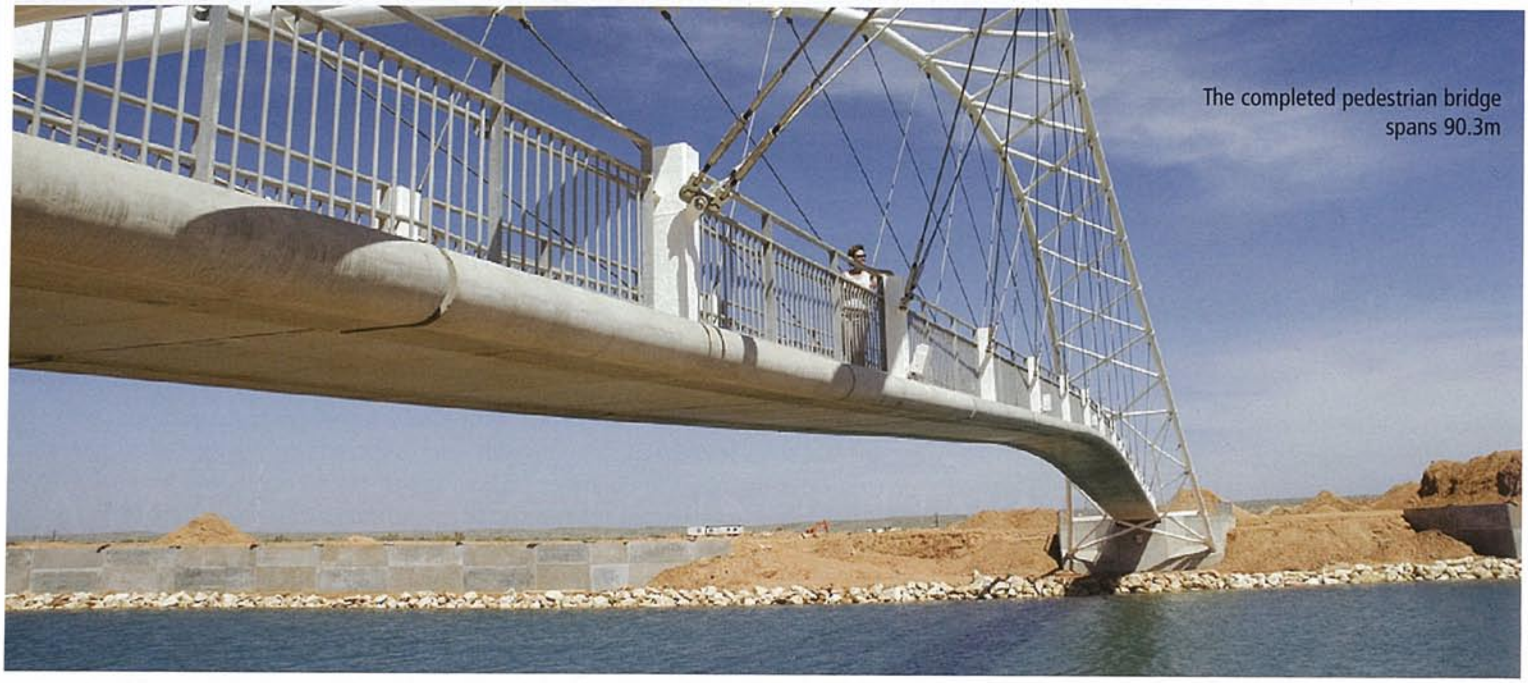

The completed pedestrian bridge spans 90.3m

WIND OF CHANGE

Designing a pedestrian bridge to resist cyclonic winds was made more challenging by the additional requirement for a landmark structure spanning more than 90m. Graeme Dundas explains how it was done

A new suspension-arch footbridge has recently been completed at Exmouth in Western Australia; the footbridge spans the main channel of the marina that is being developed, and is some 2km south of the town centre. Designed by BG&E Consulting Engineers, it has a braced pair of slender inclined tubular steel arches from which diagonal stainless steel cables suspend the precast prestressed concrete deck. This form of construction was engineered not only to resist cyclonic winds, but to control pedestrian-induced dynamic deflections and also to satisfy a requirement for an aesthetic landmark.

The bridge spans 90.3m which makes it the longest single-span footbridge in Western Australia. The arch rises to almost 20m above the water level and is visible from the main road into Exmouth. Exmouth is within the maximum cyclonic region for wind forces with an ultimate design wind speed of 99m/s at the apex of the arch in accordance with the relevant Australian standards. This represents a design wind loading of about four times the intensity of that in non-cyclonic zones.

The client, Landcorp, through project management by Benchmark Projects, was not simply seeking the design of a pedestrian bridge to cross main canal; it also wanted a landmark structure with a high degree of immunity from failure in the event of impact from an errant sea-going vessel. To meet this requirement, lateral wind stays and any other obstruction within the canal were not permitted.

These aspects favoured deep shore-based abutment foundations and a clear span over the canal. Setback was favoured principally to avoid direct collision from an errant vessel, but it also had the advantages of improving constructability and providing space for a pathway on each side of the canal with unimpeded access to the canal.

The high suspension arch type structure was recommended and selected from four preliminary designs. The structural design for each option was largely governed by the wind loading at the ultimate limit state. Wind instabilities were also investigated by considering the parameters and theory indicated in specialist literature.

The concrete deck thickness was designed to provide sufficient weight to avoid uplift under the design wind effect. In this regard the deck has a nominal average thickness of 300mm, although the 1.8m wide walkway thickness varies to include ramps and landings as required for wheelchair access in accordance with Australian standards. Balustrades and edges of the precast deck hide these undulations from the side view and are streamlined to minimise wind loading. As well as providing navigational headroom of 6m at high tide, the shallow profiled deck facilitates pedestrian access without the need to provide separate ramps and with only minimal fill above the general ground level of the marina development. In addressing the wind design for the high steel arch, the preliminary design was proportioned with curved surfaces and slender arch members. Circular hollow sections of grade 350 steel were used for the arch chords and bracing sections in this case. For ease of fabrication, the arch members lie in inclined planes and are each straight chords between welded nodes.

Slenderness of the arch members was achievable by triangulating the hanger cables. 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° of inclination. This resulted in cables crossing over each other so that at any central vertical section there are two cable pairs in each direction, 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. This doubling of cables was also designed to provide sufficient redundancy to allow for one cable at a time to be ineffective under moderate weather and loading, thus allowing for future cable replacement if ever required.

Refinements of the preliminary design included attaching the cables to stocky stanchions - bollards fabricated from 250mm SHS steel – high enough so that the cables did not provide a foothold. The bollards were designed to be bolted to fabricated steel shear heads cast into the precast deck units, avoiding extra deck thickness that would have added wind loading effects as well as raising vertical clearance issues.

In the detailed design, it was found that second-order effects magnifying the wind effects required larger foundations and a wider arch base than had been estimated, but this did not change the favour for this option. Traditional piling was not possible due to the presence of limestone at a shallow depth below sea level, and conventional footings were also precluded by the porous nature of the rock and the tidal influence on the groundwater, making dewatering impractical. The solution for the abutments, to enable them to resist the effects of cyclonic winds, included deadman anchors to engage soil and caisson-type reinforced concrete bored piles sunk below sea level in steel casings.

Construction was carried out by main contractor Bocol Constructions under a US$3 million contract. Subcontractor Structural Marine fabricated the arch steelwork and

Left and right: Construction photographs showing the arch being installed over the canal

bracing, as well as the inverted shear heads from which the precast concrete deck units were suspended. Precasting of concrete deck units was undertaken by Delta Corporation, while Bocol carried out the foundation works and in situ reinforced concrete abutment construction. Post-tensioning work was carried out by Structural Systems.

Once the arch components had been fabricated, a trial erection of the arch was carried out at the fabricator's yard. The components were then unbolted for corrosion protection treatment and transported approximately 1,000km from the Perth metropolitan area to the site at Exmouth Marina Village.

After delivery to site, the two halves of the arch were assembled on temporary supports near to their respective abutments, where the suspension cables were attached. Temporary cables of prestressing strand were also fixed to the slender arch members at this stage to provide the extra strength and stability required during the subsequent erection stages. Two large mobile cranes with capacities of 400t and 250t were then mobilised to lift the assembled arch halves over the canal to meet in the centre forming the full arch shape. The spigot and socket connection at the apex on each side was then locked in position by a simple vertical pin to provide integrity in the event of high wind or other contingent loading of the arch. The pin was inserted manually from a safety-cage suspended from a 160t-capacity crane.

Following the arch erection, the precast concrete deck units were lifted with bollards attached. The ends of the cables were then pinned in position to the bollards. This was done sequentially from each abutment maintaining symmetry to the extent required for stability of the arch until all deck units and suspension cables were connected to provide integrity to the structure. Each successive precast unit was bolted to the previous using a steel bracket within a block-out.

BG&E Consulting Engineers provided on-site advice to the contractor to make appropriate adjustments to the hangers during the deck erection as well as close assessment of structural safety during all temporary conditions of the erection of the arch and deck. After installation of the last deck unit, the adjustment of cables under crane support was repeated to fine-tune the levels to the design profile with a pre-determined camber allowance for the minor subsequent loads and for creep.

After all the precast deck units were in place, with line and level adjusted to design requirements, and electrical wiring and prestressing strands threaded through each edge of the deck, the concrete block-outs were reinforced and filled with concrete. The full-length prestressing tendons were then post-tensioned and grouted to provide the design strength to resist the full design wind loading before the onset of the following cyclone season. Subsequent stages to complete the project included balustrade installation, final approach earthworks and surfacing.

The high arch with its latticework of stainless steel hangers forms a focal landmark visible from the various approaches to the marina. The lattice pattern of inclined cables not only provides an interesting and pleasing appearance from various perspectives but also offers a high level of global stability to the relatively slender arch and hence a high degree of user comfort. The type of structure also provided the necessary resistance to the high cyclonic wind forces associated with this region without the use of lateral stay cables. Attention to detail included orienting cable cleats to minimise the area exposed to wind in elevation and ensuring that concrete at the few exposed concrete steel interfaces is non-critical to allow for repairs and reinstatement.The modular design allowed construction at a relatively remote location and the use of stainless steel cables will reduce future maintenance ■

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