Copenhagen's Metro

ROUTING

In year 2002, the first phase of Copenhagen's new Metro will open followed by the completion of the entire system during the course of a few years.

Quick, direct link
The Metro is a quick, direct link between Frederiksberg, Copenhagen City, Ørestad, northern Amager and Copenhagen Airport. The Metro is linked to the existing S-train and regional train lines – and relieves pressure on these lines in some sections.

Focus on passengers
In developing the Metro, one factor has been in constant focus: passenger needs.

This has given rise to a new, and in many ways different, Metro system. A system that will set new standards for urban public transport.

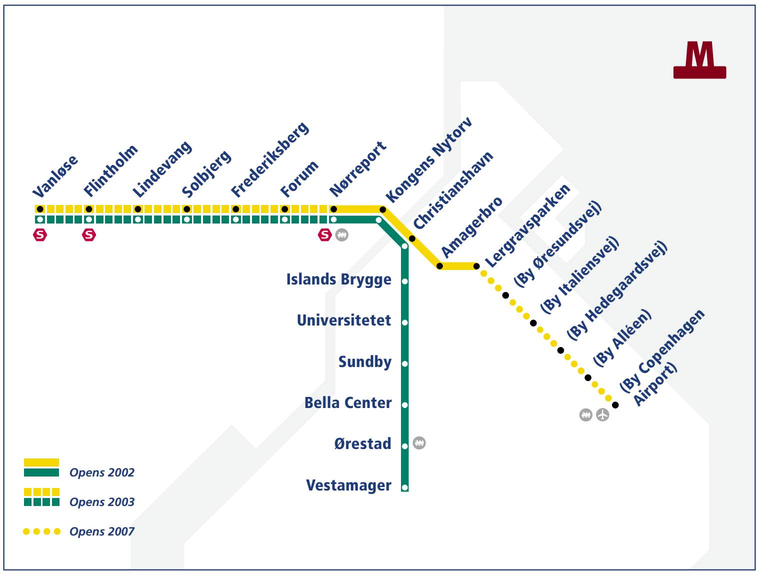
Brochure on products and processes
This brochure describes what the Metro has to offer its passengers when it is completed. The brochure also provides a number of technical details about the system and select descriptions of the construction process.

Get more information
About Metro at the website:
www.m.dk
About Ørestad at the website:
www.orestad.dk
About the Ørestad Development Corporation at the website:
www.orestadsselskabet.dk

The Metro's routing appears in the map below.

At its completion, the Metro will run from Vanløse Station to Frederiksberg Station on the section previously served by S-trains. From Solbjerg Station, the line goes underground and runs in a tunnel to the stations of Frederiksberg, Forum, Nørreport, Kongens Nytorv and Christianshavn. After Christianshavn, the line divides into two:

1. Westward to Islands Brygge Station, which is a tunnel station. From here, the Metro runs on an elevated track and embankment through Ørestad to three elevated stations and two stations on the embankment. In addition, stations have been prepared to the north and south of Ørestad Station before Vestamager Station marks the end of this section.
2. Eastward to the underground stations of Amagerbro and Lergravsparken. The Metro then resurfaces on the Amager line's former track along the east coast of Amager. From here the line continues at ground level and on an embankment to Copenhagen Airport. At Copenhagen Airport, the Metro is integrated in the terminal station. The final location of the other stations along the coast of Amager has not been determined.



The Metro lines.

The best possible passenger-friendly system

The Metro is based on an overall vision of establishing the best possible public transport system for passengers. The following table provides a brief outline of how the passenger requirements are ideally met by a carefully selected combination of technical solutions. The technical details and operating strategies are described more fully in the technical section of the brochure.

The Metro's design and features are based on the greatest possible consideration of passenger needs for efficiency, safety and comfort.

Our vision…	*is achievable by means of the technical solutions and operating strategies below*	*that have the following effect.*
Fast travel		
Shortest possible transit times for the entire trip – from start to finish	• Trains run in tunnels and on embankments and elevated tracks • Fully automatic control system • Short transfer distances • Short distances between stations • Lifts at all stations • Escalators at deep tunnel stations • Flush-floor train entry	• Trains not delayed by other traffic modes • High departure frequency means no waiting and easy harmonisation with other systems' schedules • Rapid transfers between Metro, S-trains, regional trains and buses • Short walks to the nearest station • Accessible to persons with disabilities, prams, etc. • Quick descent and ascent at tunnel stations • Quick boarding / alighting mean short stops
High operating reliability		
Trains on time – all the time	• Fully automatic control system • Driverless operation • Trains run in tunnels and on elevated track • Metro gives a passenger guarantee	• 98% of all trains on time • Limited human-factor delays • Trains not delayed by other traffic modes • If a train is delayed, alternate bus or taxi transport provided
Security		
Passengers shall always feel safe and secure everywhere on the Metro	• The stations are bright and open • CCTV surveillance of stations • Call points at stations and in trains • Staff everywhere on the system	• Passengers have an unobstructed view of station areas and other passengers • Passengers can be seen by control room staff • Passengers can get in touch with control room staff immediately • The staff provides personal service to passengers, and their presence creates a feeling of security
Good information		
Passengers must receive precise, reliable and adequate information	• Standard signs, displays, and loudspeakers • Fully automatic control system • Staff everywhere on the system	• Provide updated and timely information • Train positions, arrival times, etc., known by system and passed on to passengers • Staff responds to specific questions
High level of comfort		
Passengers should regard the whole Metro experience as comfortable	• The system uses modern trains and track • Platform doors in tunnel stations • Stations and trains are convenient for persons with disabilities	• This ensures comfortable, quiet rides • Provides pleasant climate and no noise at tunnel stations • Persons from practically all disability categories can use the Metro unassisted
Good service		
Travel should be problem-free with good service	• Driverless operation • Metro gives a passenger guarantee	• Staff focuses on servicing the passengers • If a train is seriously delayed, alternate bus or taxi transport provided
Good environment		
The Metro should generally have a positive environmental impact on passengers and neighbours	• Considerate construction methods for stations and tunnels • Much of the soil excavated from the tunnels was removed in barges • Noise limits in force at all construction sites • Trains operate in tunnels in city centre • Meticulous maintenance of wheels and rails • Electric operation	• Prevents damage to buildings from vibration and lowering of groundwater levels • Limited heavy lorry traffic in city centre • Construction site neighbours disturbed as little as possible • The Metro raises no barriers and adds no noise to the city centre • Low noise levels on embankment and elevated sections • Minimum $CO2$ level and cleaner urban air
Quality design and architecture		
The Metro has to be easily recognisable with timeless design	• Architects and designers have been involved since the start of the project • Tunnel stations located under squares • The Metro's design is functional • All design work tested on a 1:1 scale model before production • Power supplied via third rail	• The Metro has a well thought out, functional and integrated design • The Metro provides the city with several new urban spaces • Quality design means easier maintenance • Trains are convenient for all passengers, including persons with disabilities • No unsightly overhead power lines on embankments and elevated sections
Economy		
Passengers should get the best possible system per DKK invested	• Fully automatic control system • Power supply via third rail	• Means greater frequency -> shorter trains -> smaller, less expensive stations • Minimises tunnel diameter thereby reducing tunnelling costs
High level of safety		
The Copenhagen Metro should be just as safe as other metro systems	• Trains operated by fully automatic control system • Trains run separately from other traffic • Platform doors in tunnel stations • Stringent fire prevention requirements for trains and stations • Short escape routes and emergency ventilation in the event of tunnel fires	• Prevents human error • Prevents collisions with other traffic • Prevents accidents and suicide attempts • Prevents any fires from getting out of control • Enables safe, orderly evacuation

Incentives for ever better quality

FUTURE OPERATIONS

The Metro will be operated and maintained by an operating company during the first five years. The operating company is a division of the consortium and is in charge of making and supplying the trains and the technical railway systems.

Penalty and incentive

If any operational or maintenance problems arise, the operating company will be financially penalised. By linking supply, operations and maintenance, the supplier has an incentive to comply with the high operational requirements of the Ørestad Development Corporation. In addition, the contract with the operating company includes a number of positive financial incentives for continually improving operational quality to ensure not only that more passengers use the Metro but that passenger satisfaction increases as well.

24-hour operation

The Metro will run round the clock. Apart from night service schedules, the trains will run so frequently that passengers will not need a timetable.

Train frequency round the clock

	Approx. intervals between trains	
Time	Vanløse-Christianshavn	Ørestad and Airport Lines
05-06	4 minutes	8 minutes
06-09	3 minutes	6 minutes
09-15	4 minutes	8 minutes
15-18	3 minutes	6 minutes
18-01	4 minutes	8 minutes
01-05	15 minutes	15 minutes

After a running-in period, the daytime service intervals will be reduced. The average travelling speed will be about 40 kph. Transit times are shown in the figure below.

Easy transfers

All stations have bicycle parking facilities and short transfer distances wherever the Metro links up with other train lines or buses. In addition, Park & Ride will be implemented at certain stations.

Metro travel times.

At least 98% of all trains run on time
The Metro will have a service reliability corresponding to at least 98% of all departures being on time. The Metro's operating company will be paid according to the quality of the service. The company will either be penalised or rewarded, depending on whether the service reliability is above or below 98%.

Driverless – but manned
All trains are driverless, but manned by Metro stewards. Their role is to assist passengers, inspect tickets, assist in emergencies and create a feeling of security through their presence. All Metro stewards are in direct radio contact with the control room and each other. They can be immediately contacted from emergency call points at stations and in trains.

Passenger satisfaction survey
Besides the specific requirements stipulated in the operating contract regarding staff conduct and training, the operating company shall survey passenger satisfaction in several areas every six months. This includes factors like passenger security, cleanliness of trains and stations, regularity and ride comfort, as well as the conduct and service of the Metro stewards.

Travel guarantee
The Metro wishes to grant priviledges to its customers by introducing a Travel Guarantee. The Travel Guarantee entitles any passenger who is delayed while travelling on the Metro to have the expense of a taxi refunded. A minimum delay time will be fixed as a condition for issuing taxi refunds, and a ceiling will be fixed for the amount of the taxi bill. As the scheme shall be financed by the operating company, it will also serve as an incentive to achieve high quality operation and service. The details of the Travel Guarantee are still being developed, and the Guarantee will presumably be introduced in phases.

The Metro trains are driverless, but manned by Metro stewards. They assist passengers and inspect tickets, and their mere presence creates a feeling of security.

PERSONS WITH DISABILITIES

Wheelchair trials on a 1:1 scale model.

The Metro is designed to be used by everyone. Our guiding philosophy is that persons with disabilities shall be able to use the Metro with as little assistance as possible.

Dialogue with disability organisations
Consequently, the Metro stations and trains were planned in dialogue with disability organisations. In addition, initial trials were also conducted on a 1:1 scale model of a Metro car to clarify boarding and alighting conditions and determine movement patterns and handrail positions in the train.

	At the Station	*On the Train*
Visually impaired and blind persons	• Lift from street level to platform • Platform doors at tunnel stations • Uniform floor surfacing with 'guideways' • Delays announced on the loudspeaker system • Emergency call points at stations • CCTV surveillance of stations • Island platforms at all stations	• Flush-floor train boarding • Increasing tone before doors close • Appropriate handrail placement • Shielded sitting areas • Train stewards on board • Anti-trapping device on door edges • No 'chair legs'. Space for guide dogs
Deaf and hearing-impaired persons	• Totem pole display at entrance • Static information at concourse level • Information displays on platforms • Telecoil systems at call points • Light signal indicates door closing	• Information signs and displays in trains • Telecoil systems at call points
Wheelchair users	• Wheelchair bays on forecourts • Lift from street level to platform • Ticket dispenser and validation machines at a maximum height of 1200 mm • Information displays in 'elevated' position • Island platforms at all stations	• Flush-floor train boarding • Flex area in trains • Folding seats for companions • Call points at a maximum height of 1200 mm • Anti-trapping device on door edges • Train stewards on board • Appropriate handrail placement
Allergy sufferers	• Easy to clean	• Easy to clean • No smoking • 'Dog-free sections'

Functional stations – timeless design

DESIGN OF DEEP TUNNEL STATIONS

The fundamental design philosophy has been to establish smoothly operating Metro stations that give passengers ideal access conditions from street level to platforms.

Blend in with the surroundings
As the Metro shall have a long service life, the design of the Metro shall blend in with and enhance its urban surroundings – both in the existing city and the new Ørestad. To achieve this delicate balance, the stations – like the other parts of the Metro – are kept in classic, functional Scandinavian design.

Nine underground stations
A total of nine tunnel stations have been built for the Metro, six of which are deep and three of which are near the surface. The deep tunnel stations are basically large square spaces excavated at a depth of roughly 20 metres, 60 metres long and 20 metres wide. The actual platforms are 18 metres below ground level. The station area has a flat roof with skylights. The entire station is contained in this space. One of the many advantages of this solution is that all stations can be constructed in streets or on squares, which has eliminated the need to expropriate surrounding buildings.

Creating new urban spaces
From without, the tunnel station is visually unobtrusive, but provides an area where a square can be established. Such a square will contain a series of skylight wells, a glass lift, a descending staircase, as well as signs and other requisite square furnishings. Thus, the Metro is instrumental in establishing new urban spaces. Consequently, new, improved urban spaces will be established in front of the department store Magasin du Nord, at the central square, Kongens Nytorv and in front of the concert hall Forum and shopping centre.

Skylight at tunnel station. Daylight is guided down to the station area, the effect of which is controlled by prisms and other means.

3D illustration of a deep tunnel station.

Information at all levels

The first thing you notice about a tunnel station is a column at street level indicating the tunnel station entrance. The column has an electronic display with details about the train situation and other relevant information. If a train is delayed, passengers are informed of this before descending to the platforms. A stairway leads down from street level to the concourse, where there is additional information about the Metro, a route map, other public transport information, a local map, and ticket dispenser and validation machines.

Bright, even when overcast

The entire station area can be surveyed from the concourse. The space from the platform up to the station skylights is unobstructed. The skylights guide daylight and sunshine all the way down to the platform. The daylight is supplemented by artificial lighting that is regulated by the amount of daylight entering the space. As a result, the station area will always appear bright. In the evening, the station lighting will shine up through the skylights as a distinct landmark indicating the station's location.

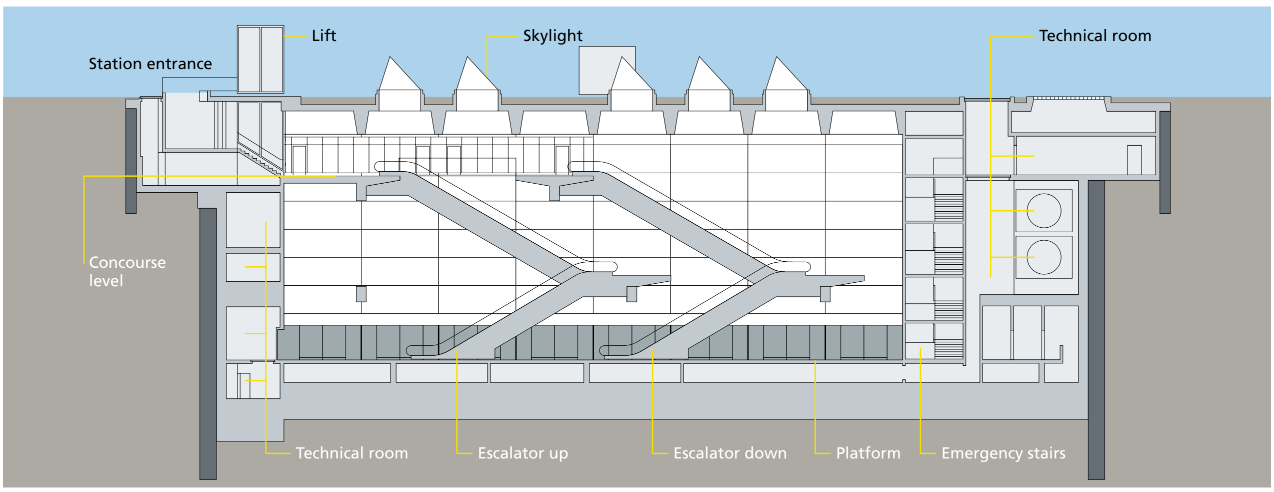
Escalators and glass lifts

Each concourse has two escalators running down to the platform and two escalators up from the platform. The escalators are staggered to disperse passenger flows. The platform can also be accessed by the lift running between street level and the platform. The lift is made of glass for passenger safety and security.

Island platforms ease passenger flows

The platform is located about 18 metres below the surface. Constructed as an island, each platform is designed to ease access and transfer conditions as much as possible. The passenger flows at the stations have been simulated on an advanced computer model to get a general idea of flow patterns – during normal operations and emergencies alike. Since the access routes were dimensioned on the basis of the simulation results, the routes are adequate for handling a possible evacuation.

Cross section of tunnel station.



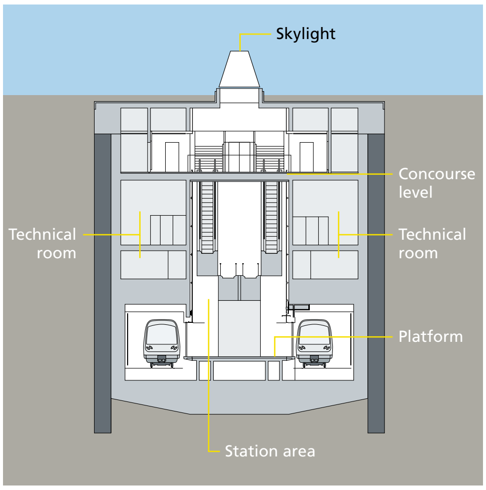
Train and platform doors open simultaneously
On the platform, a glass screen with doors lines the edge of the platform. When the train stops at the platform, the doors in the 'wall' will line up with the train doors and open simultaneously like a modern lift. The doors provide several advantages:

- Protection against passengers falling or jumping onto the track. This means fewer accidents, fewer suicides and fewer service interruptions.
- Easier, better and less costly control of the ventilation at stations and in tunnels.
- Improved indoor climate.
- Greater safety for visually impaired passengers.

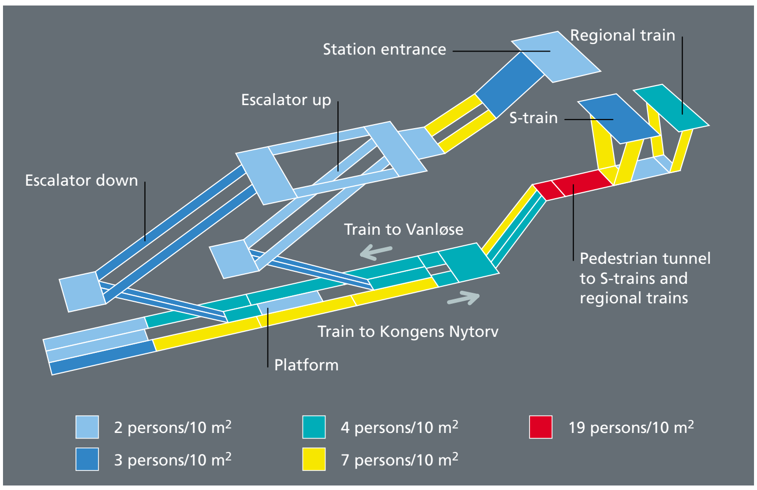
Easy access to other means of public transport
High priority has been given to providing easy access to other means of public transport at all stations. At Nørreport Station, passengers will have direct access to S-train and regional train platforms from the Metro station through a pedestrian tunnel.

Cycle racks at all stations
At the deep tunnel stations, part of the bicycle parking facilities are incorporated at station concourse level. These spaces are monitored by CCTV.

Cross section of tunnel station.



Computer analysis of rush hour passenger flows at Nørreport Station.



Displays outside the platforms
Each platform has displays with the latest service updates. The automatic control system generates accurate data on train service. As some of this data is beneficial to passengers, it will be presented on these displays. Thus, the dynamic platform displays will state the final destination of the train, the number of minutes until the next train arrives and any delays. The station information system also consists of a number of loudspeakers that, in parallel to the signs, provide train service information to passengers.

CCTV monitoring from the control room
The whole station is under CCTV surveillance so that the control room staff can see what is happening at the station. If passengers need assistance, they can contact the control room at one of two call points on the platform. These call points are primarily intended for emergencies, but passengers with special needs may also use them. This applies to persons with disabilities or to pre-school groups, for instance. The control room is capable of handling any situation immediately and is directly connected to Metro stewards and the police and fire departments.

Furnishings
The station area contains a minimum of furnishings, such as benches and wastepaper baskets, partly because the train intervals are so brief that passenger waiting time is very limited, and partly because it makes the station more open and easier to clean.

Technical room with power and ventilation
A number of technical rooms are located along the sides of the station. These technical rooms contain things like power supply and ventilation equipment. The ventilation system provides a pleasant climate in the Metro and is an important fire prevention factor if a fire breaks out. The design of the ventilation system was determined through simulations of routine operations and accidents.

The Metro's automatic operation is monitored by the control room. The staff are ready to intervene 24 hours a day in the event of operational irregularities or accidents.

In planning the Metro, priority was given to completing the project rapidly and in an environment-friendly, financially favourable manner with as little inconvenience to the city as possible.

Re-laying utility lines

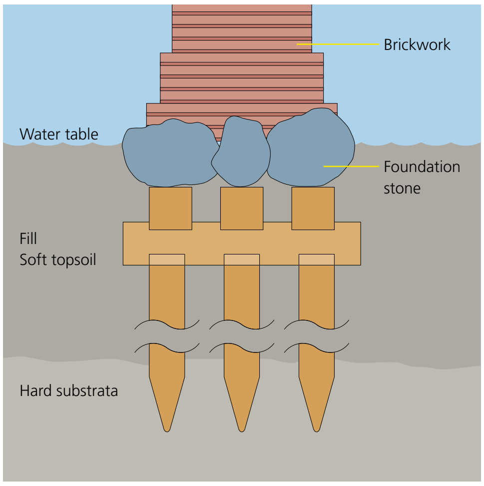
Before the actual construction work on the Metro could begin, it was necessary to relocate many utility supply lines.

Archaeologists find traces of medieval fortification

A year before construction work started, Copenhagen City Museum undertook a series of archaeological surveys. During the excavations, traces of Copenhagen's medieval fortifications were found. Copenhagen City Museum will also be following the construction work on the Metro during the rest of the construction period, so that archaeologists can intervene if anything of archaeological significance is found.

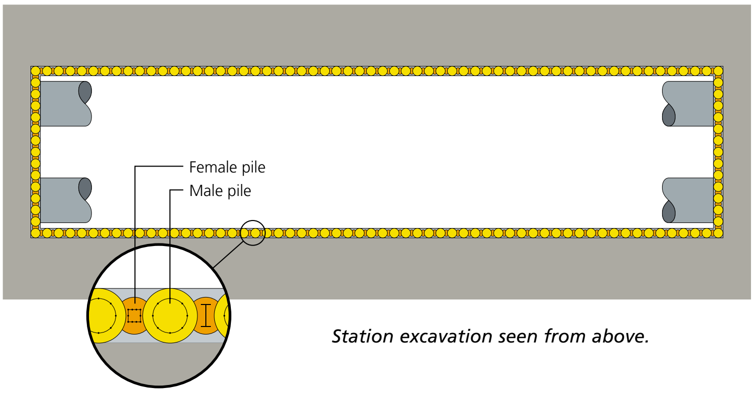
Important to prevent lowering of the groundwater table

Performing construction work twenty metres underground poses several problems. Avoiding harmful groundwater lowering is paramount, because a lowered water table could cause the surrounding buildings to settle. In some parts of Copenhagen, building foundations were made according to old piling methods using wooden piles that are under water. A lowering of the water table would expose these foundations to air, and at worst they would disintegrate in a few years as the result of fungal attack. The construction method used in making the tunnel stations prevents harmful groundwater lowering from occurring. To monitor groundwater levels, a number of bore holes have been drilled along the entire Metro. The groundwater level in these holes is continuously checked.



Cross section of typical wooden pile foundation under buildings in downtown Copenhagen.

Archaeological excavations at Kongens Nytorv.



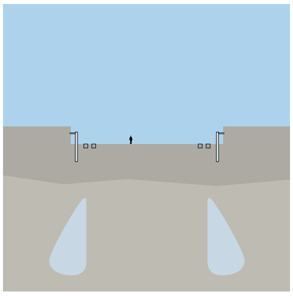
Station excavation seen from above.

Built from the top down

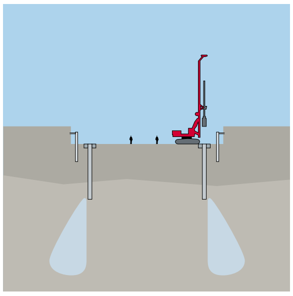
The tunnel stations are built from the top down. The basic procedure starts with the establishment of a watertight outer wall surrounding the station box. Next, the actual construction pit is excavated within the reinforcements. This ensures that the construction work occurs in a stable, dry pit that is impervious to water penetration.

Adjoining walls of concrete piles

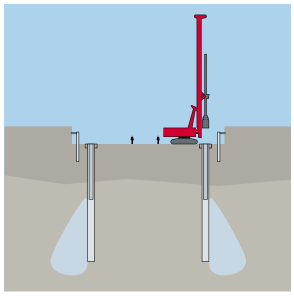
The outer walls of the station are concrete secant piles that are so tightly placed they form a cohesive watertight wall. The secant piling method was chosen because it is environmentally acceptable. Noise and vibrations are less than under conventional construction methods, such as sheet pile framing.



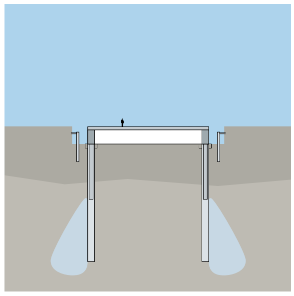
The limestone is made impervious by injecting a fine concrete slurry. A deep pit (2-3 m) is dug and reinforced with king post walls. Guide walls are cast for the piles.



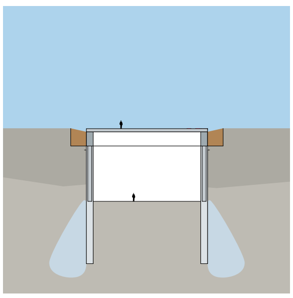
Holes are drilled ten metres down into the limestone. The female piles are cast in these holes.



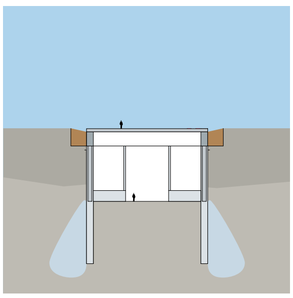
25-metre-deep holes are drilled between the female piles. These holes are reinforced and male piles are cast in them.



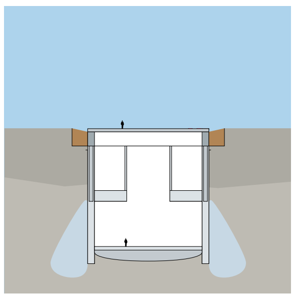
The station's support beams and roof are cast.



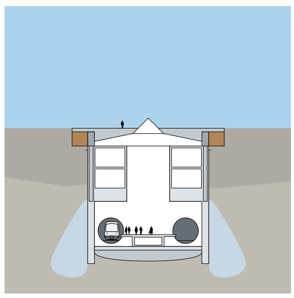
The upper half of the station is excavated in a dry pit without lowering the water table.



Cross beams and technical rooms are cast.



The remainder of the station is excavated, and the base slab is cast. The original sealing of the limestone also means that digging is done in a dry pit.



The two Tunnel Boring Machines are pulled through the station chamber and continue boring on the other side. Platforms, skylights, etc., are then built.

DESIGN OF EMBANKMENT AND ELEVATED STATIONS

Overground Metro
Eleven kilometres of the line are on embankments or elevated sections. The stations on this part of the line resemble the tunnel stations in functionality and design. For example, they have the same kind of platform design, information signs, CCTV and call points as the tunnel stations. This helps passengers to recognise the station's main features right away.

Good accessibility
Like the tunnel stations, these stations were designed with an emphasis on ideal passenger access to platforms from street level.

Lightweight steel/glass construction
The designs of the embankment and elevated stations are similar. The stations are designed as glass and steel structures suspended between the line's track structures with a lightweight, almost floating appearance. The stations are made of lightweight materials to avoid giving the stations a massive appearance that could dominate the urban scene in Ørestad. A forecourt is established in front of all stations with easy access for buses, taxis, passenger cars and cycle racks.

Information at all levels
The first thing passengers see at the station is a display column by the entrance showing train times and other relevant information. The stations have a concourse of sorts with information about the Metro, a route map, public transport information, a local map and ticket machines. A stairway leads from the concourse to the platform, and a glass lift runs between street level and the platform.

Open stations with screened shelters
Like the tunnel stations, the island-platform design provides the best possible train access and transfer conditions. As all these stations are open, shelter screens are set up for the passengers' comfort as they wait for trains. There are no platform doors as in the tunnel stations, but an electronic surveillance system will immediately stop the train if a foreign object is on the track.

Well lit and easy to see through
Road and path underpasses are well lit and easy to see through.

Elevated station, Ørestad.

Metro train en route on the elevated track at Ørestad. In all, the elevated track and embankment comprise eleven kilometres of the Metro's total track length.

Functional trains – timeless design

THE NEW METRO TRAINS

Each Metro train is designed as a small, short train unit with a 300-passenger capacity. There is complete access between all three cars of the train unit, and an unobstructed view – also in the direction of travel.

The three Metro phases are served by 34 trains.

Three cars with wide passage
Each train consists of three cars with full access from car to car. The train is designed to accommodate many commuters travelling short distances in the Metro. Each side of the train has six wide doors, and roughly 100 of the 300-person capacity is for seated passengers, the rest standing. The seats face each other except at the ends of the train where they are in rows so passengers can look out of the large front windows. There are four large 'flex zones' with folding seats along the sides, providing space for wheelchairs, prams and bicycles.

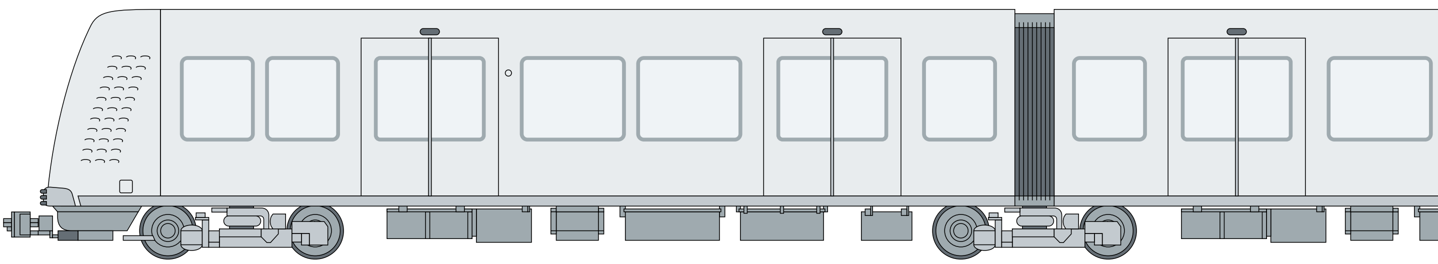
Easy to clean
In designing the train, the intention was to make the trains pleasant to look at, as well as easy to clean and maintain. None of the panels have sharp corners or dirt-collecting gaps, and since all the seats are wall-mounted, the floor is free of support legs. This makes it easier to clean. All interior furnishings and technical equipment are easy to access enabling quick replacement at the workshop.

Signs
Each car has two electronic signs with information about the time, next station, bus and train connections and other relevant messages that are particularly important in the event of delays. There will also be ordinary signs with route maps and transfer indications.

Call points to the control room
Call points are located at all six door vestibules where the control room can be contacted by pressing a button. The call points can be used in emergencies. The call points can also be used by wheelchair users or preschool groups on outings if they wish to prolong the door-opening interval, for example. There are telecoil systems at all call points.

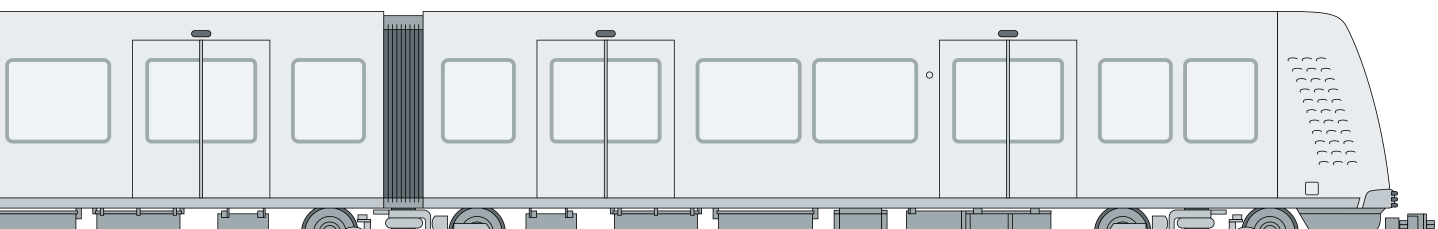
CCTV contact with the control room
Cameras are mounted in all cars so the control room staff can see selected areas of the train. If a call is made from a call point, the system switches to a camera that shows who is pressing the call button. This provides extra security to the user and reduces misuse.

Very safe door automation
By ensuring that the doors close automatically, a great effort has been made to prevent anyone from getting trapped or stuck between the doors. The closing of the doors is preceded by a distinct audio signal and a flashing light indicating that the doors are closing. If an arm, hand, handbag or the like is caught between the doors, the pressure-sensitive door edges will immediately stop the doors from closing. Even small objects are detected, and the train cannot leave the platform until all doors are fully closed and locked.



The Copenhagen Metro trains are unique. The beautiful curves and functional shapes are the result of successful cooperation between Danish designers and Italy's Giugiaro.

Design
The train was designed in cooperation with the Giugiaro Design team, Italy, who are renowned for their car designs, among other distinctions, over the past thirty years.



TRAIN TECHNOLOGY AND DESIGN

Train data

Length	39.0 m
Width	2.65 m
Car length	End cars: 14 m
Height	3.4 m
Floor height above rails	850 mm
Maximum speed	80 kph
Acceleration	1.3 m/s^2
Brake deceleration	1.3 m/s^2
Estimated total empty weight	52 t
Seating capacity (including foldaway seats)	96
Standing capacity (4 pass. / m^2)	204
Total passenger capacity	300
Bogies	4 sets of bogies, wheel diameter: 650 mm
Motors	6 x 105 kW asynchronous bogie-mounted motors
Traction control	3 IGBT shielded inverters
Power	750 V DC from 3rd power rail
Doors	2 x 6 Slide-Plug doors, width: 1600 mm
Metro cars	3 aluminium carriage bodies
Coupling	Central coupling with deformation protection and anti-climb protection
Call points	6 duplex call points with telecoils
Signs	LED displays providing information on time, destination, transfers, special messages, etc., in all compartments
Track gauge	1435 mm

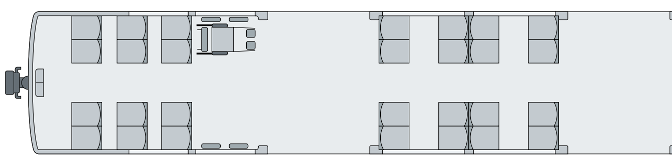
Balancing between innovative and proven technology
The philosophy underlying the acquisition of the trains has been to strike a balance between innovative and proven technology. In determining the train dimensions and performance, current European industrial standards were considered to obtain the most competitive offers and as many proven systems as possible. As a result, the system is based on known technology and design (see train data).

All important systems are duplicated
All the important systems have full redundancy (duplicated). If one unit fails, another takes over. For example, a train can keep running even if half of its motors stop working, and the call point system will function even if half of the train has been damaged. The train’s two redundant computers communicate with the control system and control all train movements and functions. The computers also have a monitoring system to register faults on the train. When a train comes in for servicing, the staff get a print-out of any faults on the train registered during the day and remedy them.

Any faults that might lead to operating disruptions can be sent to the control room staff who decide whether the train should be removed from service.

Great emphasis on fire safety
Since the trains run through tunnels, extra emphasis has been placed on fire safety. All trains are equipped with fire alarms that are

Plan of train
(72 fixed seats, 24 folding seats, 204 standing spaces).



directly connected to the control room. The train materials' fire and emission requirements adhere to very strict British and US standards, which in brief, state that all materials shall be critically assessed in terms of fire retardation and the amount of smoke and toxic substances they emit during a fire.

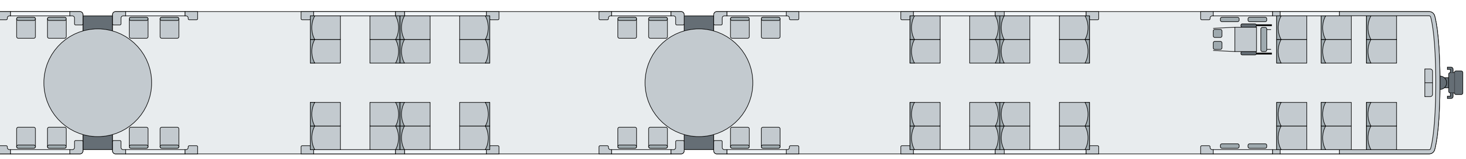
Passenger tests of special requirements
Before issuing a call for tenders for the trains, a number of passenger tests were carried out to determine factors such as door widths, seat sizes, seat modules, general layout and aisles. The tests also included wheelchair users, children and blind and walking-impaired persons.

Test mock-up
The detailed design of the train was tested on a 1:1 scale model, a so-called mock-up, consisting of a wooden carriage framework which was the equivalent of one and a half cars. Panels and seats as well as buttons and handles were mounted in the mock-up. This made it possible to test various solutions and to compare functionality and aesthetic qualities, also in terms of expedient cleaning and maintenance. The results of these tests greatly influenced the final design of the train.

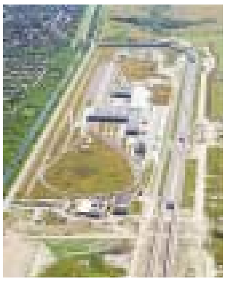
Testing and running-in the trains
The first train units were delivered from the factory some three and a half years before the Metro's operational debut. Since then, they have been exposed almost daily to trial runs testing the trains' various functions and how they interact with the Metro's central control systems.

Life cycle cost analysis
In accessing the different bids, an LCC (Life Cycle Cost) analysis was performed which in brief not only considers the actual train investment, but also the ongoing maintenance costs throughout a train's service life. Subsequently, an LCC guarantee was included in the contract. If the train's purchase price and maintenance costs do not comply with the guarantee commitments, the supplier must bring the train up to the agreed standard.

The station layouts were also tested in a series of 1:1 mock-ups. This photo shows a mock-up of a tunnel station concourse.



Train headquarters: Ørestad



Control and Maintenance Centre, Ørestad.

Two main areas of the Centre
A Control and Maintenance Centre (CMC) has been established in the southernmost part of Ørestad. This is where trains are washed, cleaned, serviced, maintained and parked when not in operation. This is also the domicile of the company administration, the control room and other operating departments.

The CMC is organized in two main areas
- A fully automatic servicing area where the trains are serviced, washed, tested and parked.
- A manual maintenance area where the trains are kept in working order.

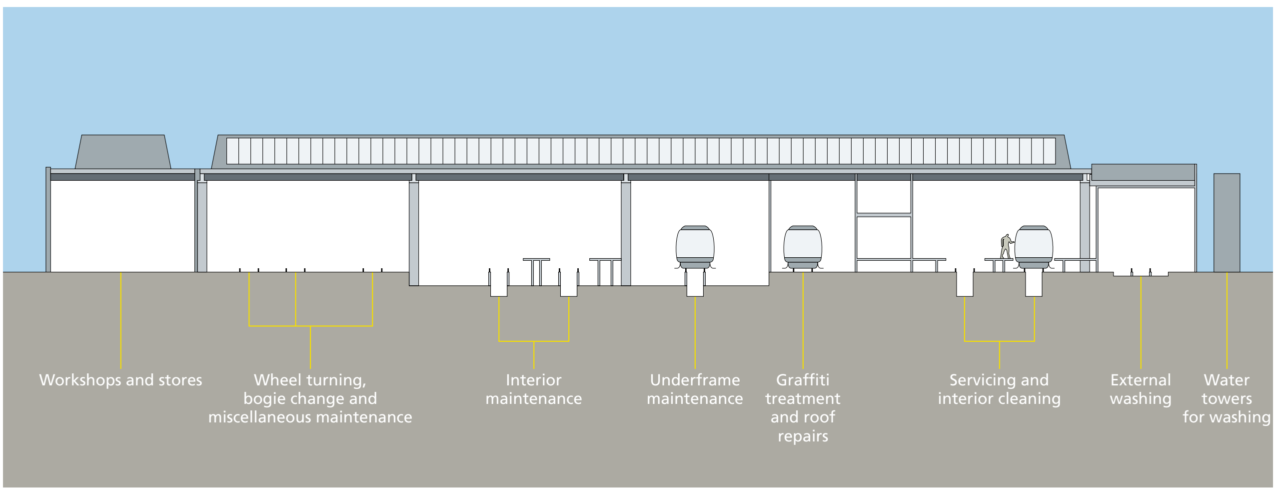
Automatic servicing and washing
When the train leaves the main line, it moves automatically through the servicing and washing areas before being driven out and parked in one of the assembly lines ready for departure.

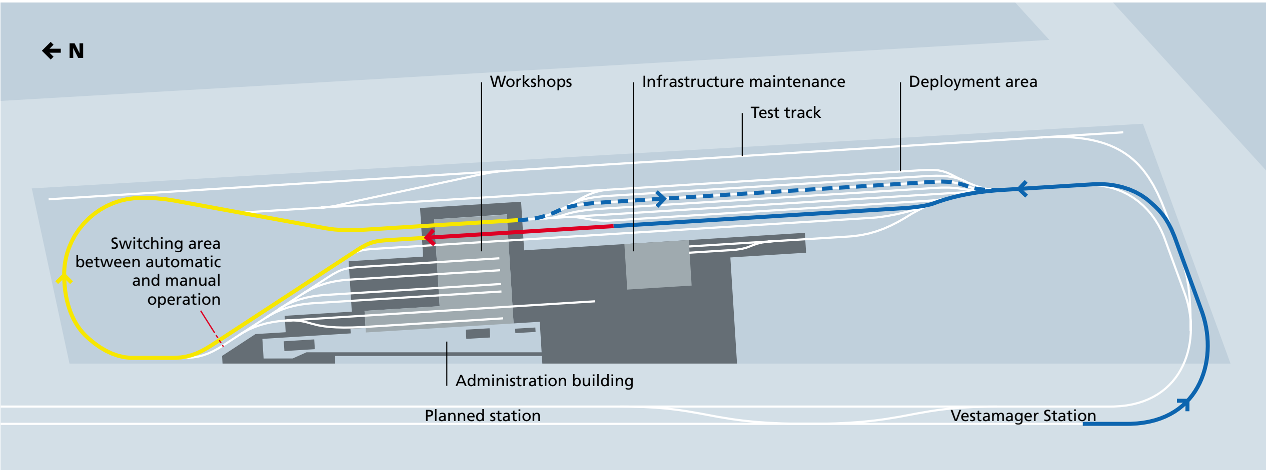
External and internal maintenance
When a train needs maintenance, this is performed in the maintenance shed. The train is logged off the automatic system and driven manually onto one of the shed's maintenance tracks, depending on the type of maintenance required. There are separate tracks for internal and external maintenance, for graffiti treatment, bogie replacement and a track with a wheel lathe. The latter is used for turning (grinding) the train wheels at regular intervals, which together with rail grinding, are the most important factors for reducing noise, vibrations and uncomfortable rides.

Replacing entire components
The philosophy underlying the maintenance of the Metro system is the replacement of entire components. They are sent to the supplier for repair instead of being repaired on site. This means that the trains spend less time in the maintenance shed and more time in operation. This results in greater productivity and reduces the need for new train investments.

Total test track
The Metro's test track, which is equipped with all the systems installed on the main line, is also located at CMC. Apart from being used to test the overall traffic and monitoring system during construction of the line, the test track is used to test train functionality after maintenance.

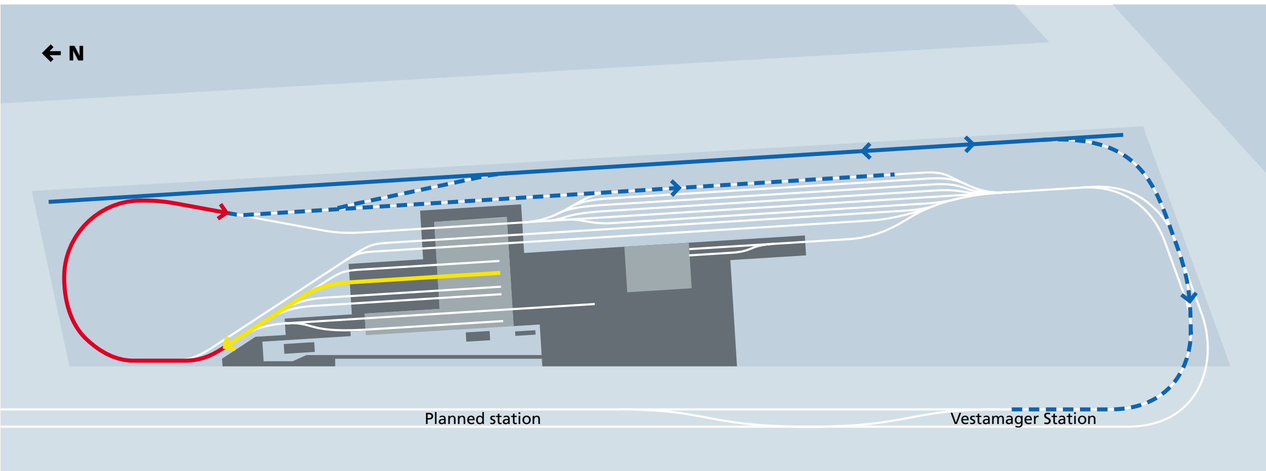
Cross section of the Control and Maintenance Centre.





Train movements at CMC after a train is removed from operation for servicing. All movements are automatically controlled.

- The train comes in from the main track and queues for servicing.
- The train runs inside the maintenance shed. It is cleaned and given a routine inspection. Minor repairs are made here.
- The train is driven to an automatic outside washing area.
- After washing, the train is deployed stand-by, ready for operation.

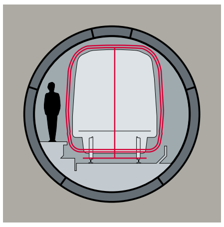


Train movements after maintenance.

- The train is manually driven to the transition area where it is checked into the automatic system.
- The train is driven automatically to the test track.
- A series of tests are conducted on the test track: brakes, communication, control system and more.
- The train is driven to the assembly area or directly back into service.

Metro – above and below ground

TUNNEL DESIGN



Cross section of the tunnel with emergency walkway. The nearest exit is never more than 300 metres away in any tunnel section.

The Metro tunnels run under downtown Copenhagen through the uppermost layer of limestone. At their deepest point, the tunnels are some 33 metres below ground level. A total of nine kilometres of twin bored tunnels have been constructed.

Dips between stations

The tunnel consists of two tunnel tubes running side by side along the whole route. The tunnels are constructed to dip between stations. This has made it possible to bore the tunnels primarily through the stable limestone layer, while the stations are built closer to the surface. This principle is financially advantageous both in the construction and operation phases, as the level differences before and after the stations reduce the train's energy consumption during acceleration.

Most of the tunnels are bored through limestone

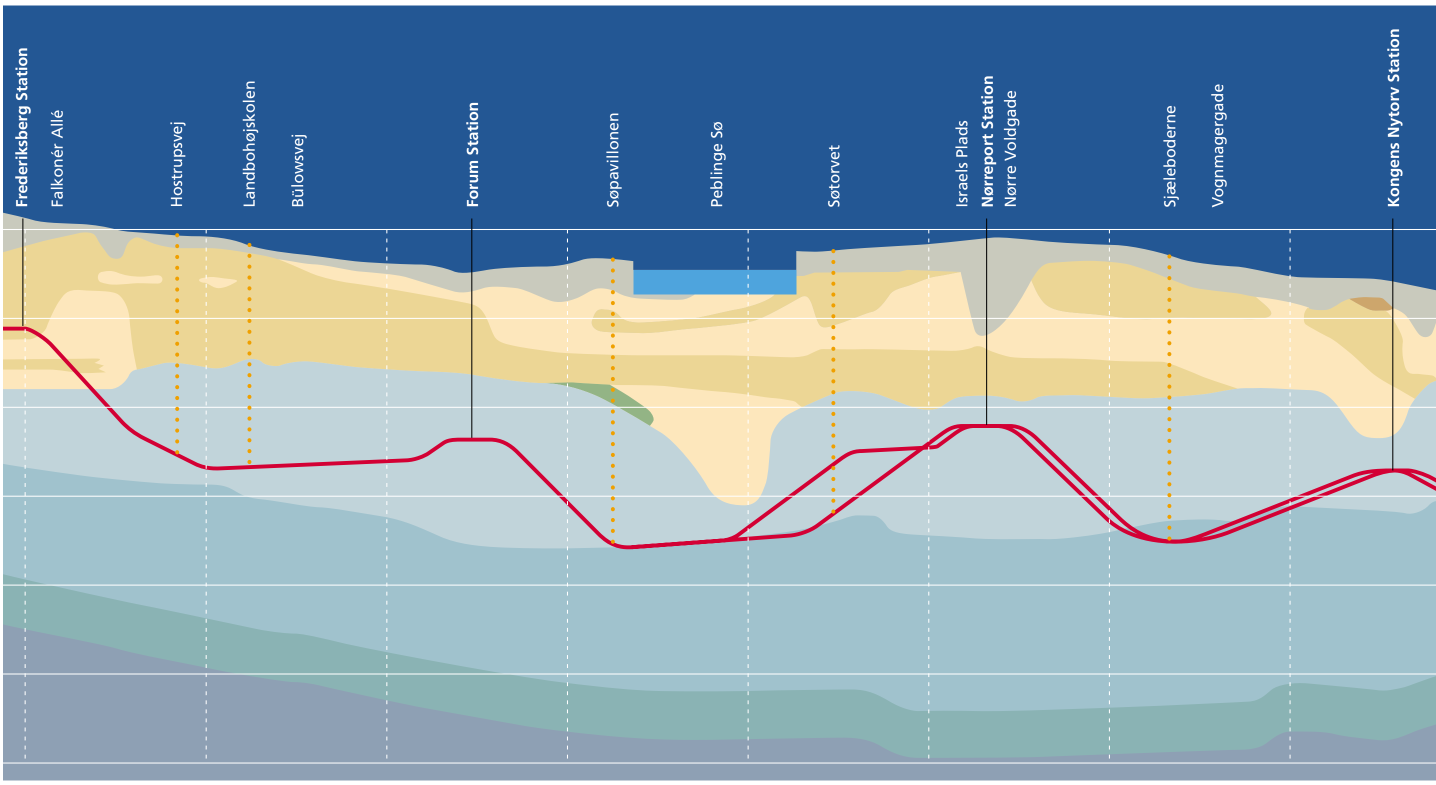
The uppermost layer of Copenhagen's substrata consists of moraine deposits on top of a layer of limestone. Most of the tunnels were bored through the limestone because it is generally a stable material that is well suited for constructing this very kind of tunnel.

Access shafts

For safety reasons, the nearest emergency exit must never be more than 300 metres away. For this reason, there are access shafts between the stations. In addition to their safety function, the access shafts are also used for ventilation.

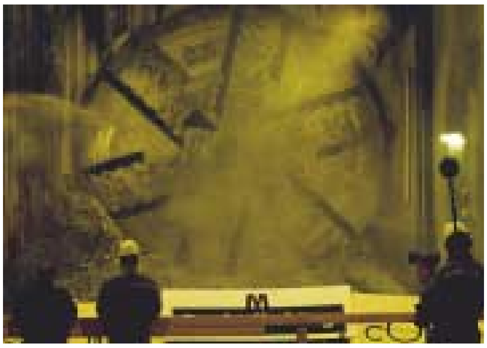
Technical tunnel data

Max. depth below surface	33 m
Distance between access shafts	max. 600 m
Shaft depth	25-33 m
Outer diameter	5.5 m
Inner diameter	4.9 m
Weight	3.13 tons / tunnel section

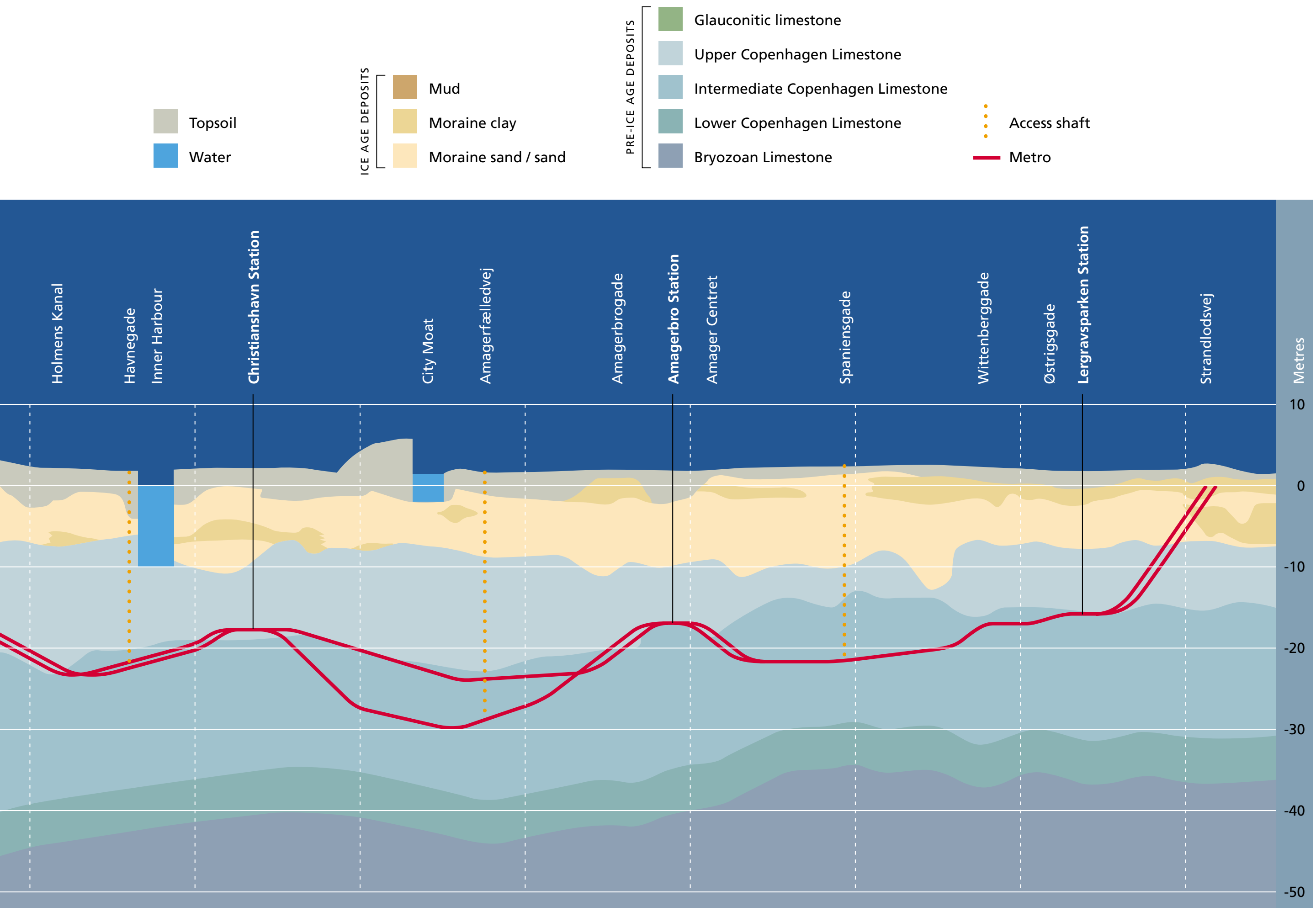


Compressed cross section of bored tunnel section. The Metro tunnels are primarily bored in the upper and intermediate layers of Copenhagen Limestone. The tunnels dip between the stations to provide optimum energy efficiency.

Tunnel cross section
The inside of the tunnel is like a smooth cylinder. The tunnel is made of six concrete panels that are assembled into a ring. A 70-cm-wide walkway is placed along one side of the tunnel. It is used in emergency situations if it is necessary to evacuate train passengers through the tunnel to the nearest emergency exit. The primary exit route, however, is right on the track – between the rails. The rails are mounted on a concrete, even surface without visible sleepers or other transverse obstacles. Cables, ducts and water mains for fire fighting are located below the emergency walkway. Lighting is placed along the side of the tunnel so passengers can see in the event of an evacuation.



From the breakthrough of a tunnel drill into a tunnel station. The tunnel drill bores a hole 5.5 metres in diameter.



Three tunnelling methods

Three tunnelling methods were used to construct the tunnel: Boring, Cut & Cover and the New Austrian Tunnelling Method (NATM). Practically the entire tunnel was bored because this is the safest method with the least impact on the surroundings.

Tunnel Bore Machine tunnelling

The tunnel was bored by a Tunnel Boring Machine (TBM). The type of TBM that bores the Metro tunnels is an earth pressure balance machine. The first part of the machine, which includes the cutter head, operates in an excavation chamber that can be sealed off.

Cutter head with cutter discs and scrapers

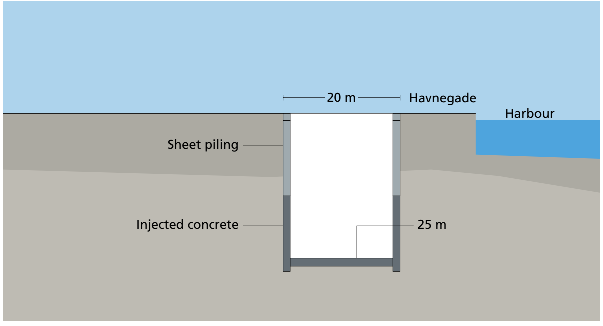
The actual cutter head consists of a large boring disc with a series of cutter discs and scrapers. The TBM moves forward by rotating the cutter head using a combination of electric drive motors and hydraulics. The number and shape of the cutter discs and scrapers depends on the strata being bored through. Scrapers are used in soft material, but cutting discs are used in hard strata to crush the material. The layers of limestone through which the Metro tunnels were bored also turned out to contain flint.

Archimedean screw removes crushed material

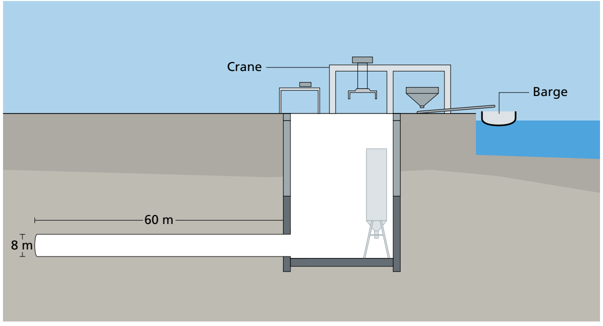
After crushing the material, it is removed from the boring chamber by a spiral conveyor that functions like an Archimedean screw. The screw deposits the spoil on a conveyor belt and from there into small work trains.

When boring in areas with heavy water inflow, the boring chamber is sealed off from the rest of the boring machine and the tunnel by pressurising the chamber and thereby

The boring operations started in Havnegade



A working shaft is established by driving piles down to the top of the limestone in a large circle with a diameter of 20 metres. The area inside the piling walls is excavated. Excavation continues into the limestone layer. The sides are strengthened by injecting concrete.



Lifting equipment, concrete silos, etc, are installed at the working shaft. An NATM tunnel is bored out at the bottom and reinforced by injecting concrete.

The former main construction site in Havnegade where limestone and soil spoil was excavated and new tunnel sections were lowered onto the work train.

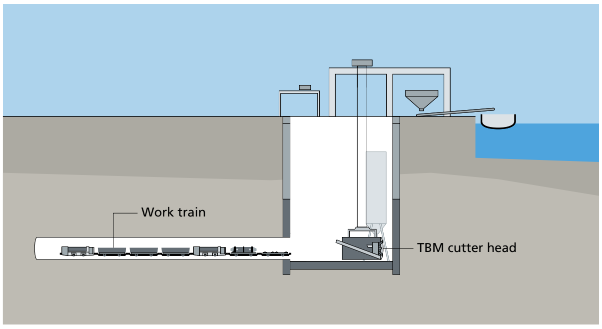
preventing water from penetrating the tunnel. When the machine works under these conditions, the excavated material and a continuously filled spiral conveyor ensure that the pressure in the excavation chamber is maintained.

An arm is fitted behind the cutter head to lift and mount the concrete panels that line the tunnel.

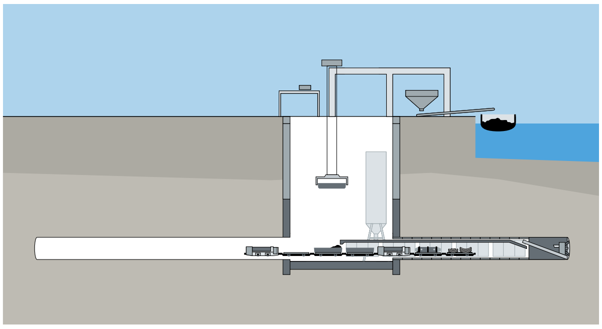
Tunnel Boring Machine cutter head.

Sea transfer of materials / spoil

The small work trains conveyed the spoil through the tunnel to the work sites at Islands Brygge, Havnegade and Søpavillonen. At Havnegade, the limestone was removed from the work train by a crane and loaded onto barges and sailed off. At other work sites, the spoil was carted off by lorry. The tunnel construction elements were lowered at the work sites and conveyed by work trains through the tunnel to the TBM. The sea conveyance of materials to and from the construction sites reduced the impact of heavily-laden lorry traffic on the city to the greatest possible extent, as lorries would normally have been used to convey materials to and from the tunnel.



A working track is laid and the work train is lowered into the tunnel followed by the TBM's cutter head.



The remaining parts of the TBM's 'tail' (motors, transformers, pumps, ventilation, crew compartments, etc.) are coupled to the head. The work train removes the limestone spoil to the shaft where it is hoisted up and shipped away on barges. In the other direction, barges convey the tunnel sections to the shaft, where they are lowered and conveyed to the TBM for installation.

Finding the way underground

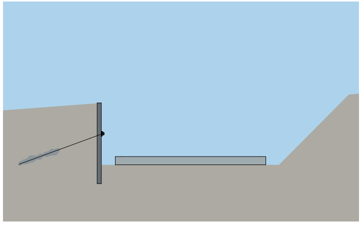
The method used to navigate underground is based on laser technology. On the surface, a baseline is set up using lasers. This baseline is re-established underground by 'lowering' the baseline into the tunnel at shafts and stations using optical instruments. Down in the tunnel, the baseline is then set up again, and the same laser beam that was above ground before, can now be used for navigating underground.

Cut & Cover

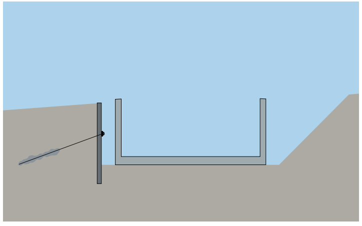
The Cut & Cover process consists of constructing the tunnel from above by digging a large open trench in the ground and casting the tunnel in the trench. The method was used to make components like the ramps connecting the tunnel to the surface at Solbjerg, Islands Brygge and Strandlodsvej.

NATM

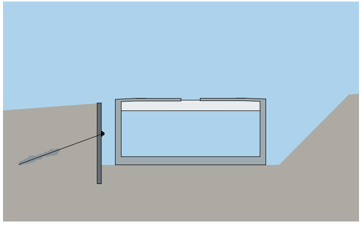
The NATM is used where the tunnel section branches in two or for making a connecting track between the two tunnels. At these locations, the tunnel diameter is greater than the TBM can bore. This boring method requires stable geological structures, since the boring is done by an excavator fitted with a hydraulic rotary cutter. During the excavation process, the walls are temporarily reinforced by injecting concrete and erecting steel arches. After this, the permanent wall is cast in concrete.



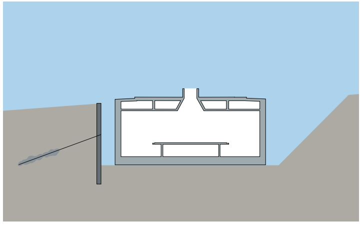
Excavation of the pit is completed and the station platform is cast.



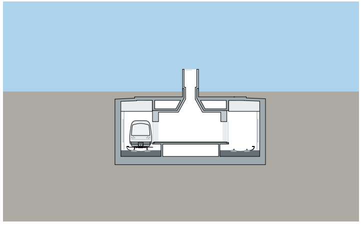
The station's bottom slab is cast. An open slope excavation is done on one side. Space limitations on the other side necessitated the use of sheet piling walls with bored-in tie beams.



The outer station walls are cast.

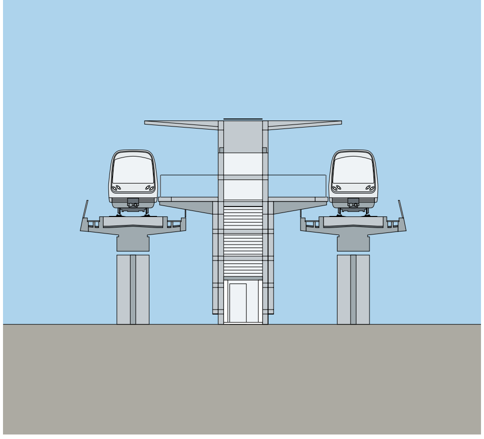


The station's roof beams and roof slab are cast. The cut-out in the roof slab for the skylight is in the middle.



The fully equipped station with platform doors, skylights, etc.

ELEVATED TRACK DESIGN

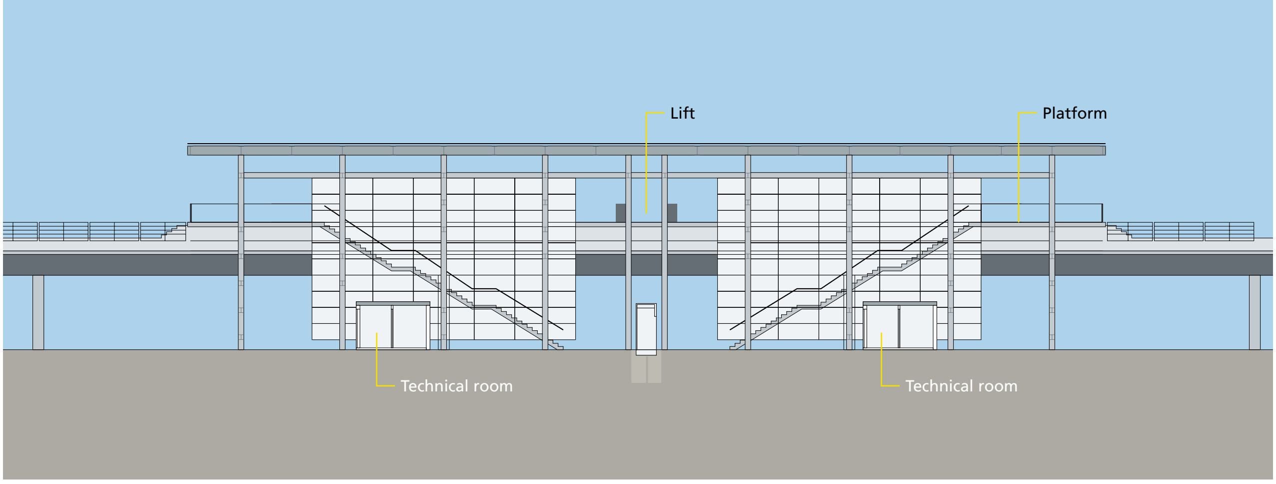


Cross section of elevated track and station.

Elevated track avoids barriers
In Ørestad, the Metro will run on an elevated track and a low embankment. The elevated track is used to lower the number of physical barriers across Ørestad and will be a striking feature of the urban landscape. It is built as two separate bridges on slender supporting pillars enabling light to fall between the two bridges. In addition, the parapets are made of steel and glass.

For environmental and economic reasons, parts of the Ørestad line are on an embankment. The embankment is constructed as steep slopes covered with vegetation that also functions as a hedge.

Cross section of elevated station, Ørestad.



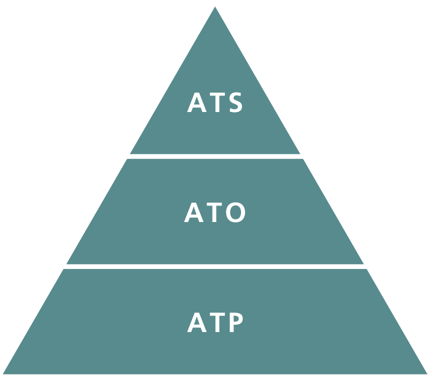
Controlling and monitoring the Metro

THE FULLY AUTOMATIC CONTROL SYSTEM

Advantages of driverless trains

The fully automatic control system makes it possible to operate trains without drivers. This provides several advantages:

- Instead of long trains with infrequent service, the Metro has many short trains with very frequent service. The interval between trains on the central section will be as short as 1.5 minutes. This means brief waits.
- The automatic operation enables the trains to run at closer intervals than under manual operation. Apart from the shorter waiting times, this also makes it easier to make up for delays.
- The trains are more punctual. At least 98% of the departures will be on time.
- Instead of driving the train, the Metro staff will serve the passengers and create a feeling of security.
- Using the Metro will be very safe since human error is avoided.



The security of the ATC system lies in the ATP sub-system. The actual system automation is mainly concentrated in the ATP and ATS sub-systems. If a fault arises in the ATS or ATO, it will be detected by the fail-safe ATP sub-system.

Automatic Train Control

The cornerstone of the fully automatic operation is the Automatic Train Control (ATC) system, which has three sub-systems:

- The Automatic Train Protection (ATP) system
- The Automatic Train Operation (ATO) system, an autopilot system
- The Automatic Train Supervisory (ATS) system, an overall traffic and monitoring system.

Automatic Train Protection

The ATP system performs a range of functions that protect passengers, staff and equipment from accidents, such as collisions, prevent excess speeds and incorrectly positioned points and make sure the doors are closed before departure. There are various fundamental approaches to the construction of ATP systems. The Metro uses a block-based ATP system that divides each stretch into track sections. When a train is located in a particular track section, no other train can enter this same section. There are a number of exceptions, such as at stations where an overlying 'floating' block system is in effect enabling the trains to run closer to the preceding train and to exchange updated information with the Control Centre.

Automatic Train Operation

The ATO system, or autopilot, controls the trains according to a fixed timetable by:

- Performing programmed stops at stations.
- Opening and closing doors.
- Verifying that stopping times at the stations are observed.
- Starting the train after station stops.

Automatic Train Supervisory System

The ATS system monitors the status of all sub-systems and all trains in operation. This is done by:

- Controlling and coordinating overall traffic movements.

- Maintaining a schematic overview of the entire line for the operators in the control room.
- Providing continuously updated data on each individual train (e.g. position and speed) to stations, points and other equipment on the line.
- Continuously updating registers of alarms, faults and other events regarding all equipment on the line and all processes being performed, whether carried out by the control system or the operators.

Quality assurance for critical safety components

The advantage of using the above functional divisions between ATP, ATO and ATS is that the ATP is the only sub-system that is critical to safety. It is the only sub-system that must be guaranteed never to fail. If a fault arises in the ATO sub-system, for example, the ATP system will intervene before the fault develops into an accident situation. This level of security is achieved by subjecting the ATP system to quality assurance testing in accordance with predetermined standards.

Not a new technology

The technology described above is not new. The principles of the ATP system date back to the turn of the millenium when the first Metros were equipped with ATP systems. ATO and ATS have been operational in the Paris Metro since 1961.

Almost all major railways and metros have some form of ATP system, and many underground railways have been operating with ATS and ATO for many years. The only task performed by a driver in these metros is to press a button that closes the doors and starts the train, which then drives automatically to the next station. There are a number of driverless systems in France, Canada and Japan that have been operating for more than fifteen years.

Automatic door closing and accurate braking

Moving up from an ATO system to a completely driverless system mainly consists of automating the door closing procedure and achieving accurate train braking.

- Door closing is designed to prevent anyone or anything from being trapped between the doors when the train starts to move. If the ATP system registers that just one of the doors cannot close and lock completely, the train cannot depart.
- Target braking is important in a driverless system because the train has to stop with relative precision at the platform doors of the tunnel stations. Therefore, the trains are equipped with several odometers that are constantly updated with their precise position by the ATC system and that compare the mutual results. In addition, the brakes are equipped with an electronic anti-blocking protection system (ABS) and the train motors are equipped with wheelspin protection. Lastly, the ATC system checks the train's precise position at the station before opening the doors.

Entire line operated from the control room

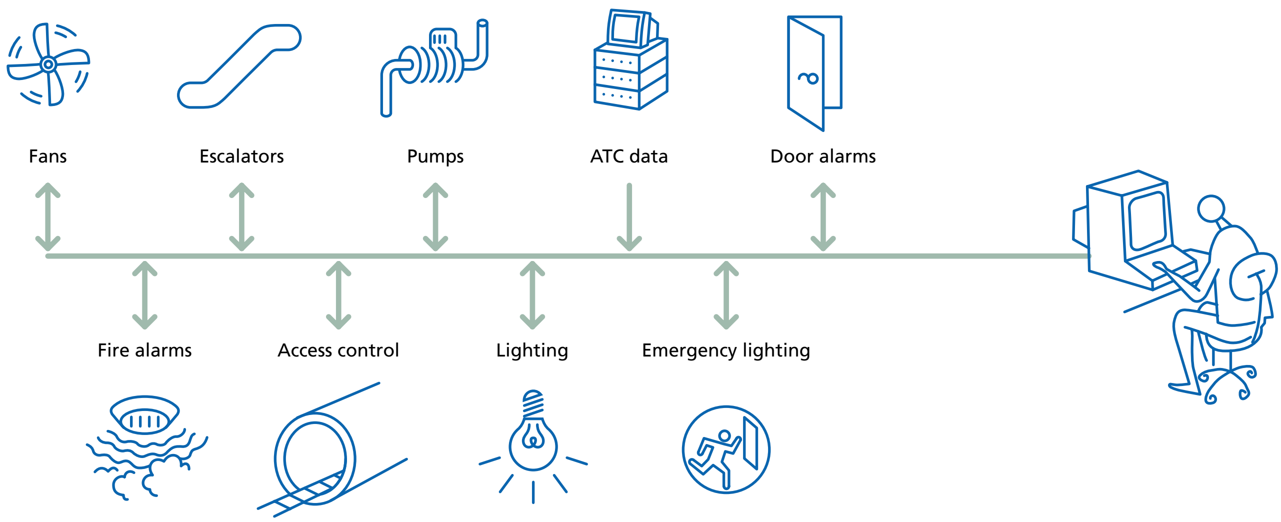
The control room is the core of the Metro and the entire line is controlled from here. The control room is staffed by four to five supervisors who monitor the automatic operations of the Metro round the clock. Typically, two persons are engaged in monitoring and controlling the actual Metro operations. One person is in charge of all communication with call points, loudspeakers, displays and Metro stewards and monitors the station cameras and, if necessary, the train cameras, and one person monitors the operations of the CMC, power supplies and the SCADA system. Under normal circumstances, Metro operations are fully automatic, and the supervisors solely monitor the system. In the event of irregularities, the supervisors intervene in the system operations to re-establish normal operations as quickly as possible.

SCADA SYSTEM

Constant system monitoring
In addition to the control system, the Metro has a great number of technical systems: traction power, other high voltage power, escalators, lifts, display screens, cameras, door alarms, tunnel alarms, tunnel pumps, a ventilation system, electrical equipment monitoring and much more. All these autonomous systems are controlled and monitored by an integrated SCADA system, (Supervisory Control and Data Acquisition). The SCADA system enables the control room staff to run a status check at any time so they can switch on/off or adjust the individual technical systems on the Metro system as required. The SCADA and ATC systems are two independent systems that exchange data.

All technical systems are controlled and monitored in the control room.

Examples of units that can be centrally monitored via the SCADA system.



Most of the Metro's technical railway equipment relies on well-proven solutions in railway technology. Several types of track construction are used depending on the specific line location. All open-air sections are conventional ballasted track. A different type of track construction was chosen for the tunnel, due to working-environment and cleaning considerations. Rails and sleepers are laid in the tunnel. After this, concrete is cast under and between the sleepers. Under particularly sensitive buildings like the Danish National Bank and the Danish Broadcasting Building, measurements are being made to see whether special anti-vibration construction methods are necessary.

Vibration testing

The need for a special vibration-dampening track construction in the tunnel is being studied by recording train vibrations on the test track set up at the Control and Maintenance Centre. The test track consists of three types of track construction: standard, damped and extra damped. Readings from the test track are compared with studies of the dissemination of vibration from the tunnel to the particularly sensitive buildings.

Power supply via power rail

The power is supplied via a power rail (third rail) that runs along the other rails. The power traction is 750 V direct current. The third rail solution was chosen partly because the tunnel diameter can be reduced in comparison with a conventional overhead power line network, and partly to avoid overhead power lines in Ørestad. This is the first line in Denmark to be fitted with this type of covered third rail found in many other metro systems in Germany and elsewhere.

Cross section of tunnel tube showing the track construction and the third rail structure.

Metro Companies

LEGAL STRUCTURE, OWNERSHIP AND BOARD

Ørestad Development Corporation
The Ørestad Development Corporation was founded on 11 March 1993. The formal basis of the Metro and Ørestad is Act 477 of 24 June 1992, on Ørestad, etc., with subsequent amendments (the Ørestad Act). The Ørestad Development Corporation is owned by the Municipality of Copenhagen (55% holding) and by the Danish State, in the person of the Minister of Transport (45% holding). The Municipality of Copenhagen and the Danish State have contributed the large Ørestad site covering 310 hectares to the company. The Ørestad Development Corporation is responsible for constructing the Ørestad Line, i.e. the Metro between Nørreport Station, Ørestad and Lergravsparken.

The Ørestad Development Corporation is managed by a six-member Board of Directors, three of whom are appointed by the Minister of Transport and three by the Municipality of Copenhagen.

Frederiksbergbaneselskabet I/S
In February 1995, the Ørestad Development Company and the Municipality of Frederiksberg jointly founded Frederiksbergbaneselskabet I/S. Ørestad Development Corporation has a 70% holding in the company and the Municipality of Frederiksberg has 30%. Frederiksbergbaneselskabet is in charge of constructing the Frederiksberg line, i.e. the section between Nørreport Station and Vanløse.

Frederiksbergbaneselskabet is managed by a six-member Board of Directors, four of whom are appointed by the Ørestad Development Corporation and two by the Municipality of Frederiksberg.

Østamagerbaneselskabet I/S
In September 1995, the Ørestad Development Corporation and Copenhagen County jointly founded Østamagerbaneselskabet I/S, which is responsible for constructing Østamagerbanen, i.e. the section from Lergravsparken to Copenhagen Airport. The Ørestad Development Corporation has a 55% holding in the company and Copenhagen County 45%.

Østamagerbaneselskabet is managed by a six-member Board of Directors, four of whom are appointed by the Ørestad Development Corporation and two by Copenhagen County.

Signing the contracts for the first phase of the Metro.

ØRESTAD DEVELOPMENT CORPORATION – ORGANISATION

The companies' primary tasks are stipulated in the Ørestad Act:

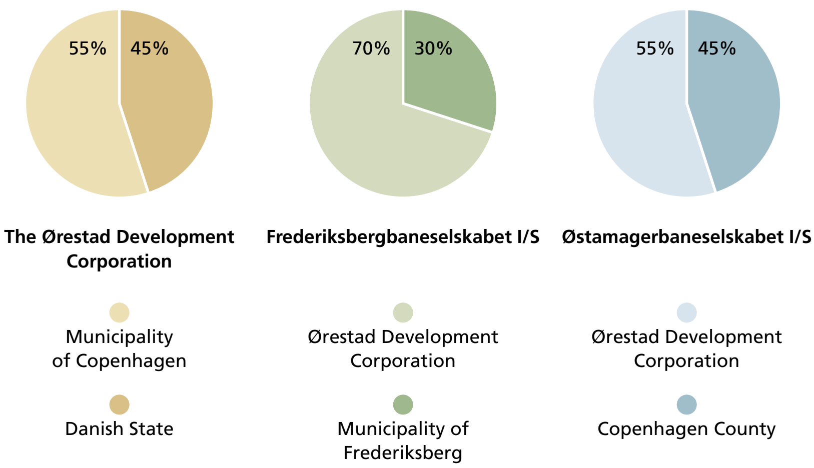
Task 1:
Construction and Operation of the New Metro
The Metro: The Ørestad Development Corporation, Frederiksbergbaneselskabet and Østamagerbaneselskabet are responsible for constructing and operating the Metro. Until further notice, it has also been decided that the administration and technical divisions of the Ørestad Development Corporation shall handle this task on behalf of all three companies.

Task 2:
Development and Sale of Ørestad
Ørestad: The Ørestad Development Corporation shall plan and develop Ørestad, Copenhagen's new urban district. This includes selling sites for development. As part of this process, the company shall also plan and construct the infrastructure of the new district.

Developed according to the New Town principle
The district is being built in accordance with the New Town Principle, i.e. the Metro is being built before the urban district has been built, which will make the surrounding areas increase in value. This increase and the working profit from the Metro will be used to finance the Ørestad Development Corporation's costs of developing the Metro.

Slim and flexible organisation
The Ørestad Development Corporation is organised as an outright development company with a comparatively small organisation, considering the magnitude of the task. As many of the company's tasks as possible will be undertaken with the help of external consultants and advisors. This makes for a slim, flexible organisation that can readily adapt to the changing nature of its tasks.

Ørestad Development Corporation – Ownership



In 1993, the Ørestad Development Corporation issued pre-qualification invitations for the consultancy tasks. After the pre-qualification, bids and evaluation, the contracts were awarded to the following consultants:

Project Management	COWI [DK] (in association with Rust Kennedy & Donkin Transportation Ltd. [UK])
Construction	COWI [DK] (in association with Parsons Brinckerhoff International Inc. [USA], Lahmeyer International GmbH [D], KHR Architects [DK])
Rolling Stock	Carl Bro Gruppen [DK] (in association with DSB [DK], Göteborg Spårvägar [S], Acer Consultants Ltd. [UK])
Railway Technology	Konsortiet Københavns Bybane Konsulentgruppe [DK] comprising Rambøll, KHR and Halcrow (in association with CAP Programmator A/S [DK], DSB [DK], Ødegaard & Danneskiold-Samsøe A/S [DK], Société Génerale de Technique et d'Etudes [F])
Traffic Planning	Carl Bro Gruppen [DK] (in association with Hague Consulting Group [NL], Intraplan GmbH [D], Transportøkonomisk Institut [N], Göteborg Spårvägar [S], Acer Consultants Ltd. [UK])
Architecture, Design and Urban Planning	KHR Architects [DK] (in association with Møller & Grønborg A/S [DK], DSB [DK], Anders Nyvig A/S [DK])
Environmental Planning	Carl Bro Gruppen in a joint venture with ERM [UK]

The above consultants make up the total project organisation of the Ørestad Development Corporation.

Project organisation duties

Since May 1994, the project organisation has:

- Prepared project proposals for three different transport systems – metro, trams and light rail
- Analysed these systems and recommended the most favourable system (the Metro system)
- Prepared tender documentation
- Conducted the tender process including clarification, evaluation and negotiation
- Supervised the work in progress.

Up to 200 staff members

The work has been done in a Project Planning Department that has varied in size depending on the level of activity. In the busiest periods, such as during the bid evaluation process, up to two hundred people were employed.

After the signing of the contract in October 1996, consultancy input has been organised as follows:

- Project follow-up, to ensure that the detailed design complies with the contractual requirements.
- Construction management and supervision, to verify that contractors are carrying out the work in accordance with the detailed design.
- Planning other enterprises that have not yet been put out to tender.

SAFETY APPROVALS

Denmark has no relevant set of rules for the specific safety approval of a railway like the Metro. After a proposal by the Ørestad Development Corporation, the Ministry of Transport has accordingly decided to 'adopt' the German standard, BOStrab.

The practical implementation of the safety assessment and inspection has been handed over to a recognised independent certification institute that will function as the assessor. TÜV Rheinland, Germany, has been selected, with Det Norske Veritas as subcontractor. Final approval and overall inspection are being undertaken by the Railways Inspectorate under the Ministry of Transport. The assessor is financially independent of the suppliers.

A central factor is that the two contractors, Ansaldo and COMET, are obligated to build up their own independent safety organisations that shall include the appointment of a safety officer who is personally responsible for safety during the construction process. In accordance with their contract, Ansaldo's safety officer is in charge of safety for the entire Metro project.

The approval procedure is as follows: Ansaldo applies for approval, supported by its own documentation and an independent assessment from the assessor. This application is then sent via the Ørestad Development Corporation to the Railways Inspectorate. The Railways Inspectorate may at any time consult directly with the assessor or appoint other parties to undertake an assessment at the expense of the Ørestad Development Corporation.

EU – TENDER AND CONTRACT ALLOCATION

The Metro was put out to EU tender in accordance with the EU Public Procurement Directive, with bids submitted after preliminary negotiations.

The Ørestad Development Corporation decided to tender the first phase of the Metro in two large contracts.

A. All construction work, i.e. tunnels and tunnel stations, access shafts, elevated sections and stations, other site works, ventilation system, etc.
B. All deliveries related to the transport system and the subsequent five years of operation. This includes train units, tracks, heavy current, traction power, control system, information systems, the entire Control and Maintenance Centre, construction work vehicles and all operation and maintenance for five years following the opening of the first phase.

TENDER DOCUMENTATION, BIDDING PROCESS AND CONTRACT

Tendering and functional requirements
One of the objectives of the Ørestad Development Corporation is that the Metro is to be a modern future-safe system consisting of proven components with limited development risk. To achieve this, the tender documentation was set up as an entire series of requirements for the design and performance of the Metro without specifying any solutions. This enabled the suppliers and contractors themselves to choose from existing components and technologies. In certain instances, however, it was not possible to specify the functional requirements. For example, the location of stations was for the most part predetermined. This resulted in competitively priced bids and a reduced technological risk in execution.

The decision to opt for two relatively large contracts, rather than many small contracts, is related to the range of functional requirements. Since the suppliers and the contractor shall themselves decide on the technical solutions, it is also appropriate that they control the interfaces between the individual technical disciplines. The fact that the Ørestad Development Corporation opted for just two contracts is related to the fact that the industry itself is naturally divided into a construction sector and a transport sector.

Following the bidding process, contracts were signed on 3 October 1996 with the COMET Consortium and Ansaldo Trasporti S.p.A. for the railway technology of the first Metro phase.

PRESENTATION OF CONTRACTORS

COMET (The Copenhagen Metro Construction Group) is a consortium comprising several large international companies with various construction competencies, which together will carry out the construction part of the project, i.e. stations, tunnels, access shafts, etc. The companies behind the consortium are:

- Soletanche Bachy Ltd., UK
- Tarmac Construction Ltd., UK
- SAE International, France
- Astaldi S.p.A., Italy
- Ilbau Gesellschaft mbH, Austria
- NCC Rasmussen & Schiøtz A/S, Denmark

Ansaldo Trasporti S.p.A. is the transport group of the Finmeccanica Group, which is the largest industrial manufacturer in Italy. The Ansaldo Trasporti division develops, manufactures and sells all sorts of turnkey train systems, from trams to high speed trains, as well as railway control and signalling systems.

The Environment

The Ørestad Development Corporation has implemented an environmental management system in accordance with British Standard 7750 for planning, construction and operation, and the contractors are obligated to do the same. The environmental management system covers the following environmental policies:

- Environmental considerations should be included in all decisions.
- Preventive measures must be taken to reduce energy consumption, the use of resources and the environmental impact.
- Landscape and archaeological values must be protected to the greatest possible extent.
- Efforts must be made to ensure good, healthy workplaces.
- There must be openness about environmental matters, and the public should be kept continuously informed on the company's environmental activities.
- The manpower and financial resources required to comply with our environmental policy must be made available.

A range of environmental targets and standards shall ensure compliance with the environmental policy. Some of the environmental standards are:

In evaluating the bids, an assessment was made as to whether the above criteria would be satisfied, and Life Cycle Analyses (LCA) and Life Cycle Costs (LCC) studies were performed on the bids.

In constructing and operating the Metro, an environmental monitoring programme is being implemented for both the contractors and the Ørestad Development Corporation to ensure compliance with the threshold values agreed on with the authorities in areas like noise and air pollution.

Subject	**Example of standard**	
Noise during construction	Noise impact (Lr) must comply with the following limits measured at the house façade in residential areas:	
	Weekdays 07.00-18.00:	Lr 70 dB
	Other days 07.00-18.00:	Lr 40 dB
	Daily 18.00-07.00:	Lr 40 dB
Noise during normal operations	Outdoor noise impact from trains, stated in day-equivalent, A-weighted noise levels must comply with the following threshold values:	
	Residential and public areas:	LAeq, 24h 60 dB
	Offices, hotels, etc.:	LAeq, 24h 65 dB
Air pollution	Dusty materials shall be kept covered or wetted down during transport.	
Soil and groundwater	Tunnelling must not cause the pollution of soil and/or groundwater	
Waste	Contractors must sort waste so that as much as possible can be recycled. Sorted waste is to be stored so as not to reduce the possibility of disposing of the individual components.	

General Data

Phase 1
Phase 2a
Phase 2b
Phase 3

Phases	Phase 1	Phase 2A	Phase 2B	Phase 3	Total
Length	11 km	3 km	2.8 km	4.2 km	21 km
– Tunnels	6 km	3 km	0.7 km	0 km	9.7 km
– Elevated	3 km	0 km	0 km	0.2 km	3.2 km
– Embankment / surface	2 km	0 km	2.1 km	4.0 km	8.1 km
Stations	11	2	3	6	22
– Tunnel stations	6	2	1	0	9
– Elevated stations	3*	0	0	6	13
– Embankment stations	2*	0	2		
Access shafts	6	4	0	0	10
No. of train units	19	7		8	34

* Excluding stations to the north and south of Ørestad, which will open later.

On 16 February 2001, the Tunnel Boring Machine Liva broke through to Frederiksberg Station thereby concluding 36 months of successful boring in the Copenhagen underground.