Gladesville Bridge – 50th Anniversary

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Hyder Consulting, Sydney

Gladesville Bridge – Opened 2nd October 1964

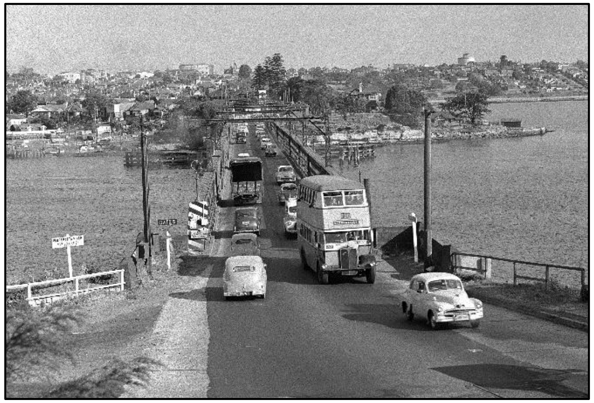
Outline of Presentation

- Old Gladesville Bridge.
- Early concept design options for replacement bridge.
- DMR tender design.
- Accepted alternative design.
- Arch falsework.
- Arch design.
- Arch construction.
- Approach spans – design and construction.
- Heritage recognition.
- Opening ceremony.

Gladesville Bridge – Parramatta River

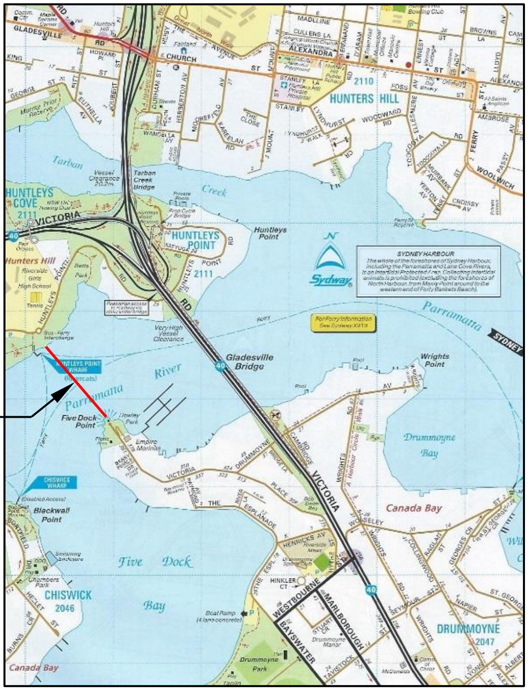
Old Gladesville Bridge

- Constructed 1878 to 1881.
- Wrought iron lattice girder spans.
- Swing span for navigation purposes.

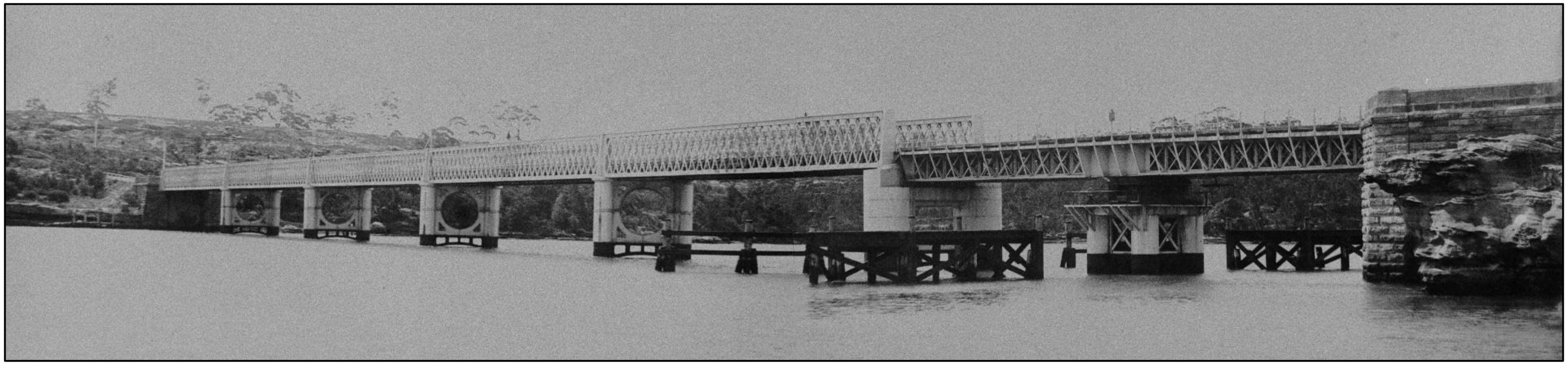


1956

Old Gladesville Bridge (approximate location)



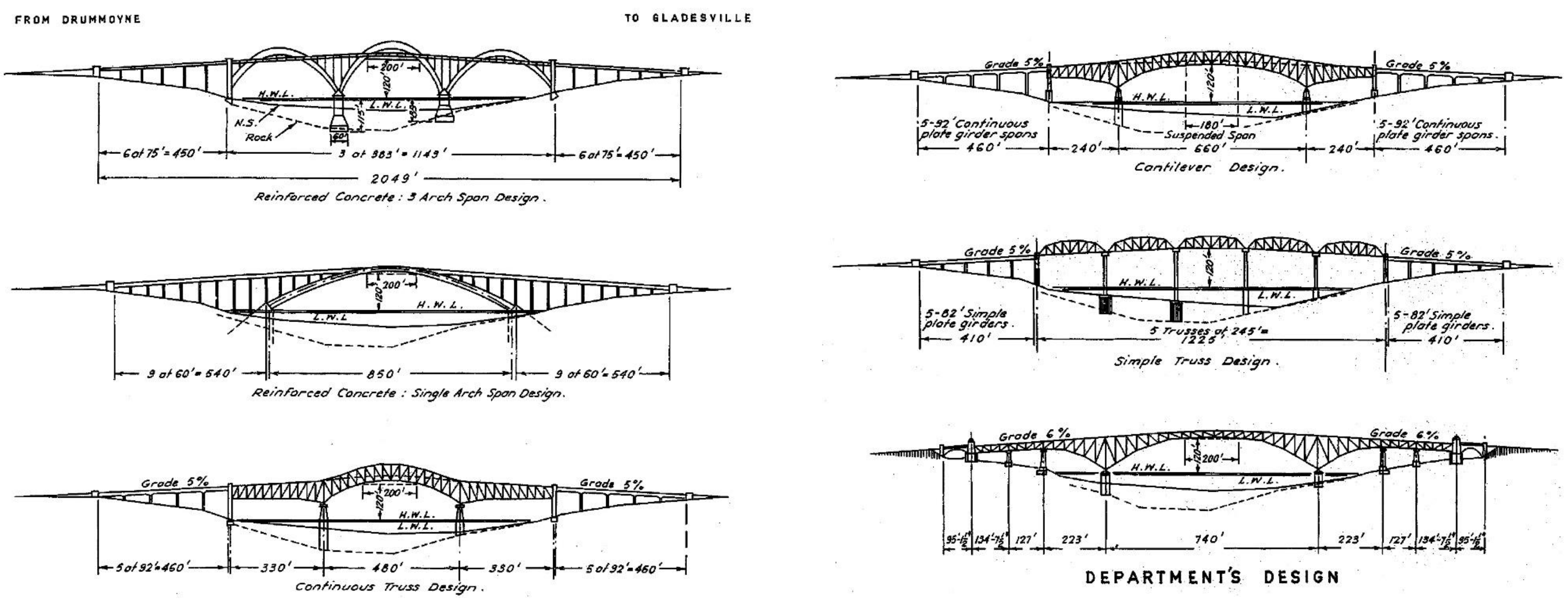
1881



Reasons for New Gladesville Bridge

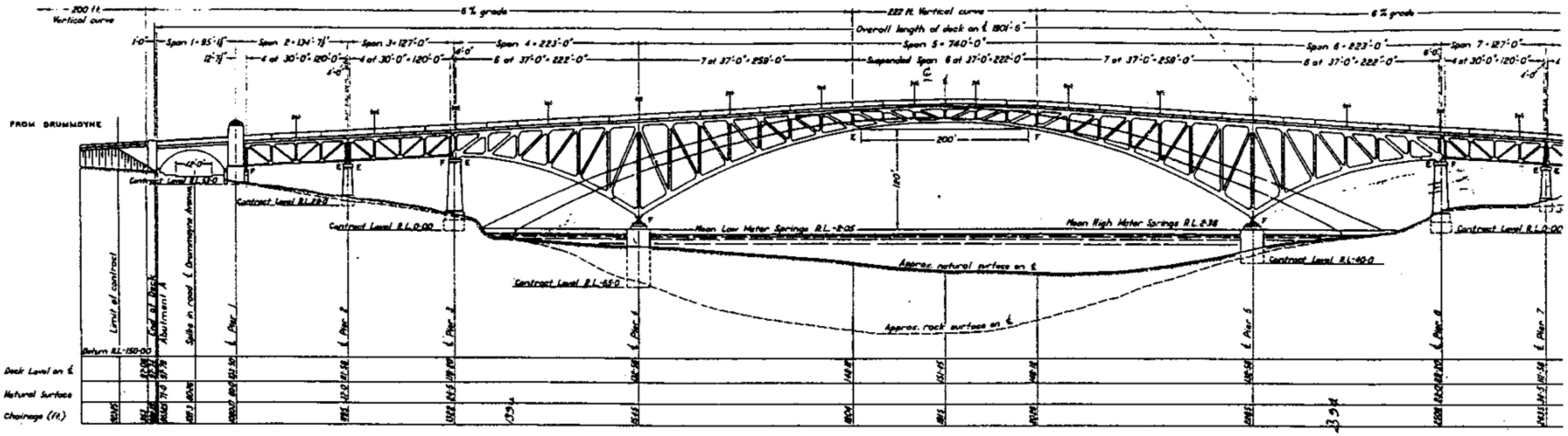
- New bridge originally intended to be part of Sydney's North Western Expressway (road linking Sydney City to the northern suburbs and through to Newcastle).
- Earlier bridge's useful service life exceeded.
- Only two-lane traffic capacity – 'bottleneck' to traffic flow.
- Swing span – abrupt interference to traffic flow.
- North Western Expressway project was abandoned in the 1970s due to protests about the freeway's projected route through inner city suburbs such as Glebe and Annandale.

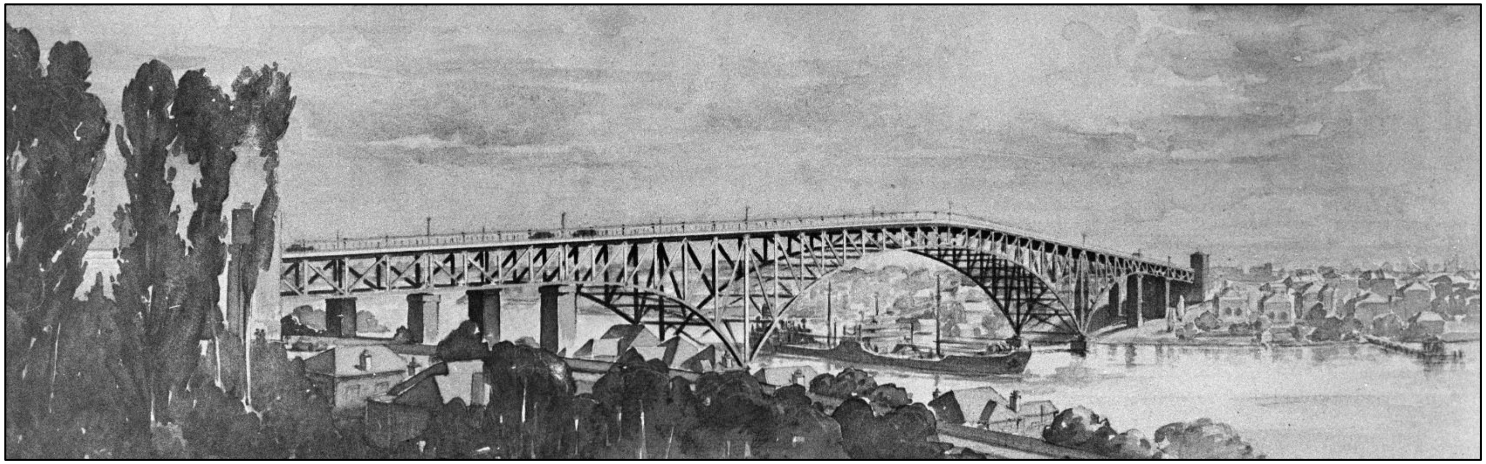
Early Concept Designs



- Concept designs developed by DMR's Bridge Section, headed by Design Engineer Cliff Robertson (one of John Bradfield's senior assistants on Sydney Harbour Bridge).
- Bridge Section of DMR included a number of other highly-respected bridge engineers during this period, namely Vladimir Karmalsky, Albert Fried and Brian Pearson.

DMR Tender Design – Steel Cantilever Bridge





Tender Process

- 1957 – tenders invited by Department of Main Roads (DMR), based on steel cantilever bridge, but alternative designs permitted (tenders closed October 1957).
- Four (4) companies tendered for the steel design.
- Tenders ranged from £2.51 M to £3.87 M.
- Alternative concrete arch design submitted for £2.39 M. Span length of 910 feet (277m).
- Concrete arch design thoroughly checked by DMR Bridge Section (assisted by University of Sydney and Eugene Freyssinet).
- June 1959 – tender awarded for concrete arch alternative.
- Span length of concrete arch increased to 1,000 feet (305m) – this increased contract price to £2.56 M.
- Final agreed contract price of £3.6 M due to northern approach revised to 10 lanes plus deeper excavation for thrust blocks.

Tender Price

Final agreed contract price in 1960 was £3.6 M. This converts today to:

- $95 M – using the consumer price index.
- $102 M – using the GDP deflator *.
- $284 M – using the per capita GDP.
- $628 M – using the share of GDP.

Source: http://www.measuringworth.com/australiacompare

* Most appropriate method when determining how much a project cost compared to the present cost of materials or labour

Design and Construction

Contractor

- Stuart Brothers and Partner (joint venture by Stuart Brothers (Sydney) and Reed and Mallik (UK)).

Design Engineers

- Messrs. G. Maunsell and Partners, consulting engineers (London and Melbourne).

Design Checker

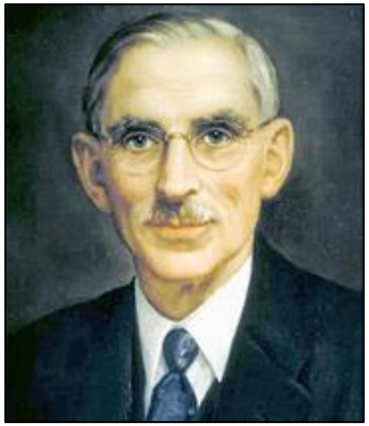
- Department of Main Roads, NSW Bridge Section.

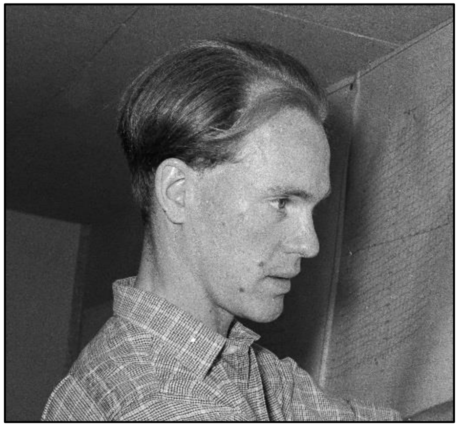
Department's Consultants

- Department of Civil Engineering, University of Sydney (Professor Roderick).
- Societe Technique pour l'Utilisation de la Precontrainte (France) (technical corporation for the utilisation of prestressed concrete).
- Professor Pippard (Imperial College, University of London).

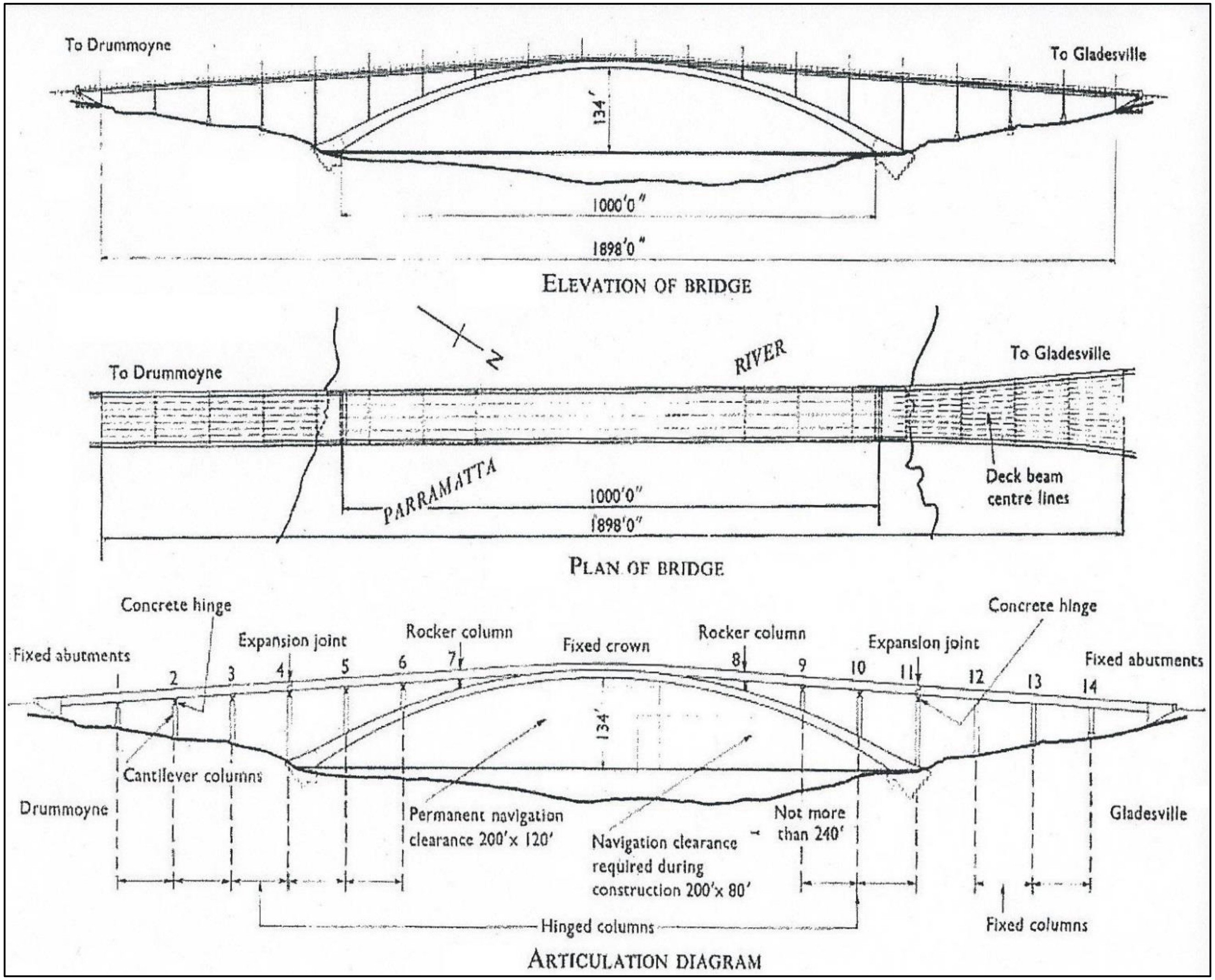
Arch Design Engineers

- Guy Anson Maunsell (1884 – 1961) – British civil engineer and founder of G. Maunsell & Partners (in 1955) conceived the design of the concrete arch alternative for Gladesville Bridge.
- G. Maunsell & Partners → Maunsell & Partners → Maunsell → Aecom.
- Anthony Gee of G. Maunsell & Partners carried out the detail design of Gladesville Bridge. Anthony Gee is now Principal of Tony Gee International.

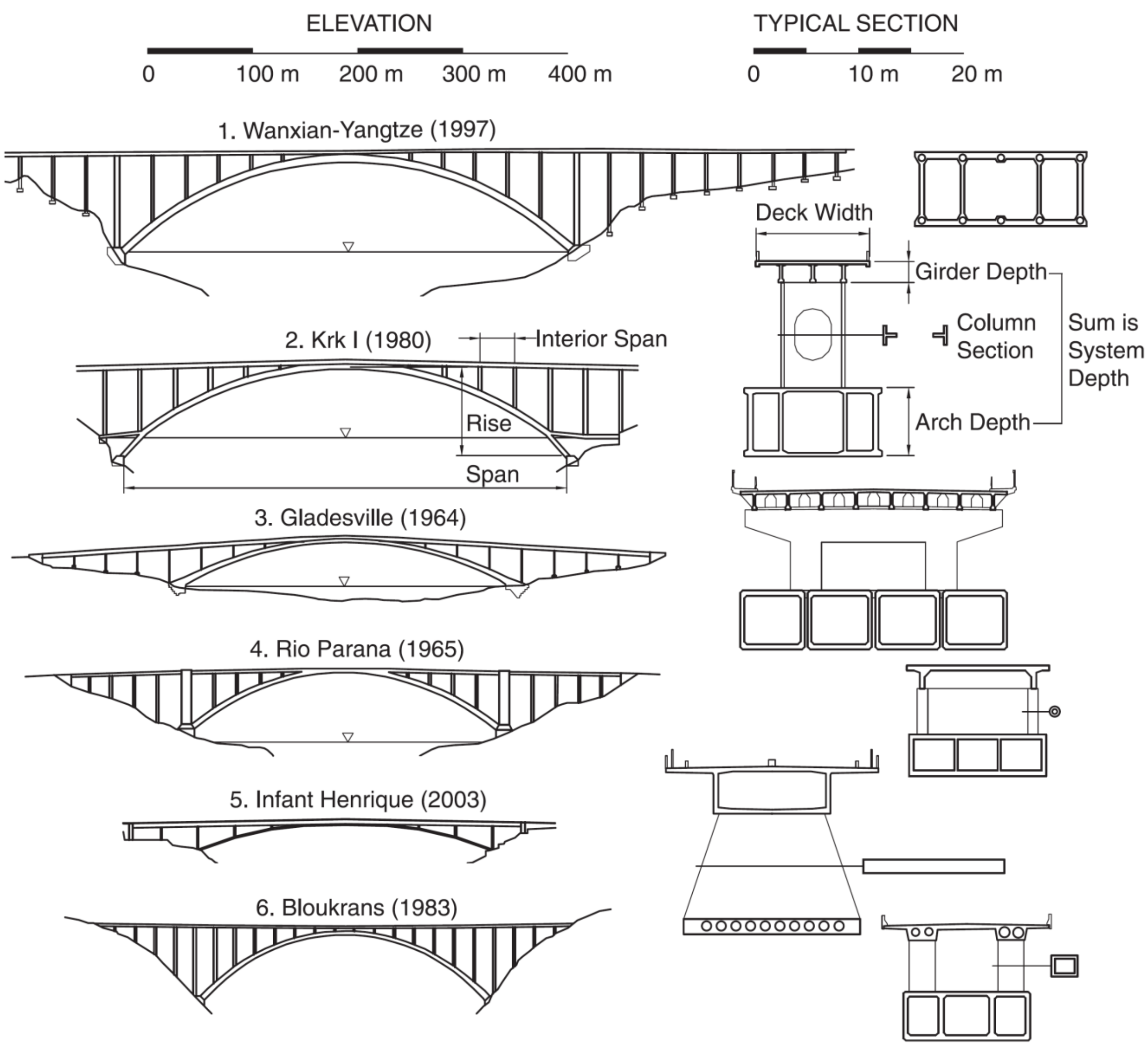

Guy Maunsell


Anthony Gee (early 1960s)

New Gladesville Bridge – Configuration



Comparative Study – Concrete Arch Bridges



Sandö Bridge, Sweden

Hyder

- Opened 1943.
- 264m span.
- Held record for longest span until 1964.
- Now 7th longest concrete arch bridge span.

Krk 1 Bridge, Croatia

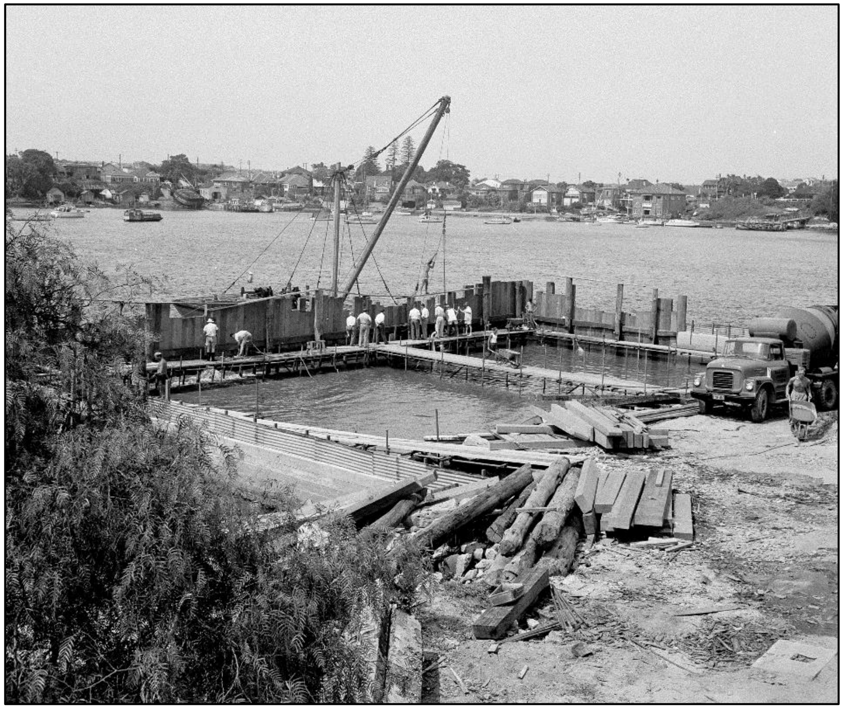
- Opened 1980.
- 390m span.
- Held record for longest span until 1997.
- Now 2nd longest concrete arch bridge span.

Contemporary Arch Bridges

Arrábida Bridge (Oporto, Portugal) – opened 1963, arch span 270m

Iguacu Bridge (Brazil/Paraguay border) – opened 1965, arch span 290m

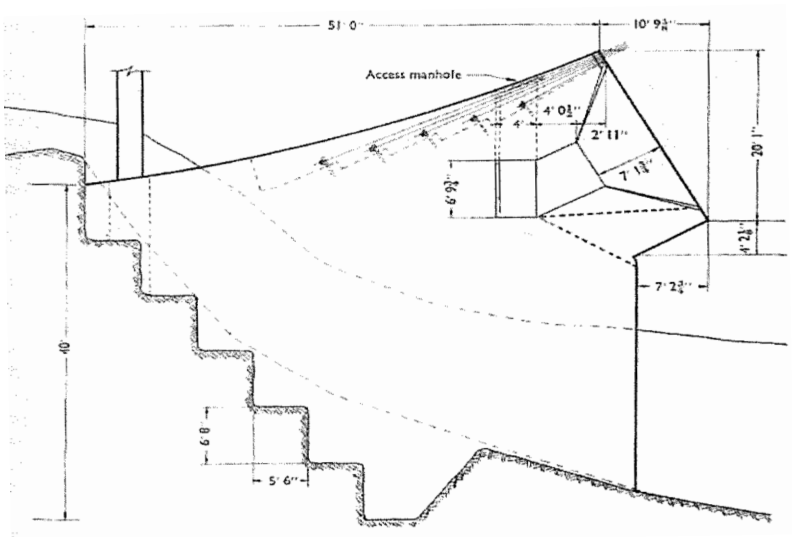
Coffer Dams for Arch Thrust Blocks



Timber sheet coffer dam under construction – Huntleys Point / Gladesville side (February 1960)

Timber sheet coffer dam under construction – Drummoyne side (1960)

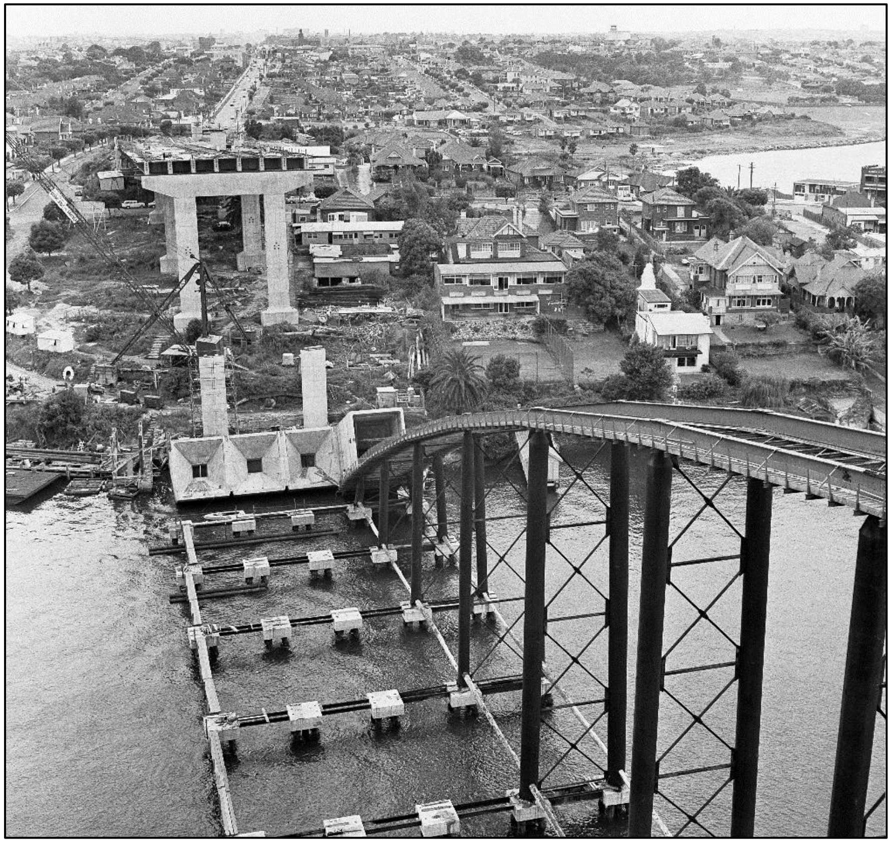
Arch Thrust Block



- Founded on steps cut in sandstone.
- Explosives used for breaking up the rock.
- Excavations filled with mass concrete – strength 6,000psi (41MPa).
- Access manhole to corridor across abutment width – provides access to interior of all four (4) arch ribs.

Arch Thrust Block

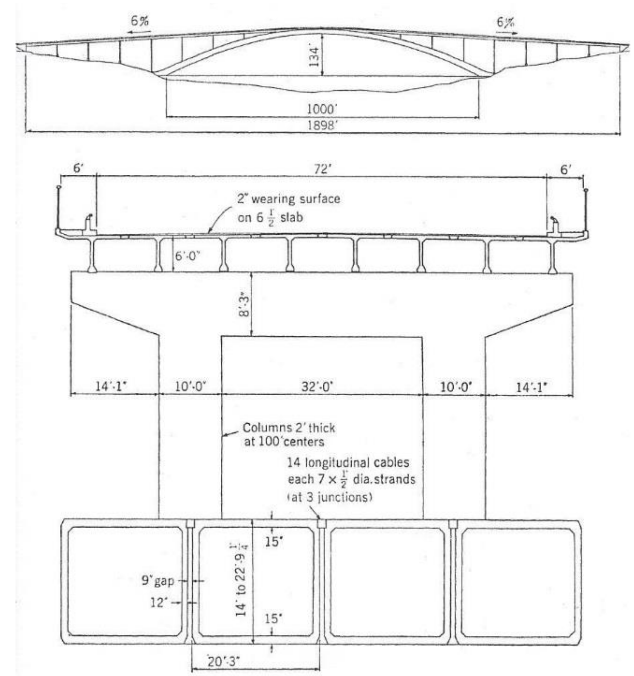
Drummoyne abutment construction

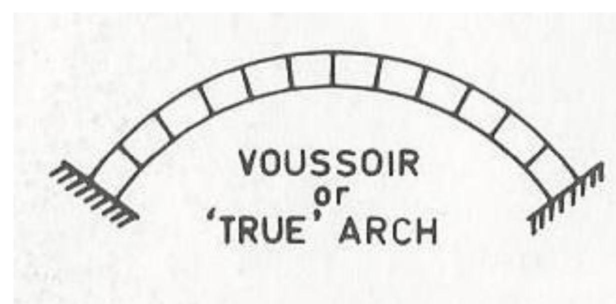


Drummoyne end of bridge

Arch Design

- Precast segmental open-spandrel arch construction (4 arch ribs, each comprising 108 precast concrete hollow blocks and 19 precast concrete diaphragm blocks).
- Similarities with Roman voussoir arch – but hollow precast reinforced concrete blocks instead of solid stone blocks.
- Reputedly the first significant bridge in the world to be structurally designed by computer: a Ferranti Pegasus.
- Was the longest concrete arch bridge in the world until 1980 (Krk 1 Bridge, Croatia).
- Today, Gladesville Bridge is the third longest concrete arch bridge in the world.





Arch Design

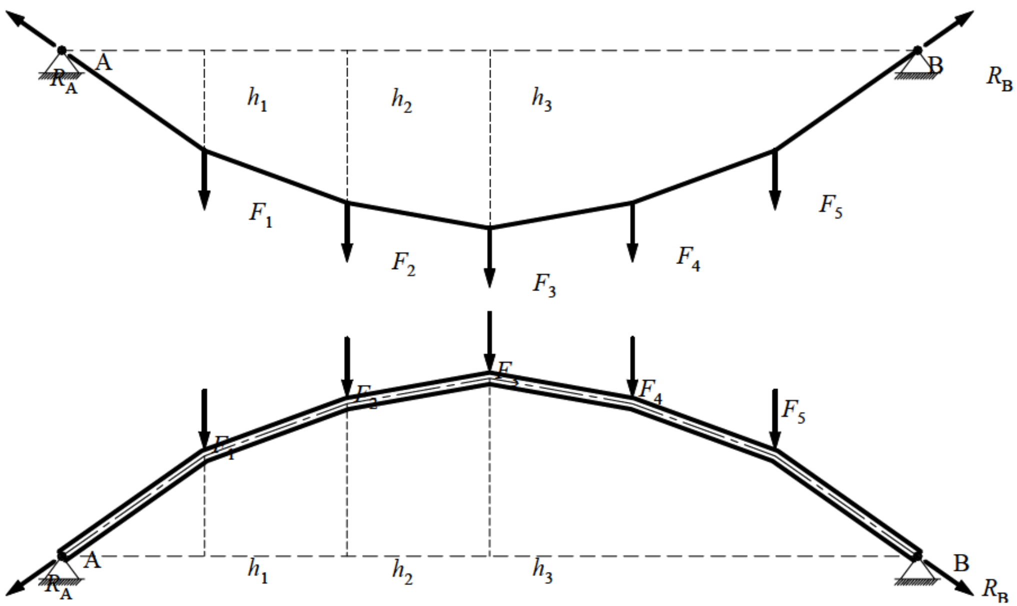
Hyder

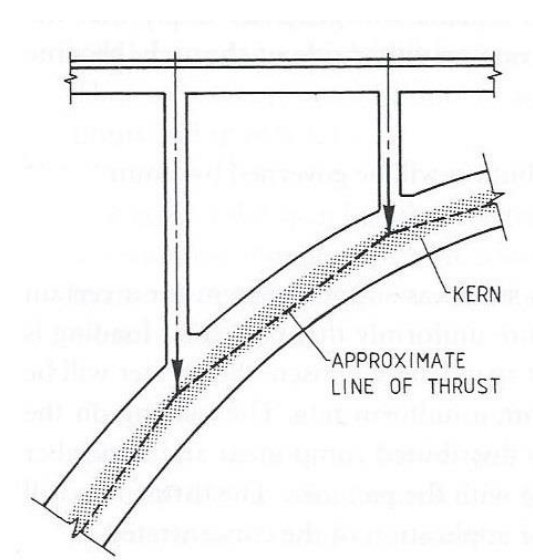
- Nineteen (19) transverse diaphragms (at 15.2m intervals) tie the four (4) arch ribs together.
- Diaphragms (610mm thick) effectively distribute loads from columns equally to each arch rib.
- Longitudinal prestressing cables between ribs (in the top slab regions) were added as a 'belts and braces' feature.
- Depth of arch at crown changed from 12 feet to 14 feet deep following advice from Societe Technique pour l'Utilisation de la Precontrainte (France) to increase FOS for vertical instability/buckling.
- Each precast concrete arch rib block was reinforced sufficiently to resist handling stresses only. Concrete strength 6,000psi (41MPa).
- Arch ribs designed so as to have no tension in the concrete under any loading condition.
- Stresses created by self weight were a large proportion of the final total stresses. As such, the arch was made perfectly funicular under its own weight.

Arch Design

- Three (3) inter-connected computer programs written specifically for the analysis of the arch:
  - 1st program determined geometric curves for both intrados and extrados to fit required arch depths along the length of the span. Program then produced section properties.
  - 2nd program calculated influence lines for unit loads, moments and strains due to unit thrust and moment and thrust due to unit strain. Also, the funicular profile of the arch under its own weight was calculated by this program.
  - 3rd program calculated the dimensions of each precast voussoir unit.

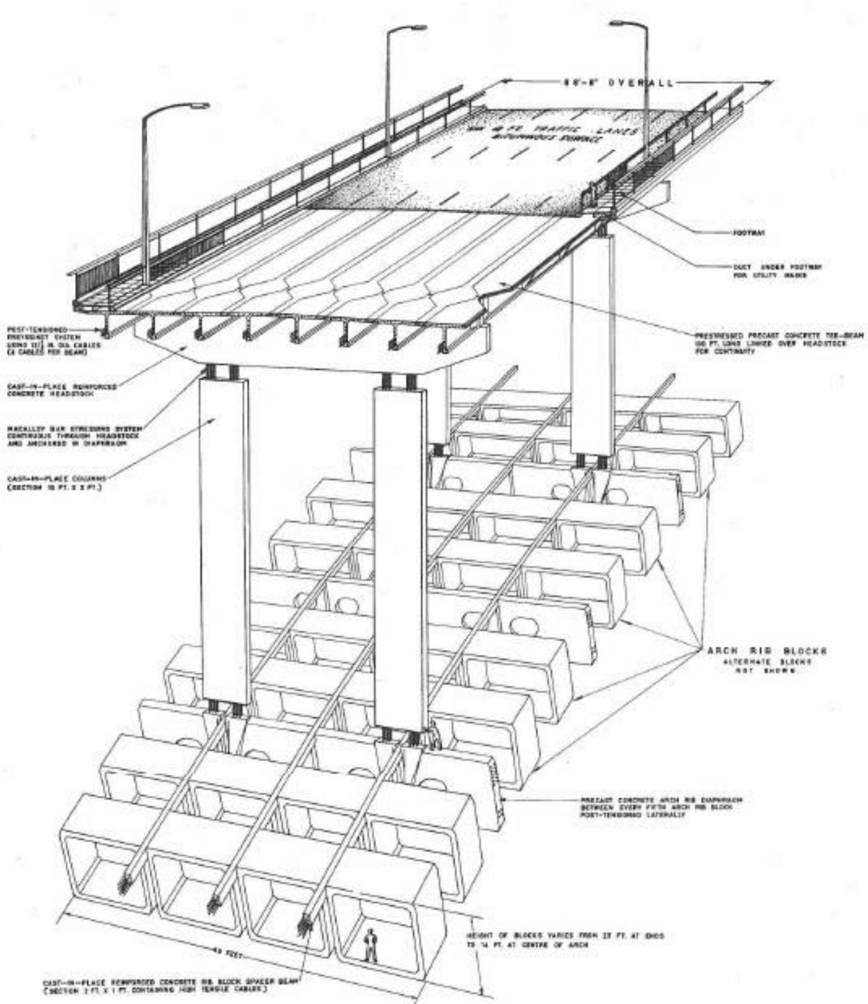
Funicular Arch



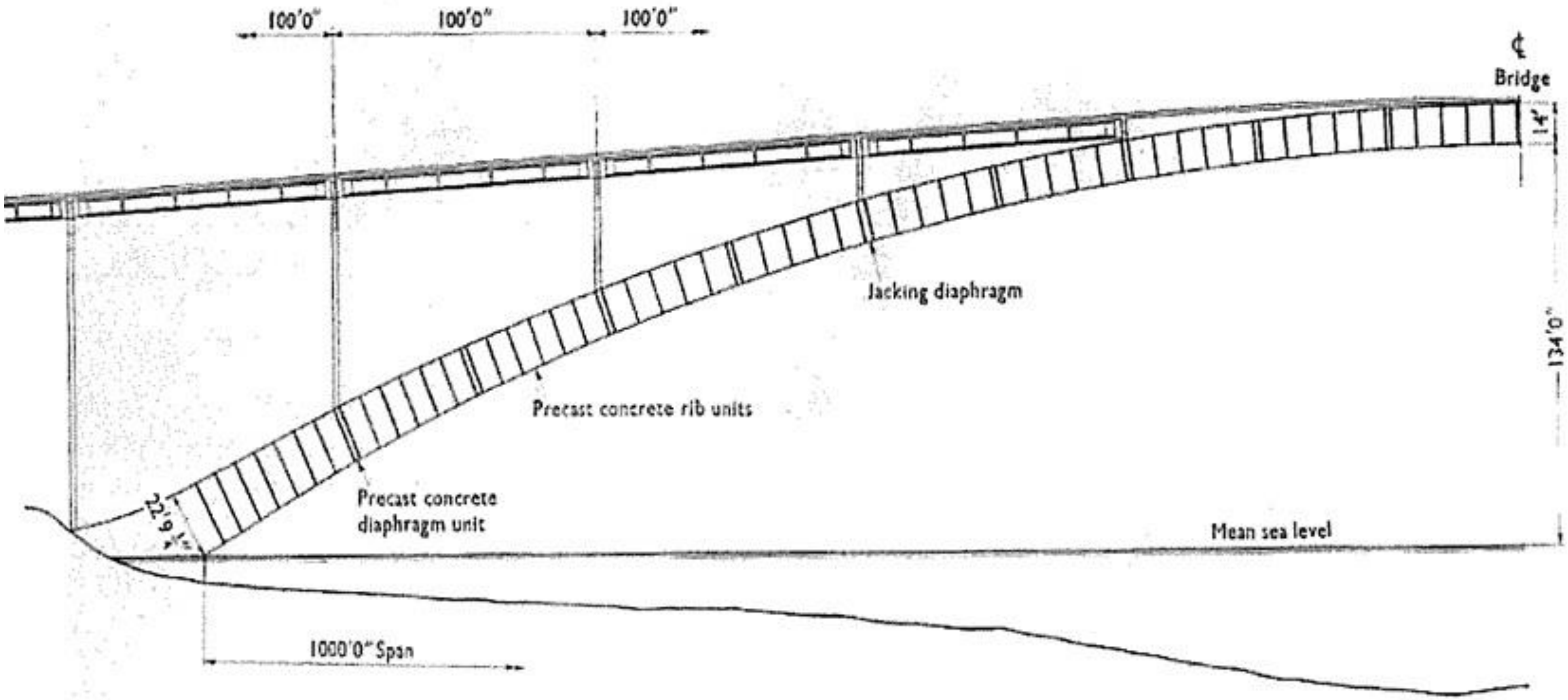


- Inverted shape of cable represents funicular ‘arch’.
- Line of thrust within middle third of section (‘kern’) ensures no tension in arch.

Bridge Schematic



Arch Elements

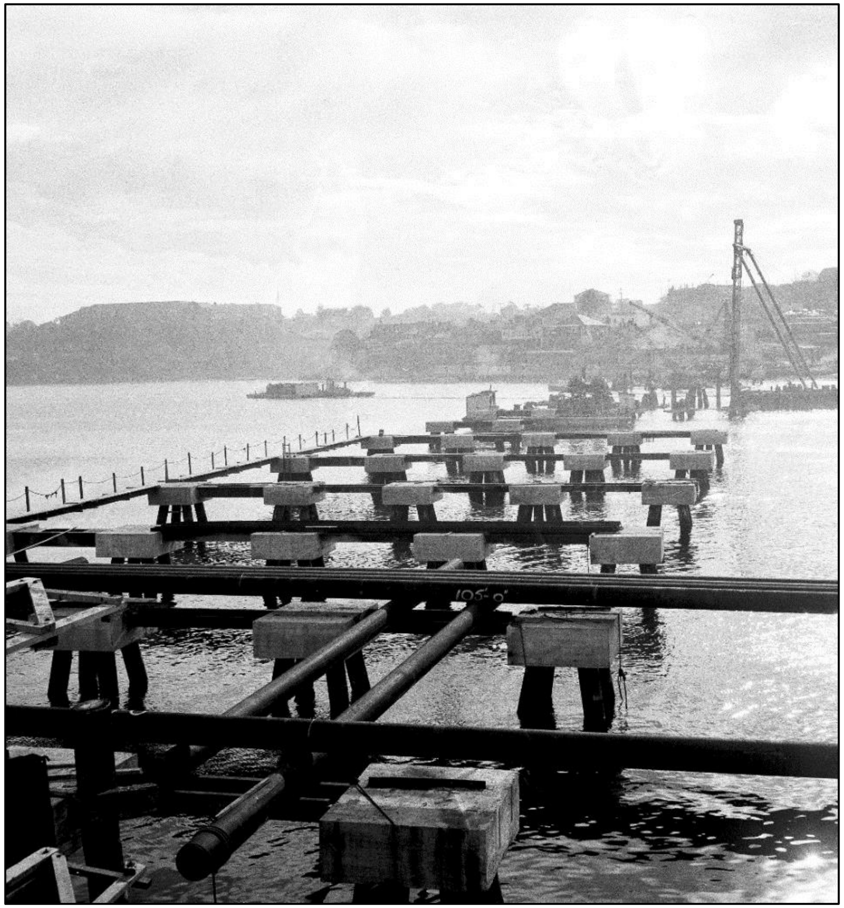


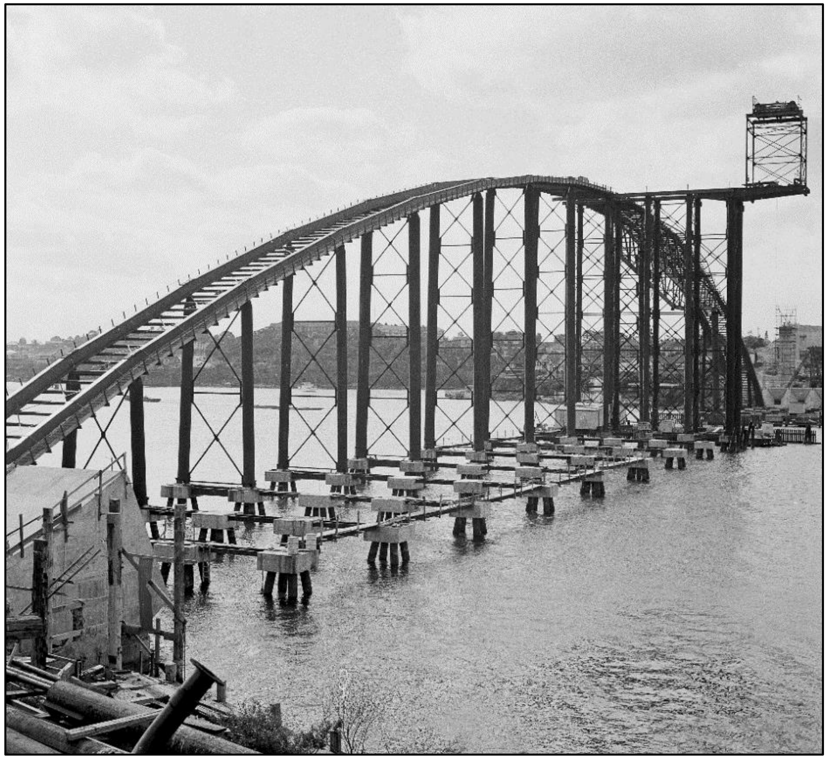
- Precast arch units vary in height from 14 feet (4.27m) at the crown to 22 feet 9¼ inches (6.94m) at abutments.
- All precast arch units are 20 feet 3 inches (6.17m) wide.

Arch Falsework

- The falsework (or centering) system was an innovative structure in its own right.
- Steel tubular piles and concrete pile caps in a grid pattern across the entire width of the future bridge.
- Braced tubular steel columns supporting steel frame decking was used to support a single arch rib.
- Slid sideways on rails for subsequent arch rib construction.
- To enable the steel falsework to move laterally, each arch rib had to be lifted off the falsework.
- This was achieved by inflating flat jacks that were placed between box segments at the one-quarter and three-quarter point locations along the arch rib span.

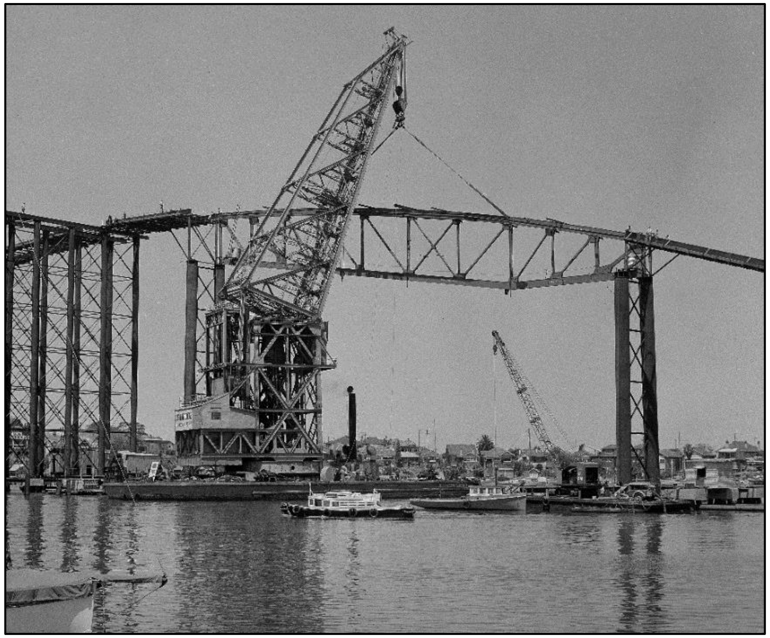
Arch Falsework



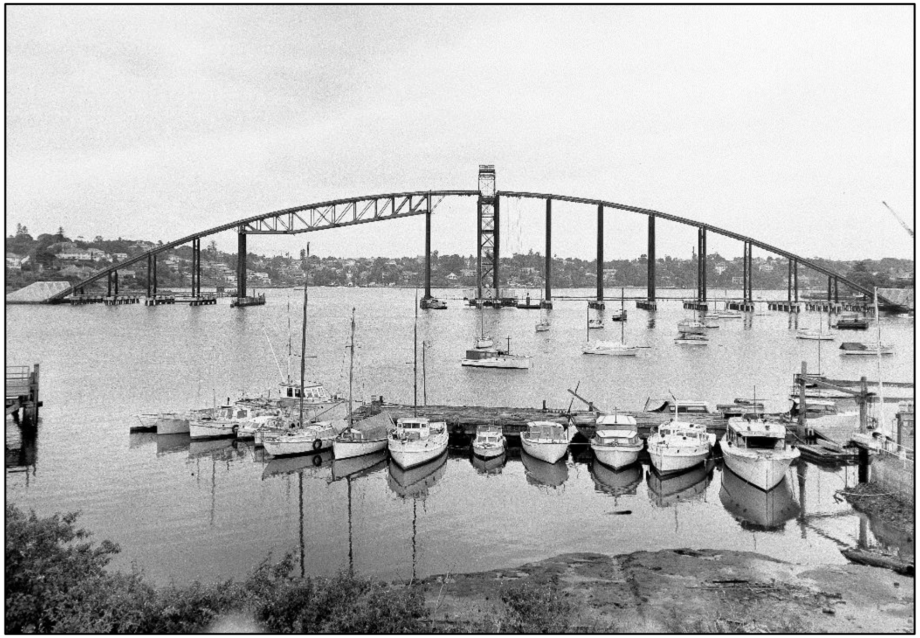


Note hoisting gantry for precast arch units

Arch Falsework



Erection of navigation span



Completed falsework system

Arch Falsework

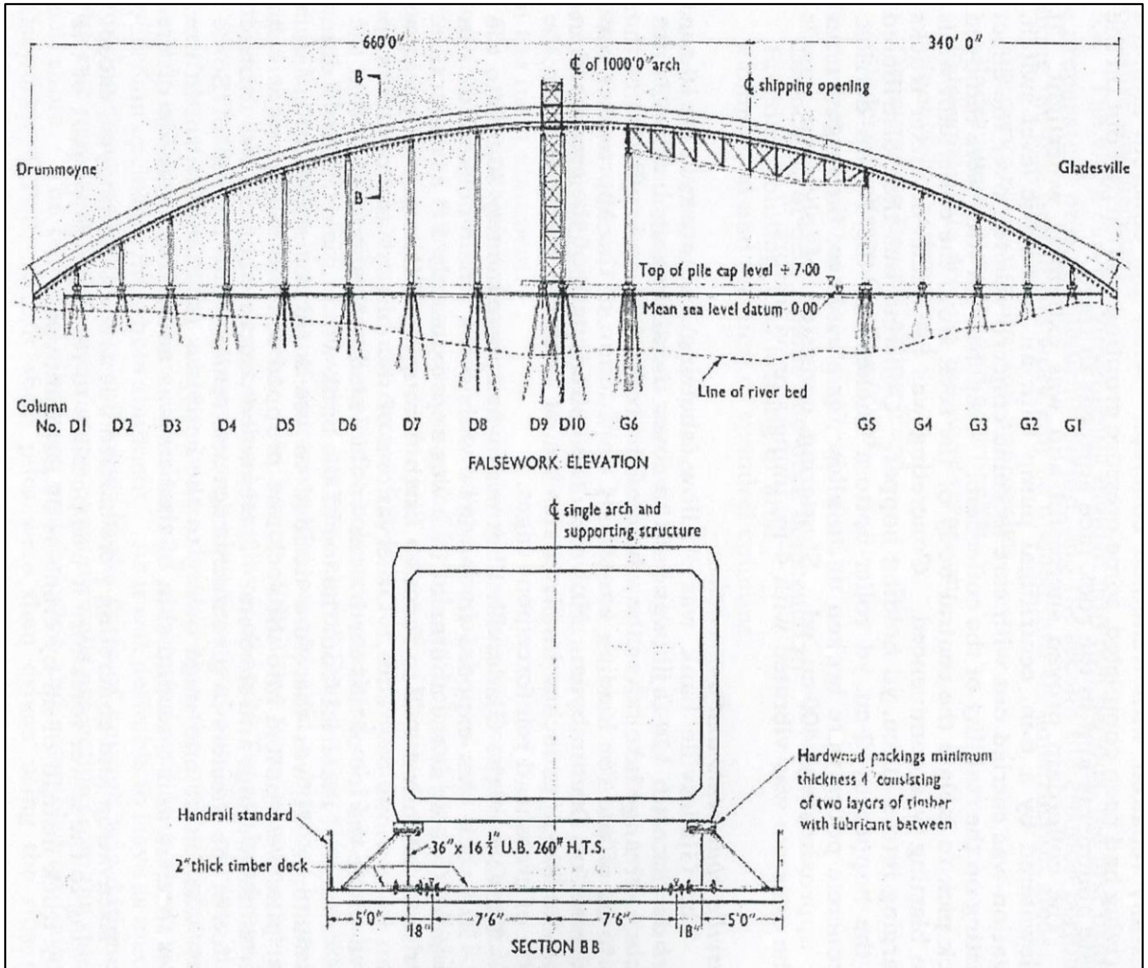


FIG. 16: DETAILS OF FALSEWORK

- Falsework designed by G. Maunsell & Partners/Reed & Mallik.
- High tensile steel girders.
- Cross girders supported rails for arch transportation trolley.
- Arch segments packed up to arch profile off falsework girders.

Woolwich Casting Yard

- 432 arch units in total were cast.
- Units cast for one (1) complete arch rib and laid out for transportation to bridge.
- Arch span pier headstocks also cast at Woolwich.

Arch Construction

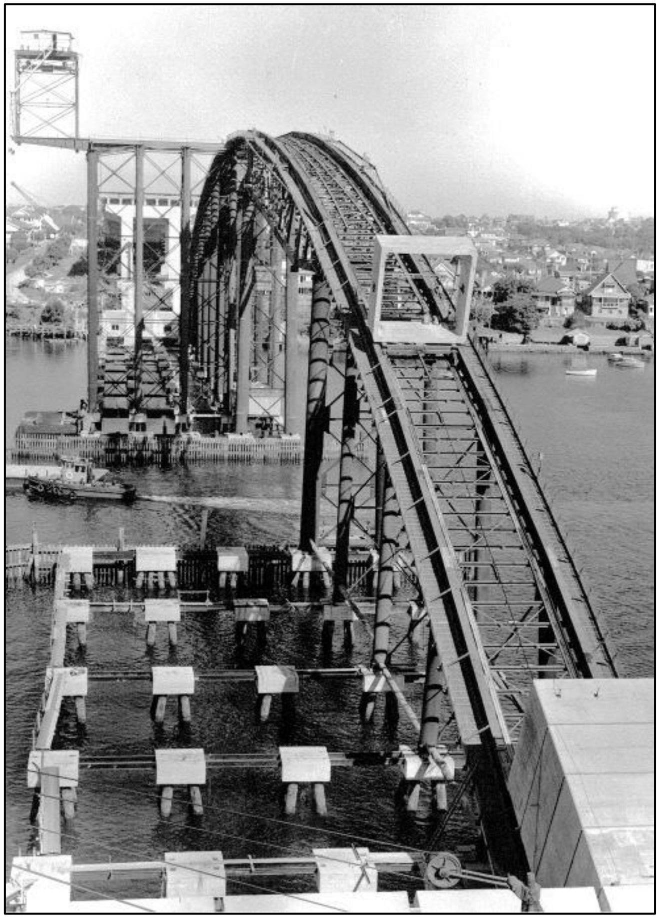
- Precast arch rib units transported to bridge site by towed barge.
- Units hoisted from barge and onto trolley.
- Units rolled laterally into position onto arch falsework.
- Units winched along arch falsework track via trolley – alternating sides to maintain a balance of loads on the falsework.

Arch Construction

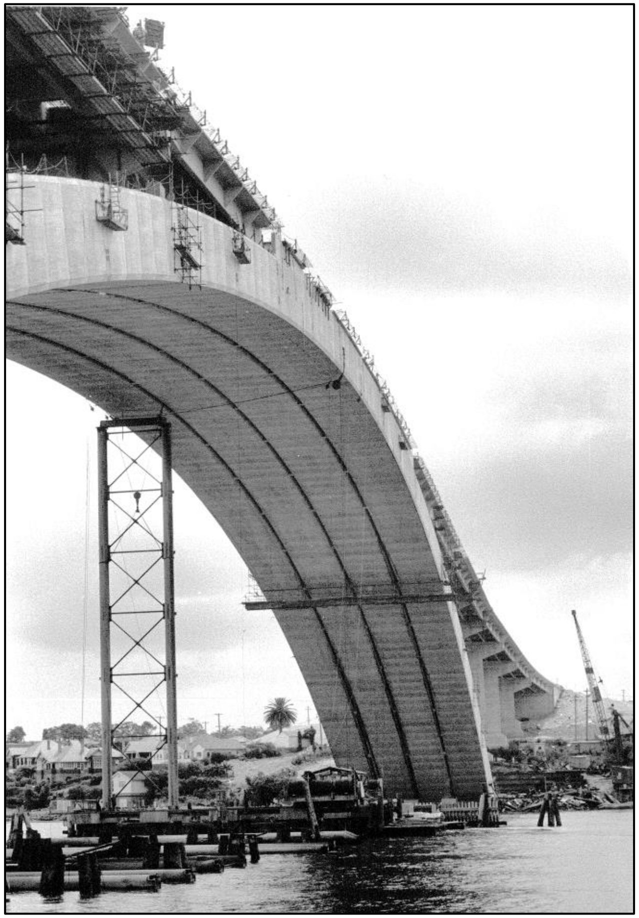
Precast arch unit winched along falsework on trolley

Final placement of precast arch unit

Arch Construction



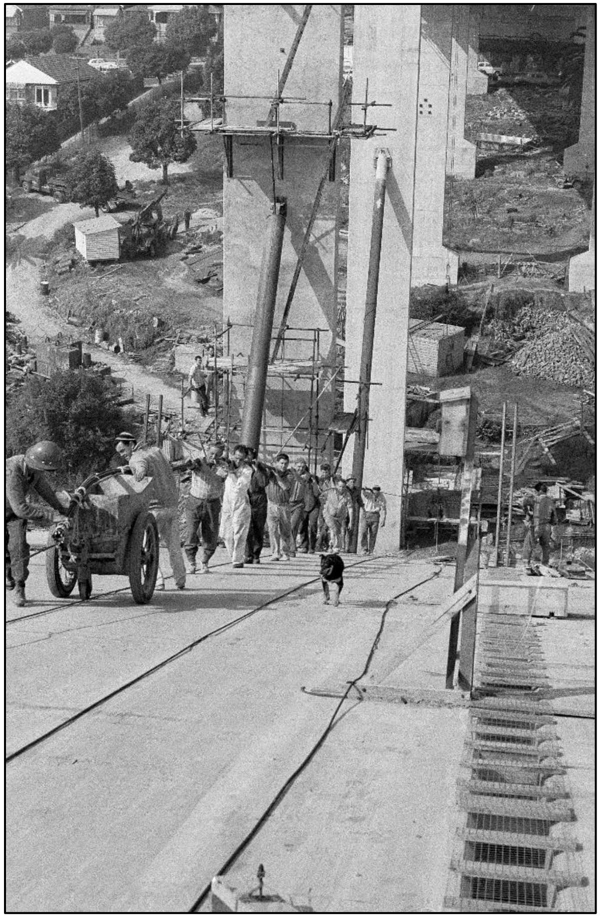
Early stages of first arch rib construction



Self-supporting arch ribs

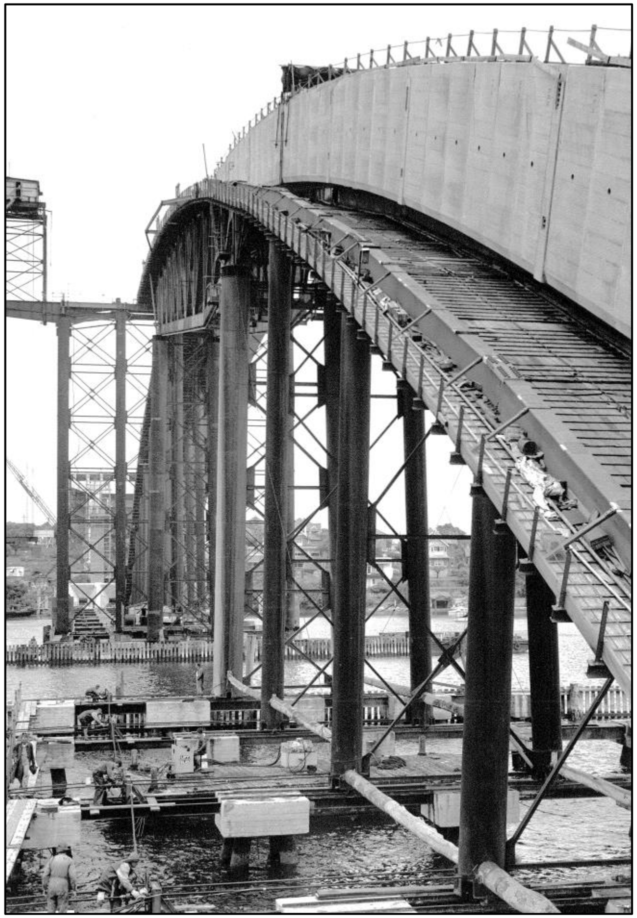
Arch Construction

Note 230mm (9 inches) gaps between arch ribs (subsequently used for post-tensioning tendons)

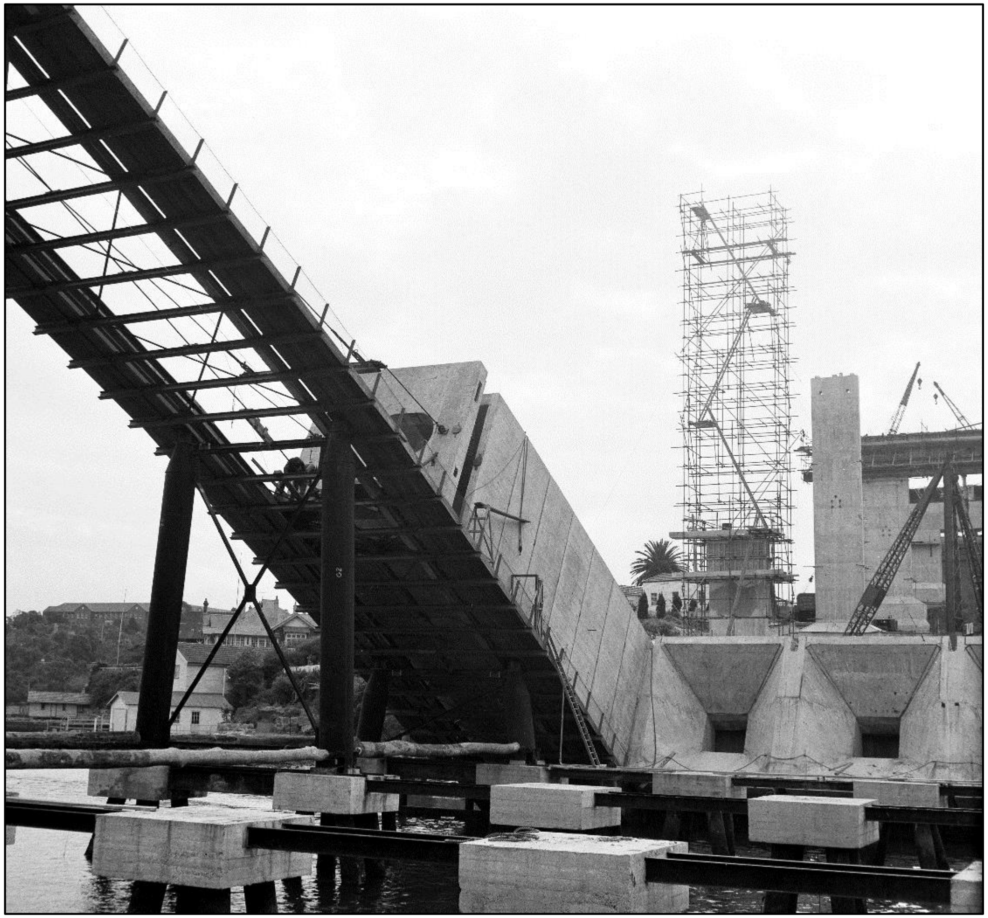


Installing post-tensioning tendons between arch box units

Arch Construction

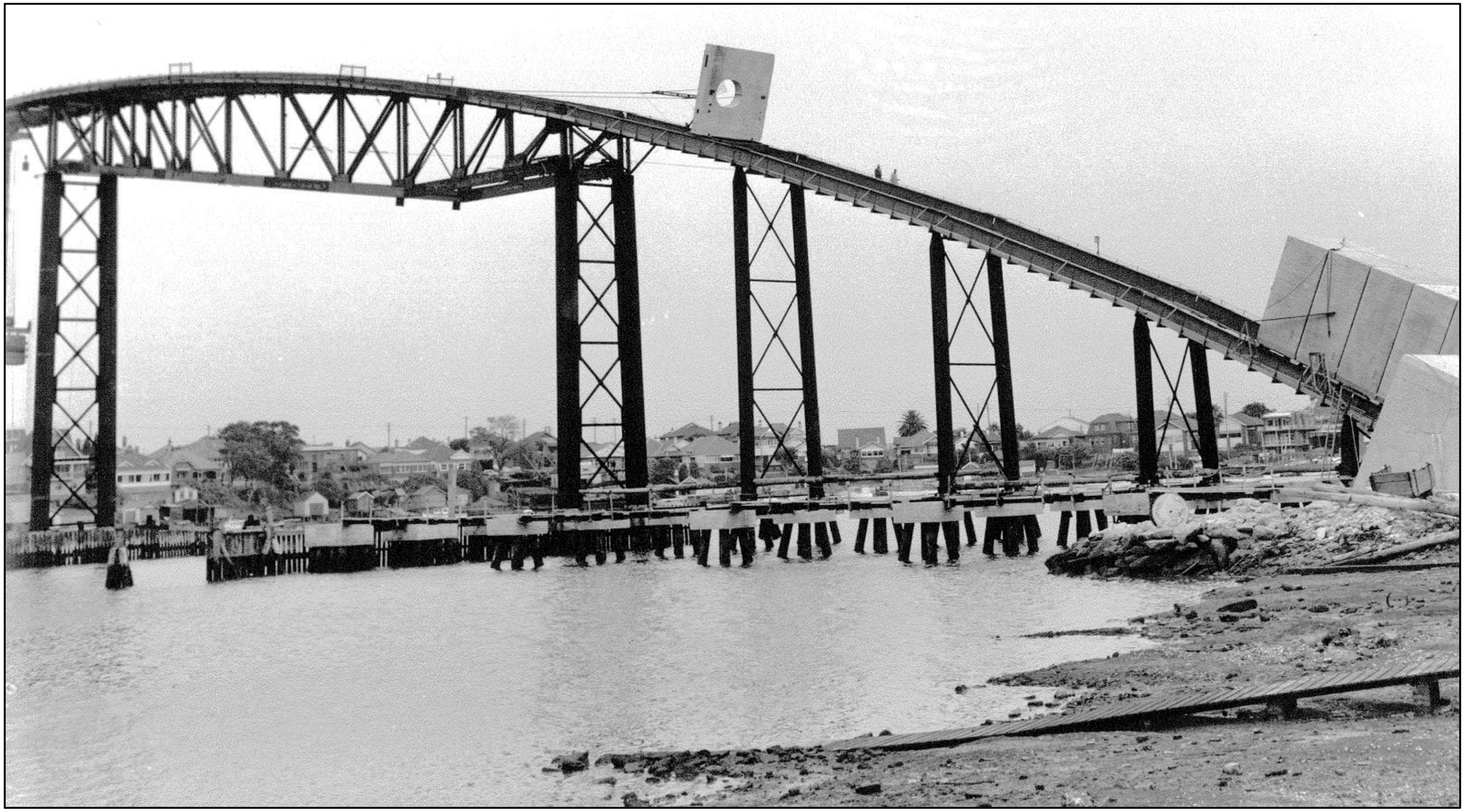


Lateral shifting of falsework



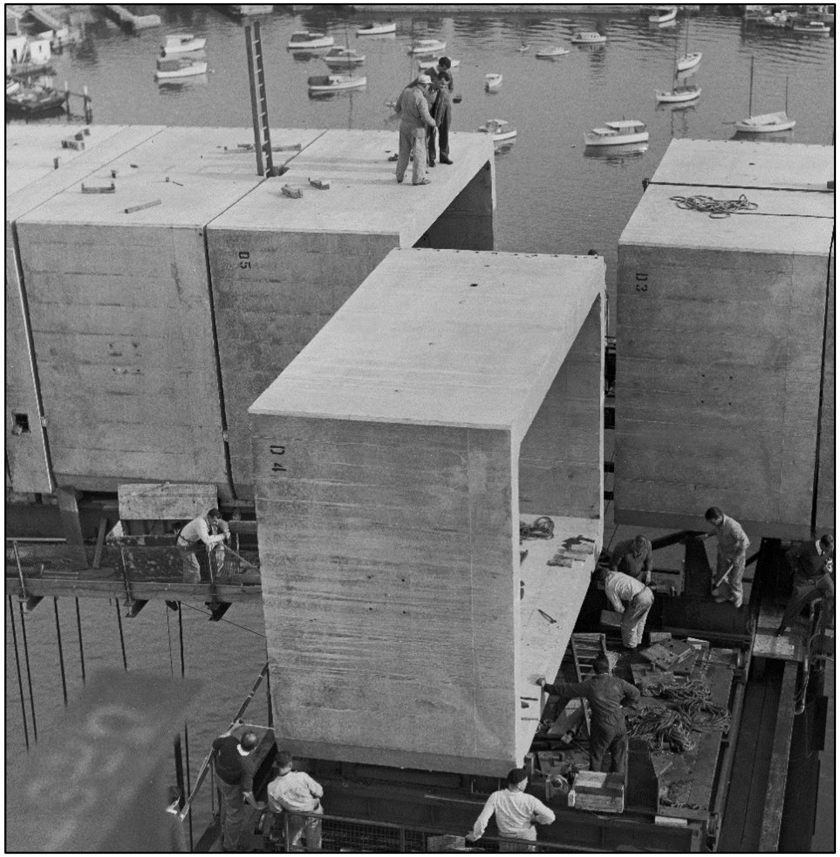
Installation of Precast Diaphragm Unit

Arch Construction



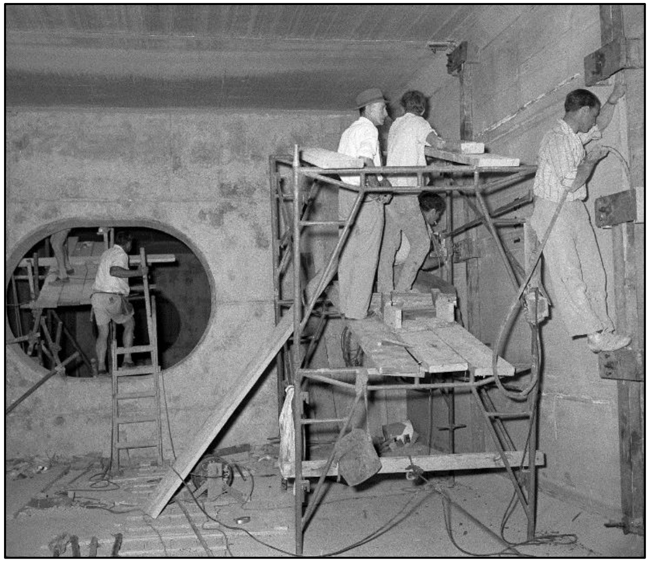
Precast diaphragm unit making its way along falsework track by trolley and winch

Arch Construction

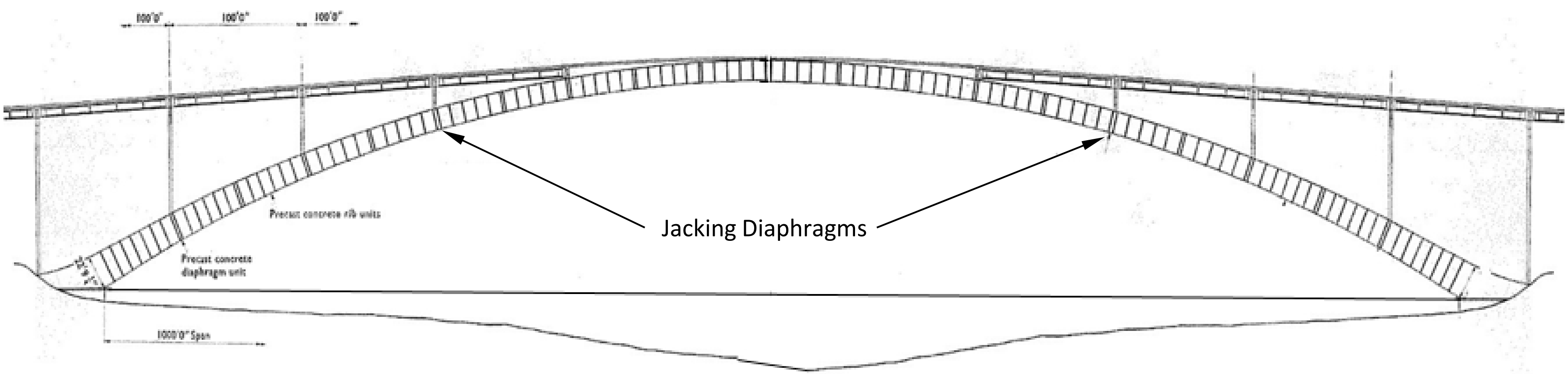


Last box unit installed in first arch rib

- 3 inch (76mm) gaps between boxes in individual rib.
- Cast insitu joints between precast arch units.

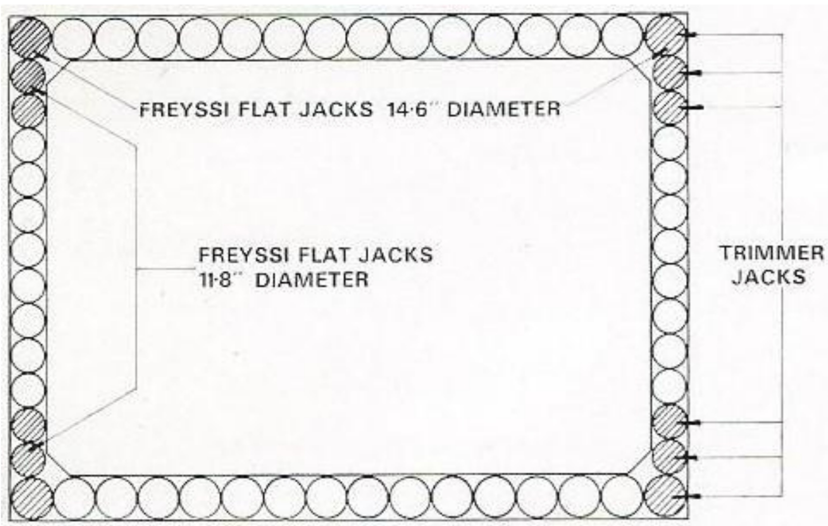


Arch Rib Jacking

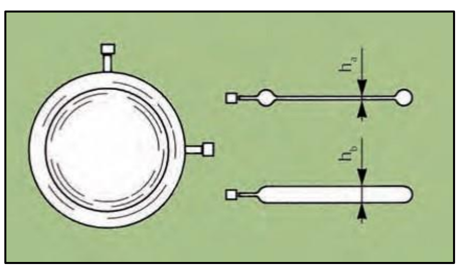


- To allow falsework to shift sideways to support the next rib, entire arch rib had to be lifted off falsework. Jacking provided upward movement of the entire arch rib.
- Arch rib sprung by jacking approximately 3½ inches (≈ 90mm), thereby raising arch rib by approximately 8 inches (≈ 200mm).
- Jacking at 1st and 3rd quarter points of each arch rib.

Arch Rib Jacking



Arrangement of flat jacks around perimeter of arch unit



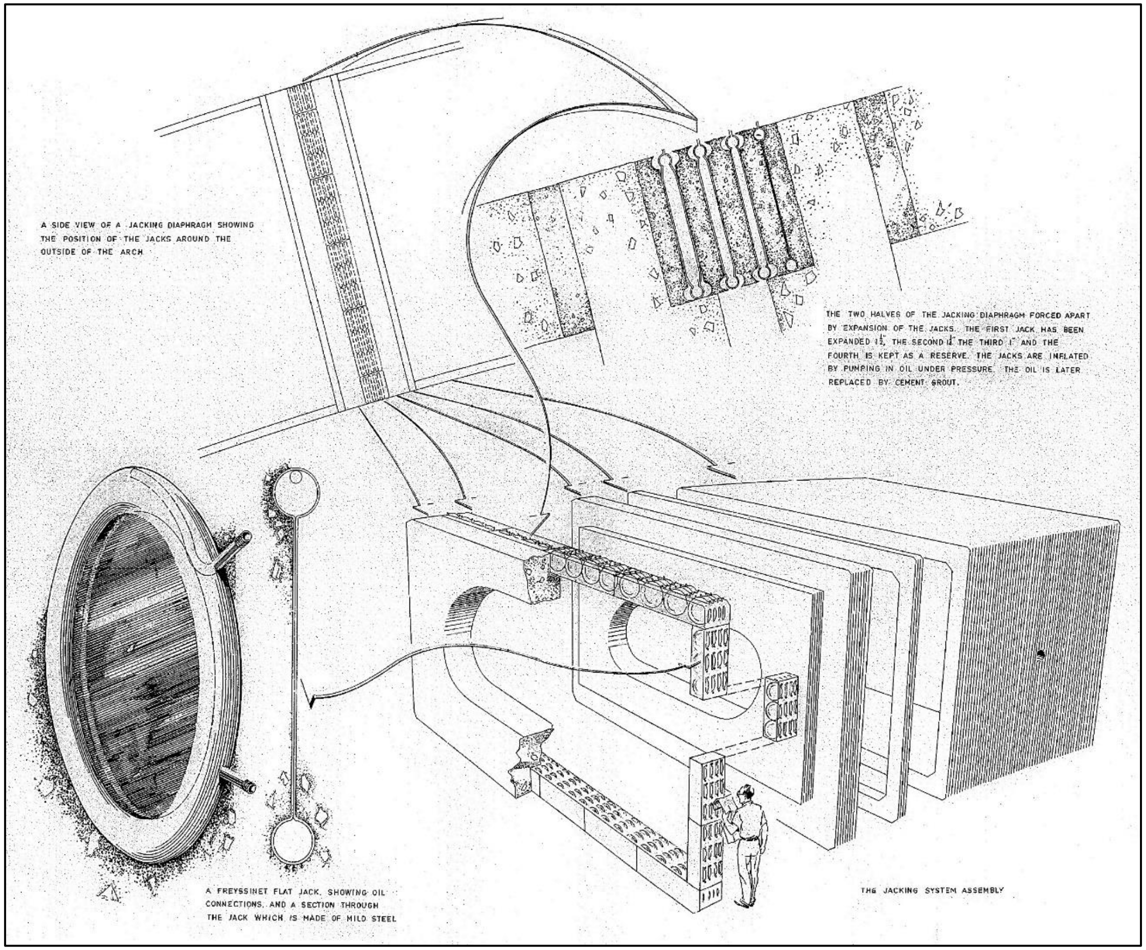
Flat jack

- 56 flat jacks per layer (4 layers in total).
- Freyssinet flat jack is a deformable steel capsule made out of two cold-formed steel halves welded together.
- Fluid injected under pressure to open the jack up to the height of the rim.
- Trimmer jacks to correct distortions (horizontal curvature) of arch rib caused by temperature gradients across the rib.
- Vertical movements calculated from theodolite readings on targets attached to arch throughout jacking operation.
- Over-jacking to compensate for arch shortening due to creep and shrinkage.

Arch Rib Jacking

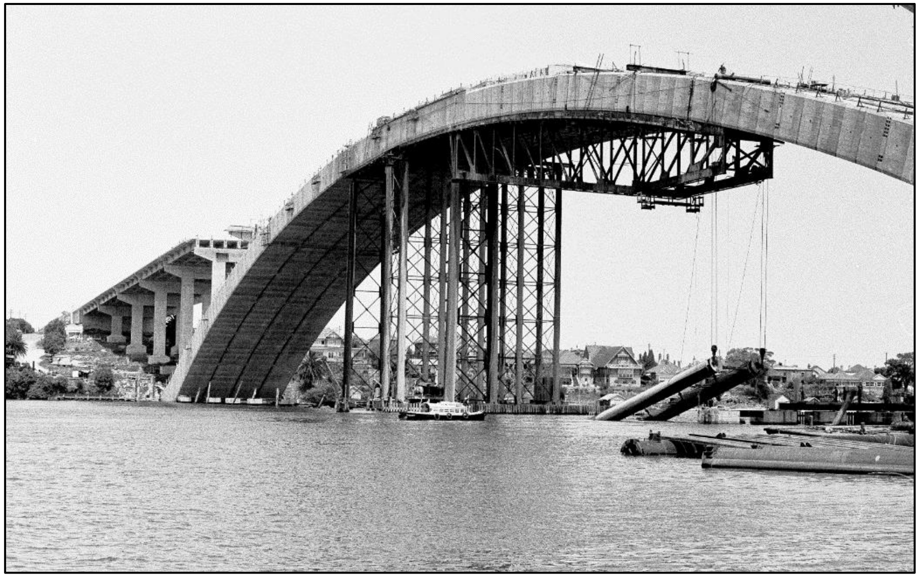
- Flat jacks were inflated one layer at a time with oil.
- Oil then drained and replaced with cement grout, as pressure had to be transferred from oil to solid.
- Allowed to set before inflating next layer of flat jacks.

Arch Rib Jacking

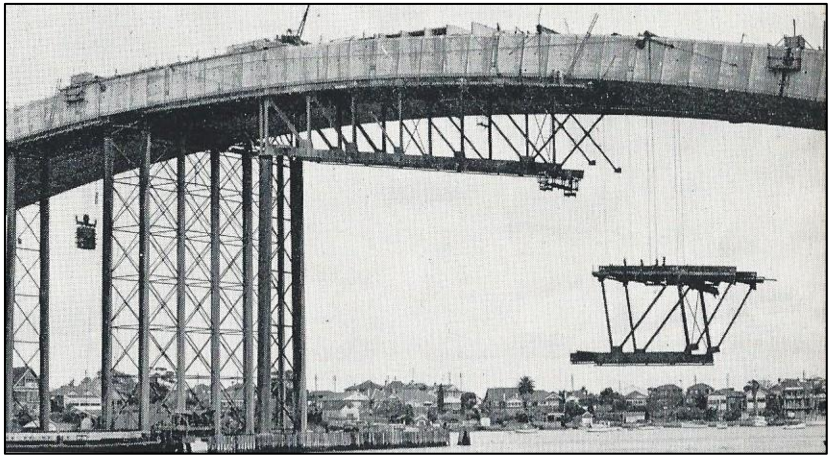


- Flat jacks inflated with oil applied a force concentric with the thrust line of the arch.
- Compressive force induced in the arch rib caused it to lift off the falsework.
- Arch rib became self-supporting.
- Method of raising arch off falsework using flat jacks developed by Eugene Freyssinet (Gladesville Bridge was Freyssinet's last project).

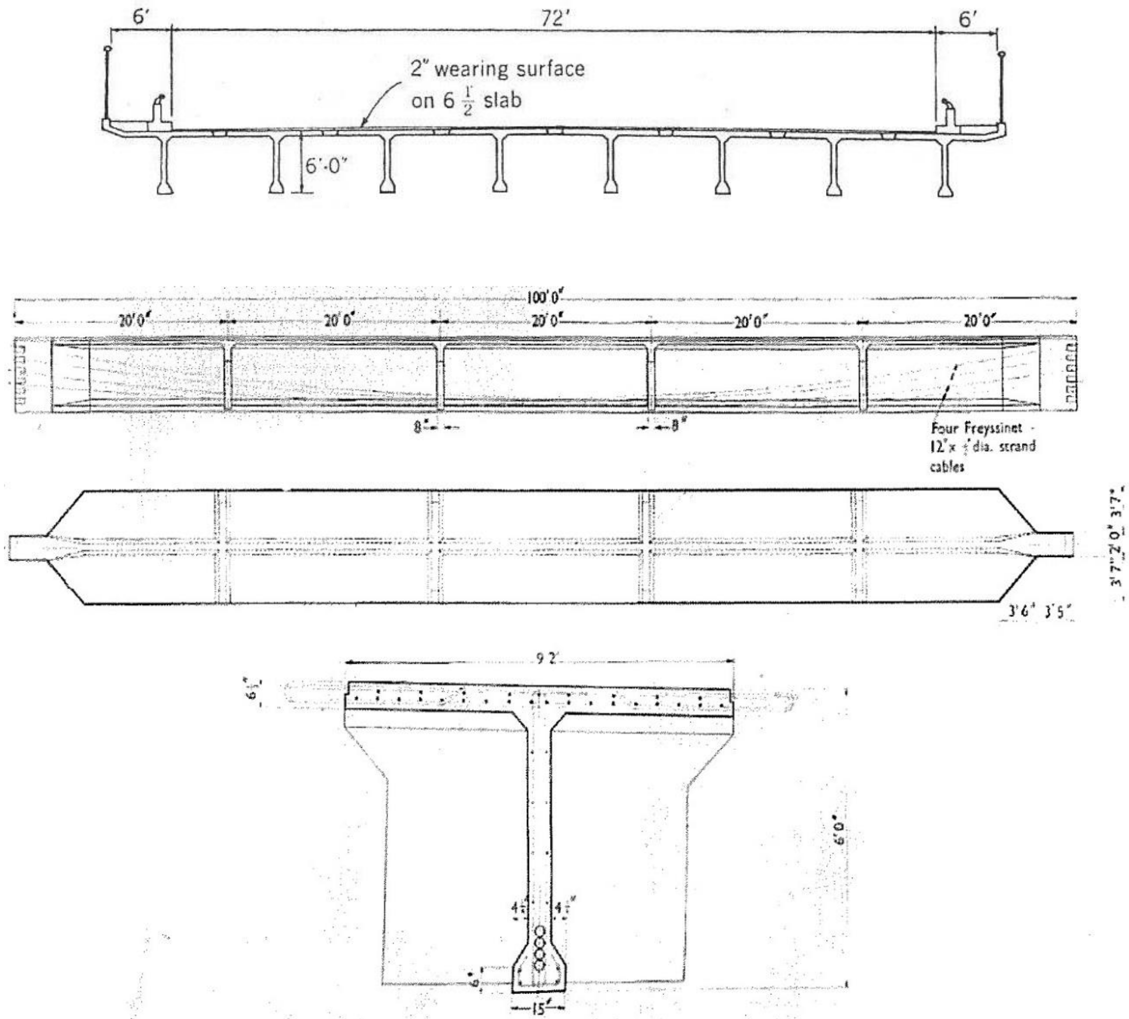
Arch Falsework – Removal



Note navigation span ‘strapped’ to arch during falsework removal



Deck Beams

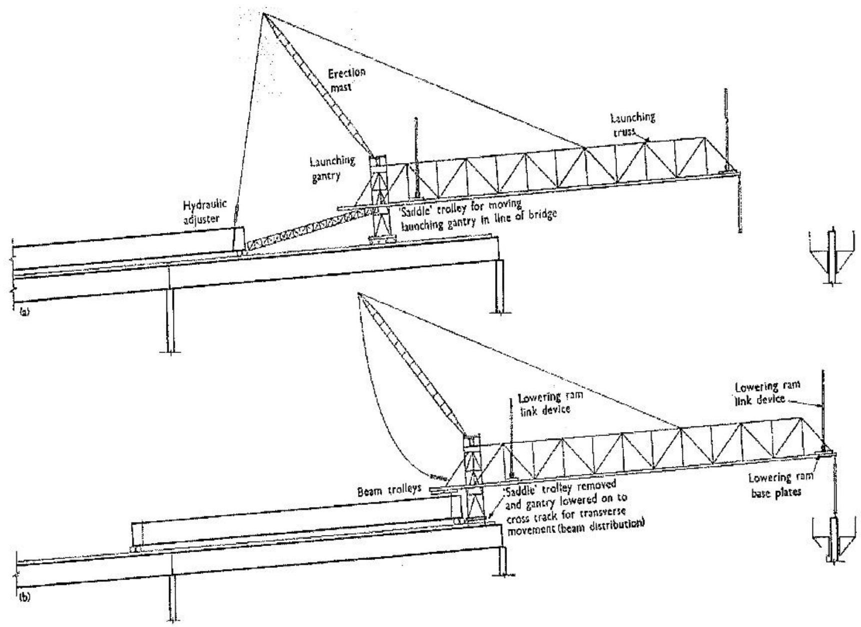


- Eight (8) 100 feet (30.5m) long precast concrete post-tensioned T-beams per span.
- Beams constructed at both bridge approaches.
- No insitu concrete topping slab.
- Spans made continuous for live load.

Deck Beam Grillage

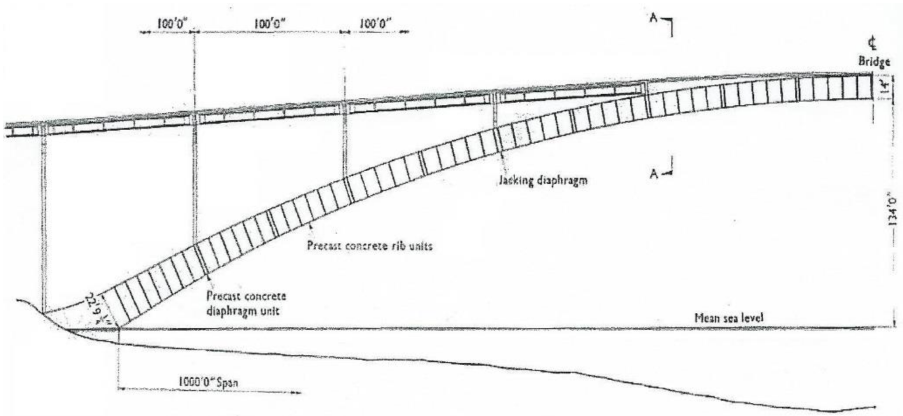
Insitu concrete used to complete beam and slab grillage

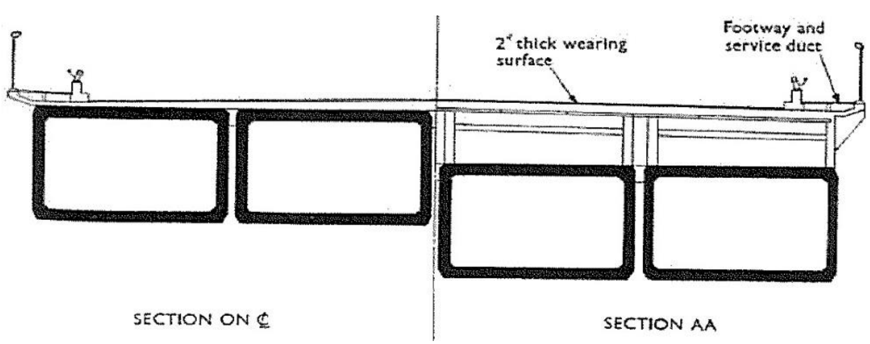
Deck Beams – Launching Truss



- Steel launching truss used to install deck beams.
- Deck beam used as a counterweight for launching truss projection.
- Whole mechanism was winched forward over the next span.

Deck – Central Section





- Cast insitu parallel transverse walls.
- Precast slabs span between walls.
- Cast insitu topping concrete on precast slabs.
- Slab cast directly on arch in central 20m length.

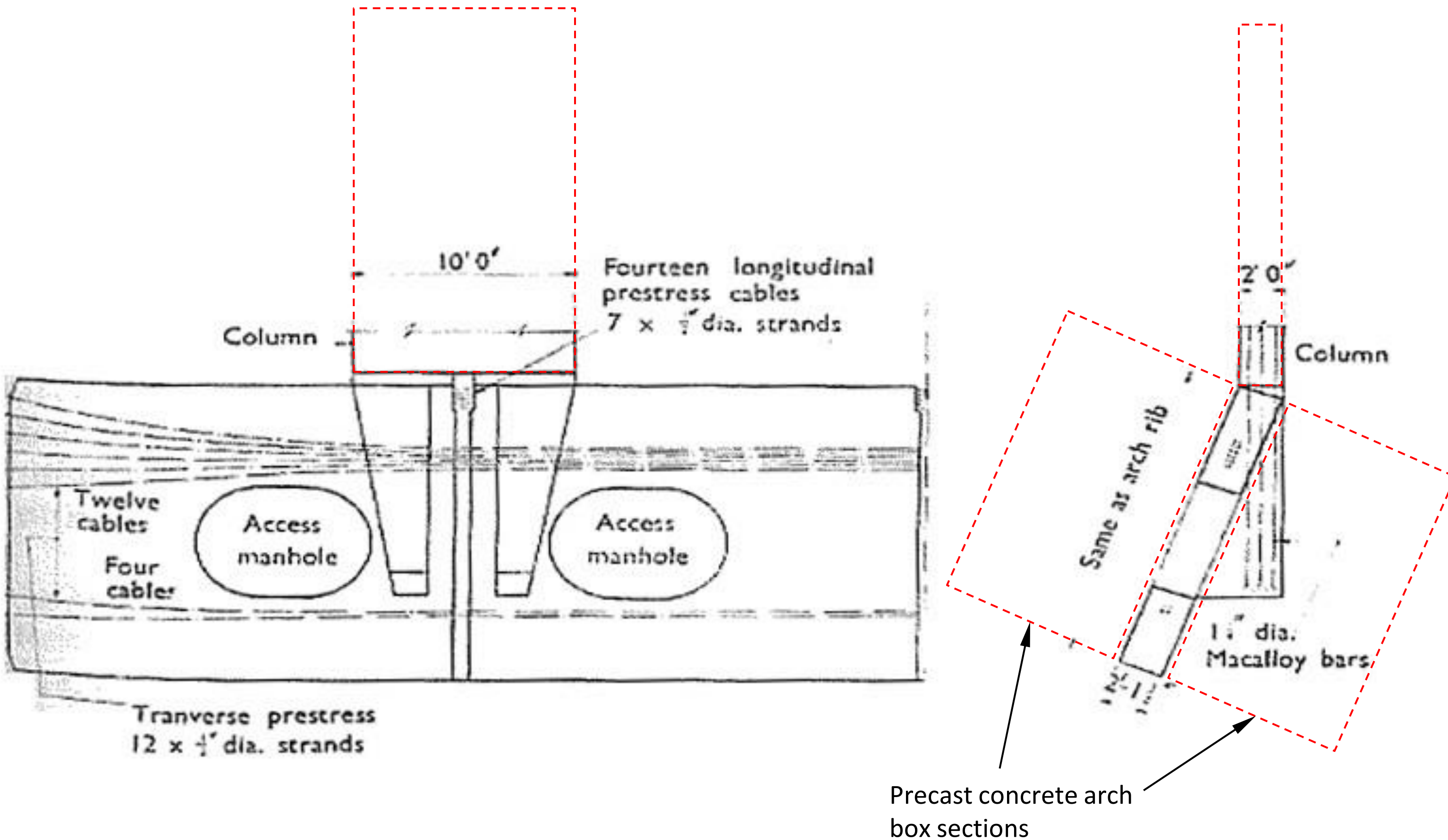
Piers – General Characteristics

- All piers are of portal frame configuration – to resist all lateral forces.
- Columns have very high slenderness ratio.
- Approach span piers – fully cast insitu concrete.
- Arch piers – fully precast concrete comprising three (3) large pieces and joined by prestressing together (to speed construction as floating crane proved successful).
- Stresses in columns due to longitudinal movements and horizontal forces are large compared with the axial stresses.
- Stability of columns ensured by prestressing out all tensile stresses. Columns stressed by Macalloy bars wrapped in Denso tape before casting.
- Crossheads are of heavily reinforced concrete.

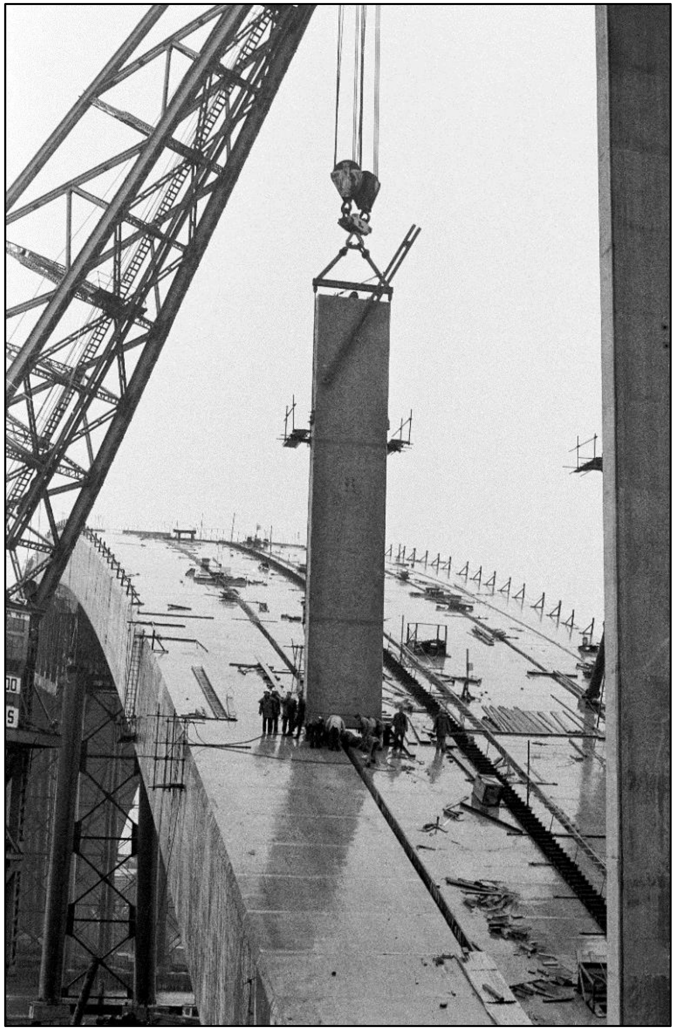
Piers – General Characteristics

Pier column geometry – compromise between flexibility (to accommodate deck movement) and stiffness (to avoid buckling)

Pier Column / Arch Diaphragm Interface

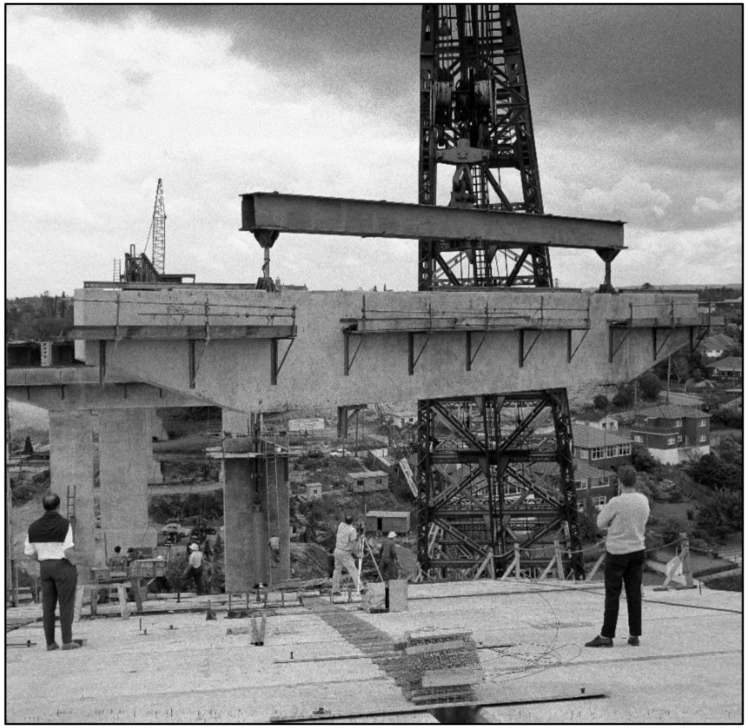


Piers – Arch Span



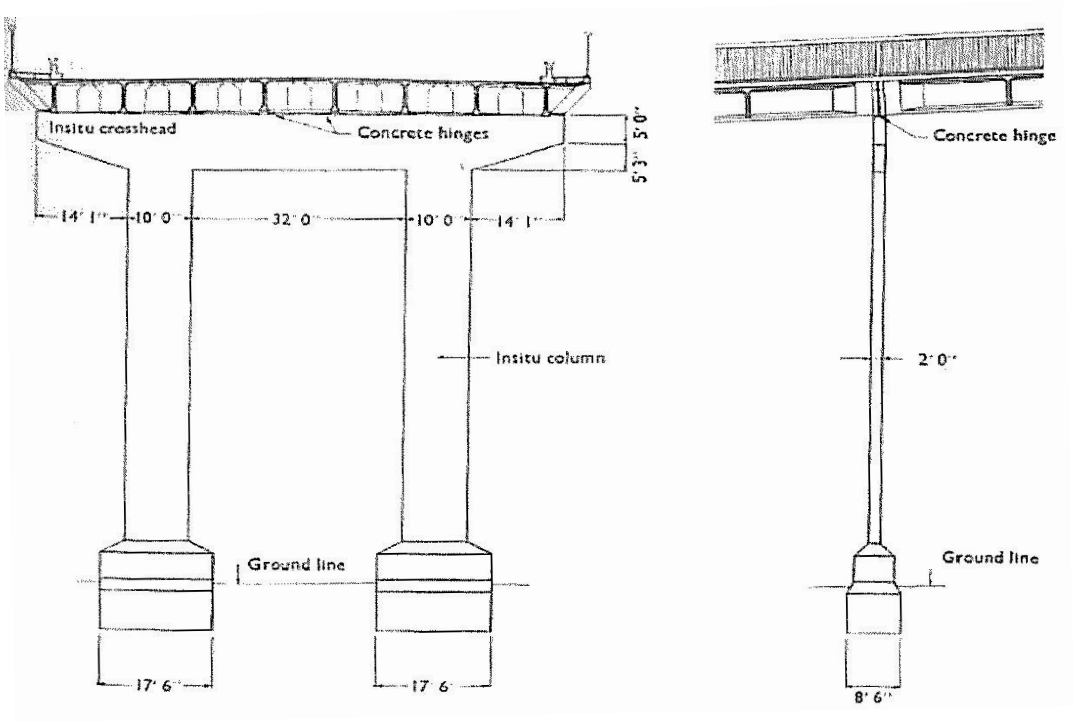
Note Macalloy bar coupler connections

Piers – Arch Span



Precast concrete arch pier crosshead installation

Piers – Approach Spans



Approach Spans

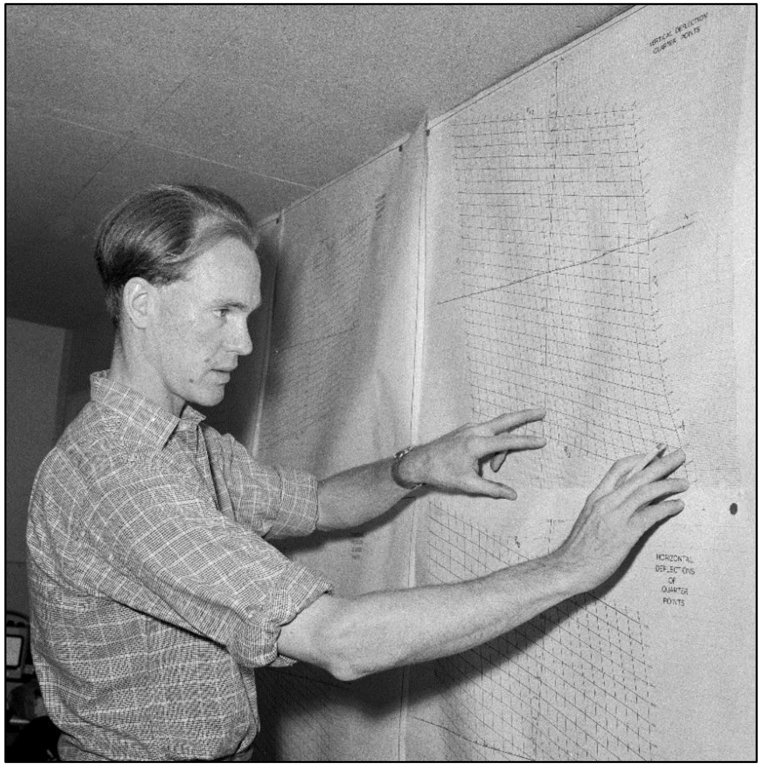
Cast insitu approach span piers

Launching gantry – approach span beams

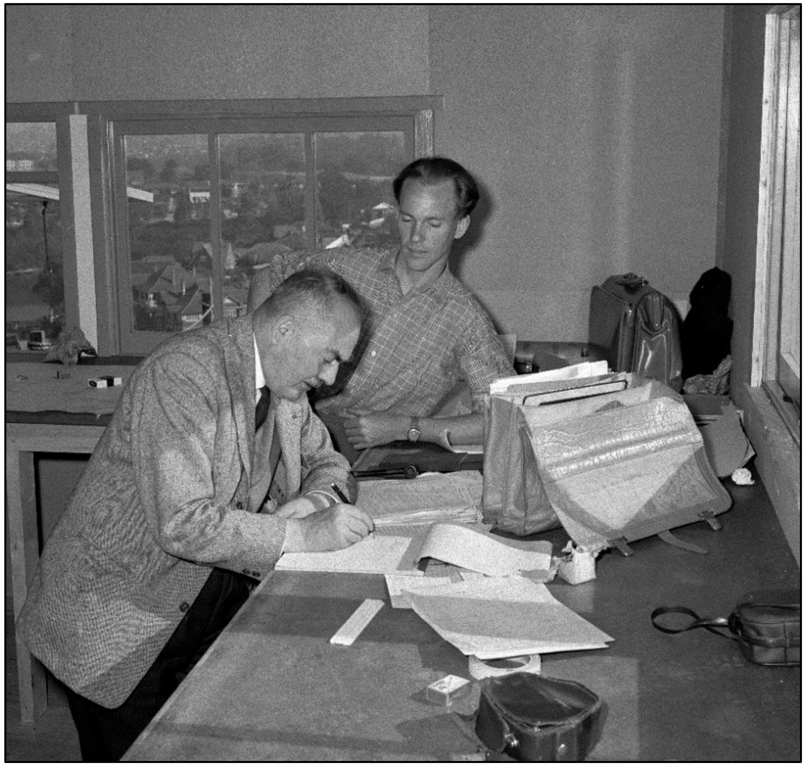
Construction Timeline

- Contract period of 156 weeks (3 years). Extension of time granted to 21st October 1964.
- December 1959 – construction of coffer dams for abutments.
- 23rd February 1962 – first box unit placed on Drummoyne side.
- 14th March 1962 – first box unit placed on Gladesville side.
- 31st July 1962 – last box unit in first arch rib placed in position.
- 31st May 1963 – last box unit placed in fourth and final arch rib.
- Between September 1962 and June 1963 – arch ribs became progressively self-supporting.
- February 1964 – last of the deck beams installed.
- 2nd October 1964 – bridge officially opened by Princess Marina, Duchess of Kent.

Bridge Design Engineers



Anthony Gee (G. Maunsell and Partners)



Yves Guyon (Societe Technique pour l'Utilisation de la Precontrainte)
Anthony Gee (G. Maunsell and Partners)

- Anthony Gee – bridge design engineer for Gladesville Bridge (also supervised stressing of the first arch rib).
- Yves Guyon – check of arch behaviour (particularly during falsework removal).

Material Quantities

Concrete

- Class PS – 22,500 cubic yards (≈ 17,200m^3)
- Classes AAA, AA, A, B & C – 20,000 cubic yards (≈ 15,290m^3)
- Total concrete – 42,500 cubic yards (≈ 32,490m^3) (≈ 80,000 tonnes)

Steel Reinforcement

- Total conventional steel reinforcement – 2,200 tons (≈ 1,200 tonnes)

High-Tensile Strand and Bar

- ½ inch diameter strand (22.5 miles ≈ 36km) – 267 tons (≈ 240 tonnes)
- 1¼ inch diameter bar (6.2 miles ≈ 10km) – 61 tons (≈ 55 tonnes)

Heritage Significance

Gladesville Bridge was assessed as being of international heritage significance under the following categories:

- Historical significance (evidence of road planning).
- Historic Individuals or Association (DMR Bridge Section design engineers, Guy Maunsell, Anthony Gee, Professors Roderick and Pippard, Eugene Freyssinet and Yves Guyon).
- Creative or Technical Achievement (represented transition from steel bridge technology to concrete, also set new standards and a number of innovations).
- Social (was an element in the North West Freeway project and is special to Australia's bridge engineers due to its size, design and method of construction).
- Rarity (only concrete segmental box section arch in Australia).
- Representativeness (is recognised internationally in the bridge engineering community as a significant bridge).
- Integrity/Intactness (although roadway widened in the late 1970s, structural configuration remains same as per constructed).

Creative or Technical Achievement

The design of Gladesville Bridge set several new standards and contained a number of innovations in bridge design and construction that have subsequently been widely adopted, as follows:

- It was the first 1,000-foot span concrete bridge.
- It held the distinction of being the longest span concrete arch bridge in the world for 16 years, until the completion of the Krk 1 Bridge in Croatia in 1980. After nearly 50 years, it still ranks third.
- It was the first major concrete arch bridge built using precast segments.
- It was the first major concrete arch bridge jacked at the quarter-points, rather than at the crown.
- It was one of the earliest concrete bridges in which the deck was made structurally continuous for live load by the use of unstressed reinforcement contained in cast-in-place concrete between the precast girders over the piers.
- It was almost certainly the first bridge to use piers of this kind constructed from precast segments.
- It was also one of the first, if not the first, major bridge to use integral abutments, later to become a popular method of eliminating the problems surrounding bearings and expansion joints at conventional abutments.

Creative or Technical Achievement (continued)

- It was probably the first major bridge to rely entirely on the flexibility of concrete columns to accommodate longitudinal movements of the deck due to shrinkage, creep and temperature effects.
- Concrete hinges were incorporated to increase the effective slenderness ratio of the columns, and hence their flexibility, and to prevent moments being transmitted into the deck by the flexure of the piers.
- It was undoubtedly one of the first bridges for which the design utilised a suite of computer programs for analysis and detailed design. These programs were written for the purpose, as there was no such thing as proprietary engineering software on the market at that time.
- Early use in Australia of very high strength concrete in reinforced concrete structures.
- A launching gantry that advanced from pier to pier to install heavy deck beams.

Heritage Recognition

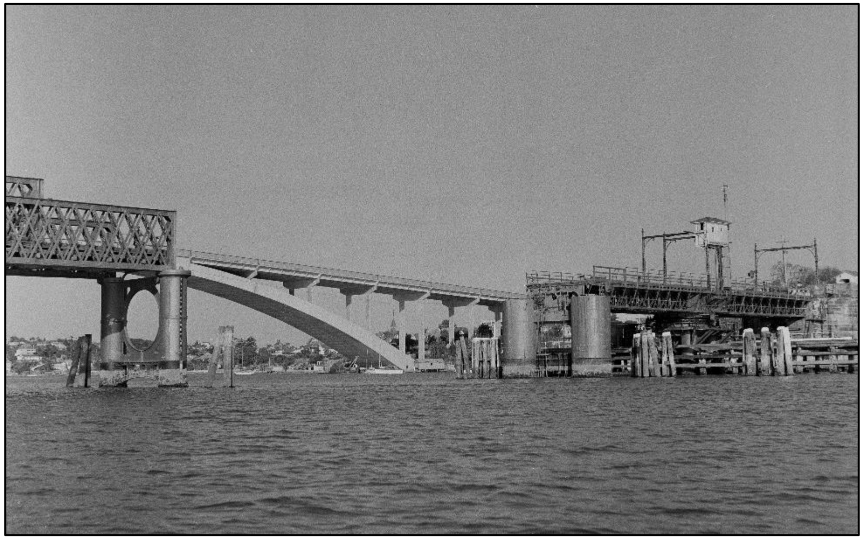
Hyder

- Gladesville Bridge's heritage significance was acknowledged by Engineers Australia at an Engineering Heritage International Marker (EHIM) plaque unveiling and 50th anniversary ceremony on 1st October 2014.
- Gladesville Bridge was placed on the NSW State Heritage Register on 1st October 2014.
- Gladesville Bridge was classified as a heritage item by The National Trust of Australia (NSW) on 31st October 1990.
- Gladesville Bridge is listed on the Register of the National Estate.
- Gladesville Bridge is listed as a Heritage Item on Hunters Hill Local Environmental Plan 2012.
- Application has been made by the Sydney Engineering Heritage Committee of Engineers Australia to the American Society of Civil Engineers (ASCE) for Gladesville Bridge to be declared an International Historic Civil Engineering Landmark (IHCEL).

Opening Ceremony

- 2nd October 1964 – bridge officially opened by Princess Marina, Duchess of Kent.
- Stand was set up on the crown of the arch.
- Invitees to ceremony – predominantly NSW politicians and DMR personnel.

Old Gladesville Bridge – Removal




1966

Gladesville Bridge – General Scenes

Drummoyne Abutment (June 2014)

Gladesville Abutment (June 2014)

Gladesville Bridge – General Scenes

View from Gladesville bank of Parramatta River (June 2014)

Gladesville Bridge – 1st October 2014

Hyder

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Roads & Maritime

Acknowledgement

- Roads & Maritime Services Photo Library.
- *Gladesville Bridge: Notes in support of Engineers Australia Engineering Landmark nomination* (prepared by Vince Taranto of Roads & Maritime Services, February 2014).
- *Nomination of Gladesville Bridge as an Engineering Heritage International Marker* (prepared by Michael Clarke for Sydney Engineering Heritage Committee, April 2014).
- Notes and technical journal articles co-authored by Anthony Gee.
- Notes prepared by John Muirhead.

Thank you for your attention

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