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The North-South Metro Line Amsterdam - Case study

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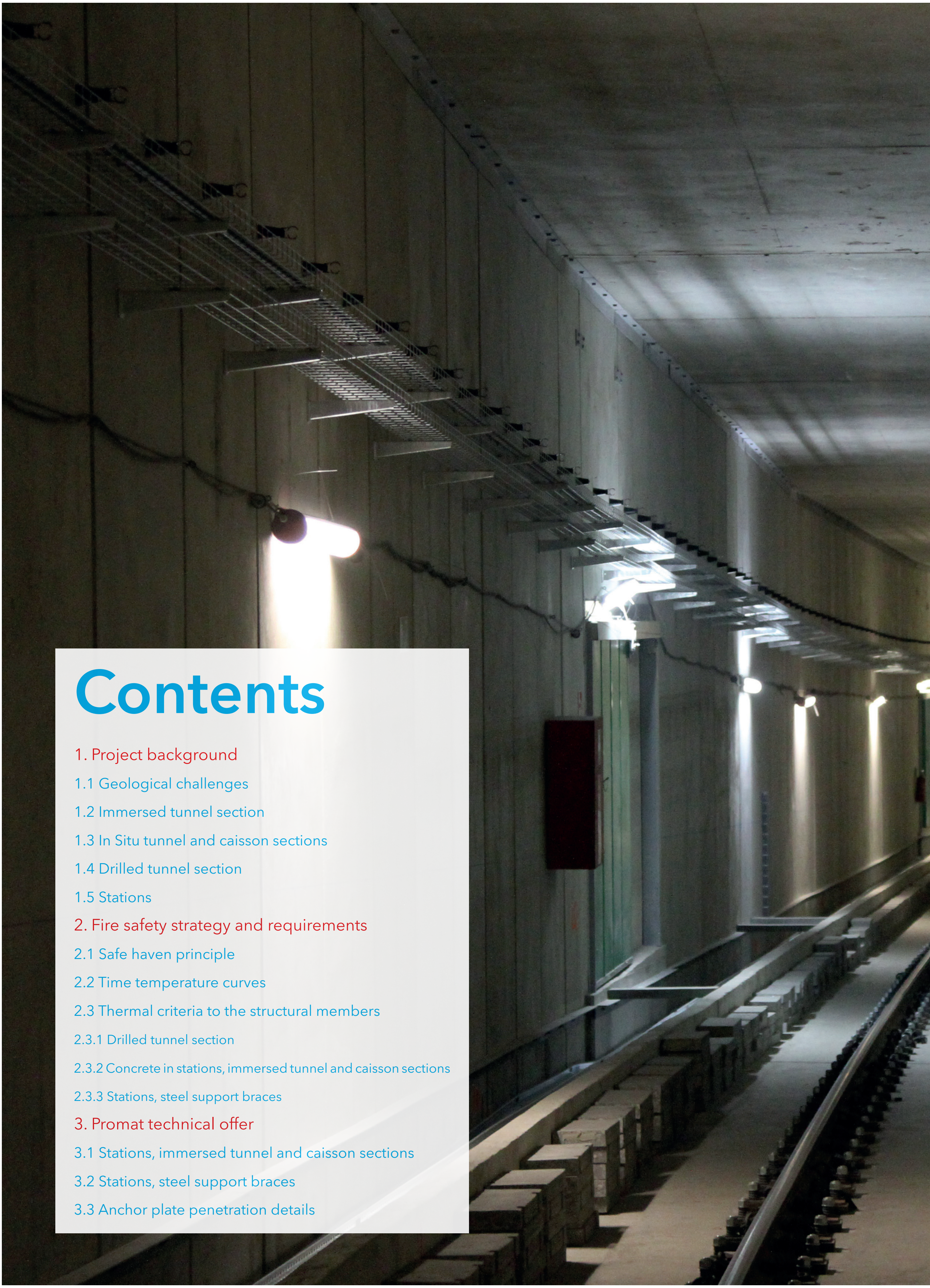


Contents

The North-South Metro Line Amsterdam, The Netherlands

1. Project background

1.1 Geological challenges

Amsterdam, the capital of The Netherlands, was challenged with an ever increasing pressure on road and rail infrastructure. As a result, the existing metro infrastructure had to be expanded with an additional line, which connects to the existing metro lines, at the Central Station. The new to be constructed line would run from the Northpark to the South Station, hence the name of the new metro line, The North-South Line.

The old city of Amsterdam was built in the delta area of the river Amstel. The sediment of more than 1000 years old is a thick soft layer which caused many geological and structural challenges for designers of buildings and infrastructure in this region. The designers and contractors were confronted with another set of challenges to build a new metro line in the densely built and populated city centre of Amsterdam, which is visited by over 9 million tourists per annum.

1.2 Immersed tunnel section

The Northern part of the city is connected with the Central Station by means of an immersed tunnel, which crosses the river IJ. The Central Station has been constructed in 1889 on wooden foundation pillars. During the construction of the new metro line the water table had to be maintained in order to avoid rotting of the existing wooden foundation pillars of the Central Station. It would only take a matter of days before the wooden pillars would have been affected.

The concrete element which connects the immersed tunnel to the station has been submerged just in front of the station, and then shifted towards the station to connect to the existing structures.

1.3 In Situ tunnel and Caisson sections

At the South end of the Central Station a short section of the tunnel is constructed by means of caissons. In these areas the soil conditions were not suitable for an open cut construction method. Instead, sections of the tunnel have been constructed at ground level and are then lowered into the ground by means of waterjets which causes the ground to become a muddy substance, which is extracted by pumps. These large concrete elements are lowered into position at 1,5 meters per day, to a final depth of 20-25 meters.

1.4 Drilled tunnel section

The 3,8km long drilled section of the metro line follows the existing street plan to a large extent and it connects to the caisson sections, going South. It contains above ground stations, as well as underground stations. At the very South end, the drilled tunnel section connects the North-South Metro line to the existing metro infrastructure at the South station.

1.5 Stations

The North-South metro line is equipped with a total of 8 stations, 3 of which are built above ground and the remaining 5 stations are constructed underground.

• 1. North Station	Above ground
• 2. Noorderpark	Above ground
• 3. Central Station	Underground
• 4. Rokin	Underground
• 5. Vijzelgracht	Underground
• 6. De Pijp	Underground
• 7. Europaplein	Underground
• 8. South Station	Above ground

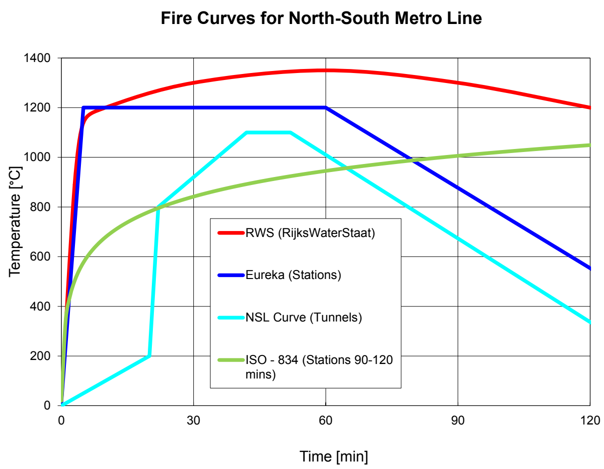
2. Fire safety strategy and requirements

2.1 Safe haven principle

The fire safety strategy is based on the safe haven principle, which means that in case of a fire the metro has to stop at the nearest station. The stations are therefore equipped with more robust passive fire protection measures. The fire scenario is based on this safety strategy and the expected fire load on particular parts of the load bearing concrete structure. As a result of this approach the North-South line is designed using different time-temperature curves for different parts of the structures involved.

2.2 Time temperature curves

As stated above, the tunnel, the stations and specific parts of the stations are designed according to different time-temperature curves. Within the tunnel there is no fully developed fire to be expected due to the fact that the metro will not come to a standstill in the tunnel itself, based on the safe haven principle described above. Based on Computational Fluid Dynamics modelling it has been determined that, for this specific project, the NSL curve applies for the tunnel sections.



A realistic worst case scenario of a fully developed metro fire has been applied to model the expected thermal attack on the concrete structure in the stations. The demarcated areas which are directly impinged by flames are designed according to a 120 minute EUREKA time-temperature curve. The areas which are not directly exposed to flame contact are designed to withstand ISO-834 time-temperature curves for 90 or 120 minutes, depending on the fire load found in the CFD modelling.

2.3 Thermal criteria to the structural members

2.3.1 Drilled tunnel section

Due to the very limited fire exposure as per the NSL fire curve, the segments of the drilled tunnel did not require any additional passive fire protection, apart from the inclusion of polypropylene fibres in the concrete.

2.3.2 Concrete in Stations, Immersed tunnel and caisson sections

The fire test procedure for tunnels in The Netherlands [1] calls for a temperature criterion on the interface, between the concrete and the passive fire protection material, of 380°C. This criterion was initially declared to be applicable, but concerns were expressed with the spalling sensitivity of the concrete. Spalling of concrete very often occurs at interface temperatures well below 380°C.

Parameters which influence concrete spalling are:

- design time-temperature curve
  - heating rate
  - maximum temperature
  - duration of the fire
- concrete type
  - permeability / porosity
  - cement type
  - water – cement ratio
  - additives
  - aggregate type
  - siliceous aggregate
  - calcareous aggregate
  - aggregate size
  - moisture content
- structure
  - geometry
  - compressive loading
  - supports and restrained expansion
  - reinforcement

Concrete spalling cannot be modelled nor predicted, even if all of the above parameters would be known.

In order to address the concerns related to potential spalling of the concrete below 380°C interface temperatures, Efectis in The Netherlands was commissioned to conduct in-situ fire tests, using a mobile furnace which exposes the concrete lining to a pre-set time-temperature curve over a surface area of circa 1m2. Using an iterative approach (educated trial and error) the exact temperature at which a certain structure starts to spall, can be determined. These temperature limits then serve the manufacturers of passive fire protection systems to select the most suitable material and thickness, in order to comply with the thermal criterion. A total of 36 mobile furnace tests have been conducted in all 5 underground stations and in the immersed tunnel section below the river IJ. It was proven that the concerns with the 380°C interface temperature were valid. Temperatures at which the concrete started to spall ranged from 200 to 400°C depending upon the location at which the test was conducted. These lower temperatures have been selected to be the design criteria for the project, resulting in an enhanced passive fire protection system, compared to the initial design.

2.3.3 Stations, steel support braces

Steel support braces are used in the stations to support walls and ceilings. Structural steel members in the commercial built environment are often designed to cope with elevated temperatures of 350 to 500°C. However, substantial deformation is to expected under such conditions. In the civil industry, deflection, sagging and thermal expansion are not desired as such actions are often leading to irreversible deformation, damage or even collapse. Thermal expansion of steel, for example, equals 1,2mm length per 100°C per 1000mm length. To allow a 10 meter steel support brace to heat up to 500°C, would cause a thermal expansion of 60mm and could cause considerable structural damage to the brace and surrounding structures.

The steel support braces in this project consist of circular hollow sections with diameters ranging from 406mm to 813mm. Based on the concerns described above these sections had to be designed to a maximum temperature of 110°C, when exposed to fire.

3. Promat technical offer

3.1 Stations, Immersed tunnel and caisson sections

As per paragraph 2.2, three different time-temperature curves have been identified for different sections of the concrete load bearing structure i.e. the 120 minute EUREKA time-temperature curve and the ISO-834 time-temperature curves for 90 or 120 minutes, depending on the fire load found in the CFD modelling.

Based on the outcome of the mobile furnace tests, as per paragraph 2.3.2, and the applicable fire curve, the required passive fire protection materials and thickness have been selected. It was the contractors preference to apply a board system, which would allow other routines to run in concurrence with the installation of these boards. Board systems typically do not interfere with other routines and do not cause workability issues for others in the direct vicinity of the installation teams. It was therefore decided to select PROMATECT®-H as the passive fire protection board material for the protection of concrete of the entire project.

Depending on time-temperature curve and the maximum allowable interface temperature on the concrete, as per the mobile furnace results, the selected thickness' were PROMATECT®-H 2 x 16mm, 2 x 18mm and 2 x 20mm. These boards come in dimensions of 2500 x 1250mm and have been post fixed to the concrete using A4 stainless steel expansion anchors, staggering the joints.

3.2 Stations, steel support braces

The maximum temperature of the steel support braces of 110°C poses challenges to passive fire protection materials because these materials are typically designed to perform at higher temperatures. Its thermal insulation capacity is utilised at interface temperatures between 150 and 400°C. The criterion of only 110°C is just beyond the stage were the moisture has been consumed.

Bespoke designs have been approved using 2 different material types i.e. a sprayed Cafco FENDOLITE®-MII system and a polygonal board system using PROMATECT®-T.

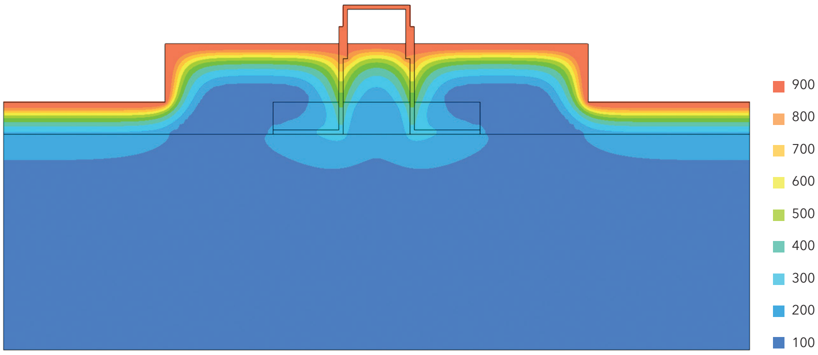
Project specific fire tests and calculations have been conducted at Efectis The Netherlands to determine the required material thickness. The PROMATECT®-T design consists of profiled PROMATECT®-T sections which receive a double layer of PROMATECT®-T material. Depending on the fire curve and the diameter of the steel support brace, the thickness of the PROMATECT®-T or Cafco FENDOLITE®-MII has been calculated by means of a software tool which has been developed for these materials and applications.

For both the PROMATECT®-T and the Cafco FENDOLITE®-MII system, the fire protection materials have been clad using a stainless steel light gauge casing. This casing is installed on pins which were stud-welded to the steel support brace. These pins penetrate the passive fire protection system, causing a heat sink into the steel support brace. The effects of this have been quantified by Efectis using Finite Element Modelling techniques to establish that no adverse effects were to be expected within the system.

3.3 Anchor plate penetration details

The anchor plates and fixing points of the architectural cladding, the suspended ceiling, cable trays etc were installed prior to the installation of the passive fire protection of the concrete structure. In case the passive fire protection system would be installed up to these anchor plates, the heat sink due to conduction of heat through the steel into the concrete, causes thermal issues. This thermal leak could potentially cause local spalling of the concrete and would definitely overrun the thermal criterion of the concrete, as per the mobile furnace results.

Each detail has been analysed by Efectis, using finite element modelling. The heat sink effect caused by steel sections which penetrate the passive fire protection system, is being compensated by additional local insulation capacity, using the same PROMATECT®-H material, in combination with a ready-mix PROMATECT®-T compound.



Reference list

[1] Fire testing procedure for concrete tunnel linings 2008-Efectis-R0695 by Ministry of Infrastructure and Environment and Efectis The Netherlands

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