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ARCADIS Design & Consultancy for natural and built assets

HICKSON ROAD ARCH BRIDGES, SYDNEY – STRUCTURAL ANALYSIS FOR PREDICTED GROUND MOVEMENTS

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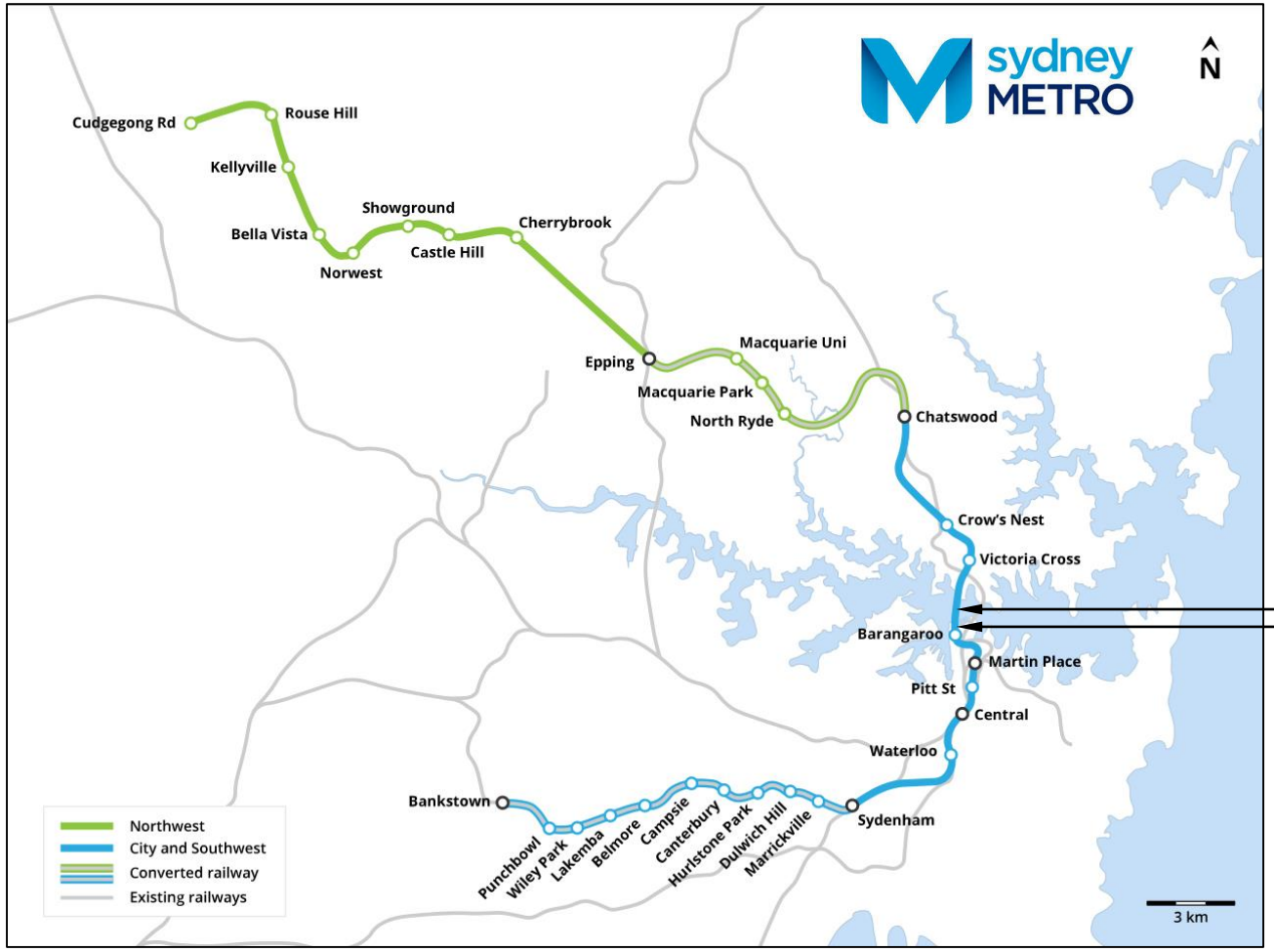
Outline of Presentation

- Location of the bridges.
- Purpose of the project.
- Existing bridge details.
- Early reinforced concrete in Australia.
- Arch bridge types.
- Earlier arch rehabilitation work.
- Structural analysis of Hickson Road arch bridges.

Location of Bridges

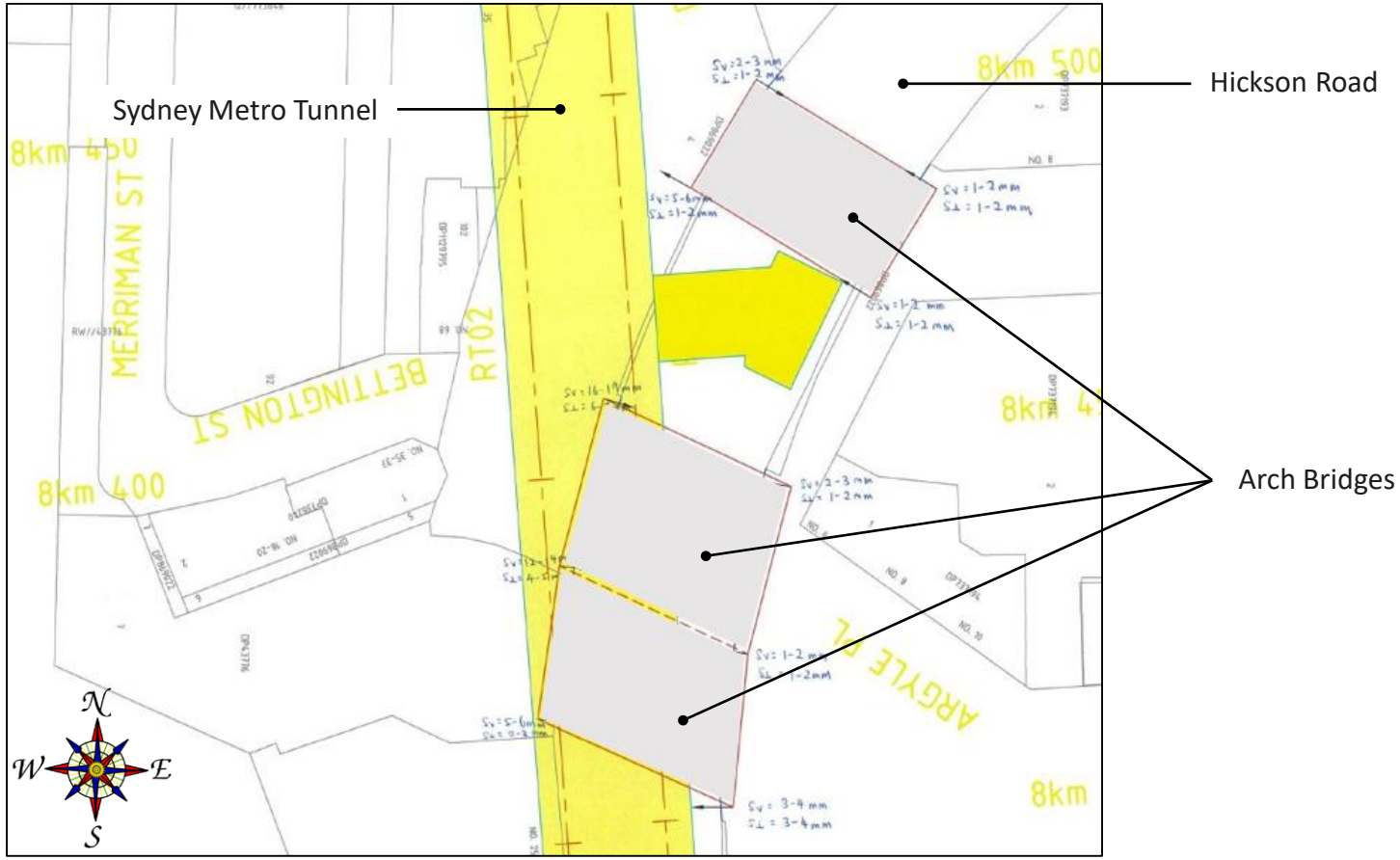
- Three reinforced concrete arch bridges – constructed between 1911 and 1914 by the Sydney Harbour Trust.
- Early application of reinforced concrete to civil infrastructure projects in NSW.

Sydney Metro Map



Hickson Road arch bridges

Purpose of the Project

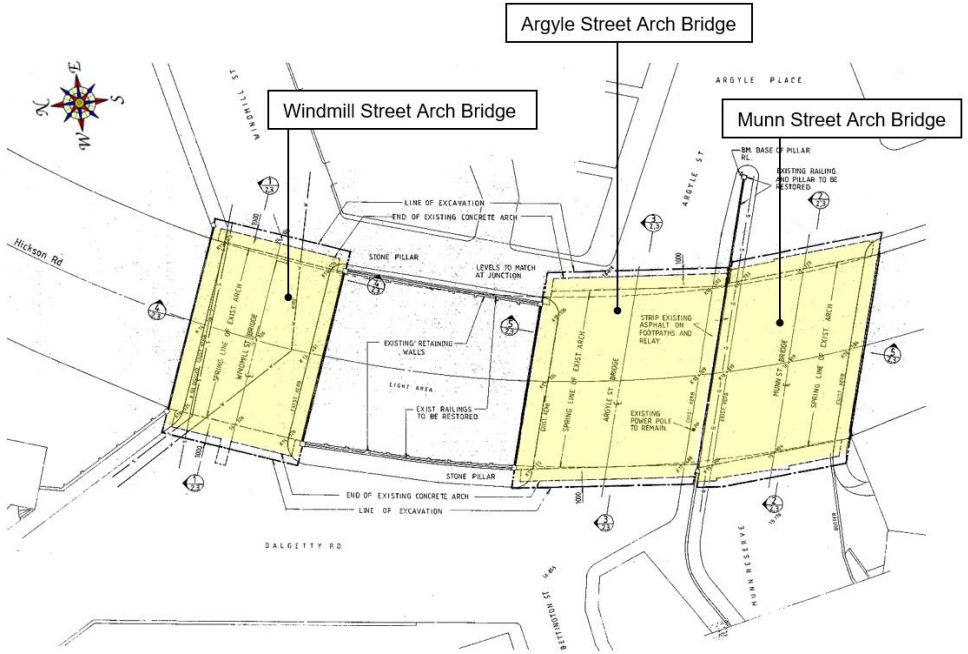


Plan of Tunnel & Hickson Road Arch Bridges

- Due to predicted ground movements from nearby tunnel and cavern excavation work for the Sydney Metro rapid transit system, the arch bridges were structurally analysed to check their capacity to withstand the anticipated horizontal and vertical movements.
- Geotechnical engineering consultants provided Arcadis with predicted ground movements (both vertical and horizontal) at the abutments (springings) of the three arch bridges over Hickson Road.

Existing Bridge Details

Windmill Street Bridge (foreground), Argyle and Munn Streets Contiguous Bridges (background)

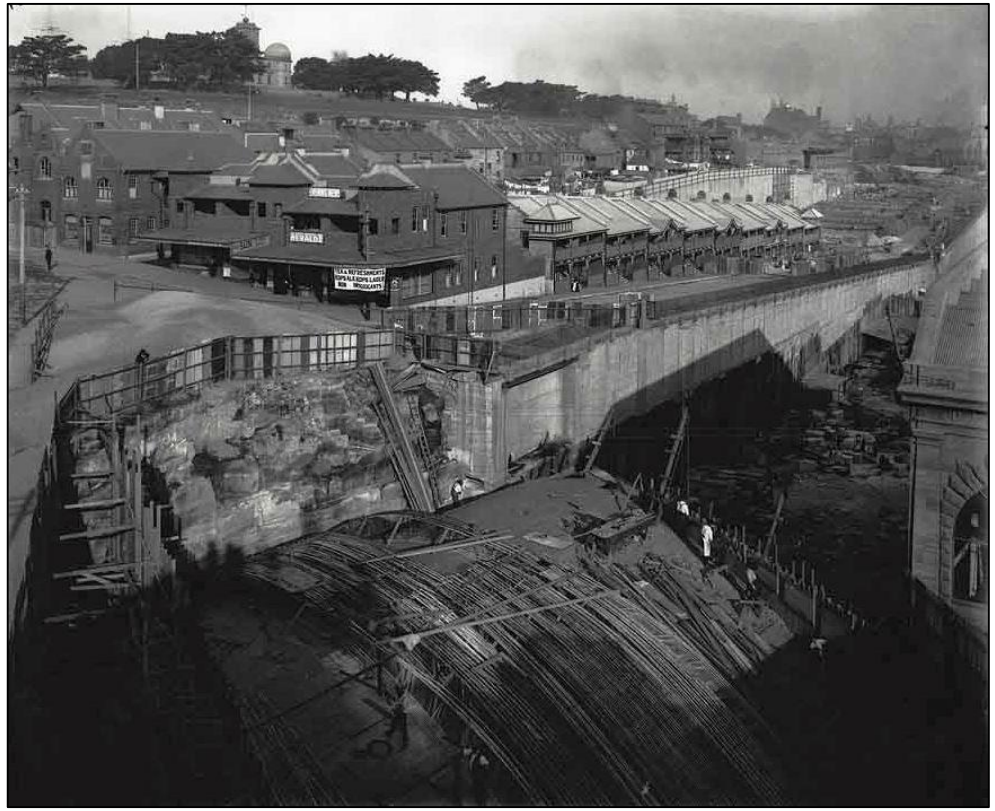


Plan of Hickson Road Arch Bridges

Existing Bridge Details

- Although there are minor geometric variations between all three arch bridges, the rationalised dimensions are:
  - Span length = 24.4 m.
  - Rise of the arch at mid-span = 4.6 m.
  - Thickness of the original concrete arch varies from 1219 mm at the springing points (abutments) and 686 mm at the crown (mid-span).
  - Overall width of arches varies between 19.3 m and 25.2 m.
  - Thickness of concrete overlay (early 1990s) = 350 mm.
  - Shotcrete layer (110 mm thick) applied to soffit of arches (early 1990s).

Historic Photos

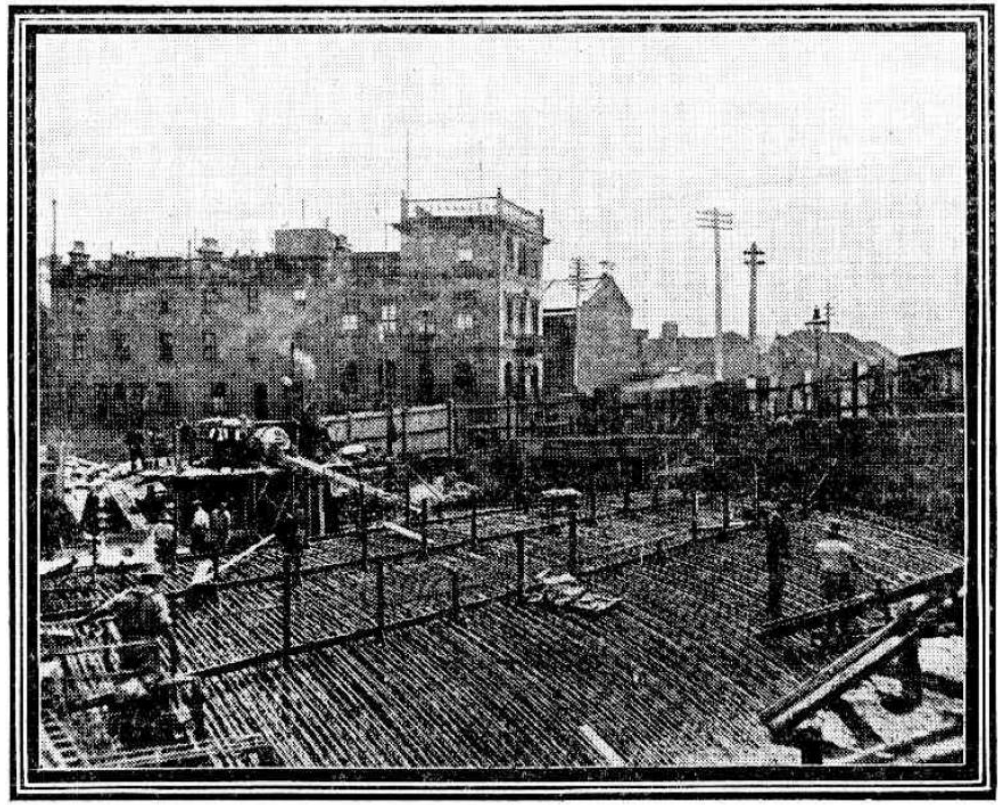


Munn Street Bridge (c1911)

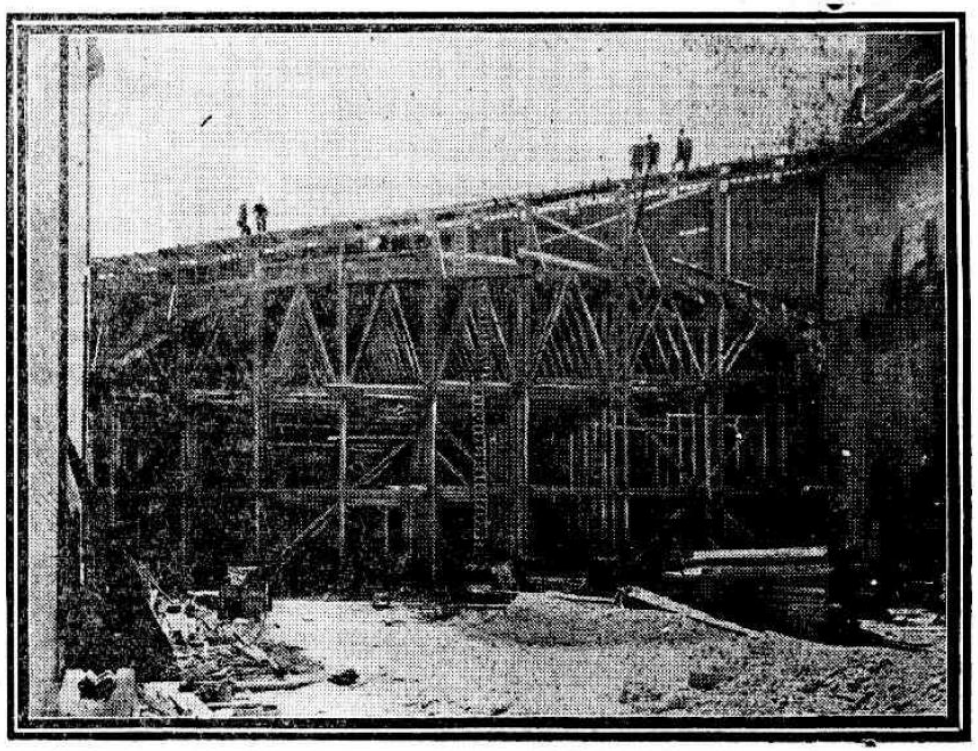
Munn Street Bridge (abutting Argyle Street Bridge) (c1918)

Daily Telegraph 30th October 1911

HARBOR TRUST'S GREAT WORK.

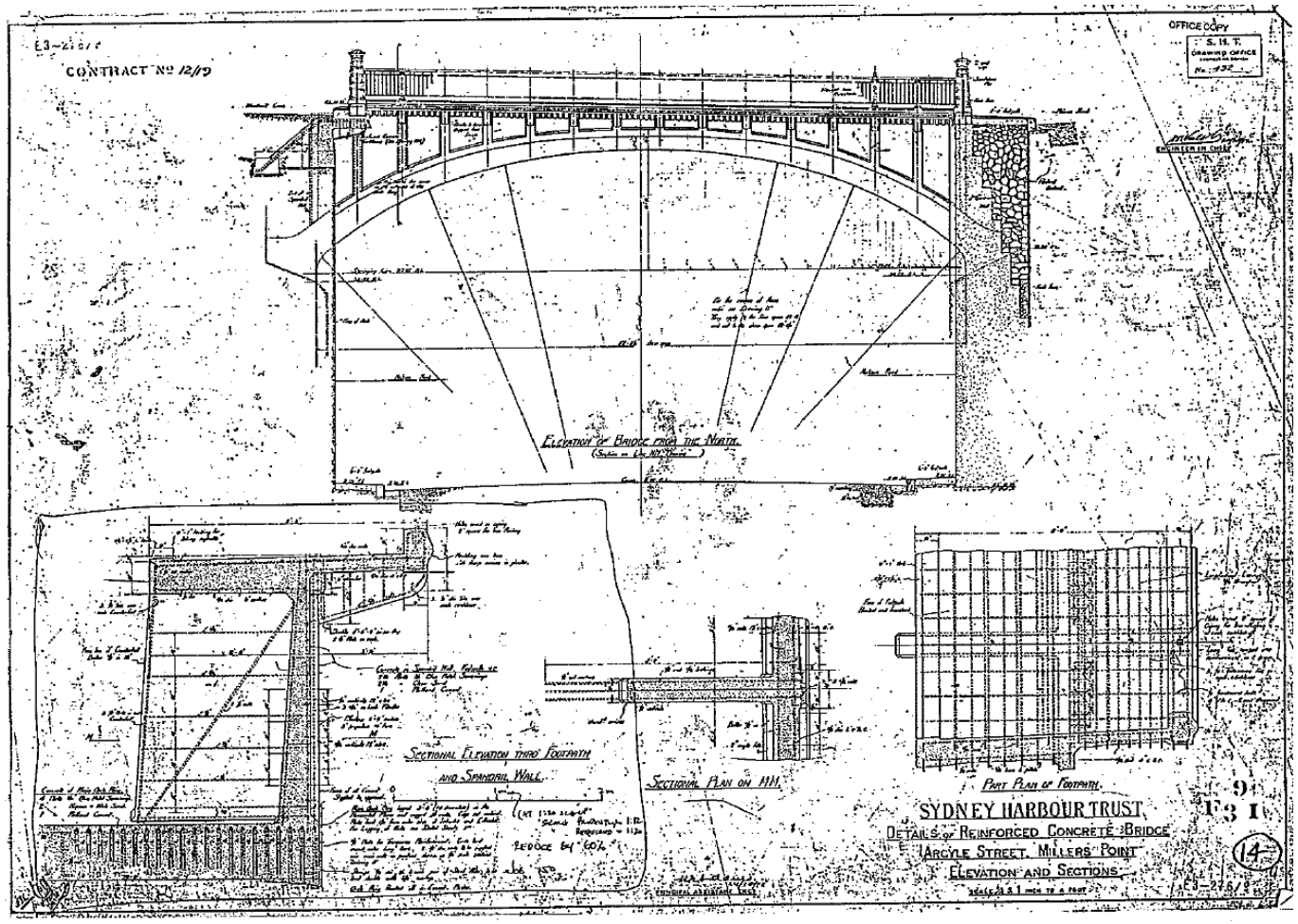


TOP OF THE BRIDGE, SHOWING ONE OF THE CONCRETE MIXERS. THE CONCRETE SLIDES DOWN THE INCLINED CHUTES AND FILLS THE SPACES BETWEEN THE STEEL BARS. THEN THE WHOLE THING WILL SET SOLID.



MAKING THE LARGEST REINFORCED CONCRETE BRIDGE IN NEW SOUTH WALES. IT SPANS HICKSON-ROAD, DARLING HARBOR.

Original Bridge Drawing



Excerpt from paper entitled *The Structural Restoration of the Hickson Road Bridges* by Stephen Burkitt, presented at a seminar entitled *Building with Shotcrete*, jointly organised by Concrete Institute of Australia and Australian Underground Construction & Tunnelling Association, March 1997.

Early Reinforced Concrete in Australia

- Reinforced concrete (RC) initially referred to as the 'Monier System' (from France).
- RC introduced to NSW in 1895-6 by Carter, Gummow & Co[1] with W.J. Baltzer[2].
- RC introduced to Victoria and SA in 1897-8 by Monash & Anderson.
- Earliest known use in Australia – Arched stormwater culvert roof, Parramatta Road, Burwood, Sydney (c1894), as an experimental project (by Carter, Gummow & Co).
- In NSW, followed by Annandale sewer aqueducts (1895-1897), Hilltop overbridge over Picton to Mittagong loop line railway (c1897), Liddell overbridge over the Main North railway (c1898), Moonbi bridge on old alignment of the New England Highway (c1900), Wallendbeen overbridge over the Main South railway (c1900), Jews Creek bridge, Larras Lee (c1903), North Richmond bridge over Hawkesbury River (c1905), Strathfield overbridge over railway(c1909), and Hickson Road arch bridges, Millers Point (1911 & 1914).

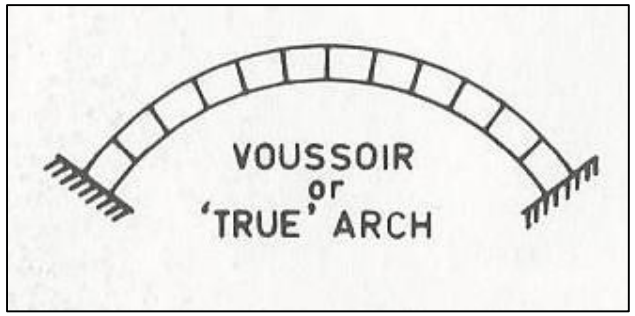
Note 1 – Construction contractor

Note 2 – Design engineer, NSW Public Works Department, then later engineer for Carter, Gummow & Co

Johnstons Creek Sewer Aqueduct, Annandale

Arch Types – Voussoir (Roman) Arch

- Arch comprises individual stone blocks or brick layers.
- Typically circular in configuration.
- Line of thrust within middle third of section ensures no tension in arch. Then check if maximum stress in compression is within limiting value for the material.
- Alternatively, if tension in extreme fibre occurs, compression is recalculated over a reduced depth (cracked) section and then compressive stress is checked.



Bowenfels, NSW (1870 & 1921)

Arch Types – Monier System

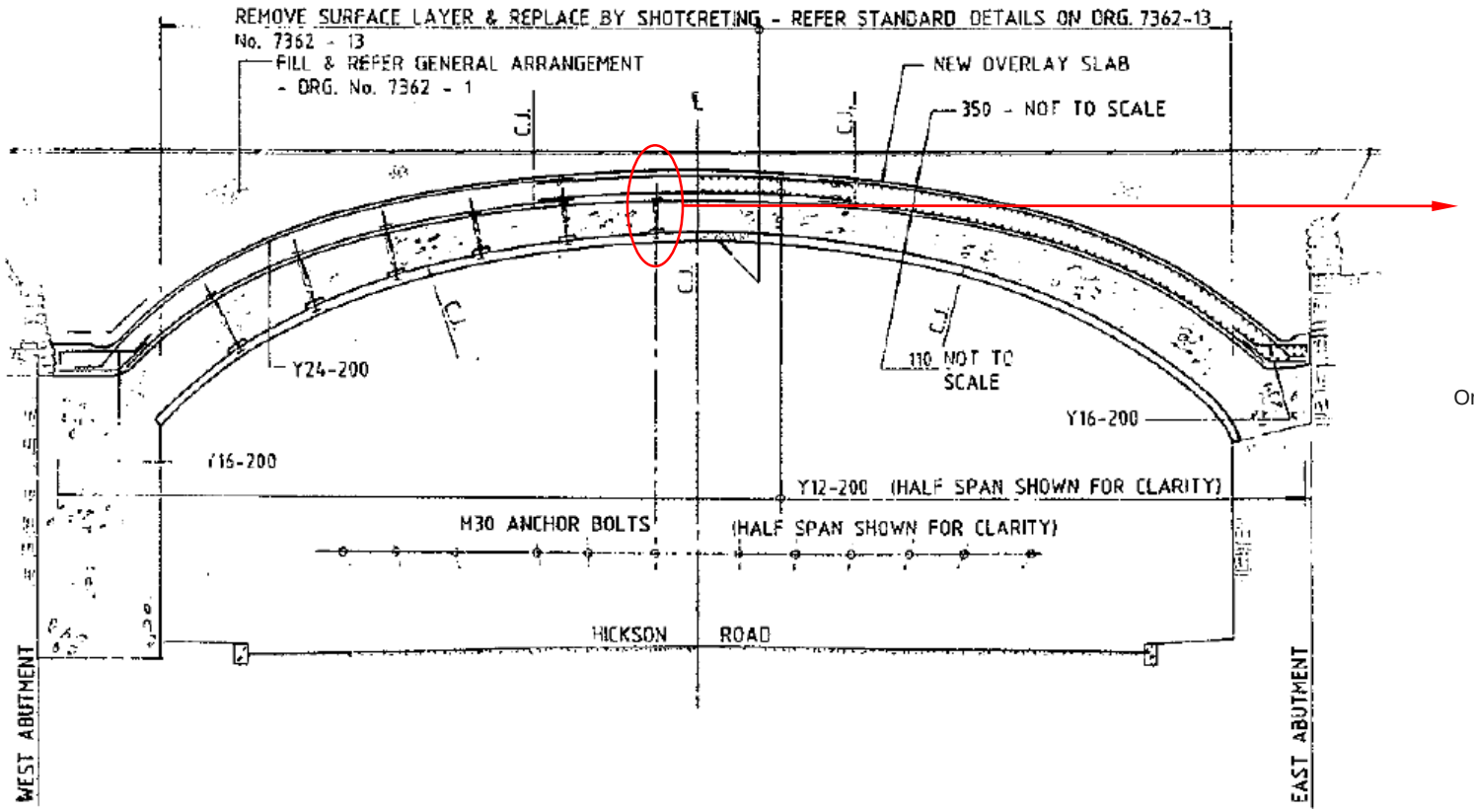
- Flatter arch than a voussoir arch.
- A reinforced concrete arch behaves differently to a masonry arch. Reinforced concrete arches are typically thinner and have reinforcement to resist bending moments (both positive and negative).
- The behaviour of a buried arch bridge represents a complex form of soil-structure interaction. When the loads are applied to the arch ring, certain portions of the ring deflect into the fill, while the other sections deflect away from the fill.

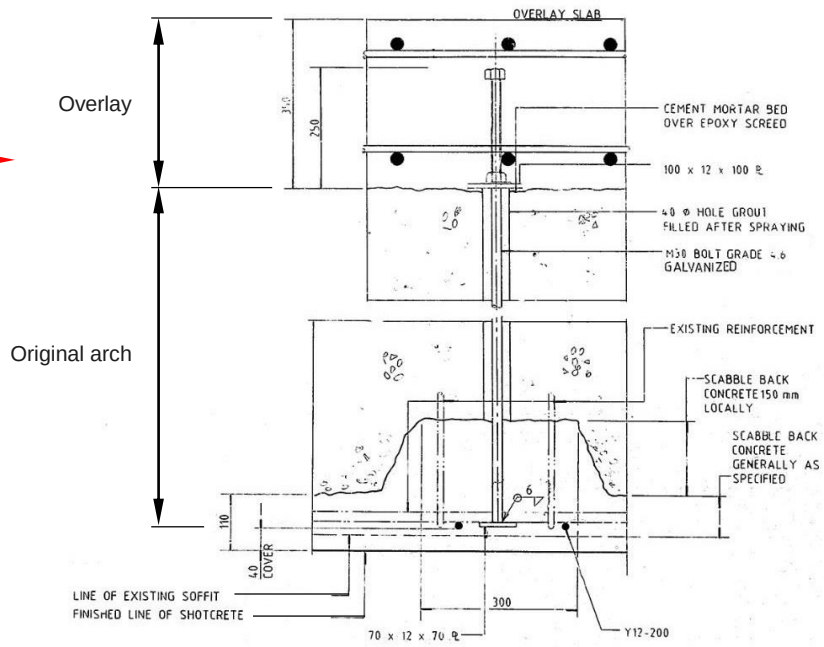
Hilltop Overbridge, NSW (1897)

Arch Rehabilitation Work – Hickson Road Arch Bridges

- Early 1990s – it was noticed that the arch bridges were severely deteriorated – low concrete cover (10 to 15 mm) to soffit reinforcement ⟶ corroded reinforcement.
- Sydney City Council engaged MBK (now Cardno) to undertake an investigation – this resulted in extensive rehabilitation work, as follows:
  - Removal of fill.
  - Removal of 80 to 90 mm of concrete at the arch intrados (soffit), to provide a minimum clearance behind the existing reinforcing bars of 30 mm.
  - Grit blasting of existing reinforcing bars and replacement of bars (with Y24 bars) where less than 75% of their cross-sectional area remained.
  - Drilling and insertion of 30 mm diameter high strength bolts through arch ring to provide composite connection between overlay and original arch ring. These bolts were anchored into the shotcrete layer.
  - Shotcrete layer (110 mm thick) was applied to the soffit of the arch.
  - Demolition and reconstruction of reinforced concrete spandrel walls.
  - Construction of 350 mm thick reinforced concrete overlay on arch extrados.
  - Waterproof membrane and sub-soil drainage lines provided on the top of overlay slab, prior to backfilling.

Arch Rehabilitation Work – Hickson Road Arch Bridges





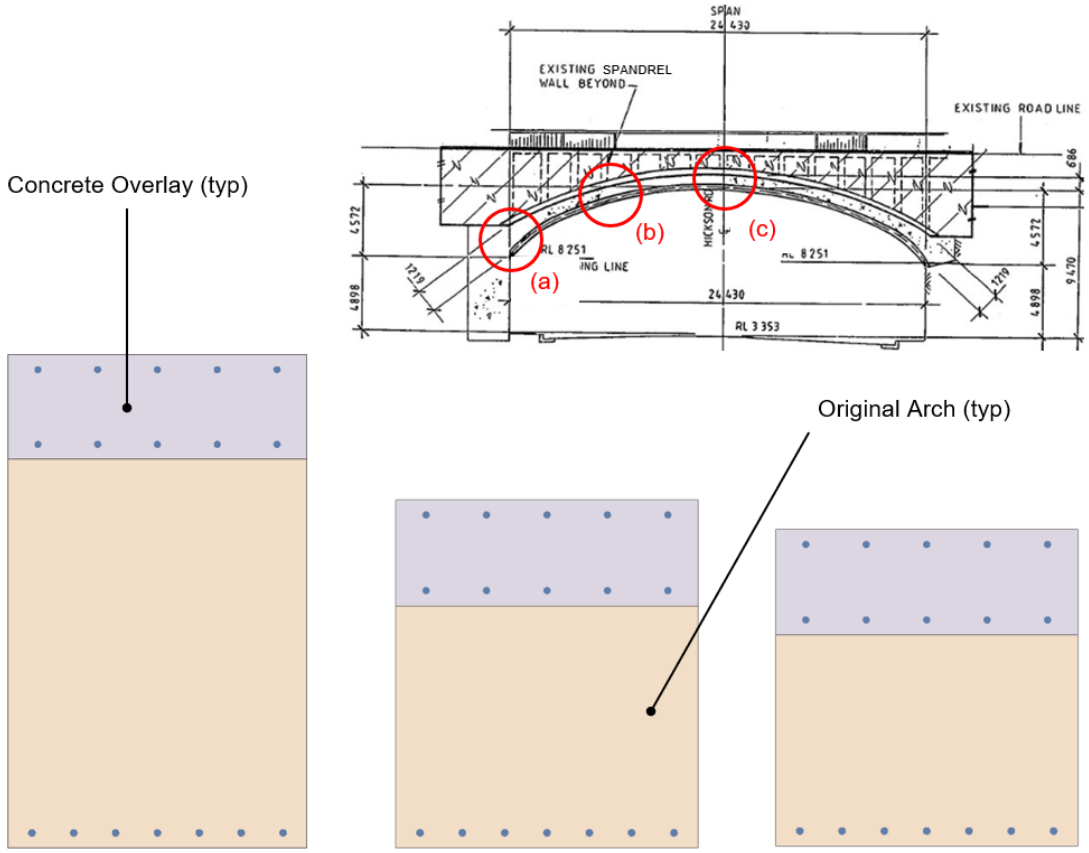
Structural Analysis: Load Effects – Hickson Road Arch Bridges

- Finite element analysis utilising Strand7 software was used.
- Axial compression, shear, positive bending moment and negative bending moment were determined.
- Existing bridge drawings were unavailable. The 28-day compressive strength of concrete in the original part of the arch ring was assumed to be 21 MPa, in accordance with clause A1.4 of AS 5100.7:2017 *Bridge design Part 7: Bridge assessment*.
- 1 metre wide strip of the arch ring was modelled in Strand7 using beam elements, with both pinned and fixed conditions at the ends of the arch.
- In the absence of the original bridge drawings, the geometric configuration of the arch was determined graphically from the details provided in the arch restoration drawings (c1990).
- Self-weight of the arch and fill, together with traffic loading and predicted displacements were applied to the arch model.
- The structural analysis of reinforced concrete arches involves determining the axial compression (P) and concurrent bending moment (M) at critical sections along the arch ring. These critical sections were the springing, crown, and between the springing and crown, as the thickness (and hence structural capacity) varies along the arch ring.

Structural Analysis: Arch Section Capacity – Hickson Road Arch Bridges

- The section capacity is then calculated, using reinforced concrete column theory, whereby a P-M interaction curve is developed for each critical section. For this component of work, Autodesk *Structural Bridge Design* software was used.
- With the critical combination of P and M identified by analysis, these points were plotted on the relevant P-M interaction diagram.
- Where the P-M load effects point is located within the column strength (interaction) curve, the arch is considered theoretically adequate to carry the load combination considered.

Structural Analysis: Arch Ring Design Sections – Hickson Road Arch Bridges



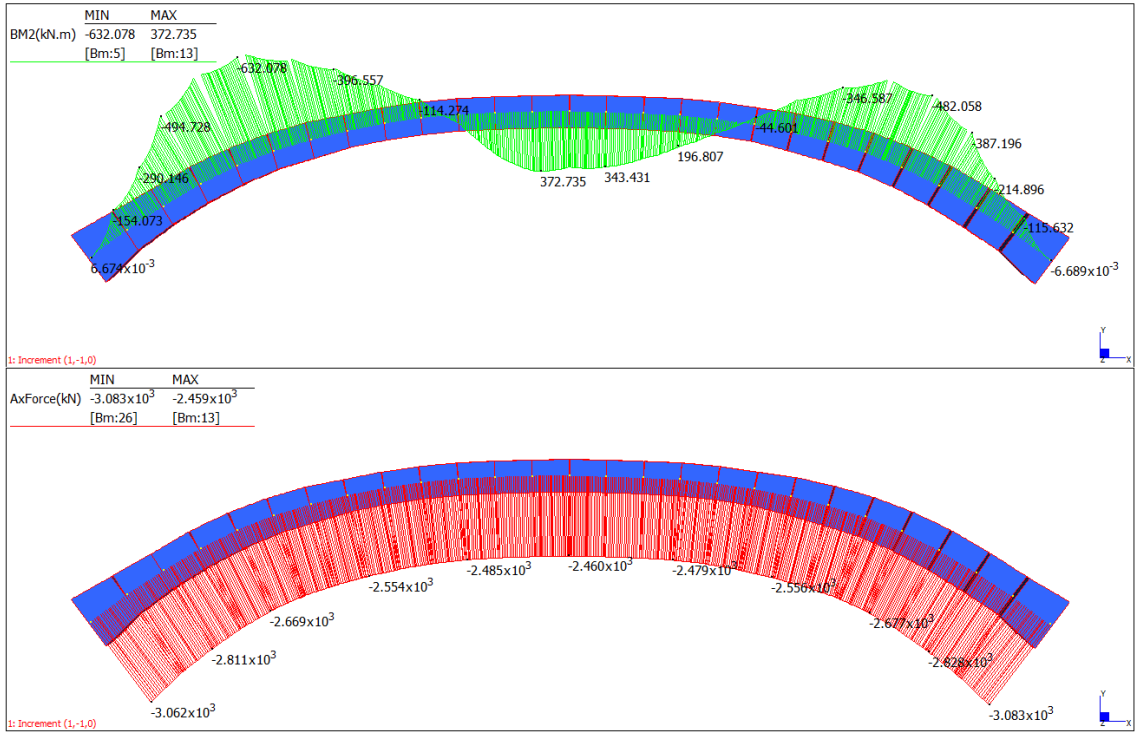
(a) End of Span Design Section

(b) Quarter-Point Design Section

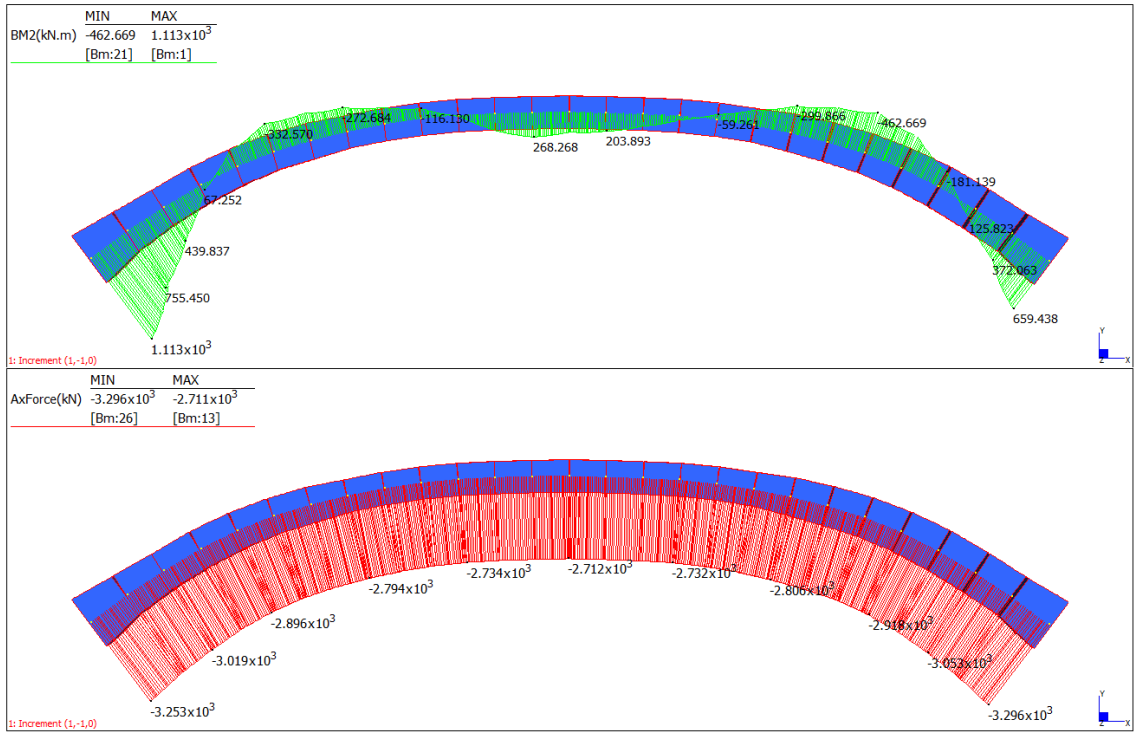
(c) Mid-Span Design Section

- Both pinned and fixed end conditions were analysed and assessed, as the degree of fixity was considered inconclusive.
- Arch sections comprised original arch ring plus later concrete overlay ⟶ different concrete strengths.
- Top surface reinforcement of original arch ring ignored ⟶ possibly severely corroded.

Structural Analysis: Strand7 Results – Hickson Road Arch Bridges

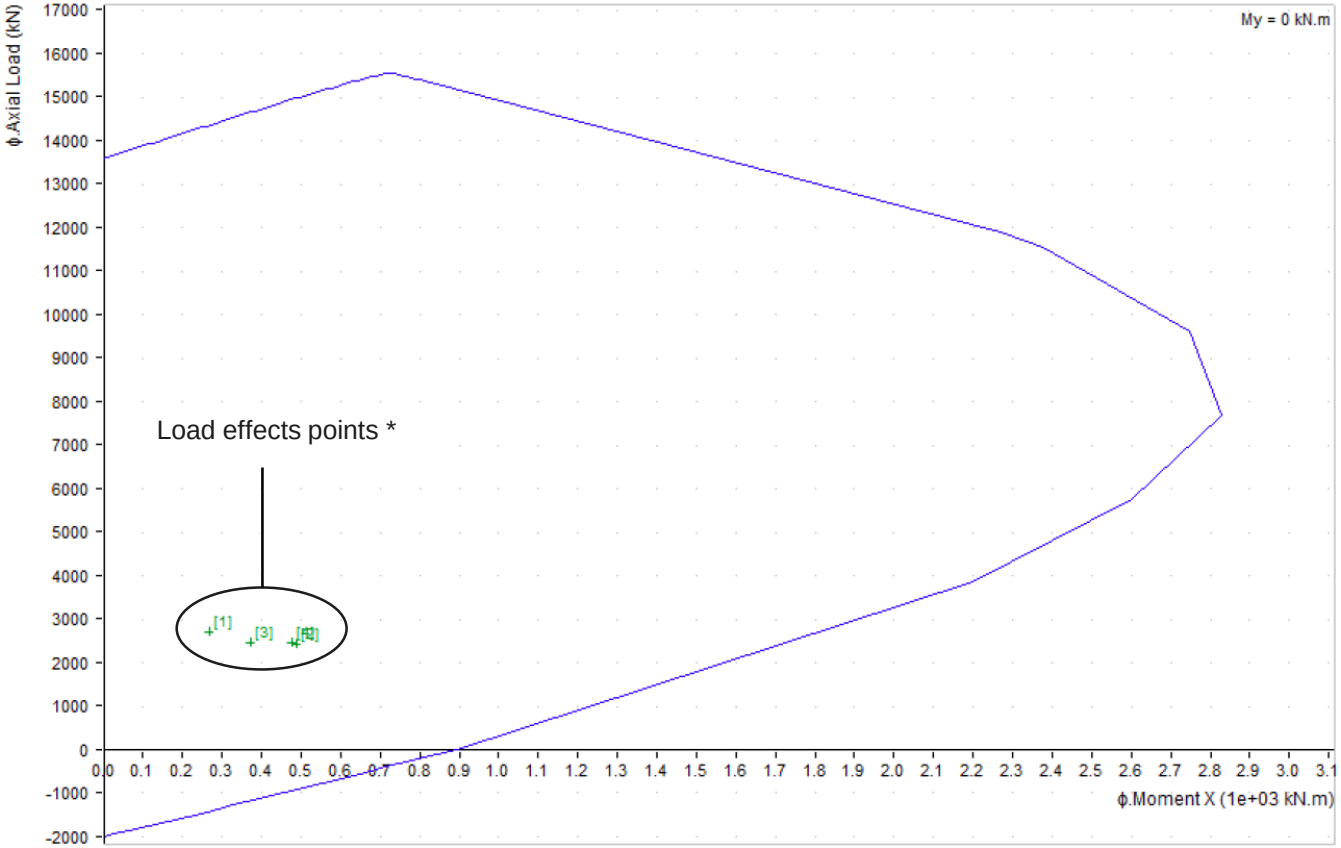


Pinned Ends – Total Loads (including Predicted Ground Movements): Bending Moment and Axial Force Diagrams



Fixed Ends – Total Loads (including Predicted Ground Movements): Bending Moment and Axial Force Diagrams

Structural Analysis – Hickson Road Arch Bridges



Column Interaction Curve – Arch Mid-Span Section

* Load effects points represent the four load cases:

(1) Fixed Ends – Existing Load Condition + Predicted Ground Movement

(2) Fixed Ends – Existing Load Condition

(3) Pinned Ends – Existing Load Condition + Predicted Ground Movement

(4) Pinned Ends – Existing Load Condition

For other arch sections (ends and quarter points), load effects points were re-arranged, but were all within the respective interaction curve.

Conclusions

- The predicted ground displacements due to proposed excavation work theoretically induces a degree of redistribution of bending moment through the arch bridges, for both arch end restraint conditions.
- Although the bending moments were shown to redistribute, they remain well within the theoretical capacity of the arch, as shown in the interaction curve plots.

Thank you for your attention