Design of Dingley Bypass Integral Bridges

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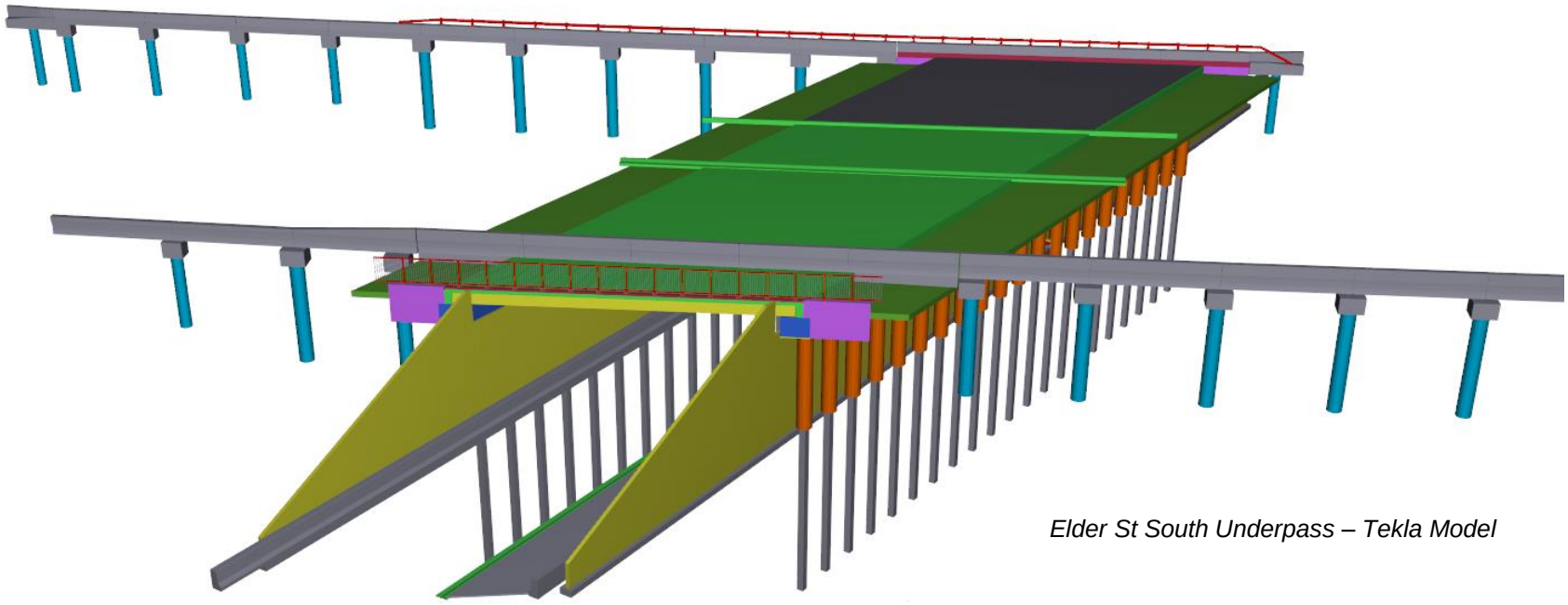
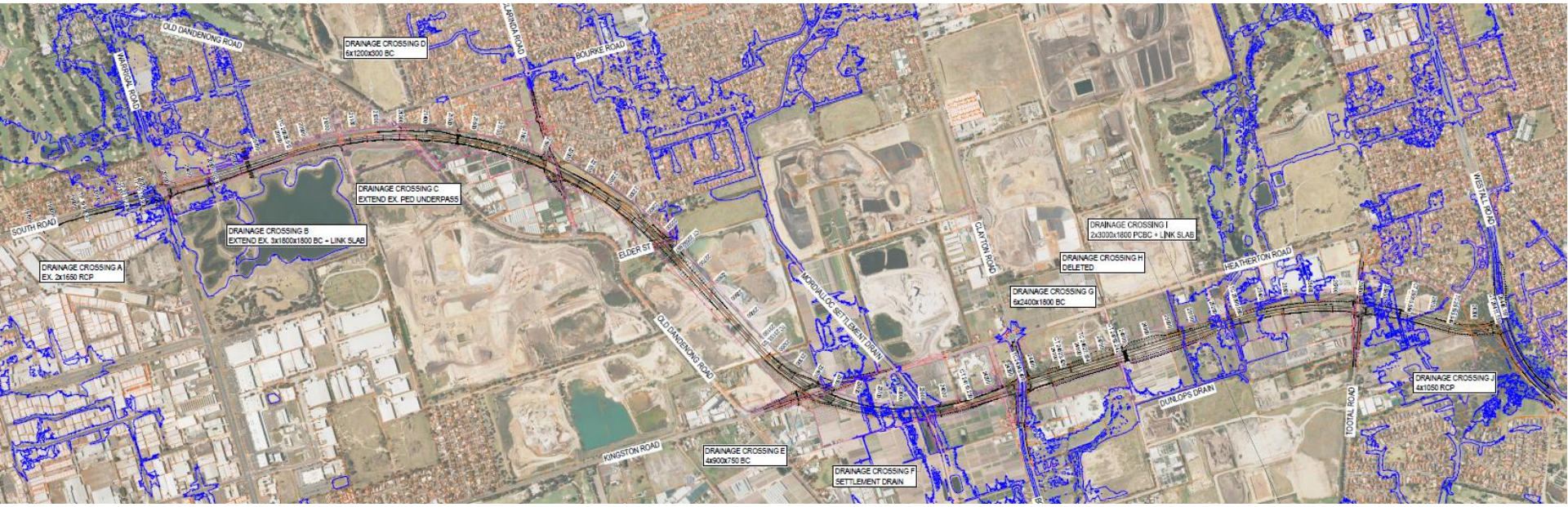


Elder St South Underpass – Tekla Model

Presentation Outline

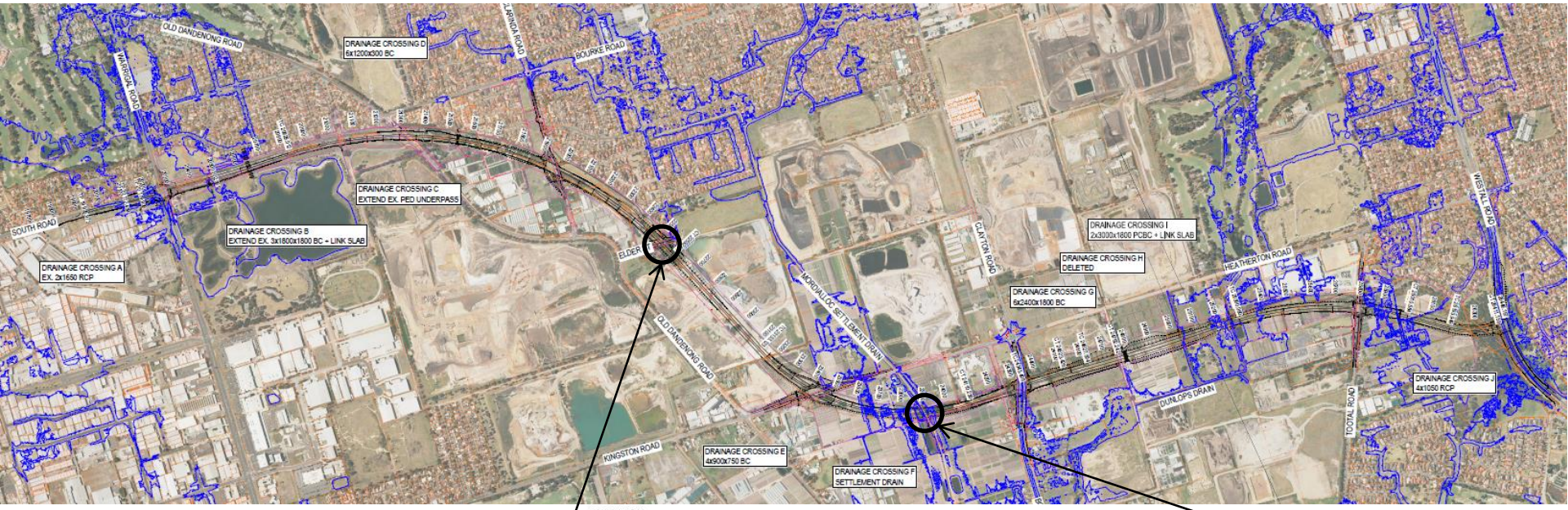
1. Overview of Dingley Bypass
2. Design of Integral Bridges
   - Why Integral Bridges?
   - Code Requirements & Literature
   - Design Philosophy
3. Developing a Structural Model
   - Mordialloc Settlement Drain Bridge
4. Design of Critical Elements
5. Conclusion

1. Overview of Dingley Bypass

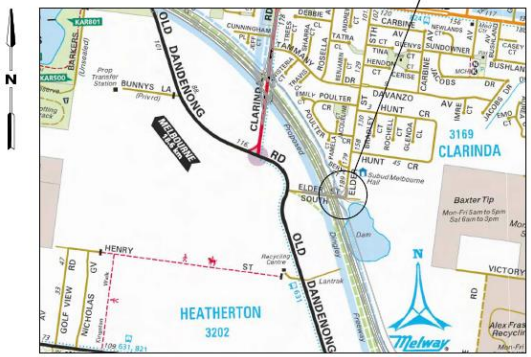


Location	: Warrigal Rd to Westall Rd
Client	: VicRoads
D&C Contractor	: Thiess/Leighton Contractors
D&C Consultant	: GHD, Coffey, URS
Contract Value	: Approx. $85 mil
Contract Period	: Two Years expected to complete end 2016

1. Overview of Dingley Bypass

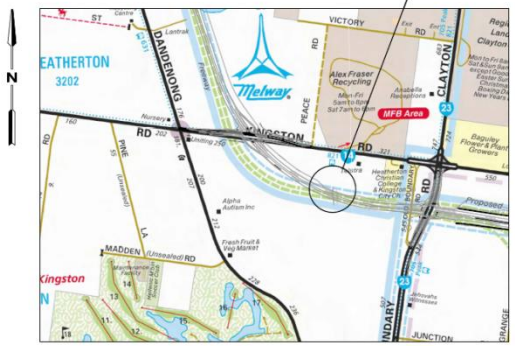


LOCATION OF WORKS



Elder St South Underpass

LOCATION OF WORKS



Mordialloc Settlement Drain Bridge

2. Design of Integral Bridges

Why Integral Bridges?

VicRoads D&C Contract

> Where the bridge length, skew and the ground conditions are suitable, consideration should be given to the use of the integral bridge form of design which eliminates the requirement for bearings and bridge joints together with the associated hazards and cost of inspection and maintenance.

Long Term Benefits

- Improved structural reliability and redundancy
- Improved ride-quality and noise reduction
- Potential for reduced initial cost
- Reduced maintenance requirement
- Reduced traffic disruption
- Lower whole-of-life cost and
- Improvement of bridge appearance

2. Design of Integral Bridges

Code Requirements & Literature

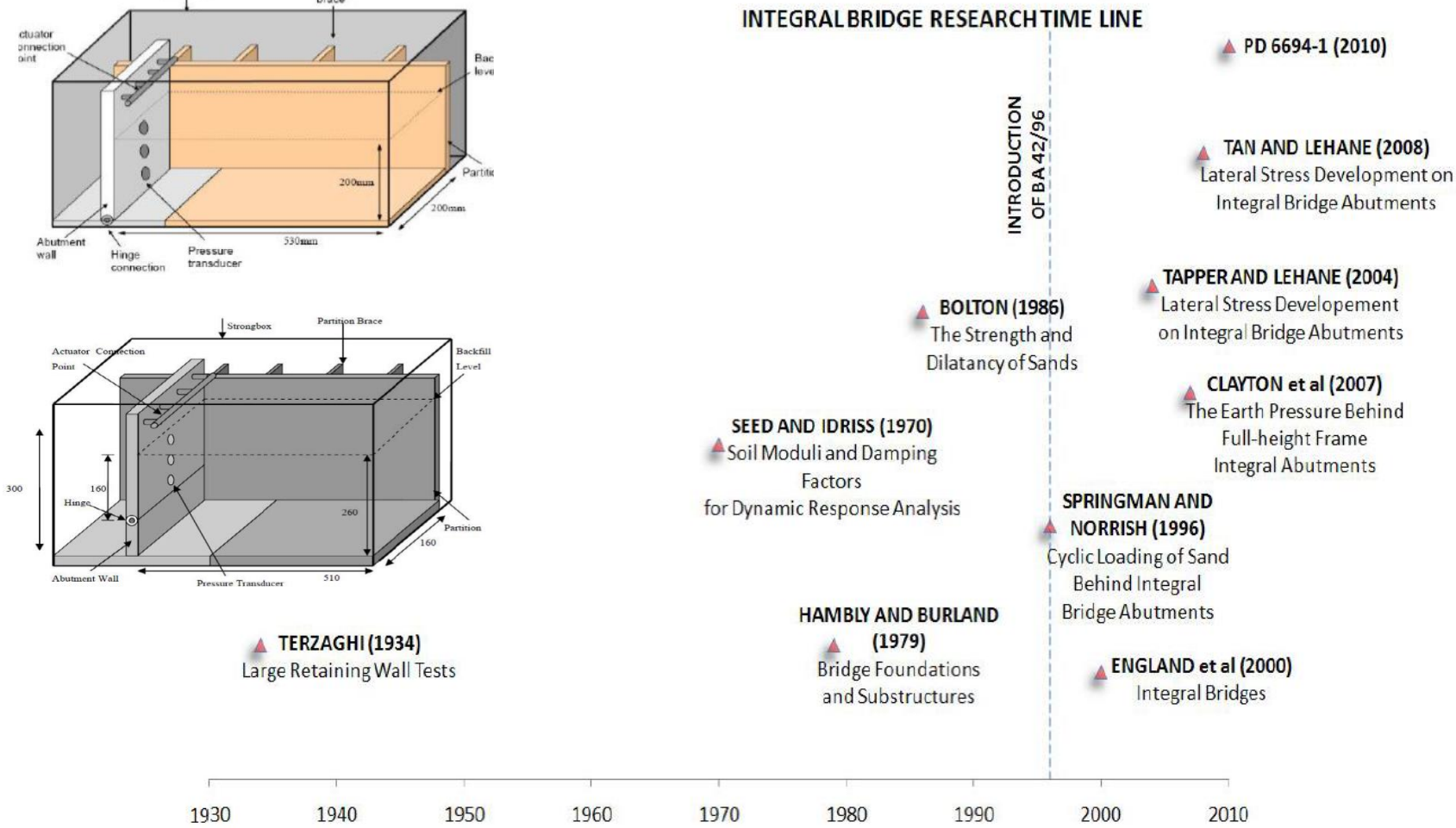
Location	Code / Design Guide
Australia Victoria	AS5100 (no guidance) VicRoads BTN 2012/003 (references BA 42/96)
UK	BA 42/96 (prior to 2011) PD 6694-1:2011 Section 9 (2011 onwards)
USA	Varies State to State

PD 6694 updates the UK recommendations in BA 42/96 to:

- Align with Eurocodes
- Address known issues with BA 42/96
- Embrace latest research in the field

2. Design of Integral Bridges

Code Requirements & Literature



2. Design of Integral Bridges

Code Requirements & Literature

Consistent approach to use of integral bridges in:

- VicRoads BTN 2012/003
- BA 42/96
- PD 6694

Restrictions on the use of integral bridges:

- Maximum bridge length = 60-70 m
- Maximum thermal movement = ± 20 mm (at each abutment)
- Skew ≤ 30°

2. Design of Integral Bridges

Design Philosophy

1. Integral Abutment Fill
2. Strain Ratcheting
3. Lateral Earth Pressure – K*
4. Plan Rotation
5. Wing wall Effects
6. Braking Effects
7. Surcharge Effects
8. Longitudinal Resistance

2. Design of Integral Bridges

Design Philosophy – Integral Abutment Fill

Integral Abutment Fill Requirements:

- Minimise earth pressure during thermal expansion
- Minimise settlement (remain dimensionally stable)
- Minimise strain ratcheting effect (tolerate cyclic movements)

Backfill material should be:

- Free-draining
- Granular

INTEGRAL ABUTMENT BACKFILL SPECIFICATION	
ITEM	INTEGRAL ABUTMENT FILL
UNIFORMITY COEFFICIENT (D60/ D10)	≥10
LOS ANGELES COEFFICIENT (%)	≤40
% PASSING 37.5mm SLEEVE	100%
% PASSING 75μm SLEEVE	<15%
EFFECTIVE ANGLE OF INTERNAL FRICTION (DEGREES)	35 TO 45
COMPACTION REQUIREMENT	95% OF STANDARD MAXIMUM DRY DENSITY IN ACCORDANCE WITH AS 1289.5.1.1
PLASTICITY INDEX AFTER COMPACTION (%)	≤10

Design for the range of friction angles specified!!

2. Design of Integral Bridges

Design Philosophy – Strain Ratcheting

Cyclic thermal expansion causes changes to the lateral earth pressure applied by the integral abutment fill material.

Strain ratcheting:

1. Thermal contraction – gap develops between fill material and abutment back wall
2. Fill material falls into gap – due to vibration/impact of vehicles and surface water runoff
3. Thermal expansion – increased soil density >> increased stiffness >> increased earth pressure
4. Process continues over many years due to seasonal effects - pressure coefficient approaches K*

Design for K* to account for strain ratcheting.

K* calculated based on the total movement of the bridge from the max contraction position to the max expansion position.

$$d_d = \alpha \frac{L}{2} (T_{max} - T_{min})$$

d_d = design movement
α = coefficient of thermal expansion of the bridge deck
L = bridge length
T_{max} = Maximum average bridge temperature
T_{min} = Minimum average bridge temperature

2. Design of Integral Bridges

Design Philosophy – Lateral Earth Pressure

K* depends on:

- Friction angle (Φ') of the integral abutment fill to calculate Ko and Kp
- Design movement denoted d'_d
- Retained height of the abutment, denoted H
- Mode of movement of the bridge towards the backfill

PD 6694 provides formulas for K* based on the most recent research.

$$K^* = K_0 + \left(\frac{40\, d'_d}{H}\right)^{0.4} K_p$$

Translation

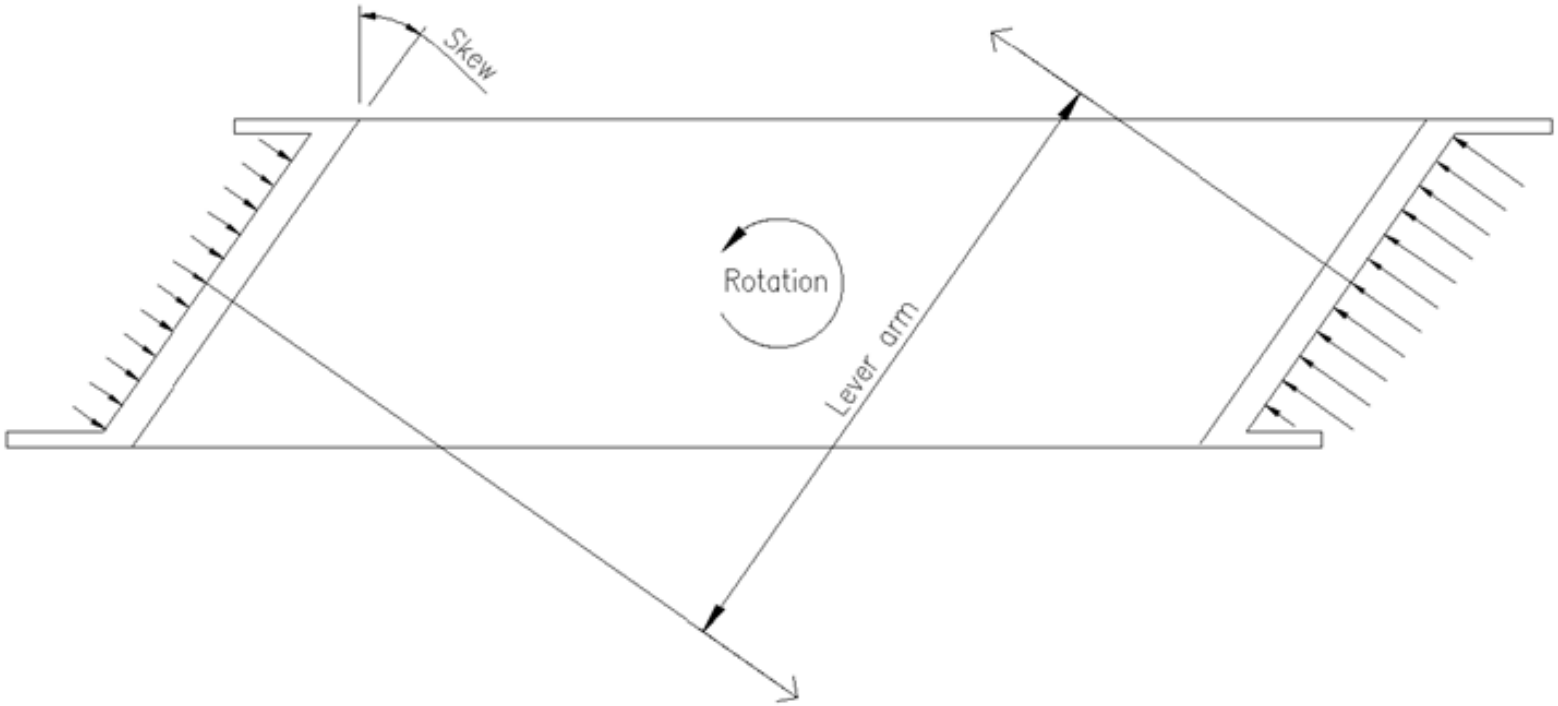
$$K^* = K_0 + \left(\frac{C\, d'_d}{H}\right)^{0.6} K_p$$

Rotation/Flexure

2. Design of Integral Bridges

Design Philosophy – Plan Rotation

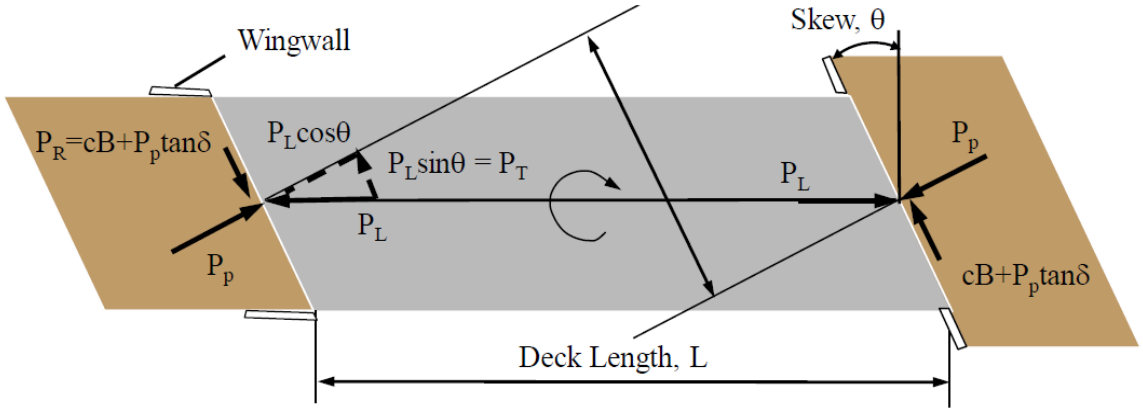
Skewed Bridges – Plan Rotation



2. Design of Integral Bridges

Design Philosophy – Plan Rotation

Skewed Bridges – Resistance to Plan Rotation



Hierarchy of resistance to plan rotation:

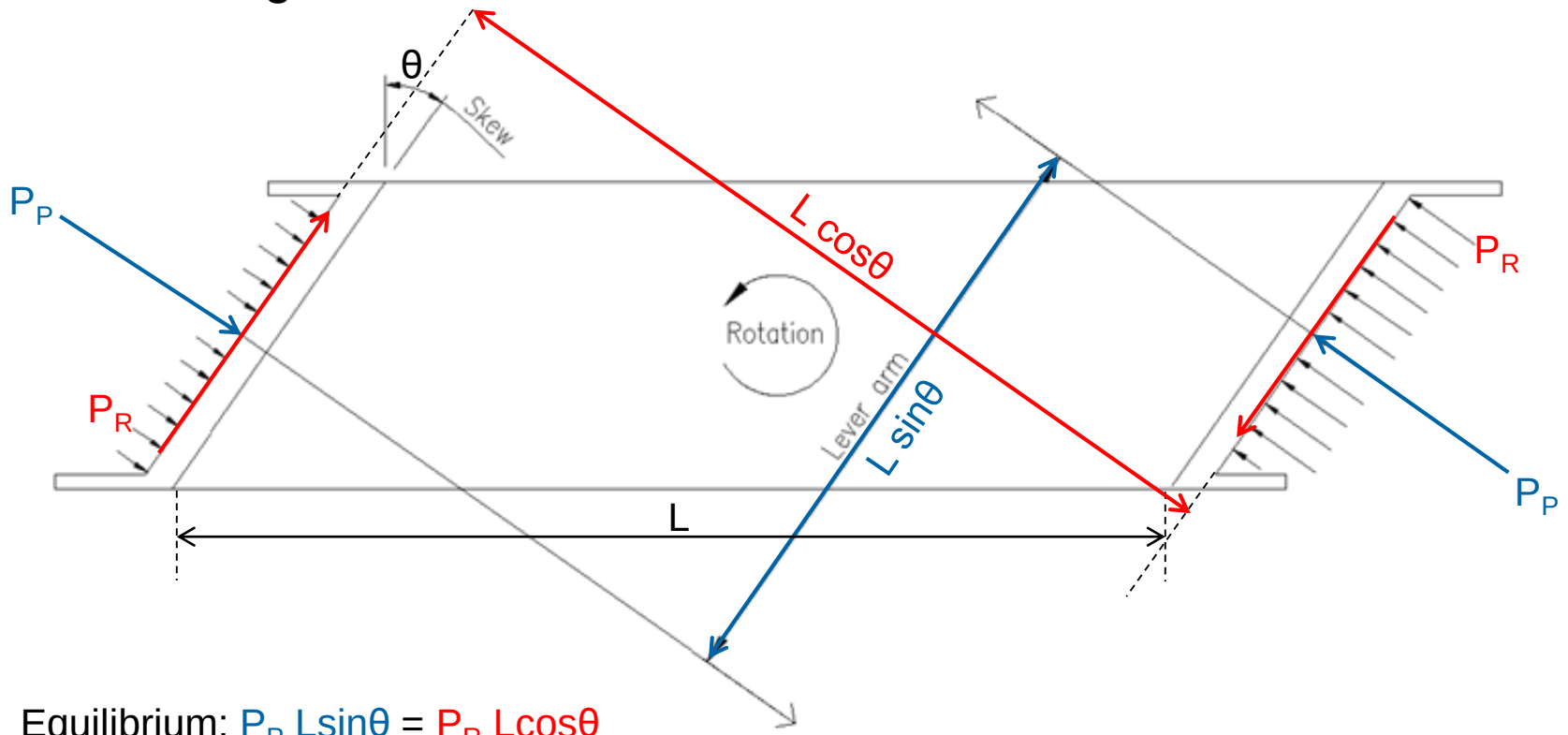
1. Interface friction between abutment backwall and integral abutment fill
2. Lateral earth pressure acting on wingwalls
3. Bending of the piles

Note: Piles should be sufficiently flexible to allow movement to occur

2. Design of Integral Bridges

Design Philosophy – Plan Rotation

Skewed Bridges – Resistance to Plan Rotation



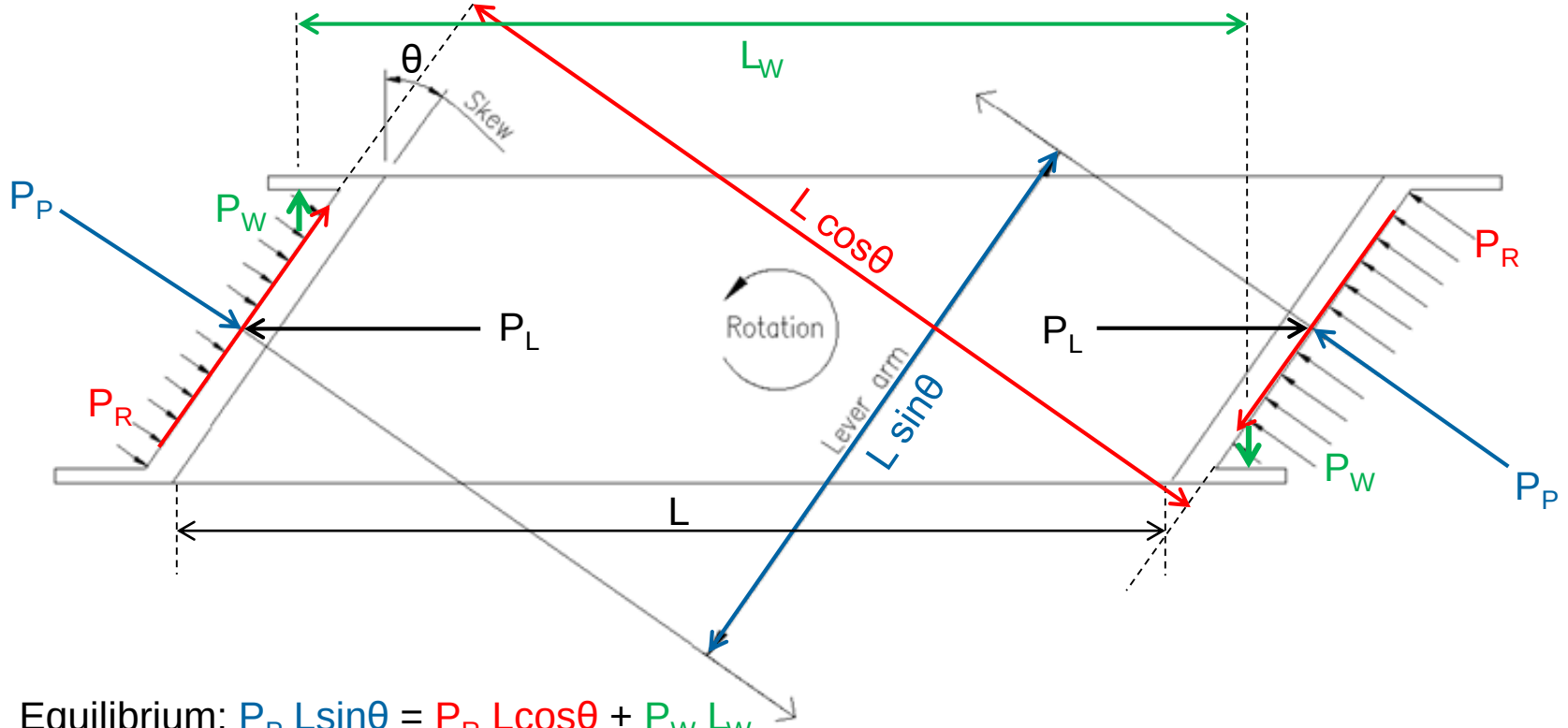
Equilibrium: P_P Lsinθ = P_R Lcosθ

If P_R is insufficient for equilibrium, small movement may occur and wingwalls will engage

2. Design of Integral Bridges

Design Philosophy – Plan Rotation

Skewed Bridges – Resistance to Plan Rotation



Equilibrium: P_P Lsinθ = P_R Lcosθ + P_W L_W

If Pr and Pw are still insufficient, piles will resist a greater portion of plan rotation in bending

2. Design of Integral Bridges

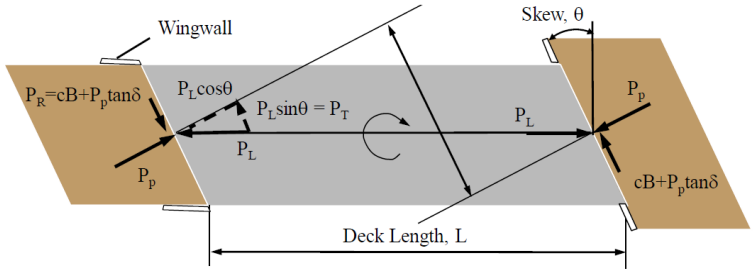
Design Philosophy – Braking Effects

Braking Effects

- BA 42/96 provides no guidance on braking effects
- PD 6694 provides guidance on considering braking for
  - longitudinal resistance (discussed later)
  - calculating K* (determine additional movement d'_d due to braking at abutments)

Recommended approach:

1. Determine the total longitudinal braking load acting on the bridge
2. Determine the longitudinal movement required to engage resistance equal to the longitudinal braking force
3. Determine the increase in K* and P_L due to braking
4. Resolve the longitudinal loads orthogonal to the abutment backwall
5. Apply P_P and P_R earth pressure loads to resist braking



2. Design of Integral Bridges

Design Philosophy – Surcharge Effects

Surcharge Effects

- BA 42/96 provides the following guidance:
  - "Live load surcharge on backfill should be ignored when calculating the passive earth pressure mobilised by thermal expansion of the deck"
  - "Earth pressures under live load surcharge in the short term should be checked at 'at rest' earth pressure conditions"
- PD 6694 provides the following guidance:
  - "Traffic surcharge loading need not be applied in conjunction with K* pressure"
  - *Denton et al* explain that this statement has been included due to:
    - Past design practice (pragmatic reasons)
    - Some physical justification – "expansion of the bridge deck necessary to develop K* pressures gives rise to friction effects in the opposite direction from those that tend to arise from traffic surcharge"… "As a result traffic surcharge effects and K* pressures are not wholly additive"

Agreement between PD 6694 and BA 42/96: Surcharge should not be combined with K* earth pressures due to thermal expansion

2. Design of Integral Bridges

Design Philosophy – Longitudinal Resistance

Longitudinal Resistance at SLS

- Check the movement of the abutment backwall to engage sufficient resistance
- Apply a reduction factor (RF) of 0.5 (recommended by *Nicolson*)
- Use engineering judgement to determine if the movement is acceptable

Braking + Surcharge + Active Earth Pressure ≤ RF x Passive Earth Pressure

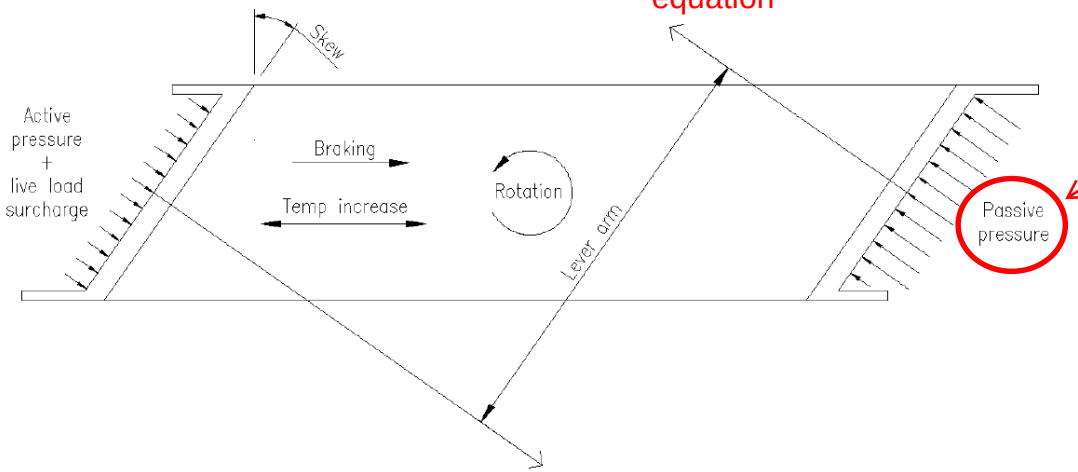
The braking force should be resolved orthogonal to the abutment

These forces should be calculated using the maximum value of Ka from the range of friction angles specified (eg. 35°-45°)

1. Determine K* for required resistance force
2. Determine the value of d'_d based on the relevant K* equation

$$K^* = K_0 + \left(\frac{40\, d'_d}{H}\right)^{0.4} K_p$$

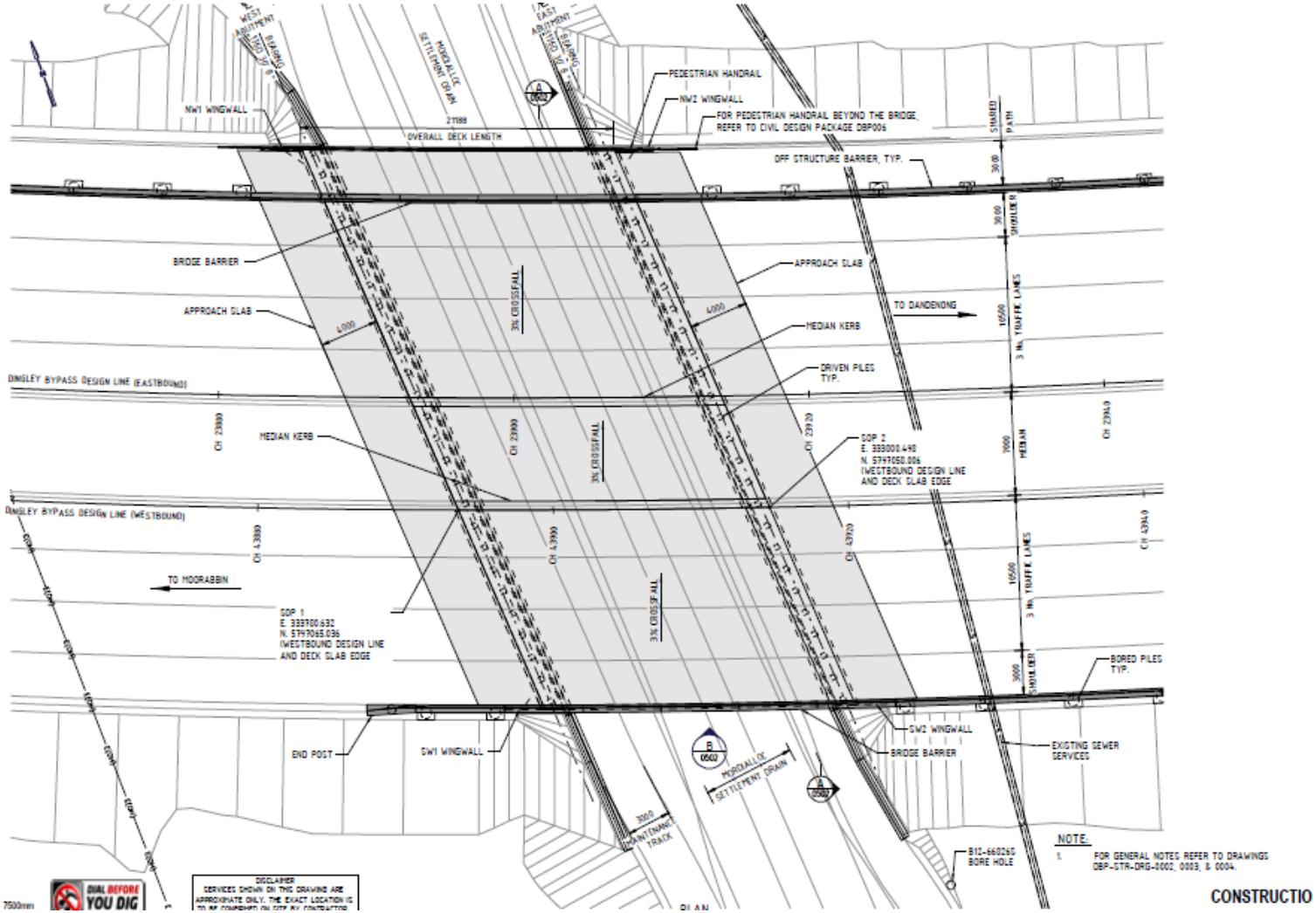
$$K^* = K_0 + \left(\frac{C\, d'_d}{H}\right)^{0.6} K_p$$



What movement is required to provide this resistance?

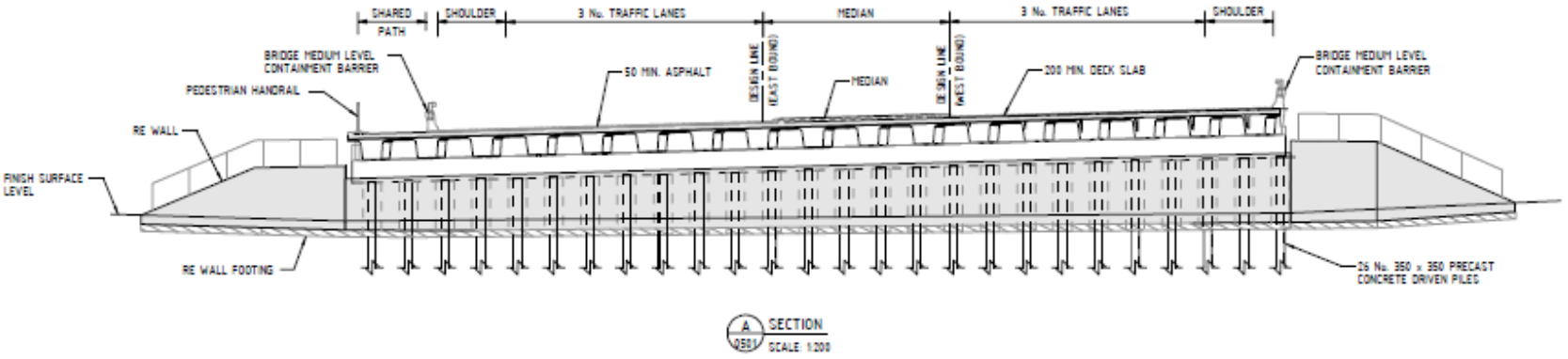
3. Developing a Structural Model

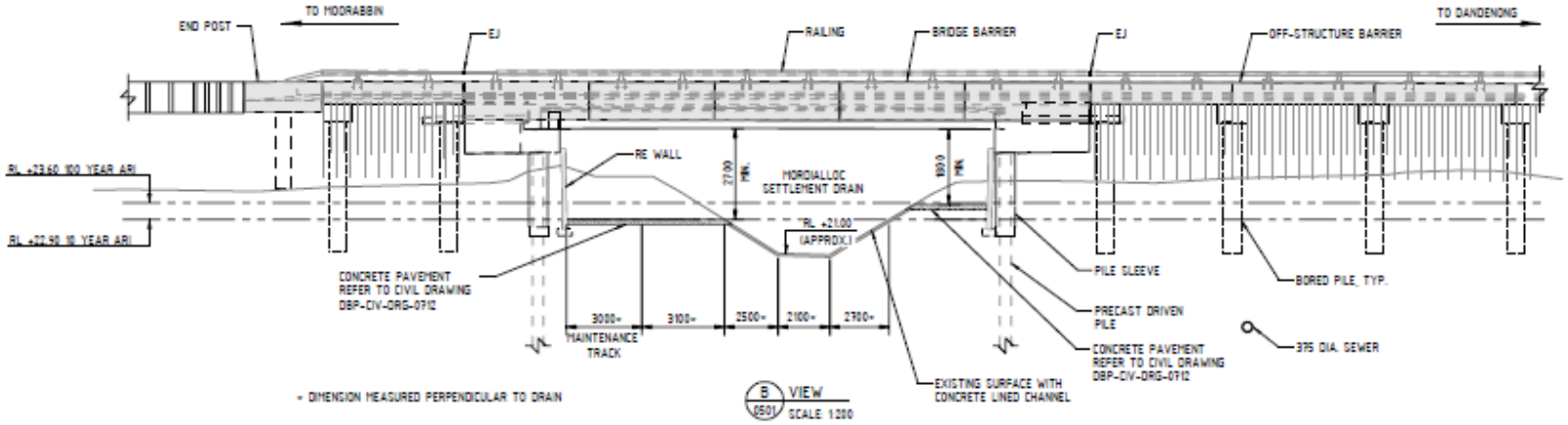
Mordialloc Settlement Drain Bridge



3. Developing a Structural Model

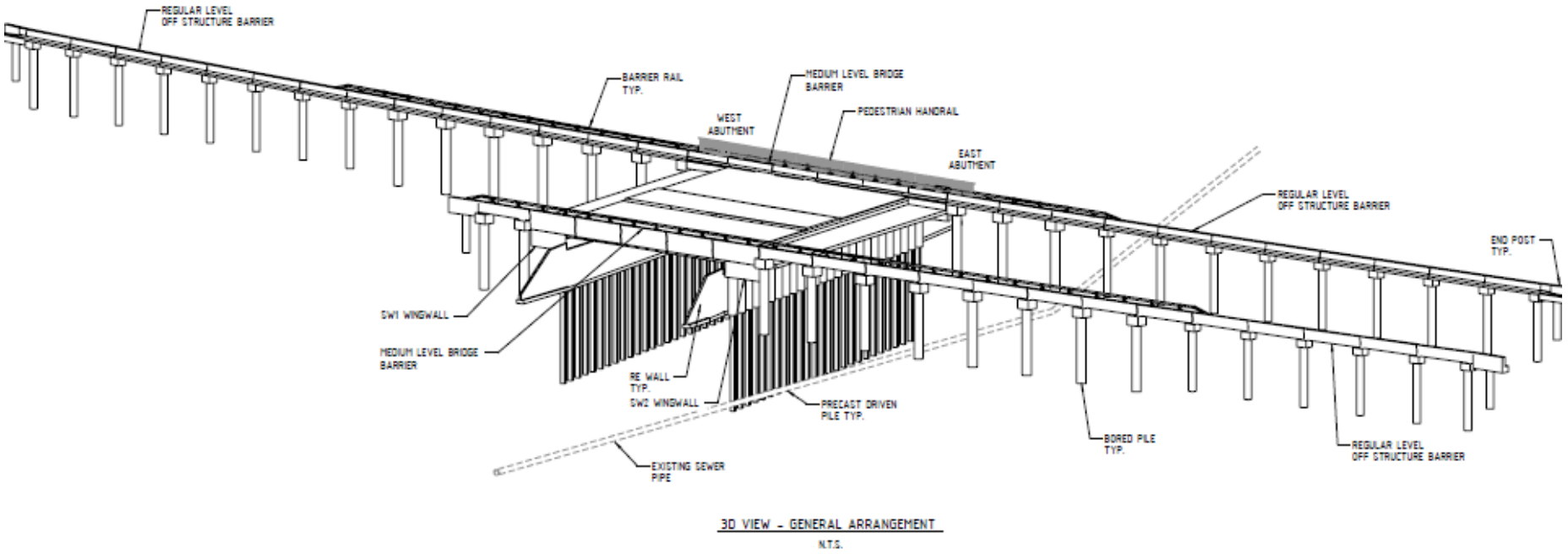
Mordialloc Settlement Drain Bridge (Integral)





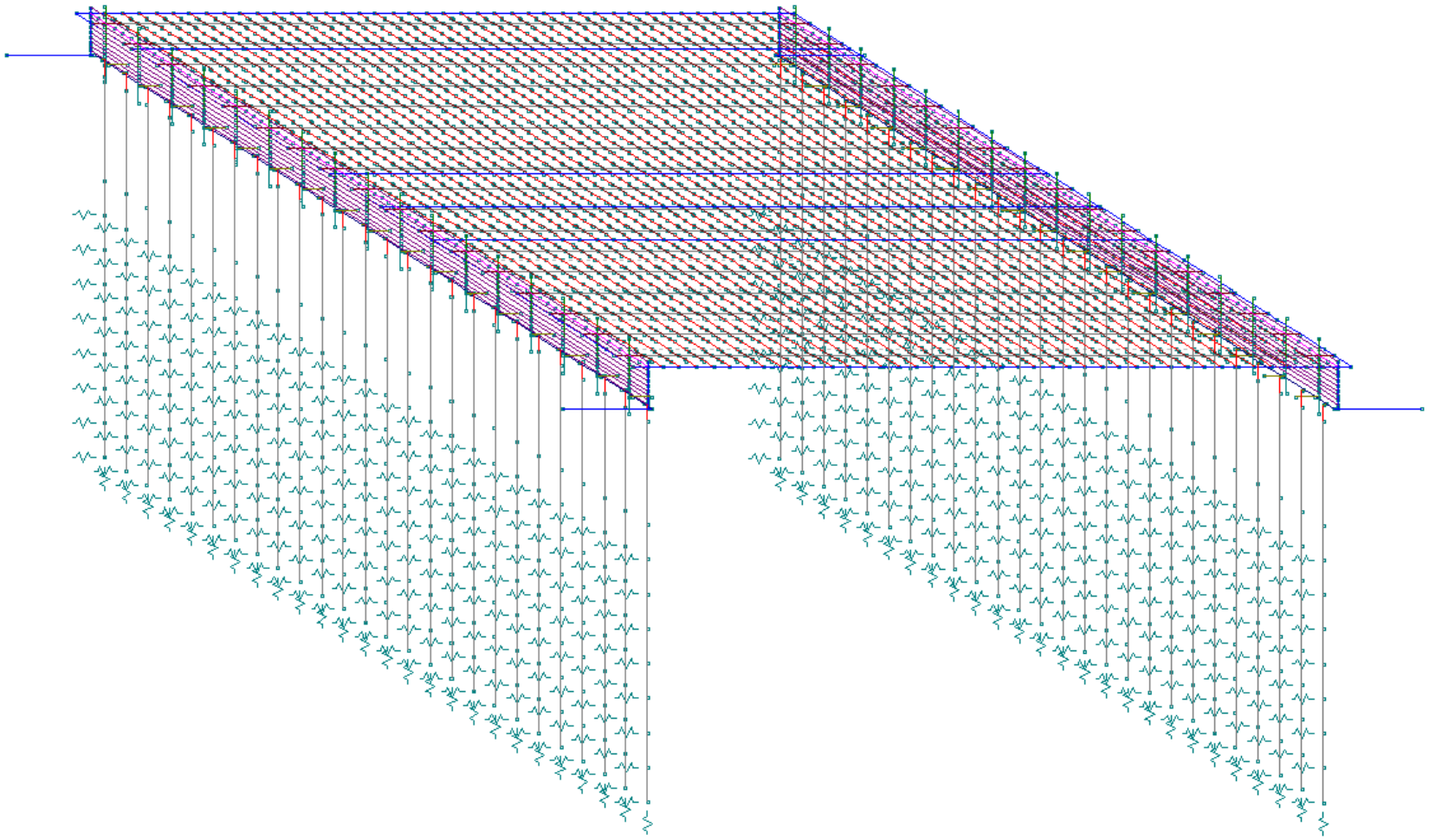
3. Developing a Structural Model

Mordialloc Settlement Drain Bridge (Integral)



3. Developing a Structural Model

Mordialloc Settlement Drain Bridge (Integral)

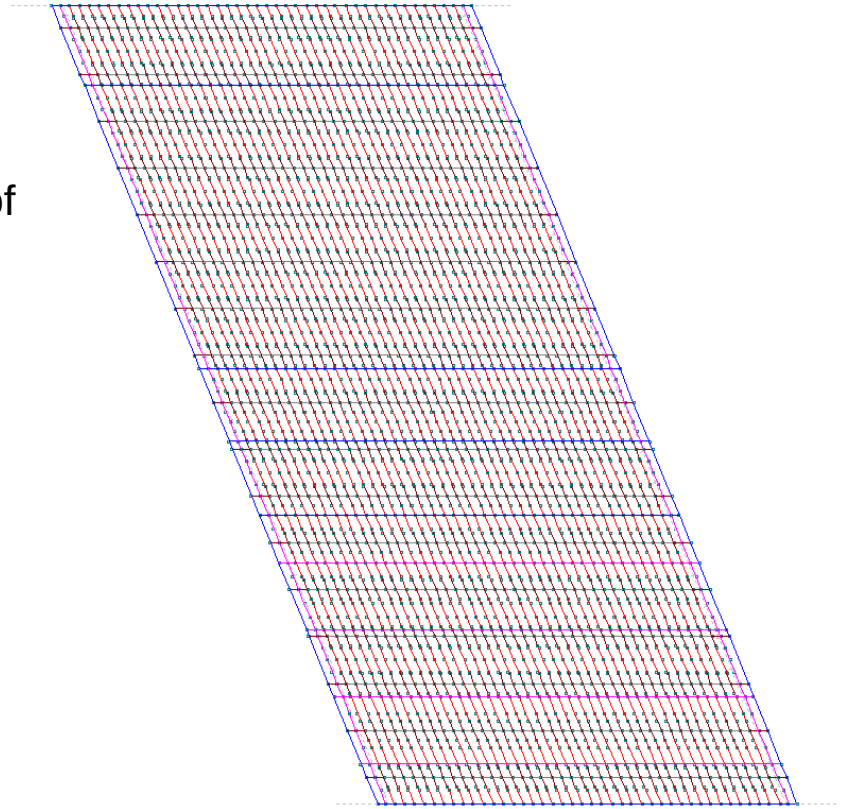


3. Developing a Structural Model

Mordialloc Settlement Drain Bridge (Integral)

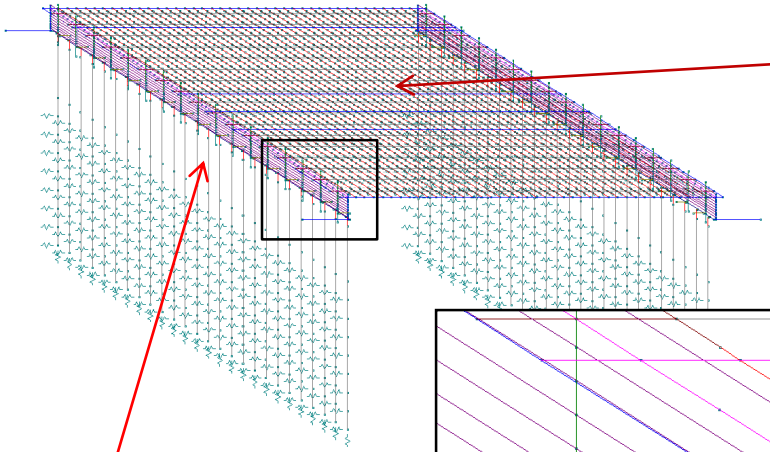
Grillage model for superstructure

- 23.7° skew modelled
- Skewed mesh adopted to match orientation of reinforcement

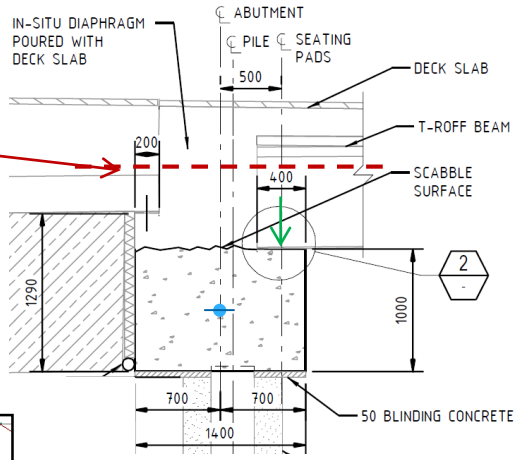


3. Developing a Structural Model

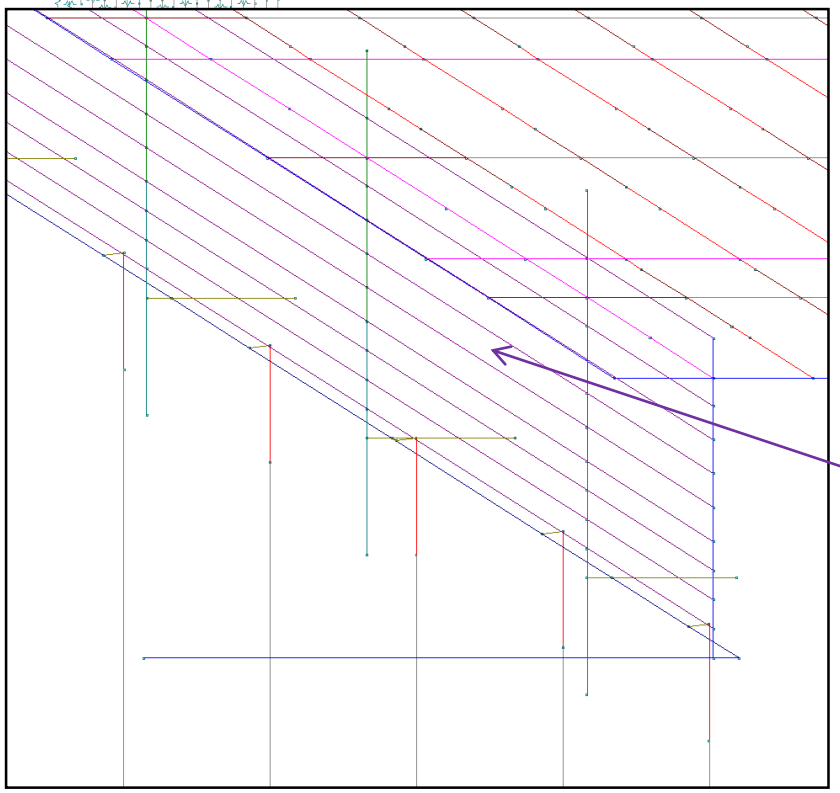
Mordialloc Settlement Drain Bridge (Integral)



Grillage modelled at centroid of composite beam



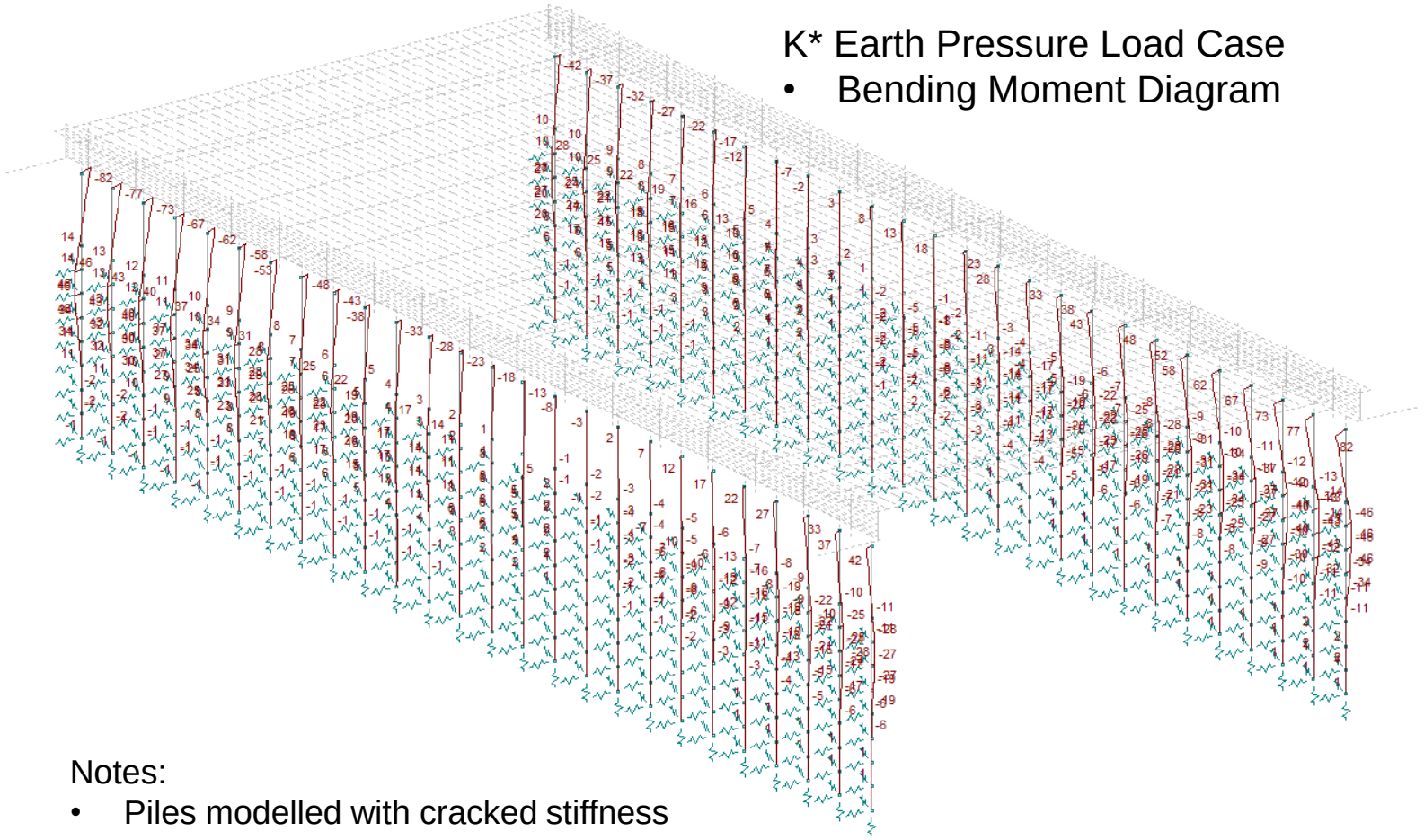
Sleeved piles (no spring applied)



Grillage modelled to represent fender wall.

3. Developing a Structural Model

Mordialloc Settlement Drain Bridge (Integral)



K* Earth Pressure Load Case

- Bending Moment Diagram

Notes:

- Piles modelled with cracked stiffness
- Plan rotation causes bending in piles
- Maximum moment occurs in piles at obtuse corners
  (these piles have the largest displacement due to plan rotation)

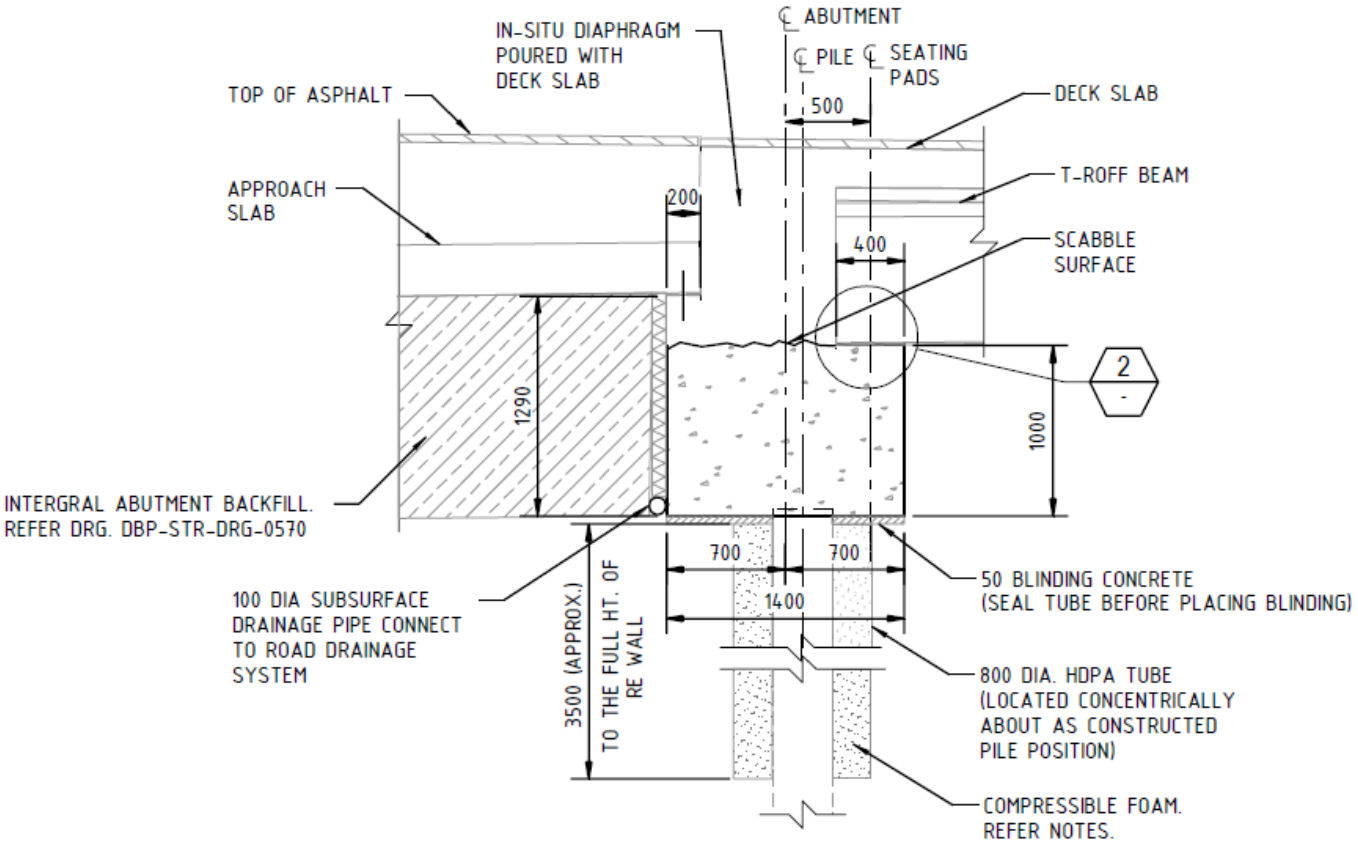
4. Design of Critical Elements

Critical Elements

- Piles
- Integral Connection
  - Fender Wall
  - Deck Slab
  - Abutment Sill
- Approach Pavement

4. Design of Critical Elements

Pile Design



4. Design of Critical Elements

Integral Connection Design

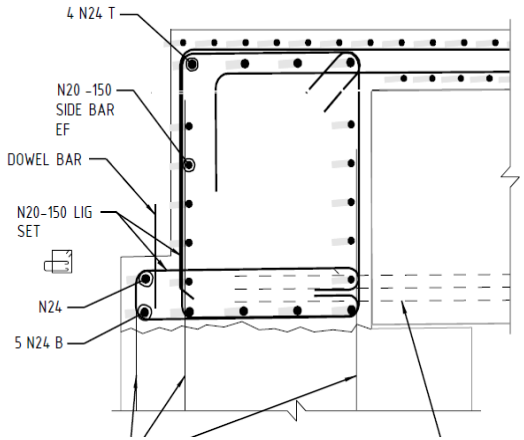
Design of Integral Connection

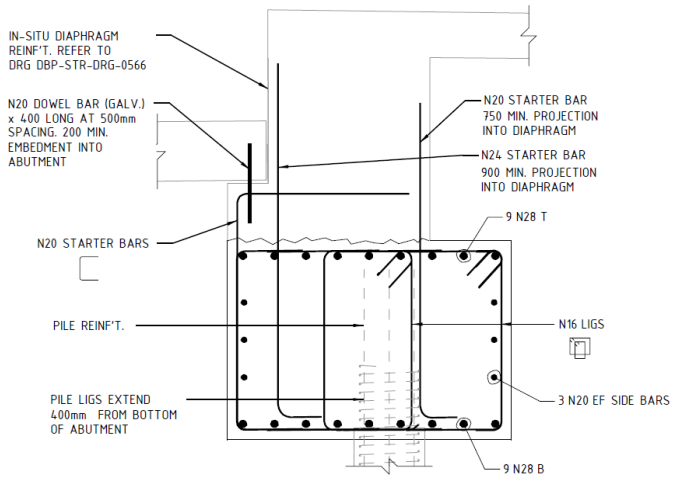
Fender Wall

- Strands from beam continue into fender wall
- Fender wall forms abutment backwall
- Acts as diaphragm between adjacent beams
- Designed for:
  - Hogging moment transferred from superstructure
  - Braking force at top of fender wall
  - K* earth pressure

Deck Slab

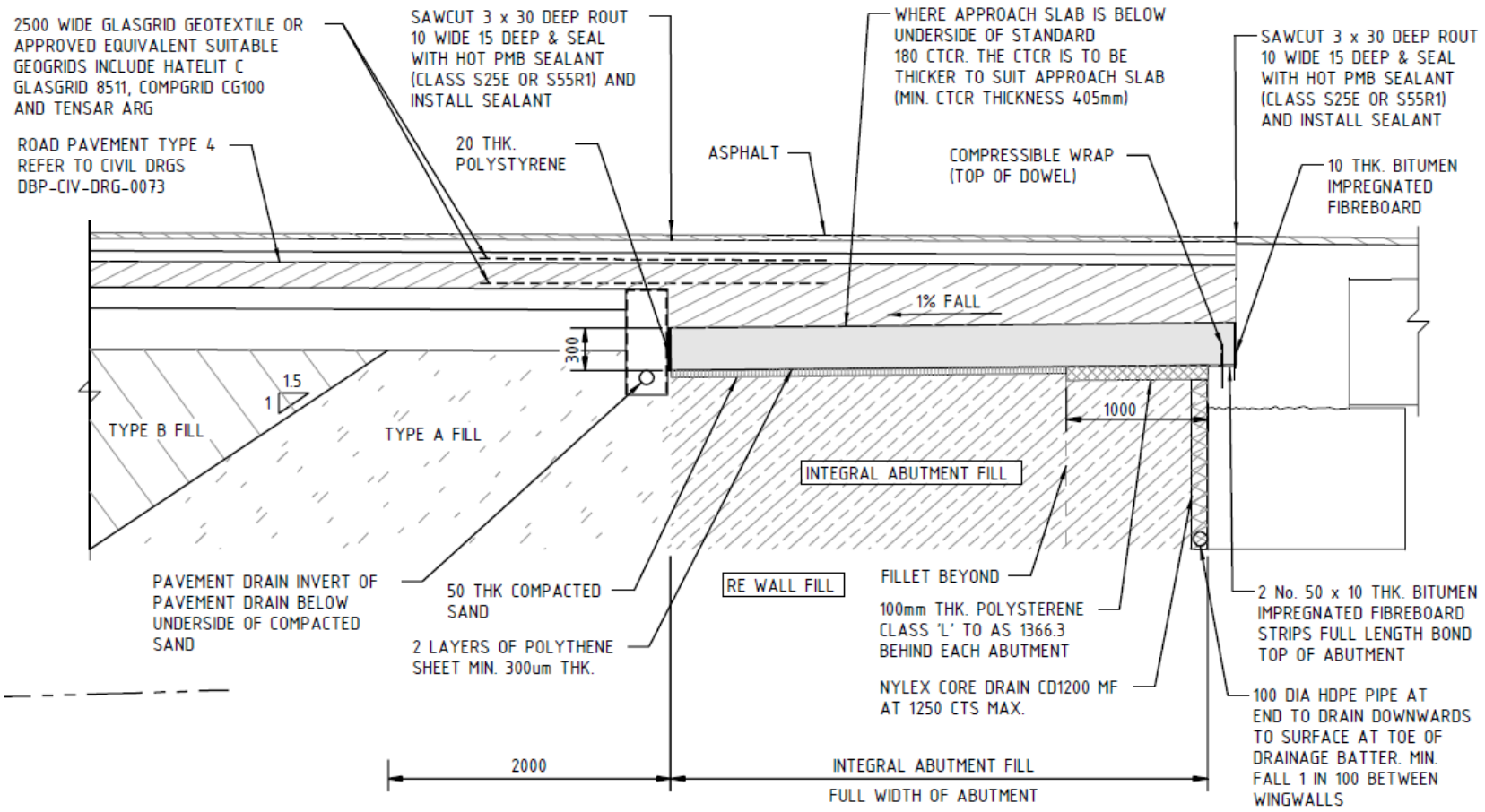
- Composite with beam
- Designed for:
  - Hogging moment transferred from superstructure





4. Design of Critical Elements

Approach Pavement



5. Conclusion

Design Philosophy

- Design integral bridges in accordance with PD 6694 (this supersedes BA 42/96)
- Determine K* based on the range of friction angles in the integral abutment fill specification
- If possible, resist plan rotation entirely by interface friction to reduce pile bending moments
- If bridge is working too hard to be designed as fully integral, consider semi-integral solution to relieve hogging moments at abutments

Design of Critical Elements

- Piles to be sleeved to provide flexibility to movement
- Account for staging effects: locked in moments in piles due to eccentric DL Beam + DL Slab
- Reinforce approach pavements with geotextiles to reduce likelihood of surface cracking

Questions?