BUSAN BLOCK BUSTER
KOREA'S RECORD BREAKING 8.2KM BRIDGE AND TUNNEL LINK
KOREAN CROSSING

The Busan-Geoje fixed link project in South Korea comprises the deepest roadway tunnel in the world and 1.6km of cable stayed bridges. Over the next eight pages Jessica Rowson explores one of the worlds biggest engineering projects.
MAJOR PROJECT: THE BUSAN-GEOJE LINK

» between Busan and Geoje city, on the island.

The need for a better road link has been obvious for some time, but considerable engineering challenges have had to be overcome. To create the new link, designer and contractor Daewoo is building the first immersed tube tunnel in South Korea.

At 48m deep, it will also be the deepest concrete immersed roadway tunnel in the world and the second deepest immersed tube tunnel after the Bosphorus tunnel in Turkey which will be 60m deep when complete.

Not only this, but the 8.2km crossing will be constructed in just six years, with contractors working in difficult ground in an area prone to earthquakes and typhoons.

GK Corporation, a seven-contractor consortium led by Daewoo Engineering & Construction is building the £1.67bn fixed link. Halcrow and TEC are providing technical consulting services to Daewoo Engineering & Construction.

Design of the immersed tunnel is by Daewoo in joint venture with Danish firm Cowi. Cowi is also designing the cable stayed bridge.

The crossing can be broken down into three main sections. The 3.2km immersed tube tunnel runs from the mainland to the islands of Daejuk and Jungjuk.

The road then moves south onto a 919m long, two pylon cable stayed bridge with a main span of 475m between Jungjuk and Jeo islands where the Korean president has a summer residence.

There is then a 676m long, three pylon cable stayed bridge with two main spans of 230m between Jeo and Geoje islands.

In addition to this there are 1.9km of approach bridges and 1km of bored tunnels.

“This is the biggest project in Korea,” says Daewoo managing director for the project Im-Sig Koo. “There have been lots of things to overcome and we are proud that we have overcome these matters as engineers.”

The bridge is being built under a public private partnership contract with most of the £1.2bn project cost raised by GK Corporation and about a quarter coming from the South Korean government.

The crossing is the subject of a build operate transfer agreement with GK Corporation responsible for finance, design, construction and operation for 40 years, charging tolls to enable it to repay the finance and make a profit.

The project is now in the fifth year of the six year construction programme and is 65% complete. Six years is not a long time for "Through this project we’ve learnt many things to present to the engineering world. With these skills we can get similar projects around the world” Im-Sig Koo, managing director, Daewoo
“There have been lots of things to overcome and we are proud that we have overcome these matters as engineers”
Im-Sig Koo, managing director, Daewoo

a project of this size and to fast-track it, design and construction have been done together. Innovations in tunnel building technology have helped to make sure that the project will be delivered on time and to budget and Daewoo hopes to capitalise on this in future and use its experience on other crossings.

“My project is Korea’s largest port. The tunnel is 3.2km long. DAEJUK ISLAND forms transition from immersed tube tunnel to bridge. JUNGJUK ISLAND Starting point for 919m cable stay bridge. TWO Pylon Bridge With 475m main span. JEO ISLAND Summer residence for South Korean president. THREE Pylon Bridge With two 230m main spans.

“The tunnel is 3.2km long. DAEJUK ISLAND forms transition from immersed tube tunnel to bridge. JUNGJUK ISLAND Starting point for 919m cable stay bridge. TWO Pylon Bridge With 475m main span. JEO ISLAND Summer residence for South Korean president. THREE Pylon Bridge With two 230m main spans.

“It’s been a difficult task but after this project we will have lots of technical knowledge,” says Koo. “Several engineering companies from Japan, Qatar, China and Europe have visited. Through this project we’ve learnt many things to present to the engineering world. With these skills we can get similar projects around the world.”

Koo is keen to use the knowledge acquired on this project to aid the construction of other strategic transport links around the region.

“A link between China and Korea would only be 330km which is not that long and in conditions similar to our project,” says Koo. “A link between Japan and Korea would be 230km long, but deeper than in this case. Japan-Korea has been discussed for 40 to 50 years. Japan would really like this road to the west; Korea and China are very keen too.

PROJECT TIMELINE
- End 2008: Six tube elements in place
- March 2009: Bridge superstructure erection begins
- May 2009: A further six tube elements to have been installed
- July 2009: All five pylons for the bridge to be completed
- April 2010: Remaining six tunnel elements and final bridge section in place

LOCATION MAP

1. BUSAN: Korea’s largest port
2. IMMERSED TUBE: The tunnel is 3.2km long
3. DAEJUK ISLAND: Forms transition from immersed tube tunnel to bridge
4. JUNGJUK ISLAND: Starting point for 919m cable stay bridge
5. TWO Pylon Bridge: With 475m main span
6. JEO ISLAND: Summer residence for South Korean president
7. THREE Pylon Bridge: With two 230m main spans

140km, three hour route from Busan to existing crossing.

Connecting road.
The cable stayed section of the Busan-Geoje Island crossing is an impressive feat. A two pylon cable stayed bridge spans between Jungjuk Island and Jeo Island, with a main span of 475m and a shipping clearance of 52m. Anda three pylon cable stayed bridge spans between Jeo Island and Geoje Island, with two main spans of 230m and a shipping clearance of 36m.

What the bridge has in common with the tunnel is the difficulty of building across the open sea.

“There’s nowhere for a big construction yard, so construction is about prefabbing as many elements as you can, as big as you can and transporting them,” explains Halcrow technical advisor Don Fraser.

There are five pylons in total for the two cable stayed bridges which have to be built in deep sea conditions. There are also numerous approach span piers also in the deep sea waters.

Caisson foundations have been used for the piers and pylons as they eliminate the need for water excluding temporary works like cofferdams. The caissons are 33m high precast concrete cellular structures and once in place take loads from the piers and pylons to the sea bed.

“With 30m of water, it would have been a significant cofferdam,” says Fraser.

The caisson foundations were fabricated at a casting yard on the mainland. The heaviest weighs 9,600t but the natural buoyancy of the open-celled structures was utilised when they were taken out to sea. By floating them, the weight could be shared between the water and the crane so a smaller 3,000t floating crane could be used.

The ground on which the caisson sits was prepared by dredging the alluvial layer so that the caisson sits on the weak rock layer below. A video inspection of the formation layer was done before caissons were positioned. Three precast landing pads were placed on the formation layer ready to receive the caisson. The caissons were sunk using water ballast which was later replaced by rock ballast once they were in place.

Once a caisson had been positioned on its three landing pads, grouting was carried out to fill the gap between its underside and the seabed, so that when the bridge is complete, pier and pylon loads can be transferred evenly to the ground.

Grouting is critical to the stability of the piers, and the team has taken extra precautions to make sure it all goes to plan.

During the grouting process on one of the Øresund bridge piers, cement particles were washed out from under the pier. This led to a loss of foundation strength.

“Mistakes have been made on similar projects which we’ve learnt from,” says Fraser. “Grouting went wrong at Øresund and took a year to fix. Øresund initially did not have the means of preventing the ocean current from washing out the cement particles from under the base.”

To stop cement washout, a trench flap was used. The trench flap is a geotextile membrane secured around the perimeter of the caisson and held down with a steel bar. When the caisson was being transported, the geotextile member was rolled up.

The 3.5km cable stayed bridge being constructed for the project is not breaking any new records, but it still poses some significant challenges.
around the rebar and then once positioned, the membrane was unrolled by divers.

“It’s enough to stop current and debris and makes for ‘still water’ conditions [around the caisson],” says Fraser.

The grout must fill all voids between the underside of the caisson and the sea bed to be effective. Venting holes with thermal sensors inside them are closely spaced over the plan area of the base. When grout reaches a sensor a change in temperature is registered indicating displacement of sea water by the arrival of warmer grout.

“When the warm grout reached the vent pipe, we knew it was in contact with the caisson under side,” says Fraser.

Two large scale tests were done to ensure that caisson grouting would work, as failure would have been costly.

A 3,000t floating crane was used to place the pier shafts onto the caisson tops where they were connected via an insitu reinforced concrete joint. The smaller approach pier shafts came with their cross beams attached, but the bigger ones had their cross beams attached insitu with couplers and post tensioning bars as the combined weight would have overloaded the crane.

The main pylons are up to 156m tall and are cast insitu. From their caissons, two legs splay outwards until they are level with the road deck, at which point they incline towards each other. The lower sections of the pylons are filled with rock ballast up to a height of 16m to protect against ship impact.

“It’s a nice shape, but it’s a challenge for the guys to build,” says Fraser. “The setting out is difficult – requiring very strict camber control and the use of temporary intermediate props between the upper legs.”

The pylons are made from insitu concrete distributed by a 180m³ capacity floating concrete batching plant. They are being constructed in 4m high lifts using climbing formwork and concrete pumps. All five pylons are scheduled for completion by July 2009.

The bridge deck consists of a steel framework which supports a concrete slab. The sections are prefabricated offsite in a casting yard in Obi. Sections of steelwork are fabricated off site and brought to the yard where they are welded together before the 300mm-thick concrete deck is cast on falsework in one seven hour sitting.

Once it has cured, the completed deck sections are “finished” as much as possible, to the extent they include drainage runs and cable trays. They are then moved to the waterside to be lifted by a floating crane and transported to the bridge site.

The depth of the steel girders for the cable stayed bridge deck is only 2m compared to the 3.6m deep girders needed for the approach spans. The deck structure for the cable-stayed spans is slightly lighter as it is supported by stay cables along its length. The concrete deck for this section is also lighter with a thickness of 260mm.

The cable-stayed deck sections will be erected in a balanced cantilever sequence. The sections are taken out to site, lifted into place, starting at the pylon and working outwards, and the cables are connected. Both sides of the pylon are placed consecutively to balance the loads.

Superstructure erection will start in mid March this year, with the last segment being lifted in April 2010.
The elements for the immersed Busan-Geoje tube tunnel are a huge 10m high by 26.5m wide by 180m long. But the smallest of cracks in the concrete could cause disaster.

The tunnel elements on the Busan-Geoje link are large: an external width of 26.5m incorporates two lanes of traffic in each direction and a central services/escape tunnel. The 3.24km length of the tunnel comprises 18 elements that are 180m long.

Each element is being cast in eight segments in the Anjeong precasting yard – a massive dry dock on the mainland to the east of Geoje Island. This can accommodate five 180m long tunnel elements at a time.

Each segment is cast in a continuous 24 hour operation. There are twin batching plants on site because, as Halcrow technical advisor Don Fraser says, the last thing you want is to be running out of concrete.

“We don’t want cracks so each segment is cast as one section,” says Fraser. “Also we don’t want early age cracking so thermo sensors are cast in and the heat development is monitored. We don’t use steam curing as such but steam is used to heat the external environment. Concrete generates heat so we need to keep the immediate environment warm.”

Keeping the exterior surface of the concrete warm reduces the thermal gradient across the segment, helping to limit the risk of early age thermal cracking.

The watertightness of the finished elements is also critical.

“Because this will be the [world’s] deepest roadway tunnel of this type, there is a big concern on water tightness,” says Fraser. “European tunnels have only one water stop at segment joints, here we’ve doubled up. “The Marmaray tunnel under the Bosphorus is deeper but it is a Japanese style steel box with no segment joints. Even in shallow tunnels in Holland they get leakage in segment joints which rely on one seal using an injectable waterstop. The design philosophy [for this tunnel] erred on the side of caution.”

The joints between the segments have two waterstops. The first is an injectable waterstop – a rubber seal stop with the facility to inject epoxy resin which can make its way into small flaws or depressions in the concrete. The second is an omega joint, which is a rubber and nylon membrane that arches over the joint, clamped to the tunnel element either side of the joint, able to accommodate movement caused by temperature changes, shrinkage, creep and earthquakes.

At either end of each element is a temporary steel bulkhead which seals the tunnel section when it is floated out from the casting yard. The steel bulkheads can be removed when the tunnel sections are sealed together on the seabed and can then be reused in further elements.

There is a lip around the edge of each element end on which the main seal will be achieved. The lip at one end has a flat steel plate and the other has a 360mm thick rubber Gina gasket fixed onto it. The Gina gasket forms a watertight seal against the steel end plate of the next element. The elements are temporarily post tensioned to help them withstand the extra forces encountered when they are floated and sunk.

When five elements have been cast, the dry dock is flooded, the elements float and are towed to a mooring area ready to be sunk onto the seabed. The dock is dewatered ready for the next five elements.

Preparing the Ground
A 12.5m deep trench for the immersed tube was created in the seabed by dredging through soft clay along most of the tunnel alignment and then blasting in the areas of bedrock at each end.

The elements at either end of the tunnel sit on bedrock but the ground conditions for the central sections are poor – around 30m deep.
of very soft mud and clay sitting on top of gravel and rock. Ground improvement in the sea bed was carried out using partial cement deep soil mixing, known as CDM. Here augers were used to mix cement with in situ soil to form soil-cement columns.

The partial CDM columns finish 3m above the gravel and rock layer. This allows the tunnel some degree of flexibility and movement, but also strengthens the seabed. Taking the columns all the way down to the rock layer, would have created rigid support points or “hard spots”. This could cause problems in an area prone to earthquakes where some flexibility needs to be maintained.

Two elements needed extra support and preloaded sand compaction piles were used to improve the ground there. Sand compaction piles work by drawing in water from the surrounding soils make them stiffer.

Before the immersed tube tunnel can be placed in the trench, a gravel bedding layer is laid down to ensure even distribution of loads from the tunnel elements to the ground.

Grout bedding layers have been used in previous immersed tube tunnel projects, as they give an accurate and level bed. But the process is time consuming as the grout needs time to set. As a result, Daewoo chose to use a gravel bed for this project as it is quicker to place but special equipment had to be developed to place the gravel with high accuracy under the open sea.

“We have developed a jack up barge and our gravel laying techniques over a period of 10 months to give us the tight tolerances needed,” says Daewoo immersed tunnel engineering manager Bong-hyun Cho. “It’s the first time a jack up barge has been used [for laying an immersed tube tunnel gravel bed in deep sea conditions].”

The gravel is dispensed via a tremie pipe into the prepared trench. Instead of laying the gravel across the trench, it is laid in a zig zag pattern where a 1.8m wide strip of gravel is laid across the 30m wide trench, the strip then continues along the trench for 1m and then traverses back across the 30m wide.
trench at 90° before continuing for another 1m and so on. The 1m gap between the lateral strips ensures that successive strips across the trench do not disturb previously laid ones while allowing space for excess gravel. There is a sensor in the tremmie pipe to ensure that the right amount of gravel is delivered.

“Along the 180m length, the element should be flat,” says Cho. “If we fail [with the gravel bed machine], the whole project fails.”

**Getting the details right**

The tunnel is made up of 18 largely similar elements – offering opportunities for continuous improvement as the project progresses.

“We did the first batch [of four] in 17 months, but the second in eight months,” says Halcrow technical advisor Don Fraser. “It’s the benefit of having a production line. In the first batch we were looking at constructability. Now we’ve reached the stage where there’s not much more we can do to improve.”

The concrete mix was crucial. Quality was important, as was the need for the concrete to be workable so it could get into the right position. “We’ve spent lots of time on site trials,” said Fraser. “We did full scale trial testing. We wanted to take concrete from lab into reality to see how it performed. We made changes to workability, concrete properties and aggregate coarseness. The mix design is not self compacting, but it’s close, as it is workable, pumpable and user friendly. Transferring this scale into the dry dock wasn’t right the first time, but it’s improved.”

“On a huge scale but has got to be water tight. We need to find the balance of looking at the big stuff and the finer detail.”

**“It’s on a huge scale but has got to be water tight. We need to find the balance of looking at the big stuff and the finer detail”**

Don Fraser, Halcrow

---

**Underwater connections**

An accurate view of the weather ahead is critical to placing tunnel segments on the sea bed. Daewoo has utilised a special weather forecasting system for the construction site. Elements are not positioned during the typhoon season which runs between July and September.

Once the all-clear is given, an element’s journey starts between 8pm or 9pm. It reaches its final location by 5am or 6am the next day.

Each element has six water ballast tanks with a combined capacity of around 6,000t. These are used to alter the weight of the element during float out and positioning.

When an element is ready to be taken down to the sea bed, the water ballast is added to increase the weight of the element and sink it. During the sinking process, it is guided by 14 anchors attached to two immersion pontoons. Once on the sea bed the element is guided into its final position using a specially designed external positioning system (EPS).

“The difficulty is that our site is facing open sea,” says Cho. “We used a special forecasting system. Weather was the main changing factor. We also developed an EPS to minimise the immersion period and ensure correct alignment.”

The EPS consists of a set of 800t vertical capacity jacks which are used to reduce the friction between tunnel bed and tunnel during final positioning. There are also two sets of 200t capacity horizontal jacks.

When an element is in position, the nose of the Gina gasket touches the steel frame of its neighbour creating a seal for the chamber between the two bulkheads. The water in the chamber is pumped out, creating a pressure imbalance between the chamber and the external water pressure. This imbalance sucks the new tube element on to its neighbour and compresses the 368mm thick Gina gasket by about 178mm to 190mm.

The water ballast is replaced by 8,000t of concrete ballast poured onto the tunnel floor.

Once the tunnel elements are connected, it is a race against time to backfill the tunnel walls to protect the tunnel against the next period of inclement weather. The first layer of locking fill comprises crushed stones which are smaller than 80mm diameter. Once they are in place, the tunnel is protected from waves smaller than 3m. Then a further layer of stones with diameters of less than 300m is placed on top to protect the tunnel from 10m high waves.

Interlocking concrete elements of the type used on sea defences have been placed on top of the tunnel in shallower depths where there are larger breaking waves and there is a risk of ship impact. These have to be carefully installed to ensure that they lock together so they can function correctly.

“There are sensors to show these elements have the right position and direction,” says Cho. “Each weighs between 36t and 25t and had to be placed by crane. It took three months to get them in the right position.”