SECOND COMING

Piers and towers of a major cable-stayed bridge in South Korea are currently under construction. **Armin Patsch** explains the development of the design

Construction of the main towers is under way on the Geumbit Grand Cable-Stayed Bridge which will be part of the fixed connection of the Geo-Geum Island to the South Korean mainland. The two lane highway bridge with its total length of 2,028m is the second stage of this fixed-link project and will connect Sorok Island to Geo-Geum Island passing Dae Hwa Island. Erection of the superstructure and cables is intended to start in 2008 with completion of the whole link currently scheduled for 2010.

This high level crossing is composed of a 912m-long approach viaduct and a 1,116m long main bridge which will carry the road over a 210m-wide shipping channel. The main bridge is a cable-stayed bridge with a main span of 480m, 198m-long side spans and 119m-long end spans, while the approach viaduct is a continuous girder with regular spans of 120m.

The main design considerations of the Geumbit Grand Bridge were how to combine its functional requirements as a highway bridge, with innovation in design and visual harmony with its surroundings. The stay cables are arranged in a single plane along the centre line of the bridge deck; their semi-fan arrangement with its bundled configuration give it a striking appearance. On completion, the bridge will be the largest of its kind in Korea.

The navigation channel has a width of 210m, a clearance of 38.5m above reference level and intersects the bridge alignment at an angle of 35°. Collision loads of 50MN at the towers and 15.8MN at the anchor piers were considered at the design stage, to resist any impacts from aberrant vessels.

Deep foundations were required to cope with the water depths of up to 35m and weathered soils. Additionally, the bridge had to be designed for high wind speeds as it is located in typhoon region. The basic wind velocity is a 10 minute mean wind speed of 40m/s at 10m above sea level. Finally, high seismic loads had to be considered, with a maximum ground acceleration of 0.385g.

At the feasibility phase various alternatives were investigated and a shortlist of seven options was made; six of these were cable-stayed bridges with spans ranging from 300m to 468m, one or two towers, and a range of truss girder and box girder decks. The seventh was a suspension bridge with main span of 450m and two towers.

The final choice was a two-tower cable-stayed bridge with 480m main span, a 6m-deep steel truss deck, bundled stay cables and approach viaducts with 6m-deep truss girders, typically 120m spans.

The horizontal alignment is straight at the main bridge and the approach bridge is curved with a radius of 1300m; for vertical alignment, the main bridge is curved on a radius of 16,667m over a length of 1200m and inclined at 1.8% over the remainder.

Towers are designed in concrete, consisting of a delta shape at the bottom, which divides at 85m height into a double leg structure. The cable anchor boxes are located between the two legs, providing unobstructed access inside the legs.

One of the most unusual things about this bridge is the cable configuration; 84 cables are arranged in bundles of seven cables for aesthetic and structural reasons. It results in almost-uniform loads in all the cables of one bundle, so loss of cables and cable replacement is no problem. It also means that if damping measures are required, they can be concentrated on the bundle rather than having to be applied to each cable individually.

This type of arrangement was developed specifically for this project and it is believed to be the only bridge in the world where it is used. From a visual point of view, it can be regarded as sunlight beams shining through clouds or through the roof of a rain forest. The use of a truss for the superstructure also fits this arrangement very well, since it provides sufficient strength and stiffness to bridge the gap between the cable bundles.

Another benefit of the truss girder is the possibility that the bottom slab can be used for a future 4m-wide cycle path, or for emergency vehicles if the main road is blocked by a traffic accident. The 120m long spans of the approach viaduct were chosen with the aim of minimising the number of piers and foundations, both to reduce costs and in order to open up the view.

The steel composite superstructure consists of a truss of 1,116m length for the main bridge and a total length of 912m for the approach bridge. The main bridge is a symmetrical cable-stayed structure with 480m-long main span, 198m-long side spans and 120m-long end spans. The deck has a 15.3m-wide concrete slab on top, which acts compositely with the top chord of the truss. The bottom slab with a width of 6.8m between the trusses is a steel orthotropic deck at mid-span and a 700mm-thick concrete slab at the supports.

The concrete bottom slab is only provided where negative moments are experienced, at the supports at the hold-down piers and at the tower axis; use of this concrete bottom flange considerably reduces the amount of structural steel required. Especially at the tower axis, where axial compression force is high due to permanent loads, the concrete section is more economic than a steel section. The 700mm thickness was selected for structural reasons to match the full height of the lower chord and cross-beams.

The horizontal distance between the axis of the trusses is 7.5m and the diagonals are inclined with 60° with an axis-raster of 6m. The height of the steel structure is 5.9m. The top and bottom chord has a size of 700mm by 700mm, while the diagonals are 600mm by 700mm. The top flange of the top chord is normally 800mm wide, but widens at

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the end span and at the support to limit the maximum thickness of the plates to 75mm.

The trusses consist of diagonals only, without vertical members, for clarity and aesthetic considerations. The outer surface is plane and clear, for that reason all plate thickness variations are designed to take place inside the truss chords. Diaphragms are arranged at the same angle as the diagonals and have large openings to allow the walkways to pass through. They are arranged at end and side spans at the third-points of the span. Additional diaphragms are provided directly above the supports and at the outer anchorage of each cable bundle.

The grade SM520 steel structure is completely welded, including the construction joints, so that the inside of the truss box is protected from corrosion. The concrete top slab is designed for the full cantilever moment in the transverse direction and is prestressed transversely with four, 15mm VSL tendons at 600mm spacings over typical areas and 300mm spacings at the section of the slab where the bundled stay cables are. The tension stress for the cantilever moment is designed to be less than 1.5N/mm^2. Studs are provided for the shear forces between the steel structure and the concrete slab, and all concrete is of Grade 450.

The most dramatic element of the link will be the towers, which rise up to a height of 171m above sea level; they are each formed of two inclined tower legs with a cross-girder at 36m height. Above 85m height, where the cable anchorages are located, the legs are connected by three steel boxes each 15.5m high.

In the transverse direction the tower legs and the cross-beam are designed to act like a frame. Considerable central prestressing is required on the cross-beam, which is acting as a frame girder, to resist the high wind loading that is expected in the final stages of construction. It is only at the centre of the cross-beam, where there is a positive moment, that the tendons can be arranged parabolically.

The 912m-long approach bridge is a continuous truss structure with regular spans of 120m length, and a 12.7m-wide concrete slab. Double composite action is achieved with a 48m-long concrete slab at the bottom chord over the supports; in the span area an orthotropic slab is provided between the bottom chords. The horizontal distance between the axis of the trusses is 6.5m and the height of the steel structure and arrangement of the diagonals is the same as that of the main bridge.

The top flange of the top chord is normally 800mm wide; but in the end of the span areas and over the support it is doubled in width in order to limit the thickness of the plate to 75mm. The top slab is reinforced concrete - the shorter cantilever meant that prestressing could be eliminated. The slab thickness at the cantilever is 450mm, while the bottom slab has a thickness of 700mm. The steel orthotropic deck is connected to the concrete slab by overlapping the steel plate and the concrete, with transfer of force enabled by the use of shear studs.

The provision of high damping rubber bearings on both the main bridge and approach viaduct was considered the best solution; use of isolation with HDRB has been proved a very efficient technique for protecting structures from earthquakes and also as a way of distributing loads across the structure rather than to a single fixed point. This technique is also sufficiently stiff to resist small wind loading, and yet sufficiently flexible to accommodate movements caused by creep, shrinkage and temperature changes.

Top: Rendering showing the full extent of the crossing *(LAP/Hyundai Engineering)*
Above: Night-time rendering of the main bridge *(LAP/Hyundai Engineering)*
Below: Construction of the main towers

Aerodynamic behaviour of the bridge was tested in the wind tunnel at the Hyundai Institute of Construction Technology, using both a section model test and full bridge model tests.

In the longitudinal direction, the tower acts as a frame with the superstructure; although during the construction process it behaves like a cantilever until the side spans have been connected. All outer edges of the tower shafts are rounded with a radius of 1m, both to reduce the wind loads and for aesthetic reasons.

The anchorage zones of the towers are designed as steel composite structures; it was considered more efficient to anchor the cables in a steel box rather than in concrete, since the steel plates can carry tensile stresses directly from the side-span stays to the main-span stays. This decision eliminates the need for any post-tensioning in this area, and a further advantage is that the fabrication of the anchorage boxes can be carried out in factory conditions, achieving higher quality and accuracy than in situ. The steel boxes are erected using heavy lifting equipment attached to the tower top, after which the composite section is completed by casting concrete infill between the tower walls and the steel boxes.

The towers are founded on concrete caissons which are supported by 30 piles with a diameter of 2.5m. The caissons are bell-shaped and are 41m and 37m deep; the base has outer dimensions of 32m by 38.5m, while the shaft is 19.5m by 26m. This solution was selected because of its high capacity in resisting the large horizontal forces from ship impact, seismic and water flow and waves. It also offers advantages in terms of construction - a crucial consideration here as the water is up to 35m deep and the founding level of the soft rock is 13m below ground.

Initially all the piles were installed, after which the steel casing of the caisson was floated in using a heavy barge crane with 3,000t lifting capacity. The hollow steel casing walls were filled with concrete before the caisson was lowered onto the piles. Finally the bottom and top cap of the caisson was filled with concrete

The main concept of the bridge erection is the use of large superstructure elements which will be floated in by the use of a heavy barge crane with a lifting capacity of 3,000t.

For the approach bridge, 120m-long segments will be floated in and lifted onto the piers. These typical segments are approximately 1,100t, with the end-span segments weighing in at 1,200t. The bottom slab concrete will be cast onto the segments and lifted together with the steel work. Since the bottom slab is constructed as an orthotropic plate between the concrete parts, the bottom level can be used as working platform from the very start of erection. The top plate concrete is placed as precast elements on top of the steel work; they are 4.5m long and are provided with openings above the top chord concentrated studs. At the construction joint a 1.5m-long cast in place section is incorporated.

Construction of the main bridge deck will begin with erection of the end-span segments in lengths of approximately 160m. After this, the main span and side span decks will be built using 72m-long segments installed on temporary falsework at the towers, and jack-up barges. These segments are erected with bottom and top slabs already in place, and weigh up to 2,400t - cables will be installed while the segments are still supported on the barges.

This erection sequence was chosen as being the best solution for delivering high-quality permanent work, since most of the welding will be carried out at the shop. It also has benefits in terms of the capacity of permanent work, construction time and safety.

The design won first prize in the competition for the design-build contract, which was held in 2002 by client Iksan Regional Construction & Management Office, which is part of the Ministry of Construction & Transportation for the Republic of Korea. The design was developed by structural engineer Leonhardt, Andrä & Partner, working as consultant to Hyundai Engineering Company. LAP carried out the feasibility and basic design and supported the detailed design at the project office at Seoul, working with its local representative Cabletek ■

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