Be inspired – be energised

The Future of Integral Bridges in eThekwini Municipality, with an Outlook to the April 2022 Floods

Jitesh Harripershad PrEng
eThekwini Municipality
Engineering Unit – Roads Provision – Structures Branch
21 February 2023

Be inspired – be energised

Presentation Overview

- General information - April 2022 Floods
- What are some of the actual problems in the rivers and their impacts?
- Basics on Integral Bridges

- Example problems and solutions from the Floods
- Design aspects of 3 integral bridges
- The future and way forward…

CEMENT & CONCRETE SA

Presentation Overview

- General information - April 2022 Floods

A severe storm affected wide-spread regions of the eThekwini Municipality on 11 & 12 April 2022

Photo of Inanda Dam overflowing during the floods

Continuous rainfall resulted in high ground saturation levels, and high intensity flow, causing wide-spread damages across large sections of the Municipality.

- Rainfall intensity exceeded a 1:100 year event for various catchments
- Ground was already saturated - increased the runoff since there is no infiltration or storage
- As a result, there has been **loss of life**, substantial **damage to private infrastructure as well as severe inconvenience to residents & businesses alike.**

Presentation Overview

- What are some of the actual problems in the rivers and their impacts

CEMENT & CONCRETE SA

Previous Storm Events

- The Problem – Multicellular Culverts – Restricting flow

Previous Storm Events

- The Problem – Solid Waste – *Informal settlements ???*

Storm Events NOW + Previous Issues

- The ***root*** of the Problem – Alien Vegetation growth

Storm Events NOW + Previous Issues

- The Problem – Upstream Siltation…

Storm Events NOW + Previous Issues

- The Problem – Alien Vegetation – does not decompose & clogs up systems compounded by solid waste!
- Bridge & Culvert approaches damaged as water forces its way…

Summary of the Problem

- Alien vegetation grows faster with shallow root system that crowds out slower growing deep rooted indigenous plants
- Alien vegetation with the shallow root system is easily pulled out of the riverbanks during a flood.
- The exposed riverbanks are more easily eroded – greater volumes of silt, larger trees are undermined and form part of the debris in the river, sewers and infrastructure along the river are more easily undermined.

Summary of the Problem

- Alien vegetation and trees form the primary blockage which collects all the solid waste in the flow – Most of the solid waste would normally travel through the culverts without causing a blockage.
- The blockage causes the overtopping and the associated damage to road and service infrastructure. Fill approaches & embankments damaged
- Force of flood water on a bigger area (blockage area) & flood impact loads – *design loads exceeded?*

CEMENT & CONCRETE SA

Presentation Overview

- Basics on Integral Bridges

CEMENT & CONCRETE SA

What are Integral Bridges

- Integral bridge structures are concrete or composite structures such that the superstructure and substructure are monolithic or "integral" in nature, one unit
- Often referred to as joint less bridges or frame bridges
- These type of bridges don't have bearings and expansion joints unless they are semi-integral
- *These types of bridge are not new since masonry arches are a typical early example of integral structures*

CEMENT & CONCRETE SA

What are Integral Bridges

Challenge is at the abutment ***

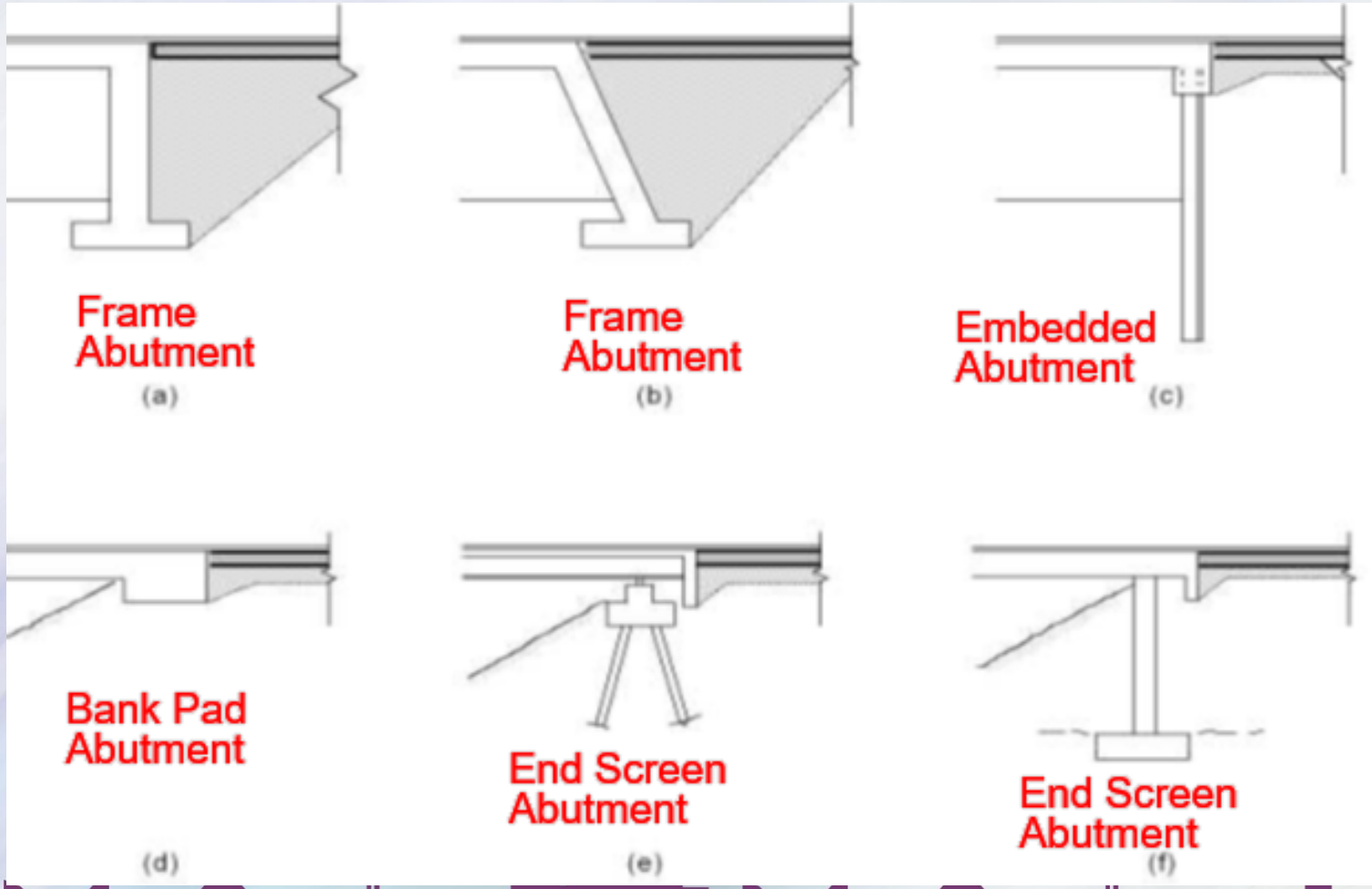
Integral Abutment Bridge (IAB)

Reference:

BA 42/96

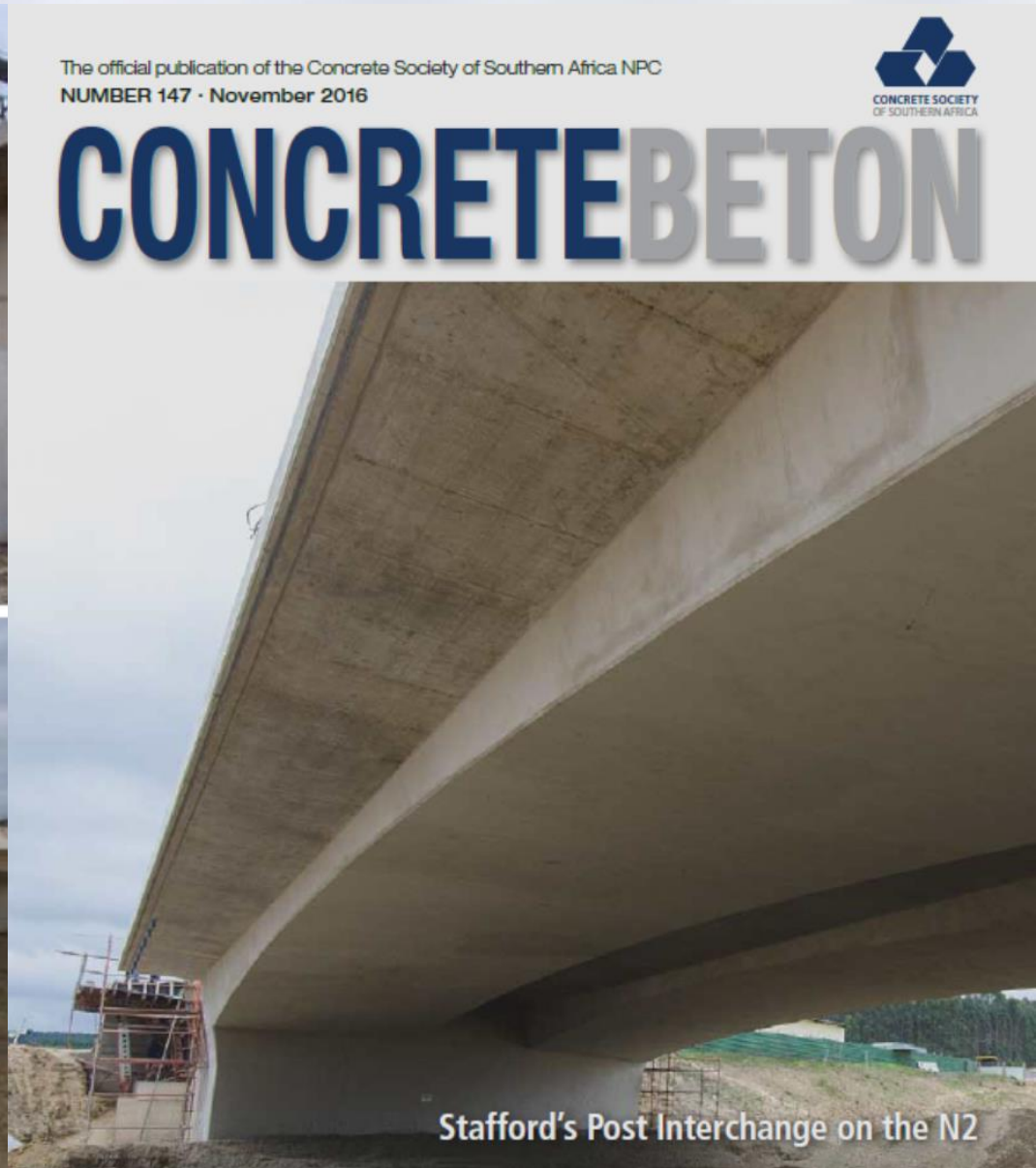
Highways Agency, 2003. The Design of Integral Bridges. Design Manual for Roads and Bridges.

(outdated)



Be inspired – be energised

Examples Stafford's Post Interchange on National Route 2 – Portal Frame



Examples Van Zyl Spruit Bridge on the N1 Freeway – Flexible Frame

Examples eThekwini Municipality C9/M25 Underpass Structure – Rigid Frame

Examples eThekwini Municipality C9/M25 Underpass Structure – highly skew

Advantages of integral bridges

- Lower Construction costs – no bearings and expansion joints
- Lower maintenance costs since in conventional bridges most of the cost arise from repair or replacement of joints. Lane closures / major routes – safety is always an issue & consideration of cost to economy…???
- Enhanced seismic performance
- Less number of piles required in foundations (more flexibility) and generally no raked piles

CEMENT & CONCRETE SA

Advantages of integral bridges

- Construction is simple (no bearings / joints)
- Due to fixity of superstructure and abutment, greater end span ratios are achievable
- Integral bridge deck surfaces are smooth and uninterrupted thus better riding quality

CEMENT & CONCRETE SA

Advantages of integral bridges

- More redundancy, monolithic unit, stronger and higher capacity to flood impacts and concrete full unit / bridge not easily prone to buoyancy , floatation or overturning…

- Better lateral stability, better flooding resistant performance then conventional jointed bridges on bearings

CEMENT & CONCRETE SA

Hindawi
Advances in Civil Engineering
Volume 2020, Article ID 1520278, 25 pages
https://doi.org/10.1155/2020/1520278

Research Article

Investigation on Flooding-Resistant Performance of Integral Abutment and Jointless Bridge

Yizhou Zhuang,[1] Keyao Wu,[1] Liang Xu,[2] Huihui Li,[3] Diego Maria Barbieri,[4] and Zhumei Fu[5]

[1]*College of Civil and Architectural Engineering, Zhejiang University of Technology, 18 Chaowang Road, Hangzhou, Zhejiang 310014, China*
[2]*School of Civil Engineering, Chongqing University, 83 Shabei Street, Chongqing 400045, China*
[3]*Department of Civil and Environmental Engineering, The City College of City University of New York, New York 10031, NY, USA*
[4]*Norwegian University of Science and Technology, Department of Civil and Environmental Engineering, Høgskoleringen 7A, Trondheim 7491, Trøndelag, Norway*
[5]*College of Civil Engineering, Fuzhou University, 2 Xueyuan Road, University Town, Fuzhou, Fujian 350108, China*

Correspondence should be addressed to Liang Xu; liangxu360427@cqu.edu.cn

Received 21 August 2019; Revised 27 December 2019; Accepted 4 January 2020; Published 21 February 2020

Academic Editor: Jian Ji

Copyright © 2020 Yizhou Zhuang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Bridge washouts connected to flood events are deemed one of the main reasons for structural collapse. Compared to traditional continuous jointed bridges, integral abutment and jointless bridges (IAJBs) have better lateral stability because there are no expansion devices. The mechanical performance of Shangban IAJ bridge, located in Fujian, China, is thoroughly investigated by Finite Element Analysis (FEA). The numerical model is created and validated based on experimental results obtained from static load tests performed on the bridge. A detailed parametric analysis is carried out to assess the correlation between the flood-resistant performance and a number of parameters: skew angle, water-blocking area, span number, pile section geometry, and abutment height. Except for the abutment height, other parameters significantly affect the bridge performance. Furthermore, the change in the span number has a meaningful impact only when fewer than four spans are modeled. Finally, pushover analyses estimate the maximum transverse displacement and the sequence of plastic hinge creation as well as the mechanical behaviour of the structure under lateral flood loads. The analysis results show that IAJBs have better flooding-resistant performance than conventional jointed bridges.

"Bridge washouts connected to flood events are deemed one of the main reasons for structural collapse"

Presentation Overview

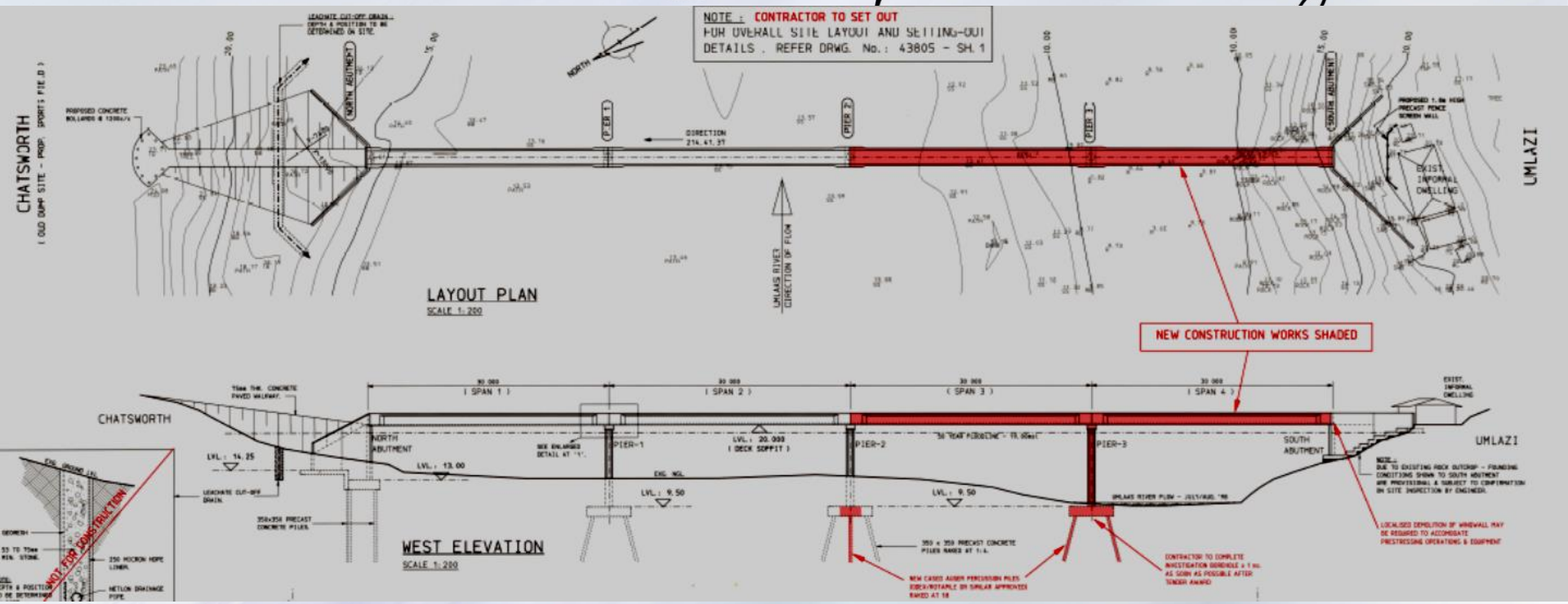
- Some actual problems and solutions from the floods

CEMENT & CONCRETE SA

- 2no. 30m long spans and pier collapsed in Umlaas River
- Bridge between Umlazi & Silverglen – high flood loads ?
- No *"proper fixity"* – deck on bearings with joints

- Huge inconvenience to community / costs / time delay / SAFETY!
- Temporary pedestrian bridge in place soon after!

Be inspired – be energised



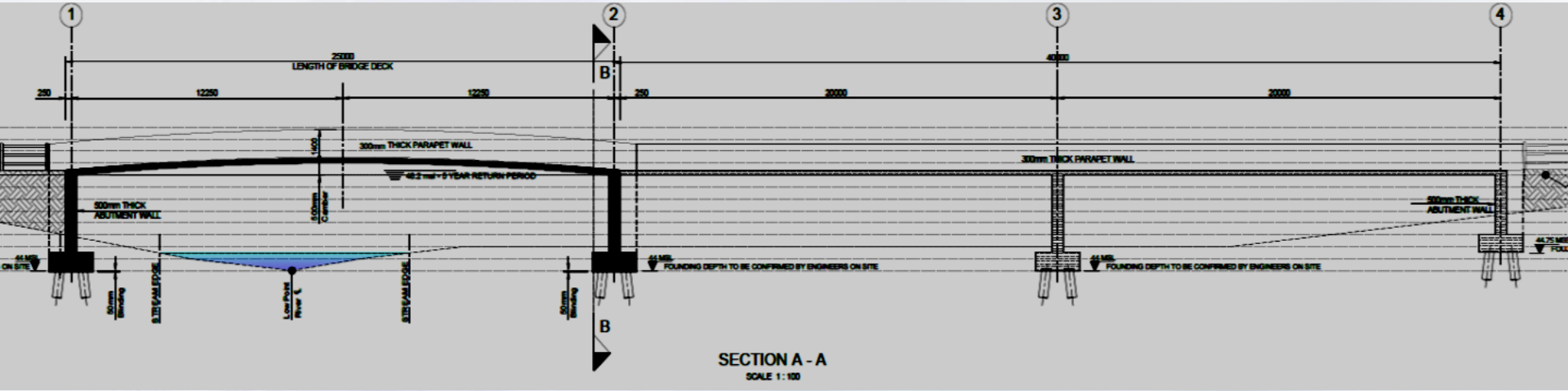
CEMENT & CONCRETE SA

- Totenham Bridge in Phoenix
- 25m fully integral – never moved and stayed in place
- Conventional deck on bearings with joints – will wash away

- Approach washed away

Be inspired – be energised

2 new spans to be added and approach works



CEMENT & CONCRETE SA

Be inspired – be energised

- Pedestrian & Sewer service bridge at Titren Road, M7
- Conventional bridge with joints and bearings
- Impact loads with buoyancy pushed deck over

CEMENT & CONCRETE SA

- Part of tree trunk and debris, provided a natural lever

CEMENT & CONCRETE SA

Be inspired – be energised

- Very heavy!!!
- Crane / jacking costs very high
- Demolish & then Build & replace & “lock in place with key”

CEMENT & CONCRETE SA

- N2 Umlali Bridge (upstream) shifted off bearings. Multiple span
- Upstream – note debris and water level

CEMENT & CONCRETE SA

- Downstream

Presentation Overview

- Design aspects of 3 integral bridges

1 – Hunslet Road Bridge over Piesang River

CEMENT & CONCRETE SA

HUNSLET INTEGRAL BRIDGE – 90m

- Replacing a flood damaged infrastructure with an integral/monolithic reinforced concrete bridge structure
- Border of Phoenix Industrial Park & KwaMashu.
- 3 sets of very old wobbly culverts (60 years old or more), first road / bridge in area. 1 Set of culverts collapsed
- Important nodal link

CEMENT & CONCRETE SA

- Picture of flood extent from April 2022
- 90m bridge proposed -4 spans (20m/25m/25m/20m)
- Reinforced concrete bridge

Collapsed cells – overtopped, reduced capacity, impact loads & poor foundation

Be inspired

"Client's Mandate"

- Fully integral bridge – Piers & abutment fixed to deck.

  90m long, on maximum limit. No joints & bearings
- Substantially reduced potential washaway or movement from floods in future.
- Industrial zone.
- To be instrumented and performance measured & monitored, assist in future recommendations for SA

CEMENT & CONCRETE SA

Be inspired – be energised

"Client's Mandate"

- Extensive research for design…local and global info

PD 6694-1:2011+A1:2020

BSI Standards Publication

Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004+A1:2013

DESIGN MANUAL FOR ROADS AND BRIDGES

VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN

SECTION 3 GENERAL DESIGN

PART 12

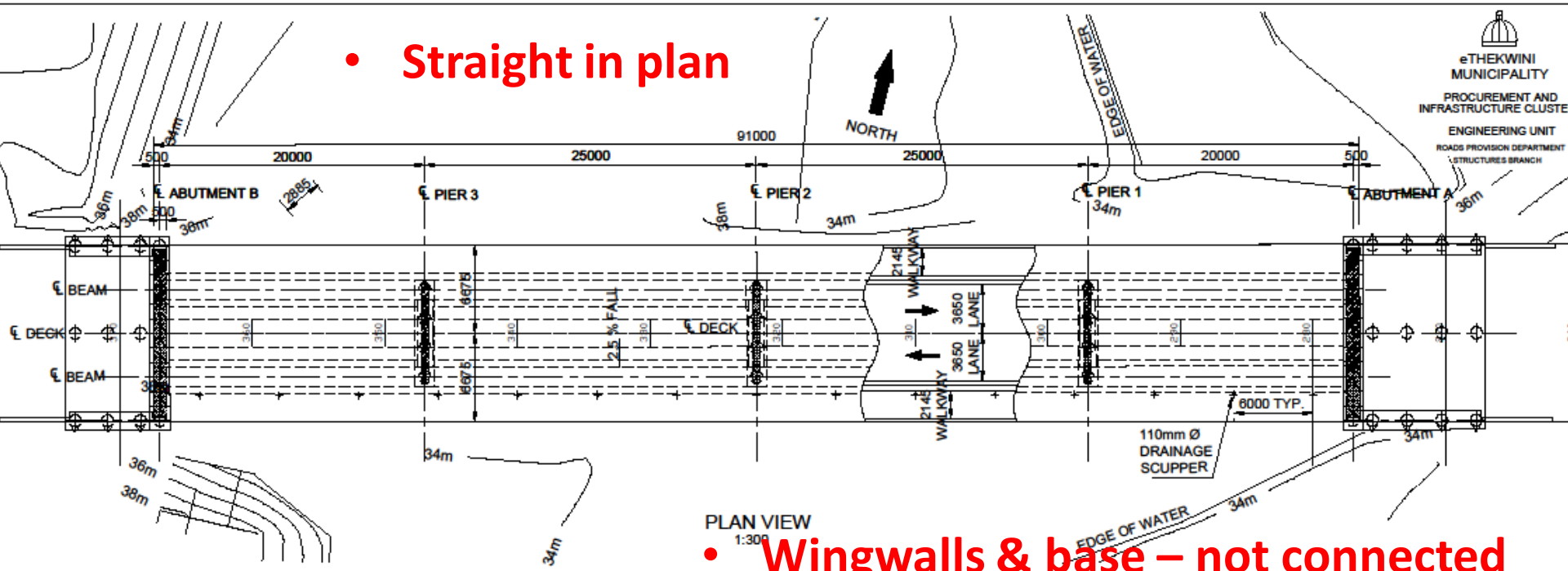
BA 42/96 AMENDMENT NO. 1

THE DESIGN OF INTEGRAL BRIDGES

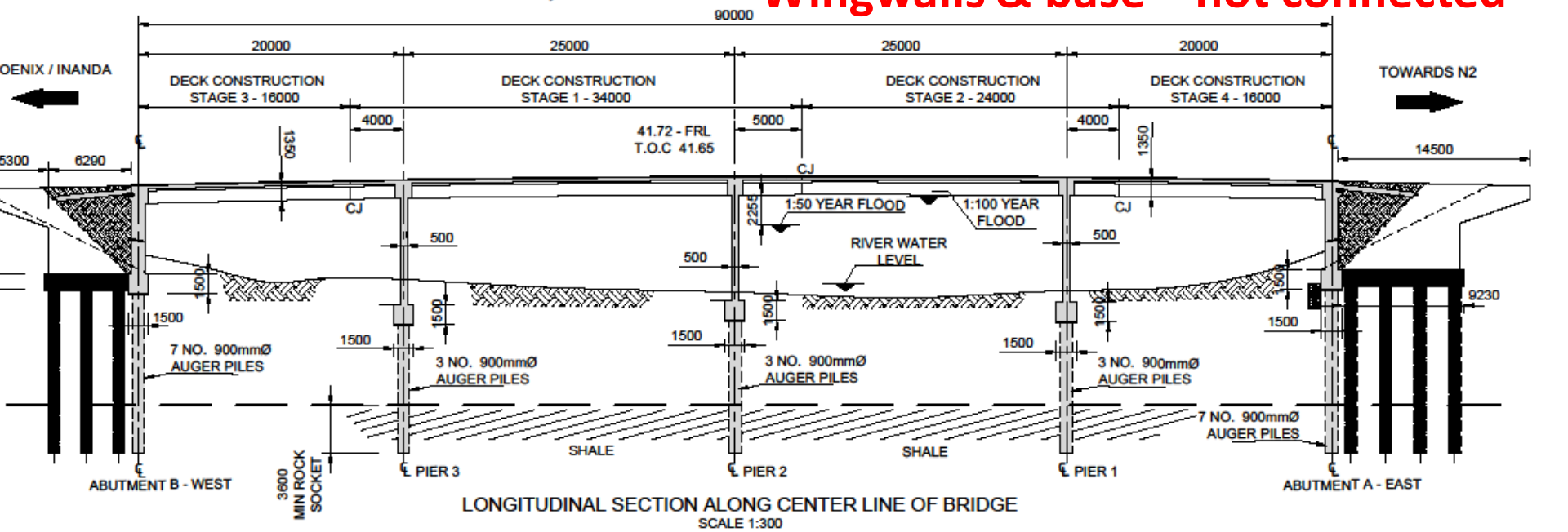
SUMMARY

This Advice Note provides guidance on the design of continuous bridges with integral abutments.

- **Straight in plan**

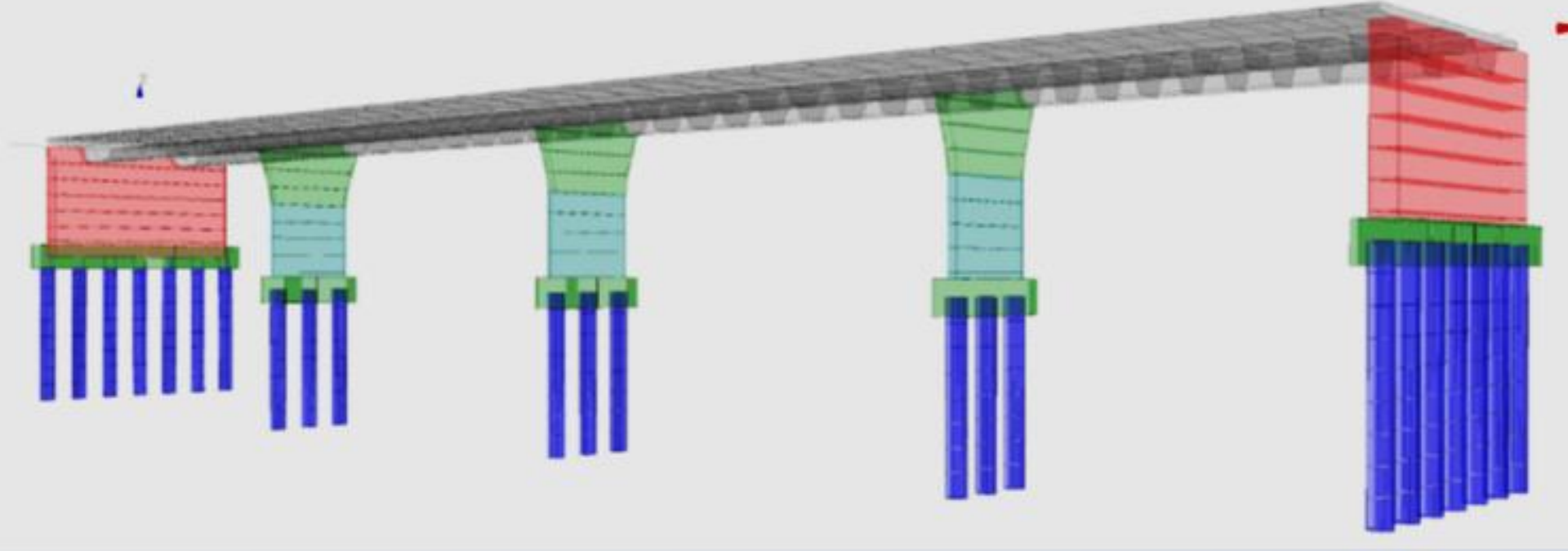


- **Wingwalls & base – not connected**



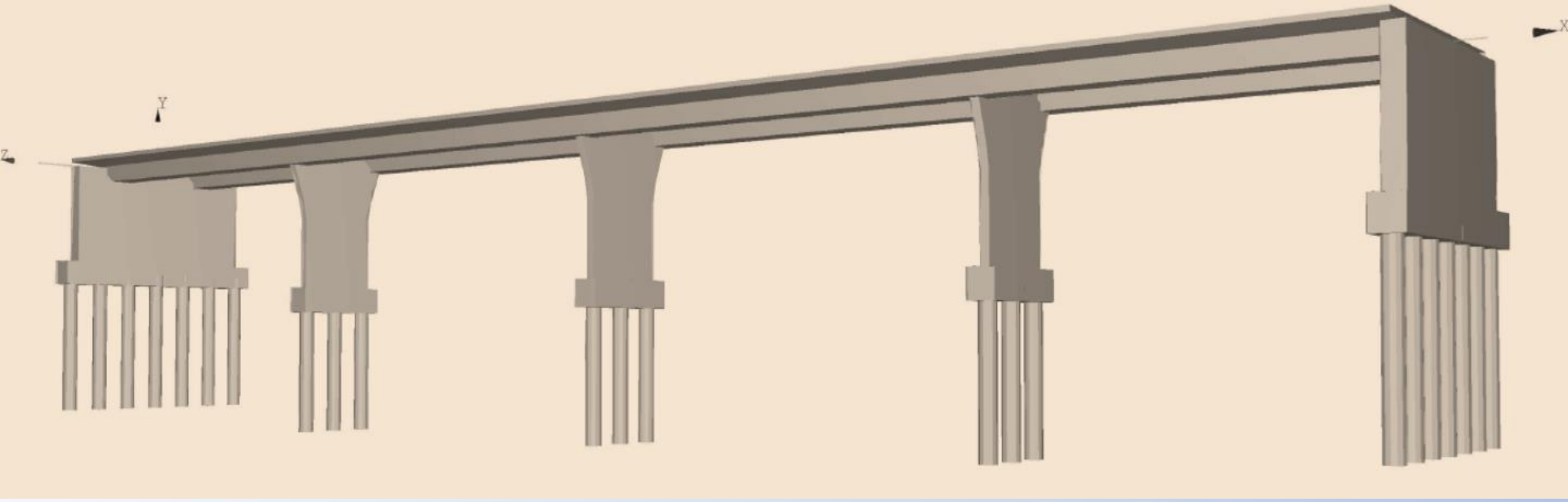
LONGITUDINAL SECTION ALONG CENTER LINE OF BRIDGE
SCALE 1:300

CONSTRUCTION OF STREET 120183 AND RIVER CROSSING | 2022/09/07

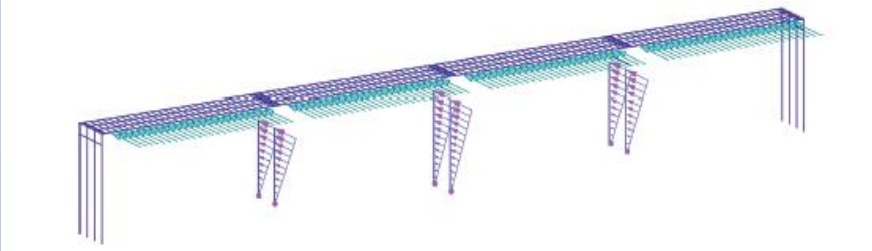


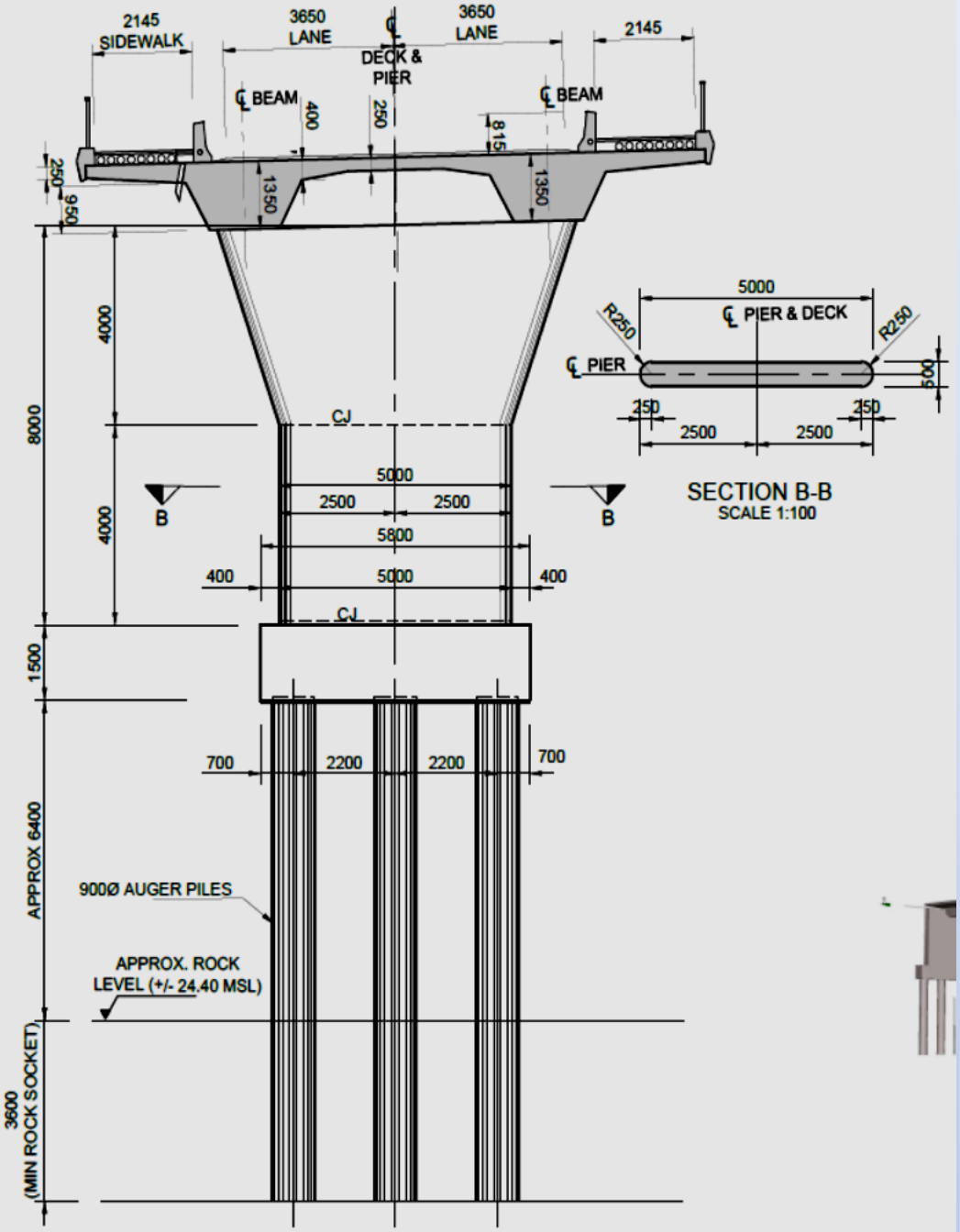
- 3d image from design software
- 1m thick abutments, 0.5m thick piers

- Large wingwall protection at approaches – completely independent to bridge and important.



- Piers –3 piles (900mm Diameter – CFA). *Normally min 4 no. (2x2)*
- Abutments - 7 no. *Normally – at least 2 rows piles*
- 40 Mpa Concrete – Complete
- Bridge to be fully instrumented –Part of SANRAL-supported research
- Sustainability goals – Doing MORE with LESS, optimise materials >>> lower carbon footprints

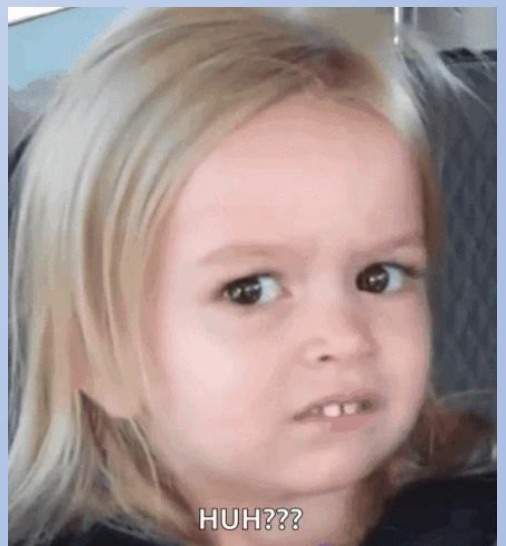


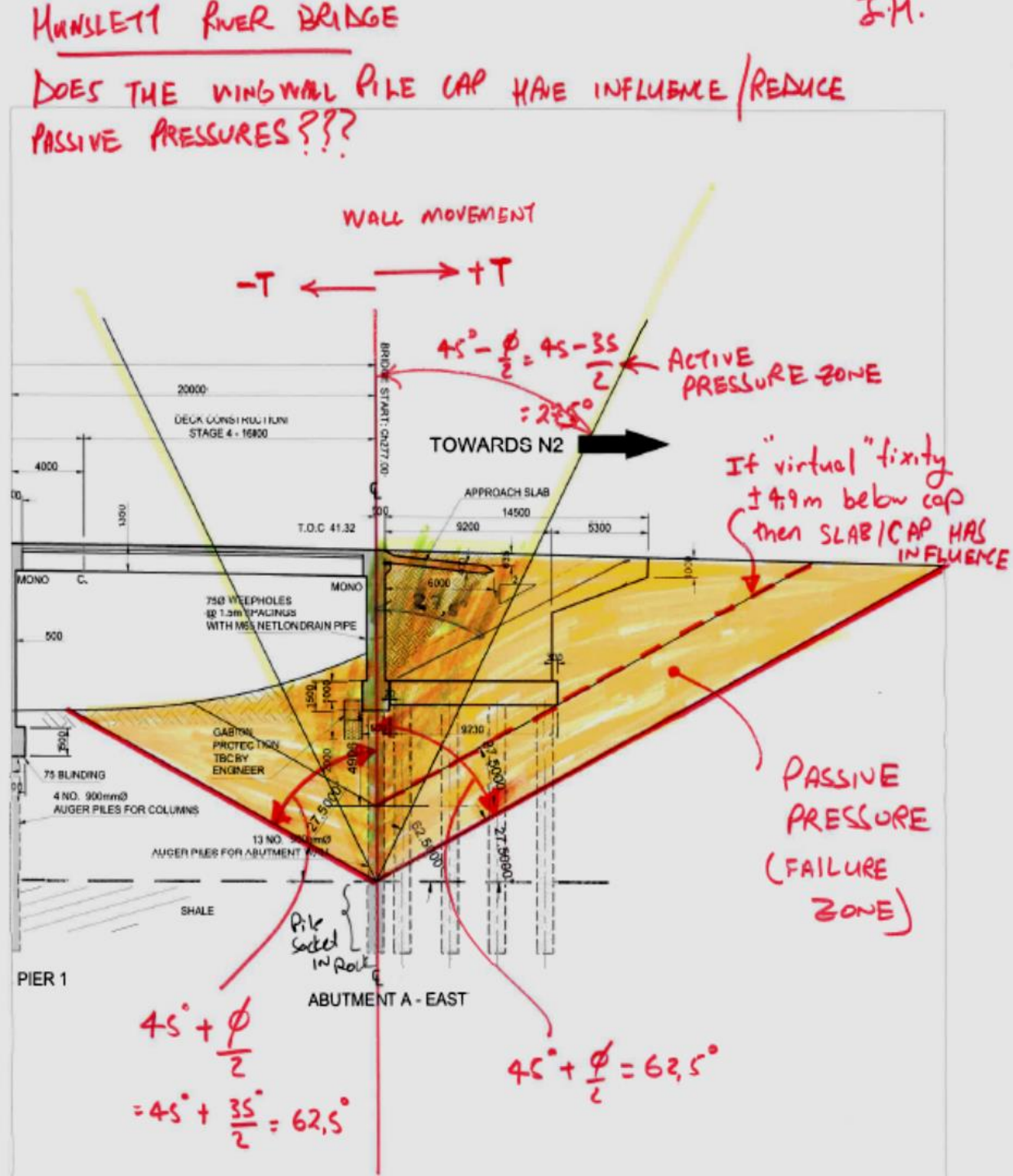


- Twin spine deck (1.35m)
- 500mm thick pier

Design regime - Flexible but stiff

Flexible enough to allow thermal effects (low restraint) BUT strong/ stiff enough for traffic loads (including skidding etc) and high flood impact forces

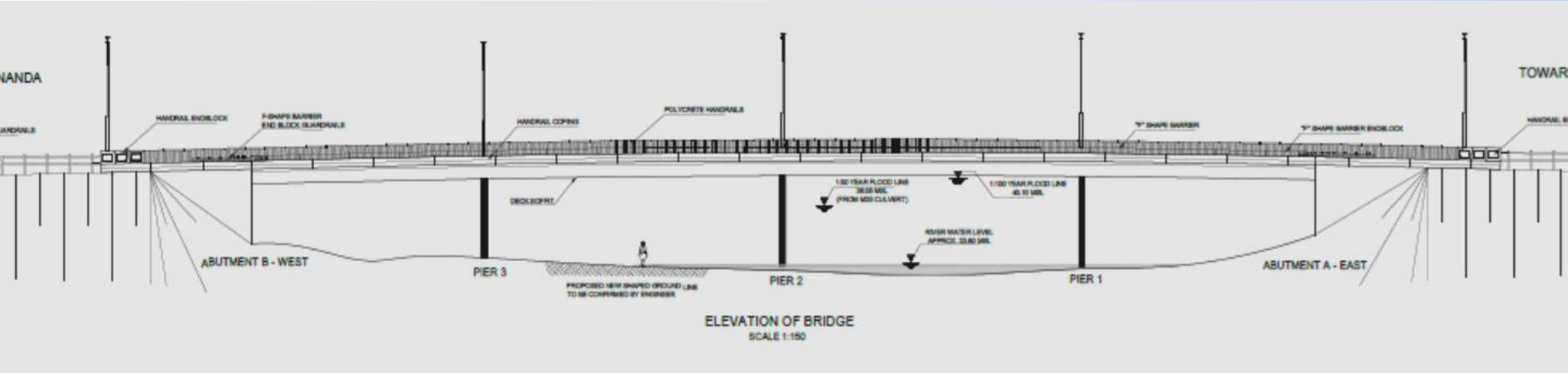




- Similar to RC walls with "relief shelves to reduce active earth pressure", the wingwall pilecap acts a relief shelve to reduce passive & active pressures on piles below cap.
- Both caps are the same length
- Win-win situation – rock is high and approximately intercepts at zone when relief shelf assistance ends

Piles could be further reduced?

More research proposed



- Construction started Jan 2023
- Big spans so tree trunks can pass

Presentation Overview

- Design aspects of 3 integral bridges

2 – Blundell Road Bridge over Umhlatuzana River

CEMENT & CONCRETE SA

BLUNDELL INTEGRAL BRIDGE – 90m

- Replacing a flood damaged infrastructure with an integral/monolithic reinforced concrete bridge structure
- Busy residential road between Shallcross and Queensburgh
- Replacing culverts (60 years old or more), with a curved fully integral bridge – 50m curve and 40m straight – road realigned
- More complex – more guidelines, global & local

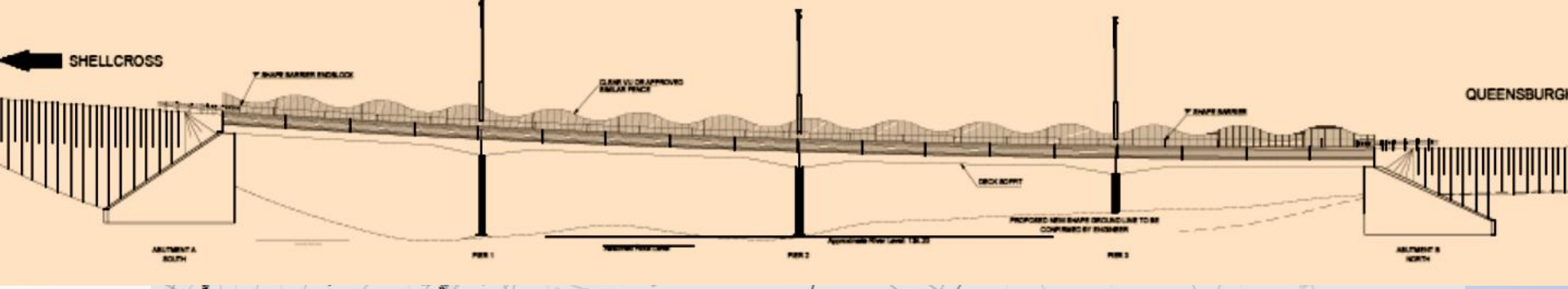
CEMENT & CONCRETE SA

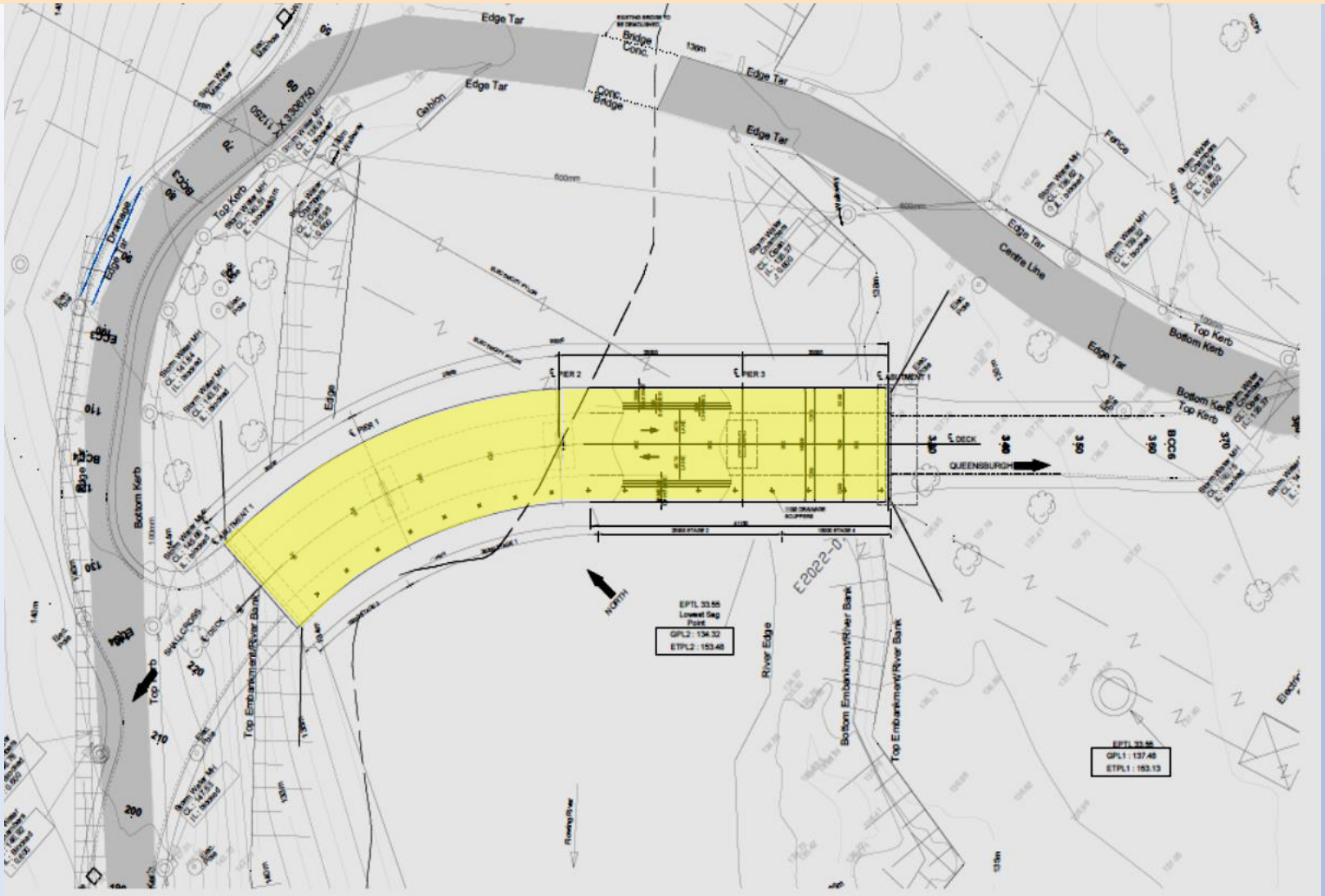
- Photo during the floods – unusable, debris blocked and overtopped…….ongoing issue in recent years!

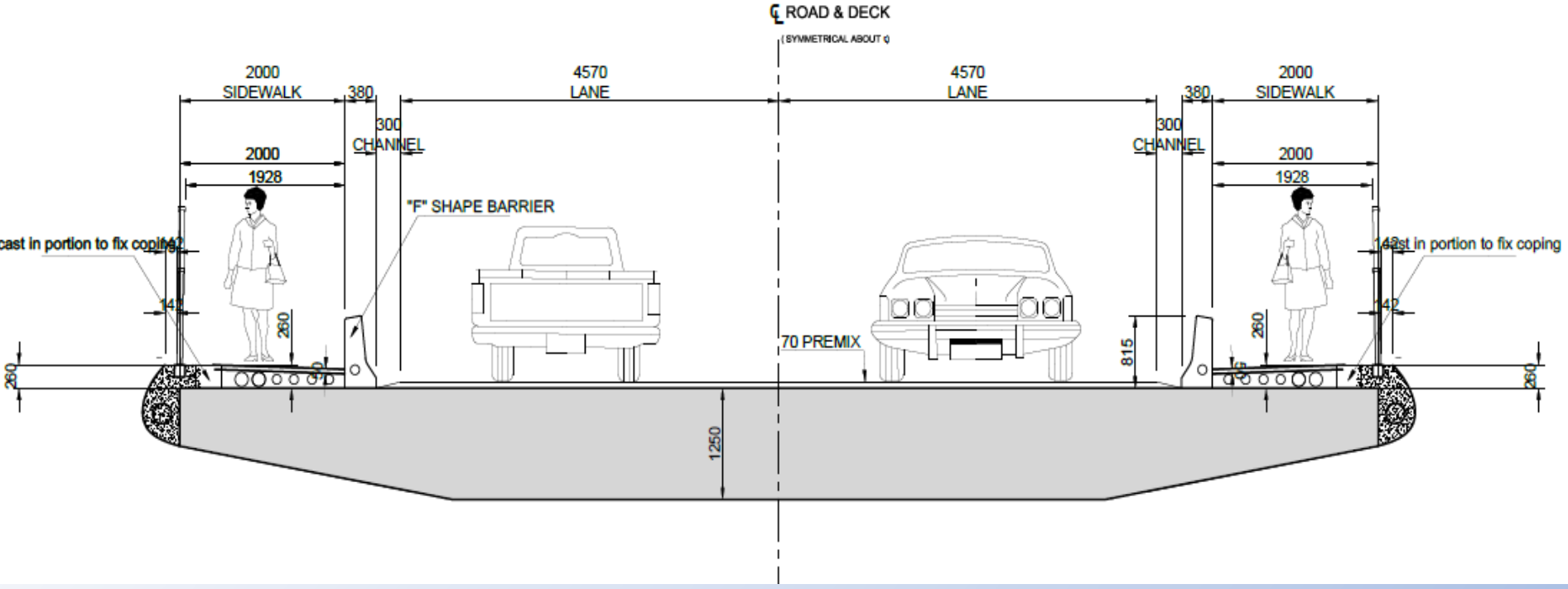
- Note – Culvert (Bridge) fully **integral** and remained fixed. Versus if it had all independent elements
- Very narrow and sharp bends. For now, embankments repaired

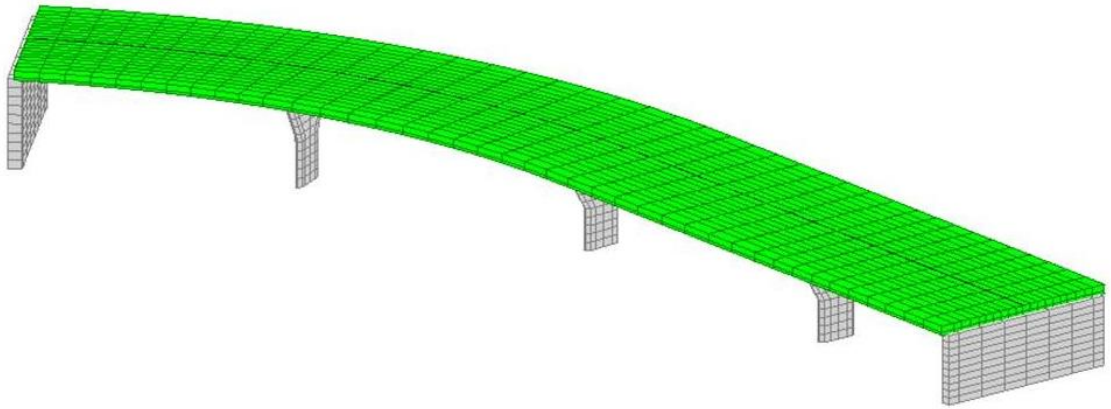
- Upstream View – Blocked by alien plant vegetation.

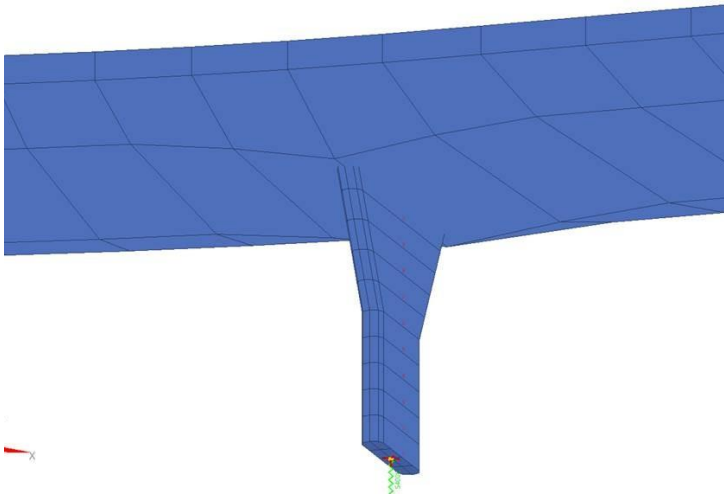
- Large tree trunk >10m long & > 1m diameter …

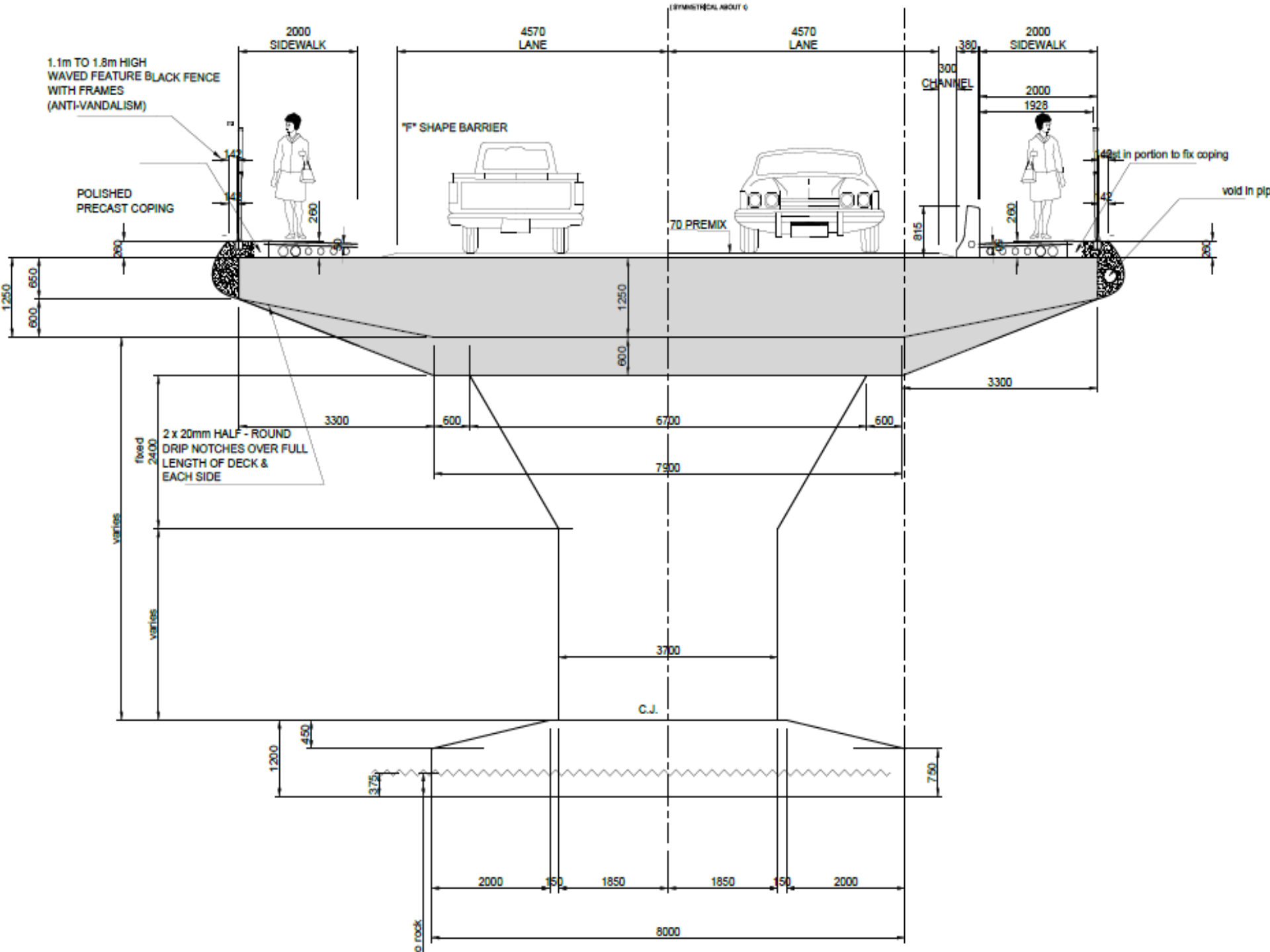

SHELLCROSS
QUEENSBURGH
DECK SOFFIT
PIER 1
PIER 2
PIER 3


Edge Tar
Bridge
Conc.
Conc. Bridge
Gabion
Fence
Centre Line
Top Kerb
Bottom Kerb
Drainage
Edge
Bottom Kerb
Top Embankment/River Bank
Bottom Embankment/River Bank
River Edge
Rowing River
SHELLCROSS
QUEENSBURGH
NORTH
EPTL 33.55
Lowest Sag Point
GPL2 : 134.32
ETPL2 : 153.48
EPTL 33.55
GPL1 : 137.48
ETPL1 : 153.13
E2022-0


℄ ROAD & DECK
(SYMMETRICAL ABOUT ℄)
2000
SIDEWALK
380
4570
LANE
4570
LANE
380
2000
SIDEWALK
300
CHANNEL
300
CHANNEL
2000
1928
2000
1928
"F" SHAPE BARRIER
cast in portion to fix coping
142
142
260
260
70 PREMIX
815
260
260
1250



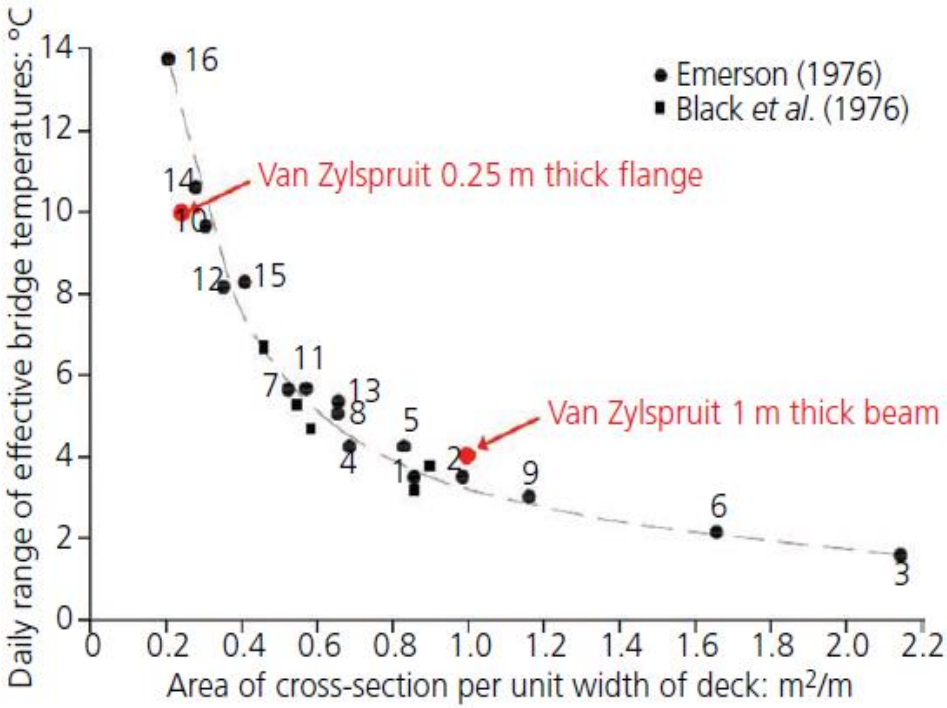



(SYMMETRICAL ABOUT ℄)
2000
SIDEWALK
4570
LANE
4570
LANE
380
2000
SIDEWALK
300
CHANNEL
2000
1928
1.1m TO 1.8m HIGH
WAVED FEATURE BLACK FENCE
WITH FRAMES
(ANTI-VANDALISM)
"F" SHAPE BARRIER
142
142
142st in portion to fix coping
142
POLISHED
PRECAST COPING
260
260
260
260
70 PREMIX
815
260
1250
650
600
1250
600
3300
3300
600
6700
600
7900
2 x 20mm HALF - ROUND
DRIP NOTCHES OVER FULL
LENGTH OF DECK &
EACH SIDE
fixed
2400
varies
varies
3700
C.J.
450
1200
375
750
2000
150
1850
1850
150
2000
8000

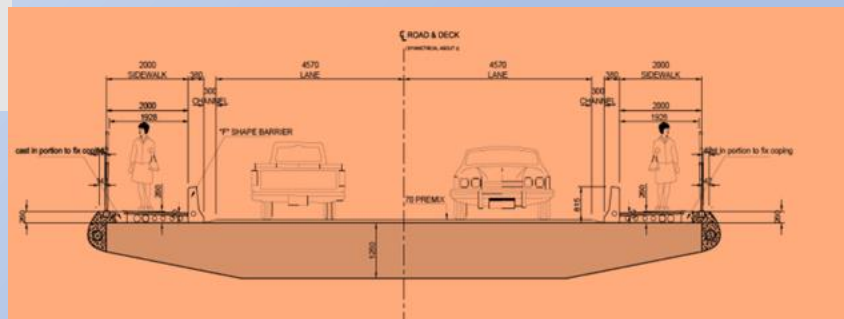
Important – due to the tight curve, height complexity & length – the most ideal concrete cross-section was purposely chosen i.e. constant cross-sectional area

10. Conclusions

Measured temperature, movement and lateral earth pressure data obtained from a structural monitoring system at the Van Zylspruit Bridge are presented and discussed in this paper. The measured data proved valuable as these show the actual temperatures, movement and loads of an integral bridge structure. The data, as well as heat flow modelling, were used to confirm the effect of deck cross-section thermal inertia on the expansion of integral bridges. An increase in the cross-sectional area per unit width of the deck resulted in a lower change in the effective deck temperature and therefore smaller movement of the integral abutments. This trend is clearly seen with the measured data and confirms the research done by Emerson (1976) and Black *et al.* (1976). The measured behaviour of the Van Zylspruit Bridge confirms that an efficient design can be achieved if accurate effective deck temperatures are used to estimate the daily and seasonal changes in length and seasonal change in earth pressure behind integral bridge abutments.



Skorpen SA, Kearsley EP, Clayton CRI and Kruger EJ (2020)
Structural monitoring of an integral bridge in South Africa. *Proceedings of the Institution of Civil Engineers – Smart Infrastructure and Construction* **173(3)**: 63–72, https://doi.org/10.1680/jsmic.20.00001



LFT
Environment
Reality Mesh
Terrain

Presentation Overview

- Design aspects of 3 integral bridges

3 – Coedmore Road Bridge over Umhlatuzana River

CEMENT & CONCRETE SA

Be inspired – be energised

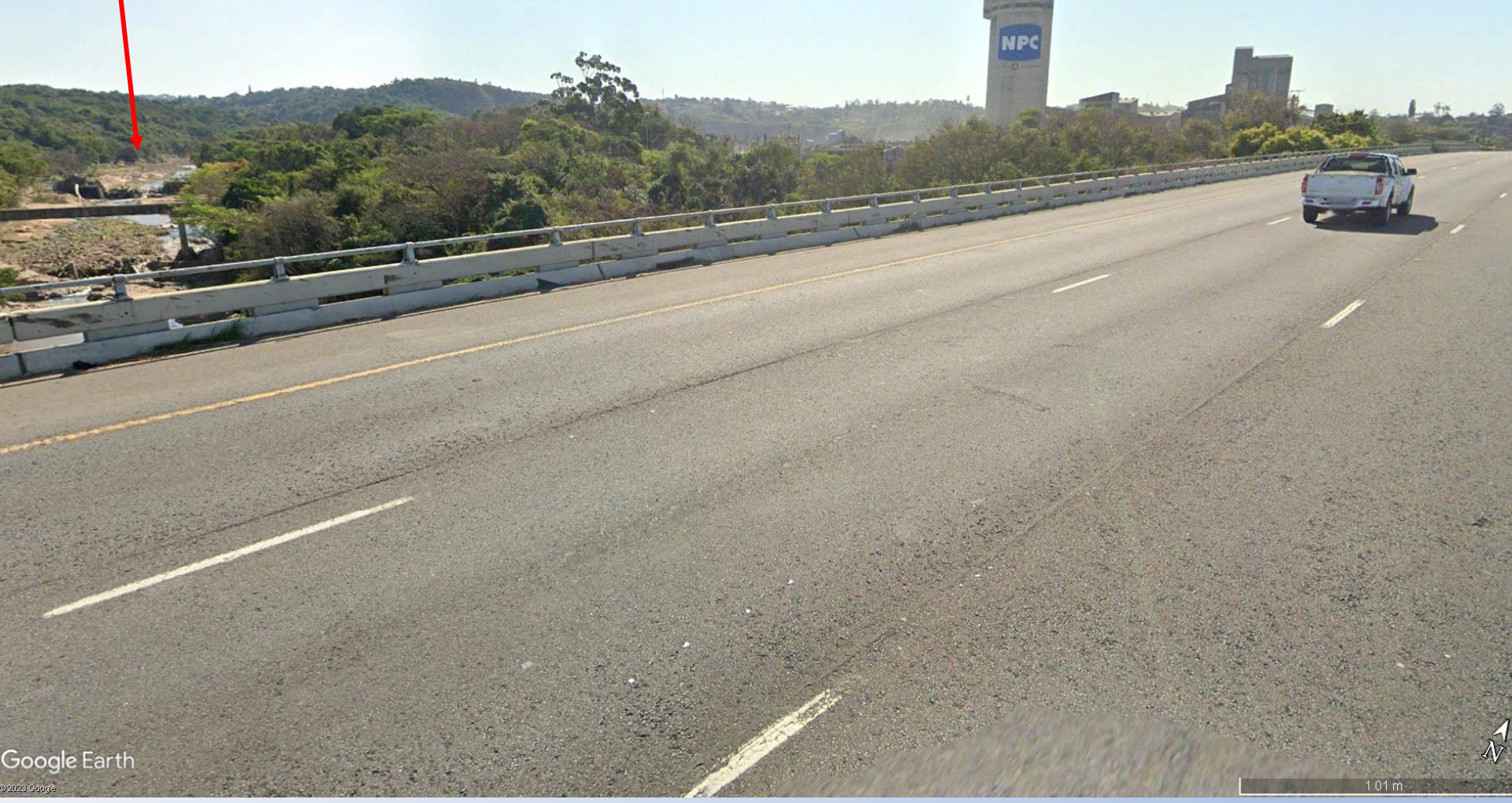
COEDMORE INTEGRAL BRIDGE – 85m

- Replacing a flood damaged / collapsed bridge with an integral/monolithic prestressed concrete bridge structure
- Bridge over topped, impact from debris & large trees .

  >>> Elements scattered. Deck on joints and bearings
- Large tree trunks required bigger spans, more capacity, no blockages = no maintenance clean up etc. & no damages
- Previous bridge was very old > 60 to 70 years. Very narrow and had ongoing maintenance issues
- Road realigned improved substantially

CEMENT & CONCRETE SA

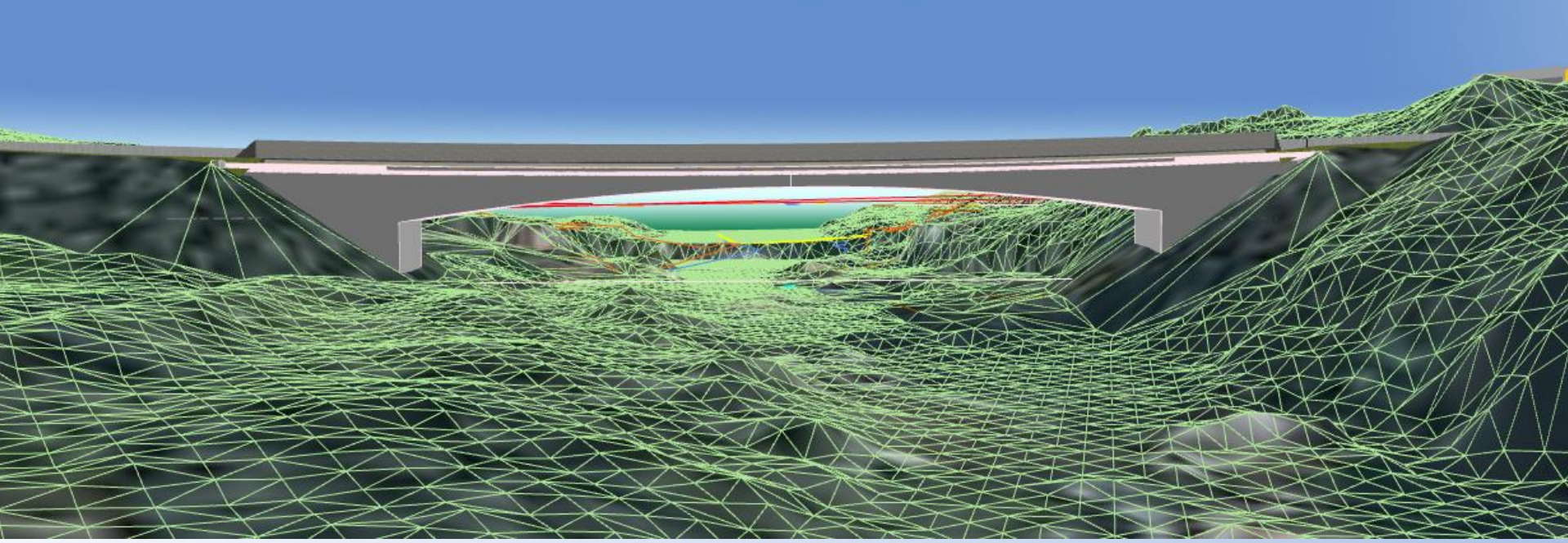
Flooded Coedmore bridge in April – still holding up…



Behind NPC Coedmore quarry, along N2 going north

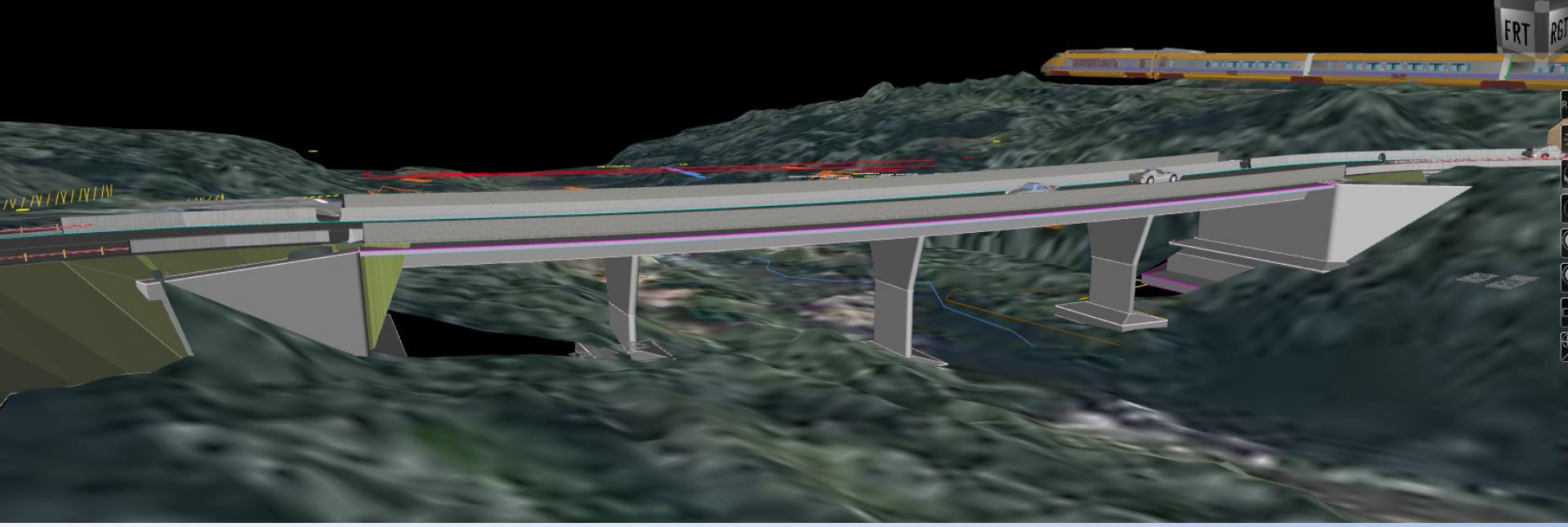
All elements dislodged and scattered including composite deck, piers & abutments

Note: a number of huge tree trunks part of the problem
(10m to 15m long)



Concept 1

- Balanced cantilever using the large abutments as counterweights
- Large span – 60m – one span , trees and debris can pass, no maintenance
- Complex construction and centre hinge detail, aesthetics not seen
- Large abutment in river still a huge risk…

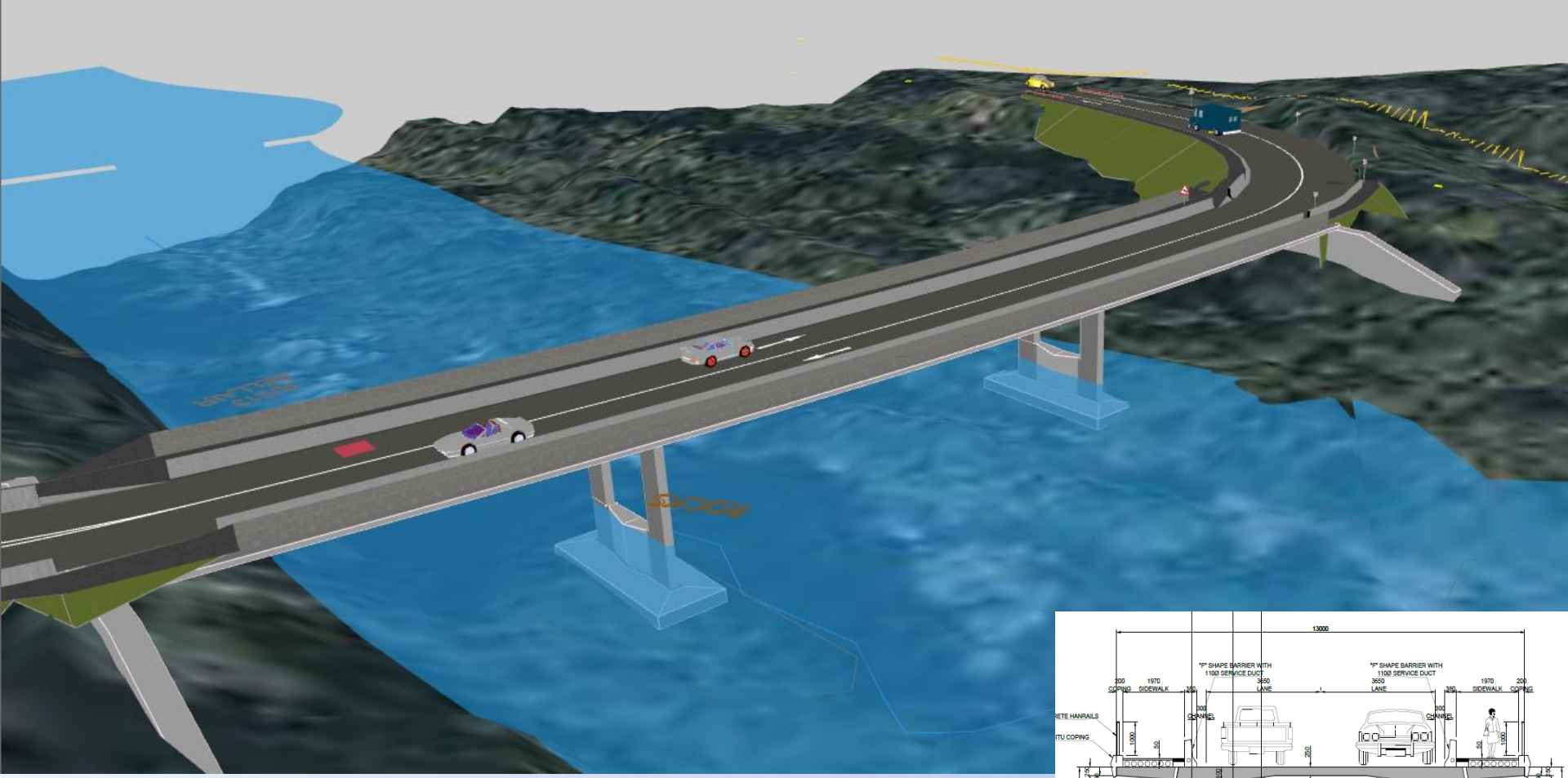


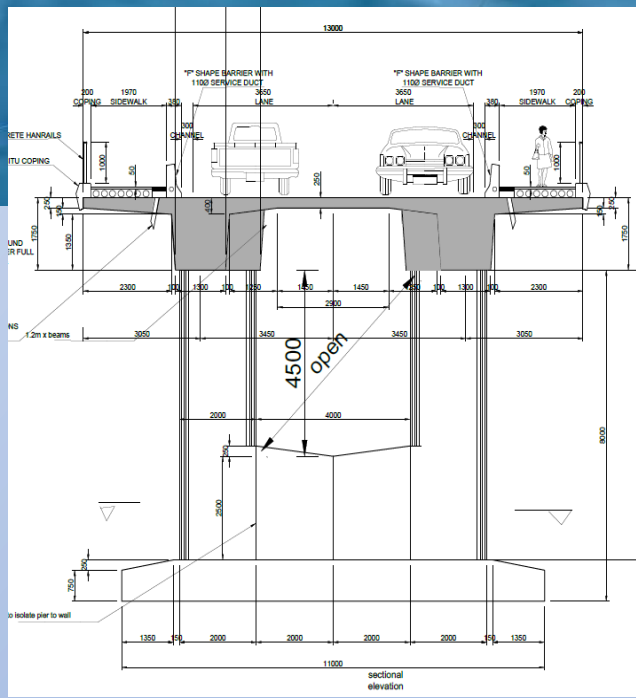
Concept 2

- 72m (4 span) reinforced concrete integral bridge
- Too many “short” spans and piers in a notorious river
- Large abutment in river still a huge risk…

Concept 3 – Approved

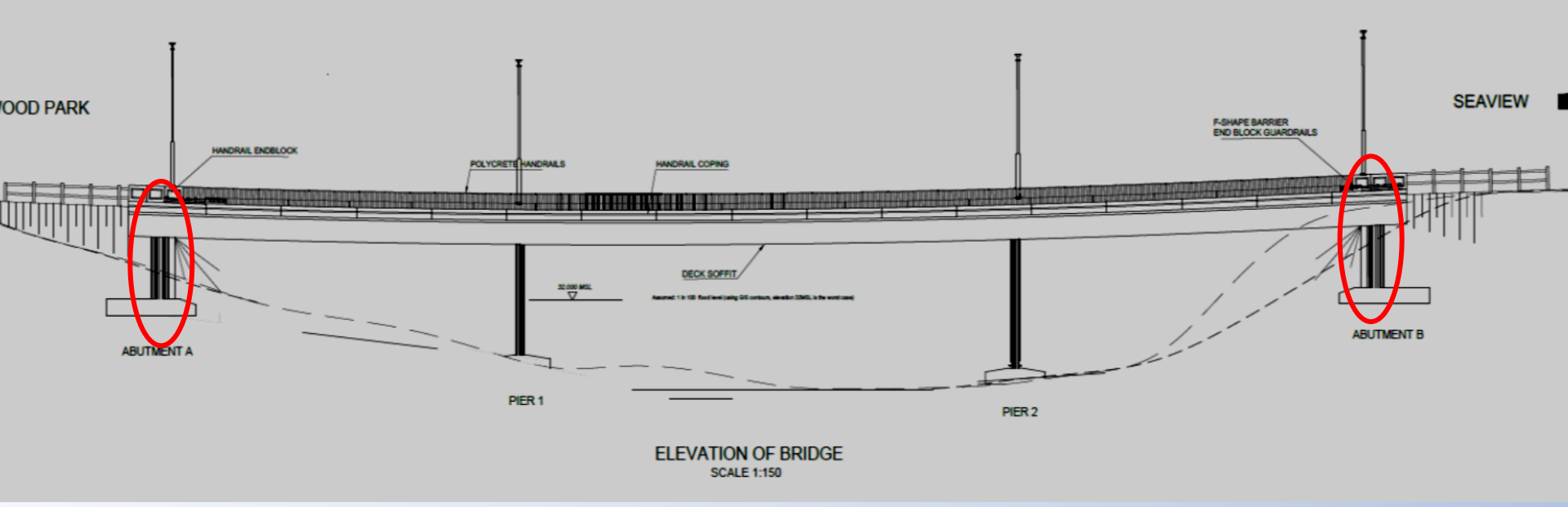
- 85m (3 span) prestressed concrete integral bridge
- 33m span will allow debris to pass
- Abutments perched - far and high up out of water range





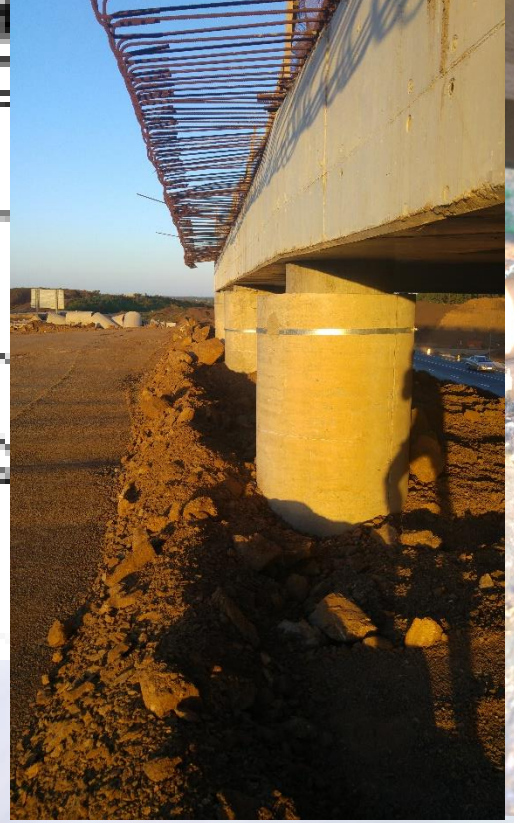
Concept 3 – Approved

- Straight bridge
- BUT prestress and short abutment (not flexible) is a challenge for integral bridges.



SOLUTION – Part 1

- Build deck and cast flexible piers into deck, full deck supported, prestress tendons and grout.
- Fully free at abutments to undergo movements in deck……
- After grouting tendons – cast connection between deck and abutment >>> now fixed / integral / monolithic but *flexible*



SOLUTION – Part 2

- Build “slender column” at the abutments to hold up deck. Isolate support columns in precast manhole rings so its independent of soil interaction.
- More flexibility allowed

What's next…Lets consider…

- Low shrinkage additives for concrete
- Crack healing additives added to concrete (and to improve durability)
- Concrete stiffness E value reduced based on aggregates, for more flexibility but still strong enough – Integral bridges in Germany
- Research – bridges instrumented, understand what actually happens >>> publish **design and construction guidelines** for South Africa. Happening currently part of SANRAL research project with UP & Dr Skorpen

The Future, just one thing to take away…

For Small to Medium span bridges in SA, Client Bodies, Designers & Contractors should strongly promote them to be fully integral or at least semi- integral.

Thank you !

ETHEKWINI MUNICIPALITY

CEMENT & CONCRETE SA