

New Ashton Arch - functional assessment of direct and indirect construction costs and evaluation of service life with respect to flooding risk

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Abstract. The bridge crossing the Cogmanskloof River in the town of Ashton, South Africa, had a history of over-topping due to severe flood events. The poor flood resilience of the bridge was aggravated by the generally hydraulically inefficient openings, the number of substructure supports in the river course, and a high debris load during flooding. The strategically important tourist route had to be closed, while localized flood damage repairs were undertaken, with resultant adverse effects on the local economy. As part of a road safety improvement project between the towns of Ashton and Montagu, improvement of the flooding resistance at the Ashton river bridge was required. This paper documents the functional evaluation of economic- and technical-assessments of the flooding risks for the existing retro-fitted bridge. A new tied-arch bridge was the selected structural form of the replacement structure – based on the assessment of the key service life and constructability criteria. The structural form of the Ashton Arch paid careful regard to the scenic location and historic character of the previous multiple arch bridge form.

1 Project background

The project, conducted under the auspices of Western Cape Provincial Government's Department of Transport and Public Works: Roads Infrastructure Branch, involved the reconstruction of parts of Trunk Road 31 Sections 2 and 3, between the Western Cape towns of Ashton and Montagu, South Africa. This 13km long road is also the start of the strategically important tourist 'Route 62'. Typically about 7000 vehicles travel through Ashton and 3600 vehicles through Cogmanskloof Pass and Montagu every day.

A particular focal point of the project is the historic Cogmanskloof Pass. The 6,5km long pass stretches through a majestic landscape of towering rock formations and a colourful pastoral patchwork. Renamed after the popular Cape Colonial Secretary John Montagu, the town's original name was Cogmanskloof, from which the pass took its name. 'Cogmanskloof' comes from the Cogmans Khoi chieftom that lived in the area in the early eighteenth century.

This section of Trunk Road 31/2, currently a single surfaced carriageway with gravel shoulders, was constructed as a gravel road and completed in 1877, and first surfaced in 1931. The last resurfacing was undertaken in 1985. This part of the route has, for some time, been in need of upgrading and rehabilitation due to marked deterioration of the road surface, traffic capacity constraints, and road safety requirements (due to substandard width and geometric alignment in some

locations). Other major considerations were the flood capacity and erosion resistance of the roadway and river bridges.

The Cogmanskloof River flows adjacent to the route for a significant distance and crosses the roadway at four discrete locations by means of existing bridge structures. These bridges do not currently have adequate hydraulic capacity. The greater Ashton-Montagu region, and Cogmanskloof Pass in particular, experienced substantial flood damage that resulted in multiple road closures and significant operational disruptions, with adverse impacts on the local economy. The largest of these recent floods occurred in March 2003 (Fig.1), while significant although less severe flooding also occurred during April 2005, July to August 2006, November 2008 and June 2012. The high debris load in the Cogmanskloof River exacerbates the effects of flooding at the existing short span bridges. Generally these bridges have wide solid wall type piers, orientated at unfavourable skew angles relative to the sometimes variable flow direction. This has resulted in severe debris blocking of the hydraulic opening (Fig. 2) and resulting overtopping, particularly at the river bridge in Ashton.

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Fig. 1. Overtopping of the existing Ashton river bridge during the 2003 flood.



Fig. 2. Debris accumulation at Ashton river bridge during the 2003 flood.

2 End of functional life assessment of existing arch bridge

The original bridge over the Cogmanskloof River in Ashton, was constructed in the 1930's. The original structural form was a five span, earth-filled arch type superstructure, allowing single lane vehicular traffic. The substructure consisted of wall type piers and abutments, with an angle of skew of 50 degrees with the river.

In 1950 a substantial structural retro-fitment was undertaken, modifying the superstructure to a cast in situ beam and slab configuration that maintained portions of the arch superstructure (Fig. 3 & 4), including the arch-profile with related hydraulic opening configuration. The retro-fitment allowed two-way single carriageway vehicular traffic of 3,35m traffic lanes and 1,8m pedestrian sidewalks. The 3m wide transverse cantilevers are supported from the arch-profiled longitudinal beams. The retro-fitted road was typically between 5m and 8m above the natural ground level, approximately representing the 1:50 floodline.



Fig. 3. View along deck of existing Ashton bridge.

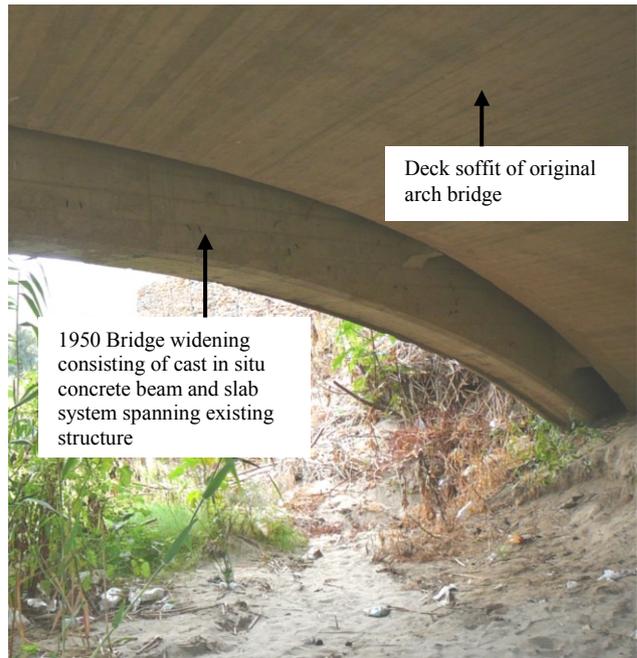


Fig. 4. View of deck underside of existing Ashton bridge.

The client's brief involved improvement, to acceptable modern standards, of the flood resilience and overall safety of the road. Technical proposals were required to address the risk of frequent- and severe-flooding at the Ashton river bridge location.

2.1 Physical and economic considerations of existing Ashton Bridge

An economic analysis evaluated the ‘do nothing’ option, where the micro-economic impact of closing the road during regular incidence of flooding and accepting substantial reduction in the road width over the existing Ashton river bridge was assessed. The most significant costs included in the economic model were flood damage cost, accident cost, lane merge delays, traffic delays, road closure during flooding, and maintenance costs. Using an appropriate discount rate over a 50 year forecast period, the modelled costs for the ‘do nothing’ option approached, but did not exceed the estimated replacement cost for the bridge. The modelled costs excluded macro-economic factors such as the strategic value of the road, the broader scope of the road reconstruction project, and other macro-economic dis-benefits and adverse consequences of flooding that further motivate the replacement of the Ashton bridge.

2.2 Bridge replacement considerations

Five bridge replacement options were investigated to assess the most suitable structural form and ensure that the final solution appropriately satisfied the client brief and the related economic, functional and constructability requirements. The key technical boundary conditions included:

- The road had to remain open to traffic throughout the construction period with limited disruption of the route,
- The hydraulic capacity and efficiency of the bridge required substantial improvement, to address current shortcomings and comply with applicable modern criteria for this route classification,
- The design needed to accommodate flood risks during the construction phase and service life,
- Improvements to the geometric alignment were required to accommodate a wider (four lane) road cross section and provide acceptable flood free-board clearances,
- Minimize the effects on adjacent properties and road intersections in Ashton, and
- Construction methods and constructability.

Three structural configurations were considered, namely a multiple span continuous voided slab deck, multiple span pre-cast beams and a single span tied arch bridge. The construction methods for the first two options were evaluated in terms of half-width construction or by the provision of an adjacent low-level bypass river crossing during construction.

The optional half-width construction strategy would result in technical difficulties and associated additional cost to stabilize the partial existing deck during construction in both the first two options.

The provision of a bypass in the river would result in a significant additional construction, traffic safety and operational risks. In addition, achieving the necessary flood resistance of the by-pass during construction to an acceptable standard would imply a significant additional

cost premium and substantially increased flood risk to adjacent property in the urban environment.

The proposed transversely launched construction method of the tied arch option allows the new bridge to be used as a traffic deviation in its temporary position, while the existing bridge is demolished. After the construction of the new permanent bridge substructure and associated roadworks (Fig. 5), the tied arch bridge will be launched horizontally into its final position. Thereafter all the temporary works will be removed from the river course.

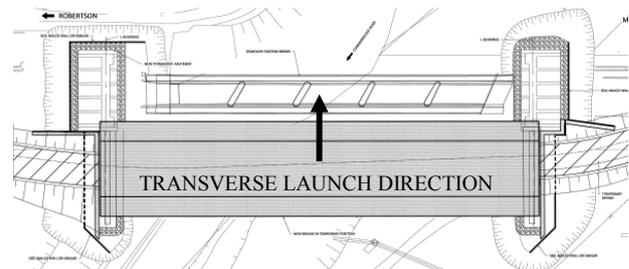


Fig. 5. Temporary position, in plan, of the new Ashton Arch prior to transverse launching.

2.2.1. Voided slab deck

A voided slab deck option would require construction of the new deck, approximately 1,5m deep, at a significantly higher elevation (+3,0m above the existing bridge) to achieve the required hydraulic capacity. The presence of piers in the water course, significantly wider than the current sub-structure, would result in additional debris accumulation risk, as well as local scour effects. Higher approach fills (in comparison to the final option) would be required with significant additional construction costs at nearby existing intersections and related impacts on existing properties.

The resulting new deck would have a 2,15m horizontal eccentricity off the current centreline (Fig. 6) with additional adverse effects on adjacent properties.

This bridge replacement option, using half width construction method, had the lowest total construction and indirect cost.

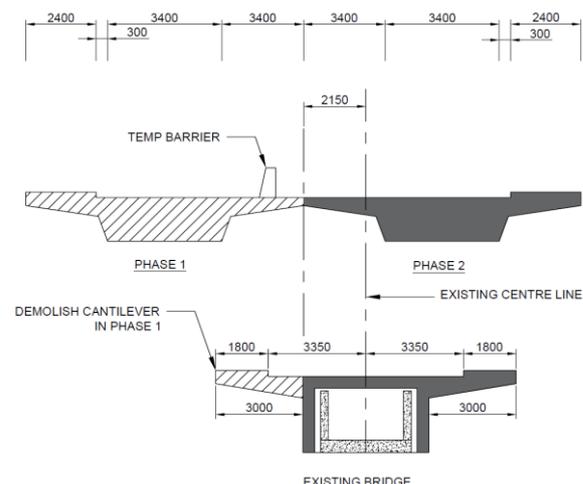


Fig. 6. Voided slab deck option.

2.2.2 Precast beam and cast in place slab deck

The precast beam and cast in place slab deck option would require construction of the new deck, approximately 1,5m deep, at a significantly higher level (+3,0m above the existing bridge) to achieve the required hydraulic capacity. The presence of very wide piers in the water course, which are significantly wider than the requirement for the voided slab sub-structure (Fig. 7), would result in the highest debris accumulation risk, as well as local scour effects, of all the alternatives considered. Much higher approach fills would be required with significant additional construction costs at nearby existing intersections.

This bridge replacement option had a total cost premium of 25% higher than the lowest cost option.

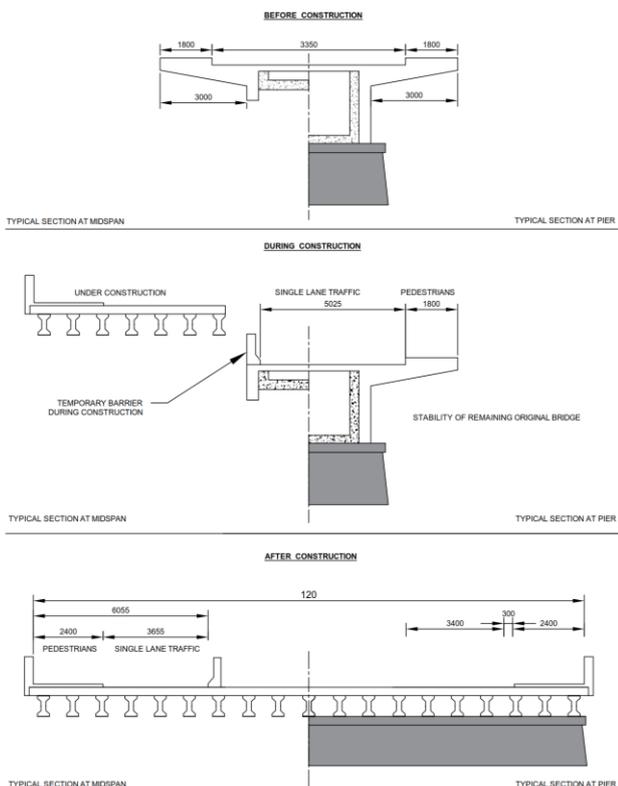


Fig. 7. Precast beam and cast in place slab deck option.

2.2.3 Tied arch, launched transversely into final position (preferred option)

The tied arch bridge, with deck depth of 1,0m, allowed the construction of the new deck at a lower level (+2,5m above the existing bridge) than the preceding options to achieve the required hydraulic capacity and free board. No piers are required in the river course, substantially alleviating the risk of debris accumulation and backwater effects. Local scour effects are also significantly reduced.

A second economic analysis, that incorporated the estimated construction costs for the preceding bridge replacement options and indirect costs associated with the posed solution, clearly demonstrated that the

preferred bridge replacement solution was the transversely launched, tied-arch bridge.

The bridge option had a total cost premium of 10% higher than the lowest cost (but high risk) option, but was showed a 15% saving relative to other plausible construction options.

This bridge replacement option was the sole technical solution that fully satisfied all the key service life and constructability criteria, as summarized schematically in Table 1, while at the same time providing significant risk-alleviating benefits and a very elegant solution.

Table 1. Key bridge replacement considerations.

Key Design Considerations	Voided Slab Deck with Temporary Bypass	Voided Slab Deck built in Half Widths	Single span Tied Arch Launched transversely	Precast Beams a) Temp Bypass b) Half widths
Hydraulic efficiency	✓	✓	✓✓	✓, ✓
Construction flood risk	✗	✓	✓	✗, ✗
Geometric Alignment	✓	✗	✓✓	✓, ✓
Traffic Accommodation	✓✓	✗	✓✓	✓✓, ✗
Aesthetics	✓	✓	✓✓	✗, ✗
Constructability	✓✓	✗	✓	✓, ✗
Ratio: Construction costs	1.15	1.0	1.35	1.20
Ratio: Construction + indirect costs	1.20	1.0	1.10	1.25

3 General details of the new Ashton Arch.

The new Ashton Arch has a tied-arch structural form, with a single span of 110m (Fig. 9). Durable, high strength 50 MPa concrete was specified for the arch rib and tie-beam members, while the remainder of the bridge structural components utilize 40 MPa concrete.

The typical cross-section of the Ashton Arch provides for four 3,4m traffic lanes and two 2,4m sidewalks. The overall height of the bridge is approximately 23m from deck soffit to top of the arch. The twin parallel arch ribs are connected via 15,5m wishbone beams that provide lateral stability to the bridge. Post-tensioned tie-beams complete the arch, along with post-tensioned longitudinal and transverse beams supporting the integral deck slab, resulting in a coffered deck arrangement (Fig. 8). Each arch has twenty-four fully-locked coil-type hangers that connect the arch rib and tie-beam by fork sockets, via a pin connection, to locally cast, engineering-grade, metal anchor plates. The anchor plates are, in turn connected to the concrete structure via high strength threaded, stress bars.

Construction of the Ashton Arch is currently well underway, with completion of the arch superstructure (in its temporary position) scheduled for late 2018, and completion of the overall project scheduled towards the second half of 2019.

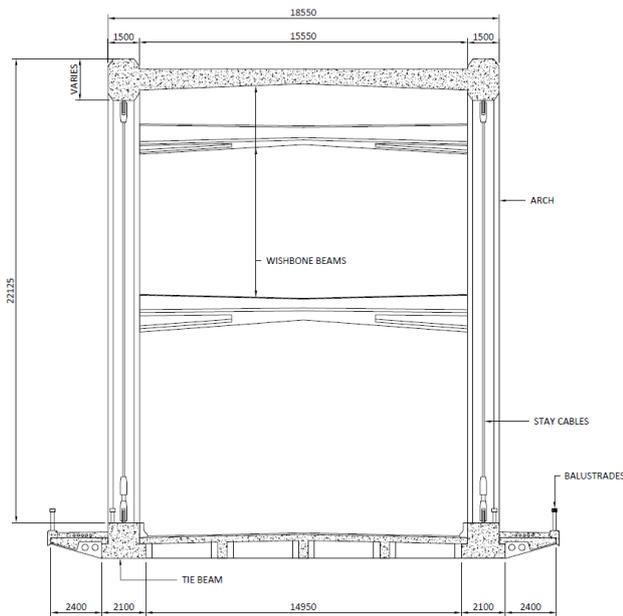


Fig. 8. Typical cross-section of Ashton Arch.

4 Modelling, instrumentation and monitoring

The arch structure was originally modelled by the Consulting Engineer's local bridge team using Bentley's RM Bridge. An internal design review was conducted by the Consulting Engineer's UK long-span bridge specialist team using SOFISTIK (Fig. 9).

These state-of-the-art bridge analysis software packages were used for the construction stage modelling, in-service analysis, and design. Both software models were updated with concrete material parameters, as determined from laboratory testing. This allowed more accurate simulation of the time-dependant material behaviour during construction. The updated models were then used for the following assessments:

- Stay cable length determination, which require long procurement lead times applicable to international suppliers. The stay cable length verification had to consider both intentional and un-intentional variations, relative to the adjustment capacity available in the fork socket assembly,
- Hanger force optimisation,
- Pre-camber requirements and influence of temporary works displacements, and
- Movement capacities of temporary and permanent bearings, and expansion joints.

An extensive instrumentation and monitoring plan is being carried out during construction. This plan comprises system identification by dynamic testing and structural behaviour verification by deformation measurement. The system identification testing is intended to inform and calibrate the software models. Thereafter actual deformations (strain and displacements) will be verified with the calibrated software model to ensure that the structural behaviour envisaged by the designer is achieved.



Fig. 9. Structural model of the Ashton Arch.

The instrument readings may also be used to verify or adapt the hanger tensioning operation during installation. Hanger tensioning is performed in four separate stages to ensure optimum structural behaviour during the structural service life. The data obtained from this instrumentation and monitoring plan will also provide very valuable information for the future modelling of similar structures, particularly time-dependent material properties that play an important part in the analysis and performance of such structural forms.

Bridge lighting also received special design attention to ensure the optimum balance between aesthetic and maintenance requirements. The latest 3D visualization software, with applicable virtual reality simulations (Fig. 10), were included as part of technical presentations to the client.



Fig. 10. Visual impression of the completed Ashton Arch.

5 Conclusions

The existing Ashton bridge over the Cogmanskloof River, has experienced multiple occurrences of over-topping during severe flooding. The strategically important tourist route had to be closed, while localized repairs were undertaken. As part of a road safety improvement project in the greater area, improvement to the flood resilience at the Ashton river bridge was required.

The client's introduced a number of constraints for the overall project, including that the road should remain open to traffic during construction, flooding risks should not be increased by construction activities, hydraulic capacity and efficiency of the Ashton bridge required

improvement, geometric improvements resulting from road safety and flooding improvements should be considered, and the construction methods and constructability should be carefully assessed with technical proposals.

Detailed economic analysis clearly demonstrated that the preferred bridge replacement solution was the transversely launched, tied-arch bridge, based on estimated construction costs and indirect costs. The transversely launched, tied arch bridge replacement option was the sole technical solution that fully satisfied all the client's- and constructability- criteria. This bridge option had a total cost premium of 10% higher than the lowest cost option (with unacceptably high construction risk), but demonstrated a 15% saving relative to other plausible construction options.

The transversely launched construction method allows the new bridge to be used as a traffic deviation in its temporary position, while the existing bridge is demolished. After the construction of the new permanent bridge substructure and associated roadworks, the tied arch bridge will be launched horizontally into its final position. Thereafter all the temporary works will be removed from the river course

A detailed record of the instrumentation and monitoring with related analysis will be the subject of a follow-up paper on completion of the structure.

This paper is published with the kind permission of the Western Cape Provincial Government's Department of Transport and Public Works: Roads Infrastructure Branch. Basil Read was the main contractor, the bridge design engineer was Mr Edward Smuts, and AECOM SA (Pty) Ltd performed the roles of Design- and Contract-Engineer for the Contract C818.