

Tunnel engineering



COWI

COWI A/S

COWI A/S is a leading international consulting company founded in 1930. COWI is privately owned and entirely independent of any manufacturer, supplier or contractor.

The COWIfonden (COWI Foundation) is the majority shareholder. The foundation supports research and development in various fields of consulting activities.

The head office is located in Kongens Lyngby, a suburb about 12 km north of Denmark's capital Copenhagen.

COWI is a highly versatile and multidisciplinary company which provide services of the highest quality in the fields of engineering, environmental science and economics.

COWI employs around 6,000 staff, of which 3,600 are based outside Denmark in subsidiaries, branch offices or project offices. 4,500 employees are professionals holding PhD, MSc or BSc degrees in civil, structural, geotechnical, mechanical or electrical engineering and other academic areas such as geology, hydrology, chemistry, biology, agronomy, sociology, economics and planning.

The annual turnover is at present (2009) EUR 537 million. More than half of the turnover of the company is generated outside Denmark in more than 175 countries around the world.

Transportation

COWI has more than 75 years of experience in transportation consultancy covering all phases of infrastructure projects from initial planning and feasibility studies over design, construction and commissioning to maintenance management and rehabilitation.

More than 8,000 kilometres of roads and railway lines including bridges and tunnels of all types and sizes have been constructed in accordance with COWI's designs.

Tunnel consultancy

COWI has provided cost-effective designs of tunnels for more than 50 years for clients all over the world.

COWI is currently involved in some 20-30 tunnel projects worldwide and the consulting activities occupy more than 100 engineers and other professionals and generate an annual turnover of EUR 12 million.

COWI's consulting services

Nature

- natural resources management
- environmental policy and regulation
- environmental protection
- coastal engineering.

Society

- welfare economics and services
- public administration
- social development and HRD
- urban and regional development
- development assistance
- cadastre and land administration
- geographical information systems and IT mapping.

Transport

- transport planning and management
- roads
- airports
- railways and metros
- tunnels
- bridges
- ports and marine structures.

Buildings

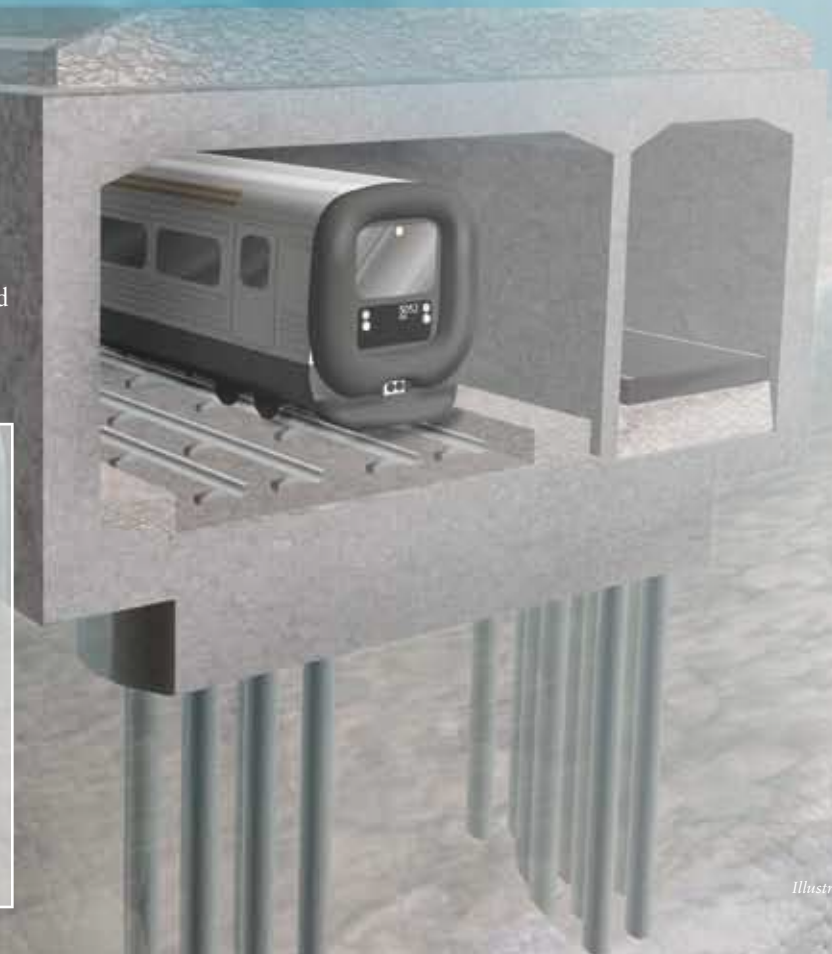
- residential buildings
- educational buildings
- hospitals and health buildings
- cultural and sports buildings
- commercial buildings.

Industry

- industrial buildings
- production and processing plants
- oil and gas
- health, safety and environment
- environmental and social due diligence.

Utilities

- municipal and hazardous waste
- water and wastewater
- energy planning and systems
- telecommunication.



Tunnel consultancy

Main types of tunnels and areas of use

TBM bored tunnels

- tunnels in congested cities for road, rail or utilities
- subaqueous tunnels for the crossing of deep waterways
- long tunnels under mountains.

Immersed tunnels

- tunnels for the crossing of waters of limited depth such as rivers, channels and harbour basins
- alternatives to bridge crossings to ensure unobstructed navigation.

Cut and cover tunnels

- shallow tunnels in urban areas with moderate surface constraints
- approaches to bored or immersed tunnels.

Rock and SCL tunnels

- tunnels with irregular or varying cross-section shape
- short tunnels under mountains or deep waters where the cost of a TBM makes TBM construction prohibitive.

Working with tunnels

COWI's longstanding experience with all phases of tunnel design and construction ensures the development of individual and optimal tunnel solutions with a long and efficient service life.

Our experience includes a number of world-class tunnel projects such as the TBM bored 8 km long railway tunnel for the Great Belt fixed link in Denmark with rails 75 metres below sea level and the 4 km long immersed tunnel for a 4-lane motorway for the Busan-Geoje fixed link in Korea with a road 50 metres below sea level.

Tunnel projects

COWI has been involved in tunnel projects all over the world. Our experience covers all types of tunnels including bored tunnels, immersed tunnels, cut and cover tunnels, rock and SCL tunnels.

Services and expertise

COWI's services cover the whole life cycle of a project from the early ideas to the operation phase and rehabilitation or decommissioning.

Our services range from professional advice on a specific problem to comprehensive planning and total engineering design and implementation of large-scale projects.

Our involvement in complex and demanding tunnel projects over the years has led to the development of particular in-house knowledge for which we are internationally renowned. TBM tunnelling under high water pressure and in soft ground, longterm durability of structures, tunnel ventilation and safety systems can be mentioned.

Customers

COWI works for tunnel owners as well as for contractors. We advocate a close dialogue with the contractor (BOT and design-build projects) in order to optimise design and construction. This knowledge is reused when we design for tunnel owners.

Quality management

COWI has established an internal quality assurance system, which is ISO 9001 certified. All design activities are carried out in accordance with individual project quality plans tailored to meet the specific requirements of each project.

Consultancy services and expertises covering all project phases:

Feasibility phase

- generation and evaluation of ideas
- feasibility studies
- studies of infrastructure needs
- alignment studies
- cost estimation (considering uncertainties)
- construction and procurement scheduling
- environmental impact assessment.

Design phase

- design management
- establishment of the design basis
- fire safety and evacuation analyses
- natural hazard analyses (storm water, flooding, seismic action etc.)
- durability design
- civil and structural design
- mechanical and electrical (M&E) installations
- operational risk assessment
- relocation of utilities from construction area.

Authority and public phase

- authority approval management
- property consultancy
- land acquisition management
- archaeological consultancy
- public consultation.

Tender phase

- development of tender design and dossiers
- management of tender procedures
- bid design
- value engineering
- preparation of contract for construction.

Construction phase

- construction management
- quality, environmental and safety management
- construction risk assessment
- building damage survey and monitoring
- interface coordination
- programme and budget control
- site supervision
- contract and claims management.

Operation and maintenance (O&M)

- O&M management system
- inspection of structures and installations
- ranking of maintenance and reinvestment needs
- repair and strengthening design.

Underwater tunnels

The construction of tunnels under wide and deep waterways requires special consideration to the design as well as to the execution. COWI has many years of experience in designing for the particular technical and practical challenges associated with subsea tunnels.



For both immersed and bored tunnels the permanent design and particularly watertightness and durability are challenging due to extraordinary conditions with regard to outside pressure and chemical attack.

The overall concepts of subsea tunnels often require special safety and ventilation considerations as they are often long and without any possibility for intermediate ventilation or evacuation shafts between the portals.

Great Belt

The Great Belt tunnel is to date the world's deepest tunnel in soft soil conditions and under the sea.

The challenge was to design the tunnel lining for extraordinary conditions with regard to outside pressure and chemical aggressivity and also to design joints to be resistant to the ambient water pressure (8 bar).

During construction the problems were related to the TBM performance in the soft and permeable glacial strata in combination with the high water pressure, ground treatments including ground freezing (with nitrogen and brine) as well as various grouting methods and methods for groundwater control.

As a matter of interest, it can be mentioned that the only subsea dewatering system known in the world was established as a method for reducing the pore pressure at tunnel horizon in order to facilitate tunnelling.

The Hallandsås tunnel

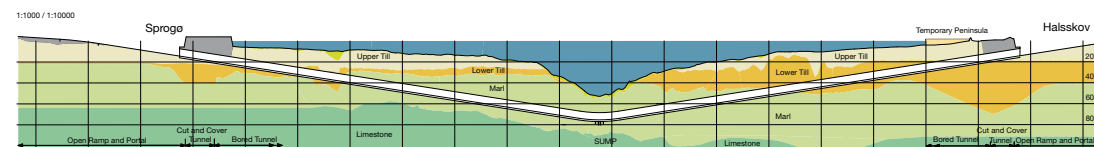
Although not a subsea tunnel, the Hallandsås tunnel is located in extremely permeable zones with strict dewatering limitations to minimise the impact on groundwater during construction and in the permanent state.

The TBM is required to operate in open or closed mode in extremely variable geological and hydrogeological conditions with water pressures corresponding to 130 metres head of water. As such, the TBM was designed to be able to excavate short distances at up to 13 bar pressure.

The Busan-Geoje tunnel

The challenge for the Busan-Geoje tunnel design was the difficult foundation and high water pressure.

These conditions in combination with seismic loads led to particular challenges for the element joints, where the extreme conditions



Longitudinal Profile,
Great Belt Tunnel Denmark

resulted in extreme joint openings. In cooperation with the producers of gaskets (GINA), we developed an innovative joint solution.

As the tunnel is the deepest concrete segment tunnel in the world, all the marine operations and solutions constituted different challenges. For instance, the excavation of the tunnel trench took place at 50 m depth with extreme requirements to excavation accuracy.



Photo: Steen Brogaard

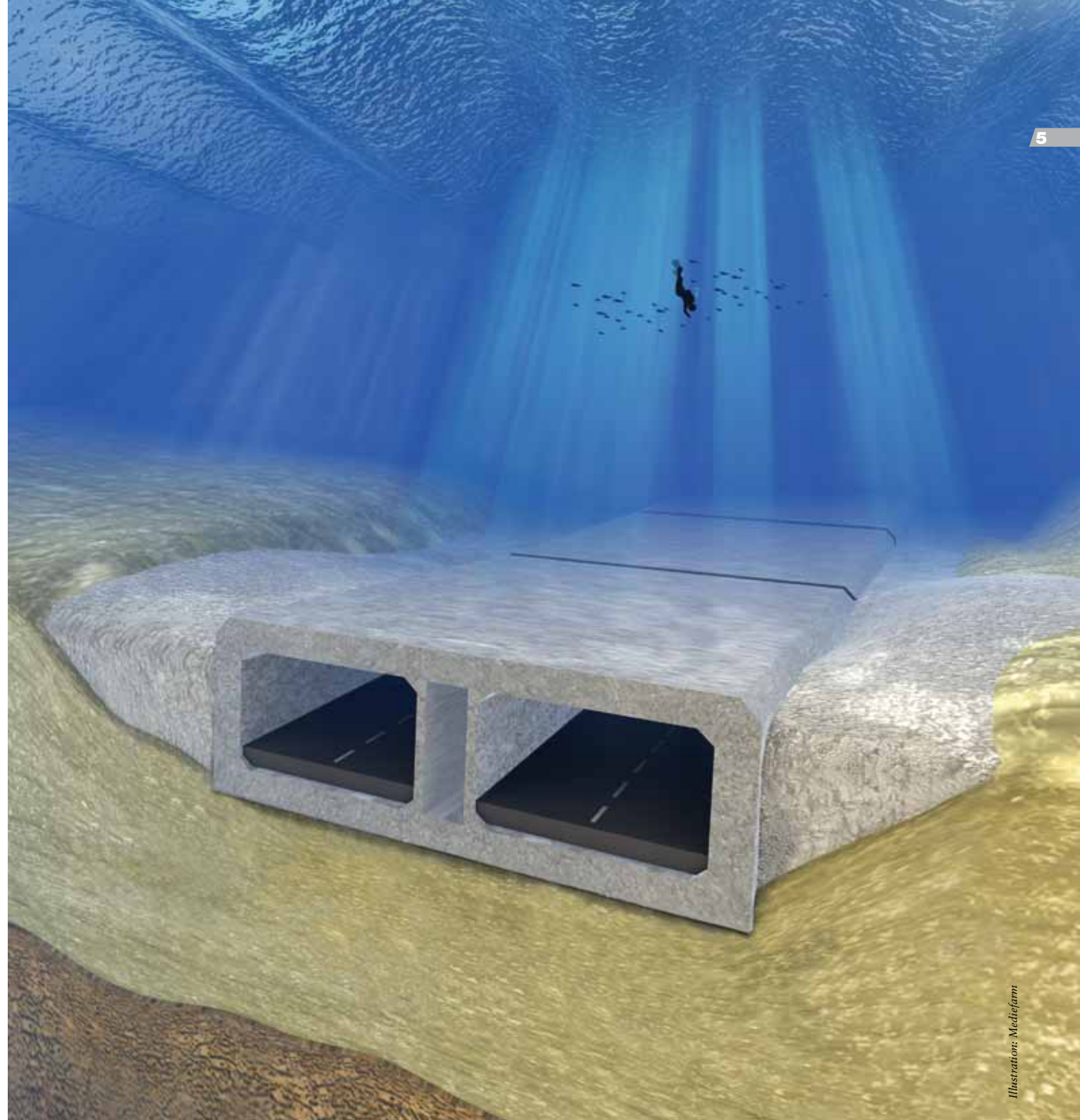


Illustration: Mediefarm



Soft soil tunneling

Tunnels in soft soil are often constructed as bored tunnels, when the use of cut and cover tunnel techniques is not possible or too costly an option.

Bored tunnelling techniques cover both tunnels constructed by the use of a Tunnel Boring Machine (TBM) and tunnels constructed by hand tools and machines, using an observational approach with temporary support of the excavation. The latter is often called sprayed concrete lined (SCL) tunnels.

Tunnel boring machines

Two typical TBM types are the earth pressure balance (EPB) machine and the slurry machine. During construction, the former is able to counterbalance the ground and water pressures in front of the TBM by the use of one or two screws between the cutterhead and the conveyor belt. The latter uses a technique where bentonite slurry is pumped into the cutterhead and mixed with the excavated material. The mixed slurry is then pumped out of the tunnel where the bentonite and the excavated material are separated again. This system also provides stability in front of the TBM during tunnel construction.

During recent years it has become possible to build larger diameter TBM bored tunnels, mainly due to improved technology and the development of larger diameter TBMs. This has opened the market for bored road tunnels sig-

nificantly, as road tunnels often require a greater cross-section than e.g. rail tunnels, but also bi-directional rail tunnels are now possible to construct. The large diameter tunnels involve large challenges during construction in terms of TBM operation, risk of settlements etc., due to the larger volumes of ground being excavated, but also ring building, with the very large concrete lining segments, is an extra challenge.

TBM bored tunnels

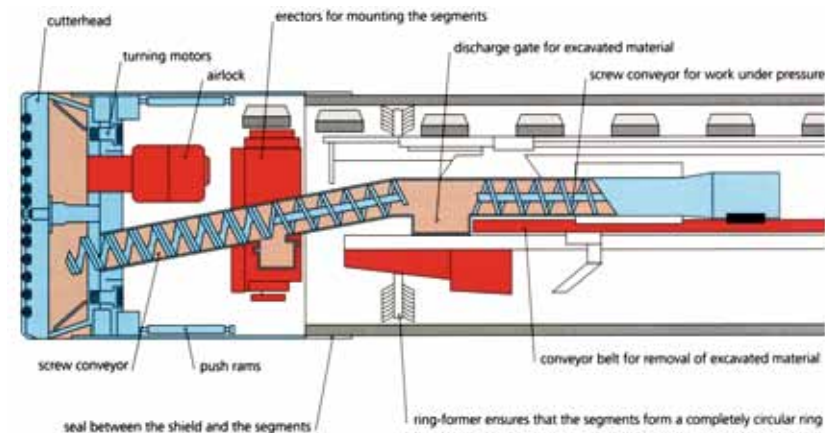
Tunnels constructed by a TBM are typically circular and used in soft ground for long tunnels. TBM tunnels are used both in urban and non-urban areas in soft soil and in a sub-aqueous environment. Compared to SCL tunnels,

TBM bored tunnels can be constructed in less competent ground and where water pressures are high or impossible to drain. TBM bored tunnels are typically lined with a prefabricated segmental concrete lining.

SCL bored tunnels

SCL bored tunnels are often used for construction of non-circular tunnels or shorter tunnels in relative competent ground conditions, where the ground can be drained during construction.

The SCL cross-section can be excavated in sections to suit the actual conditions, and excavations are temporarily lined with a primary lining consisting of shotcrete. The permanent secondary internal lining is built as an in-situ cast concrete lining.



Ventilation systems for long tunnels

Ventilation is one of the most important features when providing a functional, comfortable and safe tunnel environment for road tunnels as well as railway tunnels.



Tunnel ventilation methods

The methods for providing the required ventilation during normal, congested or emergency operation depend on the actual conditions (tunnel length, alignment, cross-section, traffic conditions, intermediate ventilation shafts etc.).

Normally, for road tunnels longer than 4-5 km the longitudinal ventilation method may not be feasible, and therefore transverse or semi-transverse ventilation systems need to be introduced. For longer tunnels the feasibility of using longitudinal ventilation depends on the actual conditions. The capability of the various systems and the choice of system depend on the fresh air requirement calculations, which are based on the estimated traffic conditions, emission from vehicles, local standards and requirements for the pollution level in the exhaust air to protect the neighbouring environment. The development of new vehicles and strict emission standards tend to increase the length of tunnels for which the longitudinal ventilation method is feasible.

For railway systems the ventilation method is normally determined by emergency scenarios to control smoke during a fire. This leads to longitudinal ventilation provided by a push-pull concept using ventilation plants at adjacent stations or intermediate shafts, sometimes combined with exhaust from large caverns as, for example, cross-overs or bifurcations.

Ventilation system – cross-section

Longitudinal ventilation can be installed by using jet fans in the tunnel cross-section or axial fans in either shafts along the tunnel or in plant rooms at the tunnel portals. It is possible to locate jet fans in niches to reduce the tunnel cross-section.

For long tunnels a full or semi-transverse ventilation concept could be introduced to supply fresh air and extract polluted air at certain points.

Tunnel design flow

Ventilation calculations such as aerodynamics, thermodynamics and fire simulations are carried out during the various design phases.

The best tunnel ventilation concept should be chosen considering safety, functionality, protection of the environment, construction and operation costs.

The simulation technique computational fluid dynamics, CFD, can be used for the dynamic analysis of fluid flow in three dimensions.

CFD is a powerful tool to analyse environmental conditions during operation. It is also used to assess safety in critical situations, for example, smoke stratification and spread along the tunnel length and visibility in case of fire. Especially these analyses are commonly used in railway and metro systems where stations and tunnel caverns are of great concern.



Risk management of tunnels

Risk management is essential in tunnel design and construction.

There is a potential for major accidents in tunnels both while the tunnels are being constructed and during

operation of the completed tunnel. The major accidents which have occurred in recent years merely emphasise this. Thus, it is important that systematic risk management is implemented in tunnel projects in order to ensure an adequate level of safety in a cost-efficient way.

COWI has many years of experience in risk management. At one point, COWI led a workgroup of the International Tunnelling Association, ITA, which established a guideline for tunnelling risk management.

Safety policy

The safety policy describes the overall safety goals for the tunnel owner or tunnel project. This policy should be established as the starting point for the risk management activities.

Safety plan

The safety plan describes the framework of the risk management process including project organisation, safety responsibilities and the activities required to document that the safety goals have been met.

Safety concept

The safety concept is a description of the main features of tunnel design and operation to be implemented to ensure adequate safety during operation of the completed tunnel. The concept should be developed early in the design process to serve as the basis for initial project approval and for the detailed design.

Risk assessment, operational risk

An overall risk assessment should be carried out in order to identify all types of risk during operation of the tunnel. For significant hazards detailed risk assessments should be carried out as a basis for the design decisions. This may include simulations of fire development and smoke spread as well as simulations of evacuation scenarios.

Risk assessment, construction risk

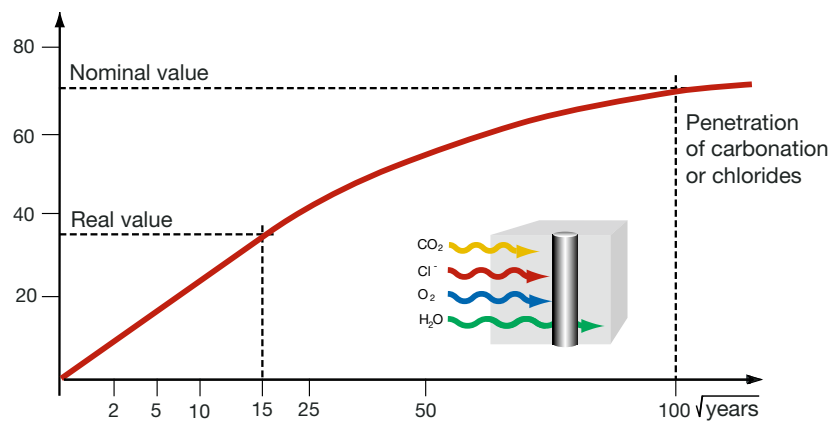
An overall risk assessment should be carried out in order to identify all types of risk during the construction of the tunnel. Design and construction methods should be re-evaluated for significant hazards, and risk mitigations should be considered in order to reduce risks to an acceptable level.

Service life design of tunnels

The modern, reliability-based service life design is implemented in most new designs, in re-designs of existing tunnels and in the strategic planning of maintenance and repair.

Tunnels are usually now to be designed for 100, 120 or even 200 years' service life. This surpasses, by far, the design life assumed according to most codes and standards.

Concrete cover, mm



service life: design value : 100 years
real value : 15 years

COWI is spearheading the international development

COWI's recognised leading position in durability design and concrete technology is based on more than 50 years of worldwide experience in the design, operation and maintenance of exposed reinforced concrete structures.

COWI has been spearheading the international research and technical development of the rational service life design of concrete structures. Selected positions have been the initiation and management of the European research projects DuraCrete, DuraNet and DARTS.

Sustainability achieved through reliability-based service life design

Internationally, COWI provides the only available reliability-based service life design methodology against chloride- and carbonation-induced reinforcement corrosion.

All uncertainties regarding environmental exposure, material properties and deterioration modelling are taken into account.

Thus, service life designs based on functional requirements can be carried out by following the same load-and-resistance factor design concept as known from structural designs.



Optimised operation and maintenance of tunnels

An optimised maintenance strategy is based on a systematic condition assessment from thorough field investigations.

If maintenance or repair work is needed a cost evaluation including road-user costs must be performed considering the best time for execution and taking into account durability and lifetime aspects.

Operation and maintenance works in tunnels will most often have an adverse effect on the traffic in the tunnel. Hence, it is essential to plan operation and maintenance works rationally and effectively.

The planning and the budgeting of maintenance and repair works are becoming more and more essential to tunnel owners and operators in order to minimise the impact on the day-to-day traffic and to ensure cost effectiveness at all times.

COWI has much experience in this field from working for road and rail authorities in countries all over the world.

COWI also offers consultancy services to evaluate the cost effectiveness of current tunnel maintenance strategies.

Services

- operation management systems
- principal inspection and condition assessment of structures and installations
- special inspection of structures and installations
- maintenance strategies and optimisation of costs
- cost estimation of operation and maintenance works
- planning of operation and maintenance works
- short- and longterm budgeting
- design of repair and rehabilitation works
- preparation of tender documents
- supervision of repair and rehabilitation works
- structural monitoring.

Construction engineering

For a tunnel or an underground project the type of structure is a direct consequence of the

selected construction method and is therefore of crucial importance to the economic and timely completion of the project.

Our engineers possess extensive expertise in tunnel and underground construction engineering and we provide the required assistance throughout the construction process from initial planning of the project to supervision during construction.

Tunnelling and excavation methods

Depending on the constraints of each project location and the time available for the construction process, the construction methods used have an important influence on the success of the project.

In COWI we have accumulated know-how concerning tunnelling and excavation methods which have been used for the construction of tunnels and underground structures under complex conditions both on land and under sea.

Planning

The planning and logistics of the tunnel and underground structure is an important issue for constructing of the structure.

We provide know-how concerning the planning and layout of the construction schemes in the following areas:





- Immersed tunnels: Pre-casting yard for element construction, casting methods for water tightness of elements (segmental, monolithic or sandwich types), mooring facilities and transportation routes, sequence of immersion and connections to land structures.
- Bored tunnels: Location of start, exit and emergency shafts, types and numbers of TBMs, progress rates of TBM related to geology, segment layout and types, joint details fitted for erection and connection between tunnels and shafts.
- Underground structures: Temporary and permanent types of soil-retaining walls (secant wall, diaphragm wall, steel sheet piles), SCL methods, excavation sequence, bracing and/or ground anchors.

In combination with the construction engineering we can also provide knowledge about economical and environmental issues related with the planning and construction of tunnels and underground structures.

Construction sequence

During the construction of tunnels and underground structures, each step of the process needs to be controlled carefully to obtain the required distribution of forces and geometry. Either with our in-house developed computer programme IBDAS or other commercially available programmes (FLAC, PLAXIS and ABAQUS) COWI provides step-by-step calculations for the construction of the tunnel and all necessary follow-up services.

The effects of cast-in stresses and deformation, creep and shrinkage of concrete and construction tolerances are included and assessed with the programme.

Temporary structures

The construction of a tunnel or other underground structure calls for interim structures to support the soil or the tunnel itself during the construction stages or to assist in the construction, and very often they are custom-made facilities.

We can provide conceptual and detailed designs of a variety of temporary structures, methods and equipments.

For immersed tunnels

- temporary support structures
- bulkhead and ballast tanks
- towers, bollards and guides
- hydraulic modelling of forces on element
- foundation layer (sand flow or gravel bed).

For bored tunnels

- facilities for fabrication and handling segments
- temporary support structures
- TBM factory test, site assembly and commissioning.

For underground structures

- soil retaining structures with loading sequence
- bracing structures and/or ground anchors
- circular shafts without bracing
- sequence of SCL construction.



Feasibility studies

Being a multidisciplinary consultant COWI offers technical and economic feasibility studies of the pros and cons of tunnels compared to other solutions such as suspension, cable-stayed, girder or bascule bridges. The range of such feasibility studies could also be a comparison between a bored tunnel versus an immersed tunnel or a cut and cover tunnel.

Traffic

Infrastructure projects often start by defining needs based on a traffic prognosis. COWI's traffic planning department is experienced with advanced traffic modelling and simulations.

Site investigations

Studies can initially be based on desk studies of the factors that decide the feasibility of the project. This goes for topics as topography, bathymetry, soil conditions/geology and nature.

Concept and outline design

On the basis of the collected information – the project basis – various solutions for the project can be developed. Initially, a wide selection of

Frederikssund

The investigation of a new road crossing of Roskilde Fjord has included different alignment with bascule bridges, high level bridges, immersed tunnels and bored tunnels. A viable solution in the sensitive areas has been a main goal.

solutions is gradually narrowed down. Concepts and sketches are prepared by COWI's experts in structural engineering, ventilation, safety, roads, railways and other relevant areas.

Environmental impact

Infrastructure projects have an impact on the environment during construction and when in operation. Assessments of the environmental impact, possible better alternatives and remedial actions for the environment are part of the studies.

Cost estimate

Most often, the cost is a decisive factor in the comparison of alternative solutions in a feasibility study. Cost estimates can be developed based on COWI's global experience.

Selection of solution

COWI offers advice in selecting the solution that should be developed into a construction project. Meetings and seminars can be arranged with the client's decision-makers and other parties. The decision process can also be supported by computer-based tools for decision-modelling.



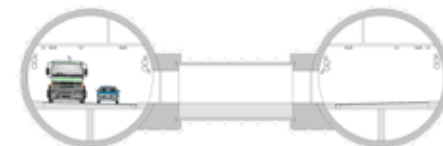
The Doha Bay link

The Doha Bay link is a planned subsea motorway connecting three parts of Doha. The study included bridges, bored tunnels and immersed tunnels, and the immersed tunnels turned out to be the preferred solution.



The Fehmarn Belt link

For the Fehmarn Belt road and railway link various bridge and tunnel variants were investigated including a bored tunnel and an immersed tunnel.





Busan–Geoje immersed tunnel, Korea

The Busan–Geoje fixed link involves the construction of an 8.2 km motorway connecting Busan to the island of Geoje. The connection includes a 3,240 metre immersed tunnel

– one of the longest and deepest in the world – and two cable-stayed bridges, each 2 km in length. Both tunnel and bridges are designed by COWI.

The total length of the tunnel is 3.6 km with two 170 metre long cut and cover sections at both ends.

Tunnel design

The design of the immersed tunnel includes the structural design of tunnel elements, joints,

foundations and tunnel protection, west approach cut and cover structure, east approach cut and cover structure, ventilation buildings and all related mechanical, electrical and communication systems.

The immersed tunnel is designed for two-lane traffic with emergency and crawler lane where appropriate. The central gallery in the tunnel, between the motorway lanes, will contain utilities and an escape route.

The immersed tunnel consists of 18 pre-cast tunnel elements placed in a dredged trench at a maximum water depth of 50 metres – the first time a concrete segment immersed tunnel is constructed at such depth. The outer dimensions of the elements are 180 metres long, 26.5 metres wide and 10.0 metres high. The maxi-

mum gradient is 5%. The design life of the tunnel is 100 years.

Due to soft soils the tunnel foundation includes soil-improvement (sand compaction piles and cement deep mixing). Towards the western landfall the tunnel elements are placed inside a subsea embankment above the existing seabed. Hydraulic model testing was carried out to establish stone sizes on the tunnel roof and to study the overall stability of the tunnel during a typhoon event. The design of the tunnel protection at the eastern portal includes a risk analysis of ship impact.

Tunnel construction

The tunnel elements were constructed in a casting basin, up to 5 elements in each batch. The



elements are cast in segments of 22.5 metres. One element consists of 8 segments and was tied together longitudinally before float-up by a number of post-tensioning cables. The cables are cut when the element is placed in the final position.

After flooding of the casting basin the elements were towed to a mooring area for temporary storage. Transportation of the elements, 36 km under sheltered conditions, took place just before immersion. The immersion site is offshore.

The foundation methods and temporary works for immersion were developed in cooperation with the contractors, taking into account the actual soil conditions and the severe wave conditions on site during immersion. Ex-

tensive physical testing and numerical models were carried out to determine sea-conditions under which safe immersion would be able to take place. The tunnel elements were placed directly on a levelled gravel bed and, in some cases, grouted underneath. Optimisation of methods and temporary works was carried out during construction with input from the designer.

Services by COWI - DEC JV

- basic design
- detailed design for tunnels
- detailed design for mechanical and electrical works
- construction engineering
- follow-up during construction.

Project period

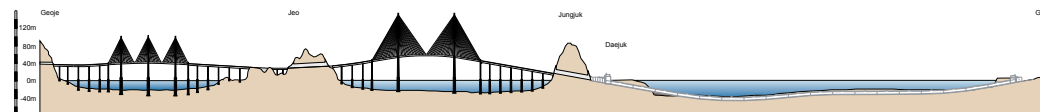
2003 - 2010

Client

Daewoo Engineering & Construction Co. Ltd.

Construction costs

Approximately USD 1 billion



Copenhagen Metro, Cityringen, Denmark

Components

Length: 15 km

Number of stations: 17

Station box size: 65 metres long x 20 metres wide x 19 metres deep

TBM tunnel: 14 km (twin tunnels)

TBM internal diameter: 4.9 metres

Tunnel depth: 20-35 metres

SCL tunnels: 0.6 km

Cut and cover tunnel and ramps: 0.3 km

Number of emergency and ventilation shafts: 3

Number of temporary shafts: 1

The new Cityringen on the Copenhagen Metro is approximately 15.2 km long, all underground with 17 underground stations and 3 emergency and ventilation shafts.

Cityringen forms a circle line

around the centre of Copenhagen and will be connected to the existing metro stations Kongens Nytorv and Frederiksberg by transfer tunnels. Furthermore, transfer facilities will be provided that connect to the existing railway stations of the Copenhagen Central station, Østerport station and Nørrebro station. Via a bifurcation, twin-bored tunnels will connect to the control and maintenance centre which will be located at ground level. Cityringen will be a driverless system.

Stations

The concept for the Cityringen underground stations is developed in cooperation with the client on the basis of the station concept for the existing metro. 13 of the 17 stations are deep underground stations and typically cut and cover box structures. Deep retaining walls of secant piles or diaphragm walls are foreseen.

Christiansborg station, is located partly below the canal Slotsholmskanalen close to the Danish parliament. This station requires a unique architectural layout and special construction methods. Kongens Nytorv station, is situated close to an existing metro station and construction works will be carried out just above the existing metro tunnels in operation. Marmorkirken station is located next to and partly below the old marble church (Frederiks Kirke) and requires a special structural and architectural concept due to the limited space on the site.

Many of the stations are located in the centre of Copenhagen very close to existing buildings. The existing buildings are often two or three hundred years old and founded on timber piles. The construction requirements prompt for the general use of watertight and rigid retaining walls.

Tunnel

The TBM construction will primarily go through the Copenhagen limestone, but in the northern part of the alignment the TBM tunnel will also drive through the overlying quaternary soil. The TBMs are expected to be earth pressure balance (EPB) machines for the sections to be constructed in the limestone. For the northern part of the alignment, slurry type TBMs may be used.

The design for the SCL tunnels is based on using the sequential excavation method and the use of shotcrete, rock bolts, lattice girders, grouted steel spiles, soil grouting and freezing in various combinations to provide initial support for the tunnel.

M&E installations

The stations, shafts and tunnels are equipped with mechanical and electrical installations in order to provide safety and comfort for passengers and operation and maintenance personnel as well as to secure well-conditioned technical rooms to provide for well-functioning, reliable and long-life installations.

Copenhagen Metro first phase

In 1994-2007 COWI performed the tender design, the supervision and the construction management for the EUR 0.8 billion Copenhagen Metro first phase with 22 km Metro of which 9 km as twin TBM tunnels and 8 underground stations.

**Services**

Civil work and architecture provided by the COWI-Arup-Systra JV for

- development of concept design
- tender design and tender documents
- tender evaluation and negotiation.

Project period

Duration: Tender design 2007-2010
Construction: 2010-2018

Client

Metroselskabet I/S

Construction costs

EUR 2 billion



 **BANVERKET**
Citybanan

 **ZOBIN**

 **pihl**
TV Årskontrollsystem AB

 **COWI**

 **MARKETEX**
BYGG & TRAFIK

Stockholms nya pendeltågstunnel

TE 2 - S

Söderströmstunnel, Sweden

The Söderströmstunneln is part of the Citybanan project in central Stockholm. The project comprises an approximately 6 km long tunnel with two railway tracks and three new underground stations. When finalised the new line will double the capacity for rail traffic through the centre of Stockholm.

Söderströmstunneln is approximately 340 metres long and situated in the eastern part of Riddarfjärden between Riddarholmen and Södermalm.

Söderströmstunneln consists of two short cut and cover tunnels at both ends, a joint house and a 300 metre long immersed tunnel in the central part.

The immersed tunnel consists of three pre-fabricated tunnel elements. The tunnel has a rectangular cross-section of approximately 10 metres height by 20 metres width. The tunnel is divided into two tubes, with a 12 metre wide railway tube for two tracks and a 5 metre wide tube for service and rescue purposes.

Due to lack of construction sites in the area and limited water depth the immersed tunnel is constructed as a composite tunnel with an external steel shell used as a permanent membrane and as a floating casting yard. After immersion the tunnel elements are cast together

and fixed to the southern end with a free northern end at the joint house where movements take place. The tunnel is placed partly above the existing seabed on 4 pile groups due to soft soil above the bed rock. The foundation depth of the tunnel varies from 14 metres to 24 metres.

COWI has been responsible for the design of the immersed tunnel and joint house throughout all phases of the project, from the beginning with the winning tender design to the final approval of the detailed design by the authorities.



Services

- tender design
- basic design
- detailed design
- construction follow-up.

Project period
2006 - 2013

Client
JVS Söderströmstunneln HB
Owner: Banverket

Construction cost
EUR 150 million
(contract 9525 only)



Malmö Citytunnel, Sweden

The new citytunnel under the central part of Malmö forms the final part of the Öresund link between Malmö and Copenhagen. It links the existing railway network from the central station to the Øresund link. The project consists of a 17 kilometre double-track railway line and three stations of which 6 kilometres and two stations are underground.

Tunnels

The underground section consists of 4.6 kilometres twin-bored tunnels and 360 metres cut and cover tunnels at the southern end and 1.6 km cut and cover tunnel and station at the northern end. The bored tunnels were excavated with two earth pressure balance TBMs

with external diameters of 8.9 metres. The tunnels were excavated in Copenhagen and Bryozoa limestone which is fractured and, in places, highly permeable and contains layers or nodules of flint with un-axial compressive strength of up to 200 MPa. The TBMs were each equipped with 55 disc cutters which had to be frequently inspected and changed.

The tunnels are lined with precast concrete rings of an internal diameter of 7.9 metres. Each ring consists of 7 segments plus a key. One segment is 1800 mm wide and 350 mm thick.

Thirteen cross-passages connect the two main tunnels every 300-400 metres, and they serve as emergency routes for passengers and house electrical and mechanical installations. Two of the cross-passages will be combined with access shafts for rescue personnel.

Triangeln Station

The Triangeln station is a mined station. It has cut and cover boxes at each end where escalators, lifts and equipment are installed. The main part of the station is a 250 metre long cavern, 28 metres wide and 14.5 metres high. The central platform is 14.5 metres wide with central support columns. The station is 25 metres below ground level with a 10 metre cover of limestone. The construction is close to St. Johannes Church and other buildings. Groundwater is controlled by a dewatering and re-charging system in combination with a grout curtain surrounding the station cavern and boxes. The excavation was carried out in stages with a central audit where the central station columns were cast prior to excavating the side audits. Excavation of the larger side audits were carried out with a top heading, bench and invert.



Photo: Klas Andersson



Services by SWECO-COWI JV

- conceptual studies
- environmental hearing
- client's design of tunnels and station structures
- detailed design of station internals and finishes
- follow-up during construction.

Project period

1999 - 2011

Client

Banverket

Construction Cost

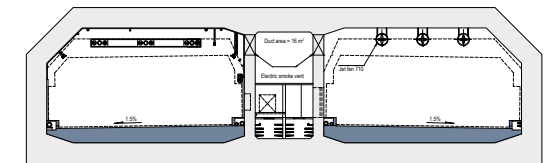
USD 0.85 billion

Hong Kong-Zhuhai-Macao, China

The Hong Kong-Zhuhai-Macao Link (HZM Link) is a three-lane high-speed connection crossing the Pearl River delta between Hong Kong and the city of Zhuhai (mainland China) and Macao on the western side. The link consists of an immersed tunnel, low bridges and two man-made islands. The top of the tunnel is placed 28 metres below the water level making the tunnel very deep. The feasibility study included a comparison of an immersed tunnel solution and a bored tunnel solution as well as an environmental impact assessment, construction risk and operational safety etc.

The Hong Kong-Zhuhai-Macao Link (HZM Link) is a three-lane high-speed connection

The immersed tunnel is 5.4 km long making it the world's longest immersed tunnel. In the conceptual design the cross-section was established based on operation requirements such as space for traffic, ventilation and other electrical and mechanical equipment. The external tunnel width is 40 metres and the height is 10 metres. The foundations at the shallow part of the immersed tunnel are in very soft soil which makes it necessary to combine soil-improvement, piles and direct foundations. The conceptual design was also used as the technical part of the bidding proposal for winning the design contract of the preliminary design.



Cross section arrangement



Services

- feasibility study
- preliminary design.

Project period

2008 - 2017
 Feasibility study: 2008
 Preliminary design: 2009

Client

Highway Plan and Design Institute (HPDI)

Owner

Project office of Hong Kong-Zhuhai-Macao Bridge

Construction cost

RMB 9 billion (tunnel only)

Marieholmstunnel, Sweden

The Marieholmstunnel is an approximately 500 metres long immersed tunnel crossing the Göta river which connects the city of Gothenburg to the island of

Hissingen. The tunnel houses two tubes, each with three road lanes. The tunnel will also house a central service gallery. The outer dimensions of the tunnel cross-section are 30 metres wide and 10 metres high. The tunnel connects to ramps at the ends that total 300 metres. The tunnel will be founded on clay.

The tunnel will be located 600 metres north of the existing Tingstadstunnel. Due to the clay

and continuous sedimentation from the river special attention must be given to the construction process. The cut and cover tunnel and ramps are planned to be installed on concrete piles in order to limit settlements and heave.

Services

In addition to the immersed tunnel design, COWI's services comprise the design of a temporary dry dock, new harbour basins near the tunnel crossing and installations in the tunnel such as lighting, ventilation fire protection and ITS.



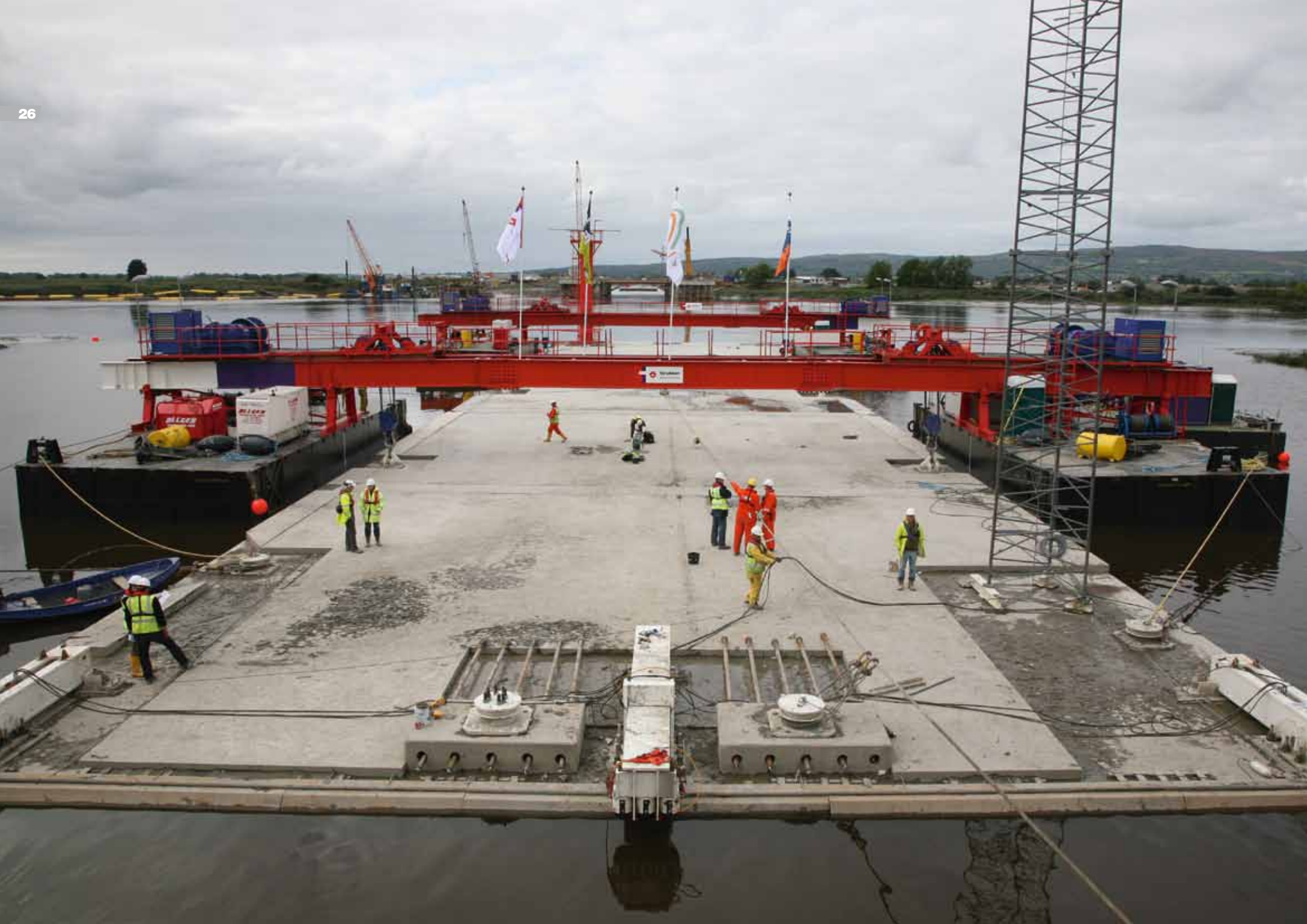
Services

- conceptual design and designer's production planning
- preliminary design
- tender documents
- risk assessments
- tender evaluation
- construction follow-up.

Project period
2009 - 2016

Client
Vägverket, the Swedish road administration

Construction cost
SEK 2.8 billion



Services 1999 - 2006

- constraints study
- feasibility study
- route selection study
- financial study
- environmental impact study
- operation and fire risk assessments
- construction risk assessment
- geotechnical investigations
- preliminary design
- construction and O&M cost estimates
- tender documents including requirements for design, construction and O&M
- consultation process during tendering
- tender evaluation.

Project period

1999 - 2006

Client

Limerick County Council

Services 2006 - 2010

- contract monitoring and administration
- review of the preliminary design, detailed design and method statements
- assistance to site personnel with regards to special construction issues
- recommendation on variations to the requirements
- study concerning restrictions to routing of hazardous goods through the tunnel, applying the OECD/DIARL risk model
- assistance to O&M procedures and activities
- monitoring and advice regarding M&E, ITS and tolling system.

Project period

2006 - 2010

Client

National Roads Authority

Limerick immersed tunnel, Ireland

The Limerick southern ring road will provide an east-west bypass of Limerick City for both regional and local traffic. The ring road will pass the River Shannon and allow unrestricted shipping traffic to the Ted Russel Dock in Limerick. A number of crossing options (low-level bascule bridge, high-level fixed bridge and immersed tunnel) have been considered with due consideration of environmental and aesthetic constraints and soil conditions.

Immersed tunnel

The preferred option is a tunnel comprising a dual-tube immersed concrete tunnel with a length of approximately 700 metres including adjoining cut and cover tunnels at each end.

The open ramp on the northern bank was temporarily drained and used as a construction dock for the tunnel elements. On the southern bank the ramp will combine with an embankment across Bunlicky Lake.

The works entailed major excavations/dredging and foundation of structures in very soft, organic clays and very hard limestone.

Public-private partnership

The tunnel and adjoining roads and bridges will be designed, built, financed and operated as a public-private partnership (PPP) scheme.

The tunnel is to be operated by the PPP concessionaire for a period of 30 years. Construction works started after award of the concession contract in 2006. Four years after the tunnel was opened for traffic in June 2010.



Copenhagen district heating tunnel, Denmark

As part of a modernisation project the district heating production company, Energi E2, decided to move production in Copenhagen from two old production plants to a completely new production block located at the Amagerværket plant.

In order to connect the new plant with the existing distribution network KE decided to build a tunnel for the pipes. The project comprised 4 km of bored tunnels and three shafts in total.

Tunnel

The heating pipes in the tunnel convey either hot water or steam. The steam pipes are built as steel in steel pipes with vacuum between the outer and the inner pipe. Despite of this insulation, the surface temperature of the steam heating pipes reach 100°C and ventilation is required to keep a uniform operation temperature of around 50°C in the tunnel. Prior to maintenance, the ventilation can be increased to further reduce the temperature to around 35°C.

These conditions are quite demanding to the structural design. The solutions must be able to resist the expansions resulting from the temperature rise during operation, and also the chemical reactions associated with detrimental processes tend to run much faster at elevated temperatures.

Consequently, it was decided to design the segmental lining without traditional reinforcement and use steel fibre-reinforced concrete (SFRC) instead. The advantage of the SFRC is that it reinforces the surface zone during construction, and even if it corrodes in the surface zone the associated volume changes will not damage the concrete due to the small size of the steel fibres.

Shafts

The shafts were designed with retaining walls of secant piles penetrating well into the limestone. From the feet of the piles down, the retaining structure was made by sprayed concrete lining (SCL) technique, which was also used for the TBM launch and receipt chambers at the bottom of the shafts.

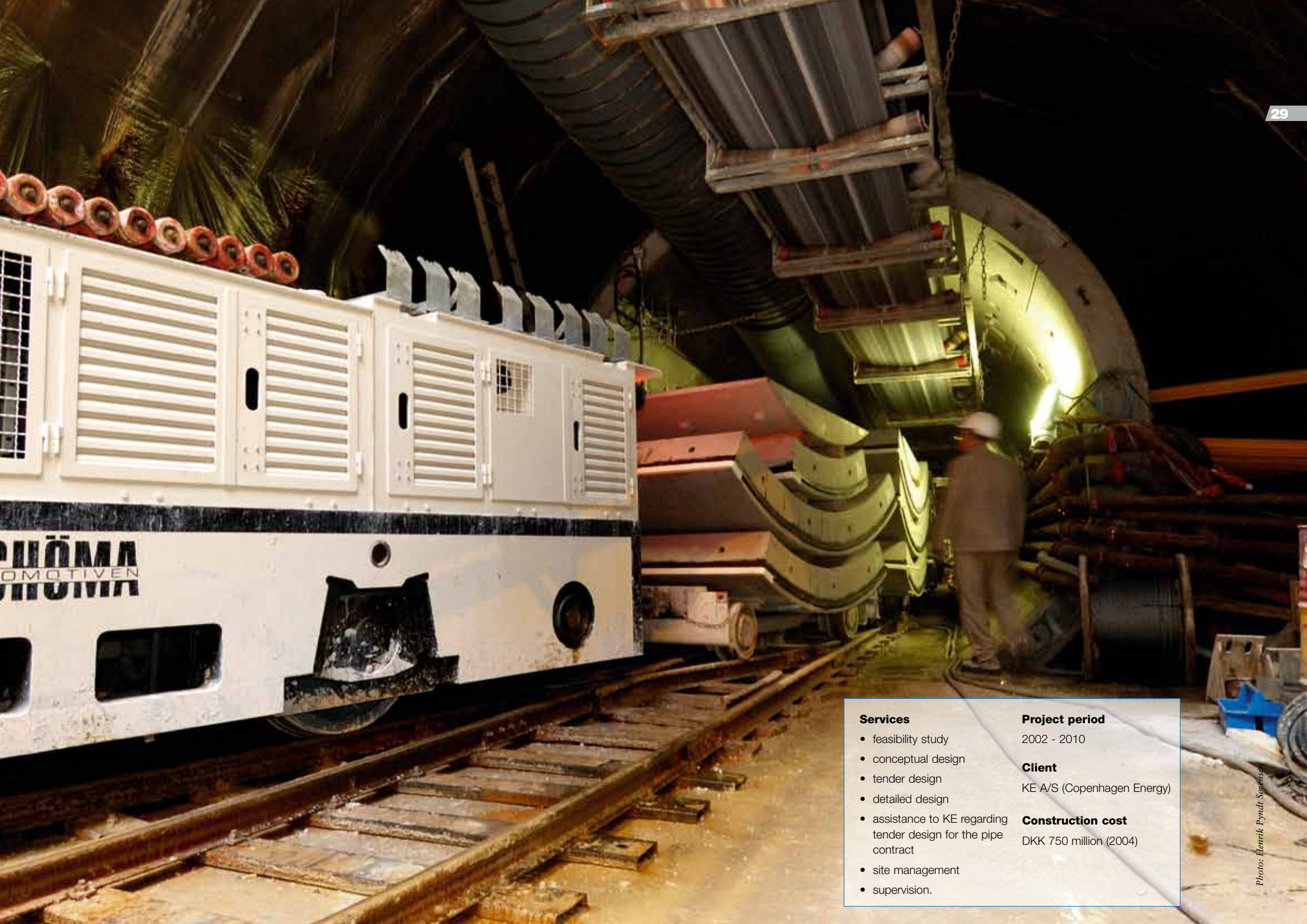
To avoid decomposition of the wooden piles forming the foundation for numerous historic buildings groundwater tables were not lowered during the works.

Partnering

The project was tendered as a 'late partnering' project, and shortly after the civil works contract was signed with the joint venture MT Højgaard–Hochtief JV, a partnering agreement between the client, the contractor and the consultant was signed. The agreement included a definition of joint success criteria, responsibilities, day-to-day organisational set-up, a conflict handling model, milestones and associated bonuses as well as a target maximum total price.

The late partnering was intended to best benefit the combined knowledge of all the parties to find optimal solutions for the project and thereby avoid the budget overruns. This intention was fully met, and the project was finalised on time and approximately 5% below the maximum target price.



**Services**

- feasibility study
- conceptual design
- tender design
- detailed design
- assistance to KE regarding tender design for the pipe contract
- site management
- supervision.

Project period

2002 - 2010

Client

KE A/S (Copenhagen Energy)

Construction cost

DKK 750 million (2004)



Services

- review of design for immersed tunnel and cut and cover tunnels
- review of risk analysis
- review of design for ship impact barrier
- review of earthquake design of tunnel
- construction supervision.

Project period

2000 - 2010

Client

Statens Vegvesen, (Norwegian Road Directorate)

Construction cost

EUR 200 million

Bjørvika immersed tunnel, Norway

The Bjørvika tunnel interconnects two existing rock tunnels in the centre of Oslo. The tunnel passes under the bays of Bjørvika and Bispevika and relieves the centre of the city of 120,000 vehicles per day when opening in 2010. The new connection is about 900 metres long and include a

676 metre long immersed tunnel. The immersed tunnel is made of six tunnel elements. Each 112.5 metre long element is subdivided into 5 segments. The elements are between 28 metres and 43 metres wide and 9.3 metres to 10.6 metres tall. The watertightness of the tunnel is ensured by the use of watertight concrete without any waterproofing membrane and appropriate double-seals at the movement joints.

The tunnel elements were constructed in an existing dry dock in Bergen on the west coast of Norway, about 800 km north of Oslo. Two elements were constructed simultaneously. When completed the elements were closed by bulkheads at the ends and floated to Oslo over five days. In Oslo the elements were initially placed in a mooring area, and during the autumn of 2008 all six elements were immersed into the excavated tunnel trench.



Hallandsås tunnel, Sweden



The Hallandsås tunnel is part of the upgrading of the Swedish west coast railway.

This upgrade is the responsibility of Banverket, the

Swedish railway administration, and involves the creation of a twin-track system capable of increasing the current rail capacity by 8 times. One of the main bottlenecks remaining is the Hallandsås or the Hallands Ridge. With its extremely complex geology combined with highly permeable rock with groundwater pressures up to 13 bar, tunnelling through the ridge has been ongoing since the early 1990s with the first two contracts ending due to problems controlling the water inflows and environmental

problems. When the work recommenced in 2002 COWI was awarded key positions for the supervision of the tunnelling by tunnel boring machine (TBM) and the concrete tunnel lining production. The two single-track tunnels will each be 8600 metres long with connecting tunnels at 500 metres intervals. The main tunnel production is being carried out by a dual-mode TBM capable of operating in open mode or closed mode and designed to be able to operate short distances at up to 13 bar.

Pre-treatment by ground freezing and grouting is being used to prepare the most unstable and permeable section along the TBM drive. The freezing has been carried out in one stage over a length of 100 metres.

Services

- supervision tunnel boring machines
- supervision segmental lining.

Project period

2002 - 2012

Client

Banverket (Swedish National Railway Administration)

Construction cost

EUR 700 million



Road, rail and subway tunnels by the Reichstag, Berlin, Germany

The project “Projektlos 2 - Spreebogen” is part of a general strengthening of the infrastructure of Berlin’s “central area”. The central construction scheme comprises cut and cover tunnels under the River Spree to the front of the Reichstag.

The project is approximately 500 metres long and consists of three tunnels, constructed as cut and cover tunnels. The eastern tunnel is a two-track metro ending in an underground station close to the Reichstag. The central tunnel contains tracks for the ICE railway starting with eight tracks at the northern end and narrowing down to four tracks at the southern end of the project. The western tunnel is a four-lane highway.

Construction pit

The construction pit was divided into four sections surrounded by diaphragm walls with one level of ground anchors and a free standing height of 20 metres. After construction of the diaphragm walls and installation of the ground anchors the pit was excavated wet. When the excavation was completed, vertical tension piles shaped as H-piles were installed and underwater concrete was placed. Finally, the pit was emptied for water. This special construc-

tion method was implemented, as groundwater lowering was not permitted.

For construction under the river Spree it was necessary temporarily to divert the river. Measures were taken to protect the construction pit from impact from the river barges.

On shore the construction pit for the metro was separated from the pit for highway and railway by a diaphragm wall. As the metro is founded higher, the underwater concrete was replaced by deep jet grouting to seal the pit from intruding groundwater.

Tunnel construction

The ICE railway tunnel varies in width from 69 metres at the north end under the river Spree to 24 metres at the south end. Under the river Spree the tunnel is tied to the vertical tension piles used for the underwater concrete in order to ensure properly against uplift. The piles work as permanent tension anchors of the tunnel.

The highway tunnel (road B96) has a constant width of 24 metres and the cross-section is divided into two tubes with two lanes in each.

The metro tunnel was constructed as a cross-section with two tubes and a constant overall width of 15 metres. The cross-section was divided into two independent tunnels close to the underground station to make room for a central platform in the station area.

Services

- planning and management of design work
- design of temporary works
- detailed design of permanent structures.

Project period

1995 - 2000

Client

Spie Batignolles GmbH



Great Belt tunnel, Denmark



The Great Belt tunnel is a subsea tunnel constructed in soft soil with a waterbearing pressure of up to 8 bar. The tunnels consist of 7,410 metres twin-bored tunnel, with 250 metres cut and cover tunnels at each end. The tunnels are connected with 31 cross-passages which house electrical and mechanical equipment for the operation of the tunnels. The internal diameter of the tunnel is 7.7 metres. At the deepest point the rails are 75 metres below sea level.

Alignment and geology

The tunnels were constructed in adverse and difficult ground conditions. The TBMs had to be started in glacial deposits of clay till, sand till and silt with sand and gravel lenses and layers. The sand layers are often hydraulically connected forming extensive aquifers. The stand up time for the glacial deposits was very short, so compressed air had to be used whenever the cutterhead was inspected. Due to the abrasiveness of the sand bodies in the glacial deposits frequent inspections and maintenance to the cutterhead was required. The glacial deposits also house a high number of granite boulders, which the TBM had to cope with.

Below the glacial deposits a Selandian marl is present. The marl is a homogeneous material with a compressive strength of 3-20 MPa. The marl is fissured with hydraulic pressures of up to 8 bar.

Bored tunnel

The tunnels were constructed by four tunnel boring machines (TBMs) of 8.75 metres external diameter. The TBMs were earth pressure balance machines and it required a double screw conveyor to balance the maximum pressure of 8 bar. The tunnels are lined with bolted segmental linings of 1,650 mm width and 400 mm thickness. Each ring consists of 6 segments plus a key. The segment steel reinforcement had to be epoxy coated to ensure 100 years' durability with the high content of chlorides and sulphates in the groundwater.

Subsea dewatering project

In order to ease manned intervention into the cutterhead a concept of reducing the pore water pressures to manageable limits by dewatering wells from the seabed was implemented. The objective was to reduce the water pressure to less than 3 bar at the tunnel axis by dewatering in the marl. The wells were arranged in six groups, three on each side of the 58 metre deep central shipping channel. The wells were generally located every 125 metres along the alignment and altering 35 metres to one or the other side. They were drilled from jack-up rigs with 300 mm diameter steel casing in the tills and without casing in the marl, but with slotted PVC screens at the pumps. Over the area of influence the reduction of pressure at the tunnel axis varied from about 3.3 bar in the marls to 1-2 bar in the tills.

Cross-passages

At each 250 metres cross-passages are located connecting the two tunnels. The cross-passages were constructed using spheroidal graphite cast iron (SGI) rings, each 600 mm wide consisting of 18 elements. This size made it possible to handle them by hand. In order to construct the cross-passage under high water pressure and in soft ground a combination of dewatering, ground treatment by grouting and freezing was adopted.

Services by COWI-MHAI JV

- tender design
- tender evaluation
- detailed design of structures and mechanical installations
- design follow-up during construction
- site supervision.

Project period

1987-1997

Client

A/S Storebælt

Construction cost

EUR 700 mio



Preveza-Aktio immersed tunnel, Greece

The project consists of a 152 metre cut and cover tunnel on the Aktio side, a 909 metre immersed tunnel under the strait and a 509 metre cut and cover tunnel on the Preveza side.

The immersed tunnel is designed for two lanes of traffic within a box cross-sectional profile of 10.6 metres internal width. The outer dimensions of the immersed tunnel are 12.6 metres wide by 8.75 metres high.

The eight prefabricated tunnel elements of 59.2 metres to 134.5 metres length were constructed in a casting basin connected to the strait by an approximately 150 metre long channel. From the casting basin the elements were floated to their final position. The ele-

ments were then installed in a pre-dredged trench.

Before excavation of the trench, 0.6 metres diameter stone columns were constructed in order to prevent liquefaction under possible earthquake loadings.

Flexible joints are provided between the tunnel elements. The watertightness of the joints is ensured by rubber gaskets. The tunnel elements are further encased in a watertight membrane in order to avoid potential leakage.

The tunnels were designed to withstand severe seismic loadings. In comparison to normal immersed tunnels, the shear keys at the joints between the tunnel elements were strengthened. Furthermore, prestressing cables were placed across the joints in order to limit differential movements during seismic events.

Services

- tender design
- detailed design
- construction follow-up.

Project period

1993 - 2002

Client and contractor

Joint Venture between
Christiani & Nielsen Ltd. (UK)
and Technical Company of
General Constructions SA
(Greece).





Selected references



Brenner Eisenbahn tunnels, Austria

Description: 33 km of tunnels of a new Brenner feeder railway in the Inn Valley.

Expected completion: 2010

Client: Brenner Eisenbahn Gesellschaft, Austria

Services by COWI: Vibration and noise measurements as a basis for the design of damping measures of the railway tracks.

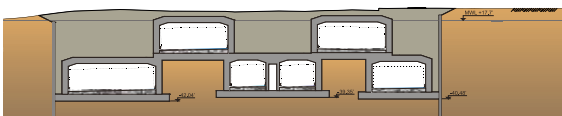
SR 520 crossing of Lake Washington, Seattle, USA

Description: Immersed and cut and cover tunnel options for parts of new crossing of Lake Washington.

Completed: 2009

Client: The Keystone Center, Mediator appointed by Washington State

Services by OCC (COWI): Feasibility study, conceptual design, experts' review, construction costs estimate and life-cycle costs analysis.



Kaunas Railway Tunnel, Lithuania

Description: 1250 metre arch tunnel from 1862 rehabilitated by installing new concrete lining with membrane, widening of the existing tunnel at a 100 metre section, new drainage system, new ballasted tracks and new railway system installations.

Completed: 2009

Client: JSC Kelvista

Services by COWI: Expert assistance regarding tunnel design and construction.

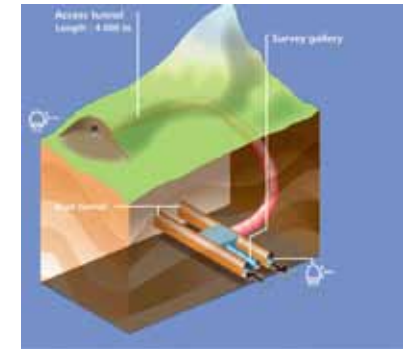
Lyon-Turin rail connection, France/Italy

Description: 53 km base tunnel, a 1 km bridge and another tunnel of 12 km to replace the existing Modane-Frejus mountain line.

Completed: 2009

Client: Commission DG-TREN

Services by COWI: Independent project review.



Waitemata harbour crossing, New Zealand

Description: 1.7 km long double-tube 2x3 lane immersed road tunnel.

Waitemata harbour crossing feasibility study of possible immersed tunnel crossing the Waitemata harbour in Auckland.

Completed: 2004

Client: Opus International Consultants Ltd

Services by COWI: Specialist assistance to feasibility study.



Nanjing Yangtze River tunnel project, China

Description: Twin 3 km subsea tunnels in soft river deposits constructed using two 14.5 m diameter slurry TBMs.

Completed: 2009

Client: China Railway 14th Engineering Corporation Ltd.

Services by COWI: Preparation of TBM specification, supervision of TBM manufacturing, supervision of TBM fabric assembly and testing, supervision of site assembly and commissioning tests, technical assistance and support during startup.



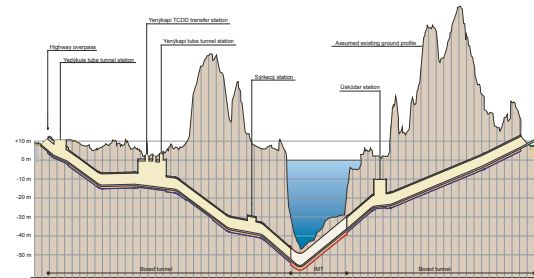
Bosporus crossing, Turkey

Description: 13.3 km new underground railway line with 4 stations consisting of 8.2 km bored tunnel, 1.8 km cut and cover sections and 1.8 km immersed tunnel.

Client: HPYG JV: Hazama (Japan), Penta-Ocean (Japan), Yüksel (Turkey) and Güris (Turkey).

Completed: 2004

Services by COWI: Tender design programme management.



Coatzacoalcos immersed tunnel, Mexico

Description: Immersed tunnel of 830 metres which crosses the Coatzacoalcos river. The tunnel is a two by two-lane road tunnel.

Expected completion: 2010

Client: Cal y Mayor y Asociados

Services by COWI: Review of design and construction.



Budapest Metro line 4, Hungary

Description: 10.5 km twin-tube tunnels and 14 underground stations with 11 main construction contracts.

Completed: 2007

Client: Hungarian Coordination Centre for Transport Development Intermediate Body

Services by COWI: Perform a technical audit of the project including an assessment of the project organisation, the contract management, the construction contracts, the time schedule and the construction budget.

Lærdal Tunnel, Norway

Description: A 24.5 km long road tunnel - the world's longest. The tunnel is bi-directional and is provided with 15 turning points and 48 breakdown lay-byes.

Completed: 2000

Client: Norwegian Road Directorate

Services by COWI: Detailed design of electrical installations (electrical power systems, control systems and emergency phone system and electrical design of the tunnel ventilation system).



Gevingåsen railway tunnel, Norway

Description: 4.4 km, 64 m² single-line railway tunnel in Caledonian greenstone and schist. The tunnel will be excavated by D&B technology.

Expected completion: 2011

Client: Jernbaneverket (The Norwegian Railway Administration)

Services by COWI: Project manager for the design and tender phase. Design and safety manager for the total project.



Fehmarn Belt crossing, Denmark/Germany

Description: Initial phase of technical and environmental feasibility study of 18.5 km motorway and railway connection crossing the Fehmarn Belt.

Completed: 2008

Client: Sund & Bælt A/S

Services by COWI: Environmental feasibility study for a tunnel and a bridge, respectively.

Photo: JW Luftfoto

Selected references

Green Heart Tunnel, The Netherlands

Description: 14.5 metre diameter, 8 km long bored tunnel through the waterlogged peats and sands of the central Netherlands.

Completed: 2005

Client: HSL-Zuid - Dutch Ministry of Transport and Public Works

Services by COWI: Review of design and construction documentation for the production, erection and repair of the precast segmental lining and TBM operation.



Shanghai Chongming Yangtze River tunnel project, China

Description: 8.3 km twin-tube bored road tunnel to be built in soft river deposits using a world-record slurry TBM with a 15.2 metre diameter.

Completed: 2004

Client: Shanghai Huchong Cross River Investment and Development Co. Ltd.

Services by COWI: Preliminary design including segmental lining design, durability design, advise on tunnelling methods in soft clay conditions, ventilation and fire-fighting design.

Baoshan-Longling expressway, China

Description: Fifteen tunnels varying between 125 and 2920 metres in length. The total tunnel length is 18.7 km. The tunnels are SCL type tunnels in weathered rock.

Client: Yunnan Baolong Expressway Co. Ltd. and the Asian Development Bank

Completed: 2008

Services by COWI: Construction management assistance, design review and inspection of construction methods.



Guldborgsund road tunnel, Denmark

Description: 460 metres immersed road tunnel with two lanes and drained ramps under the strait of Guldborgsund.

Completed: 1988

Client: Danish Ministry of Public Roads, Road Directorate

Services by COWI: Conceptual design, tender design, detailed design and supervision.



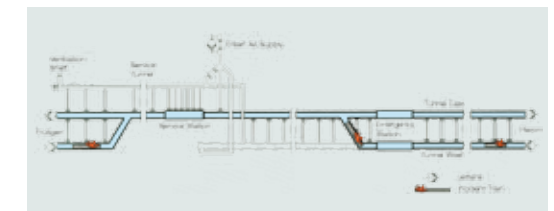
Lötschberg base tunnel, Switzerland

Description: 34.6 km long twin-tunnel as part of the Swiss cross-alpine rail tunnels from Frutigen to Raron. Rock temperatures of up to 45°C are expected.

Completed: 2007

Client: Bundesamt für Verkehr, Switzerland

Services by COWI: Review of tunnel ventilation strategy and concept design report for emergency ventilation. Suggestions on alternative design and ventilation methods.



STEP Deep sewer tunnel, Abu Dhabi

Description: Contracts T-02 and T-03 of the STEP project includes a 26 km sewer tunnel with a diameter up to 6.3 metres and ten shafts with a depth of max. 75 metres, all to transport wastewater to treatment plants in the area.

Expected completion: 2013

Client: Impregilo S.p.A.

Services by COWI: Tender design, detailed design and construction supervision.



Taiwan high-speed rail project, Taiwan

Description: The 326 km long railway line runs through tunnels and cuts, on embankments and on bridges and viaducts.

Completed: 2005

Client: Lot C240: Hyundai-Chung Lin JV, Lot C250: Hochtief-Ballast Nedam-Pan Asia JV

Services by COWI: Independent design checker of lots C240 and C250.



Lyon line B extension

Description: 300 metres immersed tunnel crossing the Rhône river: One tube, 9.6 metres wide and 6.0 metres high.

Completed: 2008

Client: SYTRAL (as a subconsultant to Egis Rail)

Services by COWI: Feasibility study, conceptual design, cost estimate, risk assessments, tender documents, tender evaluation of immersed tunnel solution.



Copenhagen airport and the Sydhavngade tunnel, Denmark

Description: 600 metre long cut and cover station and approximately 4 km cut and cover tunnels in total on the Øresund link railway line between the Copenhagen central station and Copenhagen airport.

Completed: 2001

Client: Øresund A/S

Services by COWI: For various parts of the works: tender documents, detailed design, design check, construction management, technical support and site supervision.

Conwy estuary tunnel, Wales

Description: Dual two-lane highway tunnel with a 710 metre long immersed section under the 5-12 metres deep Conwy estuary, 320 metres long in-situ section and 610 metres long ramps in alluvial sands and clays.

Completed: 1991

Client: The Welsh Office, Transportation and Highways Group

Services by COWI: Tender design, detailed design and supervision in joint venture with Travers Morgan.



Fourth Victoria Harbour immersed tunnel, Hong Kong

Description: Immersed tunnel as part of a new metro line Sha Tin-Central Link with a total length of 18 km and 11 new stations.

Completed: 2009

Client: Kowloon-Canton Railway Corporation

Services by COWI: Initial design, scheme design, tender design, post tender assistance.



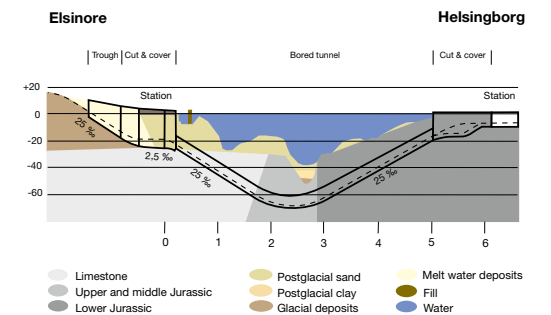
Helsingør-Helsingborg tunnel, Denmark-Sweden

Description: 5 km subsea railway tunnel between Denmark and Sweden performed as a twin-bored tunnel, an immersed tunnel or a combined bored and immersed tunnel.

Completed: 1998

Client: Municipalities of Helsingør and Helsingborg

Services by COWI: Feasibility study in joint venture with SCC.



Selected references



Chengdu Metro, Sichuan Province, China

Description: The Chengdu metro system is planned to consist of several lines. The first phase is 16 km long and has 15 stations.

Expected completion: 2010

Client: Chengdu Leading Group of Metro Construction and Kreditanstalt für Wiederaufbau

Services by COWI: Specialist advice regarding underground design.

Odense small river, Denmark

Description: A sewerage project to intercept overflow during rain from the old combined sewage system to harbour basins to reduce pollution and unpleasant conditions in the harbour.

Completed: 2007

Client: Odense Water Ltd.

Services by COWI: Detailed design, construction management and site supervision.



George Massey tunnel, Canada

Description: An engineering assessment and subsequent retrofit project was initiated to increase the survivability of the George Massey tunnel in the event of a significant earthquake.

Completed: 2002

Client: Ministry of Transportation and Highways, British Columbia, Canada

Services by Buckland & Taylor Ltd. and Ben C. Gerwick Inc. (COWI): Seismic retrofit design.



The Øresund Link, immersed tunnel, Denmark-Sweden

Description: 18 km combined road and railway link across the sound between Denmark and Sweden including a 4 km immersed tunnel section in fissured limestone to cross the main navigation channel.

Client: Skanska (SE), MT Højgaard (DK) and Hochtief (D)

Completed: 2000

Services by COWI: Tender design.



Copenhagen airport railway station, Denmark

Description: The Copenhagen airport railway station comprises a 600 metre railway station and adjoining tunnels for a double-tracked railway. The consulting services were performed in a joint venture with COWI as lead partner.

Completed: 1999

Client: Øresund A/S

Services by COWI: Detailed design, construction management and site supervision.

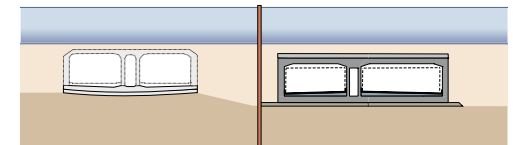
2nd Coen tunnel project, The Netherlands

Description: Immersed tunnel to be constructed adjacent to existing immersed tunnel under the harbour of Amsterdam

Completed: 2008

Client: GATE WEST, group of Dutch contractors including Structon

Services by COWI: Planning of methods to ensure existing tunnel integrity during new tunnel construction, renovation, design and durability assessment of existing tunnel, and operation and maintenance cost estimate.



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