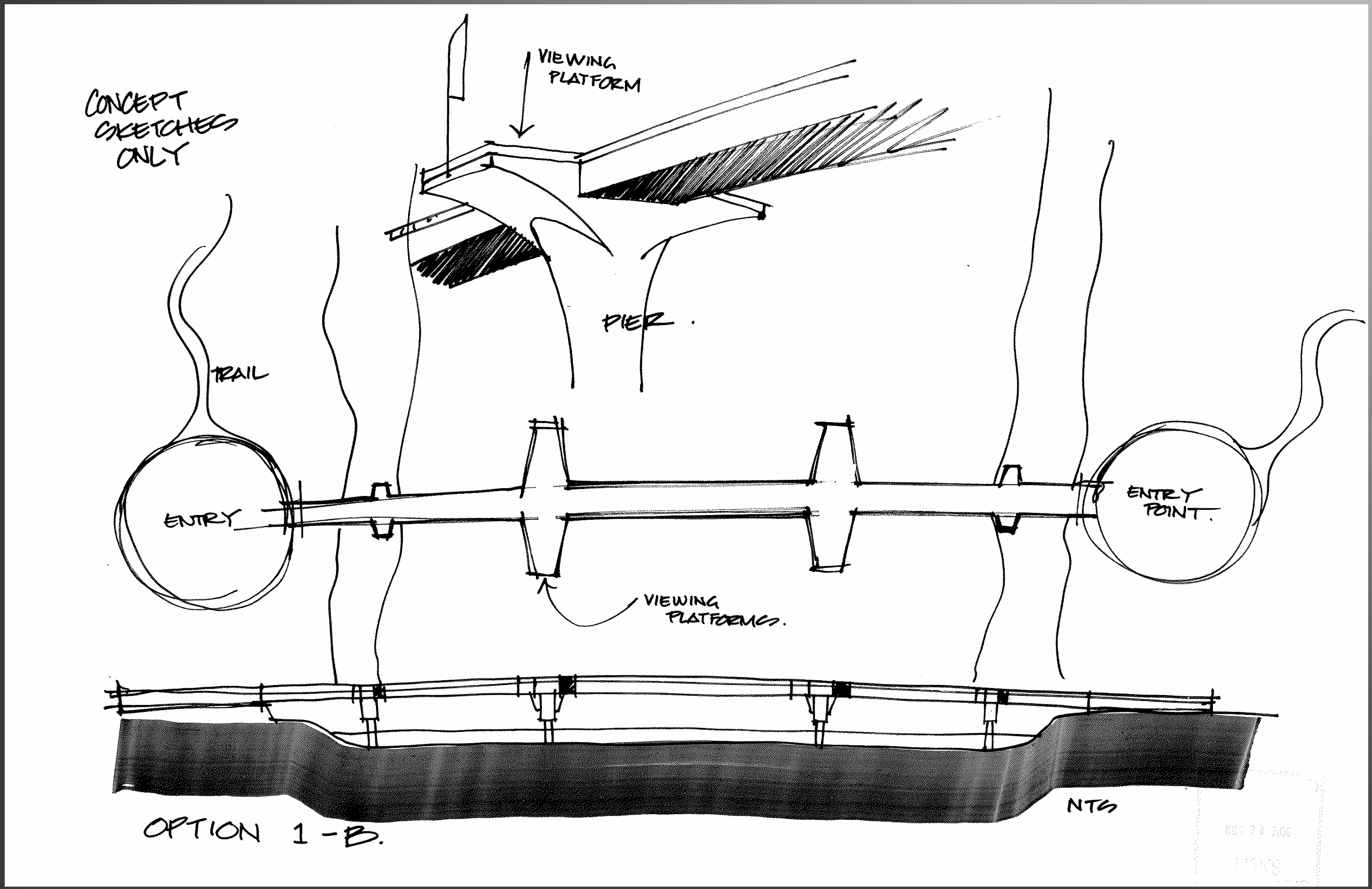
Early Concepts



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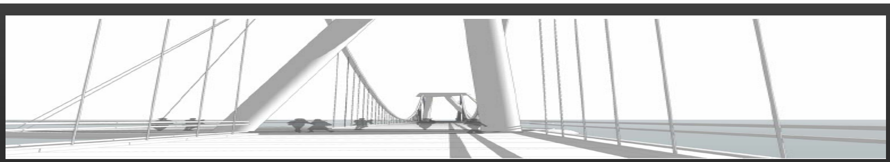

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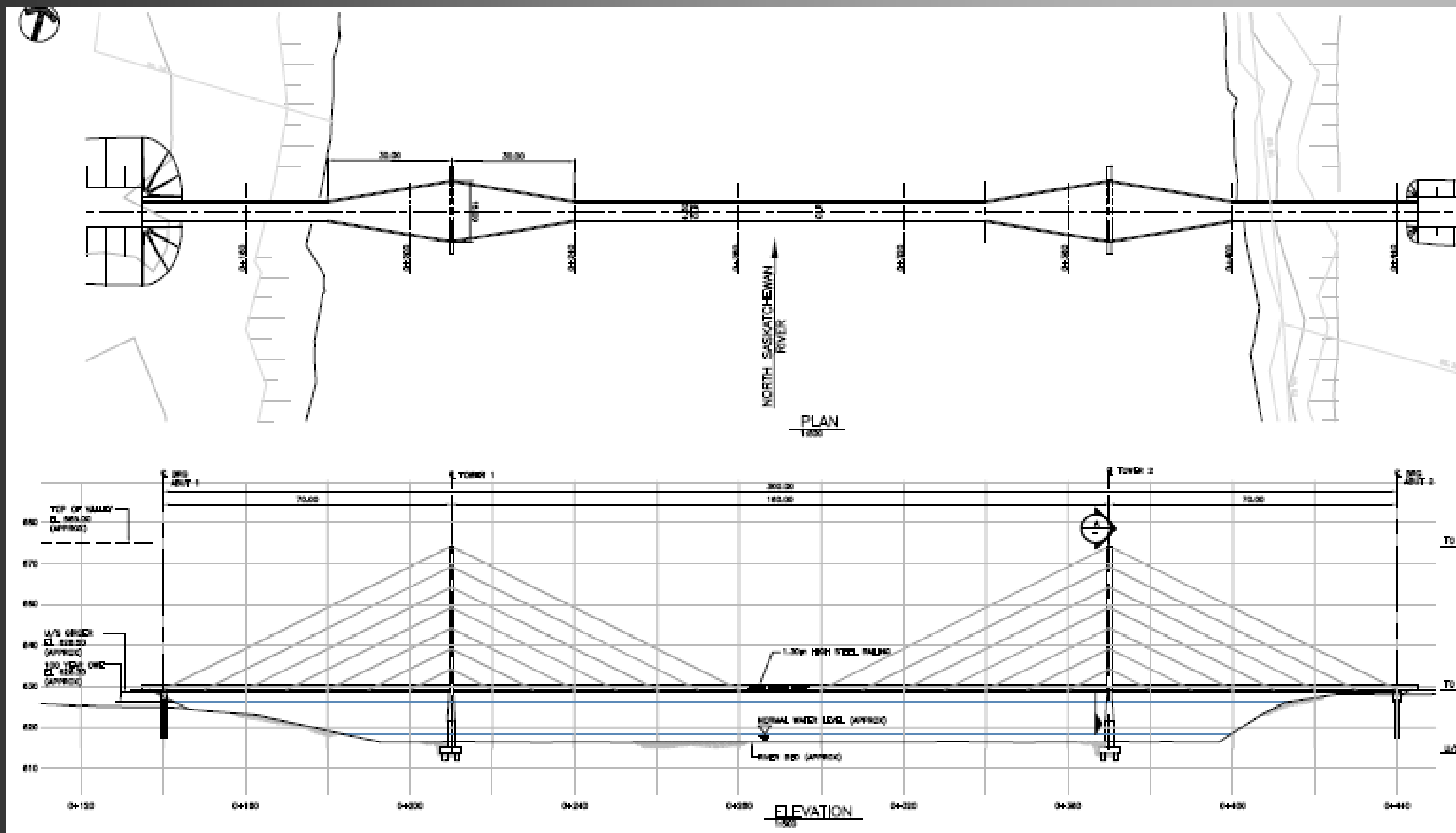
Alternatives



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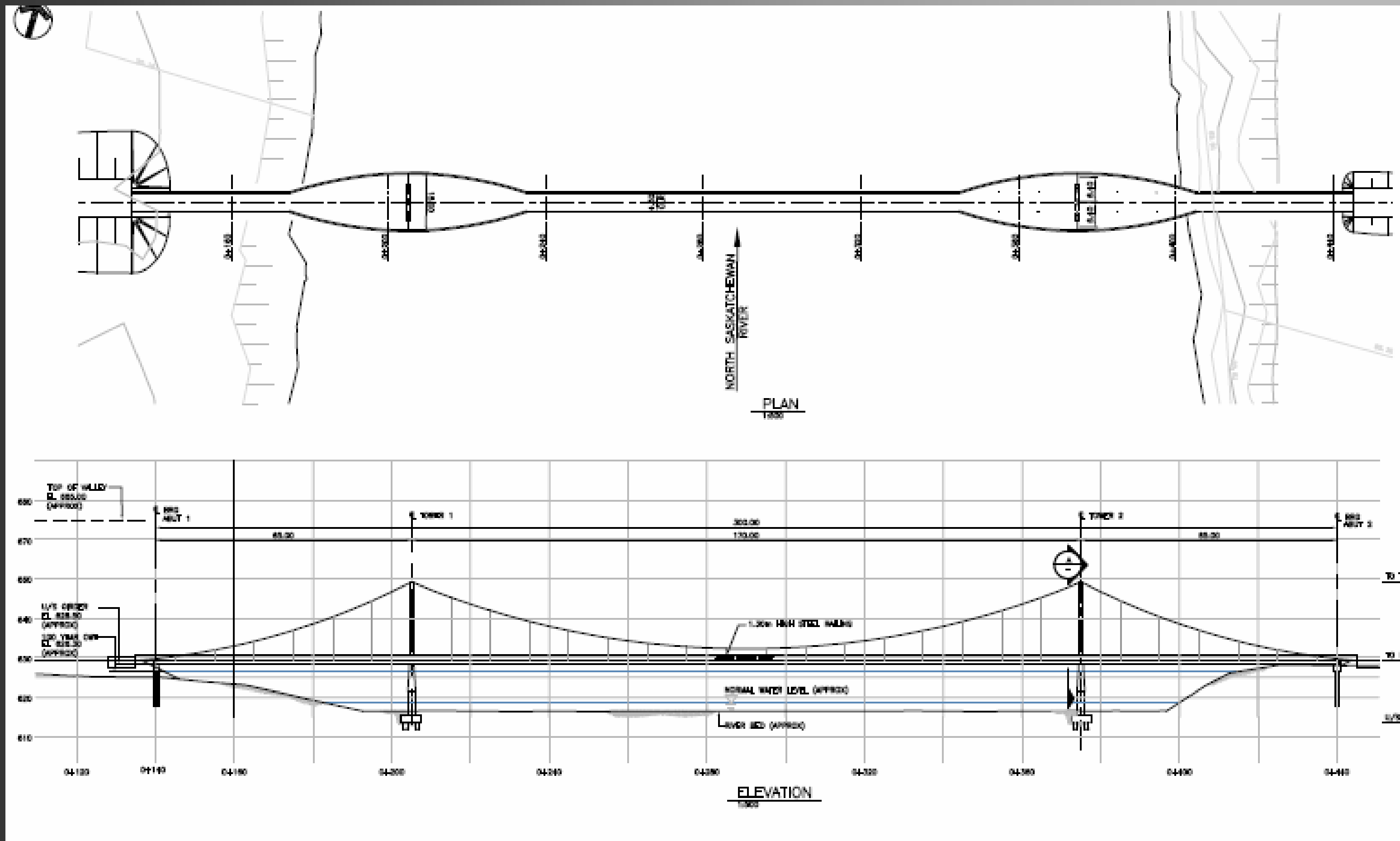

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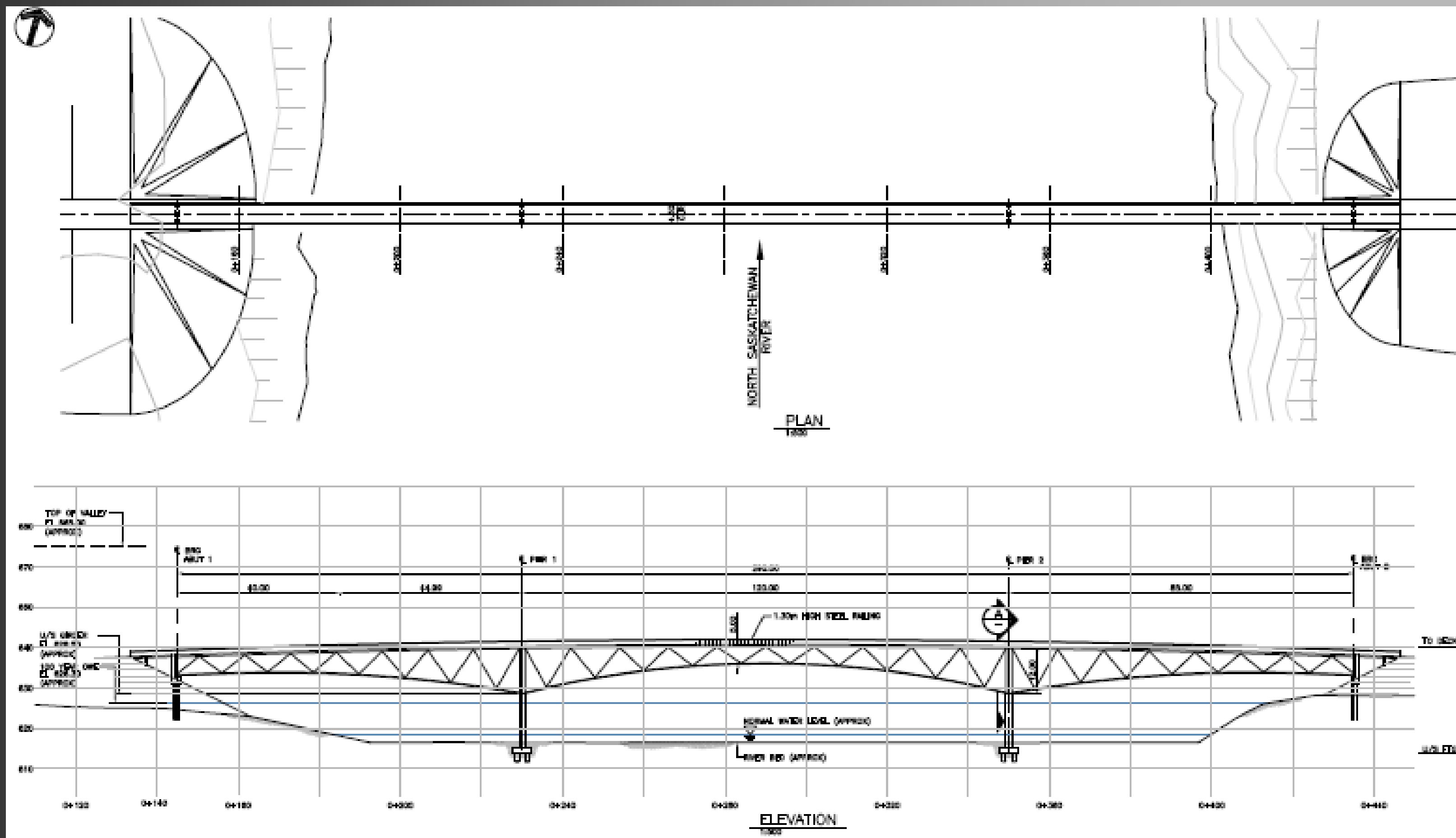

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Selected Structure

- A suspension bridge was selected for final design due to a minimum number of piers in the river and a lower more organic, light, visual profile relative to other long-span bridge types.

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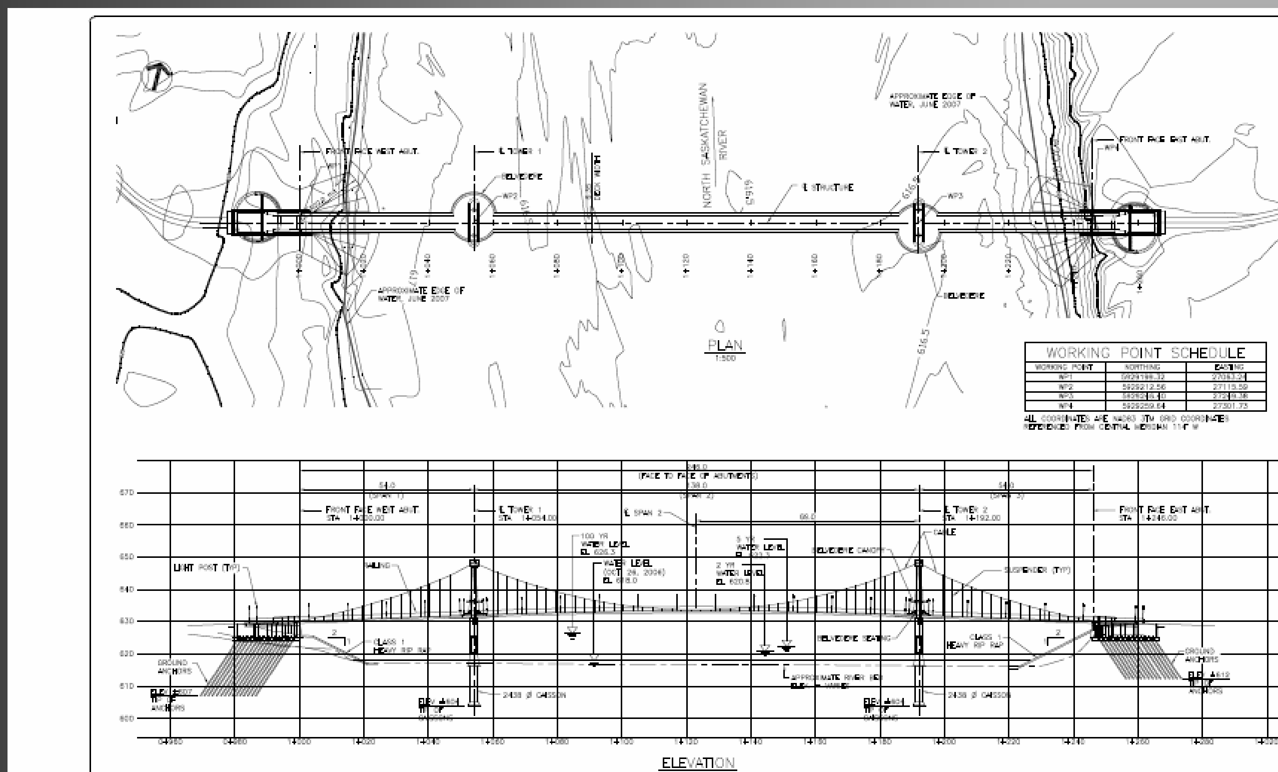
Final Structure

- The bridge has a span arrangement of 54m-138m-54m (177'-452'-177') with piers placed approximately 30m (100') from both river banks.



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Design and Construction

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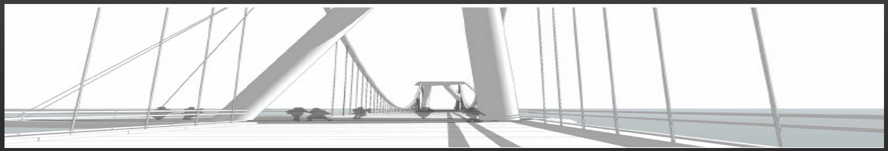
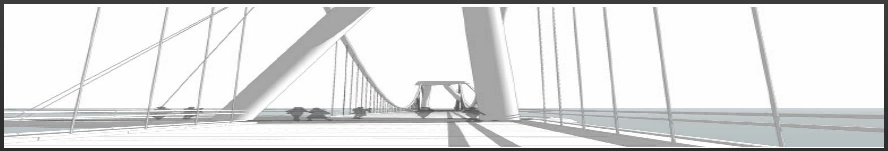


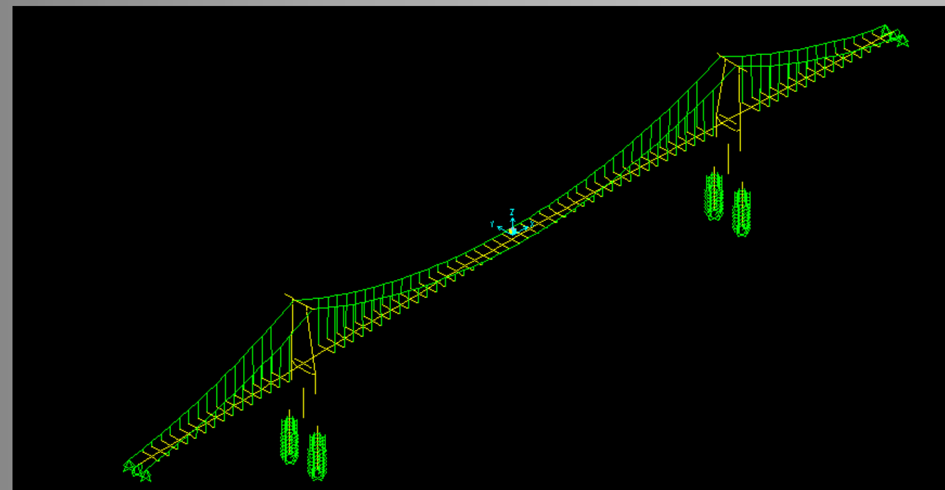
Engineering Design Issues

- Major river with large watershed
  - floods
  - ice loading
- Soils
  - erosion and scour
- Temperature
  - This area experiences dramatic shifts of temperature, with a design temperature range of 81° C degrees for this site
- Dynamic Response
  - Wind
  - Pedestrian
- Construction Access and Schedule
  - Construction season
  - Reliability of construction from the river ice
  - Environmental issues

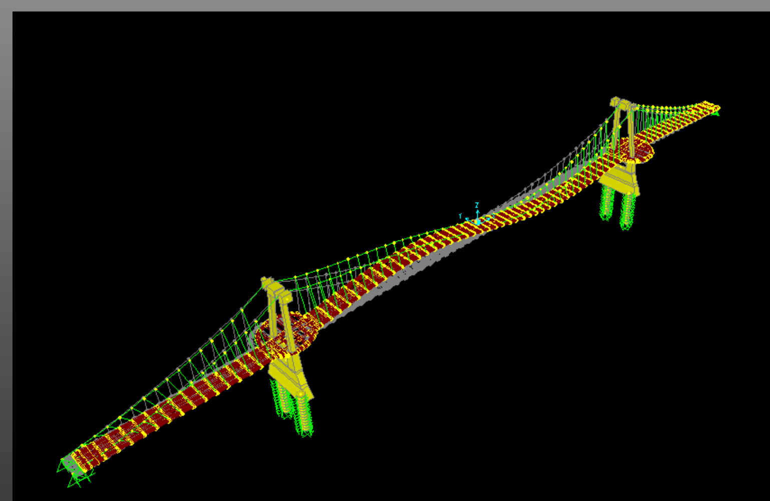


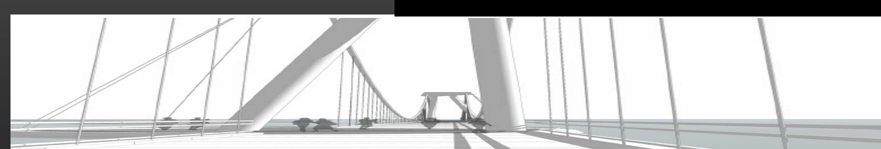
Global Analysis

- Service Loads and Ice Loads Modeled Using SAP 2000 3D Frame Element Model



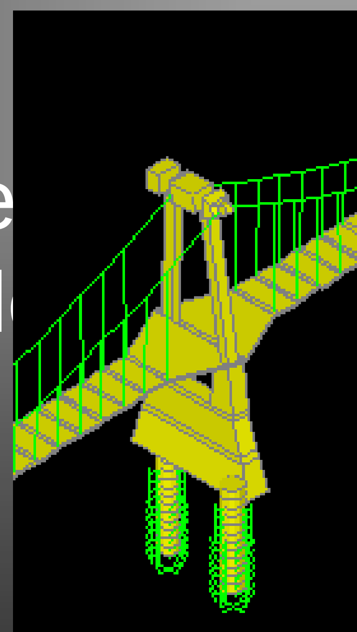
- Wind Analysis Performed using SAP 2000 Block Model
  - Mode shape Variance with Stick Model

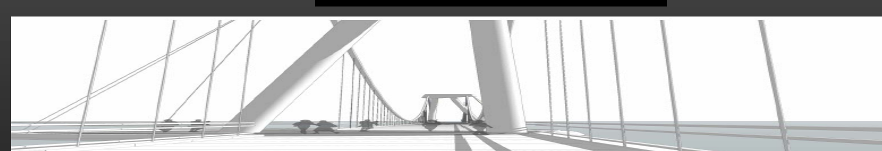




Global Analysis

- Non-linear large displacement P-Delta Analysis
- Stiffness of pier dependent on shape and force in the cabl
- 500 + explicit load case combinations



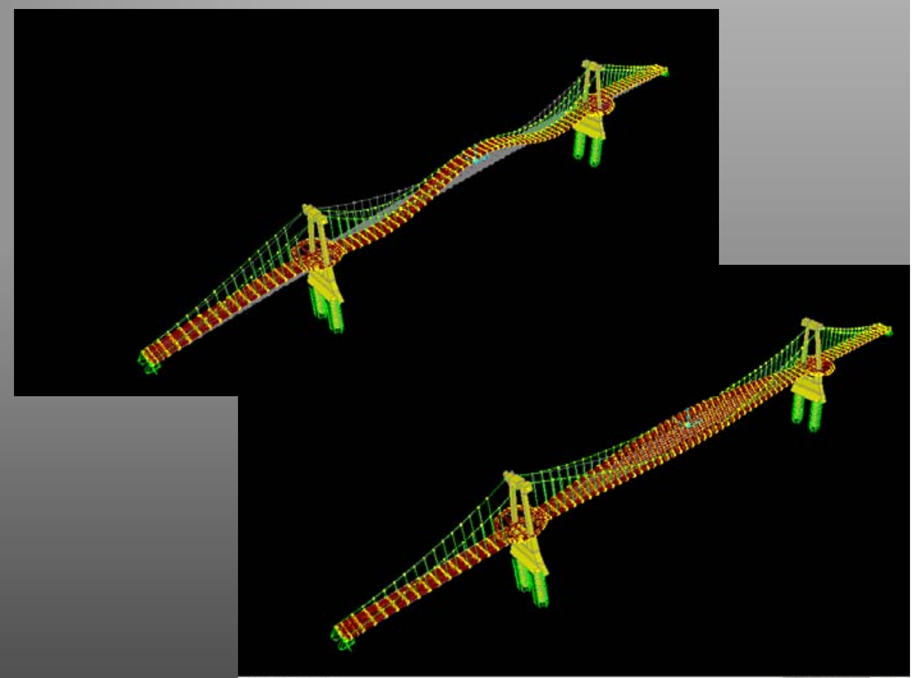


Wind and Vibration Analysis

- 100 yr Wind Design – 28.9 m/s
  - CHBDC - 8 kn/M Along Deck
  - Wind Study – Shape functions for Dynamic Response Shapes

$$R = \overline{R} \pm \sqrt{R_{1x}^2 + R_{2x}^2 \cdots + R_{1z}^2 + R_{2z}^2 \cdots + R_{1\theta}^2 + R_{2\theta}^2 \cdots}$$

$$\begin{cases} \overline{W_x}(\eta) = \overline{\alpha}_x(\eta) \cdot \overline{W_x} = 1.0 \cdot \overline{W_x} \\ \overline{W_z}(\eta) = \overline{\alpha}_z(\eta) \cdot \overline{W_z} = 1.0 \cdot \overline{W_z} \\ \overline{W_\theta}(\eta) = \overline{\alpha}_\theta(\eta) \cdot \overline{W_\theta} = 1.0 \cdot \overline{W_\theta} \end{cases}$$



- Pedestrian Vibration Study
- Potential for Tuned mass Dampers

Wind Study

TABLE 3.4 VALUES OF $\overline{w}, w_1$ AND w_2 FOR VARIOUS MEAN HOURLY WIND SPEEDS

	Mean Hourly Wind Speed of 21.5 m/s at Deck Height (The 50-year Return Period Event, Suburban Exposure)			*Mean Hourly Wind Speed of 23.0 m/s at Deck Height (The 100-year Return Period Event, Suburban Exposure)*		
LOAD COMPONENT	***X (kN/m)***	***Z (kN/m)***	***θ(kN-m/m)***	***X (kN/m)***	***Z (kN/m)***	***θ(kN-m/m)***
Loading direction	X	Z	θ	X	Z	θ
Mean, $\overline{w}$	0.31	0.37	1.04	0.35	0.42	1.19
w_1	1.16	5.36	11.33	1.39	6.08	13.49
w_2	1.32	4.75	8.57	1.57	5.36	10.23
w_3		9.58			11.06	
w_4		5.97			6.91	

	Mean Hourly Wind Speed of 27.1 m/s (The 50-year Return Period Event, Open Country Exposure)			*Mean Hourly Wind Speed of 28.9 m/s (The 100-year Return Period Event, Open Country Exposure)*		
LOAD COMPONENT	***X (kN/m)***	***Z (kN/m)***	***θ(kN-m/m)***	***X (kN/m)***	***Z (kN/m)***	***θ(kN-m/m)***
Loading direction	X	Z	θ	X	Z	θ
Mean, $\overline{w}$	0.48	0.58	1.65	0.55	0.66	1.87
w_1	1.36	5.16	12.91	1.60	5.75	15.13
w_2	1.52	4.47	9.93	1.79	4.96	11.70
w_3		9.72			10.98	
w_4		6.18			7.02	

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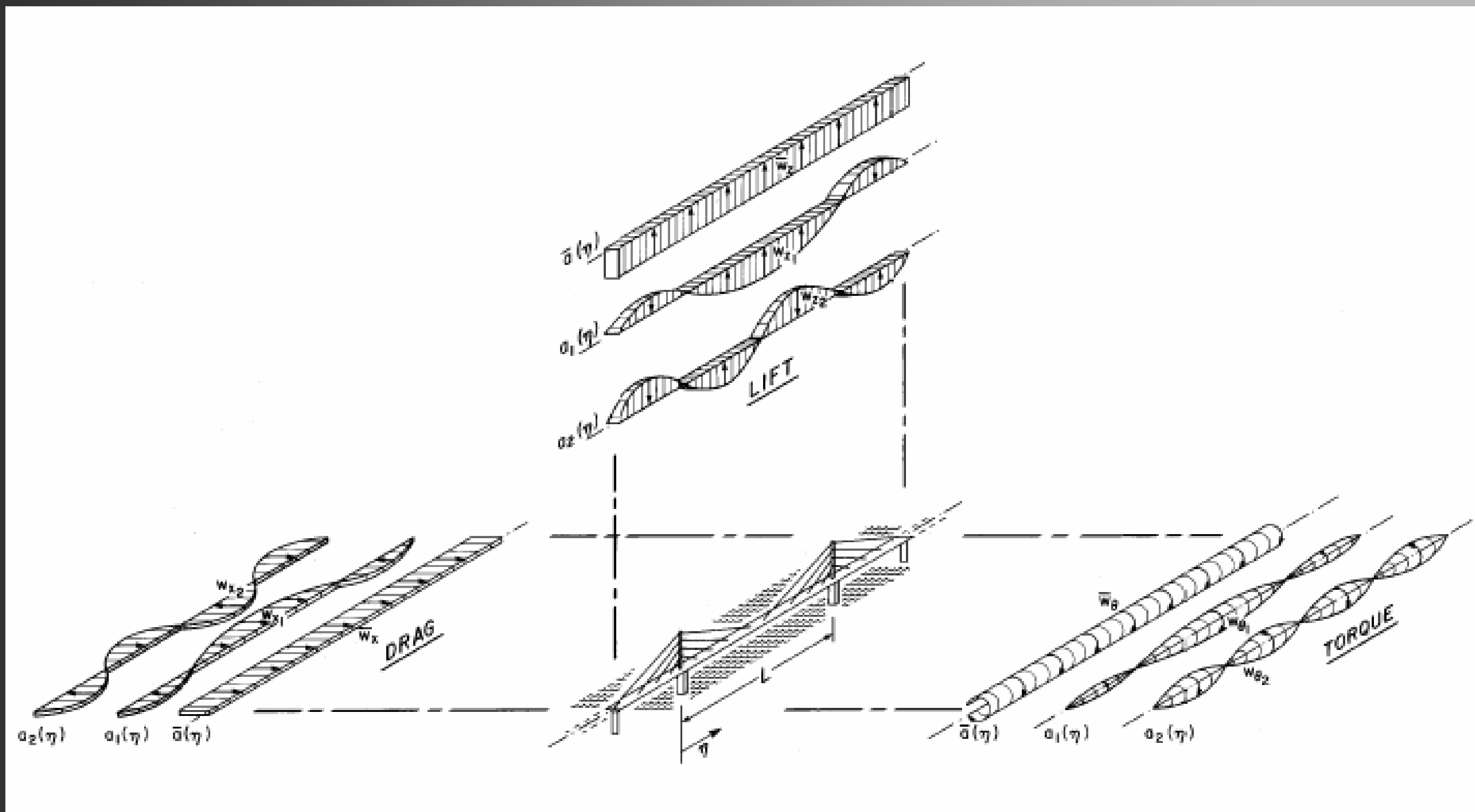
Wind Study



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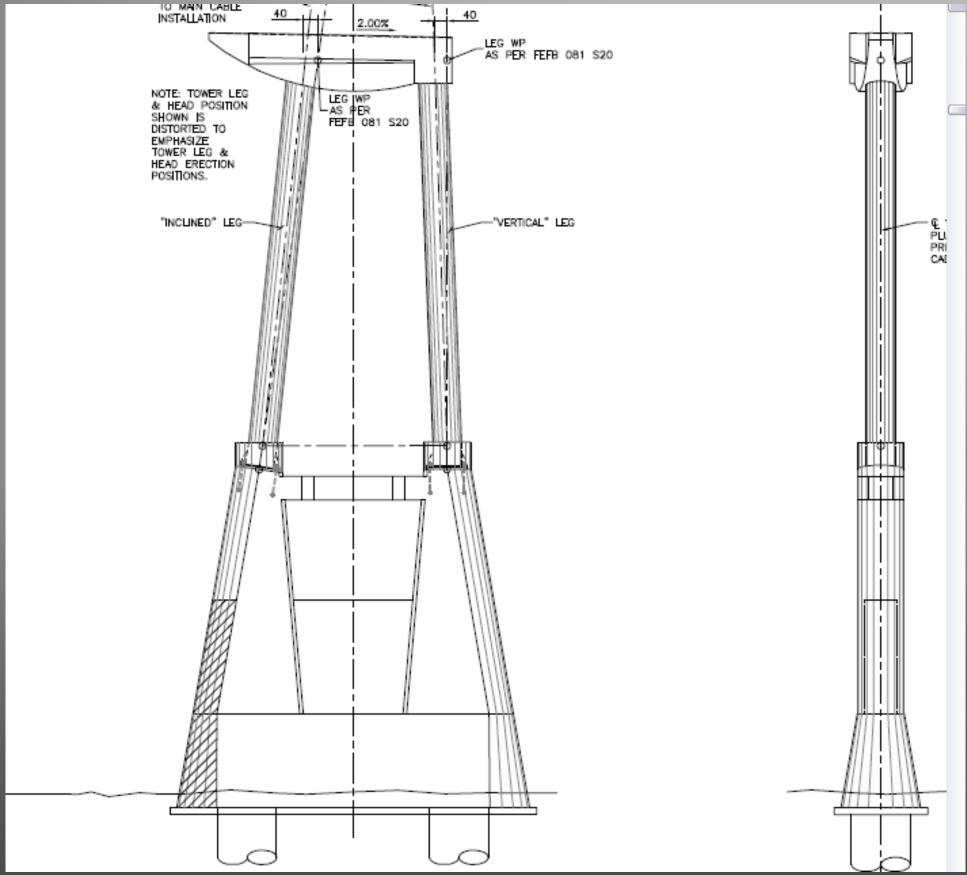
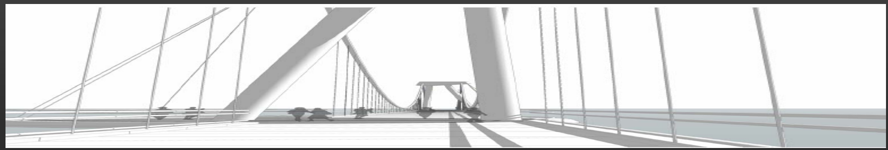
Pier and Shaft Design

- Concrete Filled Steel Tower Legs on CIP Lower Shafts
- Construction Loads Govern Upper Design
- FB Pier Soil Structure Analysis
- Designed to resist dynamic forces from ice.
- Construction Loads governed upper Pier design
- 8 meter (26’) seasonal variation in the water surface elevations





Ice Flow design issues

- Ice Impact Force 3.9 MN per Pier, perpendicular to bridge (900 kips)
- Transverse Static ice Force 3.06 MN
- Vertical Ice Force 1.6 MN
- Ice flow Forces Governed Drilled shaft design

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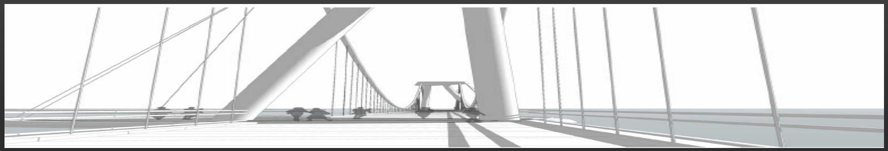
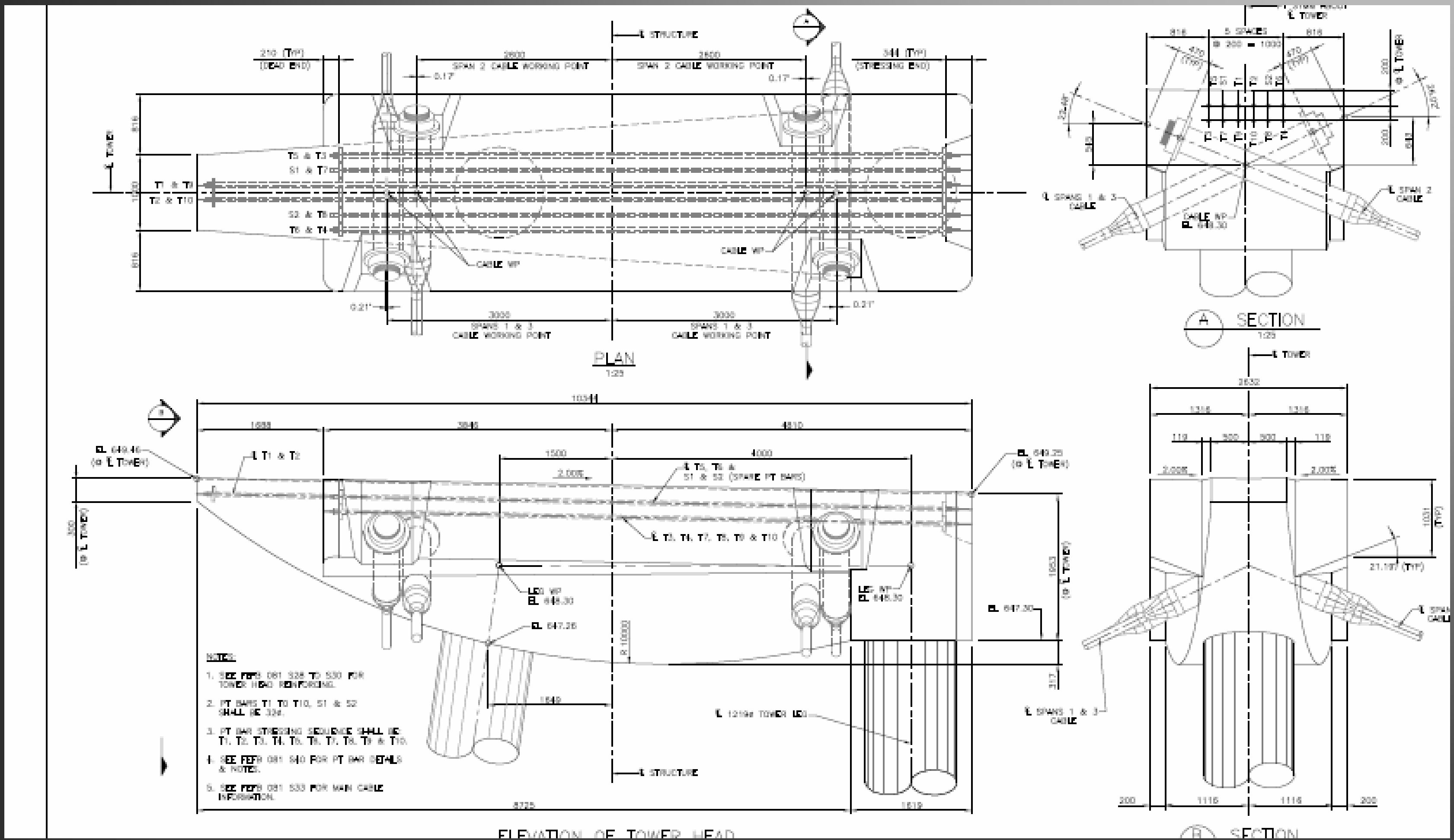
Cap Design

- Initial Cap Design Utilized Dead End PT Anchors for main cables inside tower cap
- Tower legs are offset from the main cables to avoid a conflict between projecting rebar from the tower legs into the cap.
- Contractor elected to use a Saddle System
  - Added drainage troughs for maintenance and ice issues
- Cap is transversely post tensioned with HS rods



Cap Design



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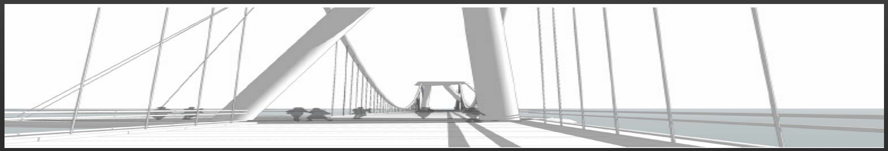

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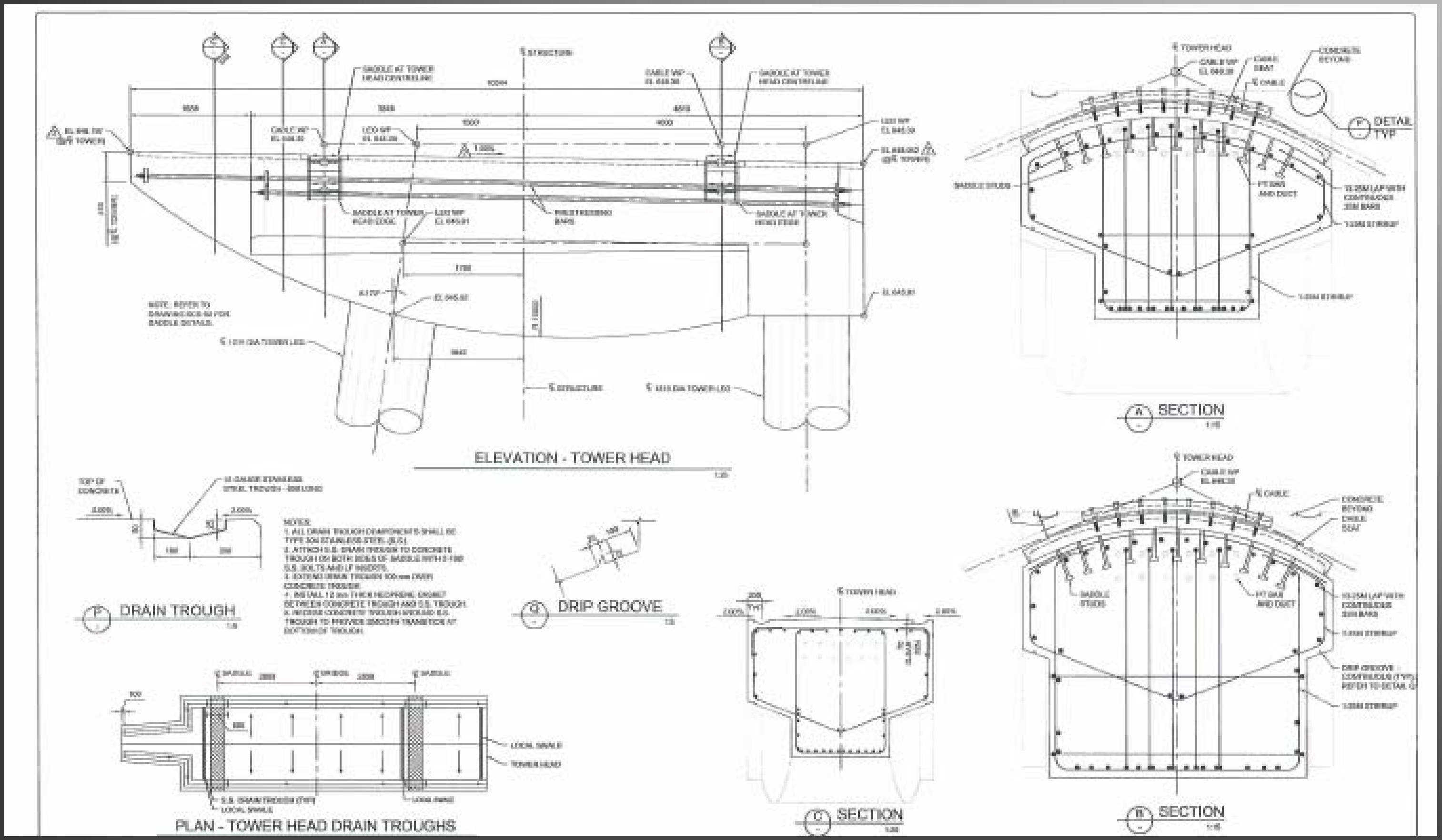

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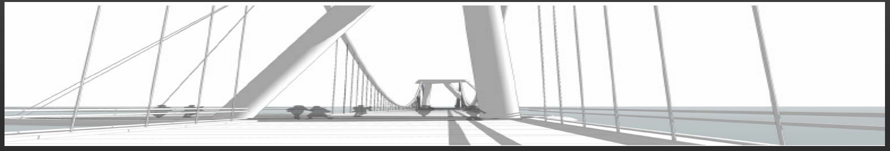
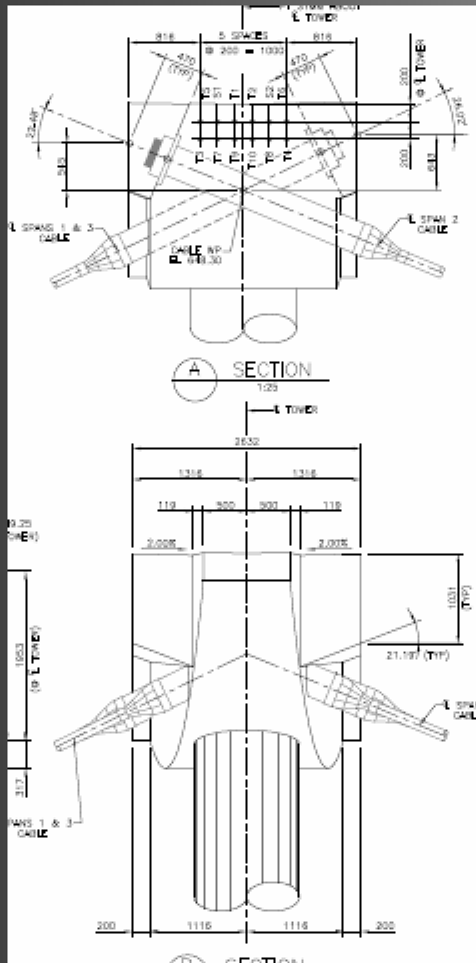
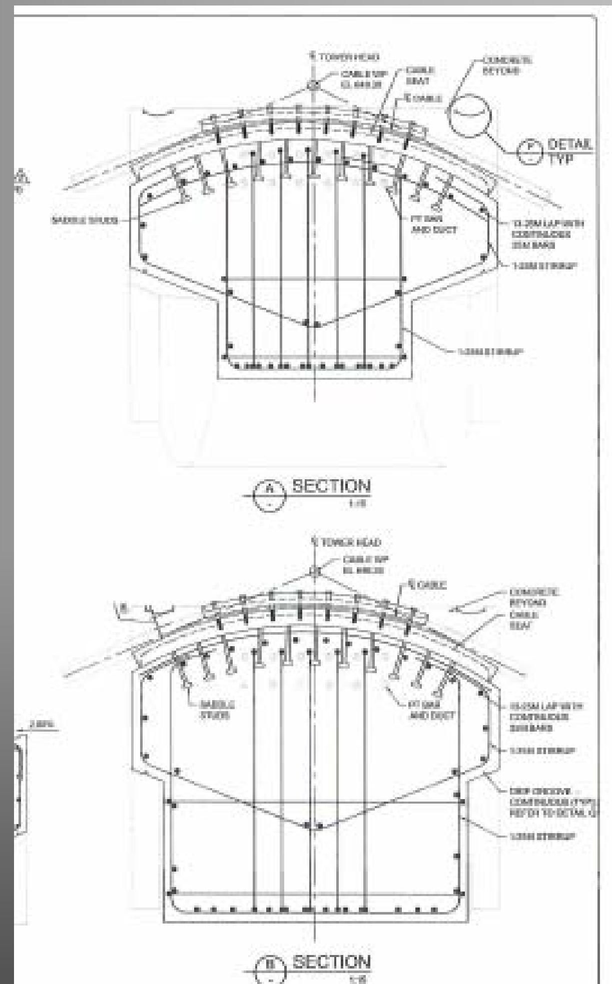




Cable Anchorages



Saddle

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Construction season and Temperatures.

- Construction occurred through all 4 seasons
- Construction stopped at temperatures below -30 degrees Celsius.
- Heat Provisions – including Propane heaters, and hoardings

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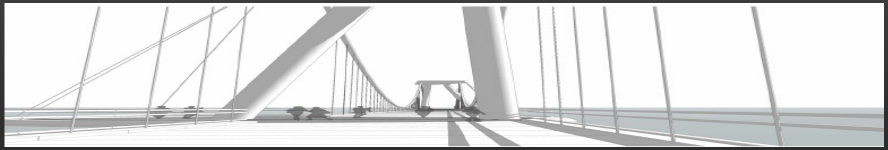

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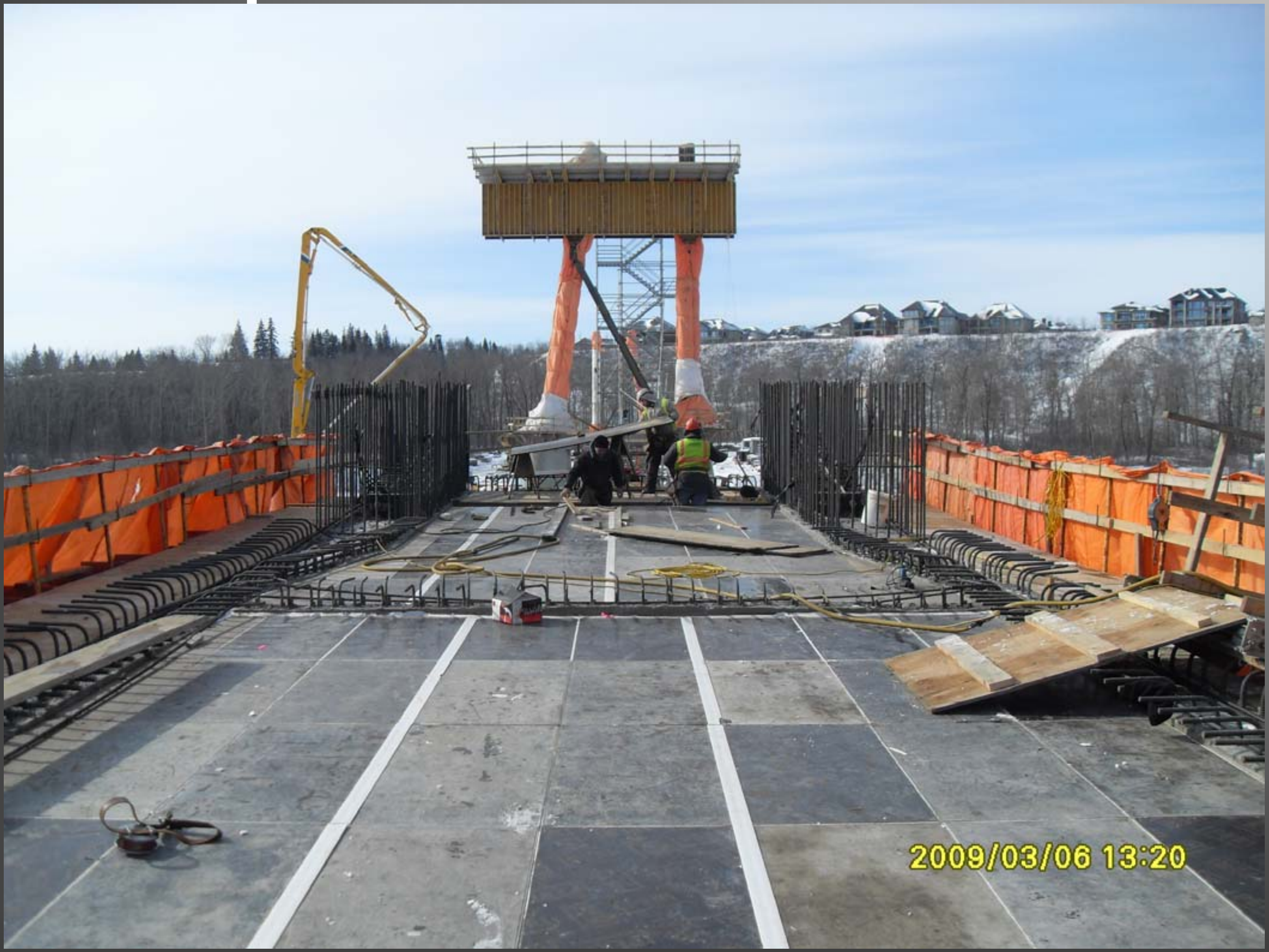
Temperature Provisions



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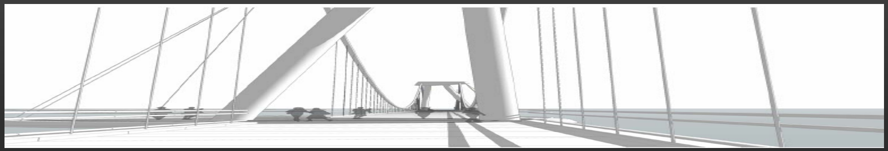

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Temperature Provisions

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Cold Weather Construction Challenges in Shafts

- Coffer Dam Built before Ice Set in
- Coffer Dam designed for 2 year flood
- Concrete froze at the top of one shaft, requiring 150 mm (6”) of concrete to be removed

Pier Coffer Dam

•Berms were constructed in the North Saskatchewan during the late summer/early fall months, in accordance with environmental permits

Pier and Shaft Construction

Pier caissons drilled during the early fall with temperature just at or below freezing

Winter Concrete Placement

Winter Concrete Placement

Winter Construction

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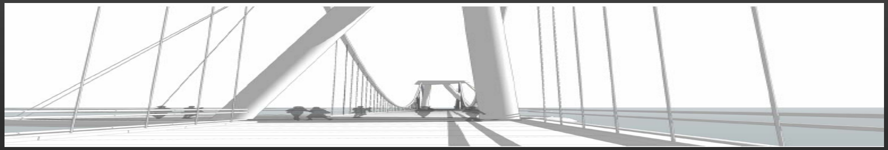

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Piers and Cap Construction

- Protect Concrete Elements Warm during curing Process
- Erect “slanted” Steel Pier
- Utilize steel pier shells as falsework for upper cap

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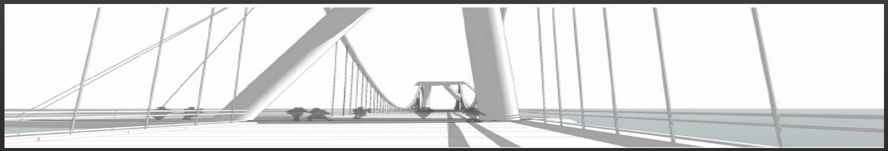

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Steel Erection

Pier Cap Construction

Superstructure Design and Construction

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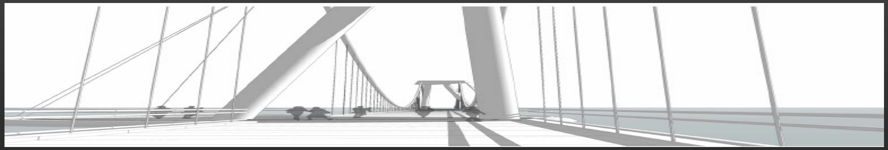

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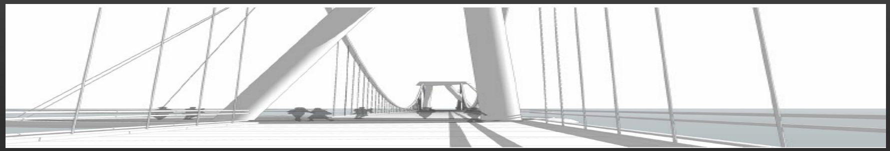
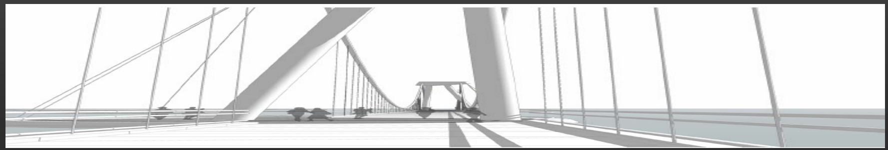
Cold Weather Environment Considerations Influences Superstructure Type

- Erection from Cranes on Frozen River
- Consultation With Construction Community
  - Warmer Climate Trends
    - => Reduced Construction Window
    - => Delays could compromise approach
- A Segmental System
  - Optional Overhead Erection from Cable System



Suspension System - Main Cable

- A586 Bridge Strand – Two Options
  - Grade 1 – 125 mm Nominal Dia.
  - Grade 2 – (85% of Grade1) <= Chosen
- Anchorages
  - Design Based on Dead End Anchorages
    - Input from Industry
    - Concerns for Shipment Limitations
  - Contractor Proposed Saddle Alternate



Suspension System - Main Cable

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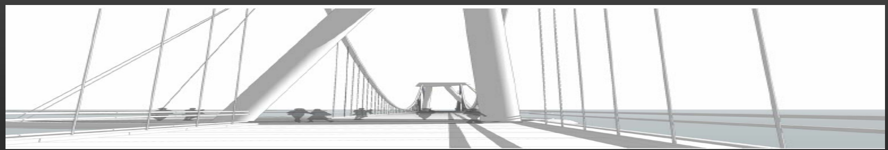

Suspension System - Main Cable

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Suspension System - Main Cable

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Suspension System – Suspenders

- A586 Bridge Strand
- Main Cable Clamps – ASTM A149 – GR 105
- Base Connection – Adjustable Socket
- Deck Connections – Embedded Steel Plate

Suspension System – Suspenders

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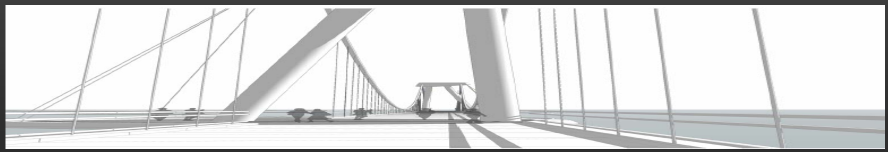
Superstructure

- Primary System
  - Precast Segments – 3 Meter Length
  - Concrete Closures Cast Between Segments
  - Longitudinal Edge Girder Post Tensioned for Global Effects
  - Transverse – Conventionally Reinforced Floorbeams
  - Deck – Two Way Slab

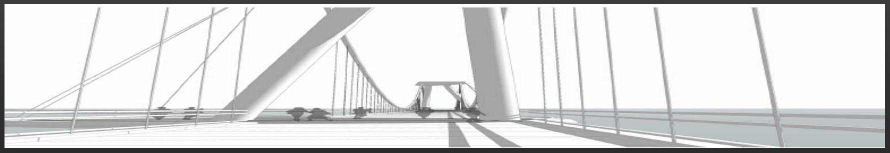
Superstructure

- Belvedere – “Place of Gathering”
  - Large Circular Area with Benches (~15 M x ~15 M)
  - Integrally Continuous with Rest of Superstructure
  - Transversely Post Tensioned
  - Large Cantilever to one side Balanced by DL
  - Large Cast in Place Mass serves as anchorage location for Post Tensioning



Precast Segment Design and Construction

- Segment Design - Local Effects
  - – Deck And Floorbeams – FEM
- Segment Design – Longitudinal Effects
  - – Global Analysis – FEM
  - – Large Temperature Design Range
    - 81°C (In real units – 146°F)
    - CR+SH+T => Significant
    - Minimum Segment Age Established to Reduce Shortening Effects of Superstructure



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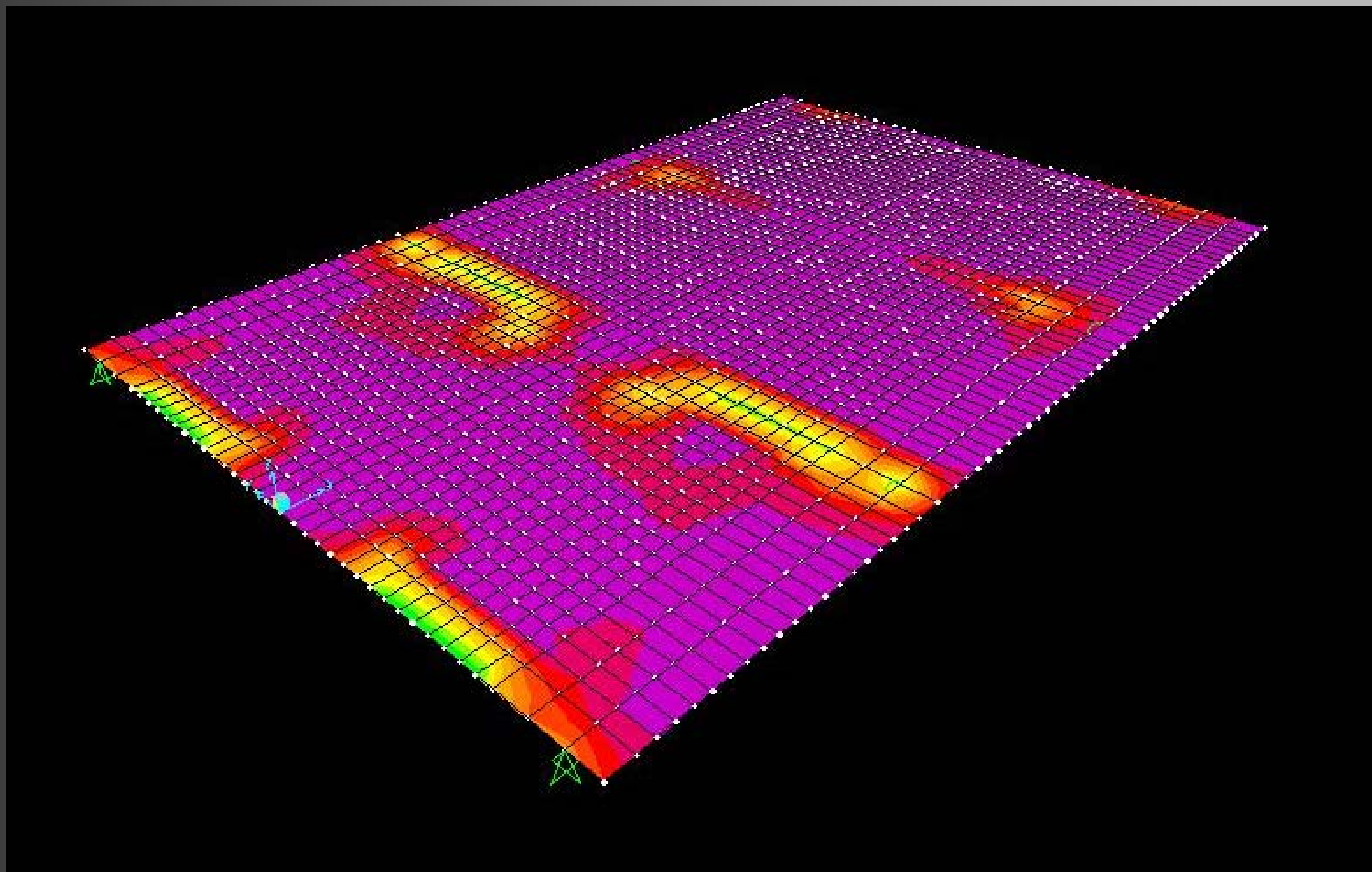

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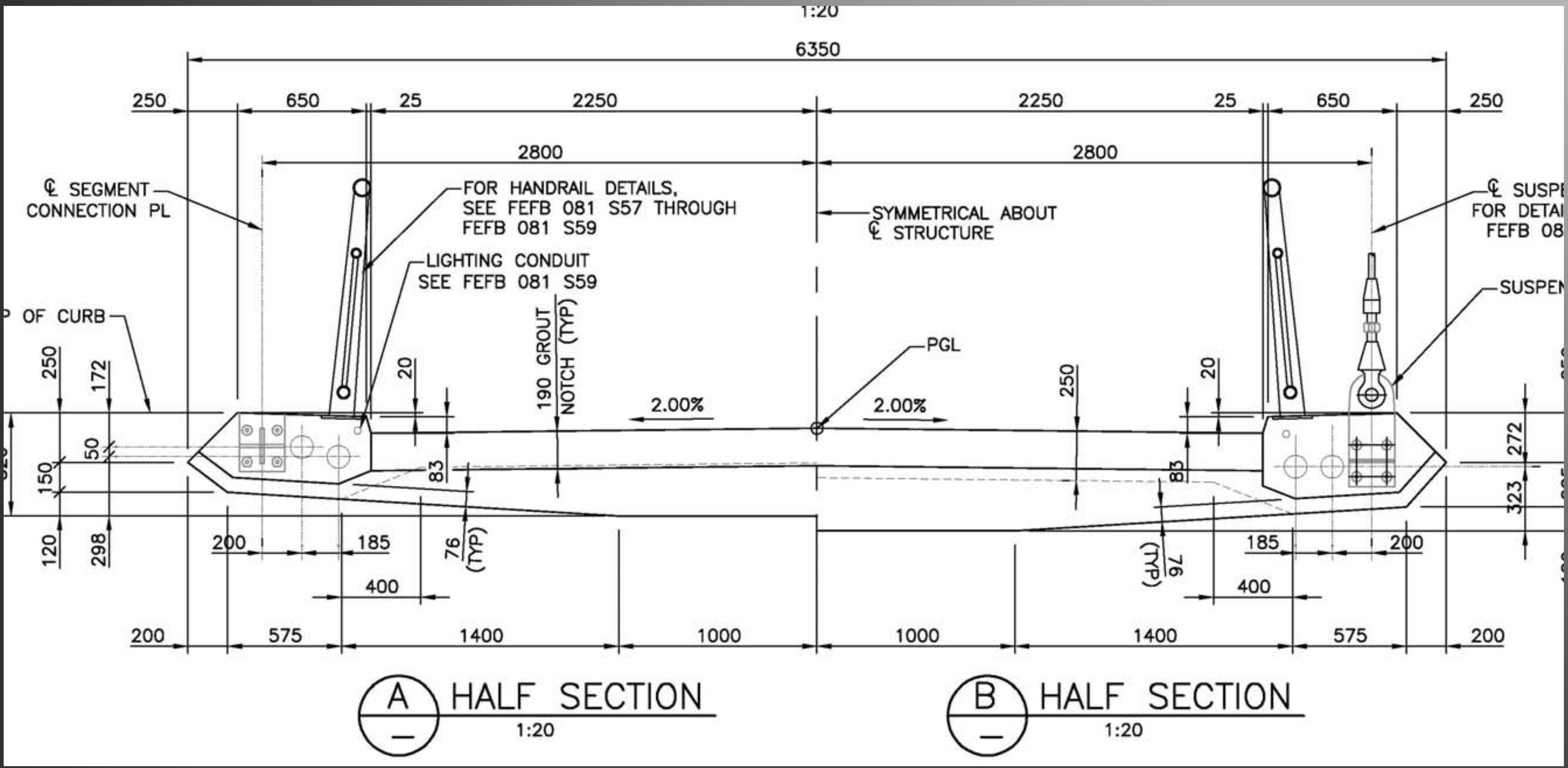

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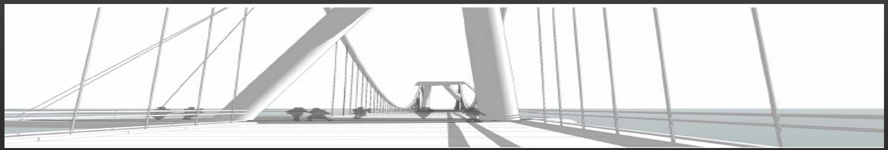

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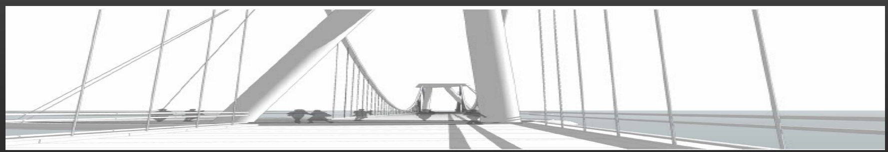
Precast Segment Design and Construction

- Segment Casting Through Cold Winter
- Segments Cast Indoors



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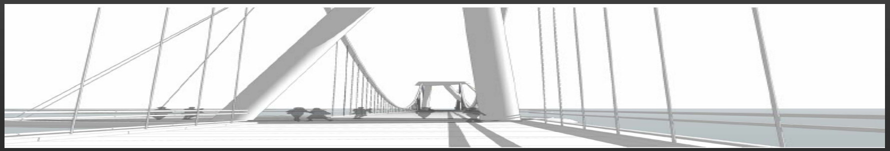

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Precast Segment Design and Construction

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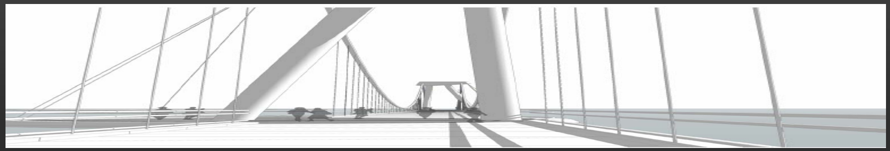

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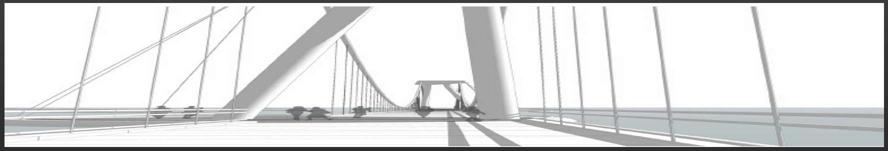

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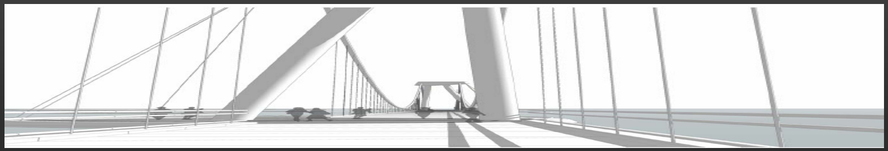

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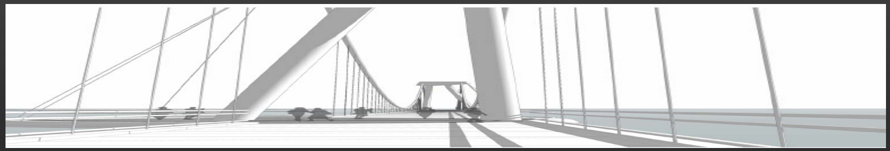

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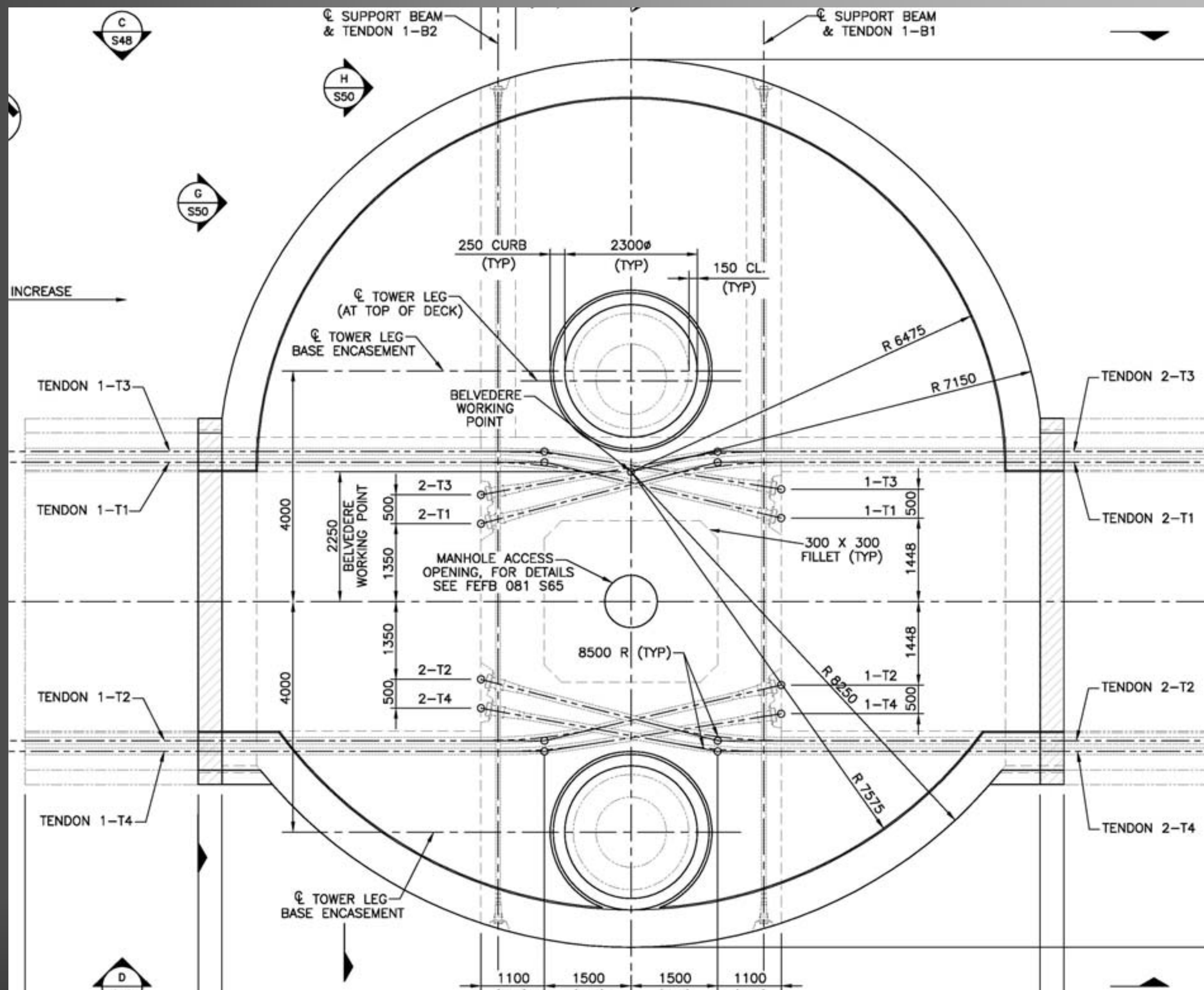
Belvedere Design and Construction



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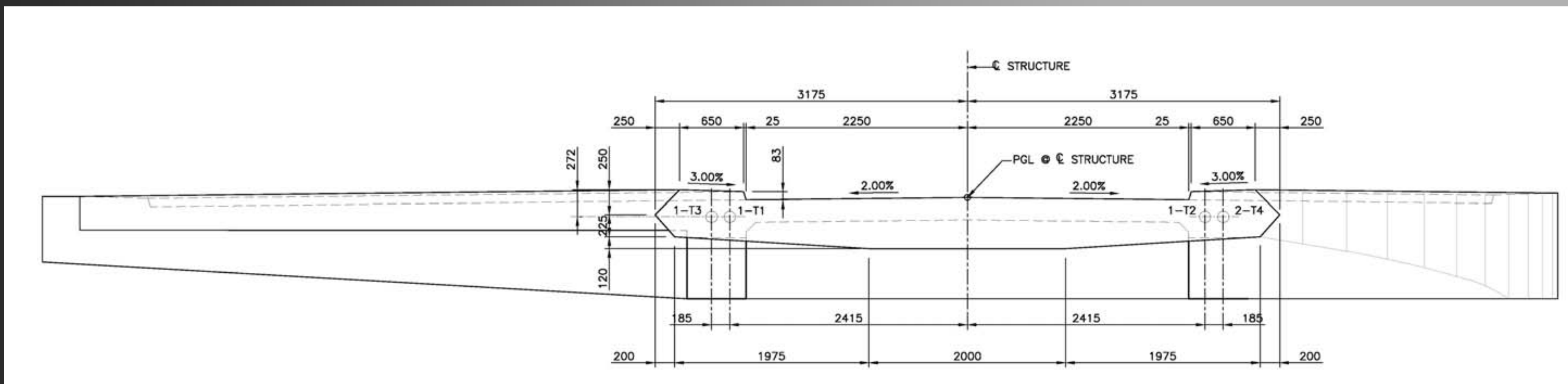
Belvedere Design and Construction



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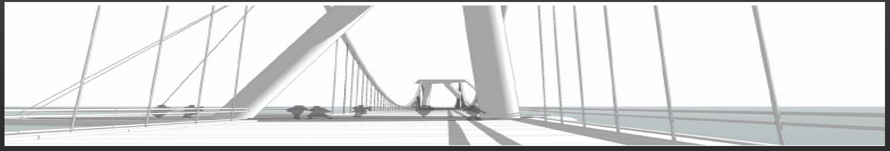

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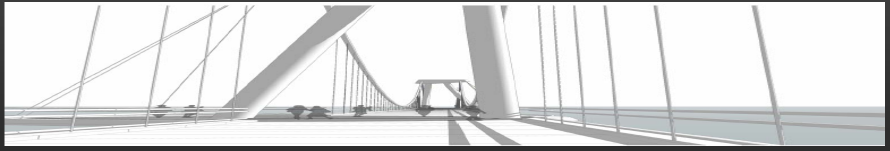

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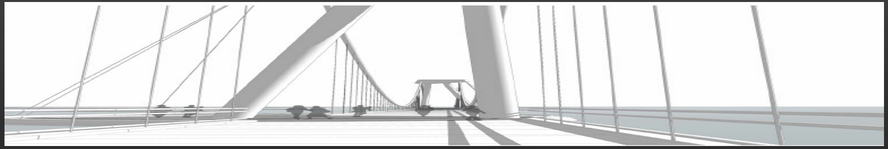

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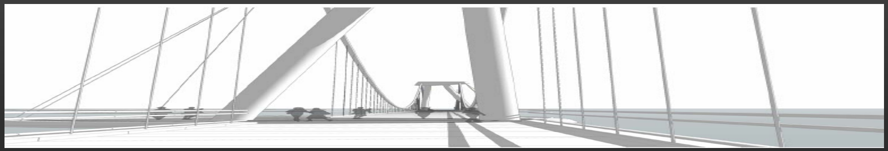
The Unforeseen Cold Weather Construction Issues

- Original Assumed Schedule
  - Superstructure Erection - Winter/Spring
  - Panel Joint Grouting – Spring/Summer
  - Grouting of Ducts – Spring/Summer

  - Grouting Sensitive to Cold Temperature

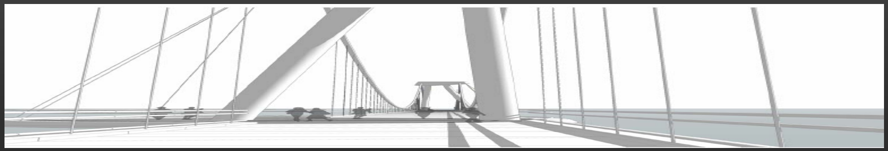


The Unforeseen Cold Weather Construction Issues

- Current Schedule Progression
  - Superstructure Erection - Fall
  - Panel Joint Grouting – Fall/Winter
  - Grouting of Ducts – Spring/Summer

The Unforeseen Cold Weather Construction Issues

- Resolution
  - Alternate Grouting Systems Considered
  - Post Tensioning to be stressed
  - As temperature is not expected to permit in fall, grouting to be delayed until Spring
  - Strand Protection Considerations
    - Galvanized Strand
    - Powder



Questions?

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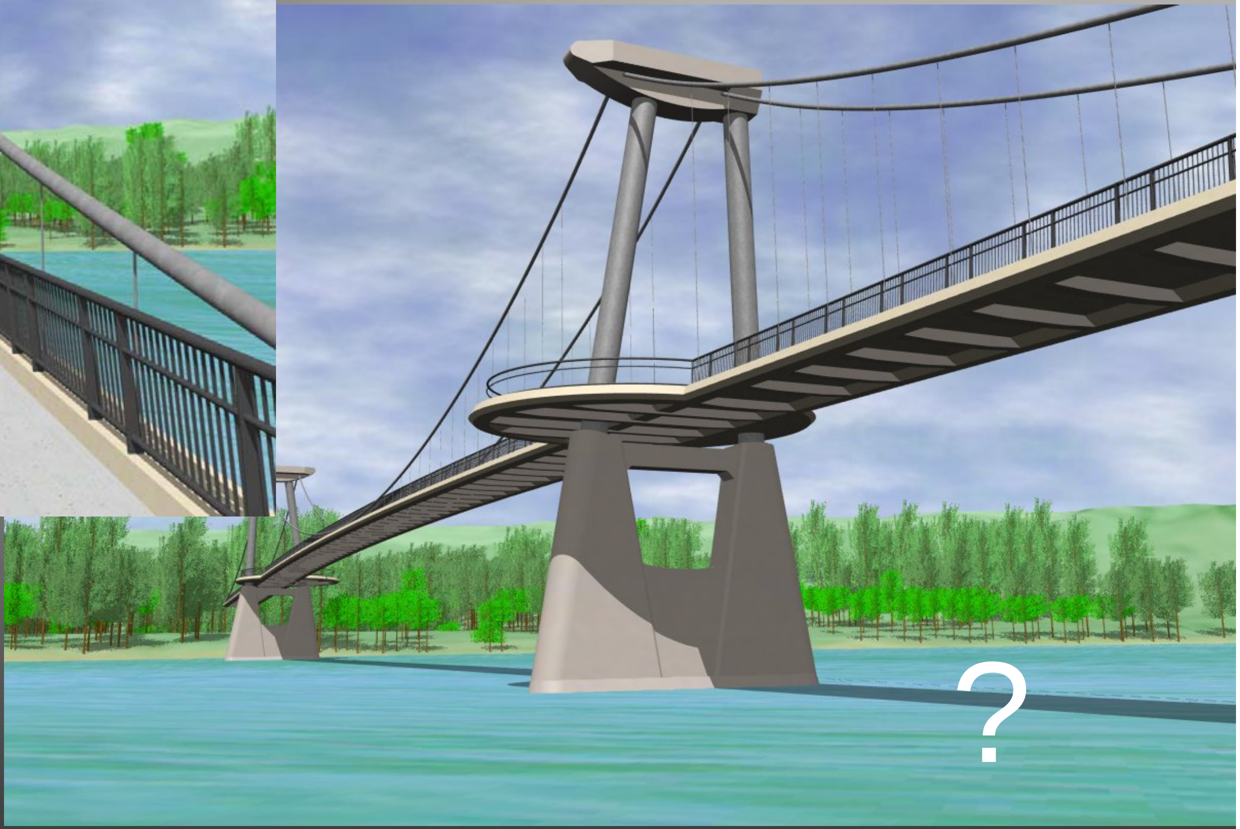

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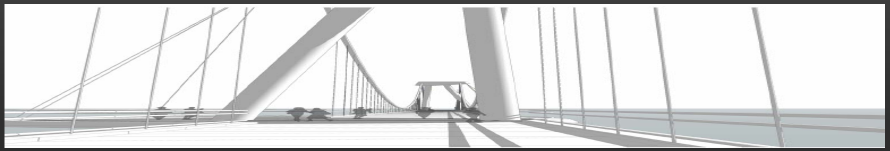

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