Examples of Recent Aesthetic Landmark Footbridges in Western Australia

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Synopsis
Aesthetic and functional design may be closely interlinked when they relate to the particular site needs. The following examples of recent footbridges designed and constructed in Western Australia are described to illustrate this principle:

1) PRESTON ST FOOTBRIDGE (COMO) – twin tower cable stay structure with sail canopy.
2) ALBANY WATERFRONT FOOTBRIDGE – cable stay trough truss with removable span.
3) PORTMARNOCK FOOTBRIDGE (Mitchell Fwy) – haunched symmetrical post-tensioned concrete.
4) SOUTH STREET FOOTBRIDGE – combination of conventional precast and insitu concrete T beam.
5) EXMOUTH MARINA FOOTBRIDGE – cyclone-resistant, 90.3m span, high steel arch over canal.

Each of these footbridges were required to provide access for the disabled and for various levels of usage by cyclists and tourists. They were also perceived by clients as potentially distinguishing landmarks. The paper describes the features that make each a landmark in its own particular way and lists some comparative statistics. It also describes and illustrates aspects of interest to design and construction engineers and architects including how various constructability and physical robustness requirements were met.

Keywords: footbridge; aesthetic; landmark; robustness; wind loading;

1. Introduction
This paper describes and discusses five footbridges recently constructed in Western Australia that were required not only to provide access for pedestrians, the disabled and cyclists, but have also been deliberately featured as landmarks. The footbridge locations range from Albany which is approximately 500 km south east of Perth to Exmouth which is approximately 1000 km north of Perth; the other 3 footbridges lie within the Perth metropolitan area. Spans range from 20.4m for the South St Footbridge to 90.3m for the Exmouth Marina Footbridge. The latter is the longest single-span footbridge in Western Australia and possibly in Australia. Comparative physical statistics are summarised in Table 1 and other data in Table 2.
Table 1: Statistics & features of 5 recent footbridges of interest in W.A.

<table>
<thead>
<tr>
<th>Bridging over</th>
<th>PRESTON ST FOOTBRIDGE (COMO)</th>
<th>ALBANY WATERFRONT FOOTBRIDGE</th>
<th>PORTMARNOCK FOOTBRIDGE (Mitchell Fwy)</th>
<th>SOUTH STREET FOOTBRIDGE</th>
<th>EXMOUTH MARINA FOOTBRIDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway</td>
<td>Freeway</td>
<td>Railway and roads</td>
<td>(greenfield) freeway</td>
<td>Arterial road</td>
<td>Marina canal</td>
</tr>
<tr>
<td>Main Span (m)</td>
<td>58</td>
<td>36</td>
<td>30.3</td>
<td>20.4</td>
<td>90.3</td>
</tr>
<tr>
<td>Vert. Clearance (m)</td>
<td>5.4</td>
<td>7.5m above top of rail.</td>
<td>5.5</td>
<td>6.1</td>
<td>6.0m above High Astronomical Tide.</td>
</tr>
<tr>
<td>Struct. Depth (mm)</td>
<td>400</td>
<td>180</td>
<td>650</td>
<td>820</td>
<td>300</td>
</tr>
<tr>
<td>Walkway width (m)</td>
<td>5.0</td>
<td>2.34</td>
<td>3.1</td>
<td>2.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Total deck length (m)</td>
<td>238</td>
<td>252</td>
<td>272</td>
<td>219</td>
<td>90.3</td>
</tr>
<tr>
<td>Ramp types included in length</td>
<td>One straight, one elliptical</td>
<td>One switchback</td>
<td>Two loops (symmetrical)</td>
<td>One loop, one switchback</td>
<td>Both straight ramps included in main span</td>
</tr>
<tr>
<td>Staircases</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Type of superstructure</td>
<td>Cable-stayed - precast concrete deck</td>
<td>Cable-stayed main span, regular truss &amp; yard cast concrete deck</td>
<td>Haunched concrete - in-situ, post-tensioned main spans, continuous with reinforced ramp spans</td>
<td>Combination of simply supported precast pre-tensioned beams, and continuous in-situ reinforced concrete ramps.</td>
<td>High steel arch suspending precast concrete deck via diagonal cables</td>
</tr>
<tr>
<td>Dynamic control, &quot;failsafe&quot; ramps</td>
<td>2 points of fixity</td>
<td>Removable portion over road</td>
<td>Collision resistance</td>
<td>Collision resistance</td>
<td>Cyclone resistance</td>
</tr>
<tr>
<td>Structural features</td>
<td>U-truss spans</td>
<td>1.5m high toprail</td>
<td>Limited space in median</td>
<td>V = 99m/sec</td>
<td></td>
</tr>
<tr>
<td>Foundation type</td>
<td>2 rafts + pad footings</td>
<td>Caissons &amp; screwpiles</td>
<td>Pad footings (below freeway fill)</td>
<td>Pad footings &amp; short bored piles</td>
<td>Caissons &amp; deadman anchors</td>
</tr>
<tr>
<td>Visual Features</td>
<td>Twin Tapered painted steel Cable-stay masts; Sail awning over viewing platform; artwork in deck</td>
<td>Twin cylindrical Cable stay towers; awnings; trusswork to toprail height</td>
<td>Smooth symmetry of haunched profile</td>
<td>Median column on robust barrier &amp; painted yellow</td>
<td>Arch profile and trellis effect of cables</td>
</tr>
</tbody>
</table>
Table 2: Other information on the 5 recent footbridges of interest in W.A.

<table>
<thead>
<tr>
<th>Client/Agency</th>
<th>Local Authority</th>
<th>Designer</th>
<th>Constructor</th>
<th>Date of Constr.</th>
<th>Approx. final cost ($A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRWA</td>
<td>South Perth</td>
<td>BG&amp;E Pty Limited</td>
<td>HEWCJV</td>
<td>November 2001</td>
<td>$2.5M</td>
</tr>
<tr>
<td>Landcorp</td>
<td>Albany</td>
<td>BG&amp;E Pty Limited</td>
<td>BOCOL</td>
<td>July 2007</td>
<td>$2.3M</td>
</tr>
<tr>
<td>MRWA</td>
<td>Joondalup</td>
<td>BG&amp;E Pty Limited</td>
<td>Macmahon</td>
<td>October 2007</td>
<td>$2M</td>
</tr>
<tr>
<td>MRWA</td>
<td>Melville &amp; Canning</td>
<td>BG&amp;E Pty Limited</td>
<td>BOCOL</td>
<td>November 2007</td>
<td>$2M</td>
</tr>
<tr>
<td>Landcorp</td>
<td>Exmouth</td>
<td>BG&amp;E Pty Limited</td>
<td>BOCOL</td>
<td>January 2008</td>
<td>$5M</td>
</tr>
</tbody>
</table>

The five footbridges described in this paper have been designed in accordance with the Australian Bridge Design Code AS 5100 including the requirements for access for the disabled in accordance with AS1428.1. This includes kerbs and handrails to follow the undulations that occur in ramps at intermediate landings. In all the examples in this paper, there has been a client requirement to conceal these undulations from external view with a smoothly profiled edge upstand, and to provide a top rail parallel to the edge upstand. The handrail, at a lower level than the top rail follows the undulations of the deck.

2. Description

2.1 PRESTON ST FOOTBRIDGE (COMO) – Twin Tower Cable Stay Structure with Sail Canopy

The Preston St Footbridge has become a landmark though the use of a sail canopy to provide shade over a viewing platform (see Figure 1). This was a design response under a design and construct contract for various freeway upgrade works that included replacement of a superseded footbridge with a cable stayed structure with a shaded viewing platform. The contract set many boundaries on the design and severely restricted space for the final construction between the freeway and Swan River at the Como jetty. It also required that the deck in the main span be 5 metre wide, and that the structure was to include a staircase and ramps and landings at each end. The footbridge was to be constructed over a 6 lane operating freeway and busway.

The winning design included cable supports at divisions of the main span of approximately one fifth allowing the shallow structural depth of precast concrete slabs for the deck to be utilised. The cables are individually greased and sheathed prestressing strands that are further encased in black HDPE and have visually expressed anchor heads at each end. The upper end is supported by transoms of two tapered towers in painted fabricated steelwork. These in turn are stabilised by backstays of similar form at complementary angles anchored to concrete blocks above stocky backstay columns. The proportions resulted from the need to control the deflections of the main span as a means of controlling dynamic behaviour whilst fitting the supporting structure, ramps and staircases within the restricted space.

The heavier features are visually lightened by the sail canopy at the western end. At the eastern end, the structure spans across a side street and along Preston Street which rises naturally to meet the abutment (see Figure 2). The effect of this adds to
the directional impression of the masts and sails heading westward.

Fig. 1 Preston Street Footbridge – the “sail” canopy over the viewing platform supported by the western tower.

Fig. 2 Preston Street Footbridge – View from Preston Street precinct

2.2 ALBANY WATERFRONT FOOTBRIDGE

The Albany Waterfront Footbridge was planned as the first stage of a waterfront development at the old port site of Albany in Princess Royal Harbour. The primary functional purpose of the footbridge is to provide safe access over the rail and road corridors that separate this new development from the town. An earlier footbridge over the railway accessing the Town Jetty nearby was demolished some decades earlier, and modern port developments had occurred that were geographically aggravating the separation of the port from the town, the town from the waterfront and the heritage precinct that lay between.

The design and construct contract for the footbridge specified that the design needed to be respectful of a number of features of this precinct. An alignment and configuration were finally agreed with the successful tenderer that provided:

- Ramp and staircase access to the waterfront;
- A 36m span supported by cable stays and divided into 3 removable portions (see Figure 3) such that the feasibility of very large items accessing the port
would not be unduly restricted;

- An adjacent span over the railway with generous clearances and a high degree of robustness in accordance with AS5100, plus a ‘sacrificial’ column set back behind the historic railway station platform within this span for deflection control (It also aided the assembly of the deck modules);
- An intermediate staircase access that lands between the Terminus of the Bibbulmun Track and the Albany Visitors Centre (in the heritage railway station building);
- Respect for returned services by passing alongside the heritage memorial garden and inclusion of plaques on adjacent concrete columns of the footbridge;
- At-grade access at the north abutment to a town footpath (superseding the use of hazardously uneven masonry stairs);
- Views to a large number of features including Princess Royal Harbour, the Albany wind farm, the historic post office tower and other nearby heritage features, and;
- Shelters at intervals along the walkway for pedestrian comfort (See Figure 4).

A shallow bridge deck was needed to optimise the vertical geometry and to achieve this, side trusses of nominally 1.5m depth fabricated from rectangular hollow section (RHS) steel composite with a structural concrete deck was developed. A truss module length of nominally 2 metres was found to be a suitable increment of the various spans required whilst providing an appearance of uniformity. This style was considered to be reminiscent in appearance of the earlier timber footbridge and footbridges designed by C.Y.O’Connor over a century earlier (C.Y.O’Connor is famous in Western Australia for construction of the Kalgoorlie pipeline and the Fremantle harbour following distinguished engineering achievements in New Zealand).

To prevent children climbing on the truss diagonals, balustrade panels of cut and pressed aluminium sheet were used to line the inside, visually framing the walkway from within. The cable stays and associated towers and also the awning shelters retained a blend of nautical and industrial styles that were also considered appropriate to the heritage railway and port setting.

![Image](https://via.placeholder.com/150)

*Fig. 3 Albany Waterfront Footbridge - Erection of last removable portion (under road closure at dawn)*
2.3 PORTMARNOCK FOOTBRIDGE (Mitchell Fwy) – haunched symmetrical post-tensioned concrete

The Portmarnock Footbridge is part of a “greenfield” freeway extension and provides continuity of access to pedestrians and cyclists who had previously used a rough track across the freeway reserve between the developed areas each side. It was specified by Main Roads Western Australia under a design and construct contract with strict aesthetic requirements. There was an appreciable amount of community involvement in determining the location and details of this footbridge as it followed a response to an unpopular alternative underpass through a high embankment fill. This contributed to the project winning an Australasian award for Public Participation Enhanced Decision Making.

The final superstructure is perfectly symmetrical about the freeway median to the ends of the loop ramps. The central pier is centred on a broad median which provides for future traffic lanes. This pier and the adjacent piers are designed for 2000 kN collision resistance notwithstanding that there are guardrails to reduce the risk of vehicle impact.

The entire structure is of in-situ concrete. The four central spans are post-tensioned, haunched in elevation and straight in plan. The adjacent three spans at each end of this are reinforced concrete helical quadrants and the remaining spans also of reinforced concrete form straight ramps that pass under the secondary spans just beyond the haunches (see Figure 5).
2.4 SOUTH STREET FOOTBRIDGE – combination of conventional precast and insitu concrete T beam

The motivation for the South Street Footbridge was to provide access for pedestrians and cyclists (for both commuting and leisure) over a busy arterial road in a rapidly growing suburban area. Preliminary designs showed that despite the complexities of a pier in the median, the cost of the alternative of spanning both carriageways was considered prohibitive. As a safety feature and a landmark, the client opted for the central pier to be painted yellow. In this case, the landmark may be seen as more of an aid to navigation than necessarily of aesthetic value, although it does complement the colour of the painted handrail.

The existence of traffic limited the practical forms of construction, and precast concrete beams of teeoff form were used to minimise costs. A high degree of hog deflection in the beams due to pre-tension was included to mitigate the angular appearance of the cusp in the profile over the median column.

The geometry of the ramps of footbridge was dictated by space availability. The southern ramp utilises super tee beams in two straight legs in switchback formation with a staircase at the intermediate landing, whereas the north ramp is a compound helix providing a smooth compact appearance, constructed of in-situ concrete of matching cross-section.
2.5 EXMOUTH MARINA FOOTBRIDGE – cyclone-resistant 90.3m span high-arch over canal

As part of a marine development to complement the boat harbour at Exmouth, Landcorp commissioned the design of a landmark footbridge over the main canal. The functional purpose of the footbridge is to provide a pedestrian link between resort and harbour facilities and proposed up-market residential and commercial developments of the main marina precinct.

A headroom of 6 metres above high astronomical tide was specified for the design to which was added the tidal allowance of 1.4m and a tolerance of 0.1m for construction and deflection. Although this was a compromise to yachting, it was seen as suitable for the majority use by motor vessels and simplified pedestrian access by not having to provide separate ramps – providing the structural depth could be kept very shallow.

Exmouth is within the maximum cyclonic region for wind forces within Australia with an ultimate design wind speed of 99 metres per second. In addition to direct wind loading is the need for consideration of immunity to impact from an errant ocean-going vessel in the event of a cyclonic storm. Similarly, a reasonable level of tsunami immunity is also a consideration in view of recent events, although no Australian standard exists for this. These aspects favoured deep shore-based abutment foundations and a clear span over the canal and avoidance of intermediate supports.

In the preliminary design four distinct options were investigated:

1. A suspension bridge
2. Cable stay options
3. A high steel arch with suspended deck
4. Haunched prestressed concrete continuous 3-span bridge on protected piers at the waters edge.

The difficulty with the first two options was that, for navigation safety reasons, the use of lateral stays was precluded from the design. Consequently, a concrete deck of sufficient weight to avoid uplift under extreme wind lift effect was included in each option. Wind instabilities were also investigated by considering the parameters indicated in specialised literature. The structural design was largely governed by the wind loading at the ultimate limit state, which in general terms is about four times the
intensity of that in non-cyclonic zones.

In addressing these design issues for the high steel arch, the preliminary design was proportioned with curved surfaces, slender arch members and shallow deck. Slenderness was achieved principally by triangulating the hangers. It was assessed that, for both aesthetics and structural economy, the height of the arch above the deck should be about twice the height of the deck above the water and that cables should be set at about 45 degrees of inclination. Thus resulted in cables crossing over each other so that at a central vertical section there are 2 cable pairs contributing to the shear stiffness of the structure in terms of considering the structure as a deep beam – this greatly improves both the resistance to buckling under one-sided live load and the control of pedestrian induced dynamic behaviour.

With these features, the high arch solution was estimated to be the least costly of the options considered and was considered to maximise immunity to events of vessel impact. Refinements of the preliminary design included attaching the cables to stocky stanchions (of 250mm SHS steel) at a point sufficiently above the deck that the cables did not provide a foothold for children to climb over.

In the detailed design, it was found that second-order effects magnifying the wind effects required larger foundations and a wider arch base than previously estimated, but this did not change the favour for this option.

The primary challenge with this structure was to be the construction over water – firstly the installation of the arch, and secondly the construction of the deck. The tender drawings were prepared showing an indicative sequence of construction that included assembling and lifting each half of the arch by crane from its respective abutment by 2 cranes operating simultaneously. A connecting pin was to be installed in the apex joint by accessing from a crane-mounted man cage.

The construction contract was awarded through a construct-only tender process to BOCOL Constructions Pty Ltd who opted to erect the arch in the manner indicated (see Figure 7), but proposed a modified deck construction that involved larger precast units than had been shown in the design. This required close co-operation between the constructor and the designer. To avoid instability of the arch during interim stages, temporary stabilising cables of untreated prestressing strand were installed and tensioned. These temporary cables were not removed until the deck was finalised and stability was provided through the web action of permanent (stainless steel) cables. (see Figures 8 and 9)

Fig. 7 The Exmouth Marina Footbridge – erection of the arch

Precast units were lifted into position by crane from a raft/barge, and the weight of each symmetric pair transferred simultaneously onto the permanent cables by...
synchronising (to within 1 tonne) through radio contact. A third crane was used to manoeuvre riggers in a man-cage to safely connect the cables. After the initial installation, the cables needed adjustment to position the precast units in line, level and distance at each edge. To avoid seizure of the stainless steel rigging screws, and to avoid asymmetrical loading of the arch, the cranes lifted the precast units from each end simultaneously for this adjustment (see Figure 8) while the third crane loaded the next precast unit on the barge. After installation of the last unit this adjustment process under crane support was repeated to fine-tune the levels to the design profile with a camber allowance for the minor subsequent loads and for creep.

Fig. 8 The Exmouth Marina Footbridge – symmetrical installation of precast deck units

Fig. 9 The Exmouth Marina Footbridge – completed bridge at night
3. Discussion of Structural Engineering considerations

Statistics and features of the footbridges described above are summarised in Table 1.

3.1 Articulation

Consideration always needs to be given to the way in which a bridge can expand and contract due to thermal movements as well as shrinkage and creep. Whereas a short bridge or a cable stay bridge with a single tower would commonly have a single point of fixity and an expansion joint at the ends of the structure, the 2 cable stay examples presented each have a point of fixity for each tower, and an intermediate expansion joint between. In each case the expansion joint has a simple cover plate and a shear key arrangement to transfer lateral loads in the event of a collision loading.

Where there are enough supports along the ramps, as there are in the Portmarnock and South Street footbridges, elastomeric bearings can be used to accommodate movement whilst sharing resistance to the 500 kN minimum restraint force of AS 5100.

The arch of the Exmouth footbridge, on the other hand, accommodates expansion by rising at the centre, and also by flexure of the lower part of the arch legs.

3.2 Use of Prestress in Superstructures

In each example, prestressed concrete has been used in the deck, but for different reasons. Prestressing steel is used for the moment capacity (both vertical and lateral) required in main spans of the Portmarnock and South Street footbridges. In the Preston St footbridge, post-tensioning of slabs allowed the use of a 400mm depth of slab for the 58m main span and beyond with cable stay spacing of 12 metres.

In the Albany Footbridge, the concrete deck is composite (for lateral stability of the top chord through transverse bending as a u-frame) with the tension chord of the edge trusses and prestressing of the deck was considered to be the most practical means of crack control.

In the Exmouth Footbridge, post-tensioning was introduced as the contractors preferred means of providing the required lateral bending strength in preference to casting a continuous reinforced concrete deck.

3.3 Foundations and Collision Immunity

AS 5100 includes provisions for collision resistance of nominally 2000 kN on columns adjacent to roadways, and a minimum lateral restraint of 500 kN to be provided for at all other support locations. Due to the light-weight of footbridges compared with road bridges it is common to require more sliding resistance than can be offered by pad footings. In the Preston St footbridge this was addressed by supporting the robust columns and towers on combined raft footings. The Albany Waterfront footbridge cable-stay towers have concrete bases capable of deflecting vehicles that are stabilised against sliding by a combination of screw piles and caissons. In the case of the South St footbridge, this supplementary resistance to sliding was incorporated in the footings of the 3 columns adjacent to the main road by augered piles. In the Portmarnock Footbridge on the other hand, the footings were cast prior to a substantial amount of road embankment fill being placed – as a result it was possible to proportion each of the resulting deep footings adjacent to the freeway to resist collision loading aided by other footings through lateral loading on the deck.

The Exmouth Marina footbridge arch and concrete deck, having been proportioned to resist cyclonic wind forces with abutments clear of the canal, did not require any further strengthening for collision loading, as the foundations needed to be substantial to resist the design wind loading conditions. Due to particular difficulties...
of the underlying variable, fragmented and porous rock, the foundation stability was finally achieved by a group of 4 caissons and 2 deadman anchors at each abutment.

4. Concluding Remarks

This paper has presented examples where the overall cost has been controlled largely by minimising structural depth and hence minimising overall length. This reduction in length also reduces journey length for users and hence enhances the amenity. Costs increase for construction over traffic and over water in comparison with greenfield construction over land.

Each bridge design presented a particular set of challenges to the designer to which the design response has become a distinctive feature. A landmark may be simply a navigational aid, or it may be a feature that enhances the aesthetics of an area.

The paper also describes design responses to engineering matters such as collision loading and wind loading.

Acknowledgements

The writer wishes to acknowledge the courtesy of Landcorp WA, the Commissioner for Main Roads Western Australia, and the respective Local Authorities, as listed in Table 1 for their permission to publish information about footbridges under their respective jurisdictions.