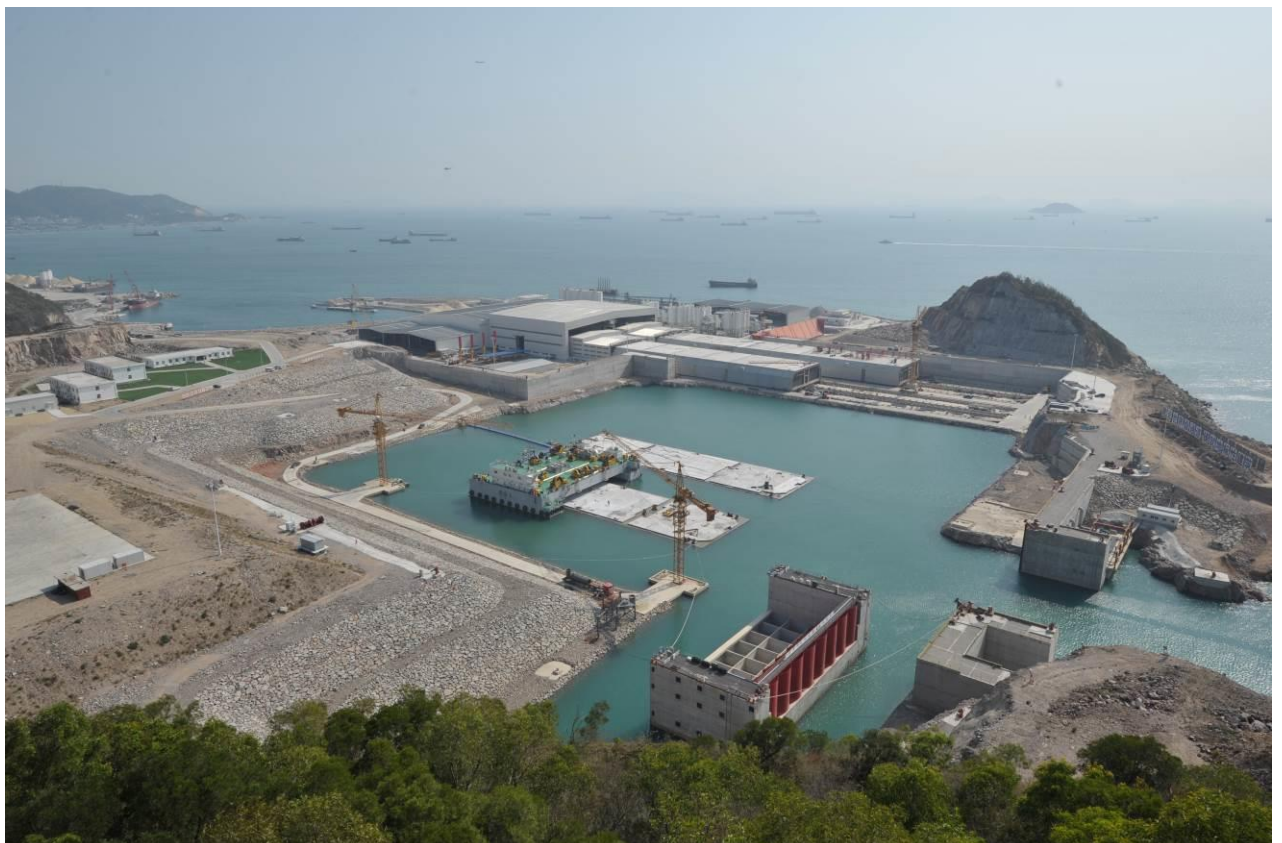




Tunnels & Tunnelling

Experience Record

Immersed tunnels



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INTRODUCTION

Tunnel Engineering Consultants (TEC) is a Joint Venture of Royal HaskoningDHV (RHDHV) and Witteveen+Bos (W+B). TEC combines knowledge, expertise and experience of the mother companies (8000 professionals) within the field of large underground projects.

TEC guarantees continuity and specialized knowledge of tunnel design and construction to solve complicated underground mobility challenges through an integral, innovative and sustainable project approach.

In addition, TEC is able to draw on the considerable expertise of two Dutch engineering consultancy firms and covering the entire range of civil, structural and architectural engineering required for small and large building projects, environmental impact assessment, legal aspects and project management.

This TEC experience record intends to give an impression of the capabilities of Tunnel Engineering Consultants in the field of tunnel related design and tunnel construction related consultancy. It will provide an overview of services that TEC can offer within the preparation and realization of tunnel project.

This document provides a selection of appealing projects in which TEC was and is involved including the position TEC had in the project.



TEC PROFILE

Tunnel Engineering Consultants v.o.f. (TEC) is specialised in consultancy works for underground infrastructure and tunnel projects. TEC is established in 1988 as a Joint Venture between two major engineering consultancy firms:

- Royal HaskoningDHV
- Witteveen+Bos Consulting Engineers b.v.

Profile

TEC's key expertise is tunnels; in-situ land tunnels, bored as well as Cut&Cover and immersed tube tunnels. The Scope of work comprises tunnel design with construction supervision including the mechanical and electrical tunnel installations. Together with the Dutch Ministry of Transport and Public Works – Tunnel engineering Department (Rijkswaterstaat), TEC developed advanced knowledge in tunnel engineering.

The participating firms employ more than 8000 engineers and specialists and have a total annual turnover of about 748 million EURO (2016). They have subsidiaries and branch offices in countries worldwide.

Royal HaskoningDHV

www.royalhaskoningdhv.com



Royal HaskoningDHV is a leading independent, international project management and engineering consultancy service provider. Specialising in planning and transport, infrastructure, water, maritime, aviation, industry, energy, mining and buildings, each year we contribute to the delivery of some 30,000 projects around the world on behalf of our public and private sector clients.

Our 6,500 staff adds value to our client's projects by providing a local professional service in more than 35 countries, via our fully integrated international office network. As leaders in sustainability and innovation, we are deeply committed to continuous improvement, business integrity and sustainable development, and work with our clients, stakeholders and communities to enhance society together.

Prior to the merger on 1 July 2012, Royal Haskoning and DHV have successfully delivered millions of world class projects during the past two centuries. With roots established in The Netherlands, the UK and South Africa, our combined experience and longevity spans more than 225 years. Now, as one company, we have the power to make a bigger difference in the world as we rise to the challenges of our 21st century planet, towards a better, brighter future.

Today Royal HaskoningDHV ranks in the top 10 of global, independently owned, non-listed companies and top 40 overall. This makes us the first choice consultancy provider for involvement in major world themes, such as 'pit-to-port', food and water scarcity, the development of mega-cities, and sustainable infrastructure and energy resources & supply, such as wave and hydro power. We are also well positioned to contribute to the latest business models, such as Public-Private Partnership.



Witteveen+Bos Consulting Engineers b.v.

www.witteveenbos.com



Witteveen+Bos is a private limited company whose shares are owned entirely by its employees, who are either participants, partners or senior partners. This unique ownership structure ensures above-average commitment, good financial performance and a high profile. It is a structure that appeals to our clients, because it gives them confidence in our commitment. Our net result is paid out entirely as a dividend to our shareholders, so they share in large measure in the company's result.

The Witteveen+Bos organisation is built around the cells concept that we have shaped in the form of PMCs (product market combinations). Organisationally, the PMCs are clustered into five sectors. The five sectors are: Ports and hydraulic engineering, Spatial development and the environment, Urban development and traffic, Water, and Infrastructure and Construction,

Next to the offices in The Netherlands, Witteveen+Bos also has offices in Belgium, Kazakhstan, Indonesia, Russia and Latvia.

Witteveen+Bos is committed to being a first-rate consultancy and engineering firm. Performing at the very highest level is a precondition for achieving this goal. We think striving for the top is a healthy ambition. A national and international orientation towards products, markets and the labour market is essential to operating being the best in our field of work.

Internationally, Witteveen+Bos has achieved a good position in the following areas:

- preparation, transport and distribution of drinking water
- effluent treatment
- water management
- environmental technology and policy
- ports, dredging, coastal water engineering, river water engineering
- tunnels



SERVICES

TEC provides a full range of consultancy services from feasibility studies, design, tender documents, tender evaluation, design reviews, value engineering, cost analysis, detailed design, and construction supervision to project management for underground engineering, related electrical and mechanical works and traffic engineering. In addition, we are able to draw on the considerable expertise of two Dutch engineering consultancy firms covering the entire range of civil, structural and architectural engineering required for small and large building projects, environmental impact assessment, legal aspects and project management.

Moreover, TEC has at their disposal specific expertise of the Dutch Ministry of Transport and Public works – Tunnel Engineering Department (Rijkswaterstaat), a governmental organisation involved as designer and owner / operator in about 26 road and railway tunnels and their installations in the Netherlands.

Expertise

- Civil
 - immersed tunnels
 - shield tunnels in soft soil
 - cut & cover tunnels
 - pneumatic caissons
- Electro mechanical installations
 - ventilation
 - pumps
 - lighting
 - power supply
 - traffic control
 - operation
- Safety aspects
 - Safety analysis
 - Operational procedures
 - QRA and Scenario Analysis
- Risk assessment & Value Engineering



IMMERSED TUNNELS

General

TEC is recognized as an international specialist in soft ground tunnelling and one of the very few international leading consultants in the field of immersed tunnelling. This allows TEC to make in depth comparisons taking into account all available tunnel options and to select, depending on the various project conditions, the right solution for our client. TEC is and has been involved in numerous immersed tunnel projects including major sea crossings. In the various projects TEC held positions from Client Consultant to Detailed Design Engineer for a Contractor, which is considered essential to cover all individual project phases in order to remain the top class consultant and engineer for every Customer (see quote).

Through involvement in various challenging tunnel projects, TEC is perfectly capable of selecting the most suitable tunnel option, being of added value to every infrastructural underground project.

TEC's ongoing involvement in major infrastructural tunnel projects guarantees TEC's key position in international tunnelling. To date TEC was involved in over 50 immersed tunnel projects. On the following pages a selection of the TEC Immersed Tunnel projects are briefly described.

Quote:

“TEC combines in depth knowledge of immersed tunnel design with a thorough and detailed expertise in all special execution aspects of immersed tunnels. For both the Client and Contractor this brings essential and unique added value to every immersed tunnel project. We consider TEC as the worlds' no.1 consultant in immersed tunnelling”

Oscar Koster
Sr Manager
Strukton Immersion Projects
www.mergor.eu



TEC has been involved in the following immersed tunnel projects, either through the TEC entity or through one of its partners:

- Noord (North) tunnel, the Netherlands
- Western Harbour Crossing, Hong Kong
- Tunnel under the Rio Guadalquivir, Seville, Spain
- Medway tunnel, Chatham-Rochester, United Kingdom
- Wijker tunnel, Velsen, The Netherlands
- Piet Hein tunnel, Amsterdam, The Netherlands
- Maliakos Gulf crossing, Greece
- Øresund Link, Denmark-Sweden
- Chang Hong immersed tunnel, Ningbo, China
- Aktio – Preveza Crossing, Greece
- Daugava river tunnel, Riga, Latvia
- Warnow Crossing, Rostock, Germany
- HSL tunnel Oude Maas, The Netherlands
- HSL tunnel Dordtsche Kil, The Netherlands
- Thomassen (Caland)-tunnel, the Netherlands
- Thessaloniki Immersed Tunnel, Greece
- Shannon river tunnel, Limerick, Ireland
- River Tyne crossing, Newcastle, United Kingdom
- Busan – Geoje Link, South Korea
- Coatzacoalcos tunnel, Mexico
- Immersed Tunnels in North/South Metro line, The Netherlands
 - Project Immersed tunnel under the IJ-river
 - Crossing under Amsterdam Central Railway Station
- 2nd Coentunnel, Amsterdam, The Netherlands
- Oosterweel tunnel, Antwerp, Belgium
- Hong Kong – Zhuhai – Macau Link, China
- Fehmarnbelt immersed tunnel, Denmark-Germany
- Shenzhong crossing China
- Söderström, Sweden
- Santos-Guarujà Crossing, São Paulo, Brazil
- Sharq Crossing Doha, Qatar
- Marieholmstunnel, Gothenburg, Sweden
- ShenZhong Link International Design Competition, China
- Shatin to Center Link, contract 1121, HongKong, China
- Rupel tunnel, Belgium



Noord (North) tunnel, the Netherlands

Project

To solve the daily traffic congestions at the crossing of the river Noord on the A15 motorway, the 2x2 lane arched bridge was replaced by a new 2x3 lane tunnel. The new, approx. 1.300 m long tunnel on the A15 motorway comprises:

- Two approaches (open ramp structure, using geotextile to create a polder and conventional cut and cover tunnels).
- An immersed tunnel section, consisting of 4 concrete tunnel elements (3 x 130m and 1 x 100 m).

The tunnel cross section contains two traffic tubes with three lanes each and a central duct for emergency and to house utilities.

The new tunnel was classified as a category I tunnel and therefore accommodated to allow the passage of hazardous goods.

The tunnel elements were built in an existing casting basin that is owned by the Public Works (and that was used for other tunnels). The casting basin was shared with another project. Along with the elements for the Noord Tunnel also the tunnel elements for the Willem Rail tunnel were built. To avoid large scale dredging on the transport route the roof of the tunnel elements was only casted partially. The remaining part of the roof was being cast upon arrival at the project location prior to the fitting out of the tunnel elements for immersion.

The mechanical and electrical installations for the Noord tunnel comprise:

- Energy supply
- Tunnel lighting
- Drainage and tunnel ventilation
- Traffic installations
- Fire fighting provisions
- Communication systems
- Maintenance building installations
- Plant control and control systems



Figure: Tunnel under the river Noord



Figure: Tunnel interior



TEC's scope of work

Overall:

- Representation of the Employer during the construction phase, carrying out site supervision and contract-administration for the execution of all tunnel civil and installation works.

Civil and Structural works:

- Update and optimization of final design including the draft tender documentation and drawings.
- Detailed design of all civil works including construction and reinforcement drawings.
- Review of contractors' detailed engineering for all temporary works, including the transportation and immersion equipment, the artificial cooling design for the avoidance of early age thermal cracking.

Mechanical and Electrical:

- Preparation of the conceptual design / project definition.
- Development of the tender documents that also included traffic management and remote control of the Noord tunnel and other tunnel and bridges located in the region.
- Preparation of Terms of References, to control and check the contractors detailed design
- Review of contractors' detailed engineering for all tunnel systems (M&E including traffic management systems).



Western Harbour Crossing, Hong Kong

Project

The 35 kilometre road between the new Chek Lap Kok airport and Hong Kong Island includes several bridges and a tunnel. The tunnel, the Western Harbour Crossing is located in the western part of Victoria Harbour between the Kowloon extension and Hong Kong Island. The Western Harbour Crossing will be a privately financed BOT project. The Cross Harbour Tunnel Co. Ltd. was one of the competing franchises for this project. Together with Mott Connell Hong Kong, TEC was invited to prepare a tender design for this tunnel project.

The tunnel alignment has a length of 2750 metre, and accommodates 3 traffic lanes in each of the two traffic tubes. The tunnel also accommodates a central corridor. At Kowloon the tunnel is built as an in-situ cut and cover tunnel in the new land reclamation. The immersed section measures 1290 metre and consists of eleven elements. At Hong Kong Island the approach is built as a top down cut and cover tunnel structure, using diaphragm wall reaching 50 m deep onto the bed rock.



Figure: tunnel in operation (source: internet)

TEC's scope of work

As member of a design consortium TEC prepared the tender design for the immersed tunnel section, the Kowloon entrance, vertical alignment and cross section. The Client was the Cross Harbour Tunnel Co. Ltd., one of the competing consortia for this BOT project.



Tunnel under the Rio Guadalquivir, Seville, Spain

Project

The tunnel crosses the Rio Guadalquivir as part of a dedicated public two by two lanes highway, class I standard, linking the banks of the river Rio Guadalquivir. The total length of the immersed section is 700m. In the design, the elements would be constructed in a temporary construction dock near the site and would have a length of approximately 125 m each.

TEC's scope of work

TEC provided the tender design for the immersed tunnel, the cut and cover tunnels for the approaches (permanent structures and temporary works) and prepared a design for the casting basin.



Medway tunnel, Chatham-Rochester, United Kingdom

Project

The Medway Tunnel is a dual carriageway motorway tunnel. In the enclosed part the two traffic tubes are only separated by a central wall. The tunnel width is 24 m. The actual structures are 1800 m long including a 600 m enclosed section and the tunnel approaches.

The immersed part of the tunnel consists of 3 elements of which two of 126 m and one of 120 m. All elements are built in the eastern approach. The project is tendered according to the “design and construct” method of the ICE.



Figure: Medway tunnel under construction (top left, right) and completed (bottom left)

TEC's scope of work

When the project was awarded, TEC delivered support to Mott MacDonald for the design of the tunnel, casting basin, the trench, immersion facilities and supervision of the works to the contractor Tarmac Construction Ltd. / HBM Civil Engineering Ltd. Furthermore TEC carried out an independent design check category II on the immersed tunnel part.



Wijker tunnel, Velsen, The Netherlands

Project

This motorway tunnel has two tubes each comprising three lanes and a central duct. The tunnel is part of the new A9 / A22 motorway situated 1200 m east of the existing Velsler tunnel, where it crosses the North Sea Canal.

The tunnel and the approaches, wide 30 m, long 1100 m have been designed for the transportation of hazardous goods, category I standards. The immersed part of the tunnel consists of 6 elements, each 96 m long. The elements have been constructed in a casting basin at Barendrecht and then transported via the North Sea to the North Sea Canal. Both approaches consist of three 20 m long tunnel sections and five open ramp sections. These reinforced concrete structures have been constructed by means of the cut and cover method. The upper part of the approaches, some 500 m, are so called “green” approaches and are built using the polder principle with soil-ballasted watertight PVC membranes.

The mechanical and electrical installations for the Wijker-tunnel comprising:

- Energy supply
- Tunnel lighting
- Drainage and pumps
- Tunnel ventilation
- Traffic installations
- Fire fighting provisions
- Communication systems
- Maintenance building installations
- Plant control system



Figure: Wijkertunnel location



TEC's scope of work

Overall:

- Representing the employer during construction and carry out site supervision and contract-administration for the tunnel works construction and installations.
- Probabilistic analyses concerning the sea transportation of the tunnel elements on the North Sea.
- Review of contractors' detailed design for the temporary works.

Civil and Structural works:

- Design responsibility, update and optimise the draft tender design, tender documentation and tender drawings.
- Detailed design for all permanent works.

Mechanical and Electrical:

- Preparation of conceptual design.
- Preparation of Terms of References and tender documentation,
- Review contractors detailed design
- Site supervision.



Figure: transport tunnel elements



Piet Hein tunnel, Amsterdam, The Netherlands

Project

The Piet Hein tunnel is part of the road link between Amsterdam Central Station and the A10-ring road and the new suburb IJburg on reclaimed land. The tunnel has a total length of 1.9 km and provides a road and rail connection between the eastern waterfront of Amsterdam and the Amsterdam Ring road.

The tunnel cross section has four tubes, two of which are reserved for road traffic, each with a width of 8.5 m. One tube is reserved for the tram line with a width of 9.1 m, and one tube is reserved for the service and escape gallery with a width of 1.5 m. The service gallery is located between the two road traffic tubes and is also used as an escape route.

The immersed part of the tunnel is approx. 1.265 m long and made up of 8 reinforced concrete tunnel elements, each with a length of approximately 160 m.



Figure: Tunnel elements in construction dock (Verrebroek dock Antwerp)

The immersed tunnel is connected to transition structures (piled abutment structures) on both banks, with a length of approx. 60m each. The transition structures also include the service buildings for the operation of two tunnels including the Piet Hein tunnel.

The western approach is about 215 m long of which approximately 40 m is a conventional cut&cover tunnel having the sheet piles (used for construction) incorporated in the final structure. About 175 m is a structure based on a polder principle with permanent sheet piles extending down to semi impermeable soil layers and a permanent horizontal drainage system.



The eastern approach is approx. 295 m long. A deep open approach structure of around 170 m is connected to the transition structure and consists of a concrete floor slab.



Figure: Off shore transport Tunnel elements on the North Sea

The immersed sections were built off-site at a dock near the Belgium city of Antwerp. Each section was towed offshore across the North Sea from Antwerp to Amsterdam and immersed into place.

TEC's scope of work

For the Belgium Construction Consortium CPHT (comprising CFE, Besix, Dredging International, van Laere & de Meyer) TEC, through its partner Royal Haskoning, prepared the winning tender design. After the contract was awarded to the Belgium JV, TEC developed the detailed design for:

- All tunnel structures
- Two service buildings
- Detailed analyses of all transport and immersion stages; this included a risk based analysis of the off shore transport of the tunnel elements and the buoyancy analyses for the tunnel elements of which some are double curved. Ballast exchange.
- Building pits for the approach and transition structures.
- Immersion trench
- Temporary works including the transportation and immersion equipment.

Also the towing design, model tests, joint design, temporary pre-stressing design as well as the failure risk analysis for the transport were provided.



Maliakos Gulf crossing, Greece

Project

The Maliakos Gulf Crossing is part of a 13 km road section for the motorway between Athens and Thessaloniki. The project comprises an immersed tube tunnel, with a length of around 4.5 km, crossing the Maliakos Gulf between the cities Hiliomili and Karavofanora.



Figure: Tunnel location

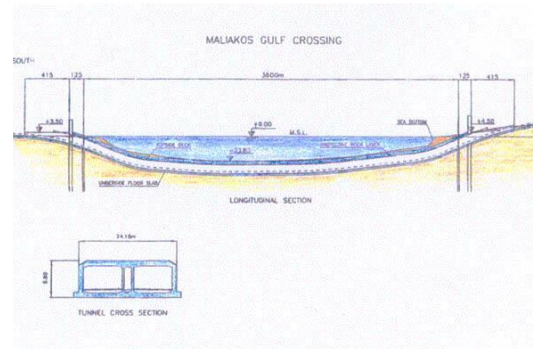


Figure: Schematic tunnel configuration

TEC's scope of work

For Ministry of Environment, Regional Planning and Public Works of Greece, General Secretariat of Public Works, TEC as part of the Maliakos Tunnel Consultant J.V. was responsible for

- Review of existing studies and recommendation for further studies.
- Technical and financial feasibility design for the tunnel.
- Pre-qualification.
- Preparation of tender document and technical specifications for a BOT contract and tender procedure.



Øresund Link, Denmark-Sweden

Project

In 1991 the Denmark and Swedish governments agreed to build a fixed link to connect the two countries across Øresund. The Øresund Link is 16.7 km long, and provides a direct traffic and train connection between Copenhagen and Malmö. The link consists of a peninsula with a length of 1km, a tunnel of 4 km, an artificial island of 4 km and a bridge of 7.7 km in length.

The tunnel is realised using the immersed tunnel method. The immersed part of the tunnel has a length of 3500 m and runs under the Drogden Channel. The Øresund tunnel is the world's largest concrete immersed tunnel comprising 20 immersed elements. Each is 176 m long and is made up of 8 segments of 22 m each. The tunnel has two railway tubes, two motorway tubes and an escape gallery. The outer dimensions of the cross section are 8.5m by 41.7 m.

The tunnel element has been constructed in an innovative and exclusive manner, located about 10 km from the site, using an industrial method with 2 parallel production lines using the incremental cast & launch method. This method involves the casting of individual discrete segments on a fixed casting bed. After a minimum curing period the segment is pushed clear of the casting bed for match casting of the next segment on the same bed. Each segment was casted in a single pour (full section casting).



Figure: tunnel entrance & artificial island

The tunnel's foundation consists of a gravel bed placed with high accuracy. For this purpose a special multi purposed pontoon was developed by the D&C contractor that allowed for the required high accuracy placement of the gravel bed (scrading method).



The safety of tunnel users was an important part of the design. Between the motorway tubes a central gallery is located that runs along the entire tunnel length with emergency exits at 88 m intervals. The tunnel is equipped with fire-protection material and state of the art tunnel installations and traffic management systems.

TEC's involvement in the project, in partnership with Øresund Link Consultants n.v., included the design, preparation of contract documents, tendering, supervision and monitoring of the detailed design and construction works for the tunnel, the artificial island, and peninsula.



Figure: Transport of tunnel element

TEC's scope of work

General

- Consultancy to the project Client Øresund Korsortiet

Civil

- Design of the immersed tunnel and tunnel approaches
- Preparation of the Tender documents and Technical Specifications
- Review of the Detailed Design prepared by the D&B Consortium
- Review of Construction Plans and Methodologies prepared by the D&B Consortium
- Construction Supervision

Dredging & Reclamation

- Design of the artificial island
- Preparation of the Tender documents and Technical Specifications
- Review of the Detailed Design prepared by the D&B Consortium
- Site Supervision



Chang Hong immersed tunnel, Ningbo, China

Project

The Chang Hong tunnel in Ningbo crosses the river Chang Hong. The crossing comprises an immersed tunnel section of 400 m in length and is made up of 4 elements each 100 m long. The tunnel width is 22.80 m and the overall height is 8.45 m.



Figure: Tunnel elements under construction

TEC's scope of work

TEC, in association with the Municipality of Rotterdam, provided special design and supervision services to the Contractor STEC from Shanghai. These services focused on the immersed tunnel part.

Aktio – Preveza Crossing, Greece

Project

The work comprises a contractor design for a 600 m long tunnel. The immersed tunnel consists of 6 elements of 100 m with two tubes with double roads for traffic. The tunnel provides a connection through a bay of the Mediterranean between the cities of Aktio and Preveza in Greece. Special about the design was the impact on the design of the high risk of an earthquake in the area.

TEC's scope of work

TEC provided for the tender design.



Daugava river tunnel, Riga, Latvia

Project

The river Daugava divides the city of Riga in two parts, the west bank and the east bank. The city is a major seaport and a cultural and industrial centre with more than one million inhabitants. Due to economic growth the amount of traffic increased fast and the capacity of the existing river crossings is too low. To meet the expected traffic growth, a new Northern extension of the ring road was planned including a new river crossing with 2 x 3 lanes.

The Daugava Tunnel project is an 8 km highway link, starting at the east bank with an approach road of 2.250 m with several junctions and connections to the existing road network, an immersed tunnel part with a length of approximately 1.300 m and an western approach road of 4.500 m, also with several connections and crossings with the existing road network. A concrete immersed tunnel as well as a steel shell tunnel was designed.

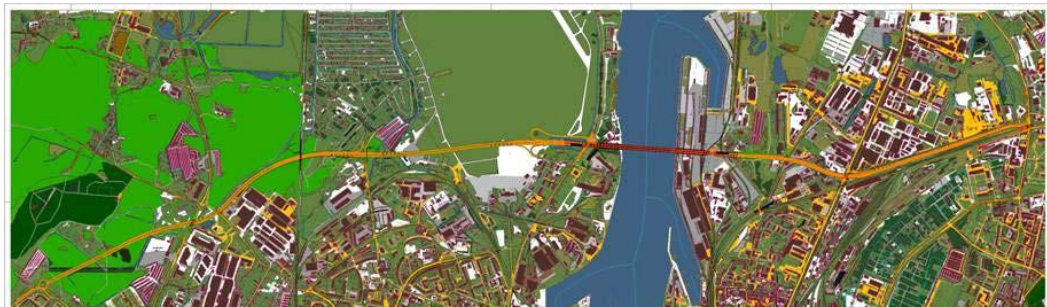


Figure: Tunnel alignment

TEC's scope of work

Design Engineer and Employer's representative for all the aspects of the project during the feasibility phase and the tender preparation phase, including:

- Quick scan of a high cable stayed bridge, bored tunnel and an immersed tunnel (concrete and steel).
- Preliminary design and Basis of Design for the immersed tunnel option.
- Employer's requirements for the Approach roads, the Tunnel Civil Structures, the Tunnel Electrical and Mechanical Installations. The Definition Drawings and the Quality System.

The design works included the following:

- Concrete immersed tunnel and approach roads, Casting basin, Cross overs.
- Dredging and reclamation works.
- Environmental aspects including contaminated soils.
- Approach roads, Viaducts and bridges, Alignments of all the roads.
- Electrical and mechanical installations.



Warnow Crossing, Rostock, Germany

Project

The Rostock Tunnel is a city tunnel crossing the Warnow River in the City of Rostock, connecting the eastern and western part of the town. The tunnel has two tubes, each comprising two lanes and a central wall. The total length, including approaches, is 1.500 m of which 800 m is enclosed. The immersed part consists of 6 tunnel elements each with a length of 120 m. The design of the tunnel is according to the German category B tunnel classification.

The project in Rostock is the first B.O.T. project in Germany.



Figure: Tunnel elements floating in construction dock

TEC's scope of work

During the tender phase TEC assisted the MDH consortium (Maculan, Dragados, Hegemann) with the technical proposal, delivering consultancy services regarding the overall tunnel design including the immersed tunnel and the casting basin.

During the construction phase TEC assisted the Warnowquerung GmbH & Co. JV, led by the French contractor Bouygues Travaux Publics. The main task of TEC was to review all documents concerning marine activities for the immersed tunnel. TEC is also leading in the supervision of those activities.



HSL tunnel Oude Maas, The Netherlands

Project

The high speed railway line section in the Netherlands runs from Schiphol Airport to the Belgium border towards Antwerp. For this railway a number of large civil works has been constructed including the crossing with the river Oude Maas. The enclosed part of the tunnel is approx. 1.500 m.

The section below the river and the deep sections of the approaches are constructed using the immersed tunnel technique, with seven elements of 150 m each. The cross section comprises two tubes with one track each. The tunnel is suited for trains with a cruise speed of 300 km/h.



Figure: tunnel elements for crossing with river Oude Maas and Dordtsche Kil in construction dock

TEC's scope of work

Civil and structural:

- Reference design
- Tender documentation, tender evaluation
- Detailed design
- Structural calculations and drawings
- Geotechnical and geo-hydrological advisory
- Cost estimates and construction planning
- Supervision on the execution of the works



HSL tunnel Dordtsche Kil, The Netherlands

Project

The high speed railway line section in the Netherlands runs from Schiphol Airport to the Belgium border towards Antwerp. For this railway line a number of large civil works has been constructed including the crossing with the river Dordtsche Kil. The enclosed part of the tunnel is 1.500 m.

The sections below the river and the deep sections of the approaches are constructed using the immersed tunnel technique, with seven elements of 150 m each. The cross section comprises two tubes with one track each. The tunnel is suited for trains with a cruise speed of 300 km/h.



Figure: Crossing Dordtsche Kil

TEC's scope of work

Civil and structural:

- Reference design
- Tender documentation, tender evaluation
- Detailed design
- Structural calculations and drawings
- Geotechnical and geo-hydrological advisory
- Cost estimates and construction planning
- Supervision on the execution of the works



Thomassen (Caland)-tunnel, the Netherlands

Project

The extension of the A15 motorway to the so-called Maasvlakte crosses the Caland Canal. For this crossing a tunnel has been constructed with a total length of 1.500 m accommodating 2x3 road lanes and a service / escape duct. The tunnel is suited for the transport of dangerous goods (category I).

The tunnel was constructed to replace the bridge on motorway A15 that contained a movable part that opened 8.000 times a year to allow the passage of the sea-vessels.

The enclosed part of the tunnel is 1.100 m. The section below the canal and the deep sections of the approaches are constructed using the immersed tunnel technique, with six elements of 115 m.



Figure: Tunnel under construction



Figure: Tunnel element during tow to site

TEC's scope of work

Civil and structural:

- Preliminary design and final design
- Structural calculations and drawings
- Geotechnical and geo-hydrological advisory
- Tender documents
- Cost estimates and construction planning
- Detailed design
- Advisory and supervision upon construction (in co-operation with the client)



Electrical and mechanical:

- Functional and design requirements
- Preliminary design and final design, including calculations, drawings and schemes
- Risk analyses
- Tender documents
- Cost estimates
- Review of contractors detailed design
- Monitoring and construction supervision





Thessaloniki Immersed Tunnel, Greece

Project

The project consists of a 3 km long road connection in the city centre of Thessaloniki. The crossing of the harbour comprises an immersed tunnel of 1200 m. The road accommodates a double three lane carriage motorway including emergency lanes. The region is subjected to seismic hazard.

The type of contract for the project is DBFOT.

The project includes access roads, cut and covers, immersed tunnel, technical installations and toll facilities.



TEC's scope of work

TEC provided the tender Design for the immersed tunnel, including casting basin to the Construction JV Bougyues / Alte / ASF / Volker Stevin.



Shannon river tunnel, Limerick, Ireland

Project

The Limerick PPP Scheme comprises approximately 10 km dual carriage way along with associated link roads and side roads. The scheme is linking the already constructed Limerick Southern Ring Road Phase I at Rossbrien with the N18 Ennis Road close to Shannon Airport. The Limerick PPP Scheme (Public Private Partnership) includes a fourth crossing of the River Shannon linking the northern bank with the southern bank at Bunlicky Lake.

The crossing comprises a 500 m immersed tunnel section constructed from five precast tunnel elements of a rectangular cross section for a dual lane in two bores. Further, the crossing includes 175 m cut and cover tunnels and 240 m ramps.



TEC's scope of work

TEC has been, in cooperation with HPR, the designer for Bouygues who was one of the partners in a Contractors consortium bidding for the project. TEC provided design services in the tender phase of the project.

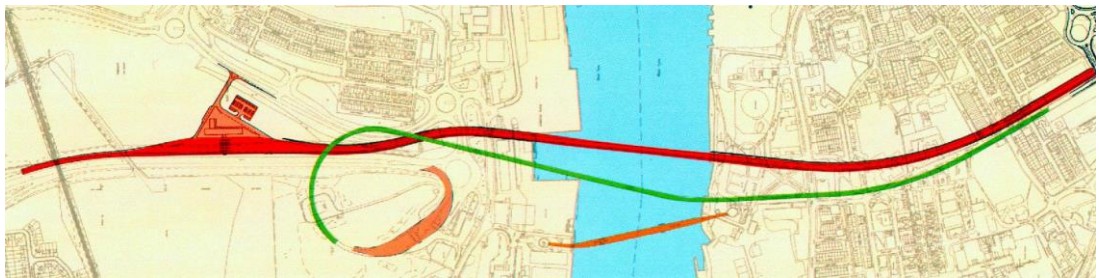
In the construction stage TEC assisted the specialist subcontractor of the winning consortium that was responsible for transport and immersion of the tunnel elements. TEC reviewed the transport and immersion design and all the associated immersion equipment.



River Tyne crossing, Newcastle, United Kingdom

Project

For many years serious congestion occurred at peak times on the A19 trunk road at its crossing under the river Tyne east of Newcastle. The bottleneck occurred in the 2 lane bi-directional Tyne Tunnel which was constructed as a bored tunnel (diameter 10.2 m and consisting of cast-iron segments) in the sixties of last century. In the reference design the existing tunnel will carry the northbound traffic (2 lanes), whereas the new tunnel carries the southbound traffic (2 lanes). The alignment of the new tunnel is mainly determined by the water depth and required depth in the navigation channel in the River Tyne and the crossing points over the existing tunnel in the northern bank.



The new crossing, comprising a 2 lane traffic tube and a 1.5 m wide escape/service tube, consists of:

- 380 m long immersed part at the river Tyne, 4 elements of approx. 95 m
- cut and cover tunnels south of approx. 800 m
- cut and cover tunnels north of approx. 320 m.

The new tunnel is required to cross the existing tunnel in two locations on the north side of the river. During construction of the new tunnel the existing tunnel will continue to be used. For reasons of protecting it is desirable to maximise the vertical separation between the two tunnels at the crossing points. This is the main reason why a 6% gradient is adopted at the northern approach of the new tunnel. Still the works required to construct the new tunnel must be carried out in such a way that the risk of disturbing loading conditions is minimised.

The Transport Authority appointed a consortium headed by Arup and including TEC partner Royal Haskoning to provide specialist advice for the proposed new crossing of the River Tyne, located adjacent to the existing Tyne tunnel. The consortium advised the Tyne and Wear Transport Authority on all financial, engineering, legal and property matters involved. Royal Haskoning was responsible for all the civil and M&E related design services of the tunnel including an immersed section.

A Reference Design for the tunnel was prepared by Royal Haskoning which formed the basis upon which all necessary approvals and parliamentary powers to construct the tunnel were obtained. The tunnel was arranged to be constructed east of the existing bored tunnels between Jarrow and East Howden. It was proposed that the new tunnel would be built and operated by a Public Private Partnership (PPP) involving private firms who will join together as the Concessionaire.



The consortium was responsible for advising the Tyne and Wear Passenger Transport Authority on project definition, developing, the PPP project, Transport Works Act processes, Public inquiry, tendering process and the structure of the Concession Agreement.



Figure: Tunnel elements in the construction dock (ship yard in Newcastle)

TEC's scope of work (through mother company Royal Haskoning)

Civil & Structural:

- Reference Design of the immersed tunnel and tunnel approaches
- Preparation of the Tender documents and Technical Specifications
- Review critical items Detailed Design prepared by PPP Consortium

Dredging:

- Design of the dredged trench and associated hydrological and environmental studies
- Preparation of the Tender documents and Technical Specifications
- Review of the Detailed Design prepared by the PPP Consortium

M&E works:

- Reference Design for the tunnel
- Preparation of the Tender documents and Technical Specifications
- Review critical items Detailed Design prepared by PPP Consortium



Busan – Geoje Link, South Korea

Project

The Busan-Geoje Link Project will provide an 8.2 km highway link between the southern city of Busan and the island of Geoje in South Korea. The overall link comprises two major cable stayed bridges, with main spans of 230 m and 475 m respectively, and a 3.24 km long immersed concrete tunnel, located in a water depth of up to 40 m, which makes it one of the deepest immersed tunnels in the world.

The immersed tunnel consists of 18 elements, each 180m long, 26.5 m wide and 10 m high. Each element consists of 8 segments each measuring 22.5 m. The tunnel accommodates 2 tubes for traffic (2 lanes each) and a central emergency / utility tube. The challenges for the Busan tunnel design included the difficult ground and foundation conditions, high water pressure and the seismic events. Another challenge was the adverse offshore conditions for the transport and immersion operation. The developments made in the field of transport and immersion of tunnel element in this project increased the possibilities for immersed tunnel for sea crossings considerably. Special immersion equipment and state of the art working methods including advanced risk management was developed for this project by the specialist sub contractor Mergor. In Addition to the position of Technical Advisor to the Client TEC provided specialist support to the sub contractor Strukton Immersion Projects for transport and immersion.

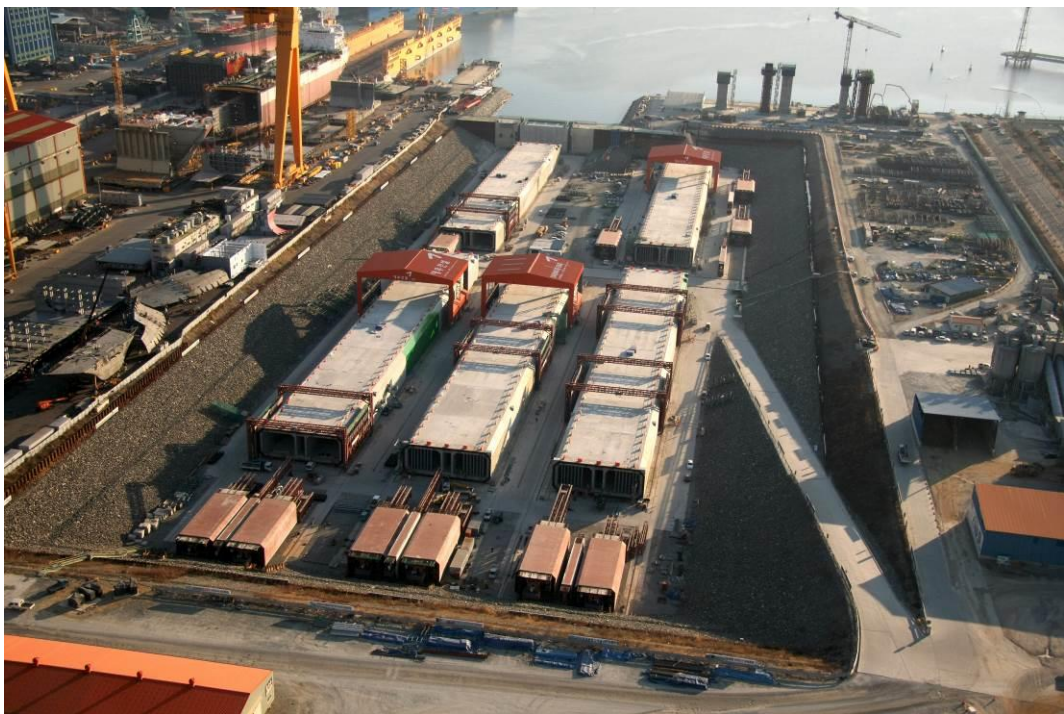


Figure: Tunnel element in construction dock



TEC's scope of work

TEC/Halcrow was the Technical Advisor to the client for all aspects of the whole of the project and during all project phases, including;

- Cable stayed bridges
- Immersed concrete tunnel
- Dredging works
- Reclamation
- Approach roads
- Bored tunnels in hard rock
- Electrical and mechanical installations

In addition TEC advised and assisted the specialist transport and immersion contractor Strukton with:

- Supervise and interpret hydraulic and physical model tests.
- Assistance design special immersion equipment.
- Assistance and advice on risk and forecast models for transport and immersion.
- Assistance and advice during transport and immersion operations.



Figure: Bridge – Tunnel transition



Coatzacoalcos tunnel, Mexico

Project

Coatzacoalcos is a port city in the southern part of the Mexican state of Veracruz, on the western bank of the Coatzacoalcos River. The city has a population of about 250.000, making it the third-largest city in the state of Veracruz. The largest community in the municipality, aside from Coatzacoalcos, is the town of Allende, with a population of about 25.000. The town of Allende is situated on the east bank of Coatzacoalcos River.

The city's industry is dominated by the petrochemical sector. The main petrochemical complexes are however located on the east bank of Coatzacoalcos River and can only be reached via an old and heavily congested bridge south of Coatzacoalcos.

To improve mobility, the State Government of Veracruz has entered into a Construction, Operation, Maintenance and Exploitation Contract for an immersed Tunnel under the Rio Coatzacoalcos. The tunnel accommodates 2 tubes, each suitable for 2 traffic lanes separated by an escape tube.

The immersed tunnel will be constructed out of 5 tunnel elements of 138 m each, resulting in a total length for the immersed section of 690 m. At both ends of the immersed tunnel, access ramps will be made by the cut & cover method using diaphragm walls. The water depth of the Coatzacoalcos River varies between 5 and 12 m. The maximum depth of the base of the tunnel will be about 30 m below water level.



Figure: Tunnel elements under construction

TEC's scope of work

TEC provided the following design services for the Spanish-Mexican construction consortium CTC, headed by FCC from Spain:

- Quick Scan
- Tender Design for the complete link (immersed tunnel and approaches).
- Detailed Design for the immersed tunnel including all related temporary structures/works.



Immersed Tunnels in North/South Metro line, The Netherlands

Project

To relieve the existing public transport system (bus, tram, metro and ferry lines) in and around Amsterdam, the existing metro system will be complemented by an additional 5th line: *the North-South line*. The new line is expected to provide transport for approximately 200,000 people a day. The 1st part of the line extends from the A10 ring road in Amsterdam North to the A10 ring road in Amsterdam South and has a length of 9.5 km. In a later stage, the line may be extended to the north, in the direction of Zaandam and to the south, in the direction of Schiphol International Airport.

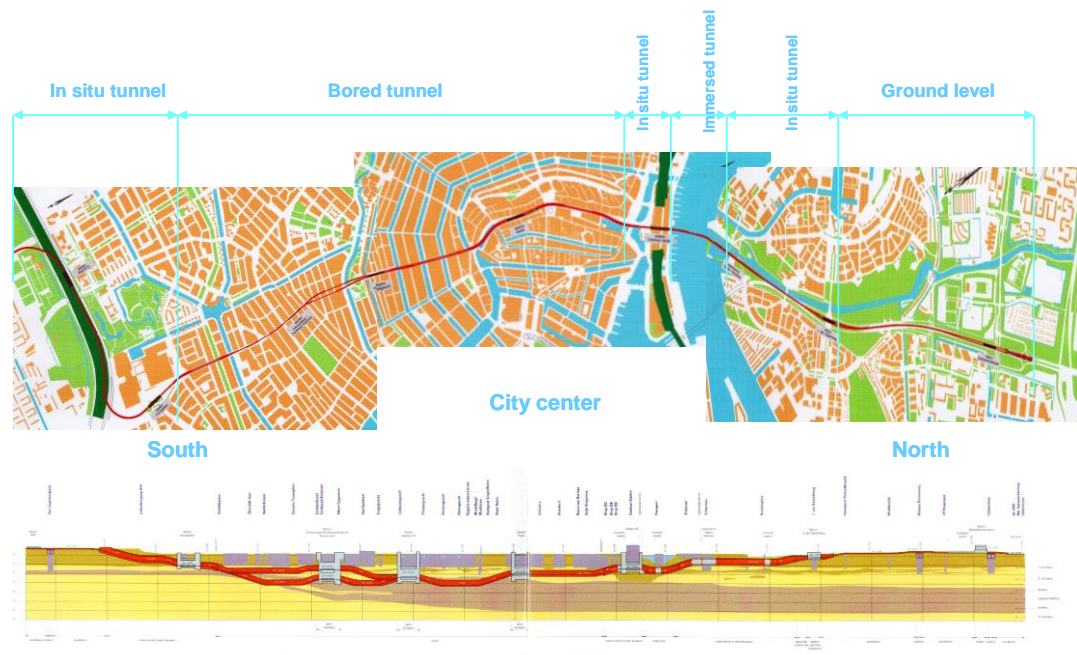


Figure Plan view and elevation of new metro line

The line will be realised on ground level in the southern and northern parts, by way of an immersed tunnel where it crosses the river IJ, and by means of a 3.4 km long double tube bored tunnel to cross the old city centre. Several sections of the metro line will be made by applying the conventional cut-and-cover technique, as well as by the less frequently used caisson-technique. Three new stations will be realised on ground level, one station will be built underground beneath an existing railway station, three deep underground stations will be constructed in the city centre, and one underground station at a relatively shallow depth. An innovative design approach containing special construction techniques was required, especially for the four stations in the city centre.

TEC's scope of work

As the Lead Consultant for the Client, the Municipality of Amsterdam, the TEC partners were responsible for the integral design (involvement since 1994). During the initial stages, the Reference Design was developed, followed by the pre-design, final and detailed designs, drawings and technical specifications, tender documents, consultancy regarding the contracting strategy, contract administration, construction supervision, as well as the preparation of



procedures and guidelines for project monitoring, assistance with the public consultation and permit process, risk management, construction safety and environmental issues.

Project Immersed tunnel under the IJ-river

The North/South Metro Line crosses the IJ-river by means of an immersed tunnel. The immersed part has a length of approx. 425 m and consists of three elements of 142 m. The two track metro tunnel is 11.25 m wide and 7.55 m high. The northernmost element is partly located in the IJ embankment and subjected to a high ground load. At the south end the immersed tunnel has very poor soil conditions.

The tunnel elements were constructed in the building pit of the northern approach. After completion the building pit was flooded, the tunnel elements were floated up and transported to the Suez Harbor in the western Amsterdam Port. The elements were moored for 4 years to wait for the completion of the northern approach and the metro station Central at the south end. The tunnel elements were immersed in autumn 2012.

The northern approach was constructed using conventional cut & cover techniques.



Figure: floating transport of tunnel element

TEC's scope of work

The consultancy services included:

- Feasibility study in which the immersed tunnel was compared with the bored tunnel.
- Pre-design, final design, tender design and detailed design.
- Tender documentation and consultation.
- Contract management and supervision.



Crossing under Amsterdam Central Railway Station

Project

A major challenge for the realization of the North/South metro line station “Central Station,” is its passage with the historic railway station. The platforms for the metro station are located directly under the railway station. The boundary conditions for the design of this station were very stringent since the railway station had to remain in full service during construction in terms of train operation and maintaining the traveller flows. In realizing this passage, a combination of the wall-roof method and the immersed tunnel technique is used. In this way parallel construction was possible and the construction activities at the railway station could be limited.

Innovative building pit concepts were used for this passage. A tailor made sandwich wall, a combination of two rows of steel piles and jet grout columns and a micro tunnelling wall was developed especially for this project. The walls were capable to absorb horizontal and vertical loads. A deck structure supported by the walls was constructed in various stages and carries the part of the railway station above the building pit.

The platform section of the station is installed using the immersed tunnel technique. The 136 m long tunnel element is constructed in a construction dock opposite the river IJ and floated to its final location underneath the railway station, and immersed under very limited headroom and in several stages, using new developed techniques.

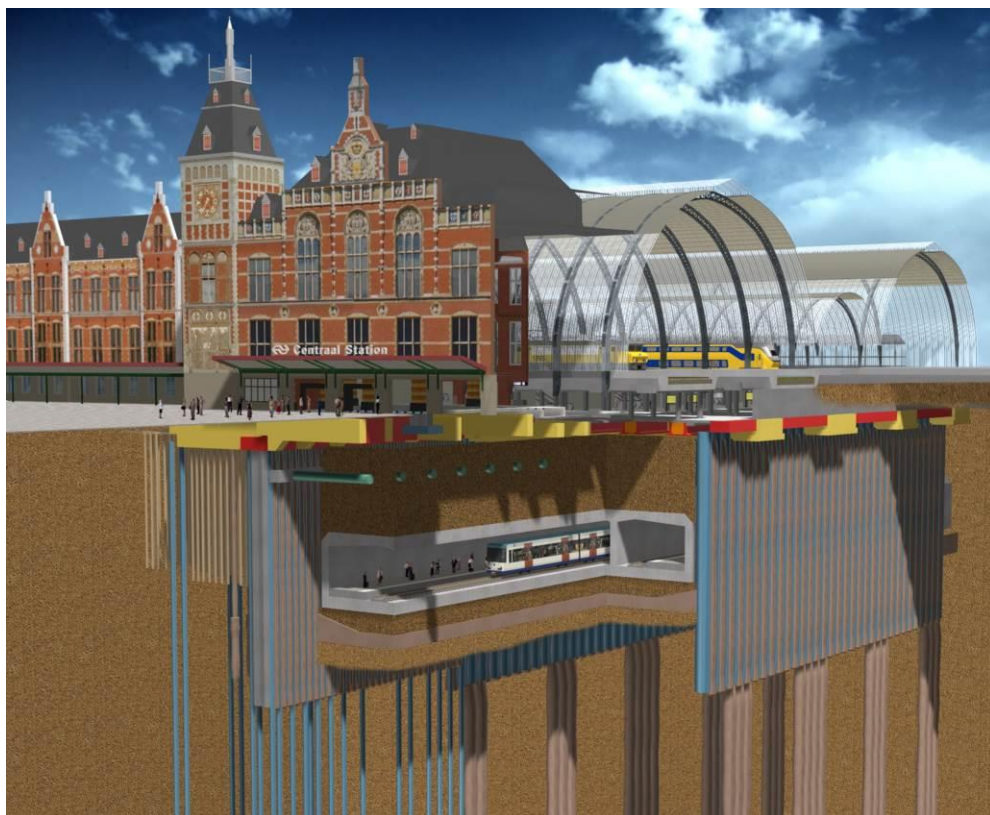


Figure: Illustration of the immersed tunnel under Amsterdam Central Station



TEC's scope of work

The consultancy services included:

- Technical studies after building pit concept to construct immersion pit
- Pre-design, final design, tender design and detailed design
- Tender documentation and consultation
- Contract management and supervision
- Alliance steering group management for the construction of the innovative building pit walls

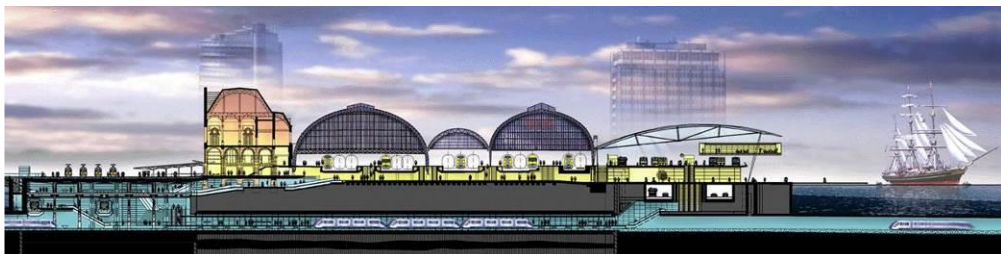


Figure : *Transport of tunnel element under Central Station (top figure)
Section of new transport hub (metro -2 and -1), railway (0 and +1), bus station (+1)
(bottom figure)*



2nd Coentunnel, Amsterdam, The Netherlands

Project

The A10 motorway is crossing the Noordzee Canal on the Western side of Amsterdam. The traffic capacity of the existing Coen tunnel, built in the sixties is insufficient with major traffic jams during the daily peak hours. Therefore on the east side of the existing tunnel a second one is planned with 2 additional tubes.

The enclosed tunnel section of 640 m crossing the canal is designed as an immersed tunnel. The immersion trench required additional attention since the existing tunnel was relatively close by; retaining structures were included in the design to achieve a limited and acceptable impact to the existing tunnel.

For the approaches of approximately 150 and 200 m various construction methods were studied. For the Southern approach the pneumatic caisson method was studied in detail, to ensure that the companies with vibration sensitive production can continue their business at all times. The Northern approach was designed as a concrete structure built in a pit with temporary sheet piles and an under-water concrete slab with tension piles.

Initially a contract was prepared for a conventional bid-built contract. Later the Client decided to go for Design Built Finance Maintain contract, for which the contract documentation was prepared as well.



TEC's scope of work

The consultancy services for the Dutch Public Works included:

- Technical studies
- Tender design for conventional Bid-Built Contract
- Preparation of tender documentation and BoQ for a conventional Bid-Built Contract
- Preparation of tender package for DBFM contract and management during tender procedure



Oosterweel tunnel, Antwerp, Belgium

Project

The Oosterweel Link is an important project. This closure of the inner Antwerp ring road (R1) extends over a length of approximately 10 kilometres and forms the link between a new R1 (Kennedy Tunnel) – E17 – N49 traffic interchange, which has yet to be constructed; on the left bank via a new Scheldt cross-river connection (Oosterweel Tunnel) and an Oosterweel junction on the right bank, with the R1 (Merksem Viaduct) – E19 – A12 on the right bank.

The works on the left bank include two flyovers, several multi-level intersections, sewers and landscaping. Furthermore, during the tendering phase a toll plaza on the left bank had to be fitted into the traffic scheme.

The tunnel under the Scheldt has 2 x 3 lanes plus a cyclist tunnel and a service tunnel. The overall width is about 44 m and the total length is 2650 m. The tunnel consists of an open access section 445 m long, cut & cover sections on both banks of 405 m and 450 m, and an immersed tunnel 1350 m long.



Figure: Rendering of the new interchange and southern entrance of the tunnel

TEC's scope of work

TEC partner Royal Haskoning provided the geotechnical, civil, and structural design as well as all roadway engineering for the works on the left bank and the tunnel for Noriant-DC, a Belgian construction consortium. In addition, Royal Haskoning provided all of the tunnel's technical installation engineering.



Hong Kong – Zhuhai – Macau Link, China

Project

The Hongkong Zhuhai Macao Bridge Link (HZMB) can be considered as one of the most challenging infrastructural projects to date. The Link comprises various bridges, causeways, artificial islands and tunnels. The full HZMB project measures over 50 km in total.

The Main Bridge offshore section has a length of approximately 30 km and includes a 6 km immersed tunnel (at completion the worlds' longest) with 2 artificial islands on either side to accommodate the transition to the bridge part that runs towards Hong Kong and Macau / Zhuhai. The bridge part of the Main Bridge section includes various box-girder and cable-stayed bridges. The Link will carry a three-lane dual carriageway with a design speed of 100 km/h and is designed for a 120 year design life.



Figure: Rendering of the Link

Tunnel design

The immersed tunnel is constructed in reinforced concrete and one of the most challenging parts of this project. The structural design of the immersed tunnel is determined by various boundary conditions. Since the tunnel has to carry a three lane dual carriageway, the roof spans are relatively large with 14.55 m. The tunnel is placed 30 m below sea level (roof level) and deep under the existing seabed to allow for the future deepening of the shipping channel to accommodate passage of 300.000 tons vessels. Until this future deepening the immersion trench is allowed to fill with sedimentation up to the existing sea bed, resulting in a ground cover on the tunnel of over 20 m.

The geotechnical conditions at the project location are unfavourable and have a significant impact on the immersed tunnel design. Although the immersed tunnel can be applied in relatively poor soil conditions additional measures are required



especially in the shallow part of the immersed tunnel. To limit settlements sand / gravel replacement and sand compaction piles with a replacement ratio up to 70% have been used. For the transition between the immersed tunnel and the existing soil a gravel bed is used.

Transport and Immersion

The immersed part consists of 33 tunnel elements with a length of 180 m. With the cross sectional dimensions of 11.5 * 37.95 m the elements will be the largest concrete tunnel elements in the world. The tunnel elements are built in a construction dock located at some 10 km of the project site, and are transported and immersed under offshore conditions.



Artificial Islands

At the transition from the tunnels to the bridge parts artificial islands are constructed. The land reclamation for these islands is carried out in relatively soft soil conditions. For the design the very soft top layers are replaced by sand; the underlying soft layers are treated with sand compaction piles. Large steel cylinders (diameter 20 m, height 40 m) are used to create the perimeter of the island. After the installation of these cylinders the area was filled with sand thus creating the island. On the islands cut & cover tunnels are constructed which connect to the immersed section.



TEC's scope of work

In this project TEC holds the position of Client Consultant for the HZMB Authority and has provided consultancy and review services for the immersed tunnel, cut and cover tunnels and the artificial islands during the design and construction phases.



Services:

- Review of HZMB Special Standards that covered the Design, the Construction, the Operation & Maintenance and the Quality Control for the project. The review had to ascertain that these Special Standards were not only in compliance with China, Macau and Hong Kong Codes and Standards but also state-of-the-art from an international perspective.
- Review of the Conceptual Design, to ensure the accuracy and rationality of the design and related studies and research results.
- Review of Preliminary, Final design to confirm before entering the tender and procurement stage. In this stage TEC prepared the technical specifications and assisted the Client in the compilation of the tender documentation for the first large D&B contract in China.
- Review of Detailed Design and Consultancy during Construction phase. TEC is supposed to bring in the specialist expertise regarding interaction between immersed tunnel design and construction and knowledge about critical details (ongoing).
- CPT-U special study to introduce in China the use of cone penetration tests as an economic way to explore ground conditions (study was performed for HZMB project).
- (detailed) parallel analyses (special studies) to confirm the detailed design on critical issues, such as the longitudinal design including joint design, seismic analyses and cross section structural analyses.



Fehmarnbelt immersed tunnel, Denmark-Germany

Project

The Fehmarnbelt Fixed Link will be the third major fixed link in the Danish Road Network and will serve as a direct road and rail connection between Scandinavia and continental Europe. The Fehmarnbelt Fixed Link will specifically connect Rødbyhavn in Denmark to Puttgarden in Germany and is expected to bring economic benefits to the entire region around the Fehmarnbelt. The opening of the Fehmarnbelt Fixed Link will significantly reduce the travel time between continental Europe and Scandinavia and eliminating the time spent on embarking, disembarking and waiting for ferries.

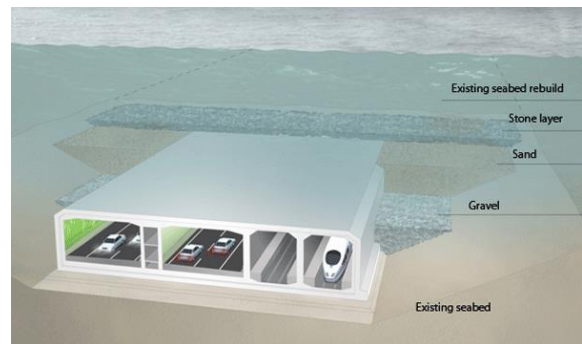


Figure: Tunnel location and typical cross-section

In a feasibility study carried out the cable stayed bridge was selected as the preferred option for this approx. 20 km long fixed link. The immersed tunnel option was identified as the best alternative.

From 2009 the selected bridge and tunnel option were investigated and compared in more detail in a true design competition. These designs are undertaken by separate groups of consultants commissioned by the state owned organization Femern A/S (Client). The two designs were prepared in isolation and it was the intention to select one of the options for further development. The immersed tunnel option design was assigned to the RAT JV, comprising TEC, Arup and Rambøll. After a design period of approximately 2 years the JV submitted an integral state of the art immersed tunnel design. In February 2011 the immersed tunnel option was selected by the Client as the preferred option to realize the fixed link between Germany and Denmark.

After the immersed tunnel option was selected, detailed documentation was prepared for the German plan approval procedure and those for the German and Danish environmental impact assessments. The plans are made available to the public and for interested parties to comment. In parallel with the permitting procedure, further detail was put on the bones of the project and the Client was assisted in the preparation of the tender documentation. The tender process started late 2013 using the principle of a competitive dialogue during which shortlisted construction consortia are challenged to introduce innovative and competitive ideas. The project will be divided into a number of procurement packages, including Immersed tunnel North and South, Dredging and Reclamation, Portal and Ramps and tunnel systems. If everything runs according



to plan, the construction will start in 2015 and the tunnel will be open for traffic in 2021.

The Fehmarnbelt Link is special in a number of ways, but especially the length of the tunnel stressed the Designers to come up with innovative and advanced design concepts in order to “beat” the bridge option. An integral design approach was essential to come up with a balanced, competitive and above all safe solution. The challenges of Fehmarnbelt tunnel are summarized below:

- Since no Code or Regulation is covering the design of a 19 km tunnel a special state of the art safety concept had to be developed and agreed with the Authorities of Germany and Denmark (including ventilation concept and advanced traffic management and information systems).
- A construction planning of maximum 6 years required a further extension of existing construction techniques (factory method using cast & launch principle).
- An economic but safe cross section had to be developed.
- A tailor made operational and maintenance strategy was developed using special tunnel elements accommodating operational and maintenance features and guaranteeing maximum availability of the Link during operation.
- To reduce the environmental impact the project objective was to achieve a closed ground balance. Dredged material was used for land reclamations on the Danish and German side (landscape design), that were developed into ecological zones.



TEC's scope of work

TEC plays a key role in the JV RAT design team to develop the Integral Immersed Tunnel option. E.g. from 2009 mid 2011 and from December 2012 – to date TEC held/holds the position of the Project Manager of the RAT JV.



The Tunnel Design services comprise:

- Conceptual Design (completed)
- Plan Approval Design (completed)
- Tender / Illustrative Design (completed)
- Assistance in preparation of tender documentation (completed)
- Assistance in prequalification process and evaluation (completed)
- Assistance during the (preparation of the) Competitive dialogue (ongoing)
- Tender Evaluation
- Review of Basic / Detailed Design of selected Construction Consortia
- Monitoring and Supervision of construction works



Shenzhong crossing China

Project

The Shenzhen-Zhongshan link is located in the Pearl River Delta, approx. 40 km north to the Hong Kong Zhuhai Macau Bridge (HZMB) and connects the Shenzhen Economical Special Zone with Zhongshan and Jiang-Men in the Guangzhou area.

This link is supposed to carry 2 x 4 traffic lanes and has a length of about 50 km and of which over 20 km is under marine conditions. The marine section of the project is considered to be the most challenging in which the selection of the appropriate alternative and associated technical solutions was extensively studied by both a local Chinese Design Institute and in parallel by an international consultant (awarded to TEC).



TEC's scope of work

For this project a parallel study was carried out on a conceptual design level that focused on the 20 km marine section including the main navigation channels, Fan-Shi and Ling-Ding channels.

In the study several options were studied and compared, as follows:

- (1) Full Bridge from East to West
- (2) Two Bridge-Tunnel options
- (3) Full Tunnel from East to West)

For the tunnel sections, the immersed tunnel, bored tunnel and mined tunnel construction methodologies were compared for each of the above tunnel sections, where the lengths varied between approximately 6 km and 21 km. In addition the dimensions of the artificial islands appeared to be a critical issue from a hydraulic blockage perspective. Apart from the civil works aspects, tunnel safety and associated ventilation concepts played a dominant role in the studies.



Söderström, Sweden

Project

The tunnel in the Söderström is part of the Citybanan project and comprises a 340 m long immersed tunnel which is located between Riddarholmen and Södermalm. The immersed tunnel will be part of a 6 km long tunnel with two railway tracks and connects the rock tunnels at either side of Lake Ridderfjärden. The Söderström tunnel consists of three prefabricated tunnel elements, two short cut and cover tunnels and a joint house. Unique for Europe and due to the limited water depth the immersed tunnel is constructed as a sandwich tunnel with concrete and a double steel shell. The tunnel is placed partly above the lake bed on 3 pile groups due to the soft soil on top of the bedrock. After the immersion operations the three tunnel elements will be connected by means of prestress. The tunnel will be fixed at the southern end in the rock at Södermalm and has a free end at the joint house (at the northern end) where movements can take place.



TEC's scope of work

- Review of the immersion process plan and all related documents which are prepared by the Contractor.
- Supervision / observations on behalf of the Client during the immersion operations.



Santos-Guarujá Crossing, São Paulo, Brazil

Project

The project is located in the Port of Santos, between the two cities Santos and Guarujá in the state of São Paulo coast, some 80 km south west of the city of São Paulo.

The two cities are separated by an approx. 500 m wide entrance channel to the busiest port of South America. The connection between the cities is currently operated by ferry boats, but there is a desperate need for a fixed link to accommodate the increasing transport volume and regarding the foreseen extension of the harbor as a consequence of the economic growth. The realization of a fixed link will reduce the current travel distance on the road from approx. 45 km to less than 1 km.

An immersed tunnel has been selected by the government as the most viable option to establish a fixed link between the two cities. This option, the first of its kind in Brazil, combines a safe and secure connection with least impact on city life and port development against a reasonable investment. TEC has provided consultancy for the selection process.

The tunnel will consist of an enclosed section of about 760 m and approaches, all-in-all some 1,800 m length. The harbor channel depth is up to 21 meters to allow for deeper draft vessels to enter the port area. The tunnel will consist of 2x3 lanes for road traffic and a separate tube for pedestrians and cyclists.



TEC's scope of work

TEC's involvement consists of three parts:

Knowledge transfer

As this is the first immersed tunnel to be constructed in Brazil, there is a requirement to build knowledge about this technology in the country. TEC will contribute by writing a design and execution manual, specifications with regard to construction and operation & maintenance manuals. Such documents are to be used by local partners for this project.



Design review

The project will be designed by local Brazilian consultancies. With regard to the specific immersed tunnel aspects, TEC will review the designs and propose improvements.

Design experts

As part of the project management team of the Client, TEC is supporting the design process carried out by a local design consortium. This is being done by having permanent presence in São Paulo by the general design coordinator and on top of that experts are participating in the design process on topics like:

- Immersed tunnel structural design
- Geotechnical design associated with immersed tunnels
- Tunnel Safety Aspects
- Tunnel Element transport and immersion process
- Construction site selection and preparation



Sharq Crossing Doha, Qatar

Project

Conceived by world renowned Architect and Engineer Santiago Calatrava on behalf of the State of Qatar's Public Works Authority ASGHAL, the unique 21st century bridge-tunnel connection across Doha Bay comprises three bridges, two immersed tunnels with a total length of approx. 6 km and three cut-and-cover tunnels.

Tunnel Engineering Consultants (TEC), together with Santiago Calatrava Engineers and Architects worked on the validation of the original concept design of five tunnels that are part of Qatar's new landmark Sharq Crossing.

This is one of the most iconic and prestigious bridge-tunnel connections TEC has been commissioned to work on to date, and the first ever immersed tunnel project in the Middle East region. Of particular interest is the Marine Interchange as a complex underground interchange, connecting the two immersed tunnels and the West Bay Bridge. Also the West Bay Bridge will have the world's largest arch span connecting the shore with the Marine Interchange.

Background

The approximately 12 km bridge-tunnel connection Sharq Crossing is a vital part of the Greater Doha Transportation Master Plan. In recent years the city of Doha has seen considerable increase in population, car ownership and new city districts. It is forecast that the area will experience serious traffic problems in the near future.

When the project completes in 2020, Sharq Crossing will link Doha's city center with the new Hamad International Airport and new city and business districts. It will also help Qatar receive all visitors to the 2022 FIFA World Cup events.

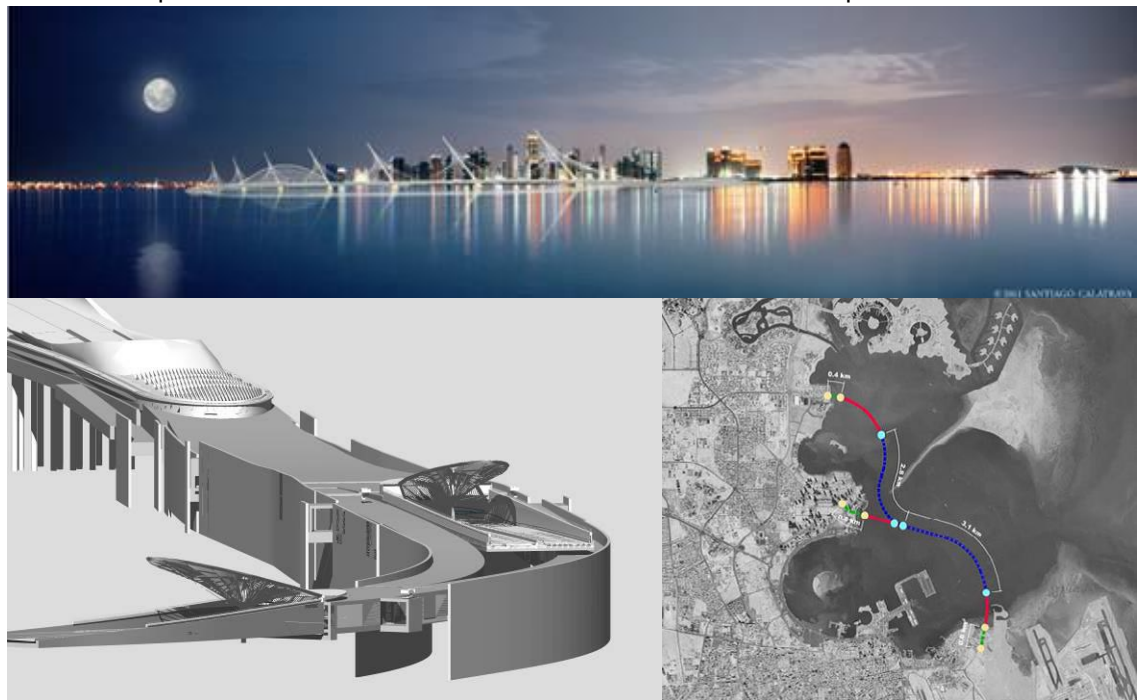


Figure : Renderings and plan view of the project



TEC's scope of work

TEC prepared the validated Concept Design of the two immersed tunnels of 3.1 and 2.8 km and the three cut-and-cover tunnels with a length of approximately 950-1250 m connecting the bridges to the main land and the Marine Interchange, connecting the two immersed tunnels and one of the bridges.

The assignment also included the design of bridge foundations, roads, utilities, mechanical, electrical and plumbing (MEP) systems, the integral safety concept including ventilation and construction schedule.

TEC worked together with HBI Haerter Ltd. (Zurich, Switzerland) for safety and tunnel ventilation and Geotechnical Consulting Group (GCG; London, UK) for geotechnical expertise.

The total project includes 5 phases. The recent sub consultancy agreement covered the first project phase: Concept Design Validation. TEC has executed the first phase in 5 months time, which started in September 2013 and was completed by January 2014.



Figure : Interior of the tunnel



Marieholmstunnel, Gothenburg, Sweden

Project

The Marieholm Tunnel in Gothenburg is a road tunnel with three lanes per direction and a central gallery. The tunnel consists of an immersed tunnel section with cut & cover tunnel and open ramp sections at both ends. The immersed tunnel section crosses the Göta Alv river, measures 306m in length and is made up of 3 tunnel elements of equal length.

The tunnel elements will be fabricated in a construction dock at the Marieholm-side of the crossing, within the alignment of the tunnel. The construction dock has room for a single tunnel element which requires the dock to be used 3 times for the IMT after which the cut & cover tunnel can be realised at that side of the crossing.

The tunnel elements will be segmented and will be placed in a dredged trench on a sandflow foundation.



TEC's scope of work

Permanent civil works for the immersed tunnel section of the project:

- Preliminary Design
- Final Design
- Detailed Design



ShenZhong Link International Design Competition, China

Project

The People's Government of the Guangdong Province plans to build a sea-crossing link between Shenzhen and Shongshan. This Shen-Zhong Link is located about 30 km to the south of the Humen Bridge in Guangzhou and about 38 km to the north of the Hong Kong-Zhuhai-Macao Bridge Link.

The new link will shorten the commuting distance of two economic circles sitting on the east and west shores of the Pearl River. The link is not only a corridor for Shenzhen and Zhongshan, but is also for strategic importance to the Nansha, Qianhai, Cuiheng and Hengqin areas of the city of Guangzhou, Shenzhen, Zhongshan and Zhuhai respectively. Upon completion of the link, the travel time from Shenzhen to Zhongshan will be significantly reduced, from more than two hours to twenty minutes in clear traffic.

The connection has a length of 24 km, has 4 lanes in both directions and starts at a new artificial island south of the Shenzhen airport where the link is connected with the Guangzhou-Shenzhen Riverside Expressway. From there it passes underneath the Dachan waterway, the Airport Secondary Fairway and the Fanshi Waterway with a tunnel. At the West Artificial Island the tunnel switches to a bridge crossing the Lingdin West Fairway and the Hengmen East Waterway with a suspension bridge, approach bridges and a cable stayed bridge. At the Hengmen Interchange the link is connected with the Zhongshan-Kaiping Highway.



The immersed tunnel possesses 2 traffic tubes and a central gallery with a total width of 46 m and a length of 5.25 km. For the deep sections, reaching water depths of 35 m, full steel sandwich elements turned out to be most economical. For the less deep and wider sections single shell elements were proposed. As



this will be the first full steel tunnel in China the cross-sections were developed in detail. An overall construction schema was set up and a casting basin for production of the tunnel elements on the Shenzhen side of the river was selected. The geology along the alignment was analysed from which the dredging methods for the trench were selected. For a number of hard spots along the alignment soil treatment like sand compaction piles and soil replacement were advised.

Besides being a transition between the tunnel and the bridge also recreational functions were assigned to the island and the entrance to the tunnel was turned into a landmark. For land formation of the main body of the artificial islands large diameter steel cylinders with rock revetment in front are proposed. Settlement and stability is controlled through soil replacement, vertical drainage and dewatering of the main island body and through sand compaction piling underneath landscaped rock revetment.

TEC's scope of work

TEC, in combination with the Guangdong Highway Reconnaissance Planning Design Institute and Information Based Architecture, prepared a set of design documents covering all aspects of the tunnels, islands and bridges.

The TEC, GDDI and IBA joint venture ended second in the competition. The client amongst others valued the technical depth of the study and the practical knowledge and experience brought in from other large tunnelling projects.

The TEC scope of services covered the integral design of the immersed tunnel and the artificial islands. The following items were prepared by TEC and were included in the competition documents:

- Architectural design and landscaping
- Structural safety and foundation design
- Mechanical and electrical installations
- Life safety
- Construction methodology and schedule
- Construction cost estimate

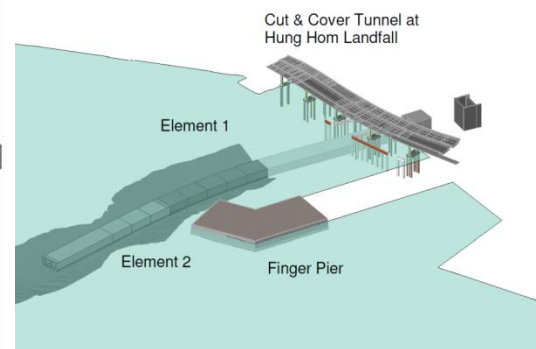


Shatin to Center Link, contract 1121, HongKong, China

Project

The Shatin to Center Link is a new to build subway line between Shatin station on Kowloon Island and HK Central station on HongKong Island. Contract 1121 consists of the connecting Cut and Cover tunnels at Hung Hom Station and the Causeway Bay Typhoon Shelter, and in between an immersed tunnel with a length of 1.3 kilometres suitable for 2 track metro. The tunnel elements will be built in a construction dock (Shek'O) at the south side of HongKong Island and transported to the site in the Victoria Harbour. The Client is MTR, the public transport company of HongKong.

Tender process in a competitive dialogue with the Client and in two stages: 1st Stage submission is a technical bid and 2nd Stage submission is a financial bid and updated technical design.



TEC's scope of work

TEC has been working together with MottMacDonald HK as a sub consultant for the Contractors' JV consisting of Zublin (Germany), Samsung (South Korea), Strukton (The Netherlands) and Hsin Chong (HongKong).

TEC was responsible for the design of the immersed tunnel; the baseline design and several alternatives resulting in an Innovative Design.

TEC Deliverables for the Tender Bid:

- Design Basis of Immersed Tunnel
- Design report Immersed Tunnel
- Design report Innovative Tunnel Design
- Structural Drawings of baseline IMT and Innovative IMT
- Temporary works of Immersed Tunnel
- BIM/Revit Design



Rupel tunnel, Belgium

Project

To promote shipping traffic between Brussels and Antwerp the Brussels-Schelde channel is being prepared to allow passage of ships up to a Gross Register Tonnage of 10.000 (GRT). The channel will be prepared by deepening to a water depth of 9.50 m over at least 25 m width. TEC studied the impact of deepening of the channel on the structural integrity of the existing tunnel.

Construction of the Rupel tunnel started in 1972 and the tunnel opened for road traffic in 1982. The Rupel tunnel comprises a 6-lane motor road, about 1,650 m long with a closed tunnel length of 595 m. The tunnel contains two main tubes, each with a 3-lane roadway, a narrow central gallery and is made up of two submerged tunnels (under the river Rupel and under the channel) connected by a tunnel constructed in situ.

Based on the original design documents buoyancy, cross-sectional and longitudinal analyses were performed to analyse the impact of deepening of the channel on the structural integrity of the tunnel. The analyses were validated by comparing calculated deformations with recent settlement surveys. Also a design for the dredging and protection of the river bed above the tunnel was made.



The anticipated settlements would lead to additional rotations in already leaking segment joints. The cause of leakage was investigated, multiple proposals for repair were given and weighed to risk and costs. Eventually an integral plan for deepening of the channel in association with the repair of a leaking joint and monitoring of settlements during dredging was delivered.

TEC's scope of work

- Research characteristics of the fairway and the shipping traffic
- Checking of structural integrity of the tunnel due to deepening of the channel
- Design of tunnel protection
- Inspection of the tunnel
- Proposal for repair of a leaking segment joint
- Review of tunnel's dredging monitoring plan

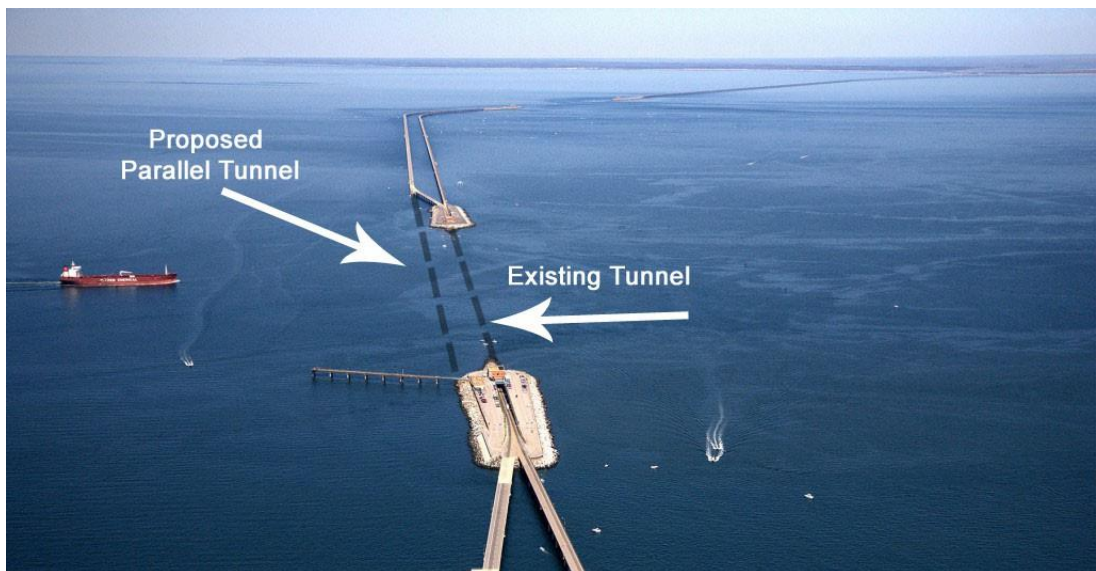


Chesapeake Bay Bridge Tunnel - Parallel Thimble Shoal tunnel

Project description

Tunnel (CBBT) is a 30-km long 2-lane facility consisting of highways, bridges, tunnels (2 sections of 1.8km each) and artificial islands (connecting tunnel and bridge sections) connecting the Eastern Shore of Virginia with the Virginia mainland. The Bridge-Tunnel was opened to traffic in 1964, replacing the ferry service that had served the Eastern Shore for more than 30 years. The facility was expanded in the late 1990s to include parallel bridges (becoming 2x2 lane), which were opened to traffic in April 1999.

In 2015-2016 the expansion of the first of the two tunnels was tendered. The Parallel Thimble Shoal Tunnel Project will construct a new two-lane tunnel under Thimble Shoal Channel. When complete, the new tunnel will carry two lanes of traffic southbound and the existing tunnel will carry two lanes of traffic northbound.



Scope of work

TEC was a member of a design JV led by Arup New York and covered the following scope of work:

- Design development of immersed tunnel option, parallel to the existing immersed tunnel including mitigating protective measures (for comparison to the bored tunnel option, which finally became the preferred and selected option);
- Review of Geotechnical FE analyses (Plaxis), carried out by the BTM design team to analyse the impact of the bored tunnel (construction) to the existing tunnel
- Assessment of the existing steel immersed tunnel regarding the impact due to the construction of the new parallel bored tunnel.
- Marine works design of the island protection and protective works on the tunnel
- Assessment of ship impact on the new tunnel and the protective works on top of the tunnel
- Design temporary jetty (construction purposes)
- Participation in (internal) design workshops and Clients' meetings