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Tunnels AND TUNNELLING

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COPENHAGEN COPES

Alex Conacher speaks to **Guy Taylor**, project director of client Metroselskabet, and **Soren Eskesen**, head of Cityringen tunnelling for the client, and chair of the Danish Tunnel and Underground Works Association for this update from site, and a new project offshoot, as the first machine arrives in port and site preparations draw to a close

SITE PREPARATIONS are drawing to a close as the last of 21 worksites, Trianglen is handed over on 3 December 2012. Four TBMs from the newly partnered Seli-Kawasaki manufacturing JV are being used on the Copenhagen Cityringen, the first arrived in December, with the remainder arriving in two-month staggered shipments. Main assembly was underway as *Tunnels* goes to press, for which Seli is responsible. Mobil Baustoffe Of Germany established a segment casting factory in Sassnitz on the Baltic Coast of

Above: The historic city of Copenhagen was founded in 1167

Alex Conacher
The *Tunnels* features editor has been with the magazine since 2010

Project vitals

- **Main contractor:** Copenhagen Metro Team JV: Salini Costruttori, Tecnimont and Seli
- **Client:** Metroselskabet
- **Ground engineering:** Trevi with equipment from Soilmec
- **Design:** Arup, Cowi and Systra
- **Funding:** Copenhagen 50 per cent, Denmark 41.7 per cent, and Frederiksberg 8.3 per cent
- **Geology:** Quarternary sequence of meltwater sands and tills on Danian Limestone
- **Methodology:** TBM driven tunnels
- **Equipment:** Four 5.78m Seli-Kawasaki closed face EPBMs
- **Segment supply:** Mobil Bau

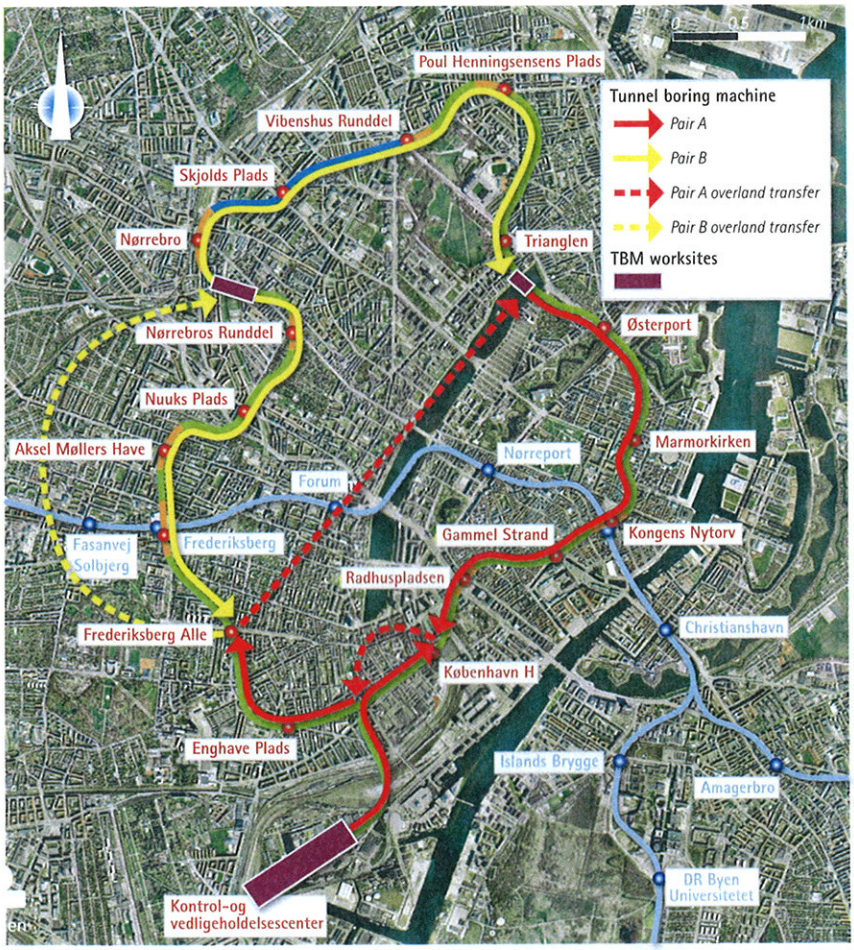
northern Germany. Segments are shipped into Copenhagen for storage prior to the start of tunnelling. Segment moulds were manufactured by Seli's subsidiary SAME, with a further nine sets coming from Herrenknecht.

"It is a very difficult task just to manage the vast number of locations," says Guy Taylor of client Metroselskabet. "We have a complexity of volume here with many separate designs split between hundreds of packages. An enormous challenge, but we are very well on the way and I would say progress is satisfactory. The next challenge will be constructing so many sites simultaneously. Because of the phasing of works, the important thing is to ensure delays do not accumulate."

SCHEDULE

Following the political green light to proceed on the project in 2007, and design work commencing in November that year; ground engineering works at the TBM launch sites and other worksites have been underway since the contract award on 7 January 2011. The first worksite, Norrebros Park, was handed over on 10 July 2011.

When tunnelling begins following the first machine's assembly in March, the first twin drive will be executed from the Norrebros Runddel station site (see first yellow route, Figure 1). The TBMs will then be transferred by road back to Norrebros Runddel for the drive to Trianglen. The second pair (shown as 'Pair A' in red) will drive from the Kontrol-og vedligeholdelsescenter ('control and maintenance centre') site, through a bifucation executed with a small overland transfer. The machines will then by taken by road to Trianglen



Above: Figure 1, The Cityringen alignment showing overland TBM tansportation route plans

510

The value of the soon to be tendered Nordhavn Branch Line arm of the tunnelling project in USD millions

2007

The year in which work on the Copenhagen Cityringen project received a political decision to proceed

Table 1 - TBM main characteristics

Main drive	
VFD electric motor	6
Total installed power	1,200kW
Speed	0-5rpm
Maximum torque	4,790kNm at 2.3rpm
Minimum torque	2,180kNm at 5rpm
Unlocking torque	6,237kNm
Cutter head	
Excavation diameter	5,780mm
Opening ratio	30 per cent
Cutting tools	38 17-inch cutters
Maximum individual load	267kN
Copy cutter	Up to 5,880mm
(Wear detection system equipped)	
Thrust system	
Thrust rams	32 (16 by 2)
Maximum working thrust	37,000kN
Maximum total thrust	54,500kN
Articulations	
Front active articulation	30,000kN
Rear passive articulation	10,000kN

Source: Seli

Geology

The ground conditions along the alignment of Cityringen comprise a quaternary sequence of meltwater sands and tills resting on Danian limestone. The quaternary deposits are overlain by fill as well as post- and late-glacial deposits. Deposits belonging to the Selandian (Middle Palaeocene) Greensand Formation are also found locally subjacent to the quaternary deposits.

The fill layer is of varying thickness, with thick deposits found in areas with previous moats, lakes and canals, as well as old clay pits and sand/gravel quarries.

In the quaternary deposits two layers of till are observed, an upper till unit and a lower till unit, separated by meltwater sediments. Locally the two till layers constitute a contiguous layer e.g. as seen in the Frederiksberg area. The tills are typically heavily over-consolidated, very stiff to hard sandy clays.

Three meltwater layers have been identified. The upper meltwater unit is of very limited extent, the middle meltwater unit is separating the two till units, and the lower meltwater unit is mainly observed as coarse grained sediments filling erosion valleys in the project area.

Across much of the alignment the quaternary sediments are directly underlain by the Copenhagen limestone of Danian age. However, Selandian Greensand deposits are observed locally adjacent to quaternary deposits within the southern part of the alignment. The Copenhagen limestone is a fractured soft rock, which has some similarities to fractured chalk. Based on geophysical logging, the Copenhagen limestone has been subdivided into three sub-units, upper, middle and lowers Copenhagen limestone. The upper Copenhagen limestone is horizontally bedded with layers of different hardness and thickness from a few centimetres up to 1m. Flint occurs in beds of 0.2 to 0.4m thicknesses, occasionally up to 1m in thickness and can be followed continuously over long distances.

The pre-quaternary surface is characterised by meltwater erosion valleys, incised in the limestone surface. The interface between the quaternary deposits and the Copenhagen Danian limestone takes one of two forms, either more fractured than lower in the limestone (glacially disturbed) or unaffected by glacial disturbance.

The geological conditions that will be encountered by the TBMs will vary along the alignment. The tunnelling in the southern section is predominantly in the limestone, whereas the northern alignment is in glacial deposits, limestone and mixed conditions giving more difficult tunnelling conditions.

It should also be noted that although the tunnels in the southern half of the alignment are generally in limestone, often the tunnels rise as they approach or leave the stations. In several cases the tunnel next to the stations are bored within mixed face deposits with corresponding larger amounts of ground movements. This is the case for instances close to Kongens Nytorv, Radhuspladsen and Kobenhavn H.

to commence the main drive back to meet the first (eastern) arm of the bifurcation. The total length of the project will be 15.5km with 17 underground stations, excluding the control and maintenance centre.

New arm

It has been decided to launch a new branch of the metro off towards the city's northern port. This will run for 2.3km and will tender in Q2 of 2013. Called the Nordhavn Branch Line, it will run from Ostersodgade and will link the Cityringen with a new riverside urban development by the client's sister agency, Byoghavn. The value of the new project will be DKK 2.9bn (USD 510M).

IMPACT

Cowi, Arup and Systra handled vibration analysis as well as all other design and engineering works. A local process involves an expropriation committee being appointed to decide on compensation for local residents affected by the works. This process began in 2007, with planning and design. As an example of the results of this, a main station is situated in a narrow street in front of residential apartments. The noise and vibration was deemed

Below: The EPBM is accepted in Seli's yard

sufficient for compensation to the inhabitants, but no one was re-housed.

WATER, SETTLEMENT

Taylor and Soren Eskesen, in charge of tunnelling for Metroselskabet, believe that the limestone geology of Copenhagen is well understood and should not offer too many surprises, though the shallower sedimentary layers are of course less stable (see geology box, page 29).

There are no settlement or damage criteria, and the risk is on the JV. Pre-investigation has been done with a three-stage building assessment.

"Some of the older buildings are built on timber piles," says Eskesen. "We must not lower the groundwater around these areas – if these wooden piles are exposed to air, they will [drastically] deteriorate.

"Hence the choice of a closed face TBM for the tunnels. There is better control enabled, and we are less likely to lower the water level.

"We also require 90 per cent water re-infiltration during station construction. Retaining walls stretch down well below the foundation level, with the deepest reaching down to 45m and the shallowest to 25m.

"The contractor has opted for secant piles down to 28m and then diaphragm walls for anything deeper. Of the 21 sites, seven have diaphragm walls. These are all part of the permanent works, while the inner lining is designed to take the water pressure."

Engineering

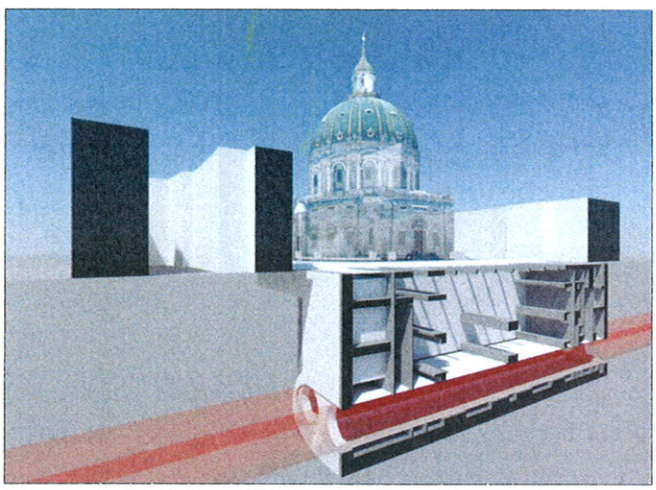
Trevi has been subcontracted to do the enormous amounts of ground engineering. Eskesen says, "This includes ground treatment in some areas. Trevi currently has 11 secant piling machines working at the stations and five d-wall rigs. At this time [18 December] secant piling work has been completed at two stations and the roof slabs are going on."

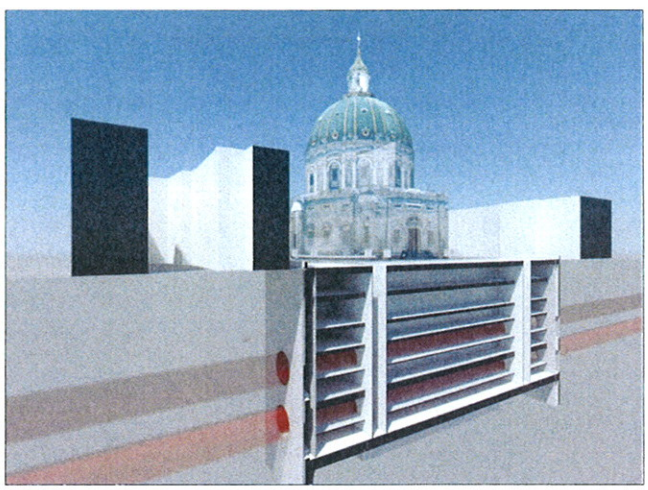
Above: Figure 2, The complete map of Cityringen stations

Starter's orders

The Cityringen should open in 2018 at the end of the contract. Ansaldo is the company responsible for tunnel operation over a five-year period, and will supply rolling stock. A Ramboll-Atkins JV will oversee the railway infrastructure engineering works

■ *For a detailed look at the challenges constructing Cityringen, especially the redesign of Marble Church Station, see the feature written by the contractors and client in Tunnels International, February 2012, pp.24-28.*





Below: Figures 3 and 4, changes in design of Marble Church Station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