Urban railway line Wehrhahn route, batch 1
Foundation engineering works
Düsseldorf, Germany

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Contract Value (net):
300 million EURO (total contract)
100 million EURO (foundation engineering share)

Construction Period:
2007 - 2013

Client:
Landeshauptstadt Düsseldorf
Amt für Verkehrsmanagement

Services:
Railway station building pits with diaphragm walls using
Cut-and-cover method Single-phase cut off walls, sheet pile walls
Temporary and semi-permanent anchors, bracing,
Grouted piles (GEWI)
Compensation injections
Jet grouting:
- Protective walls
- Jet gruting vaults
- Jet grouting floor
- Jet grouting building underpinning
Primary columns
Ground freezing
Dewatering, water treatment

Execution:
Bilfinger Construction GmbH with
- Tunneling Division
- Bilfinger Spezialtiefbau GmbH
Federal state capital Düsseldorf realizes a new city underpass, the central line of the Wehrhahn route as an underground urban railway in order to improve public local transport. The new 3.4 km-long two-platform tunnel route with a total of 6 stations and 2 above-ground stops runs underground from Bilk urban railway station to Wehrhahn urban railway station. It is linked with the existing underground railway network via the Heinrich-Heine-Allee hub.

Bilfinger Construction GmbH with its technology divisions Tunneling Division and Bilfinger Spezialtiefbau GmbH received the contract to build batch 1. Batch 1 comprises the entire route apart from the already completed subsection batch 1S underneath today's Heinrich-Heine-Allee station, which was built in 1983, and batch 2, the adjoining Heinrich-Heine-Allee station under the Kaufhof department store.

Batch 1 thus consists of 2 phases. The “southern branch” starts in the south above ground at Bilk urban railway station, is led underground via a ramp and follows Elisabethstraße and Kasernenstraße underground until it connects with the existing Heinrich-Heine-Allee underground railway station on a level with Grabenstraße. The underground railway stations Kirchplatz, Graf-Adolf-Platz and Benrather Straße are built during this phase.

The “eastern branch” starts in the west underground on a level with Königsallee with connection to batch 2. Under ground it intersects the development between Königsallee and Berliner Allee and then follows the course of Schadowstraße and the street “Am Wehrhahn.” Outside Wöringer Straße the line is lead back to the surface via the Wehrhahn ramp. The underground railway stations Schadowstraße (formerly Jan-Wellem-Platz) and Jacobistraße/Pempelforter Straße are located in this phase.
After completion the Wehrhahn route will replace five tram routes that currently circulate above ground.

**Construction Method**

The client's draft for the Wehrhahn route stipulated construction methods that would keep effects on the surface to a minimum. For example, larger "open building pits" were only in the vicinity of the "Bilk" and "Wehrhahn" ramp routes and in the vicinity of the starting and finishing shafts for the tunnel drilling machine. The railway stations and the area in Kasernenstraße to the north of the Benrather Straße railway station were produced using the **cut-and-cover method**, which reduced works on the surface to a minimum. (Explanation see following page)

The **tunnel tubes** between the stations were created completely underground in a closed construction with the aid of shield tunnelling. Expansion of the tunnel using 45 cm thick lining segments was performed under the protection of the shield. The tunnel drilling machine, dubbed "Tuborine", was launched in the Bilk starting shaft, travelled under the finished covers through the stations Kirchplatz and Graf-Adolf-Platz and was dug out of the finishing shaft in Kasernenstraße at the southern end of the Benrather Straße station after a journey of 1,298 m. After removal to the Kö starting shaft, to the east of batch 2 on Corneliusplatz, the tunnel drilling machine travelled through the stations Schadowstraße and Jacobi-/Pempelforter Straße and stopped after 955 m in the finishing shaft to the east of Kölner Straße.

The break-out diameter was 9.52 m.
The cut-and-cover method proceeds for example as follows:

1) At the commencement of the works the traffic (tram, private vehicles and heavy-goods vehicles) was displaced to one side of the road, the other side of the road is the construction site. On the construction site, channels, pipelines and cables were laid between the houses and the subsequent building pit walls. Then, the up to 40 m deep diaphragm walls are produced, the up to 40 m deep drill holes $d = 1.50 \text{ m}$ to accommodate the primary columns are drilled and wells for the subsequent dewatering are bored.

2) After production of a longitudinal pit lining between construction site and traffic space, excavation is performed down to the lower edge of the partial cover. After concreting of the partial cover that is mounted on the diaphragm wall and the primary supports, and in this phase still on the soil too, this area above the partial cover is filled. Channels, pipelines and cables are laid in their final position and following road and platform construction, traffic is displaced onto the surface above the finished partial cover.

3) The same works as on the opposite side are performed on the new construction site.

4) The cover is thus complete. The overground traffic can be relocated to the final position and is independent of the construction works that subsequently only take place under the cover.
**Tertiary building pits**

The railway station building pits are so-called "tertiary building pits." In Düsseldorf the tertiary is located beneath fillings and quaternary sands and gravels. The tertiary consists of densely packed fine sands and is only slightly permeable to water. Depending on water level, ground water ranges between 5.50 m and 10 m below ground level. The excavation depth in the railway stations is between 19 m and 23 m below ground level.

The building pit walls, consisting of diaphragm walls having wall thicknesses of 0.80 m to 1.20 m and panel depths down to 40 m, are integrated into the tertiary by up to 12 m.

Thus the building pits are sealed against water entry on the sides by means of the diaphragm walls and underneath as far as possible by means of the tertiary. Due to the pumping off of the ground water in the building pits with the aid of gravity wells, soil excavation and tunnel production can be performed in the dry under the cover.
**Principal trades, foundation engineering**

**Diaphragm walls / anchors**

The diaphragm walls having panels depths down to 40 m were produced under constricted inner-city spatial conditions at great logistical effort, partly directly outside existing buildings.

At the Commerzbank pedestrian bridge, Kasernenstrasse 39, and under the "Tausendfüßler" elevated road the diaphragm walls had to be produced under a restricted height.

In the construction state they were supported on top by the cover, underneath they were rear-anchored, respectively braced, in several layers by means of temporary or semi-permanent anchors. In the vicinity of Kasernenstrasse 39 they were additionally propped by a bracing floor, which was produced below the subsequent excavation floor from above using the jet grouting method.

The diaphragm walls on the front walls of the railway stations traversed by the tunnel boring machine were given, instead of steel reinforcement, fibreglass reinforcement so that the cutting tools of the tunnel boring machine could be conserved when travelling through.

**Quantities:**

- 81,000 m² diaphragm and sealing wall, d = 0.80 m
- 2,900 m² diaphragm wall, d = 1.00 m
- 1,400 m² diaphragm wall, d = 1.20 m
- 3,500 t diaphragm wall reinforcement
- 62,350 m temporary, respectively semi-permanent anchors, lengths up to 30 m, up to 9 strands, partly against water pressing down
Compensation injections

The subsidence hollow from the shield journey, respectively subsidence impacts arising from building pit warping could lead to burdensome building deformations if there are no countermeasures. In order to counteract the subsidence impacts and thus guarantee high-quality securing of the building, compensation injections were executed. To this end horizontal small holes were bored in a fanned shield shape under the buildings to be secured from 4 injection shafts and from 2 railway station building pits. Injection pipes, so-called "sleeve pipes", were installed in the drill holes. An injection medium (Blitzdämmer) was grouted (injected) through these pipes at the desired points. As a result of this the overlying soil with the buildings was raised before and during the shield journey. The elevations thus generated were checked and controlled through the use of measuring systems and special software. The measures were monitored by means of electronic water level gauges. All measuring data converged in a central measurement database, leanings and/or subsidence unfavourable for buildings as a result of targeted elevations were successfully compensated for on the basis of this database.

Quantities:

4 pieces injection shields from shafts (secant bored pile walls, underwater concrete)
2 pieces injection shields from railway station building pits
15 pieces documented buildings
3,600 m² compensation injection area
8,650 m injection drill holes (up to 50 m individual length)
4 pieces compensation floors with surface area 1,200 m²
Primary columns

101 pieces primary columns were produced in order to support the cover. In drill holes \( d = 150 \text{ cm} \) at depths of up to 40 m reinforced piles were concreted to the lower edge of the floor of the subsequent structure and steel pipes positioned as supports. Subsidence in the primary columns was reduced to a minimum by means of base and shell grouting.

Quantities:

101 pieces bored piles with positioned steel primary supports, drilling diameter 150 cm, drilling depths down to 40 m

Jet grouting method

During the jet grouting method the surrounding soil is loosened in its structure by means of a high-pressure nozzle jet and blended with a cement suspension. A "soil concrete" is obtained as a result.

The channels to be laid in front of the buildings for the cover production lay in many cases at a depth that made it necessary to lay the foundation lower edges further down. Therefore various buildings were underpinned using the triplex method.

In order to reduce warping of the diaphragm walls in the vicinity of the finishing shaft at Kasernenstraße, a bracing floor \( d = 1.50 \text{ m} \) was produced there underneath the subsequent excavation floor using the duplex method.
In order to reduce subsidence impacts arising from the shield journey 4 pieces protective walls d = 1.0 m were produced using the triplex method.

At the building "Am Wehrhahn 13-15" the tunnel boring machine cut the piles in the pile foundation. Therefore, using the duplex method a jet grouting method vault was produced in advance to take on the deflection of the pile loads.

**Quantities:**

• Building underpinning for channel construction works using the triplex method. Drilling depth down to 10 m, column diameter 1.5 m, cubature approx. 3,500 m³

• Bracing floor d = 1.50 m underneath the excavation floor using the duplex method. Drilling depth down to 25 m, column diameter 2.35 m, surface area approx. 650 m²

• 4 pieces jet grouting method protective walls, d = 1.0 m using the triplex method. Drilling depth down to 20 m, column diameter 1.50 m, surface area approx. 600 m²

• Jet grouting method vault as securing measure using the duplex method, partially inclined columns, drilling depth down to 21 m, column diameter 2.00 m, volume approx. 3,000 m³.
Ground freezing

During ground freezing, with the aid of freezing pipes in the soil through which an approx. minus 35 °C refrigerant (brine) is pumped, using the existing or supplied water the ground is frozen in column shapes around the freezing pipes. These frost columns merge after a certain period (congealing phase) into one frost body. The finished frost body stabilizes the soil and seals against ground water inflow.

In the case of the Wehrhahn route batch 1, ground freezing became necessary for 3 tasks where the southern branch connects with the existing batch 1S:
- A diaphragm wall segment in the connecting area could not be produced owing to massive obstructions in the soil. As a substitute this wall was produced in the form of a frost body.
- The existing diaphragm wall of the frontal pit lining in batch 1S had to be extended in the tertiary, in order to be able to furnish proof against hydraulic base failure without large-scale ground water level reduction. This extension was performed by means of ground freezing.
- Water circulations in the connecting area around the existing batch 1S tunnel were closed by freezing.

Quantities:

1 freezing aggregate having 320 KW total refrigeration output,
1,000 m freezing pipes, 300 m temperature lances with temperature sensors
Frost body as diaphragm wall substitution approx. 200 m³
Freezing as building pit wall extension approx. 400 m³
Freezing of connection to existing batch 1S structure approx. 200 m³
Dewatering and water treatment

Except for a small area of the Wehrhahn ramp, dewatering in the building pits was performed using 44 pieces quaternary gravity wells. With the aid of this dewatering it was possible to excavate the building pits "in the dry" and create the concrete structures.

In the vicinity of the Wehrhahn ramp the building pit was pumped out following underwater excavation and production of an anchored underwater concrete floor.

The pumped ground water was captured in collecting mains and predominantly conducted and diverted via supported conduit lines (2,300 m) to the 4 inflow points (northern Düssel, Schwanenspiegel, southern Düssel, Kö Ditch). Continuous checks were made for pollutants. If contamination was above established limits, the pumped water was treated in one of the 5 pieces construction water treatment facilities prior to introduction into the outlet.

Quantities:
- Dewatering in 16 pieces sub-building pits by means of 44 pieces quaternary gravity wells, drilling diameter 72 - 78 cm estimated total pumped quantity: approx. 15 million m³
- 1 sub-project with underwater concrete floor (pumping facility)
- 42 pieces ground water gauging points, respectively small wells, drilling diameter 273 - 323 mm
- 2,300 m supported conduit lines in the inner-city area. As required, sumps, drainages, tertiary dewatering by means of panel filters and vacuum lances
- 5 pieces construction water treatment facilities for the decontamination of chlorohydrocarbon, PAH, chromium having a total capacity 670 m³/h
- 1 piece mobile neutralization facility