Design of the Second Geo Geum Grand Bridge

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1 Introduction

1.1 General

The Second Geo Geum Grand Bridge will be part of the fixed connection of the Geo-Geum Island to the South Korean Peninsula. The 2 lane highway bridge with its total length of 2028 m is the second stage of this fixed link project and will connect Sorok Island to Geo Geum Island passing Dae Hwa Island. This high level crossing is composed of a 912 m long approach viaduct and a 1116 m long main bridge which has to cross a 210 m wide ship channel. The main bridge is a cable-stayed bridge with a main span of 480 m, 198 m side spans and 119 m long end spans. The approach viaduct is a continuous girder with regular spans of 120 m.

The main design considerations of the Second Geo Geum Grand Bridge were functionally as a highway, innovation in design and visual harmony with its surroundings. The stay cables are arranged in a single plane at the center line of the bridge deck. Their semi-fan arrangement with bundled configuration give a special and unique appearance to this cable-stayed bridge which will after its completion be the largest of its kind in Korea.

Fig. 1 Situation Map

1.2 Basic Requirements for the Design

The project limits at both ends to the existing infrastructure were fixed, in between those limits the alignment had to be determined by the designers.

The navigation channel has a width of 210 m, a clearance of 38.5 m above reference level and crosses the bridge alignment under an angle of 34.8°. Collision loads of 50 MN at the towers and 15.8 MN at the anchor piers had been considered at the design to take care of aberrant vessels.

Water depths up to 35 m and weathered soils required to provide for deep foundations.

The bridge had to be designed for high wind speeds as in the South of Korea typhoons can occur. The basic wind velocity is a 10 min mean wind speed V = 40 m/s at 10 m above sea level.

In addition, high seismic loads had to be considered in this region, with a maximum ground acceleration of 0.385 g.

2 Design

2.1 Investigated solutions

At the feasibility phase various alternatives had been investigated. The 7 finalists of the investigated alternatives are listed below, refer to Fig. 2,

Alternative 1: Cable-stayed bridge (CSB) with truss girder, main span 300 m, 1 pylon
approach bridge with regular spans 90 m and one span of 150 m with haunches at a potential secondary navigation channel

Alternative 2: CSB with box girder, main span 300 m, 1 pylon
approach bridge with regular spans of 90 m and one span of 150 m with an arch

Alternative 3: CSB with truss girder, main span 300 m, 2 pylons
approach bridge with regular spans of 90 m and one span of 150 m with haunches

Alternative 4: CSB with truss girder, main span 468 m, 2 pylons
approach bridge with regular spans of 120 m

Alternative 5: Suspension bridge with truss girder, main span 450 m, 2 pylons
approach bridge with regular spans of 120 m

Alternative 6: CSB with truss girder, main span 300 m,1 pylon
approach bridge with regular spans of 120 m

Alternative 7: CSB with truss girder, main span 370 m, 1 inclined pylon
approach bridge with regular spans of 90 m and one span of 150 m.

2.2 Final Layout Design

2.2.1 General

The selected layout is similar to Alternative 4 and is composed of

- a two pylon cable-stayed bridge with 480 m main span
- a 6.0 m deep steel truss
- bundled stay cables
- approach viaducts with typical 120 m span truss girders, again 6.0 m deep.

The horizontal alignment is straight at the main bridge and curved with R = 1300 m at the approach bridge. The vertical alignment is curved with R = 16667 m on a length of 1200 m at the main bridge and inclined with 1.8 % over the rest.

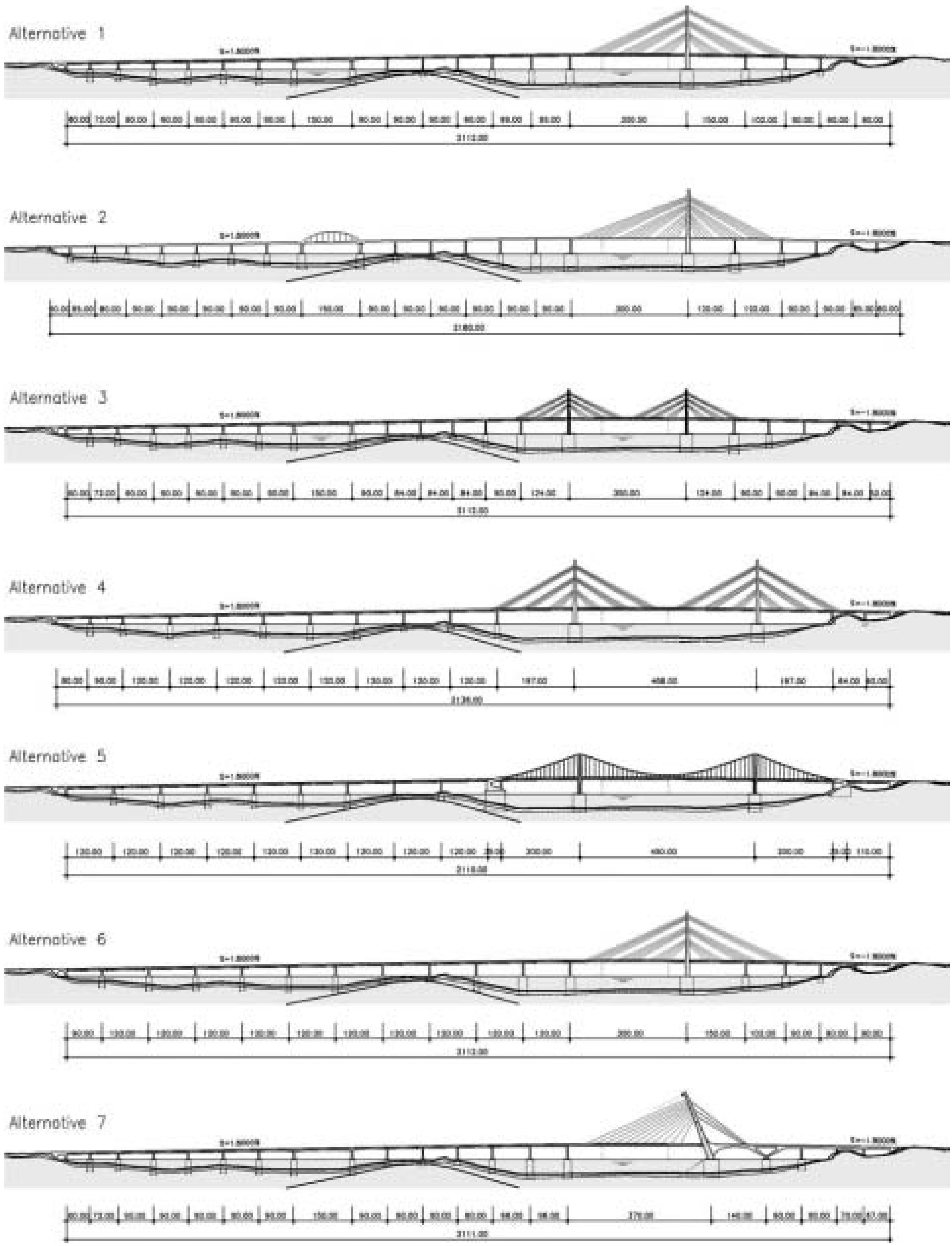

Fig. 2 Investigated alternatives

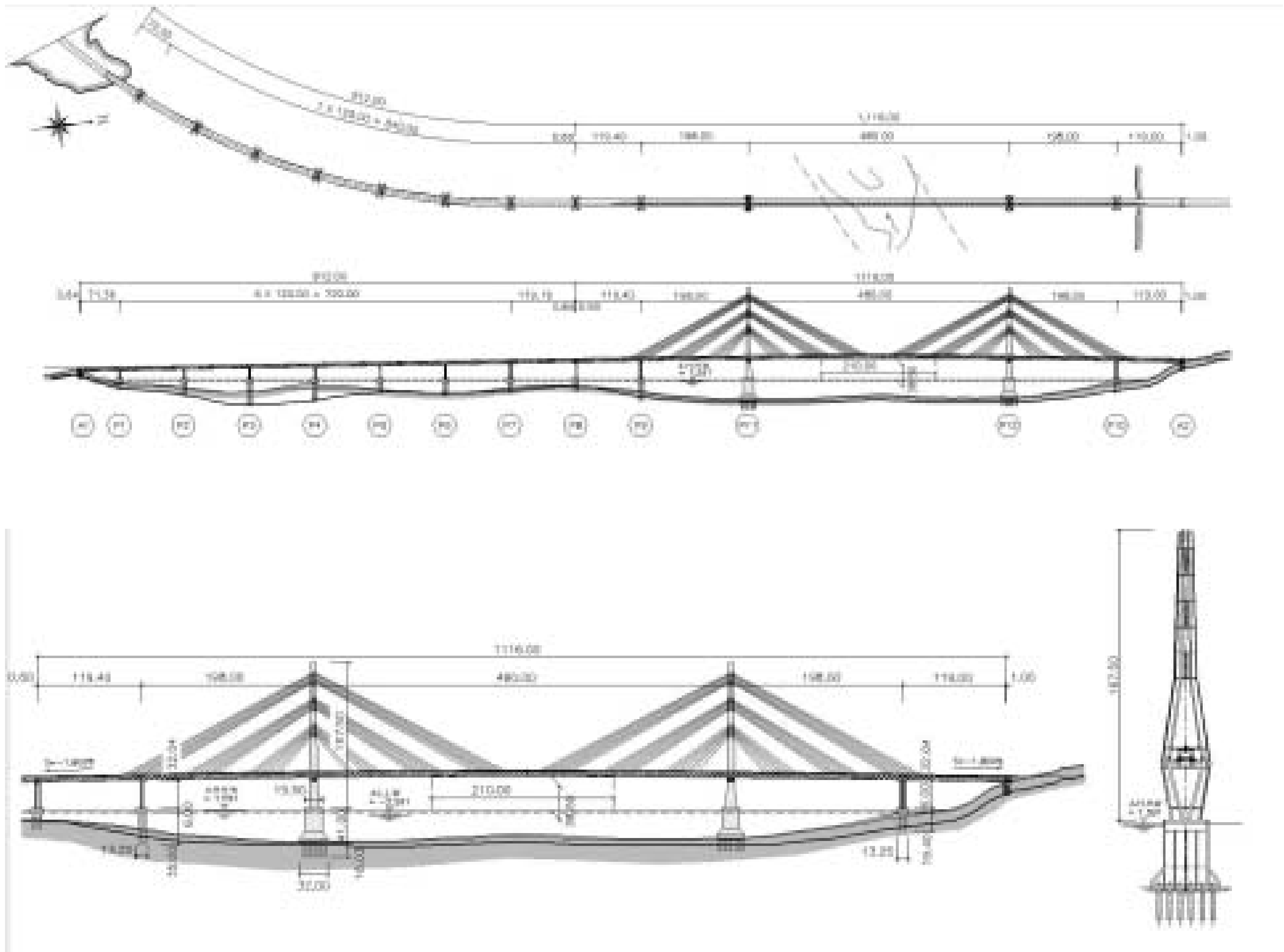

Fig. 3 Overall scheme and main bridge

The concrete pylon consists of a delta shape bottom part, merging at about EL 85.00 m to a double leg structure. The cable anchor boxes are arranged between the legs, this provides an un-obstructed access inside of the legs.

The cable configuration is very unique, 84 cables are arranged in bundles of 7 cables for aesthetic reasons and for structural reasons (almost uniform loads in all cables of one bundle, loss of cables and cable exchange is of no problem, possible damping measures can be concentrated per bundle).

This type of arrangement was developed specifically at this project and is, according to our knowledge, unique in the world. It can be considered as sunlight beams shining through clouds or through the roof of a rain forest. The truss concept of the superstructure fits also very well to this arrangement, since it provides sufficient strength and stiffness to bridge the gap between the cable bundles. The dominating dimensions of the pylon gives the bridge a very strong and save impression, while the open superstructure fits perfect into the seaside environment, not closing the channel, and floating high above the water.

The truss girder has the advantage that the bottom slab can be used for a future bicycle path, 4.0 m wide, or for emergency (ambulance) vehicles in case the upper roadway is blocked due to a major car accident.

The 120 m long spans of the approaches results in the least amount of piers and foundations, again in order to open up the view and to reduce foundation cost.

2.2.2 Superstructure

The steel composite superstructure consists of a truss of 1116 m length at the main bridge and a total length of 912 m at the approach bridge.

The main bridge is a symmetric cable-stayed bridge with 480 m main span and 198 m side span and 120 m end spans. The deck is a 15.30 m wide concrete slab on the top acting as composite section together with the top chord of the truss. The bottom slab with a width of 6.80 m between the trusses is a steel orthotropic deck in the mid span and a 70 cm thick concrete slab at supports. The concrete bottom slab is provided only in parts of negative moments, at the supports at the hold-down piers and at the tower axis. This concrete bottom flange saves a considerable amount of structural steel. 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 thickness of 70 cm 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 7.5 m. The diagonals are inclined with 60° with an axis-raster of 6.0 m. The height of the steel structure is 5.94 m. The top and bottom chord has a size of 700 x 700 mm, the diagonals are 600 x 700 mm. The top flange of the top chord is normally 800 mm wide, in the end span and at the support it is widened to limit the maximum thickness of the steel plates to 75 mm.

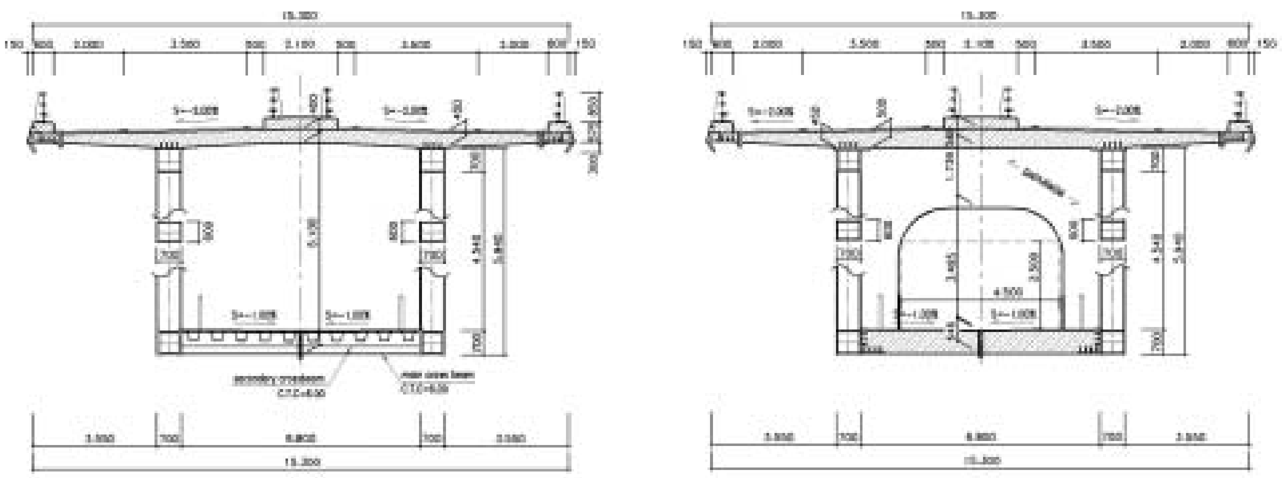

Fig. 4 Main bridge cross section, a) at midspan, b) near tower

The trusses are composed of diagonals only (without vertical members) for clarity and aesthetical reasons. The outer surface is plane and clear, for that reason all plate thickness variations take place at the inside of the truss chords.

Diaphragms are arranged in the same angle as the diagonals and are provided with large openings to allow the pedestrian lanes passing through. They are arranged at end and side spans at the 1/3-points of the span. Additional diaphragms are provided directly above the supports and at the outer anchorage of each cable bundle.

The steel structure is completely welded, including the construction joints, so that the inside of the steel truss boxes is corrosion protected.

All steel of the superstructure is of Grade SM 520.

The concrete top slab is designed in transverse direction for the full cantilever moment. The slab is prestressed in transverse direction with tendons VSL 0,6"-4 @ 600 mm at typical areas and 300 mm spacing at the slab area with the bundled stay cables. The tension stresses for the cantilever moment is designed to be smaller than < 1.5 N/mm².

Studs are provided for the shear forces between the steel structure and the concrete slab.

All concrete is of Grade 450.

The 912 m long approach bridge is a continuous truss structure with regular span of 120 m and a 12.70 m wide concrete slab. Double composite action is achieved with a 48 m long concrete slab at the bottom chord over the supports. In the field area an orthotropic slab is provided between the bottom chords. The horizontal distance between the axis of the trusses is 6.5 m. The diagonals are inclined with 60° with an axis-raster of 6.0 m, similar as at the main bridge. The height of the steel structure, the top and bottom chord size, the diagonal size are equal to the main bridge.

In the 2 diagonals, which are leading to the bearing area, diaphragms are integrated. Two additional diaphragms are installed in the 1/3-points of the field.

The top flange of the top chord is normally 800 mm wide, in the end fields and over the support it is widened up to 1600 mm due to limit the thickness of the plate to 75 mm.

The top slab is of reinforced concrete, prestressing could be avoided because of the shorter cantilever. The slab thickness at the cantilever is 45 cm. The concrete bottom slab again has a thickness of 70 cm. The connection of the steel orthotropic deck to the concrete slab is done by overlapping of the steel plate and the concrete. The force introduction is done by shear studs. This concept successfully has been performed by LAP in several other projects.

The provision of HDRB (high damping rubber bearings) at the main bridge and approach bridge was considered as the best solution. The use of the isolation with HDRB has proven to be a very efficient technique

- to protect structures from earthquake
- to distribute loads to more structures than one fix point only
- to be sufficient stiff for small wind loads
- to be sufficient flexible for movements caused by creeping, shrinkage and temperature
- to get the structure back in the starting position.

The good aerodynamic behavior of the bridge has been proven at the wind tunnel of Hyundai Institute of Construction Technology by a section model test and full bridge model tests.


Fig. 5 Wind tunnel tests

2.2.3 Towers

Rising 171 m above the sea level, the towers of the cable-stayed bridge will be the most dominating part of the link.

The towers consist of two inclined tower legs tied together at the elevation of +36.09 by the tower cross girder. Above +85 m, at the parts of the cable anchorage, the tower legs are connected by 3 steel boxes each 15.5 m high.

In transverse direction the tower legs and the tower cross beam are acting like a frame. Due to high wind loads in the final stage, the bending moments in the cross beam, which is acting as frame girder, require a considerable centric pre-stressing. Only for the positive moment in the middle of the cross beam the tendons can be arranged parabolic.

In longitudinal direction the tower acts together with the superstructure as a frame. In the construction stages, before closing the side span, the tower behaves like a cantilever.

All outer edges of the tower shafts are rounded with R = 1.0 m to reduce the wind loads and for aesthetic reasons.

The anchorage zones of the towers are designed as steel composite structures. It was considered as more efficient to anchor the cables in a steel anchorage box rather than in concrete, since the steel plates carry directly tensile stresses from the side span stays to the main span stays. Hence any need for posttensioning in this area is avoided. A further advantage is, that the fabrication of these steel anchorage boxes can be done in the shop where higher quality and accuracy can be achieved than 85 m and more above ground. The complete steel boxes can be lifted in by using heavy lift equipment attached to the tower top. The composite section will be completed by casting of concrete infill between the tower walls and the steel boxes.

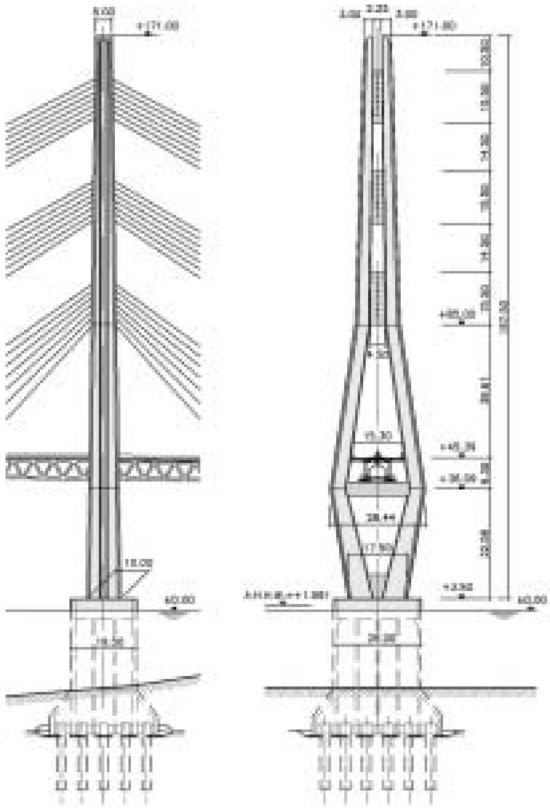

Fig. 6 Tower layout

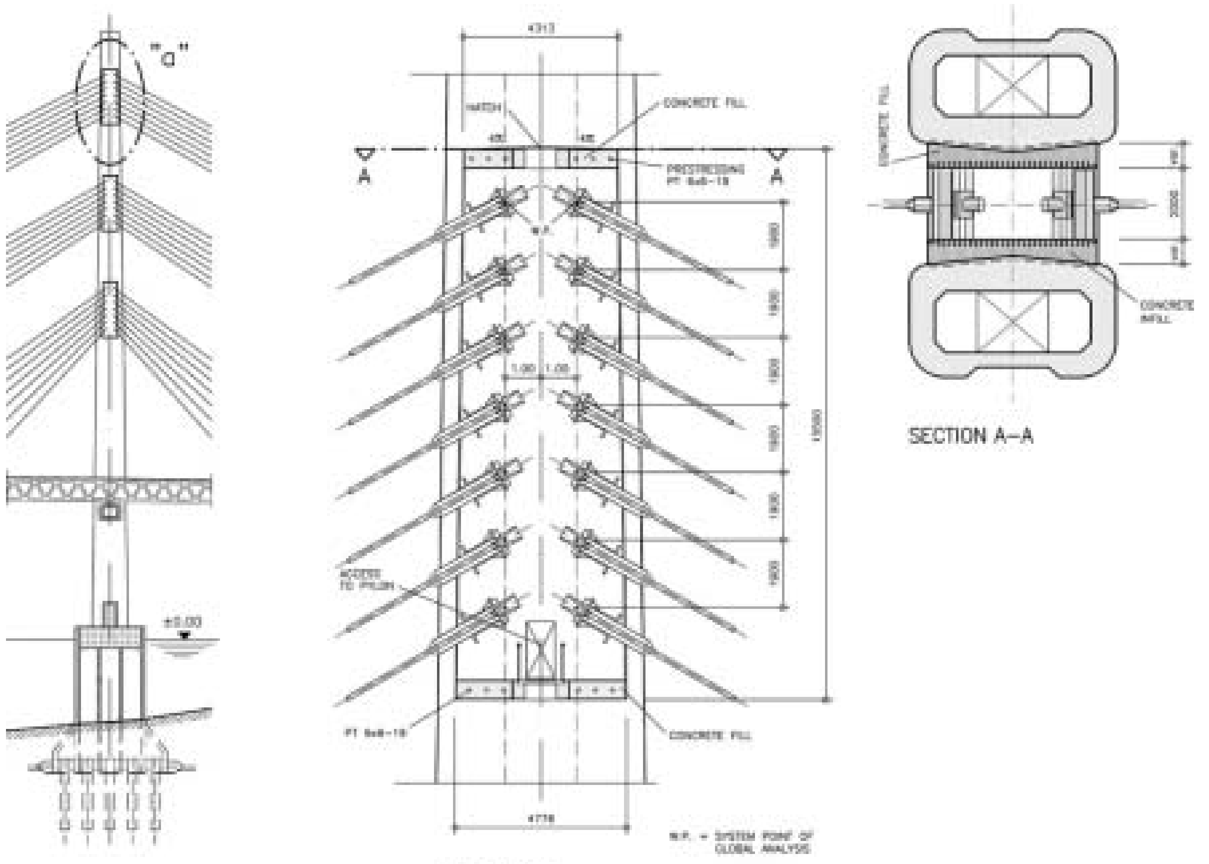

Fig 7 Tower cable anchorage

The towers are founded on concrete caissons which are supported by 30 piles Ø 2.5 m. The bell shaped caisson has a depth of 41 m respectively 37 m, the base has outer dimensions of 32 m x 38.5 m while the shaft is 19.5 m x 26 m. This solution was selected from a number of alternatives because of its high capacity to resist the large horizontal forces from ship impact, seismic and water flow and waves. This foundation type also has advantages regarding the construction method, which is very essential here, as the water depth is up to 35 m deep and the solid foundation level of the soft rock is 13 m below ground. First, all the piles Ø 2.5 m will be constructed, then the caisson consisting of a steel casing is floated in by using a heavy barge crane with 3000 tons lifting capacity. The hollow steel casing walls will be filled with concrete and the caisson subsequently is lowered onto the piles. Finally the bottom caisson which connects the piles with the caisson and the top cap of the caisson are filled with concrete.

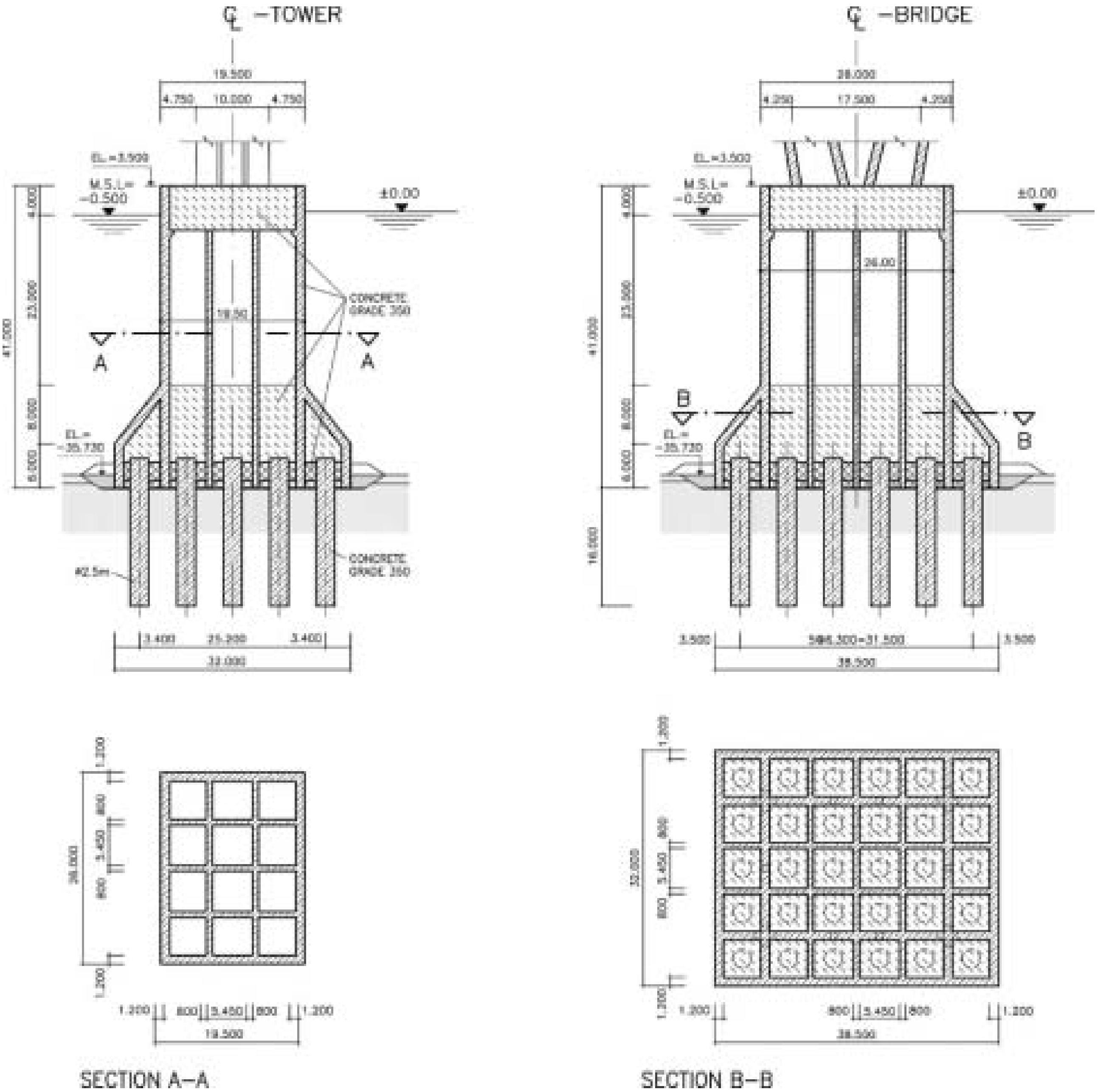

Fig. 8 Pylon caisson layout

2.2.4 Piers

The anchor piers as well as the typical piers of the approach bridge are hollow concrete piers with rounded edges. For aesthetical reasons, at the central part of the shaft the outer wall face is offset and provided with small concrete ribs.

All the piers are founded on 8 large diameter (∅ 2.5 m) reinforced concrete piles.

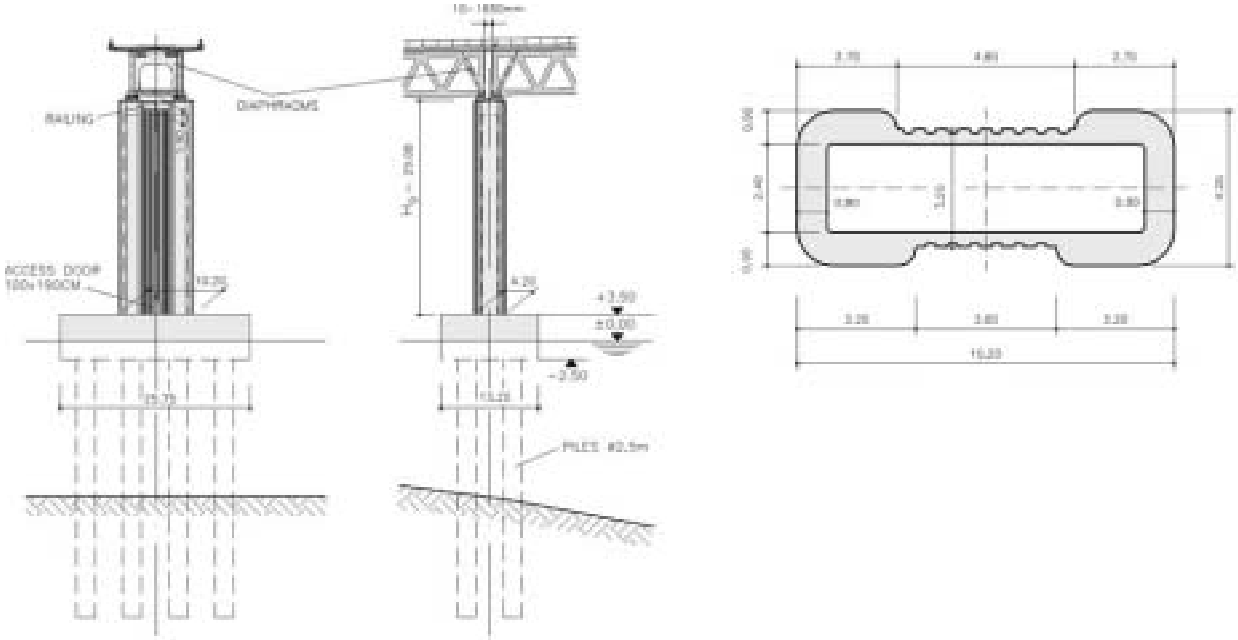

Fig. 9 Anchor pier layout

2.2.5 Cables

The cables consist of ∅ 15.7 mm mono strands with a tensile strength of 1860 N/mm². Only 3 different types of cables composed of either 55, 61 or 75 mono strands will be used. The strands are galvanized, covered with wax, individually sheathed and then placed inside an outer colored HDPE tube without grout. The outer HDPE tube is provided with helical filets at the outside face to improve the aerodynamic behavior of the cables. Stressing of the strands will be done by applying the Iso-tensioning method which incorporates a monostrand jack. The stressing operation will take place at the lower cable anchorage, where the bottom slab provides good access and a good working platform, refer to Fig. 10.

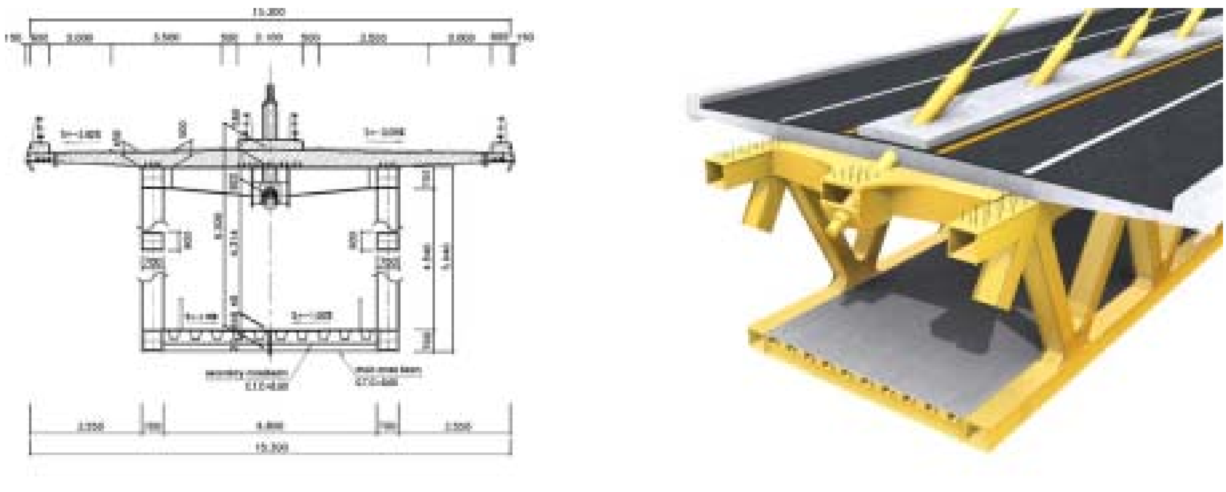

Fig. 10 Main bridge cross-section with cable anchorage

3 Construction Method

The main concept of the bridge erection is to use large superstructure elements which will be floated in by the use of a heavy barge crane with a lifting capacity of 3000 tons.

At the approach bridge segments with 120 m length are floated in and lifted on the piers. The total weight is about 1,100 tons maximum for the typical segments and 1,200 tons for the end-span segments. The 48 m of the bottom slab concrete will be cast on the ground and lifted together with the steel work. Since the bottom slab is constructed as a orthotropic plate between the concrete parts, the bottom level can be used as working platform all along from the very beginning of the erection. The top plate concrete is placed as precast elements on top of the steel work. These precast elements have lengths up to 4.5 m and are provided with openings above the top chord concentrated studs are provided. At the construction joint a 1.50 m long cast in place section is provided. In this space the lap splicing of the rebars and the splicing of the steel elements will take place. A casting formwork has to be provided to construct this CIP (Cast In Place) Joint.

At the main bridge, first the end span segments with lengths of approx. 160 m will be lifted-in and completed similar as the approach bridge, Fig. 11. Then segments with a length of 72 m are installed at the main span and side span, supported by a major temporary falsework at the towers and jack-up barges. These segments are provided already with bottom and top slabs and have weights up to 2400 tons. The cables are installed as long as the segments are supported by the barges.

Several different scenarios for erection had been investigated. It was found that the proposed sequencing is the most favorable solution with respect to the quality of the permanent work (most of welding at the shop), the capacity of permanent work, construction time and safety.

4 Final Remarks

This design had been selected as first prize winner at a design and built competition in 2002. Leonhardt, Andrä und Partner GmbH has prepared as international consultant to Hyundai Engineering Co. the feasibility and basic design and supported the detailed design at the project office at Seoul.

Hyundai Engineering & Construction Co., the contractor, will start construction by end of this year. Our thank is to both corporations for their confidence and the occasion to design and construct such an unique and beautiful bridge, Fig. 12.

Fig. 12 Visualization

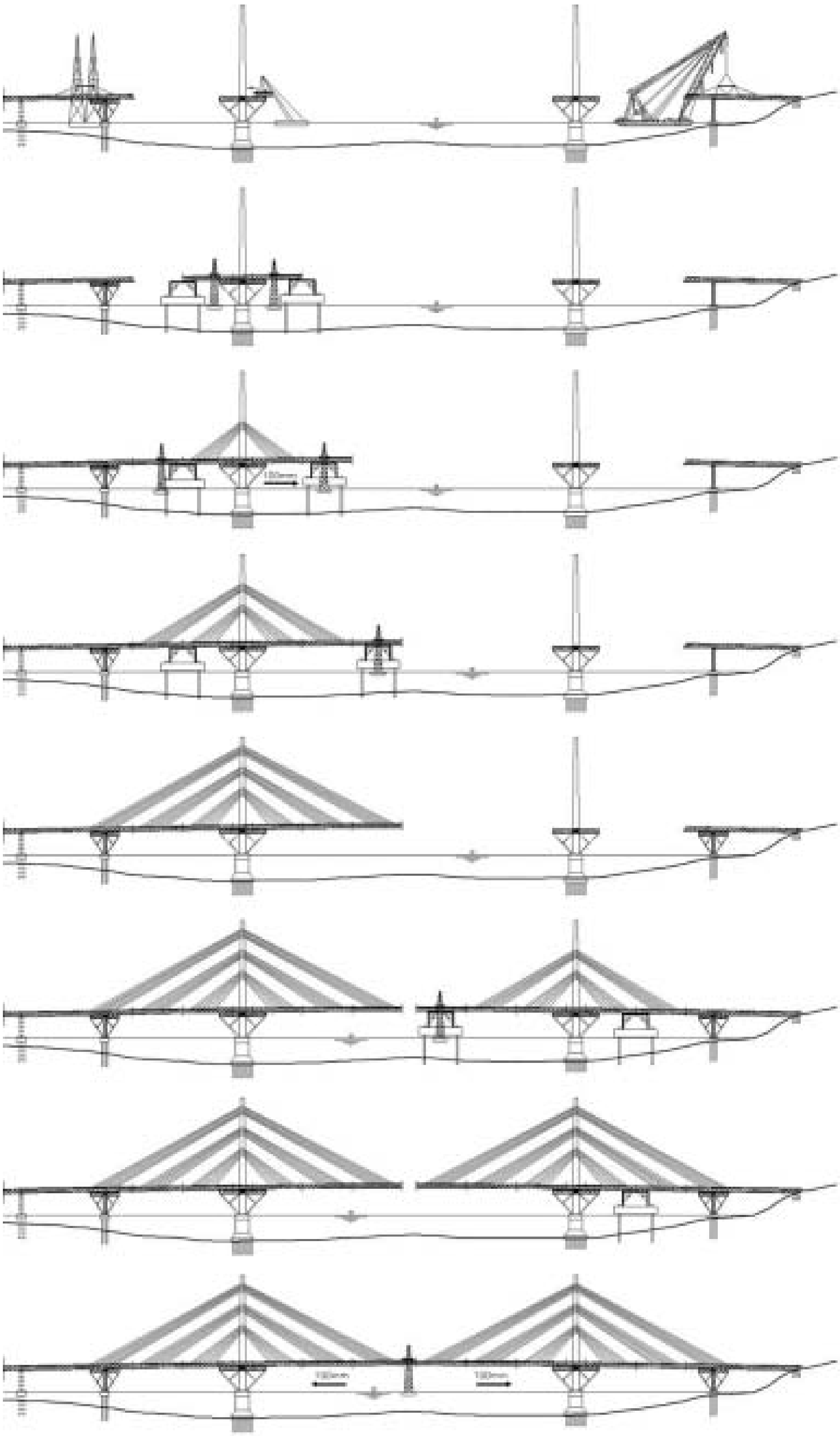

Fig. 11 Erection method of the main bridge