Agenda

Introduction

What is an extrados bridge

Principles, aesthetics, and behavior

Case studies (Arup recent experience):

Case Study 1. RFK over the River Barrow (Ireland)

Case study 2. Tawatinâ bridge (Edmonton, Canada)

Concept design and key details. Construction processes and issues

Conclusions

RFK river Barrow

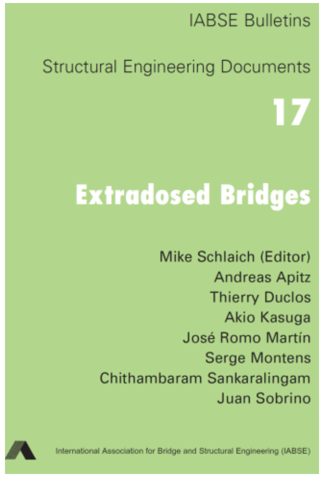
Marcos Sanchez

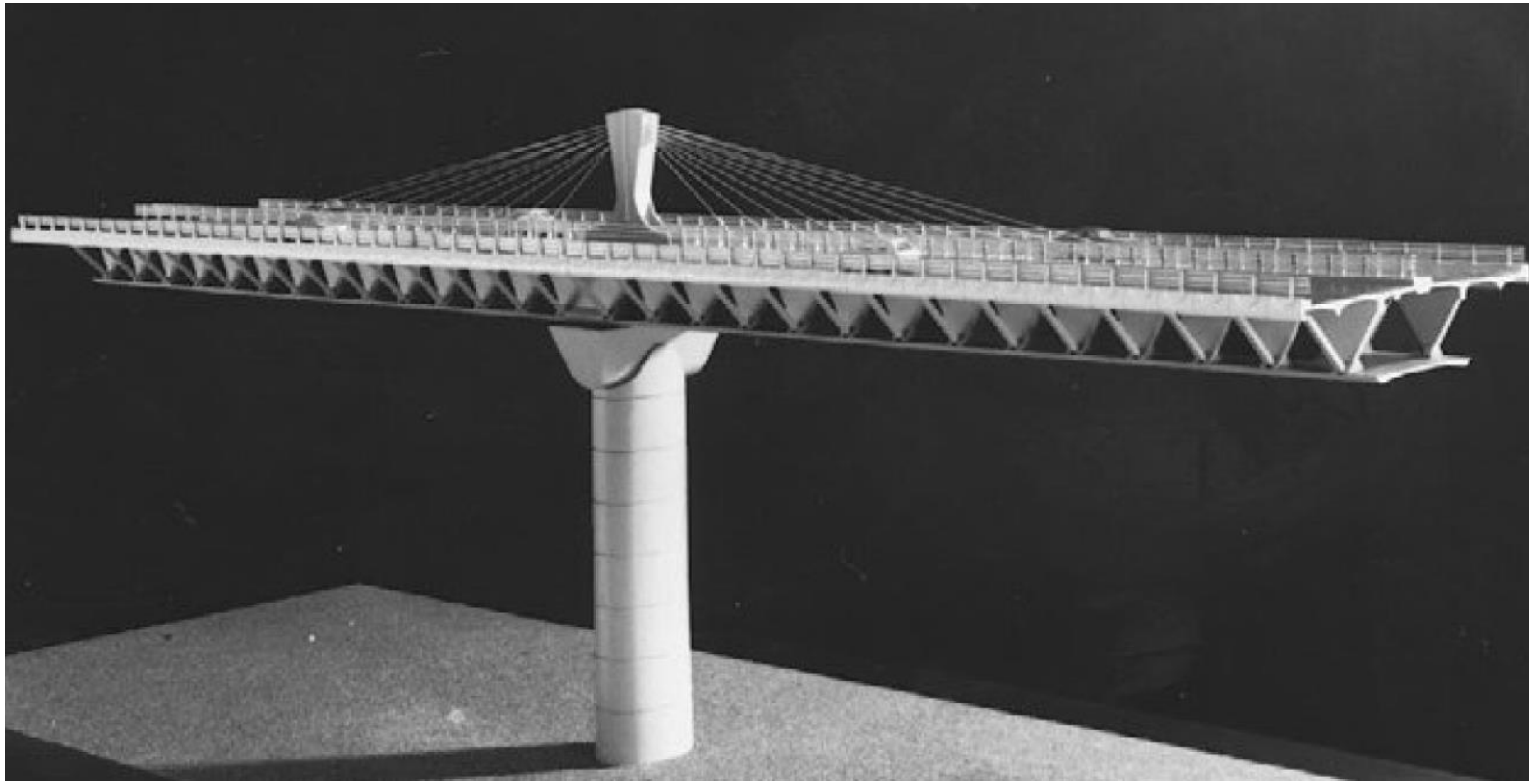
Kwidzyn bridge (*)

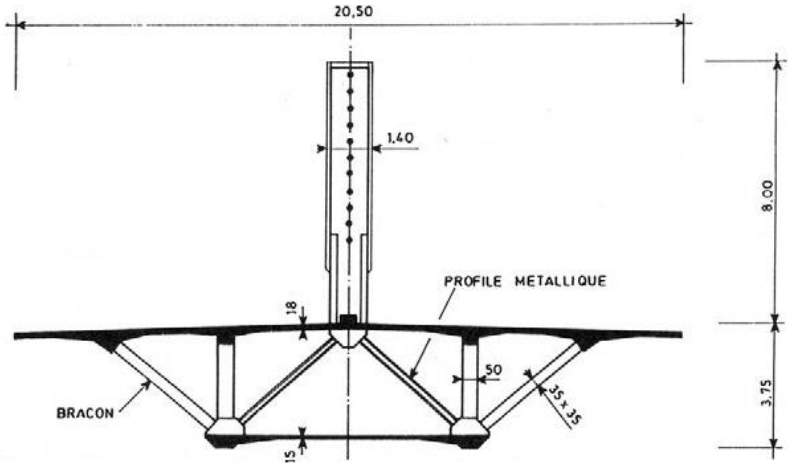
© Structurae

River Erne(*)

© RoD





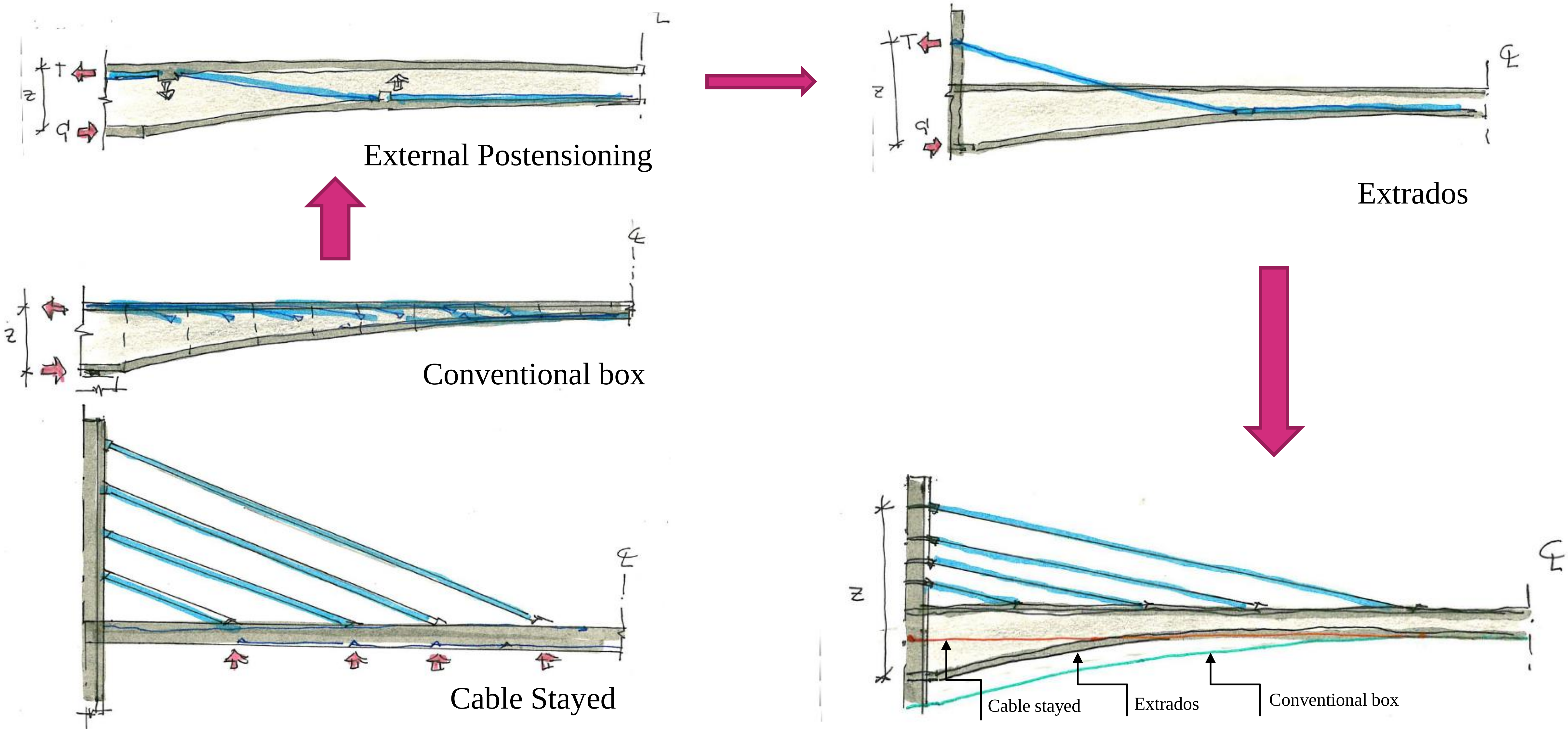


Jaques Mativat concept, 1988

Design and Construction of Concrete Segmental Extradosed Bridges

Introduction to extrados bridges

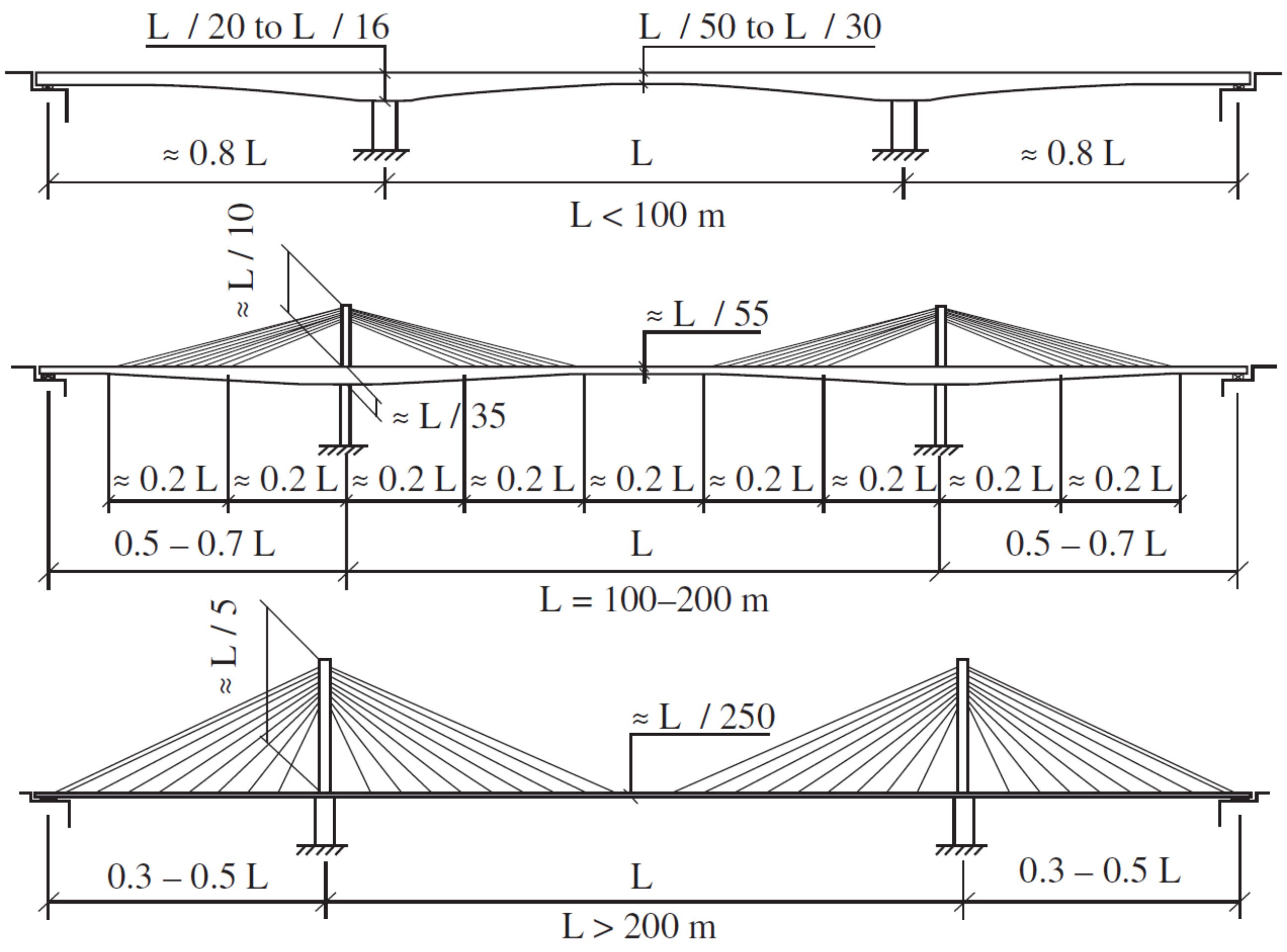
American Segmental Bridge Institute



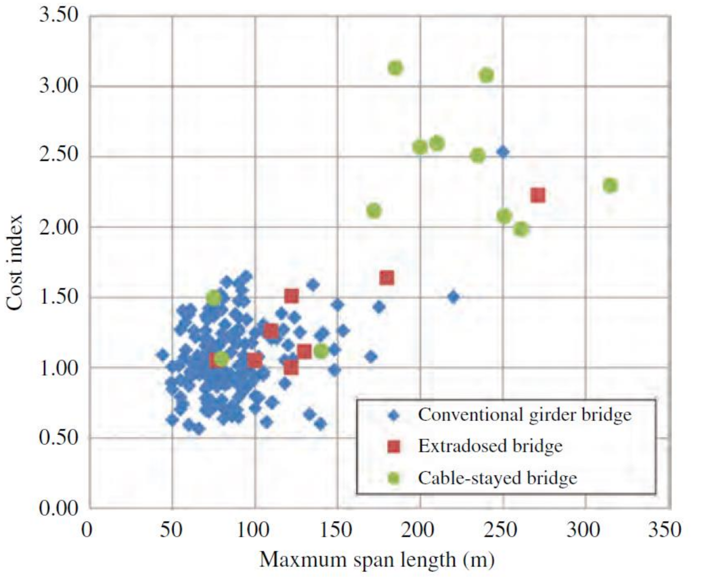
Design and Construction of Concrete Segmental Extradosed Bridges

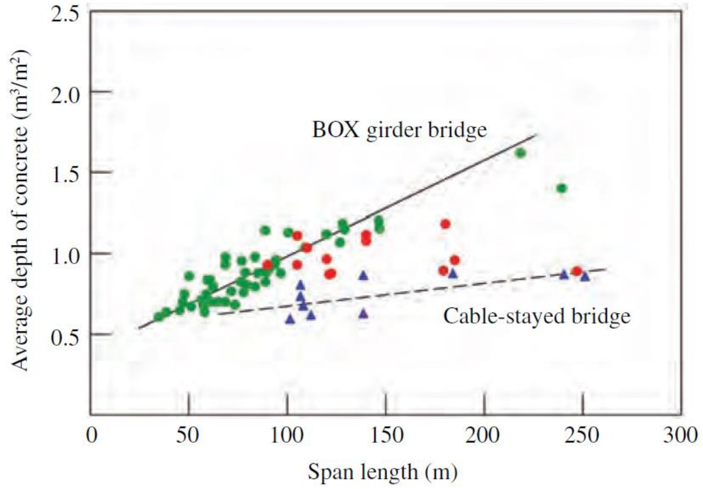
Introduction to extrados bridges

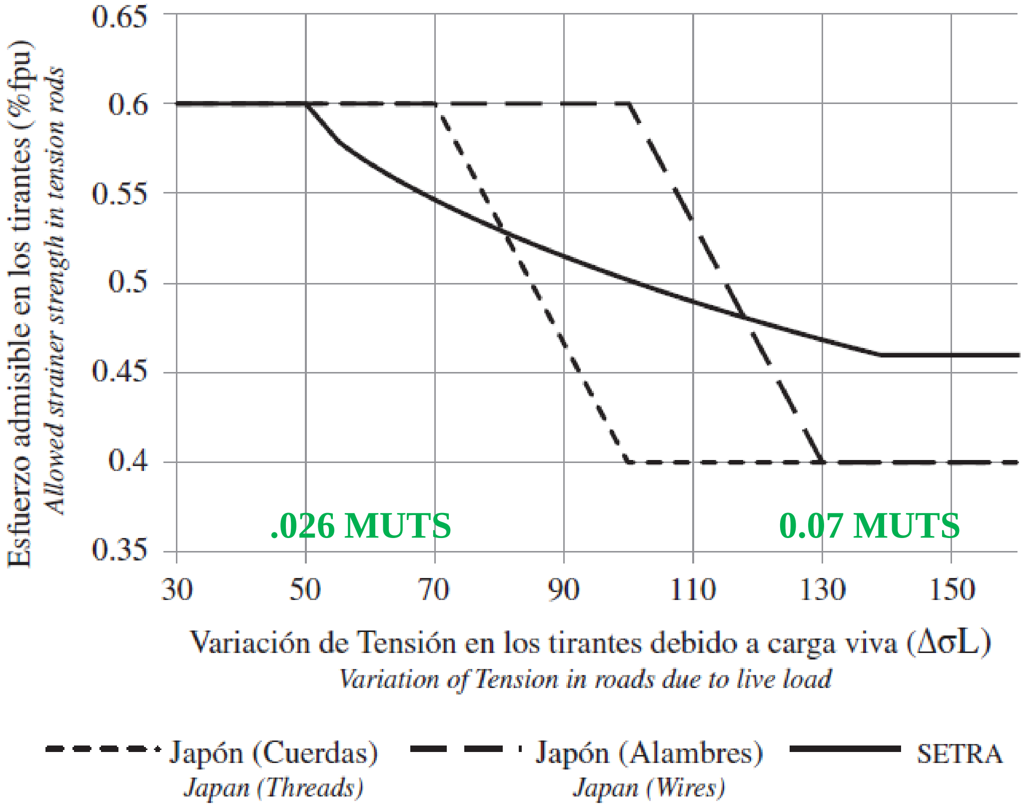
American Segmental Bridge Institute



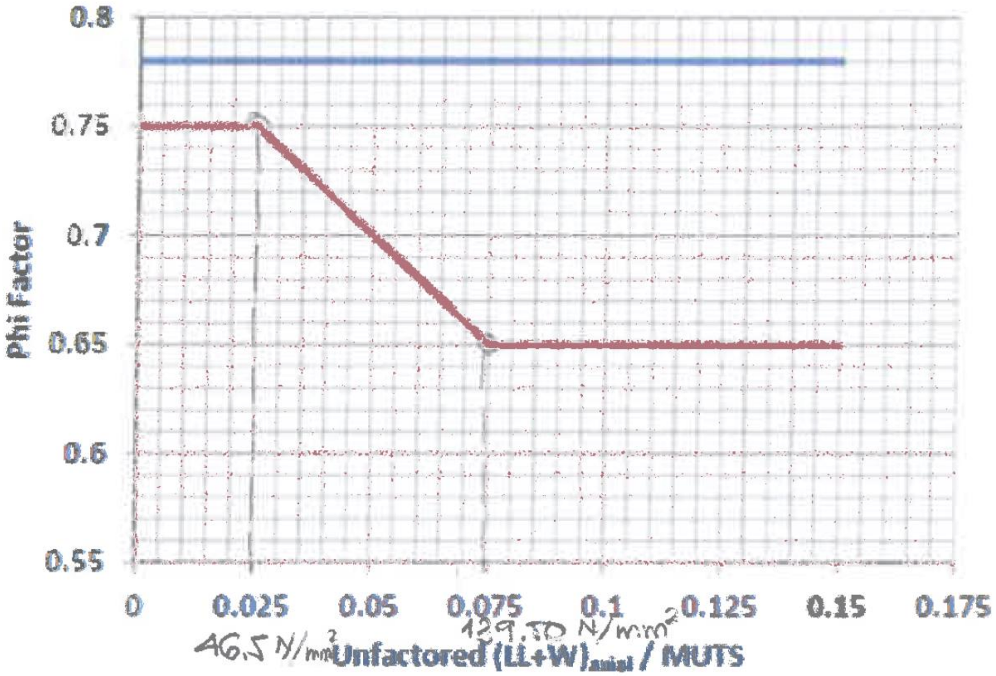
Main dimensions of Continuous box, extrados and cable stayed bridges (Source IABSE SED 17)







Cable stress range vs maximum stress in cables (Source IABSE SED 17)



Cable stress range vs maximum stress in cables (Source PTI DC45.1-12)

MUTS= 1860 mPa = 270 ksi

Summary

- Cable system technology of cable stayed bridges
- Hybrid behaviour (box stiffness vs cable system)
- Shallower cable than in cable stayed bridges
    - Cable less efficient => Deeper deck or tapered at supports.
      Lower range of cable stresses => Higher Stress limit allowed (?)
    - Higher deck compressions close to supports => High strength concrete
    - Shorter tower => Saddles vs anchor box
- A stiffer deck allows for multispan bridges with multiple towers

Why extrados bridges?

Aesthetics. Geometry constraints. Multispan. Cost compromise

Why extrados bridges?

Aesthetics. Geometry constraints. Multispan. Cost compromise

Case Studies

RFK River Barrow

Tawatinâ

American Segmental Bridge Institute ASBI

Case Study 1

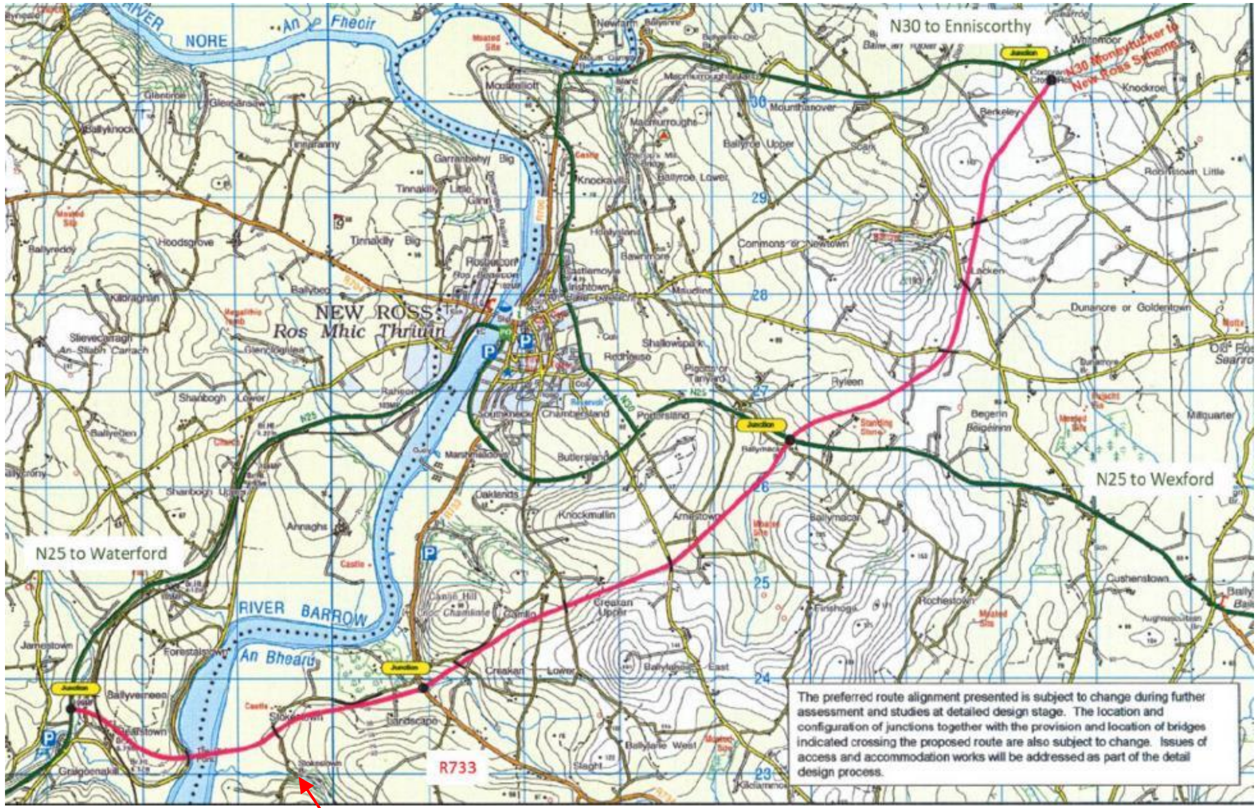
Rose Fitzgerald Kennedy bridge over the river Barrow

American Segmental Bridge Institute ASBI

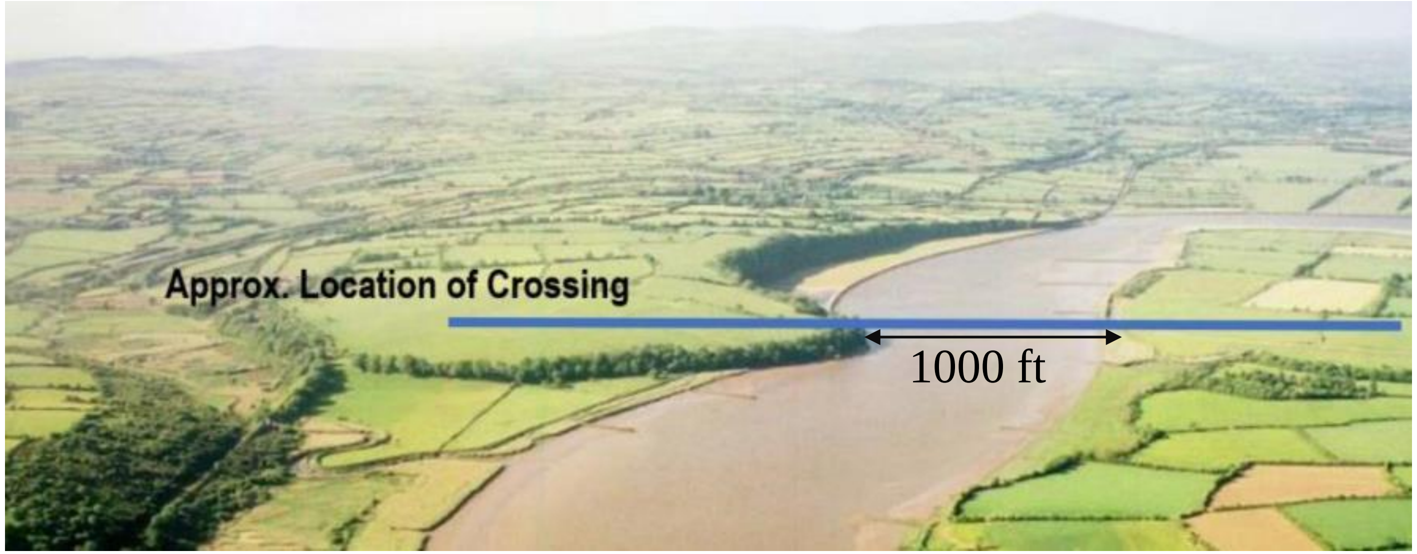
Case Study

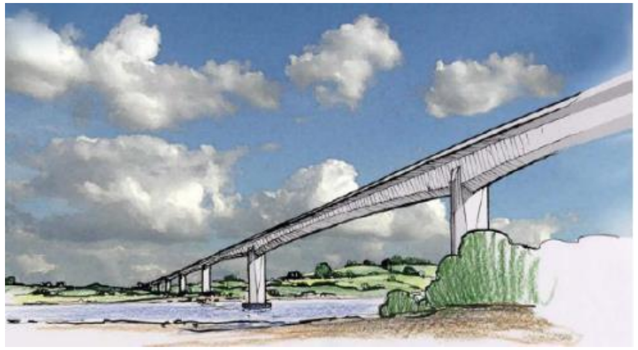
Rose Fitzgerald Kennedy bridge over the river Barrow

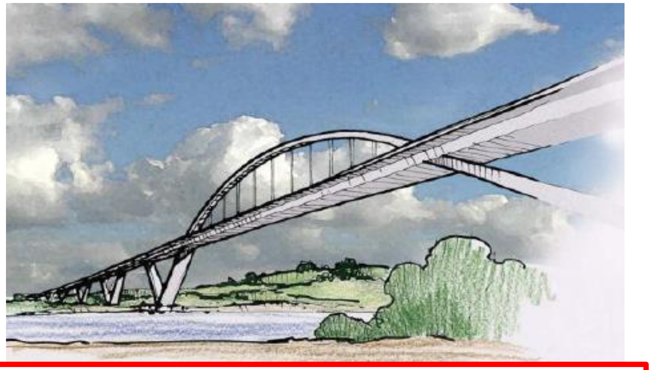
Introduction. Project History. Constraints and Value Engineering

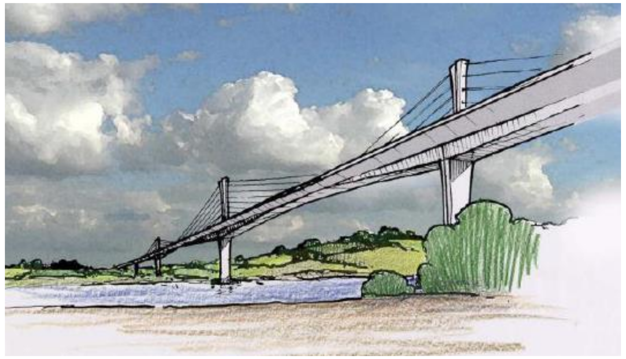


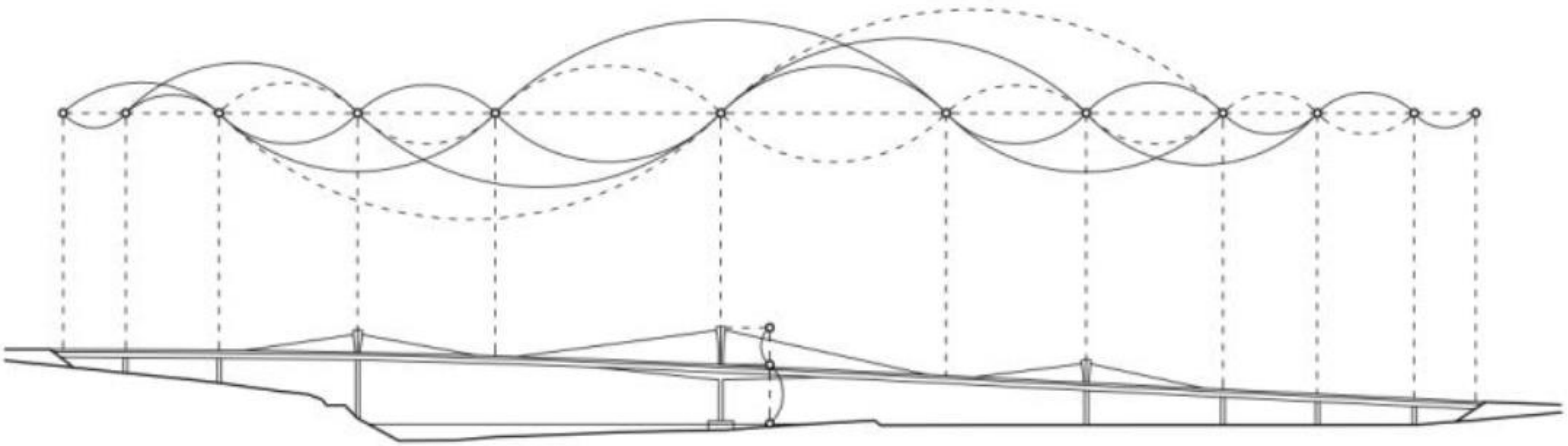
John Fitzgerald Kennedy Homestead


Approx. Location of Crossing
1000 ft









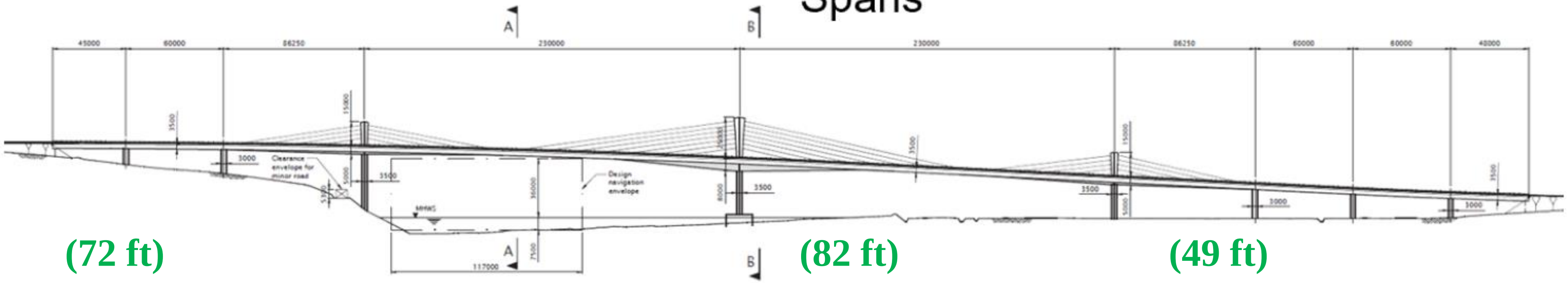
Architectural concept (planning stage)

(2950 ft)
900m
Length

9
Spans

(755 ft)
230m
Main Spans

3
Pylons



(72 ft)
22m
Deck Width

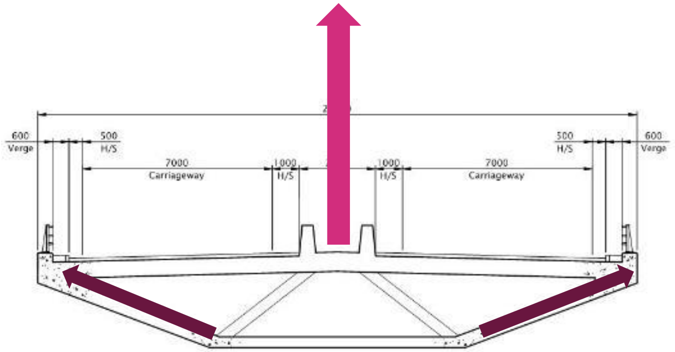
36m
(118 ft)
Navigation Clearance

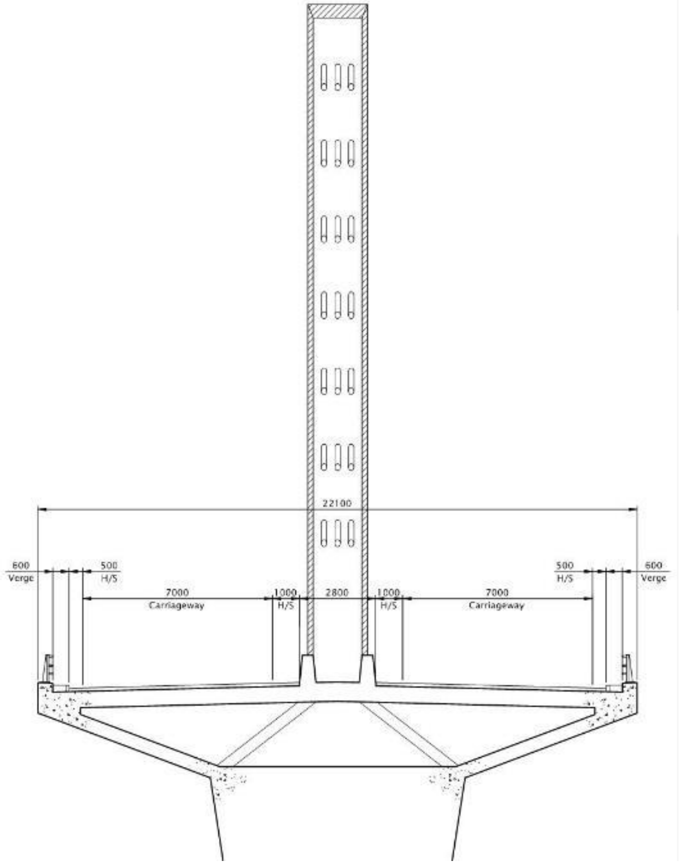
(82 ft)
25m
Central Pylon

(49 ft)
15m
Side Pylon

Constraints (planning stage)

Specimen design. Pre D&C Tender

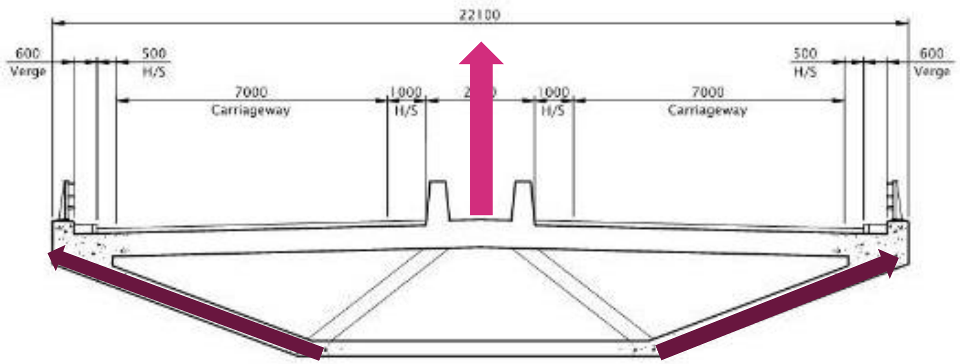




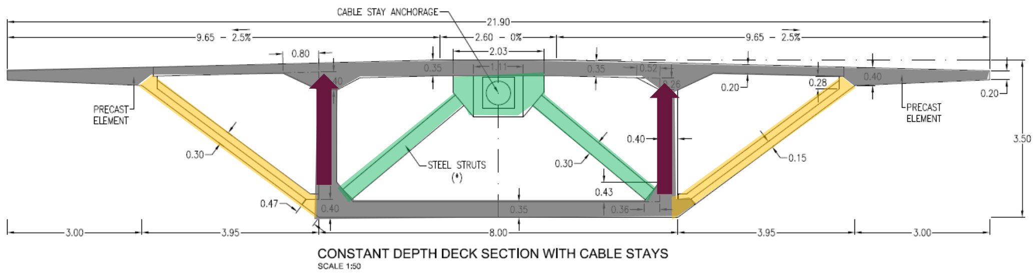
Value Engineering

- Change cross section
  - central webs @ 8m spacing
  - precast slabs/props to reduce the cantilever
- Minimize bridge width:
  - Pilon width 1.6m (5.2 ft)
  - Single cable max 127 strands
  - Minimum cable spacing 6.5m (21 ft)
- Optimize elevation layout
  - Tower height 27 and 17m (88 & 55 ft)
  - Depth 6.5 and 8.0m at towers. (26 & 21 ft)
  - Depth 3.5m for the rest of the bridge

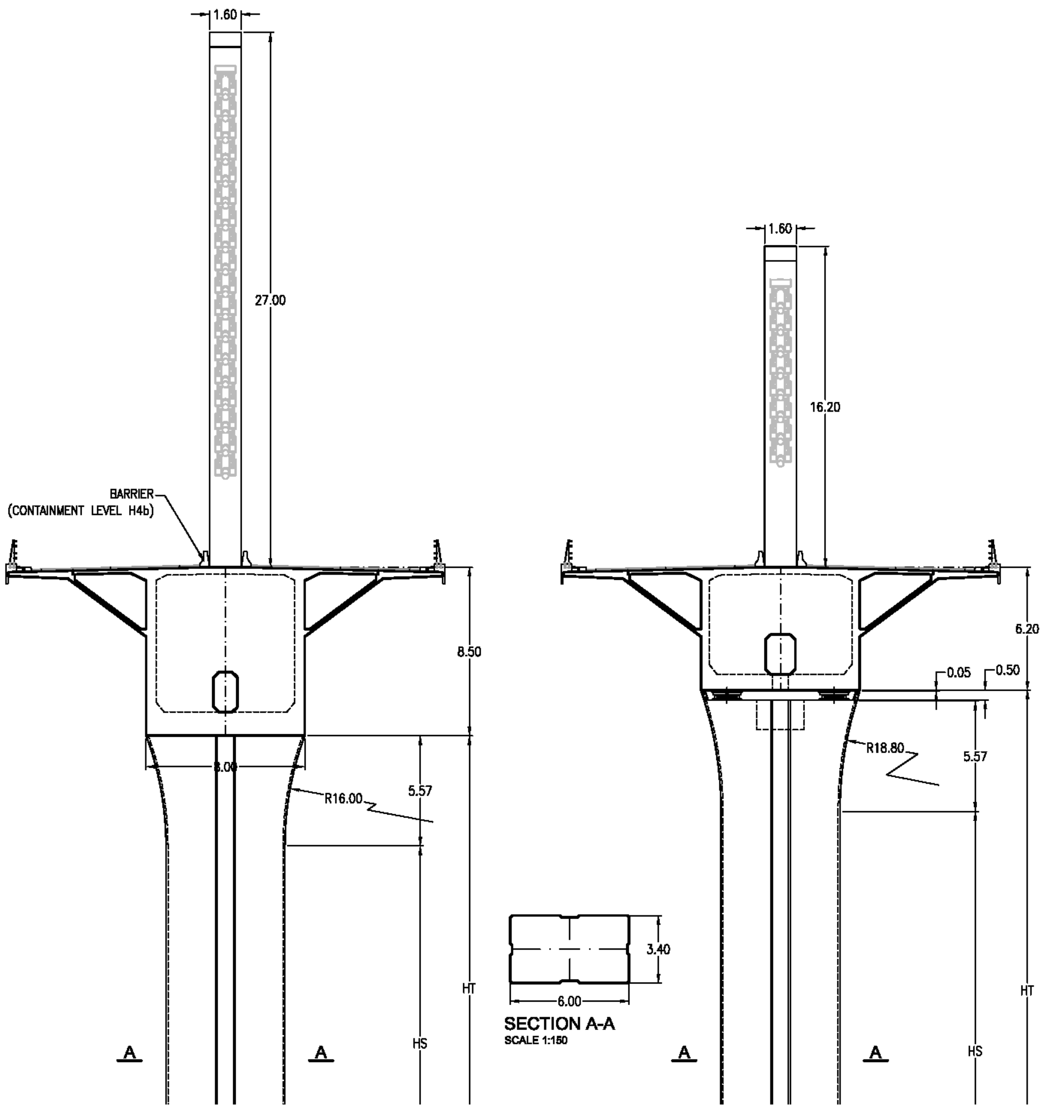
Slenderness: L/65 at midspan, L/28 at central tower and L/35 at side towers

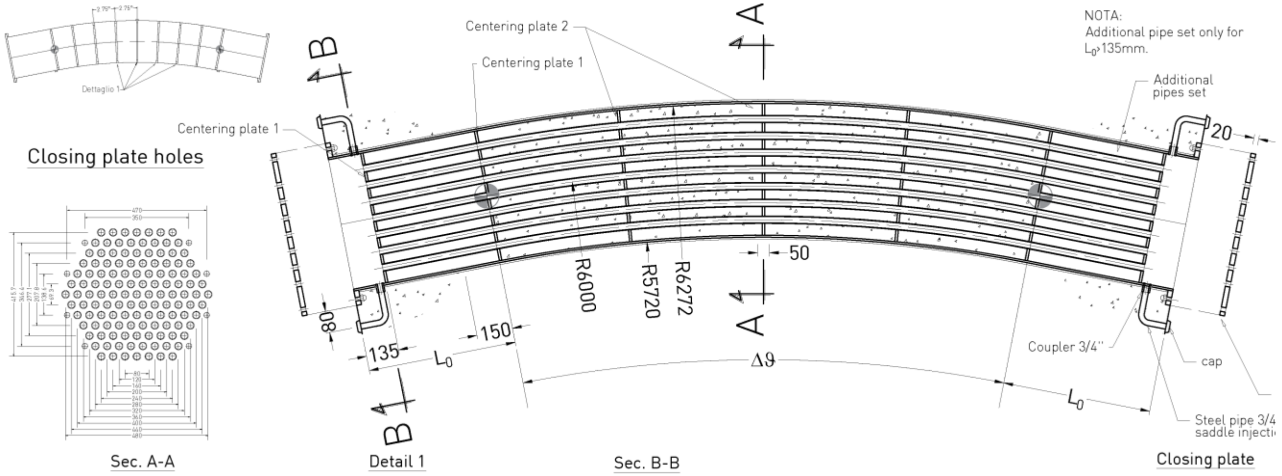


Specimen design



Final Solution



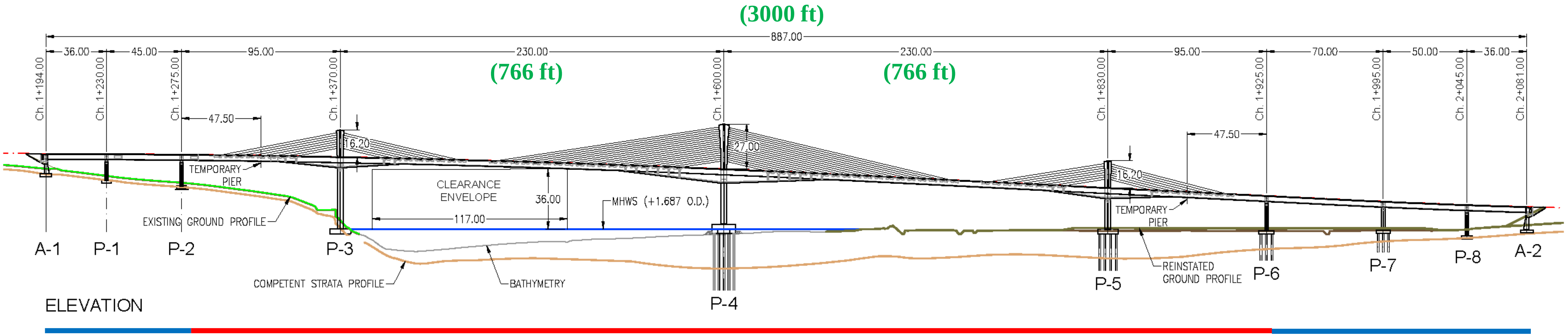


Saddles are critical for minimizing tower size (both width and depth)

Design and Construction of Concrete Segmental Extradosed Bridges

Case Study: RFK over the River Barrow

American Segmental Bridge Institute



- Total length 887m (311ft + 755 ft + 755 ft +311 ft)
- 9 spans (36 m + 45m + 95m + 230m + 230m + 95m +70m + 50m + 36m)

  (main spans very slender L/65 at midspan and L/35 & L/28 at towers)
- West and East approach spans 70 to 36m
- Main supported by parallel inclined cables, single vertical central plane

- Full concrete deck with a closed cross section
- Tower height and main supports (P3-P4-P5) fixed by planning
- Single central plane of cables

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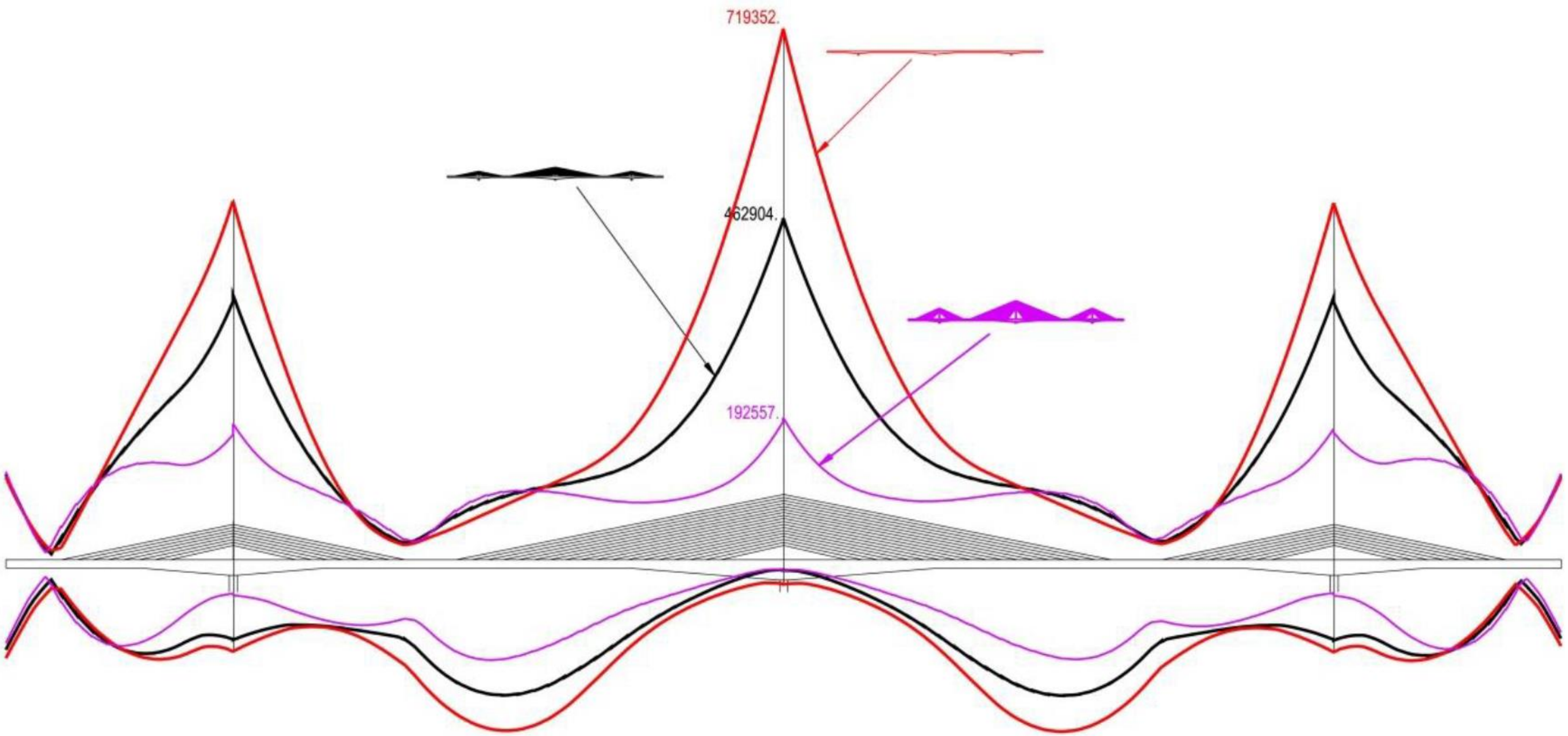
M6 Ostroda Motorway. Poland. 2018. Full concrete deck. Main span 206m

Kiso Gawa. Japan. 2001. Steel composite (midspan) deck. Main span 275m

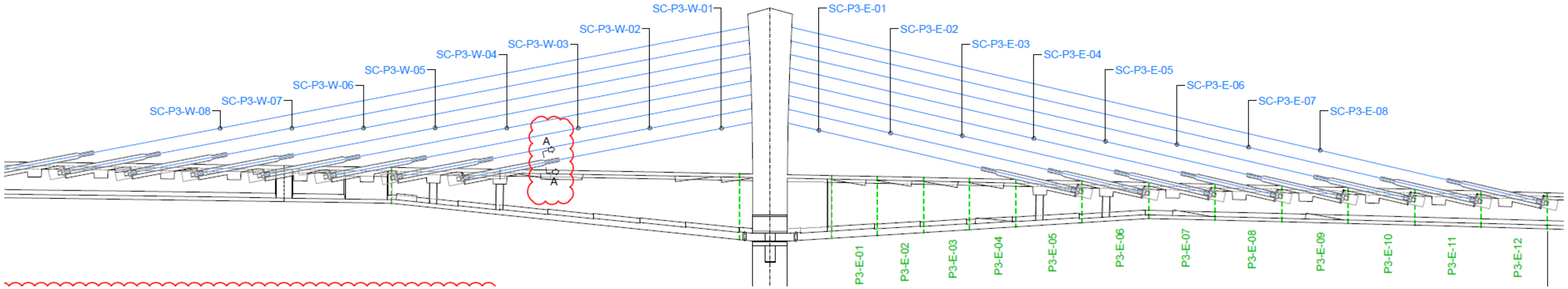
Case Study

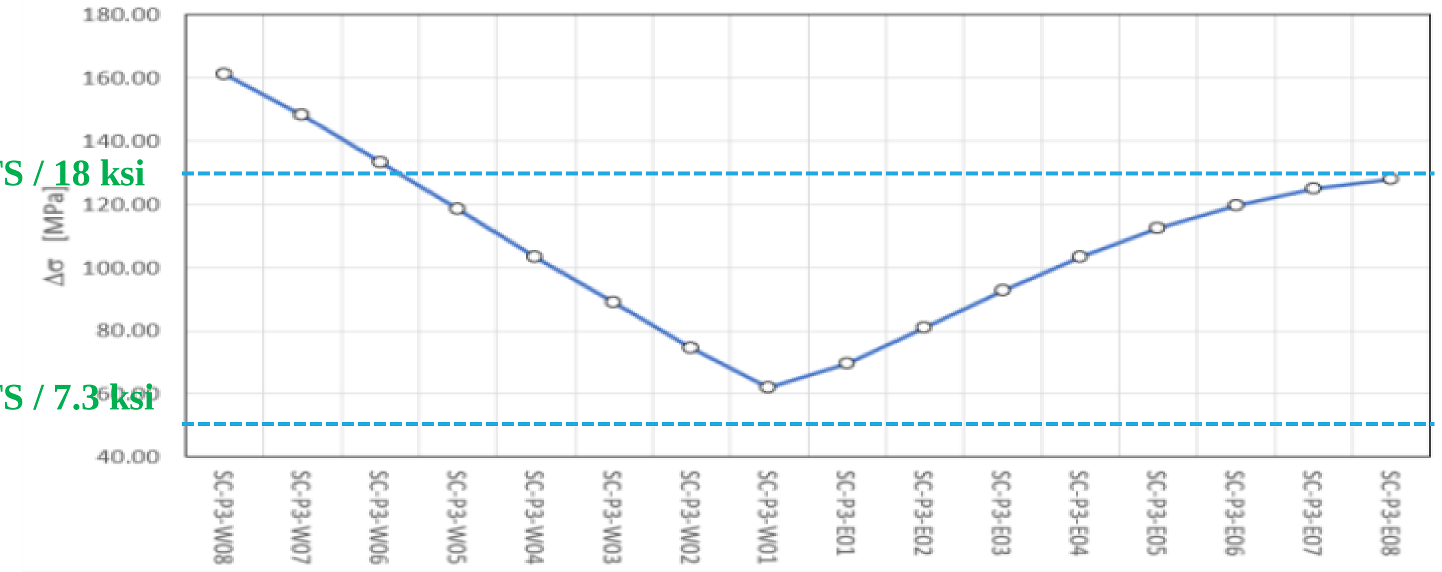
Rose Fitzgerald Kennedy bridge over the river Barrow

Detailed Design



RFK over the River Barrow. Detailed design. Global behaviour





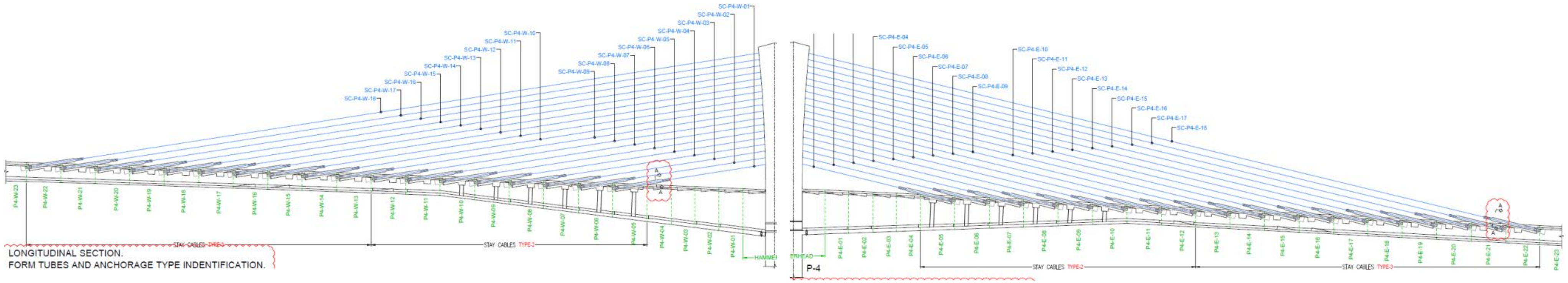
Cable stayed: 200 N/mm² .10 MUTS

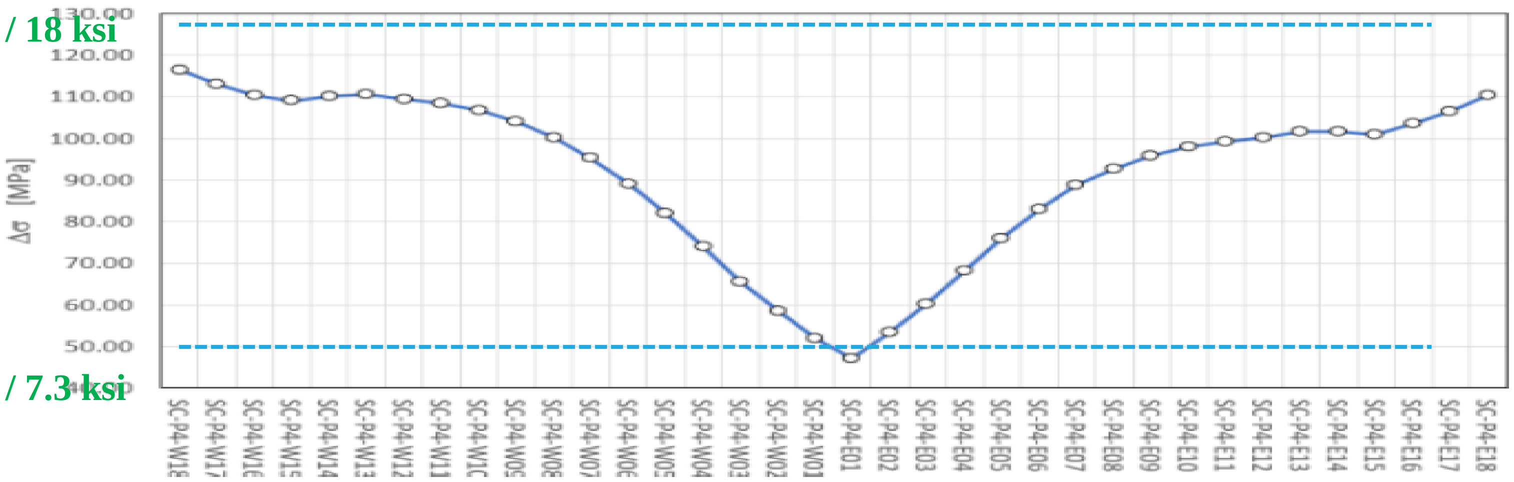
Extrados: 50-80N/mm² 0.026 =-.043 MUTS

MUTS= 270 ksi

Design and Construction of Concrete Segmental Extradosed Bridges

Case Study: RFK over the River Barrow





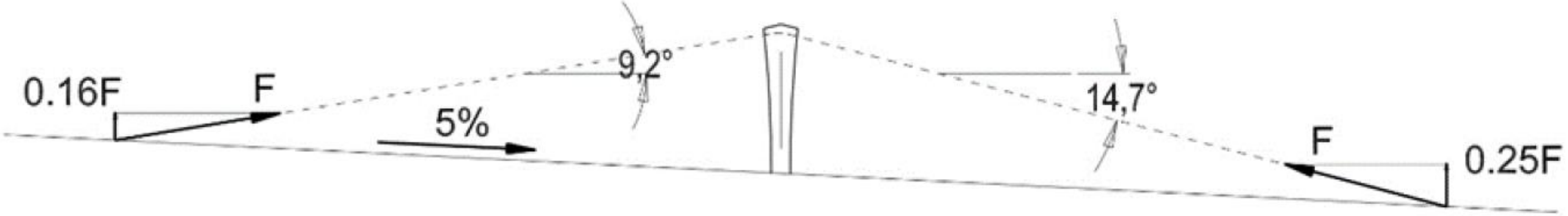
.10 MUTS

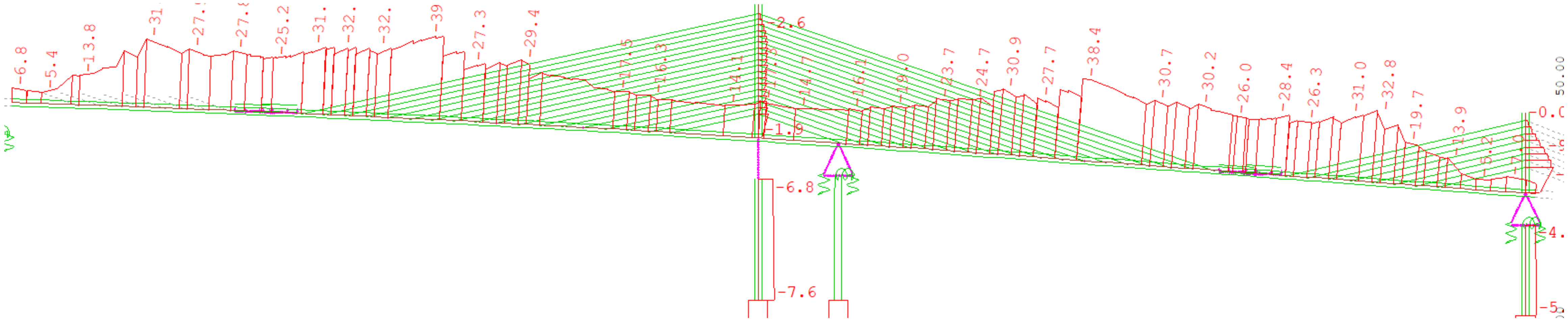
Cable stayed: 200 N/mm^2

Extrados: 50-80N/mm^2

0.026 =-.043 MUTS

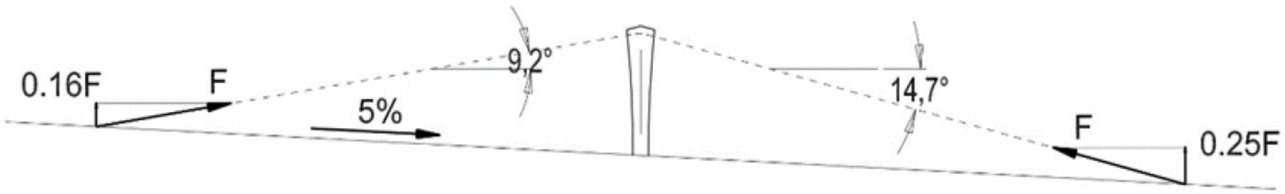
MUTS= 270 ksi

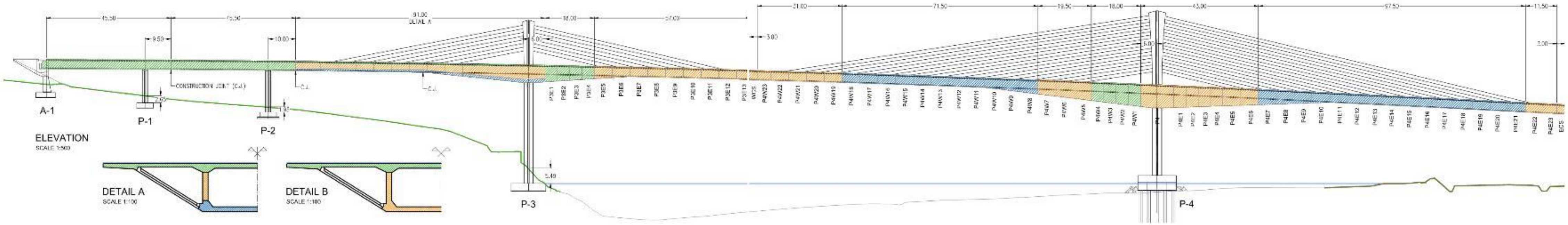




Concrete stresses top flange. Permanent Loads.

(40 Mpa = 6 Ksi)





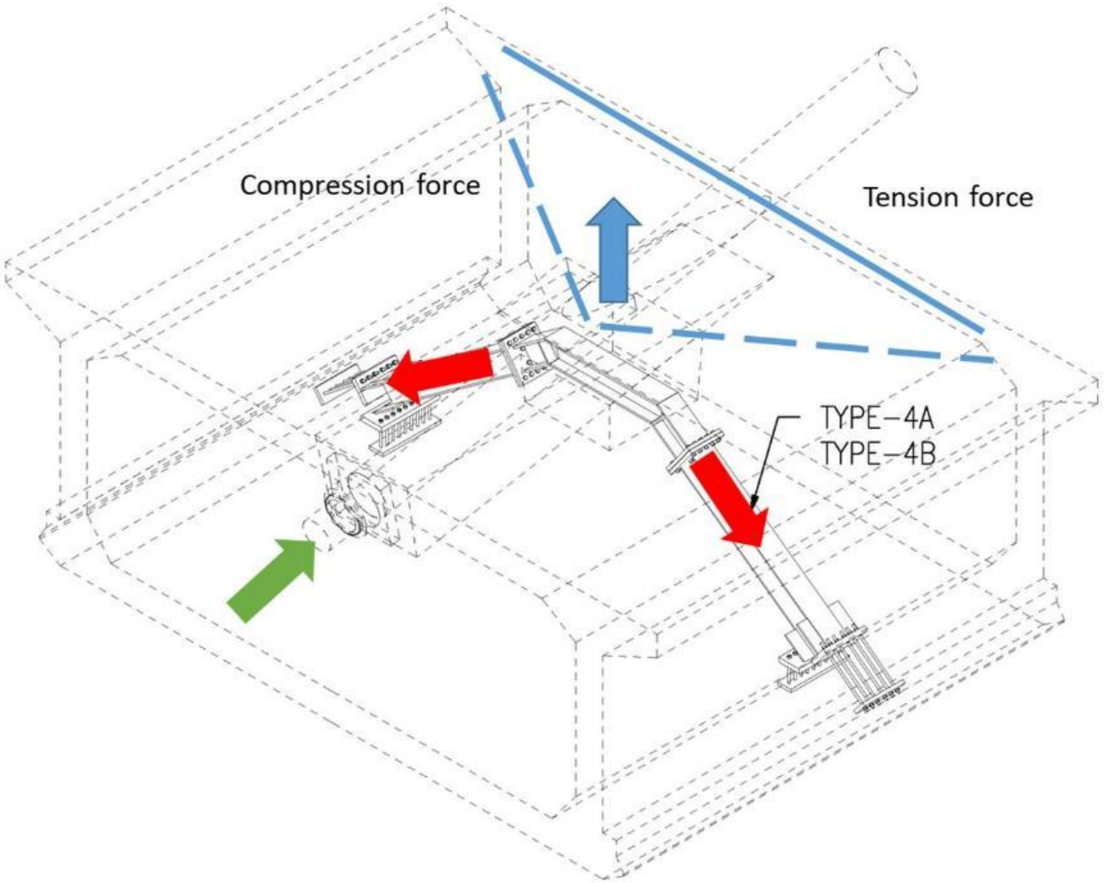
CONCRETE C50/60

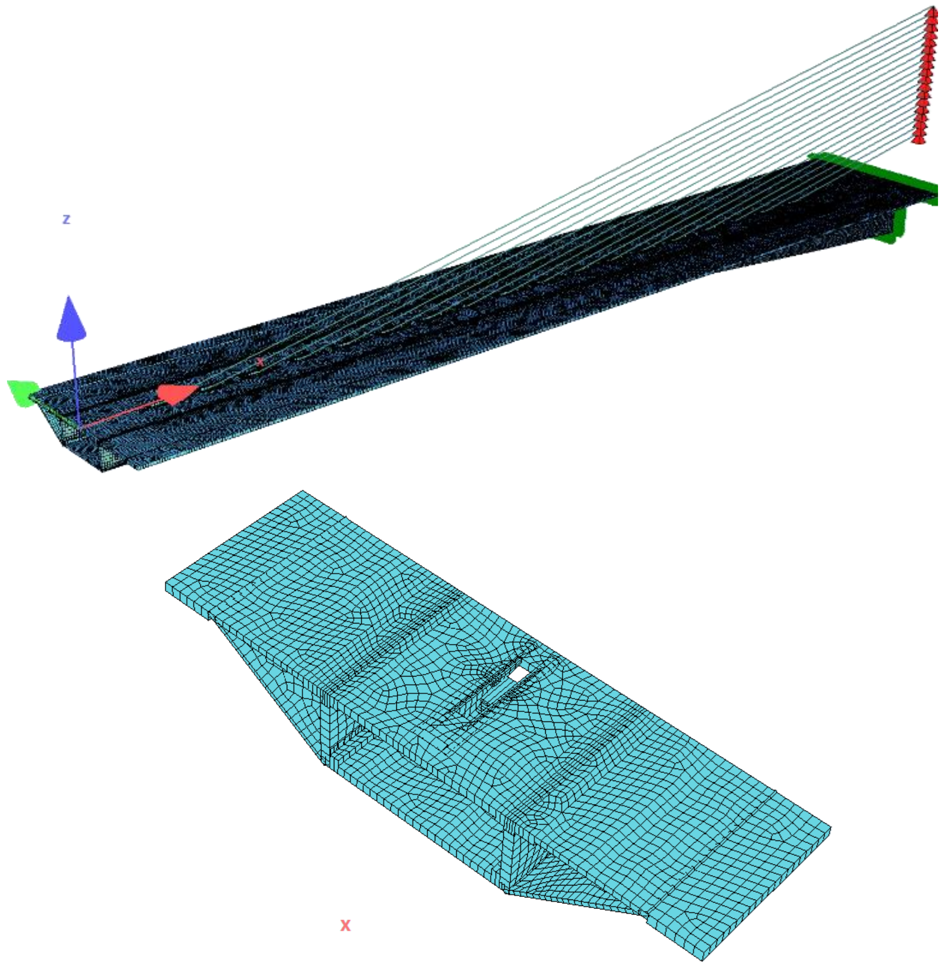
CONCRETE C60/70

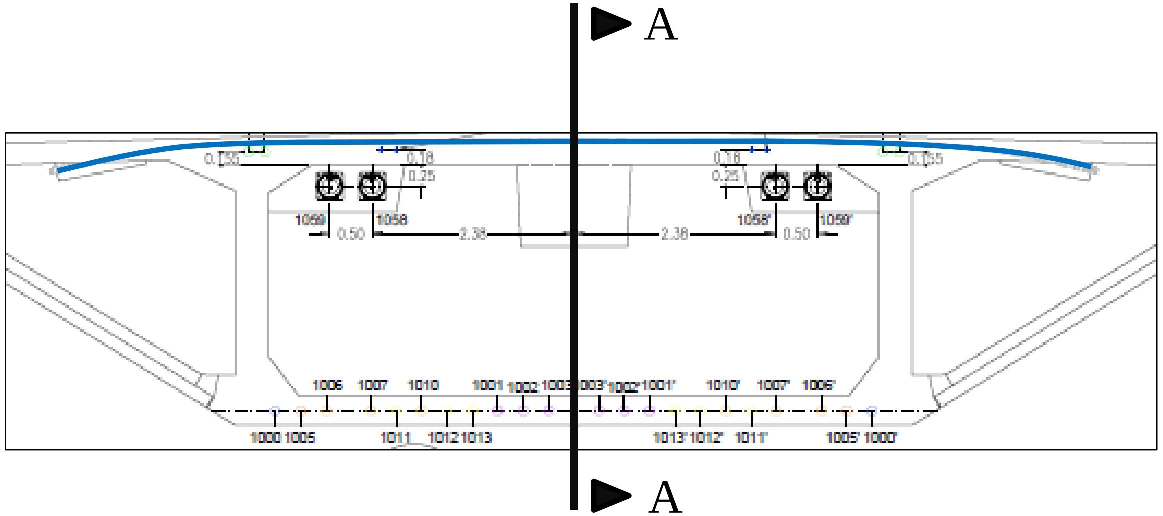
CONCRETE C80/95

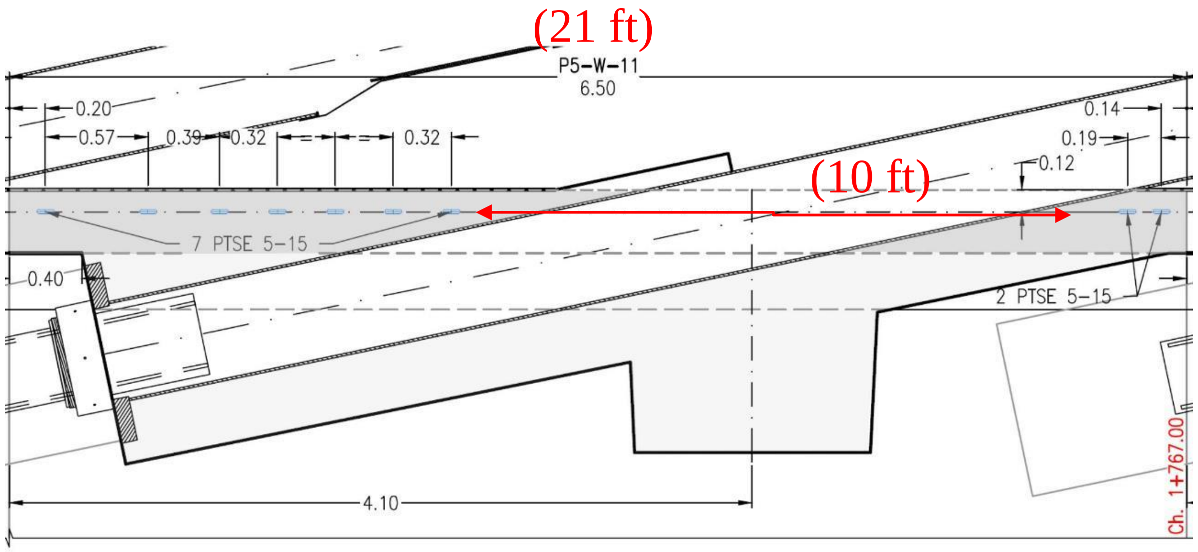
C50 => 5 ksi
C60 => 9 ksi
C80 => 11 ksi

ARUP

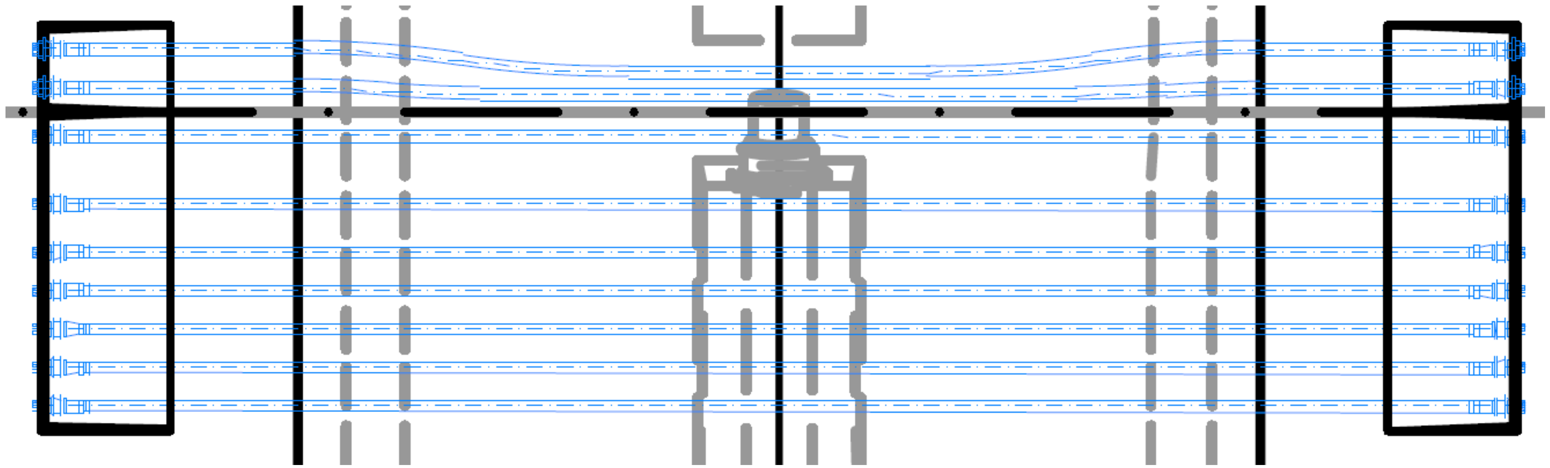

Compression force
Tension force
TYPE-4A
TYPE-4B







Section A-A

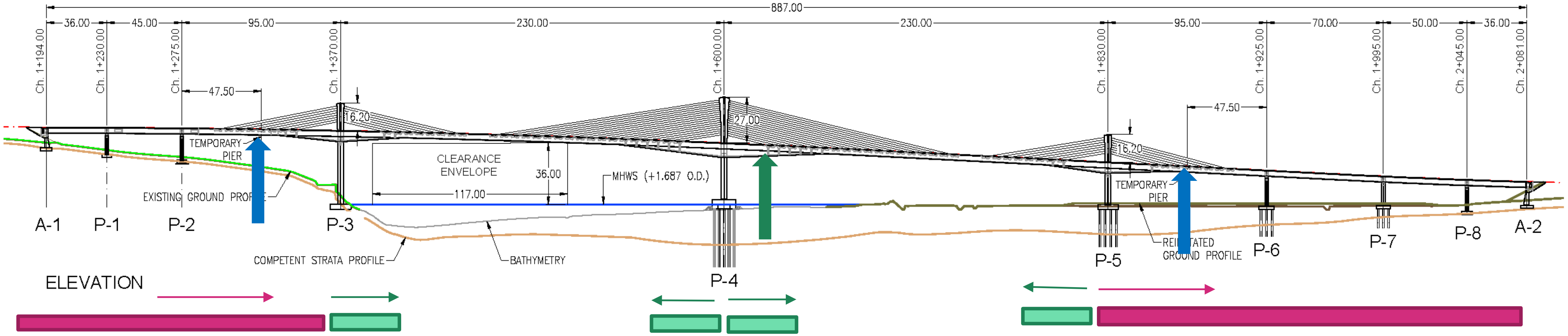


Plan View

Case Study

Rose Fitzgerald Kennedy bridge over the river Barrow

Construction



Superstructure construction:

- Approach spans, including extrados side spans: Scaffold and wing traveller
- Main spans. Full section form Traveller (4 fronts)

Temporary Props

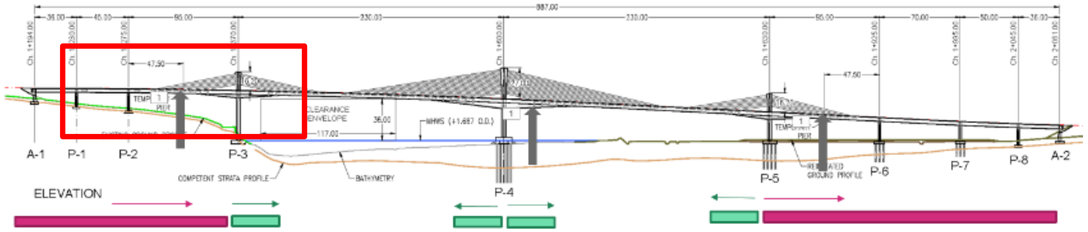
Push-Pull Prop (prestressed)

Design and Construction of Concrete Segmental Extradosed Bridges

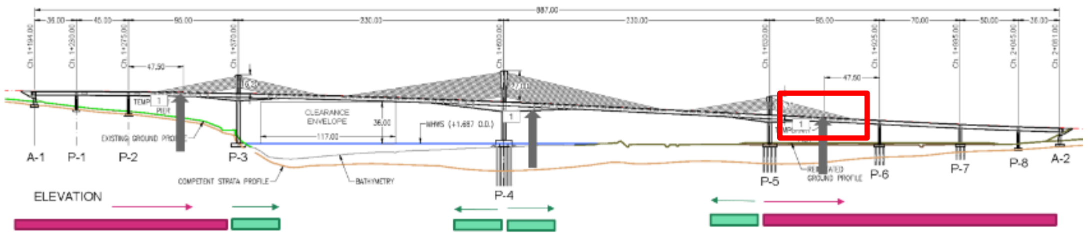
Case Study: RFK over the River Barrow

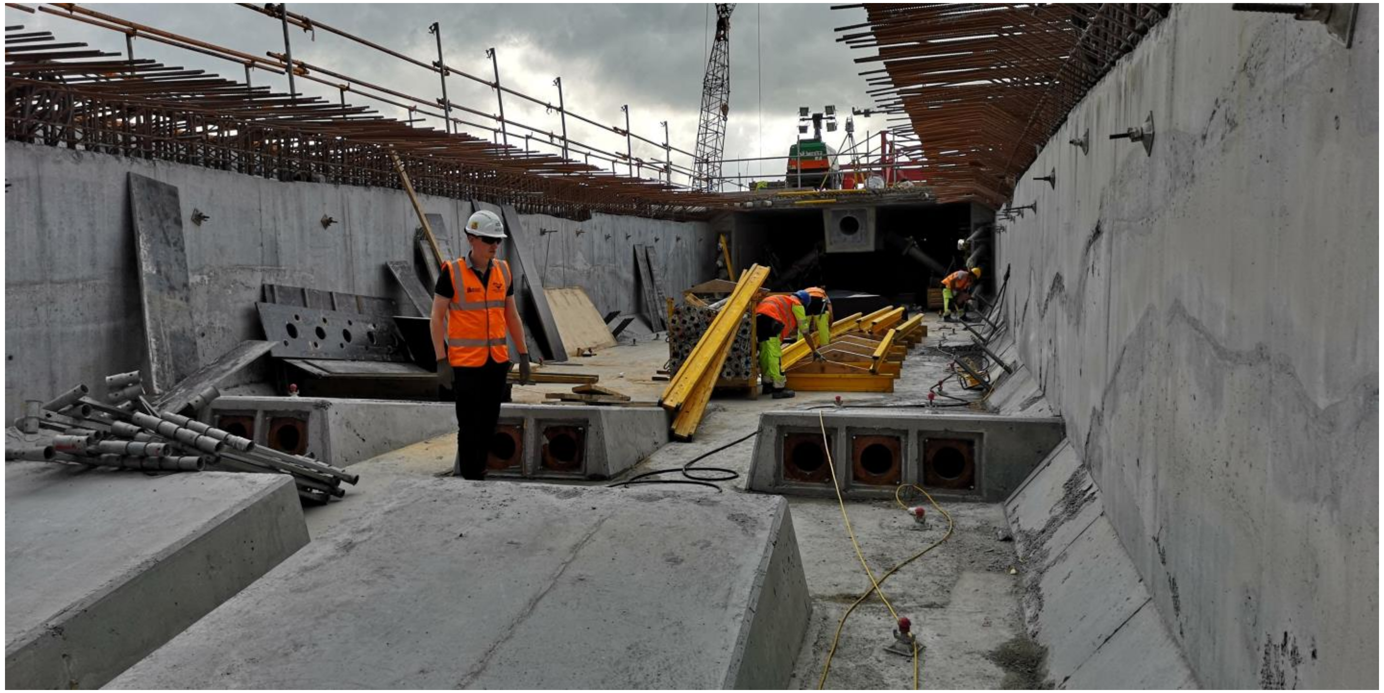
American Segmental Bridge Institute

Approach Spans Construction

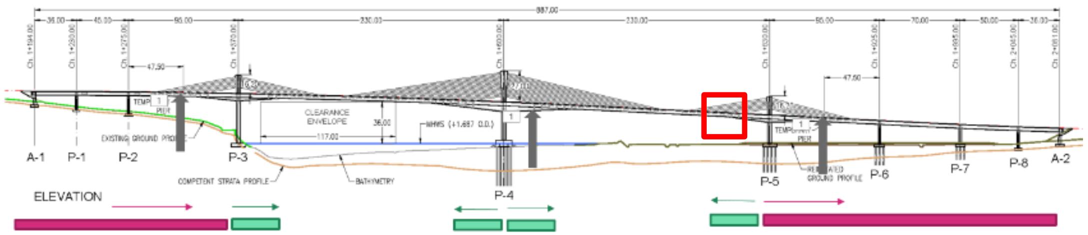


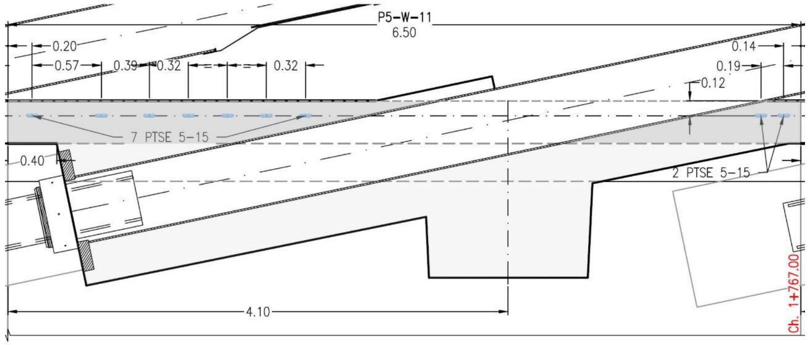
Approach Spans Construction

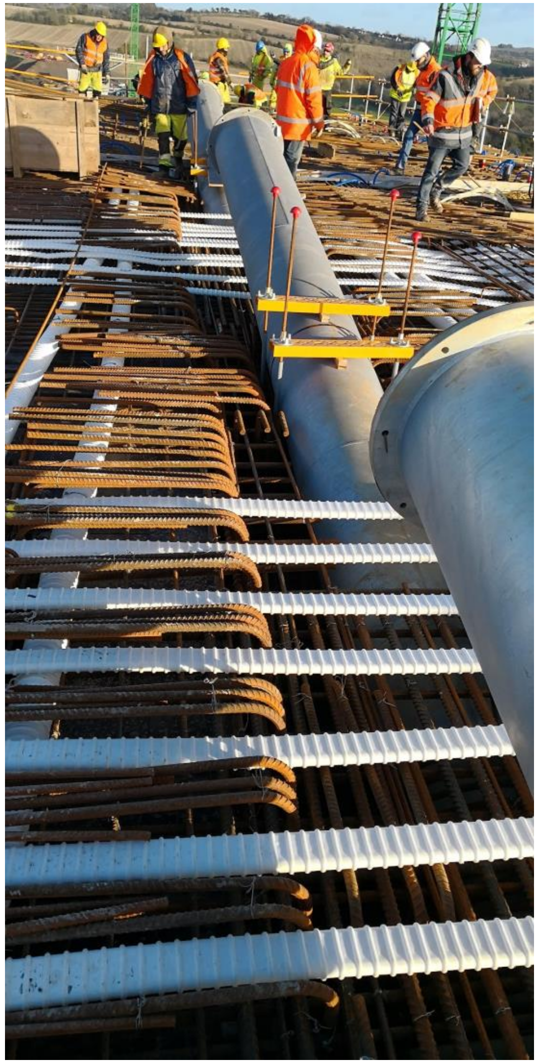




Approach Spans Construction

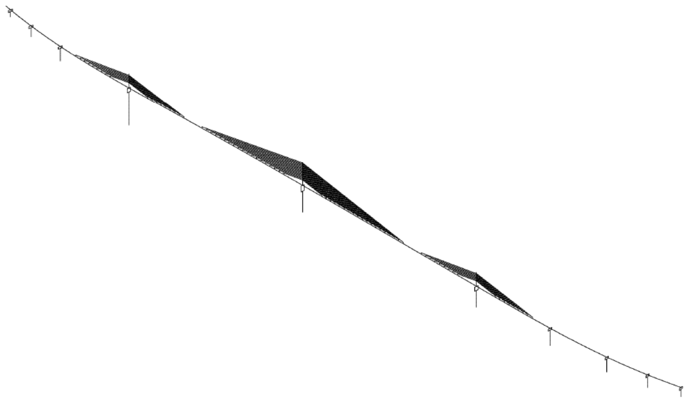






Geometry control uncertainties

1. Form Traveller settlement / deflection
2. Segment Weights (concrete density)
3. Concrete Young modulus (time dependant)
4. Creep and Shrinkage curves
5. Construction loads map
6. Real segment Cycle



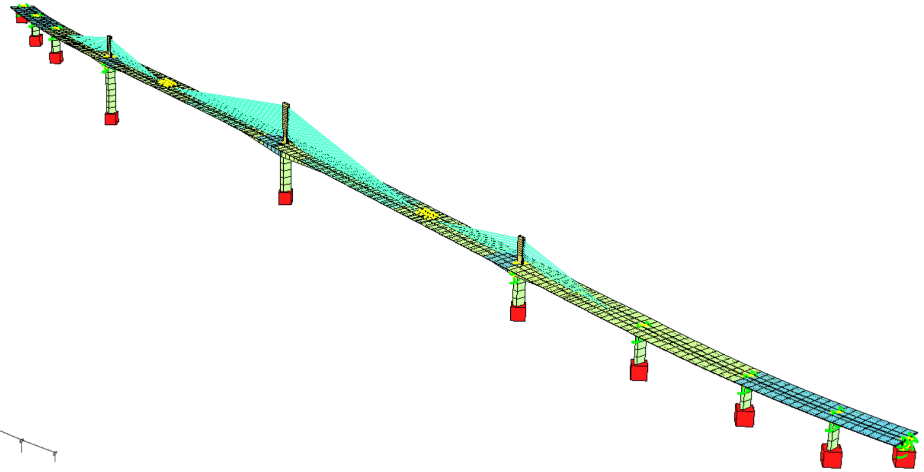
Modelling

A. Two independent models

B. If possible, slightly different assumptions

C. Sensitivity checks

D. Update model properties with real information



Geometry Control

EN1992-1. Annex B

Slab Geometry

A	22500	mm2	Area of concrete
u	300	mm	
h0	150	mm	notional size cross section Eq. (3.10) = 2Ac/u

Tension

σ	15	Mpa

Concrete material

fck	80	Mpa	
K(fck)	13.2	18 if fck<= 55 Mpa	
		30-0.21 fck if fck>= 55 Mpa	
fcm	88	MPa	(fck +8) Table 3.1
Ec	44721	MPa	$E_c = 5000\sqrt{f_{ck}}$

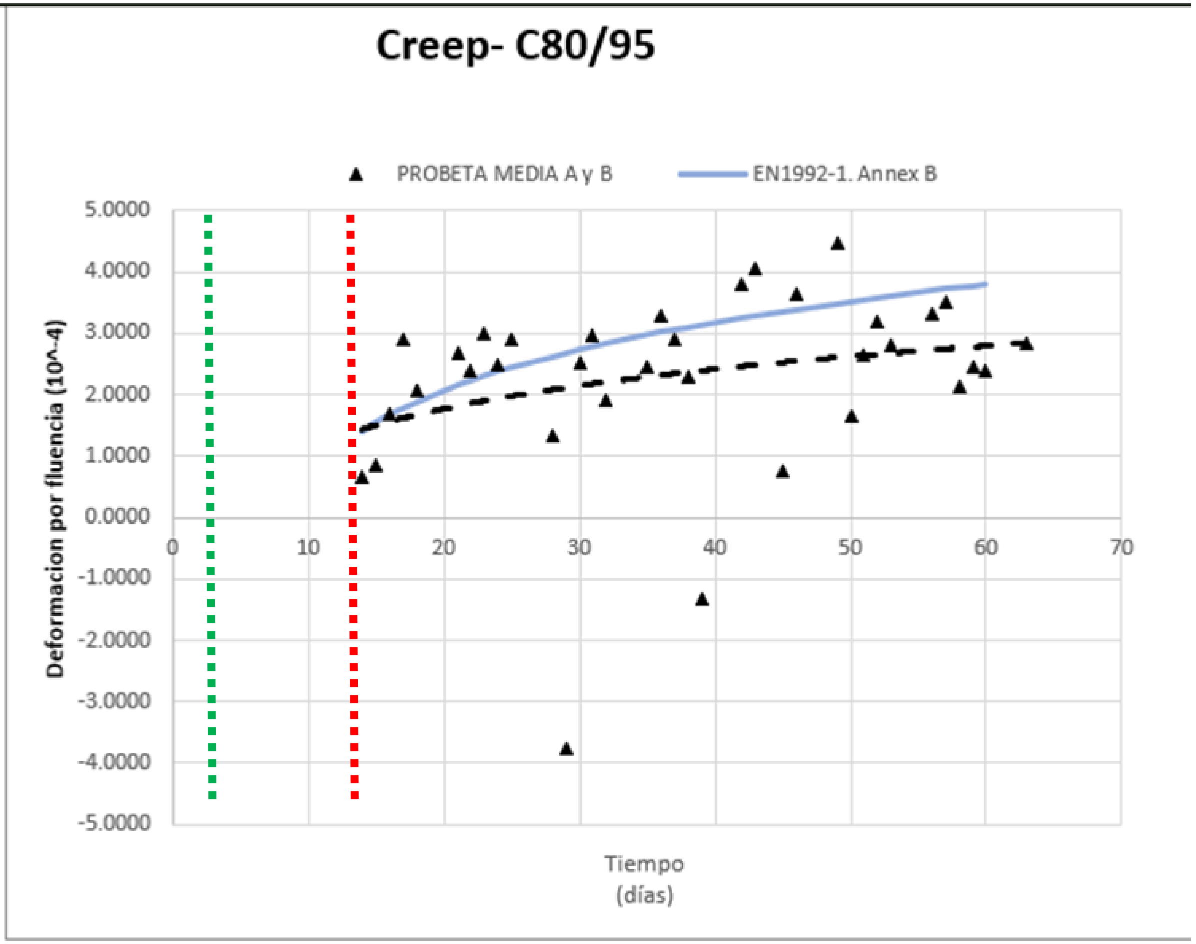
βcc (t)
fcm (t) (3.1)

$$f_{cm}(t) = \beta_{cc}(t)\, f_{cm} \qquad \beta_{cc}(t) = \exp\left\{ s\left[1-\left(\frac{28}{t}\right)^{1/2}\right]\right\} \qquad (3.1)$$

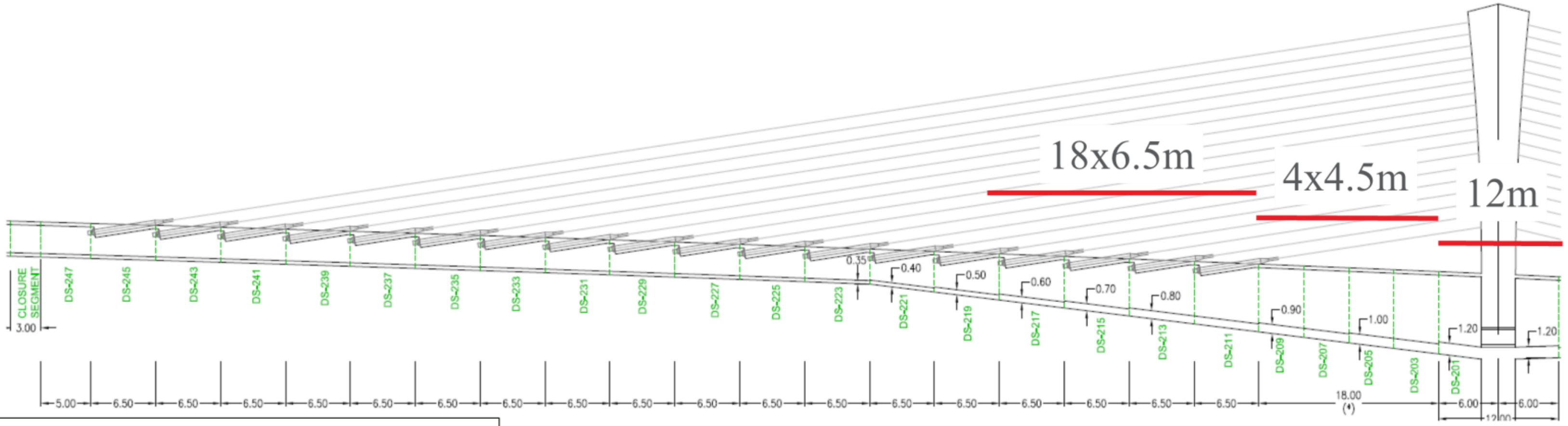
s 0.2 is a coefficient which depends on the type of cement:
= 0,20 for cement of strength Classes CEM 42,5 R, CEM 52,5 N and CEM 52,5 R(Class R)
= 0,25 for cement of strength Classes CEM 32,5 R, CEM 42,5 N (Class N)
= 0,38 for cement of strength Classes CEM 32,5 N (Class S)

Creep & Shrinkage parameters

RH	47	%	
ts	10	days	time beginning drying shrinkage (after curing)

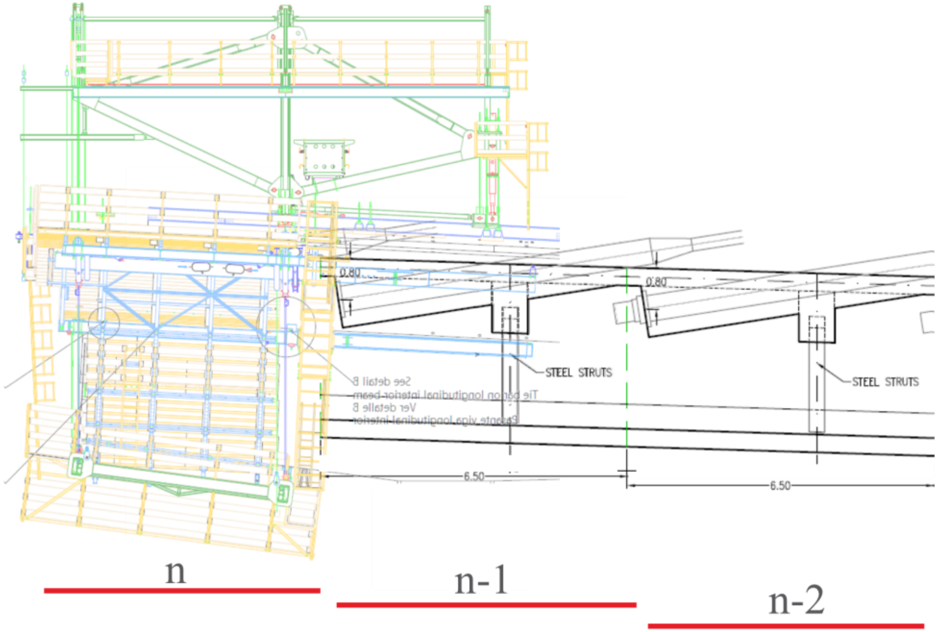


Geometry Control



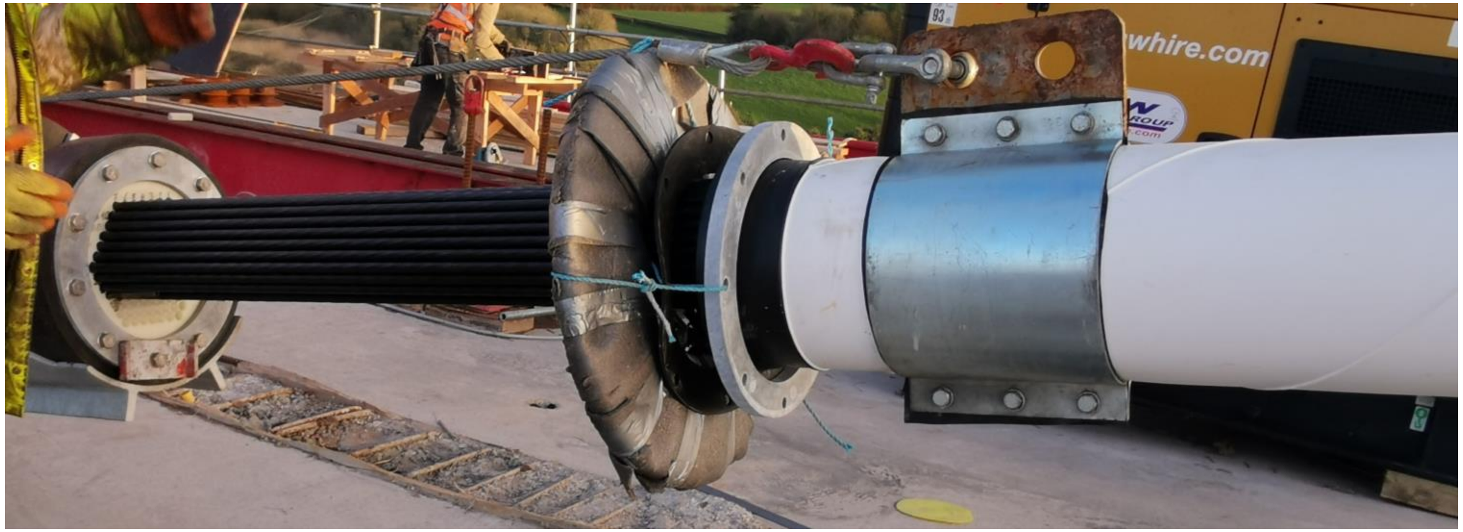
Cantilever Construction Cycle (optimum time 7-12 days)

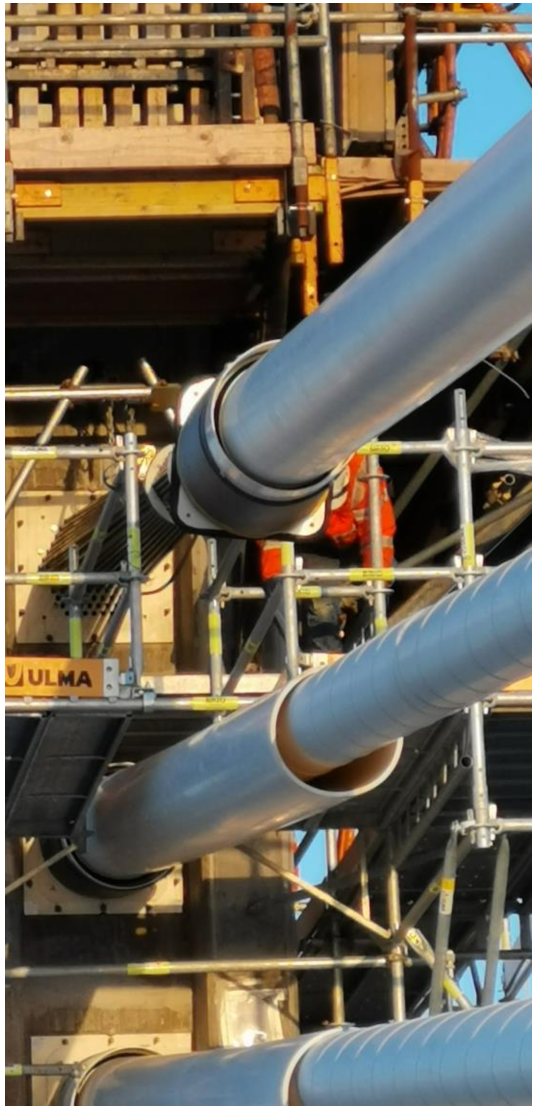
1. Stressing of cantilever PT or bars in segment “n-1” (**36h** or 30N/mm2)
2. Form traveller movement and **setting out for segment “n”**
3. Bottom slab & Webs rebar and post-tensioning fixing
4. Internal Props and form tube for the main cable fixing
5. **0- 50% Stressing of cable in segment “n-2”**
6. Installation of precast panels
7. Top Slab transversal posttensioning and rebar fixing
8. Stressing of transversal PT in segment “n-2” & part of “n-1”
9. **50-100% Stressing of cable in segment “n-2”**
10. Casting of Segment n

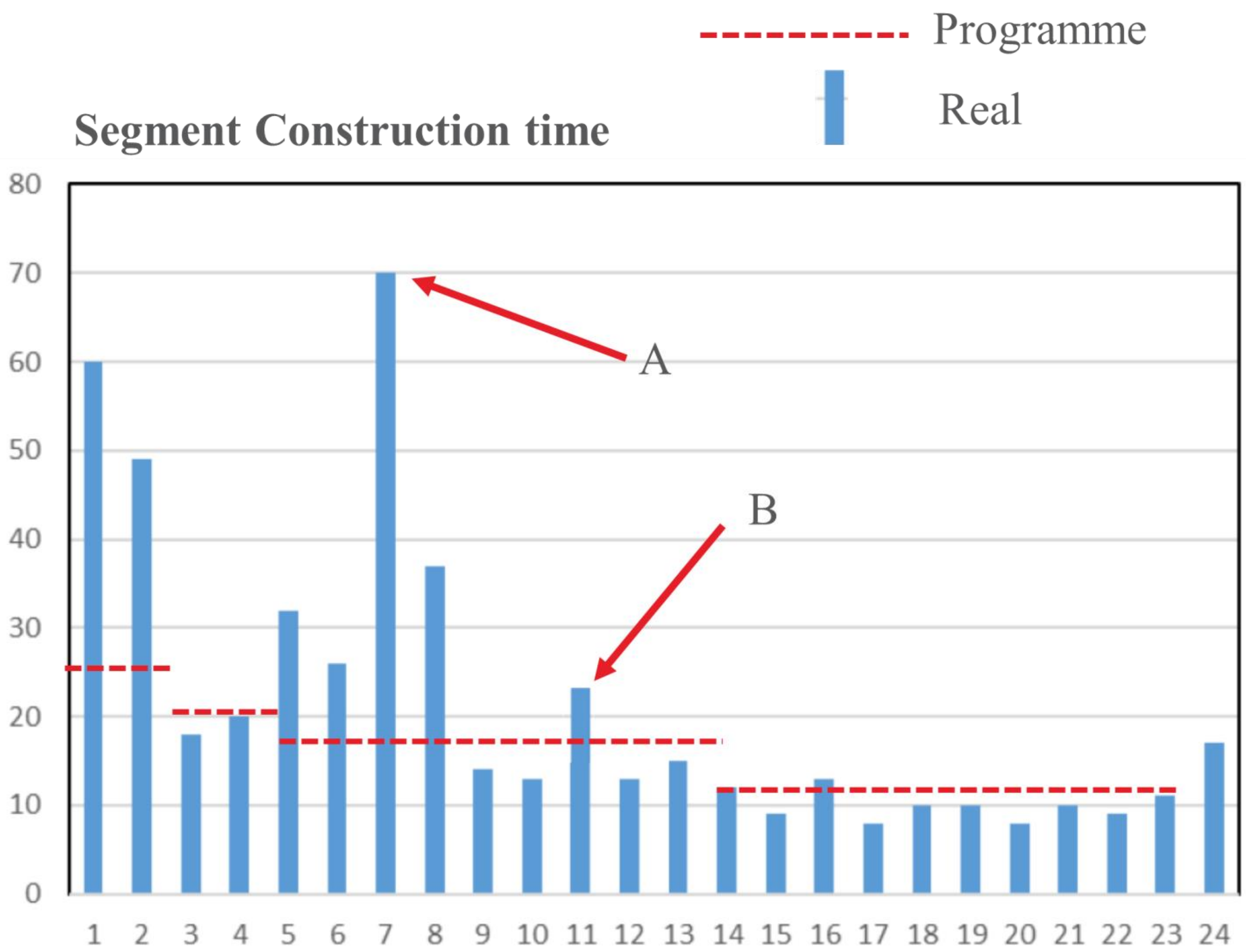


Design and Construction of Concrete Segmental Extradosed Bridges

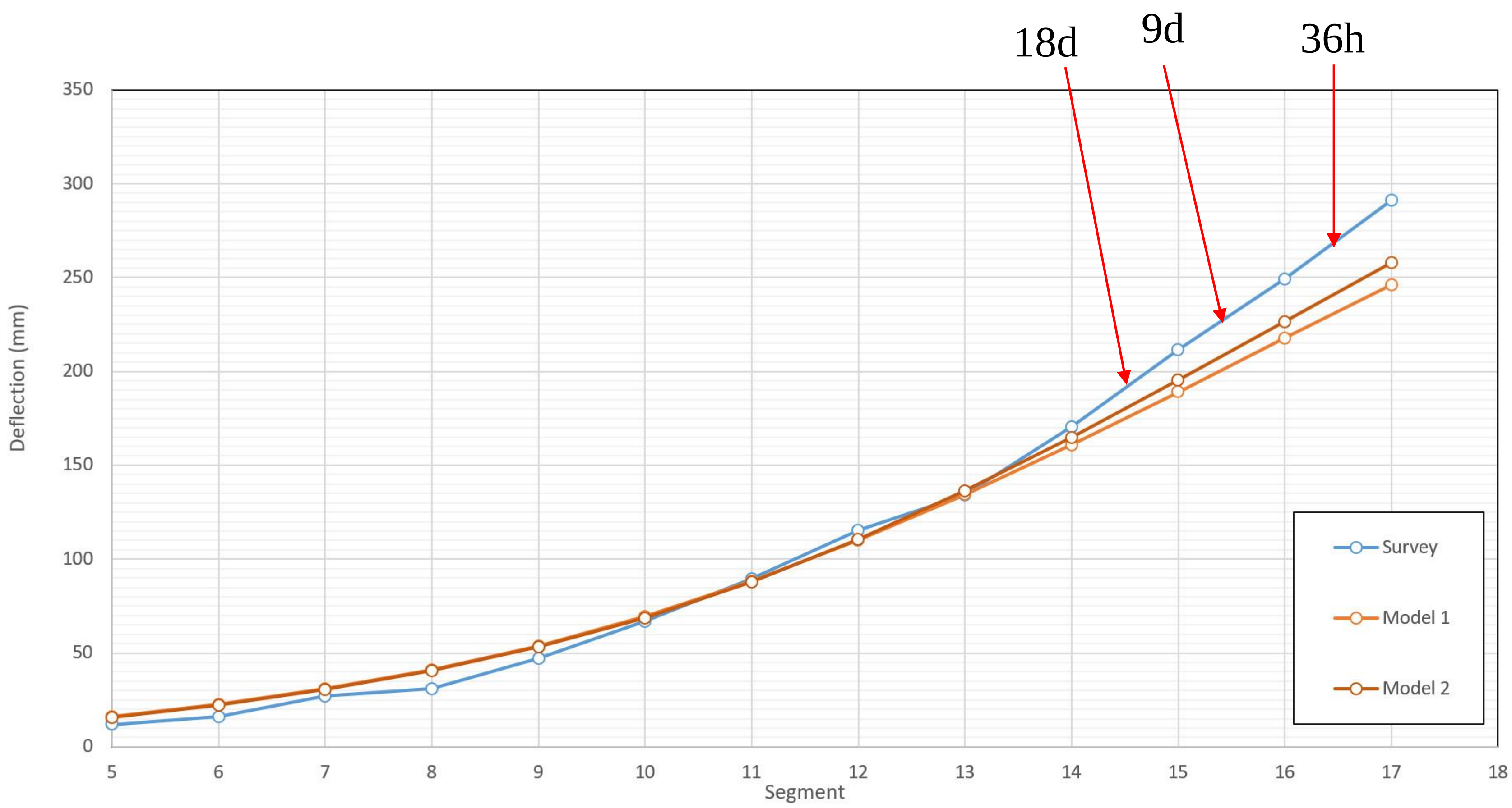
Case Study: RFK over the River Barrow






Programme
Real
Segment Construction time
80
70
60
50
40
30
20
10
0
A
B
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Deflections due to cable stressing (upwards). Cable 12



Design and Construction of Concrete Segmental Extradosed Bridges

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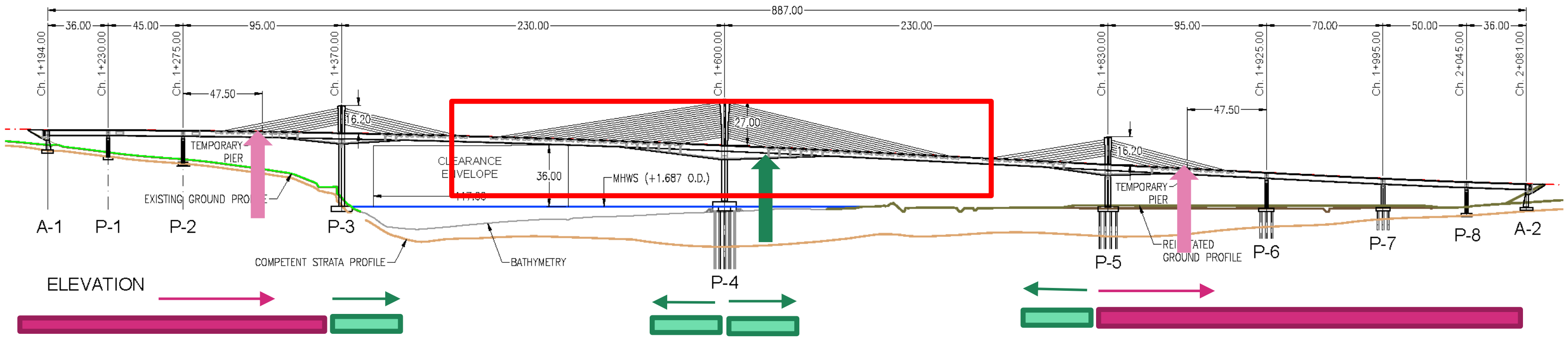
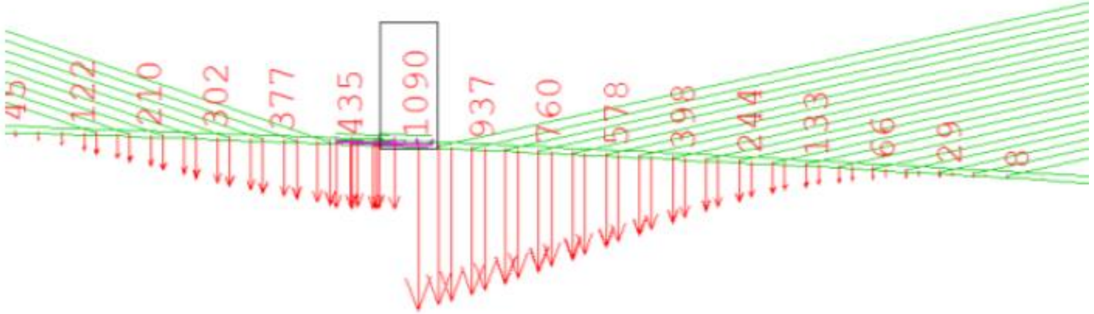
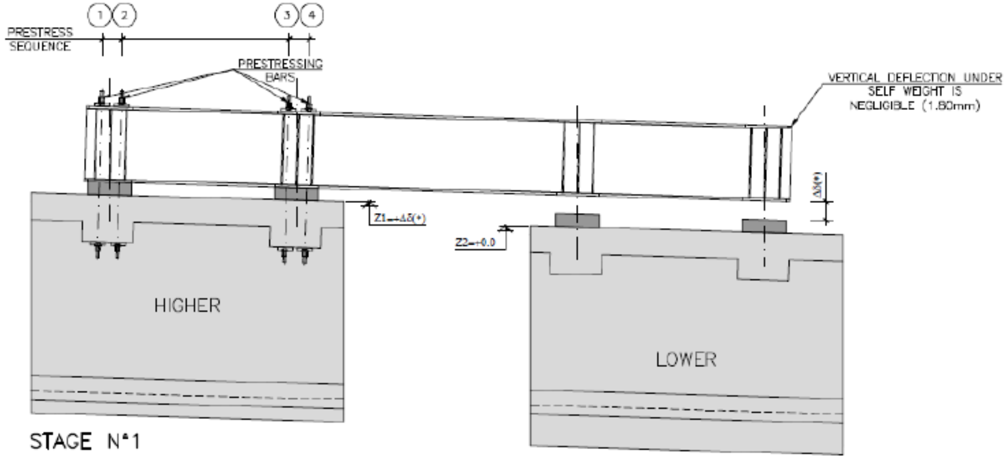






RFK over the River Barrow. Detailed design. Global behaviour


Genie S-65
KAVANAGH

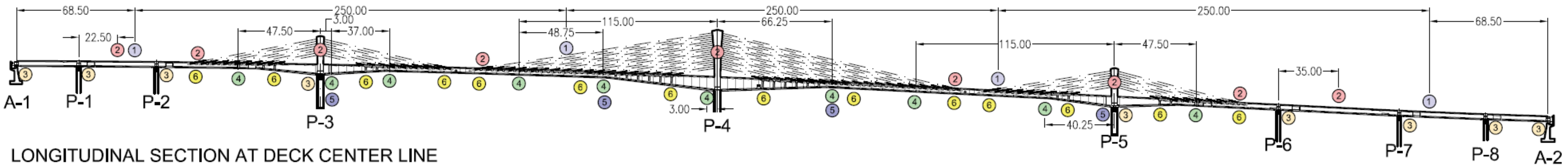
American Segmental Bridge Institute

Case Study

Rose Fitzgerald Kennedy bridge over the river Barrow

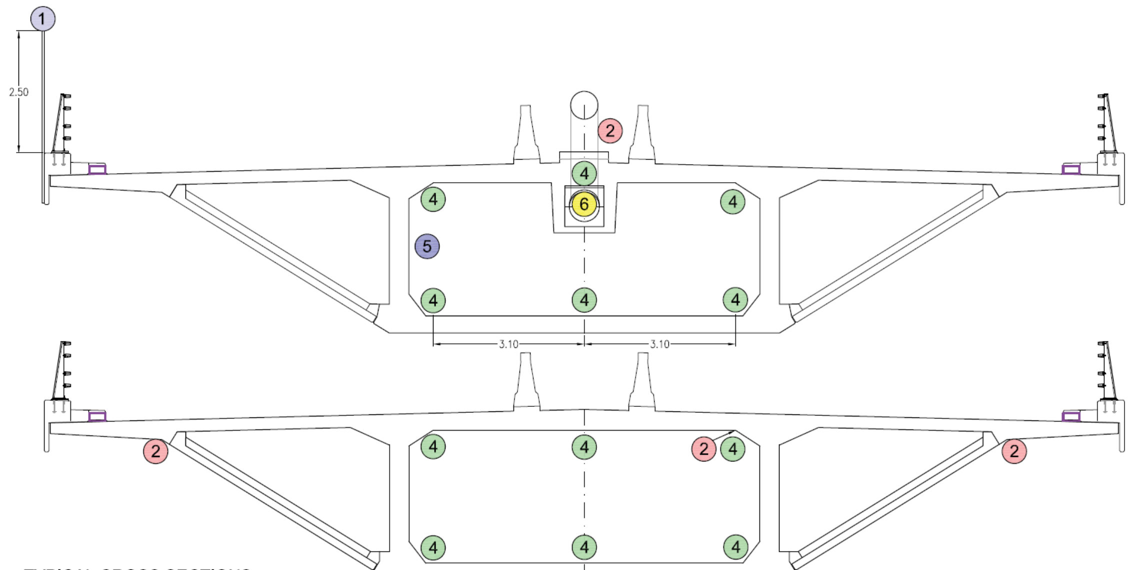
Structural Health Monitoring

ARUP



LONGITUDINAL SECTION AT DECK CENTER LINE

SCALE 1:1500



TYPICAL CROSS SECTIONS.

SCALE 1:50

LEGEND:

1 ANEMOMETER

2 TEMPERATURE SENSOR

3 LOAD INDICATOR AT BEARINGS

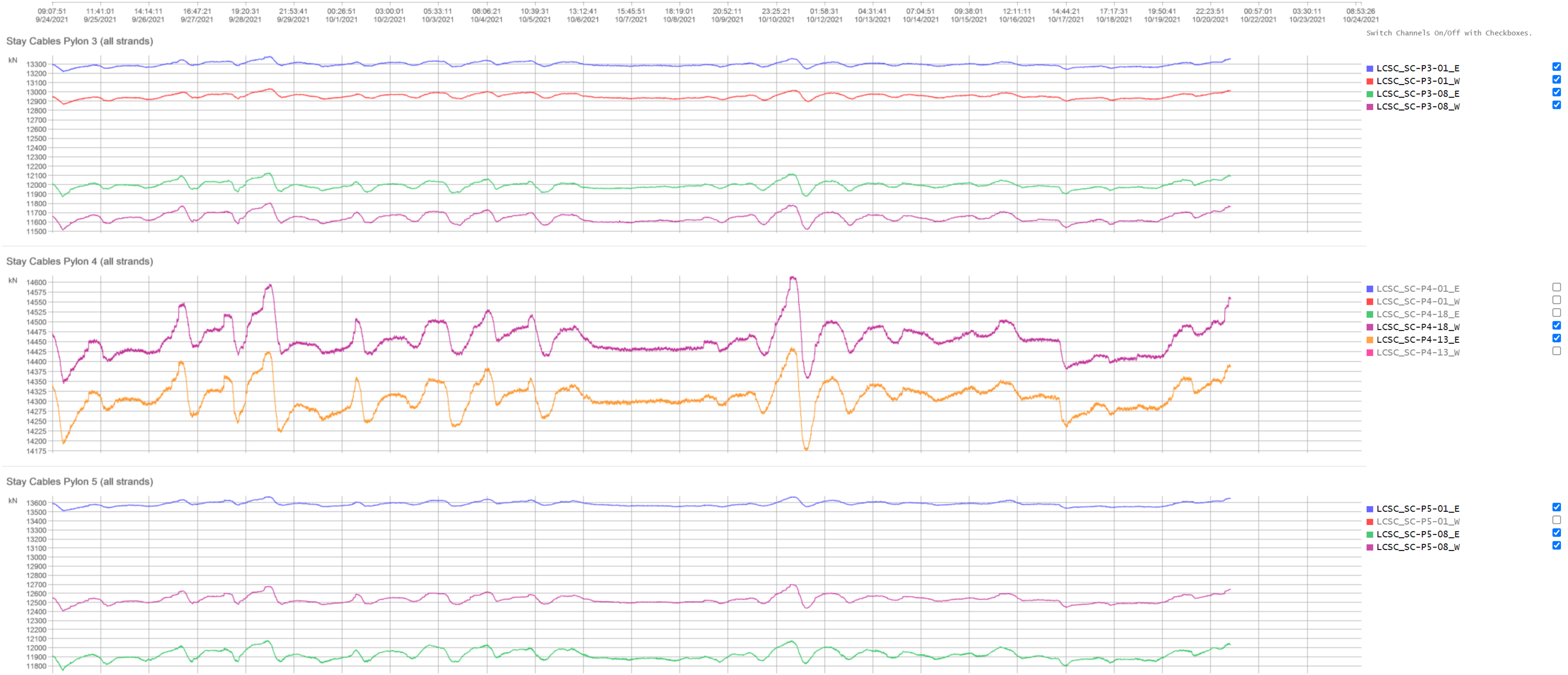
4 STAIN GAGES

5 INCLINOMETERS

Design and Construction of Concrete Segmental Extradosed Bridges

Case Study: RFK over the River Barrow

American Segmental Bridge Institute



American Segmental Bridge Institute

Case Study 2

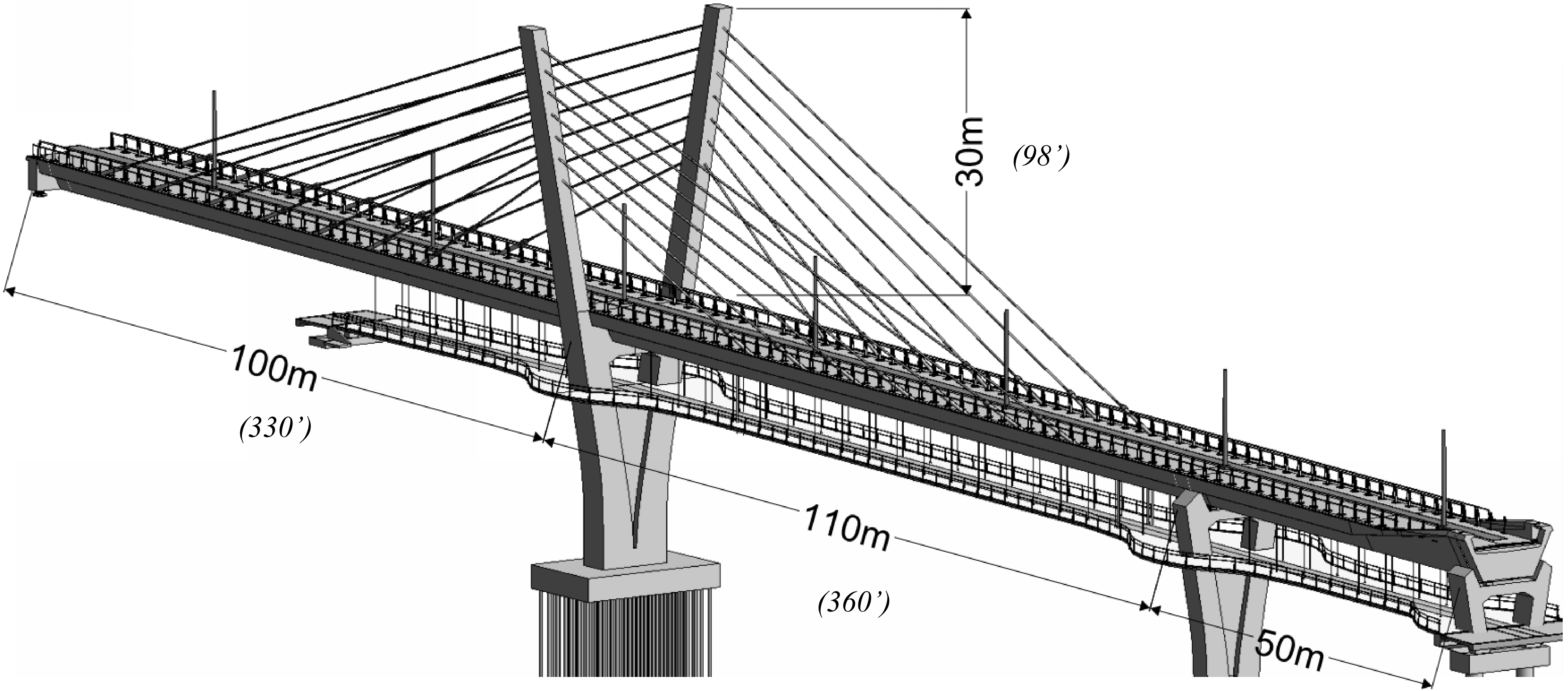
Tawatinâ Bridge over the North Saskatchewan River

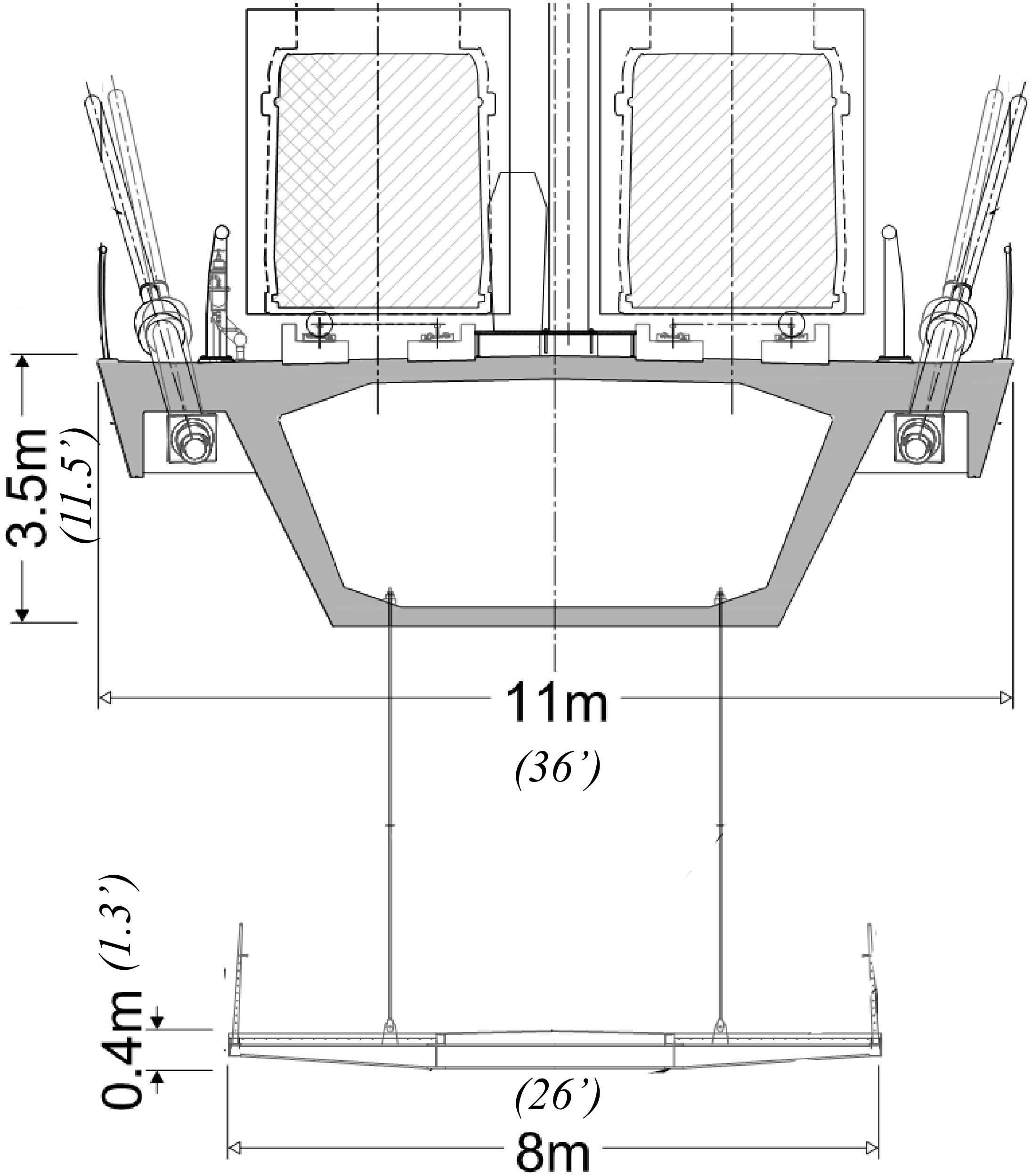
Case Study 2

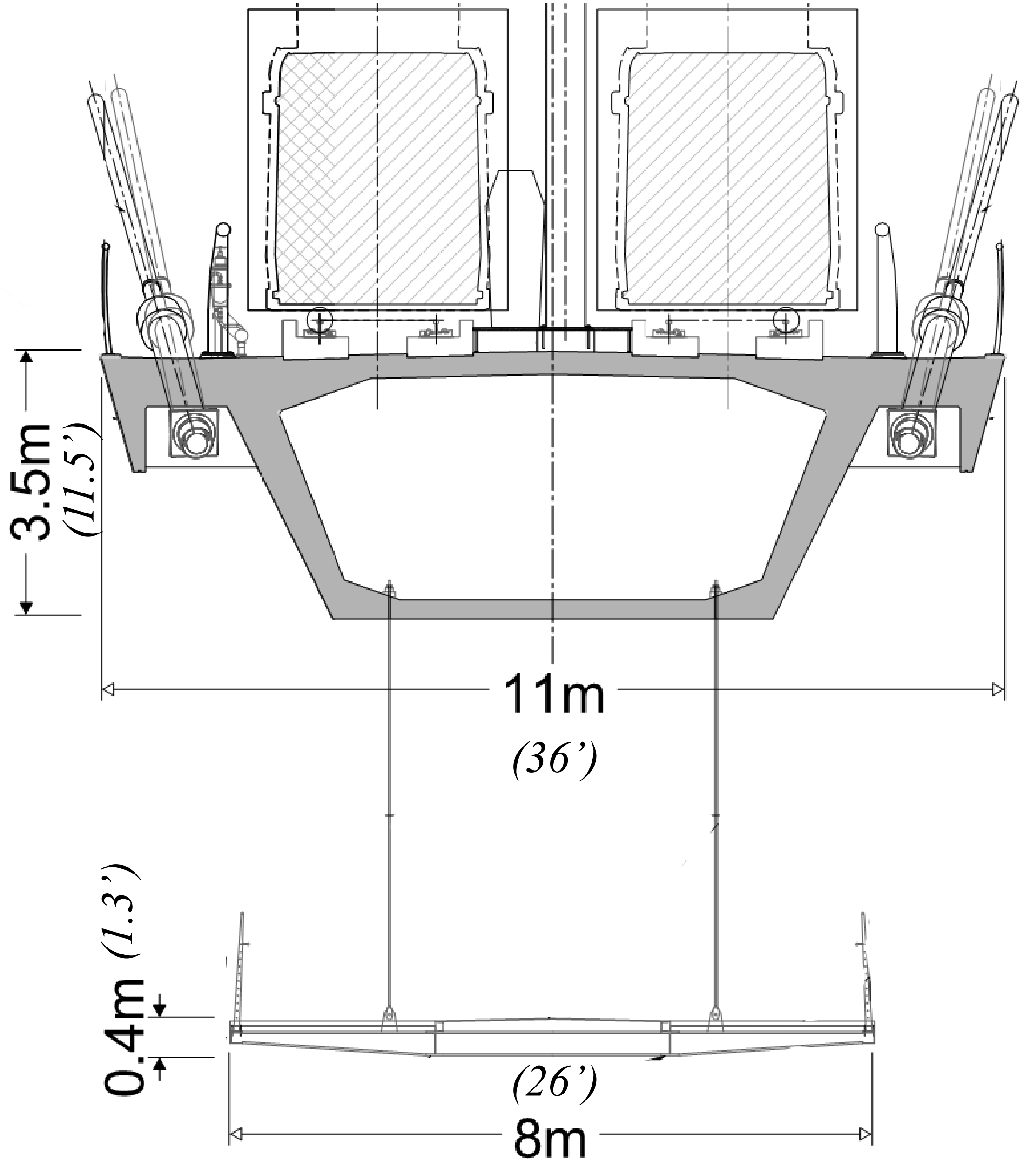
Tawatinâ Bridge over the North Saskatchewan River

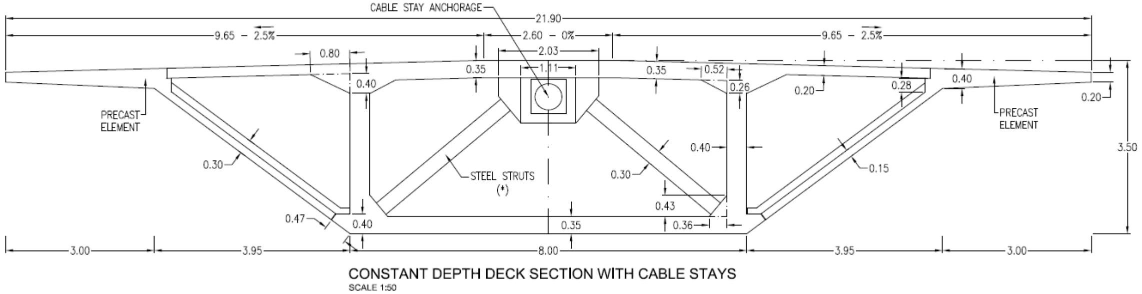
Introduction. Project History. Constraints and Value Engineering


TELUS

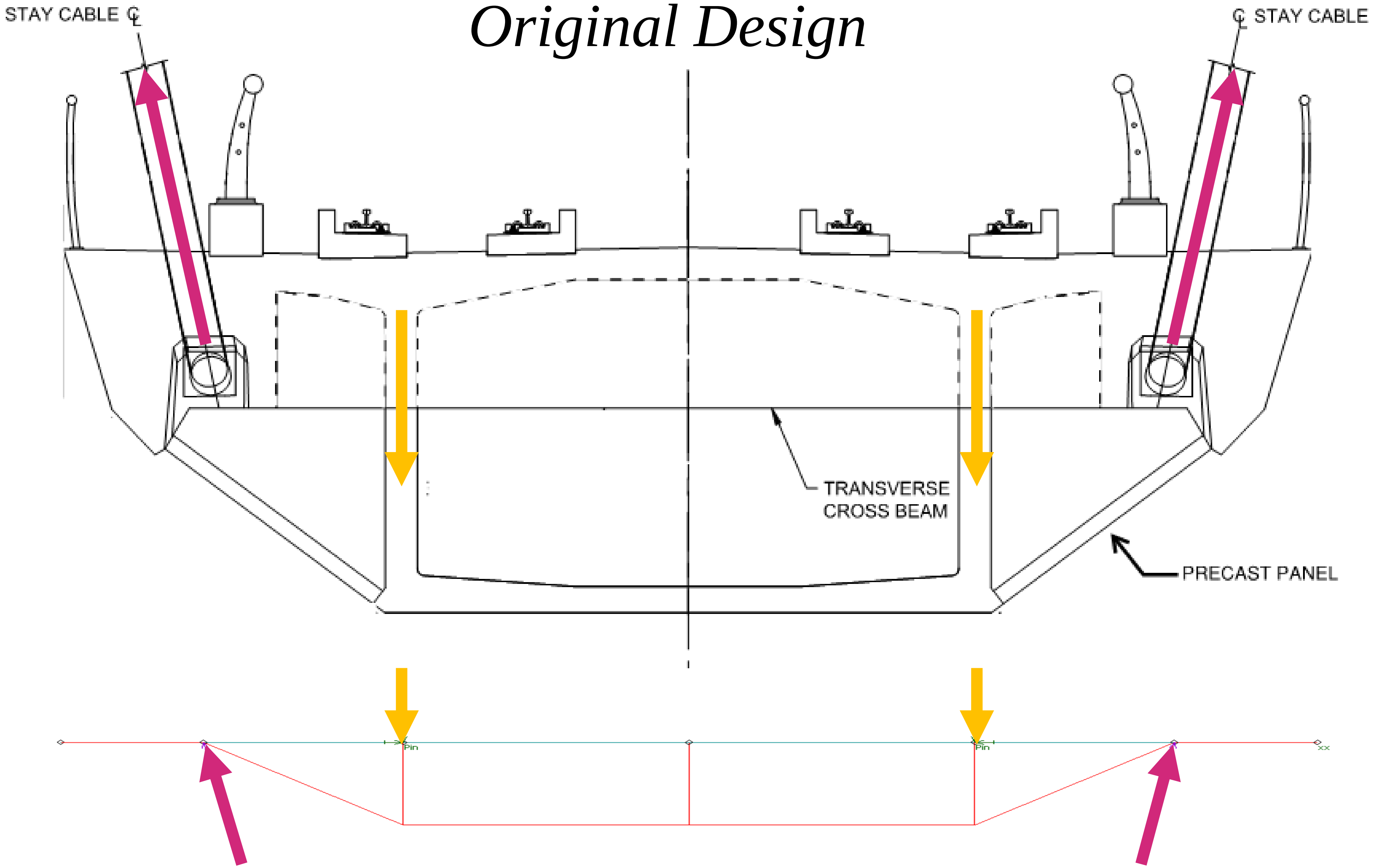

30m
(98')
100m
(330')
110m
(360')
50m
(165')


3.5m
(11.5')
11m
(36')
0.4m
(1.3')
(26')
8m

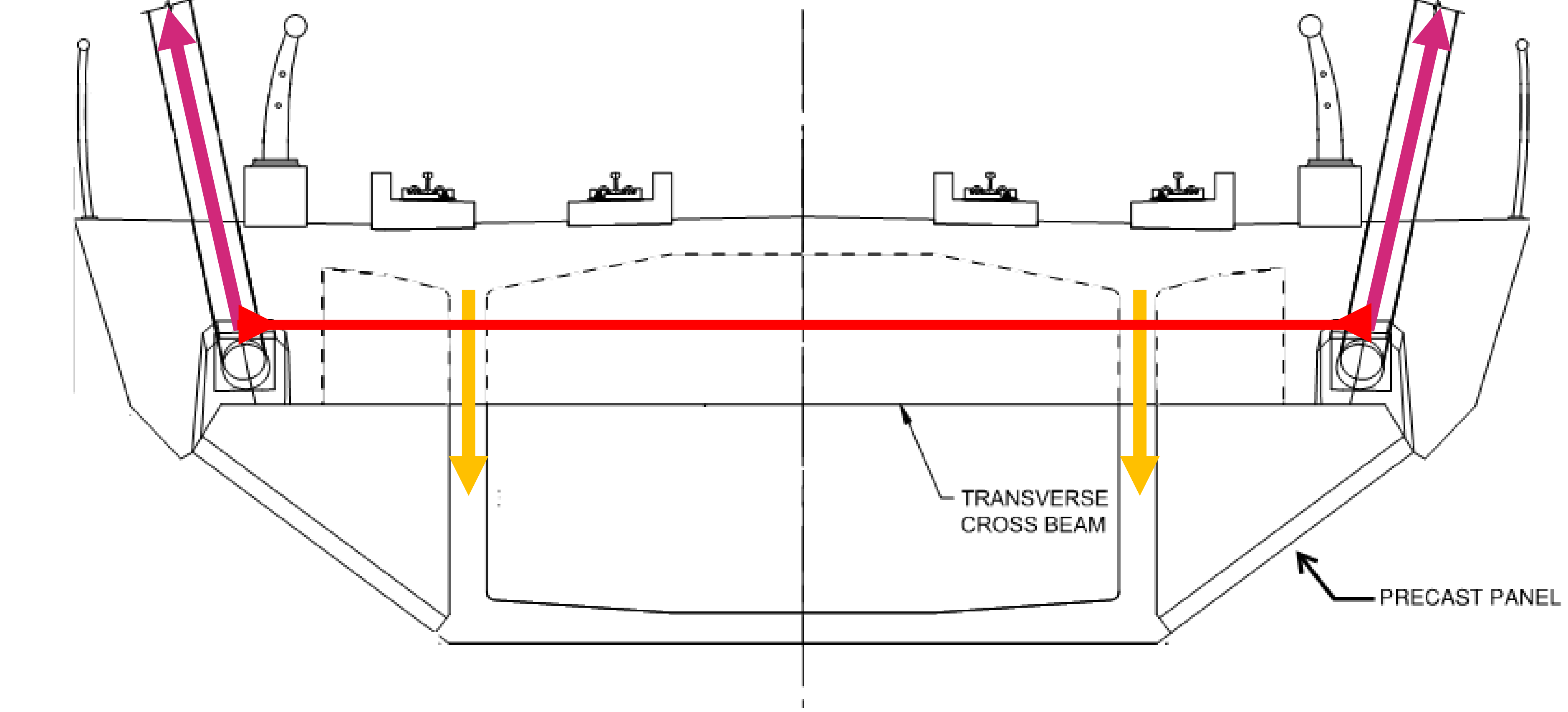

3.5m
(11.5')
11m
(36')
0.4m (1.3')
(26')
8m


CABLE STAY ANCHORAGE
21.90
9.65 – 2.5%
2.60 – 0%
9.65 – 2.5%
PRECAST ELEMENT
STEEL STRUTS
3.00
3.95
8.00
3.95
3.00
3.50
CONSTANT DEPTH DECK SECTION WITH CABLE STAYS
SCALE 1:50

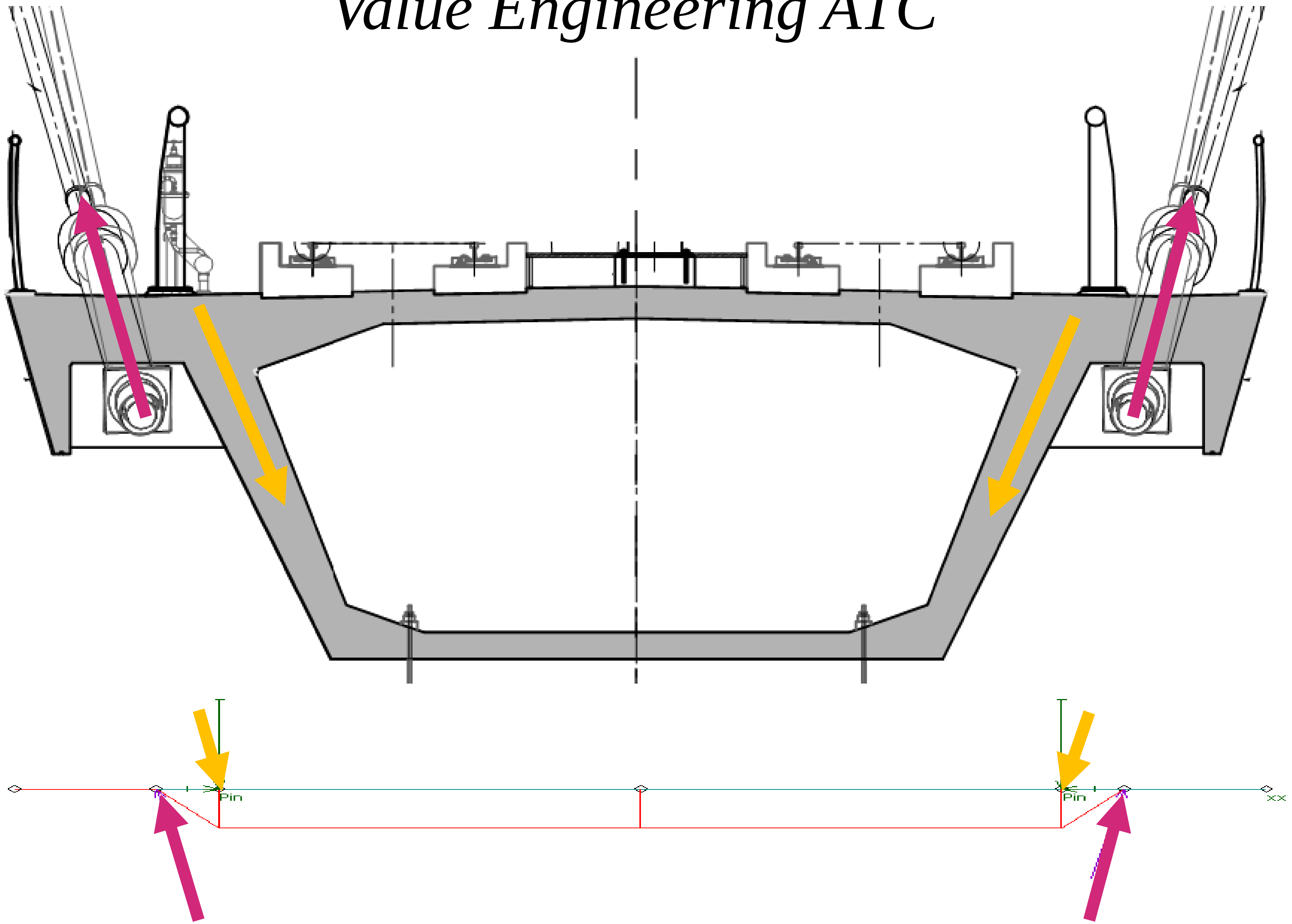
Original Design

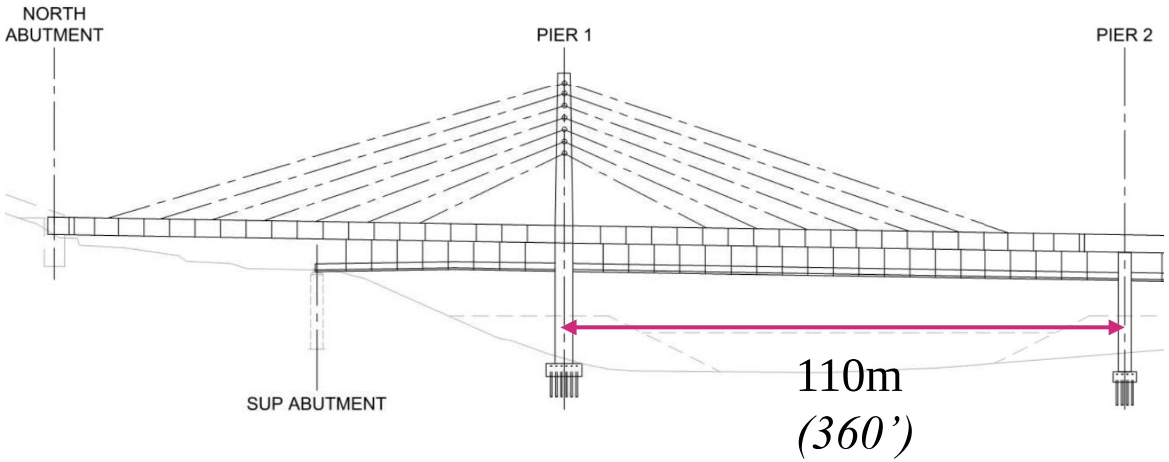


Original Design

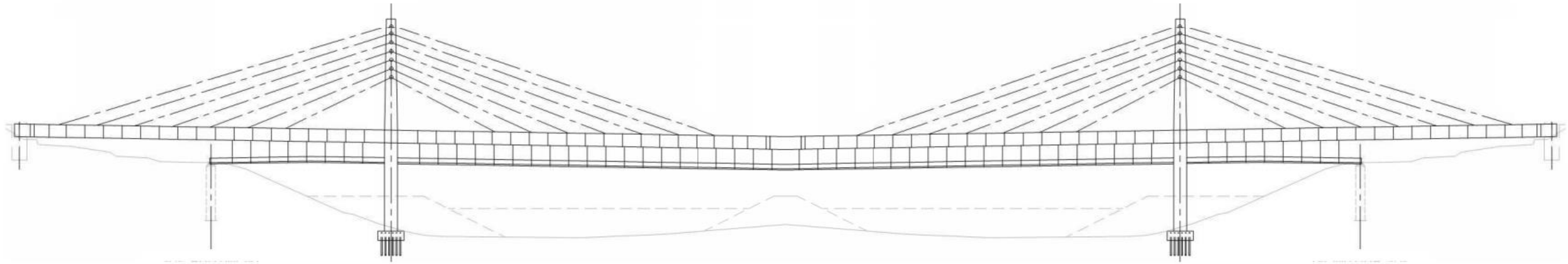


Value Engineering ATC





Span Length – 110m or 220m? (360’ or 720’)



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Case Study 2

Tawatinâ Bridge over the North Saskatchewan River

Detailed Design

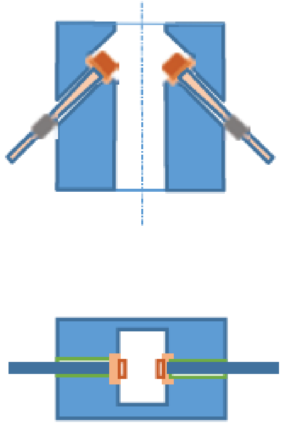
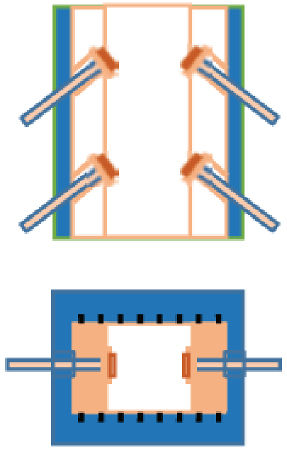
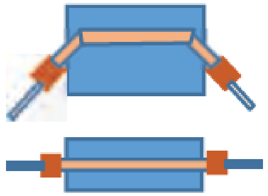
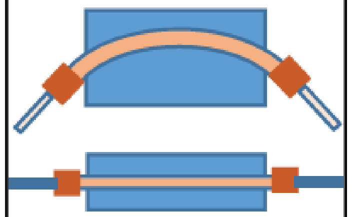
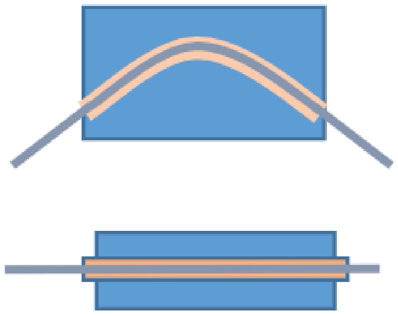
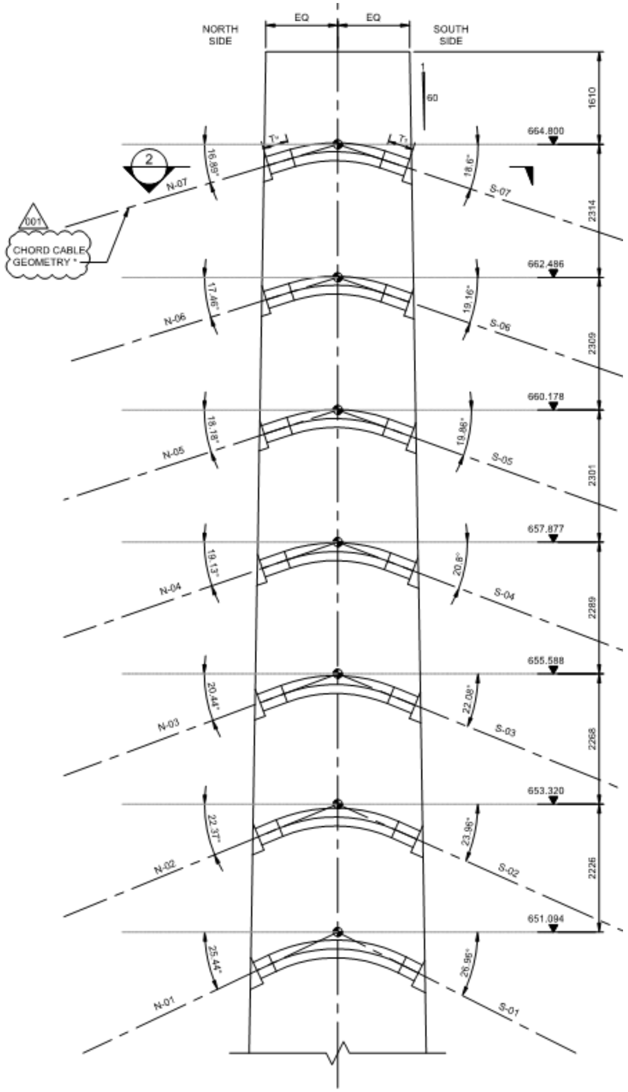
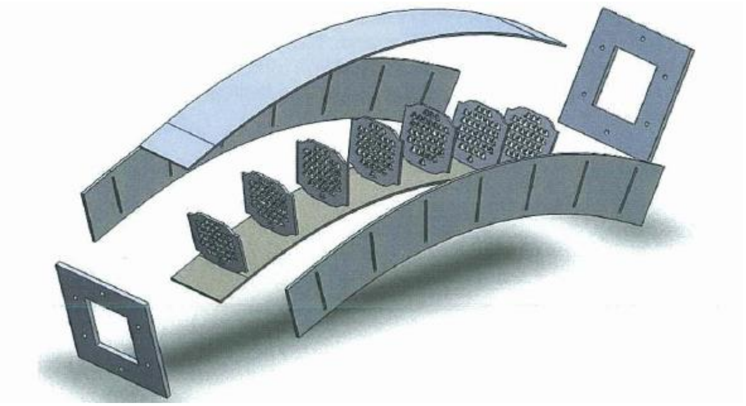
TYPE	A	B	C	D
cross section of pylon head Elevation Plane view	Concrete: 		• Laminated steel elements • Cable element • Anchorage  Steel welded elements  Steel curve element connected to concrete	
Comments	Cables anchored inside concrete pylon	Cables anchored inside composite element or in pylon head steel	Cable anchored to a cast-in steel element	Continuous cables running through saddle in concrete pylon

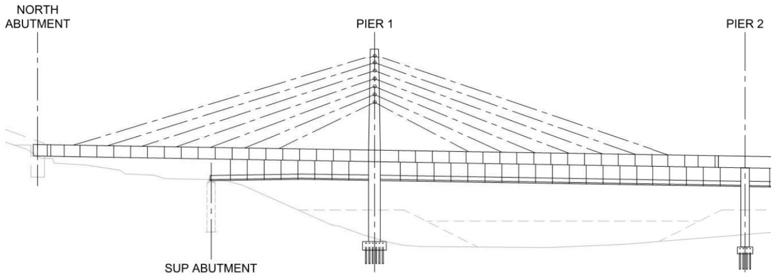
Table 5.1 Type of anchorages in pylon

Salesforce Transit Center Bus Ramp Bridge


NORTH SIDE
SOUTH SIDE
EQ
EQ
1610
60
664.800
662.486
660.178
657.877
655.588
653.320
651.094
2314
2309
2301
2289
2268
2226
2
001
CHORD CABLE GEOMETRY
N-07
S-07
16.89°
18.6°
N-06
S-06
17.46°
19.16°
N-05
S-05
18.18°
19.98°
N-04
S-04
19.13°
20.8°
N-03
S-03
20.44°
22.08°
N-02
S-02
22.37°
23.96°
N-01
S-01
25.44°
26.96°




Date/Time: 2019-06-10 08:22:57-06:00
Location: 53.54249°N 113.47756°W ± 165 m WGS84
Altitude: 696 m ± 62 m
Direction: 156 deg(T)
Address: 10020 95 St NW Edmonton AB T5H 2A4 CA



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Cable ID	# Strands	Unfactored Live + Wind Stress / MUTS	ø
1 (Shortest)	39 (Size 43 anchorage)	0.049	0.70
2		0.046	0.71
3		0.040	0.72
4		0.033	0.73
5		0.024	0.75
6		0.020	0.75
7 (Longest)		0.021	0.75

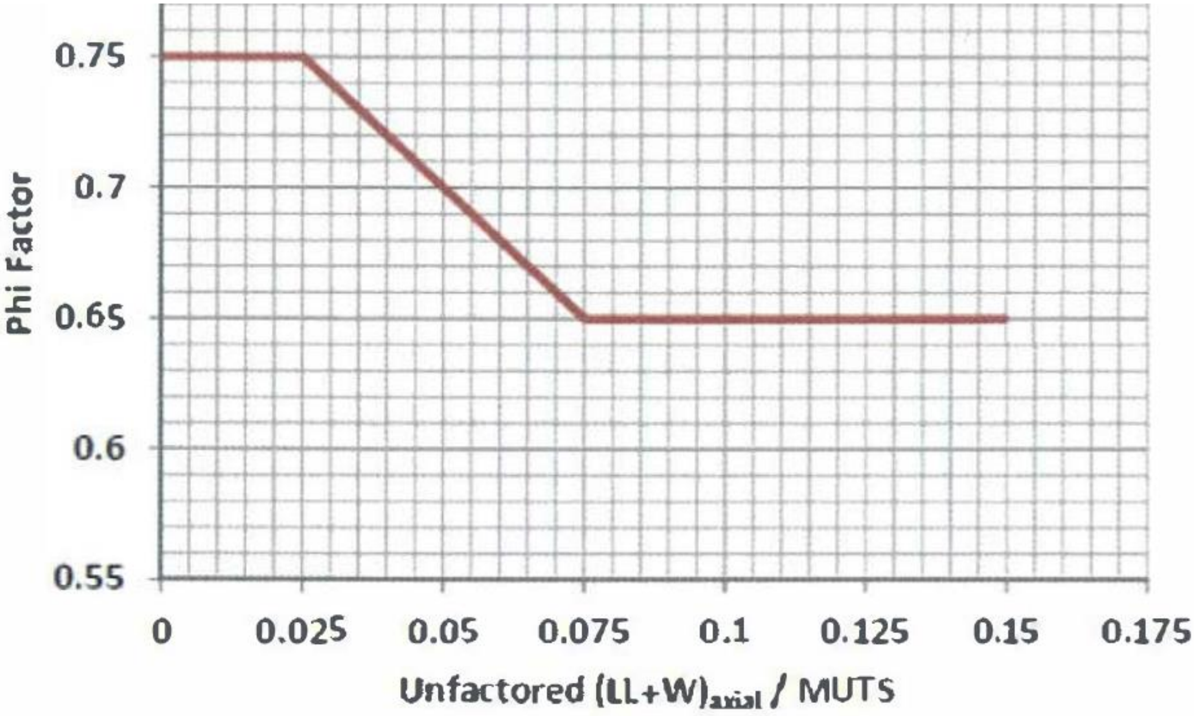

Fig. 5.1—Strength resistance factors ϕ.

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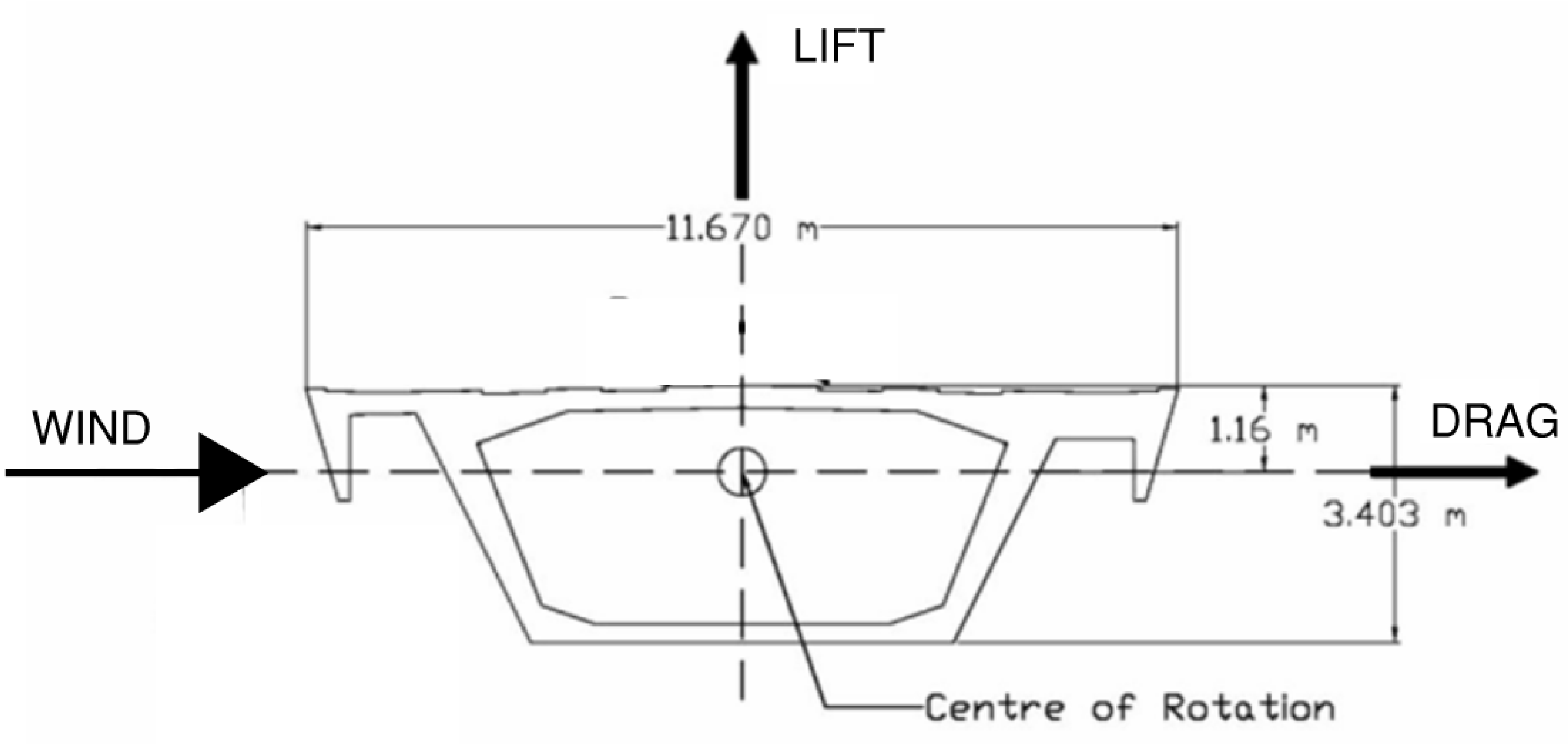
5.12.5—Segmental Concrete Bridges

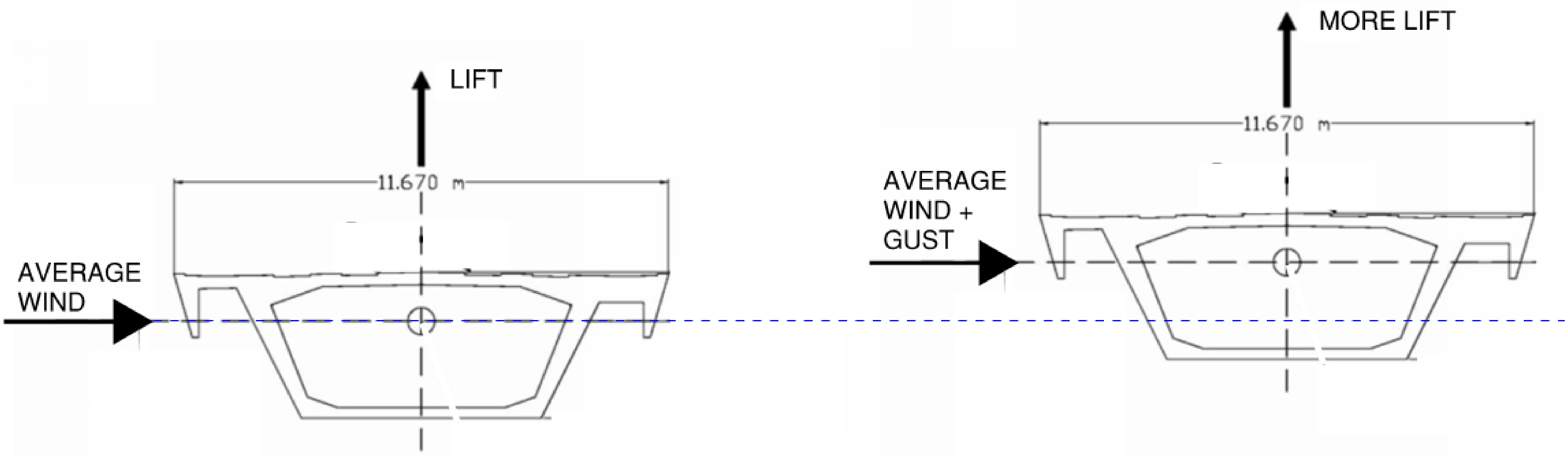
5.12.5.3.2—Construction Loads

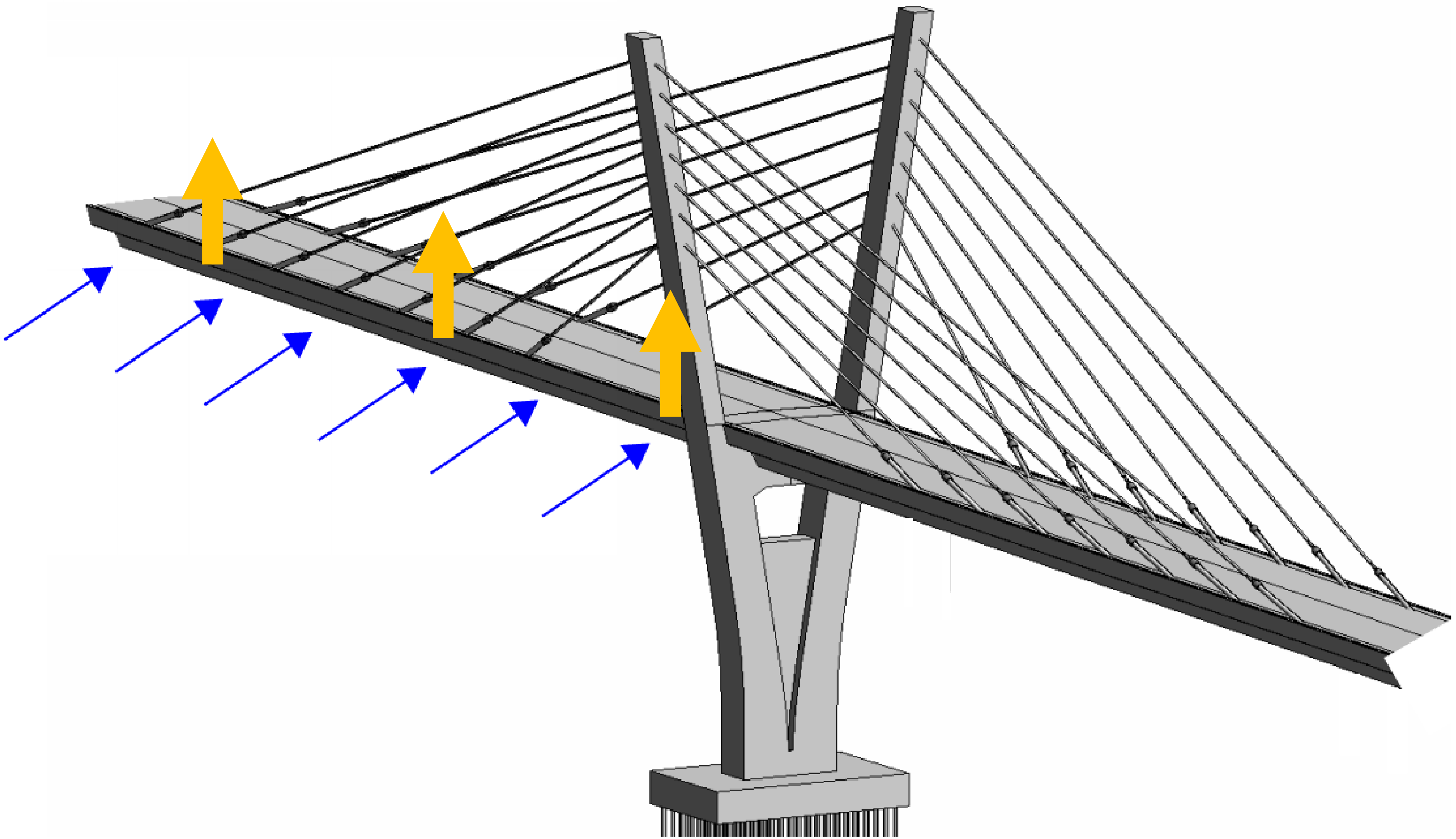
WUP	=	wind uplift on cantilever: 0.005 ksf of deck area for balanced cantilever construction applied to one side only, unless an analysis of site conditions or structure configuration indicates otherwise (ksf)

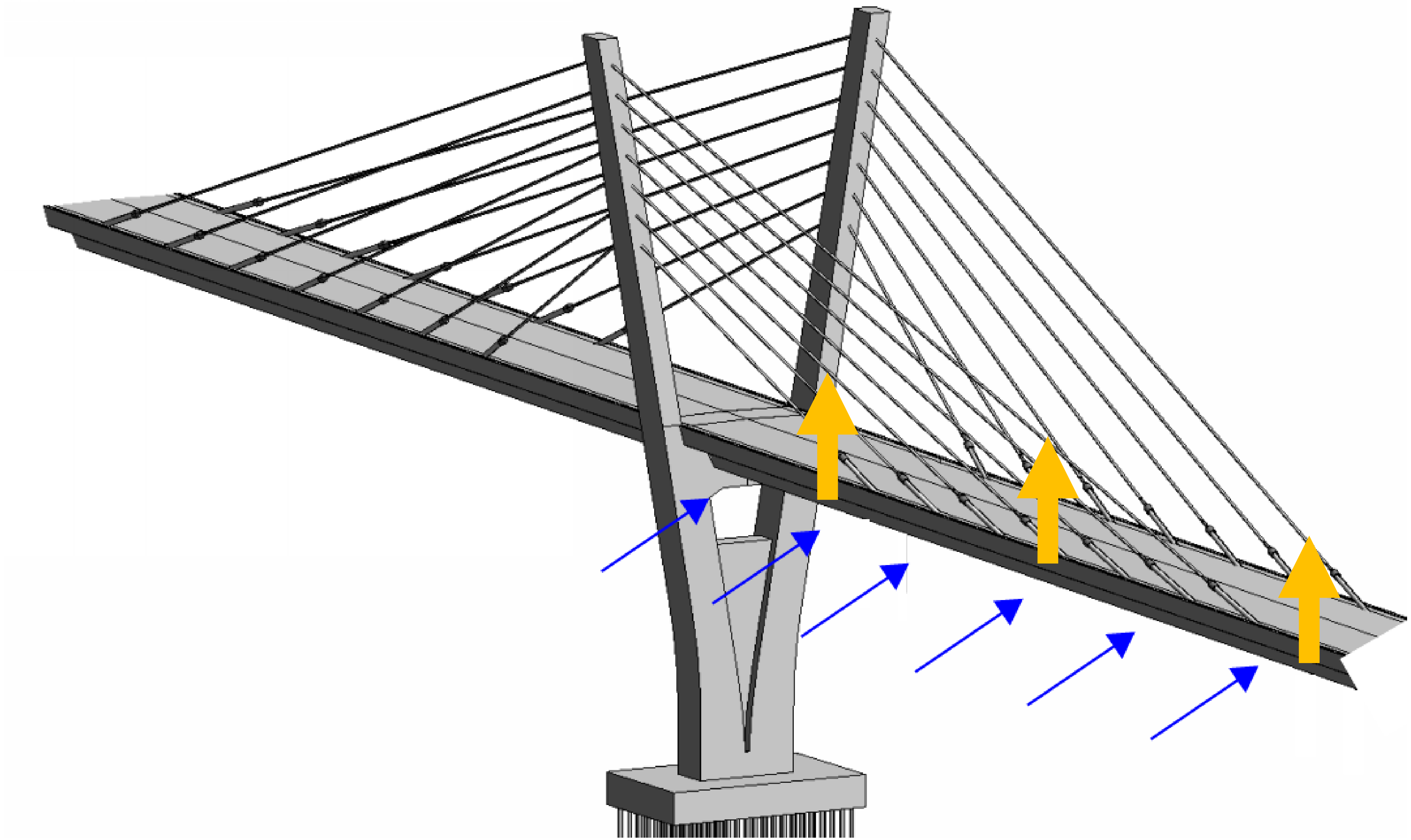


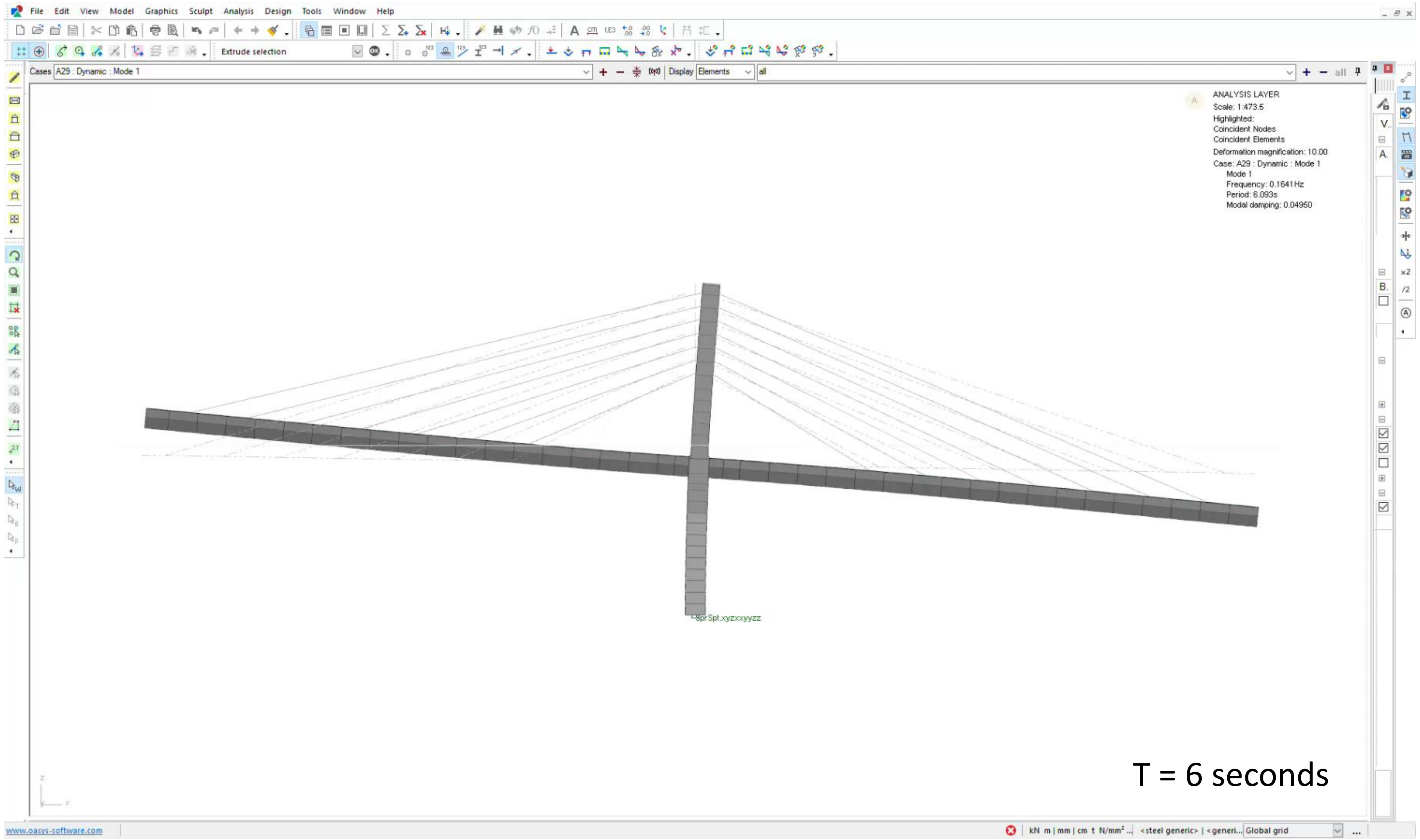
Aero-coefficients

Drag = 0.346
Lift = 0.616

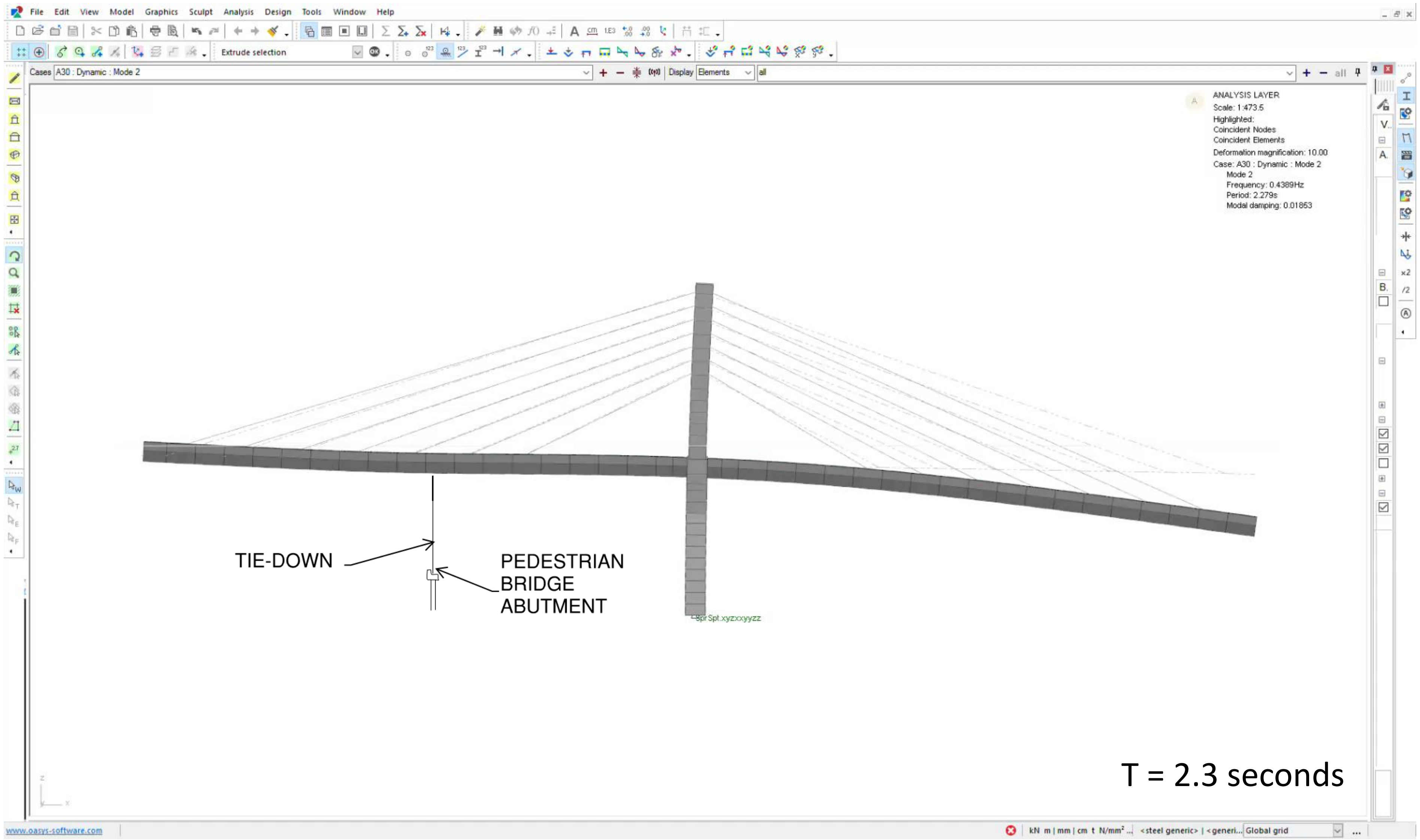

LIFT
11.670 m
AVERAGE
WIND
MORE LIFT
11.670 m
AVERAGE
WIND +
GUST



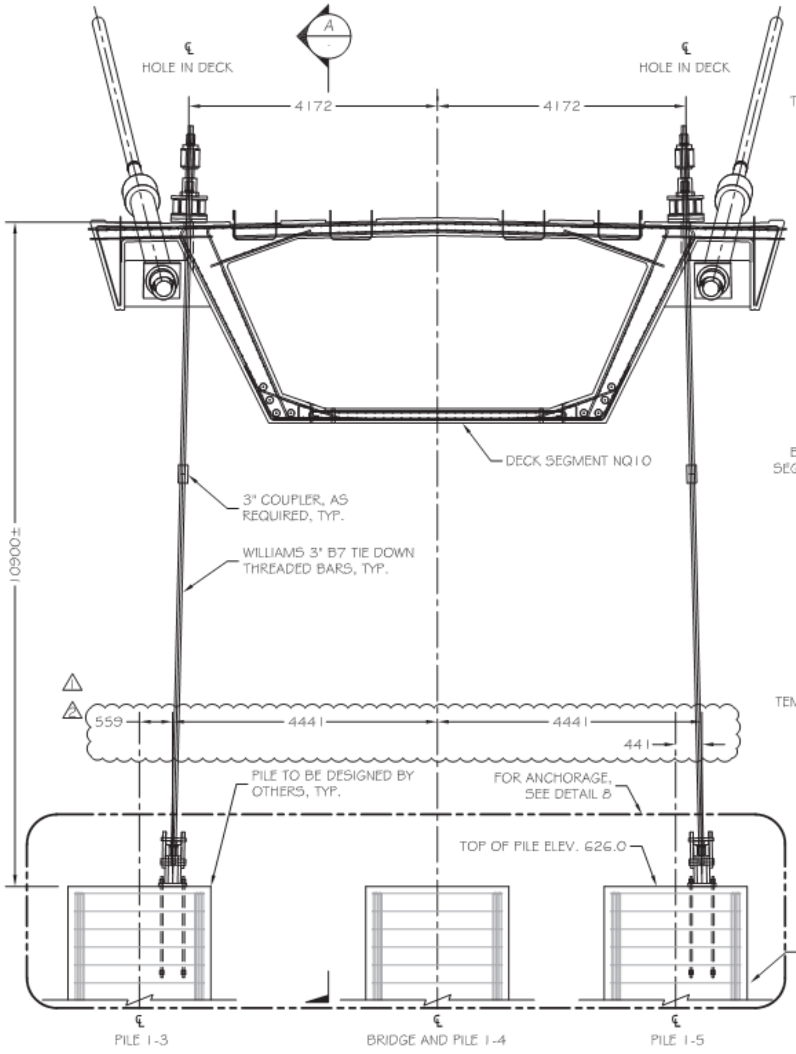



ANALYSIS LAYER
Scale: 1:473.5
Highlighted:
Coincident Nodes
Coincident Elements
Deformation magnification: 10.00
Case: A29 : Dynamic : Mode 1
Mode 1
Frequency: 0.1641 Hz
Period: 6.093s
Modal damping: 0.04950

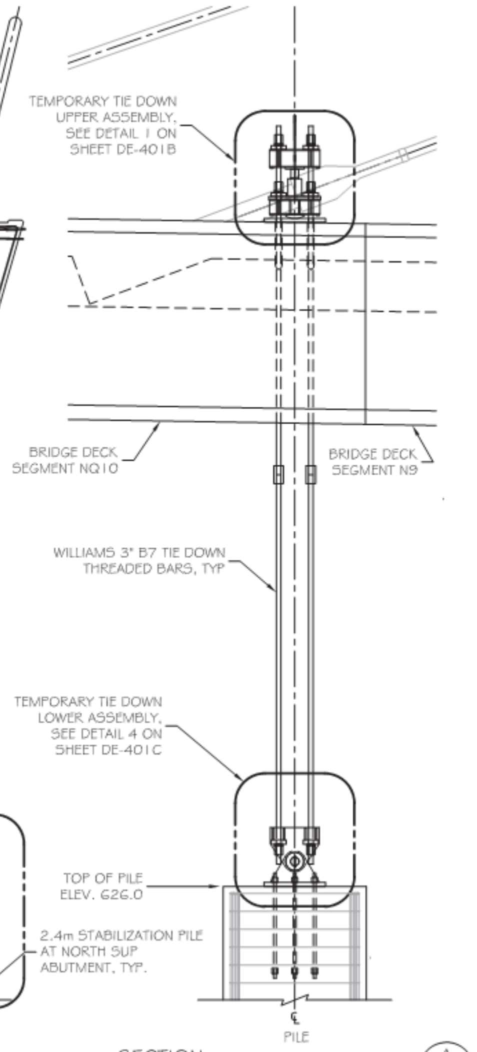
T = 6 seconds


TIE-DOWN
PEDESTRIAN
BRIDGE
ABUTMENT
ANALYSIS LAYER
Scale: 1:473.5
Highlighted:
Coincident Nodes
Coincident Elements
Deformation magnification: 10.00
Case: A30 : Dynamic : Mode 2
Mode 2
Frequency: 0.4389Hz
Period: 2.279s
Modal damping: 0.01853

T = 2.3 seconds



TEMPORARY TIE DOWN - SECTION VIEW
(LOOKING SOUTH)



SECTION A
ELEVATION VIEW - LOOKING EAST

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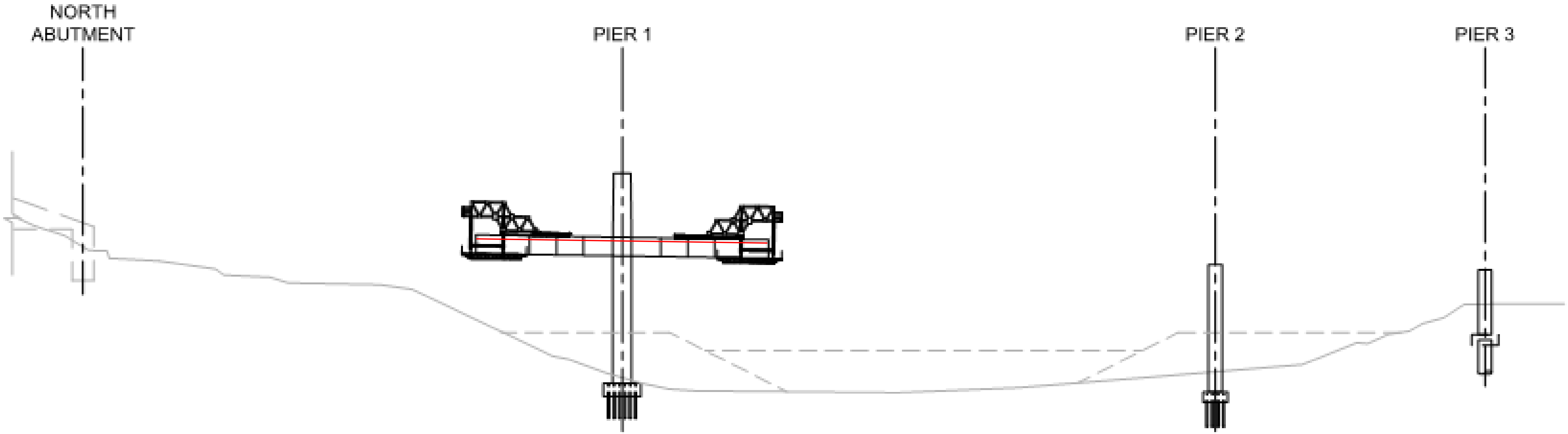
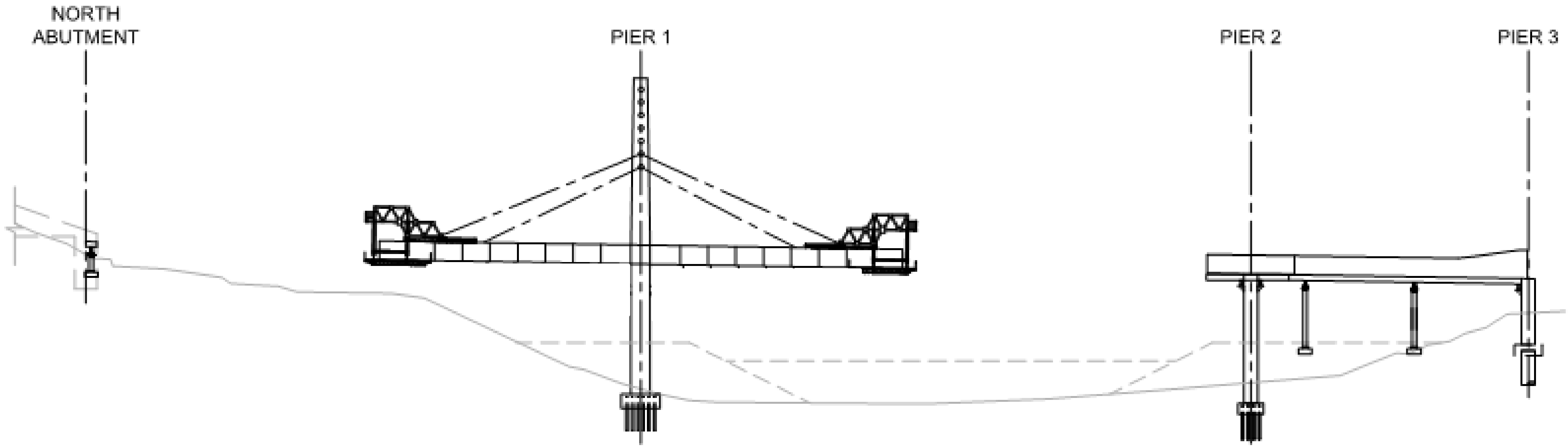
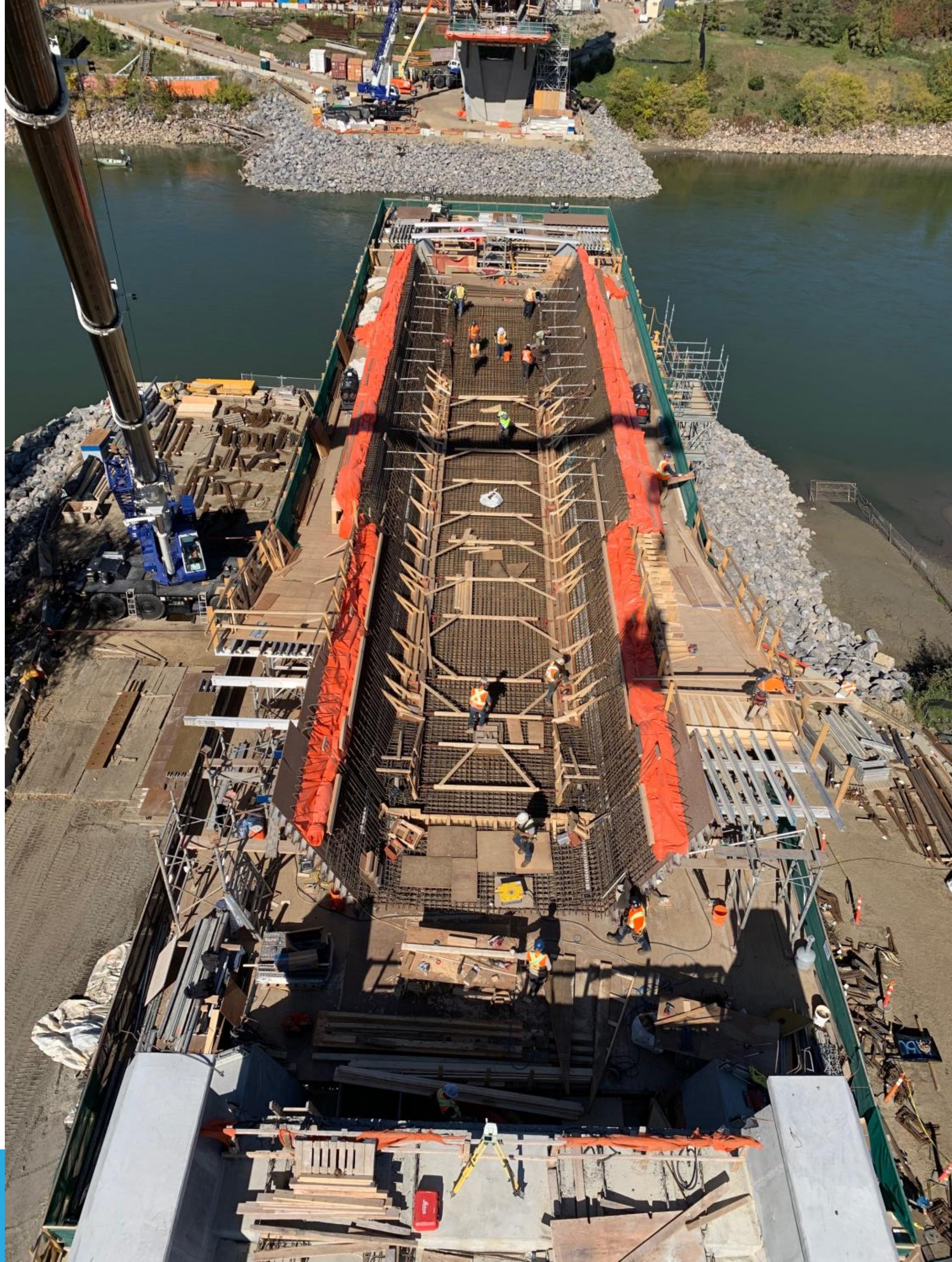
Case Study 2

Tawatinâ Bridge over the North Saskatchewan River


NORTH
ABUTMENT
PIER 1
PIER 2
PIER 3

Texas Department of Transportation


NORTH
ABUTMENT
PIER 1
PIER 2
PIER 3

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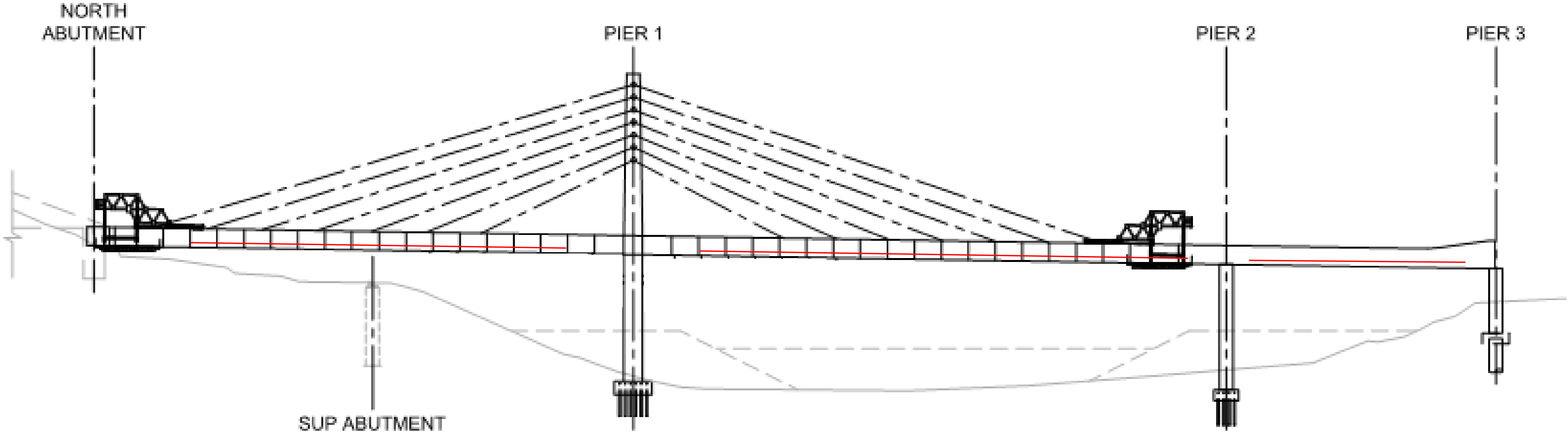

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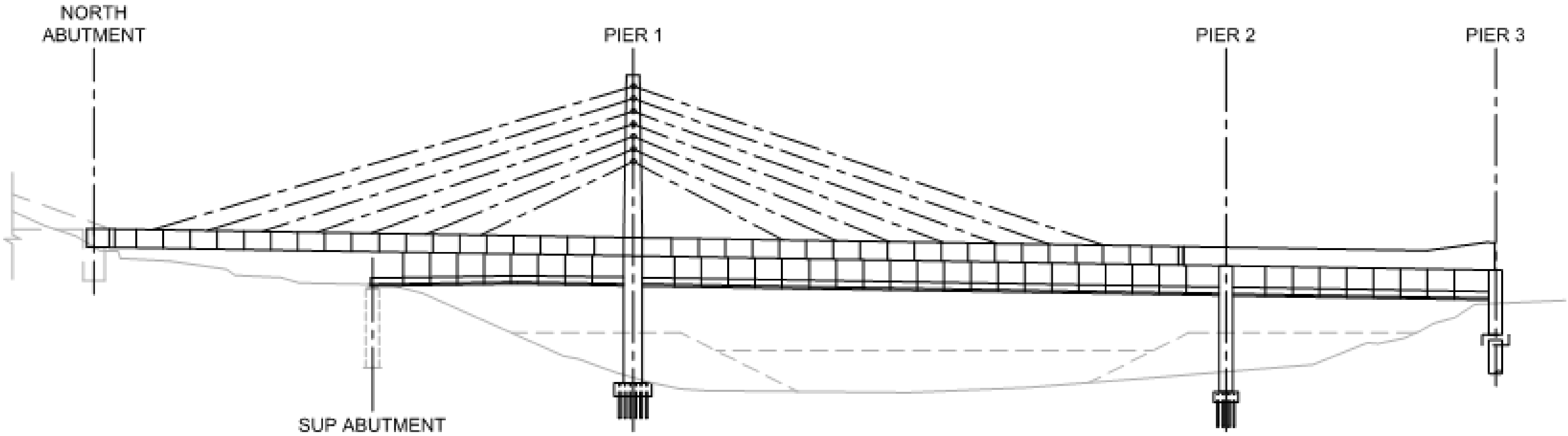
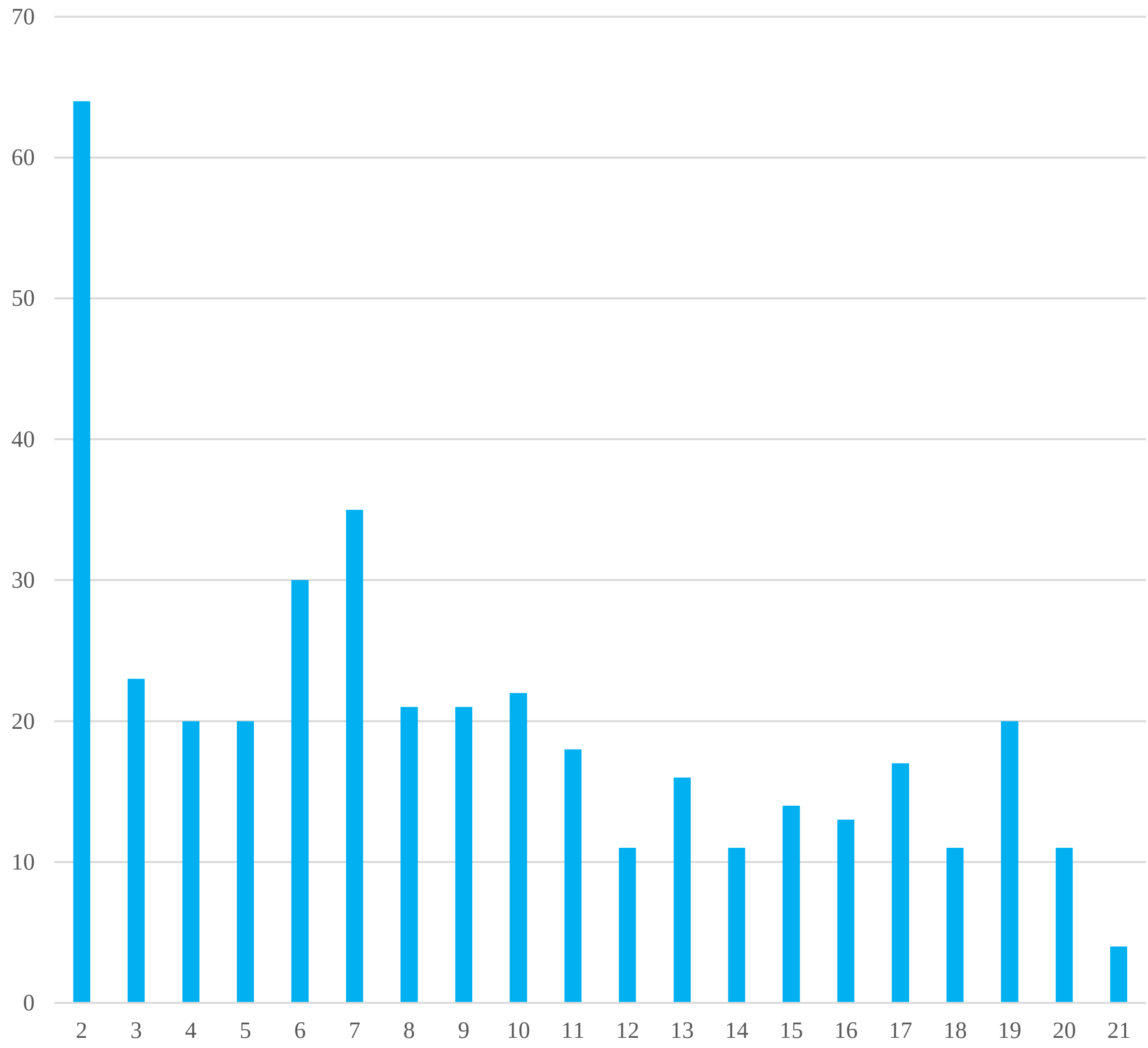


Segment Construction Time (for a pair of segments)



Conclusion

- Extradosed bridges are an intermediary between girder and cable stayed bridges
- Useful in the span range between 300’ to 800’ (between girder and cable stayed)
- Generally more expensive than girder bridges but can competitive for some projects
- Cables have a smaller live load stress range allowing for higher phi factor
- Definition of cross section and position of cables in the deck should be chosen carefully
- Shorter, smaller and simpler pylons can be built using saddles
- Extradosed bridges are typically longer span bridges that require particular attention to wind effects and geometry control during construction

Design and Construction of Concrete Segmental Extradosed Bridges

Thank you very much

Any Questions?

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Luke.Tarasuik@arup.com

Ill be at ASBI 2021 in Tucson