Hendon Park Footbridge and the Waterview Shared Path Bridges Connecting Communities

Will Pank
Technical Director, Structural Engineering, Beca

Abstract: The Waterview Connection completes Auckland's Western Ring Route and is NZ Transport Agency's largest ever motorway project which also includes a raft of community facilities to re-invigorate the area including a new cycleway network. The shared path bridges connect neighbourhoods around the new motorway linking up a cycle route from south Auckland to the CBD. Four bridges carry the cycleway through parkland, over Oakley Creek, across rail and road to enable walking and cycling as an alternative mode to the motorway.

The Hendon Park Footbridge is an architectural landmark that will be a recognisable feature of the area for future generations. The southern approaches cross a wetland and the re-aligned Oakley Creek, offering views into the re-invigorated environment. Beca's design of the 100m steel arch structure supporting a reinforced concrete deck appears simple in form but was complex to construct. The diagonally-aligned deck helps to stabilise the slender arch in wind and seismic events. Nine approach spans are supported on diamond-shaped piers integral with a post-tensioned concrete deck that is continuous with the main span. The whole crossing is designed holistically combining architecture, structure, lighting and urban design integrally with the reformed landscape.

Innovative construction techniques were used to fabricate and erect the arch. The deck was cast insitu to allow alignment of outrigger girders with hangers. Tight tolerances were required for hanger rod connectors so fabrication and installation of the steelwork was closely controlled. A stage-by-stage hanger stressing sequence was devised to control internal forces and arch deflections. Construction quality was followed through to the finer details of this landmark bridge to deliver a world class asset that will be handed back to the community on completion of the Waterview project in early 2017. The shared path links local communities as a legacy from the major project connecting Auckland's motorway network.

Keywords: Shared Path, Footbridge, Architectural, Innovative Construction.

Figure 1. Architect's render of Hendon Park Footbridge.

1. Waterview Shared Path Bridges

The Waterview Connection makes up the final link in the 48km Western Ring Route around Auckland providing improved journey times, reducing congestion in the CBD and making business and commuter travel safer and more reliable. The 5km of six-lane motorway, 2.5km of twin bored tunnels, 2km of multi-level bridges are complemented by a major contribution to the local communities through which the motorway has been constructed. There are over 9km of cycleways, new parks, sports fields, a skate park and playground along the alignment of the motorway, linked by four new shared path bridges with a strong focus on urban design. The project was delivered by the Well-Connected Alliance on behalf of the NZ Transport Agency and will be opened in April 2017.

The Waterview Shared Path connects communities at each end of the road tunnel via a 2.5km overland route mostly through existing parkland. The commitment to provide the shared path was made during the planning stage of the project and was a $17.5M variation into the Alliance target out-turn cost through the collaboration of the Agency and Auckland Transport (AT) with the design and construction partners.

A key aspect of the delivery of this section of the works was engagement with stakeholders where the route passes through land belonging to a range of diverse community groups including iwi, Unitec Institute of Technology, KiwiRail, Auckland Council, several sports clubs and residents. Each stakeholder held a different view on what was important to them and had a say in what was delivered. The results are a great example of what can be achieved through community liaison, collaboration and good design.

For example the Alford Street Bridge forms a new gateway into Unitec that also provides access over Oakley Creek to planned subdivisions on iwi-owned land. The 90m long structure crossing a well-loved and preserved environment is elevated 16m over the stream to avoid impacting on the riparian environment and protected trees. The location dictated by the entry points to Unitec offered significant geotechnical slope stability challenges and large piled abutments and anchored palisade walls were needed to protect the bridge foundations from slips during seismic events. Liaison with mana whenua led to incorporation of tree-like tapered precast concrete piers embossed with cultural patterns designed by local iwi providing cultural relevance to each side of the gully. Pou whenua (carved totem poles) mark the entry points at each end of the bridge. While the beams are straight, the in situ deck has a wavy form responding to the meandering stream below. Barriers reminiscent of taiapa (traditional Maori barrier fences) create a complex three-dimensional form leaning out from the wave-shaped deck at varying angles. The curved barriers create interest for users and soften the heaviness of the twin super tee girders below. AT led the consultation with an iwi panel and local boards. The design team responded to a range of stakeholder inputs during design development of this bridge. It is hoped that ownership of the urban design and cultural elements make this a special community feature and helps to reduce vandalism.

Figure 2. Alford Street Bridge over Oakley Creek.

Further south at Harbutt Reserve the shared path crosses a steep gully on the side of Oakley Creek linking two separate reserves which otherwise require a diversion around local roads. Two 35m spans comprise super tee girders with a deck slab curved horizontally to avoid significant Mahoe trees and achieve 5% gradients. The complex geometry challenged the precast fabricators who used the designers' CAD files for setting out formwork.

The third bridge at Soljak Place crosses the railway on a curved parabolic vertical alignment to clear the rail safety envelope. Post-tensioned girders are also curved in plan to enable a horizontal alignment that connects the cycleway into Soljak Place with minimal impact on residents. While these are functional bridges using cost effective structural forms, input from a range of stakeholders has been taken into consideration in the design development and specific details are included to respond to their requests.

2. Hendon Park Footbridge Integrated Design Philosophy

The fourth bridge on the shared path carries the cycleway over the new motorway and future railway corridor to connect two sides of Hendon Park. This bridge is intended to be a landmark structure for the Waterview project, offering drivers a visual marker on their journey and creating an architectural feature for the Owairaka neighbourhood in the revitalised public realm.

The design team liaised with community groups at an early stage to listen to views and preferences. The Friends of Oakley Creek had concerns about the impact on the natural stream environment. Local boards and neighbours did not want a brightly lit beacon in their back yards so the lighting was designed accordingly. The bridge is integrated sensitively into the new environment on either side of the motorway.

The geometrical shape of the shared path springs directly from the site constraints. In order to rise over the road and rail envelope with safe clearance a 120m long southern approach ramp climbs at 7%. Six southern approach spans cross the re-aligned Oakley Creek twice and a new wetland. The arch footing is actually located in the stormwater pond with planting over the submerged footing. The curve of the southern approach ramp provides the maximum possible radius for cyclists that fits within the site boundary. The northern ramp is aligned hard up alongside Oakley Creek with a green mechanically stabilized earth (MSE) wall dropping onto the stream bank. On the west side an embankment slopes down to a new football pitch. Figure 3 shows an aerial view of the bridge in its urban context during construction.

Figure 3. Aerial view of Hendon Park Footbridge under construction.

The architectural design of the main arch and suspended deck is integrated with its structural form and developed in close collaboration between architect and engineer to respond to structural demands. Architects from Warren and Mahoney designed the bridge with Beca engineers developing the three-dimensional form to fit with site constraints. 3d models of the structure were created in Rhino software with parametric modelling of geometric rules using Grasshopper to find a form that fitted over the obstructions and confines of the plan. The 80m main span crosses the motorway, a future rail corridor and shared path clearance envelopes without the need for intermediate piers allowing adaptability in future.

The arch spans 100m from footing to footing and is 25m high at mid-span – a limit requested by constructors to enable access with standard cherry-pickers. The same outer cross section of the deck as defined for the 20m post-tensioned approach spans is carried across the main span, but with a voided reinforced concrete section internally for lightness. This reduces dead load allowing the arch structure to be as slender as possible. The steel arch rib is a tapered trapezoidal box section fixed at the base. Hanger rods are connected at regular spacing to support the concrete deck.

The deck includes steel outrigger girders which hold the hanger rods far enough out from the deck so that the shortest pairs of end hangers provide at least 2.5m clearance above deck level for the safety of cyclists. The deck passes through the single arch on a skewed alignment so the angles of the hangers vary along the arch creating visual interest in a hyperbolic paraboloid arrangement shown in Figure 4.

All the elements of this composition are functional structural members and nothing is superfluous. The design team's aim was to create architecture from pure structural form without adornment or unnecessary features. The shaping of the arch, girders, footings and deck is designed in response to the flow of forces to the ground. The members are as slender as can be to resist the gravitational, seismic and wind load effects on the structure. The connections and details are intended to appear as simple, uncluttered and elegant as possible to contribute to the overall aesthetic.

Figure 4. Concept design of hanger arrangement compared with site photo.

3. Structural Design of Main Arch Span

The main span comprises a fixed steel box section arch rib suspending the deck on a curved alignment. The three-dimensional structure was analysed using CSi Bridge software to calculate internal forces from pedestrian, wind and earthquake load effects in combination with dead loads. A number of notable outcomes were found to arise from the complex geometrical form. While the skew of the concrete deck passing through the arch resulted in biaxial bending of the box section, the continuous deck also provided stability to the arch under wind and seismic loading.

The lower arch segments are straight members mainly for aesthetic reasons, which results in bending effects from their geometry, as well as hangers inclined both in and out of plane of the arch, that are additional to the axial forces arising from traditional parabolic arches. The lower straight segments are larger in cross section than the upper parabolic curved portion, which enhances the visual slenderness of the arch rib. Stress analysis of steel box sections was carried out at 3m centres along the arch at points coinciding with hanger locations. The steel trapezoidal box section tapers from 1500mm depth at the base to 900mm depth at the crown as shown in Figure 5. The dimensions of the tapered section and the variation in plate thickness from 25mm to 35mm are driven by structural demands.

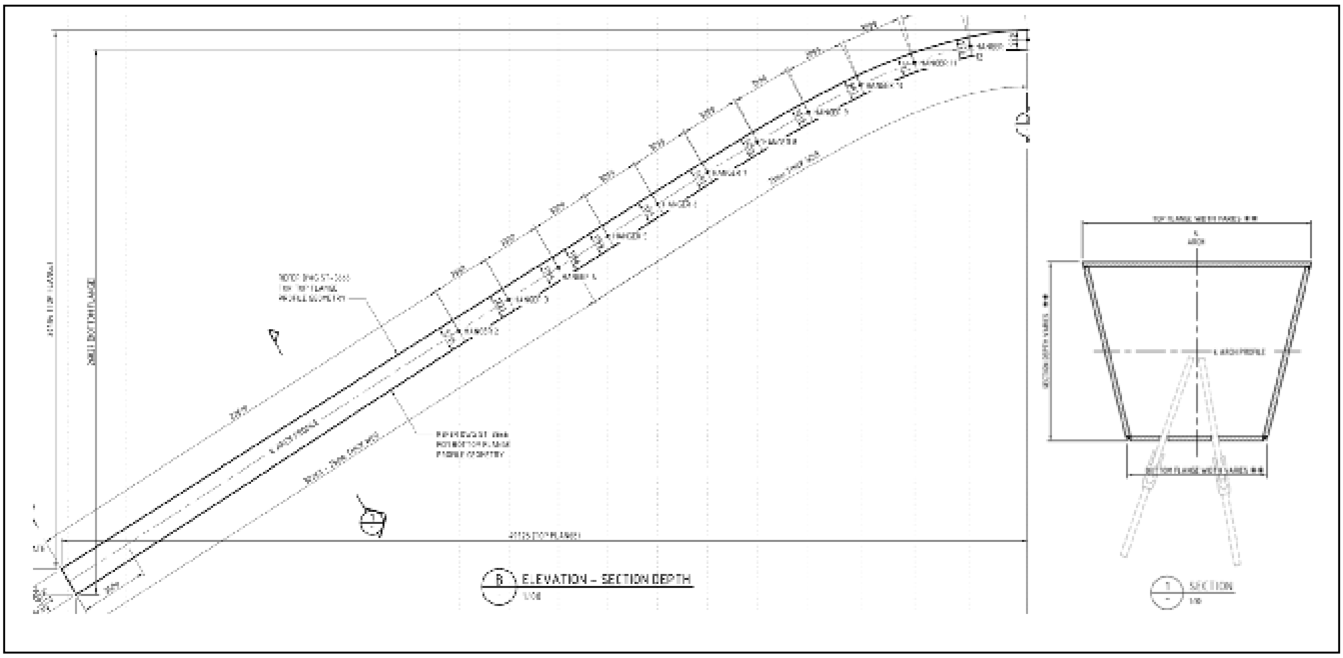

Figure 5. Elevation of half arch structure and typical cross section.

Transverse loading from wind and seismic were both found to be critical in different portions of the arch. Wind loads applied to arch, deck and hangers were analysed as equivalent static loads, while seismic loading was applied in a response spectrum analysis of the 3d model, with mass distributed according to the weights of each element. The horizontal loads are shared between the arch and the approach span piers, with the end vertical piers on either side of the main span 1m x 2m diamond sections, larger than the typical 0.75m x 1.5m approach span piers to cater for the resultant lateral forces. Overturning effects are resisted by 8m x 8m arch pad footings and widened pads to suit the transverse forces at end piers.

The modal analysis used for seismic design was used to inform the assessment of wind-induced vibrations of the whole bridge. The tall lightweight arch was found to respond in combination with the low heavy concrete deck in unusual ways that result from the three-dimensional geometry. The stiff continuous deck and the triangulated angles of inclined pairs of hangers act to limit lateral vibrational response of the slender arch rib. Horizontal vibrations of the deck were found to be minimal. However, at critical wind speeds a vortex-induced motion of the arch rib was assessed as the dominant aerodynamic issue. In this case the weight of the concrete deck transmitted via tension in the hangers had the effect of damping a second order vibrational response - with each side of the arch trying to moving up and down but restrained by the deck. The amplitude of vibration and the associated acceleration was found to be acceptable in accordance with BD 49/01 Design rules for aerodynamic effects on bridges.

The shape of the arch was designed for both architectural and structural reasons and expresses the flow of forces to the ground. The alignment was varied during design development to provide optimal structural performance. The individual elements were tailored to suit the resultant design actions. For the further information on the modelling, structural analysis and design refer to the paper presented at the Austroads Bridge Conference in 2014 entitled “Hendon Park Pedestrian Bridge – a Bridge for the Future”.

4. Construction Stages

Underlying the architectural engineering design philosophy described above the principle of design for constructability was pursued from inception to detailed design. The design team liaised with constructors in the Alliance during design development to tailor details for the most efficient construction processes and to suit their timeframes. The bridge was constructed in three stages to fit with the overall Waterview programme. First, the southern approach spans were accelerated to enable construction prior to re-alignment of Oakley Creek. This allowed construction to proceed over the old creek alignment. Second, the northern approach spans were built while the tunnel construction continued, with the spoil conveyor system passing through the bridge site. Third, after demobilisation of the tunnel boring machine (TBM) and spoil-handling system, the main arch span was installed. Each stage had its own challenges in constructability and prefabrication. The designers worked from the concept stage towards structural members that were efficient, able to be fabricated and installed to the constructors' proposed methodology. Great collaboration between Beca engineers and the Fletcher Construction and McConnell Dowell site team enabled temporary works design for installation of the main arch and the suspended deck to be carried out in a seamless process to achieve the required quality standards.

4.1 Southern Approach Spans

The first stage of construction of the bridge began with foundations for the southern approaches and the arch footings. The site is underlain by a basalt flow which thins out towards the southern boundary. The Oakley Creek was to be re-aligned from a Victorian era man-made trench structure to its old natural flow path around the edge of the basalt. The bridge spanned the re-aligned creek and in order to make construction most efficient the southern approaches were built first, allowing the stream works to follow on under the bridge as shown in Figure 6.

Figure 6. Oakley Creek being re-aligned under Southern Approach Spans.

The approaches comprise a shaped post-tensioned deck slab structure that is cast integrally with reinforced concrete piers. Diamond-shaped piers are arranged on the curved alignment in locations dictated by stream crossing points. The post-tensioned superstructure was chosen to achieve a slim deck profile while spanning 20m between piers on the stream banks. The 20m span length was repeated for the six southern approach spans and three northern spans. The deck has a structural depth of 600mm with eight tendons draped from high points over piers to low points at mid-span.

Post-tensioning was designed for a construction sequence to allow continuity with as few tendon anchorages as possible, and for maximised re-use of formwork and falsework for each span. There are eight draped tendons in the deck. Four first stage tendons were stressed for the southern-most Span 1 which was cast integrally with Pier 1 up to a construction joint at the quarter point in Span 2. Span 2 was then cast and four second stage tendons stressed to complete post-tensioning of Span 1. The end span was temporarily propped. Falsework was moved to Span 3, deck reinforcement placed and the next four continuous tendons stressed. The prop in Span 1 was removed at this stage revealing an uplift of less than 10mm which was almost exactly as predicted – the draped tendons profiled to balance dead loads so that the vertical alignment of the slender deck was undeflected in its final state. Span-by-span construction proceeded in this methodology up to Pier 6 where there was an expansion joint between approach and main spans. After Stage 1 constructors had access to the site underneath the bridge to re-align Oakley Creek during summer months.

4.2 Main Arch Fabrication

A great deal of design effort went into making the arch rib as slender as possible to align with the architectural vision for the bridge. The steelwork was detailed for ease of fabrication and transportation in four pieces from the fabrication yard to site. The top section of the arch follows a parabolic profile but the lower ends are straight for aesthetics, geometrical reasons and ease of fabrication.

During detailed design several geometrical curves were explored to find a shape that minimised out of plane warping of the variable depth web plates. Fabrication was considered throughout design to make details as easy to build as possible while seeking the apparent simplicity of form desired for the bridge architecture. Hangers have forked end connectors pinned to welded cleats that protrude through the bottom flange of the arch box section. Internal diaphragms align with the plane of the external hangers to transfer forces evenly from hanger cleats to the box section, avoiding unwanted stress concentrations. This looks simple from the outside but each diaphragm is unique to suit the changing angles of the hangers and required great precision in fabrication. Another complication was the variable pre-camber built into the arch so that after deflections during installation the designed curvature was achieved in the field. In order to make the workflow from design to fabrication smoother three-dimensional models were shared between the Alliance and steelwork fabricators Eastbridge. This enabled accurate checking of the geometry of the Solidworks shop model used for steel plate cutting, and was the only way to confirm the arch curvature envisaged by the designers was actually achieved in the fabrication process.

Box sections were seal welded and pressure tested to prove air-tightness in the yard. After painting, the arch was transported by truck from Napier to Waterview in pieces weighing up to 40 tonnes. Two halves of the central curved section were welded together on site ready for erection.

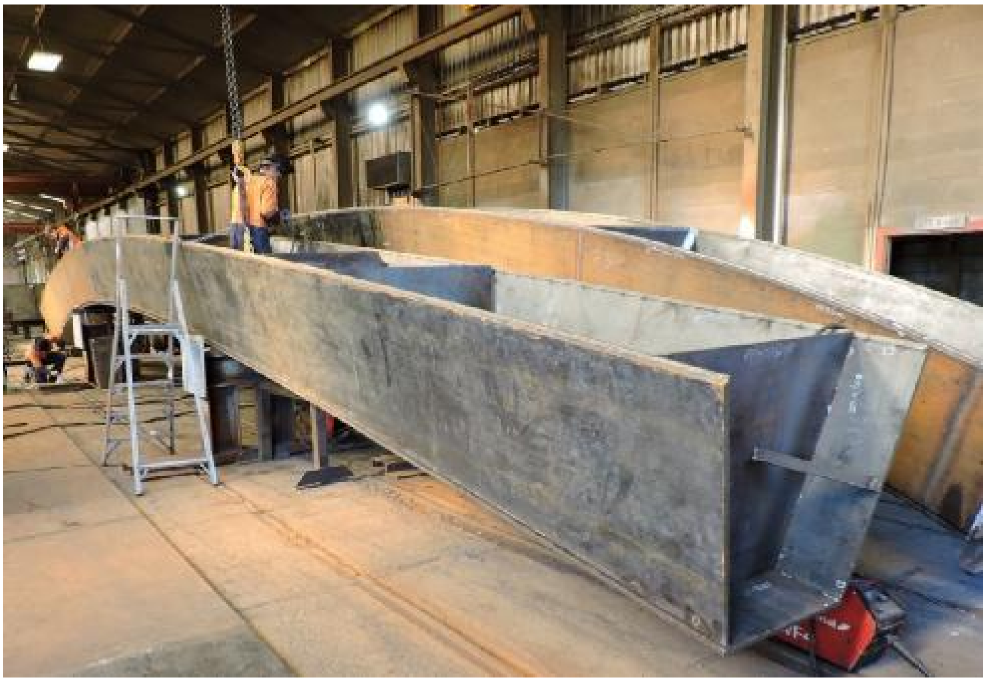

Figure 7. Fabrication of arch rib with internal diaphragms.

4.3 Arch Installation on Site

The arch was designed to be erected in three pieces supported on temporary towers and fully welded on site. While design of the finished structure is the key deliverable, it is the designer's responsibility to produce a design that can be constructed. The steel box section has different vulnerabilities at various stages of erection that were investigated to confirm stability and control geometry. The design team carried out significant construction engineering in collaboration with the constructors to enable the safe design of temporary works for supporting the arch during erection, and to confirm accurate installation.

The straight legs of the arch were lowered onto 40 Macalloy holding-down bolts cast into the reinforced concrete footings. The arch segments were supported on temporary towers that served several functions:

- Support steelwork dead loads with temporary fixings to secure the segments
- Provide access for installation of central segment, welding and painting
- Resist transverse wind loads and provide restraint to the arch rib before the deck is suspended
- Allow continuous deck construction to pass through
- Accommodate adjustment for deflections during hanger stressing.

When the arch was erected and the three pieces welded together the 110 tonne steel structure had a natural frequency that made it prone to excitation at relatively low wind speeds, which could develop a galloping motion leading to damage of the unfinished bridge. Restraint forces were calculated by the designers, and the contractors' temporary works engineer designed the temporary works to ensure stability at each stage.

Installation by crane was successfully carried out in December 2015 after the TBM had been removed from site along the haul road through the bridge site. After the arch was up and secured in place, deck construction commenced in 2016. The photo in Figure 8 shows the central arch segment being erected.

Figure 8. Arch segment being lifted onto temporary towers.

4.4 Hanger Stressing

After the main span deck had been cast on falsework the final stage of the structural works on site was to install and stress the hanger rods which suspend the deck from the arch. Attention to minute detail was critical in this operation to make sure that the loads in each hanger were as designed, and that the arch and deck were installed to the intended geometry. As part of the Alliance, it was agreed that Beca were best placed to carry out the analysis to determine the hanger stressing sequence and provide jacking loads to achieve the required balance of stress and deflected profile. A planned process of hanger installation and stressing was agreed between constructors and designers. The designers carried out a stage-by-stage structural analysis of each step of the sequence using CSi Bridge software. The output was a detailed plan showing jacking forces together with calculated arch and deck deflections at each of the twenty-one stages.

Working from the centre of the span outwards hangers were stressed two pairs at a time in a coordinated sequence so as to control the geometry of the flexible arch. Because of the varying angles of the inclined hangers this sequence caused incremental horizontal movements as well as vertical deflections of the steel arch. The construction team installed a monitoring system using targets that had been fixed to the arch prior to erection and survey points along the deck. An innovative measuring system was applied to record the position of each survey point along the structure that could be downloaded directly to a spreadsheet for comparison with the table of predicted displacements. After each set of four hangers was stressed a check on the resultant geometry was made before proceeding to the next stage.

The stressing proceeded without hitch and deflections at each stage confirmed the intended behaviour of the structure and final geometry. A round of load take-offs and re-stressing of some of the outer hangers that were found to have lower than predicted tensions completed the operation. At this stage the deck could be seen to have just lifted off supporting falsework with tiny gaps appearing. So when the falsework was removed the design and construction team was confident that there would be no significant movement.

Figure 9. Hanger stressing and arrangement after removal of deck falsework.

The final stages of construction included installation of pedestrian barriers, construction of access stairs at Pier 5, electrical wiring and handrail lighting fitting, planting and landscaping around the bridge.

5. Conclusions

The Waterview Shared Path bridges and Hendon Park Footbridge comprise a suite of high quality structures for walking and cycling paths around the final link in Auckland's Western Ring Route. The Alliance partners of this major road project have delivered on the NZ Transport Agency's promise to connect communities along the route of the new motorway. A significant contribution of new sporting, recreational and social facilities has been handed back to the affected communities. These are linked by the shared path bridges aiming to revitalise the neighbourhoods of Owairaka and Waterview after construction.

The focus of the Alliance on urban design, planned in consultation with local community groups has meant that shared goals have been achieved through the collaboration of a range of stakeholders. Sustainability principles were applied to achieve triple bottom line outcomes with a balance of social, environmental and economic benefits. These include provision for alternative modes of transport in and around the neighbourhoods, improved environments such as Oakley Creek and the Valonia Wetland, new sports grounds, parks and recreational assets for the area.

The Hendon Park Footbridge is a landmark architectural feature of the project that is integrated into the revitalised environment. Conceived as a simple geometrical form, considerable design input was needed to deliver the bridge through close collaboration of engineers and architects and to follow the vision through to the final details for construction. The aim was to make the structure slender and elegant, while performing efficiently in transferring loads across the motorway and rail corridor. A holistic design approach meant integrated architecture and engineering combined seamlessly right down to the finer details of hanger connections, outriggers, shaped concrete deck, piers, barriers and lights.

Staging of the bridge works enabled alignment with the overall project programme for tunnel and road construction. Complex engineering and innovative construction techniques were applied to make the structure as sleek and simple as the conceptual vision. Working in an Alliance form of contract enabled designers and constructors to collaborate closely, and provide the most appropriate expertise to manage risks during fabrication and installation of complex steel structures. Innovative monitoring tools were used to deliver the accuracy and quality of construction needed to meet the design intent. Erection of the arch and suspension of the deck were successfully completed to the required tolerances for structural purposes and to produce the desired architectural outcome.

The success of the bridges will be judged during the coming years, if the community start using the new facilities in their neighbourhood, if more people are encouraged to ride their bikes for recreational trips and commuting, and if drivers passing beneath the Hendon Park Footbridge enjoy a dramatic moment on their journey through this gateway to Waterview.

Figure 10. Hendon Park Footbridge viewed across Valonia Wetland.

6. Acknowledgement

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