Copenhagen Cityringen Metro Stations

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1.0 Introduction

Cityringen Metro in Copenhagen was, with the submission of tender documents to prequalified contractors, tendered in October 2009 and contracts with successful contractors are expected to be signed in September 2010. Cityringen is planned to open in 2018. Cityringen is a 15.1km long circular underground metro system with 17 stations.

Cityringen Metro in Copenhagen is a good example on the general trend in development of large cities worldwide, to utilise underground space in order better to be able to meet the increasing demand for public and private transportation, while simultaneously considering environmental friendly solutions. By the use of underground space for metro systems, the pressure on existing transportation systems with insufficient capacity at street level is eased, the supply of public transport is increased and in best case urban spaces can be freed for more recreational purposes due to less transportation at street level.

Figure 1 Cityringen alignment.
Cityringen is the second metro system being implemented in Copenhagen, but more metro lines are already being considered as part of a long term transportation planning within the greater Copenhagen. Cityringen will run perpendicularly to and connect to existing railway and metro lines and link areas within the city which today are mainly connected by bus routes. As a result travel times will be reduced, and the mobility between some of the densest residential and work areas of the city will be improved significantly. The increased mobility will generate better conditions for the citizens in general and it will create better conditions for the economy. With the implementation of Cityringen, Copenhagen is taking an important step towards becoming a modern city prepared for the transportation challenges of the future.

Great effort has been given to locate the 17 underground stations at optimal locations in the City and to design and shape them in order to obtain the most optimum station layout and geometry for the passengers and to ensure an optimal fit to the local urban environment at street level. The paper presents the Employer’s station Tender Design with examples for three different underground station types. The reason for the stations being tendered as they are, is discussed including how station works are split into different contracts and contract types and to which level of detail the civil works are tendered.

2.0 Project organisation

Cityringen’s Employer is Metroselskabet I/S (MS), the former Ørestadsselskabet I/S. MS is a fully public owned company with the owners being the Danish State (41.7%), Copenhagen Municipality (50%) and Frederiksberg Municipality (8.3%).

The Employer’s consultant for civil works is CAS JV, an international consultant joint venture consisting of COWI A/S (DK), ARUP (UK) and SYSTRA (F). The consultant services comprise both services for civil engineering, architecture and mechanical and electrical engineering. The Employer also employed other consultants, mainly for the transportation system and for area, rights and utilities.

3.0 Station locations and layouts

Station locations were defined in a Programme Study (“Udredningen om Cityringen”) carried out by the Danish Ministry of Transportation and the Municipalities of Copenhagen and Frederiksberg during 2002 through 2005 [1], and in the Cityringen Law (“Lov om en Cityring”) [2], which was rectified in 2007. The exact locations were, however, to be defined in detail during Conceptual Design and Tender Design phases.

During the Conceptual Design and the Tender Design phases from October 2007 through October 2009 the underground stations design was developed and defined in great detail. Stations were developed on the basis of the deep underground stations from the existing metro with the intention to keep all Copenhagen metro stations, including the new Cityringen stations, within the same “family”. All stations on Cityringen vary; however, to some degree in their design and some stations have their own unique configuration, due to local constraints in the urban environment. Compared to the solutions outlined in the Programme Study, some stations were further developed on the basis of new architectural and structural ideas and solutions. The 17 stations of Cityringen can be divided into three station types:

- “Deep underground stations” (12 nos.) of which the design follows the basic concept of the existing metro deep underground stations with platform 20m below ground.
- “Semi shallow stations” (2 nos.) of which the design concept is developed on the basis of the deep underground station design, but with platform only 15m below ground level.
- “Special stations” (3 nos.) within the City Centre with their own unique configuration due to local constraints and requirements.

During the design phases also the surface area layouts of the stations were developed and discussed with the Municipalities, and the exact station positions as well as the positions of station elements at street level, including main stairs, emergency exit stairs, skylights and ventilation openings were defined, as the position of the openings to a great extent were dictated by the underground station design.
4.0 Tender Design of stations

In this section some examples of station Tender Designs are presented to provide an impression of the stations the Copenhagen citizens will enter in 2018. A station from each of the above categories of station types is presented, namely the stations at Nuuks Plads, Vibenshus Runddel and Marmorkirken, although Marmorkirken station can not be considered as representative for the other special stations which have their own unique configuration.

4.1 Nuuks Plads deep underground station

Nuuks Plads station is located at a small square outside the City Centre beside a very trafficked ring road, Jagtvej. The station is in layout and construction technique quite similar to the existing metro stations. All station functions, with the exception of the main stair and emergency exit stair, are contained within a deep rectangular cut & cover box structure with an external width of app. 21m, length of app. 66m and a depth of app. 24m. Access to station is from street level down the main stair via a concourse area located 7m below street level and from here via two flights of escalators, two up and two down, to the platform 20m below ground. The platform is a 44m long and 7m wide island platform. Alternative access from street is provided via two parallel lifts. Lifts are go-through lifts and provides also access to the concourse area. Public spaces within the station are shown in blue on figure 2 below.

Station construction is with deep retaining walls with a permanent in-situ cast concrete inner lining. Structural walls and slabs are of in-situ cast concrete.

Figure 2 Nuuks Plads station.
4.2 Vibenshus Runddel semi-shallow station

Vibenshus Runddel station is located within a park outside the City Centre beside a very trafficked ring road, Jagtvej. The station is in layout and construction technique quite similar to the deep underground stations, with a rectangular cut & cover box structure with an external width of app. 21m, length of app. 66m and a depth of app. 19m. As for the deep underground stations, the main stair and emergency exit stair extend outside the main station box, and due to the restricted space inside the main station box, compared to the deep underground stations, the semi-shallow stations have in addition two shallow underground appendices for technical facilities which are not possible to locate inside the main station box. Public spaces within the station are shown in blue on figure 3 below.

Access to station is from street level down the main stair via a concourse area located 7m below street level and from here via one flight of escalators, two up and two down, to the platform 15m below ground. The platform is a 44m long and 7m wide island platform. Alternative access from street is provided via the two parallel lifts. Lifts are go-through lifts and provides also access to the concourse area.

Station construction is as for the deep underground stations with deep retaining walls with a permanent in-situ cast concrete inner lining. Structural walls and slabs are of in-situ cast concrete. Shallow underground structures are concrete structures constructed within temporary retaining walls.

Figure 3 Vibenshus Runddel station.
4.3 Marmorkirken special station

Marmorkirken station is a station with a unique configuration, located at a small site within the City Centre between the dominant church Frederiks Kirke, also called Marmorkirken - or “the Marble Church”, and the very trafficked road, Store Kongensgade. The station consists of a shallow main stair structure and a narrow and deep station body which connects the concourse area with an underground cavern housing the metro tracks and the platform. As the narrow station body provides only limited space for technical facilities, space for technical installations are provided in two station end shafts. The length of the station structure is app. 79m and the narrow station body is app. 12m wide. The below cavern is app. 20m wide. Access to station is from street level down the main stair via a concourse area located 6m below street level and from here via three flights of escalators, two up and two down, to the platform 24.5m below ground. The platform is a 46.2m long and 7m wide island platform. Alternative access from street is provided via the two parallel lifts. Lifts are go-through lifts and provide also access to the concourse area. Public spaces within the station are shown in blue on figure 4 below.

Station construction is with deep retaining walls with a permanent in-situ cast concrete inner lining. Structural walls, beams and slabs are of in-situ cast concrete. The cavern housing the platform and metro tracks is constructed by the use of Sprayed Concrete Lining (SCL) techniques. Due to the restricted space and the listed and vulnerable adjacent buildings, including the 18-19th century church, design and construction is particularly challenging in order to fulfill strict requirements e.g. to groundwater control and to limit settlement during construction, which may require an extensive use of grouting and/or ground freezing techniques.

Figure 4 Marmorkirken station.
5.0 Tendering station works in different contracts

Considerations on how to tender the Cityringen station works were given on the basis of lessons learned from the existing metro system, as well as trends and experiences from the international civil works industry. All experiences and lessons learned were tabled and discussed and arguments for various solutions had to be proven valid before final decision was taken.

The pros and cons of tendering design and build contracts with either functional requirements or alternatively detailed project requirements are described in [3]. Generally, the philosophy defined in [3] is that "a project part, which will be very visible in the operational phase and will be exposed to the public, will require many requirements to geometry, layout and architecture. Also a large number and high complexity of interfaces between contracts and to third parties will require many requirements to manage the interfaces." Further it is stated that "these types of project parts could be ideal for a general construction contract based upon the Employer's Detailed Design. The alternative is a design and build contract with very detailed project requirements." On the other hand, as stated in [3], "a project part that will not be directly visible to the public during operation, and involve fewer and simpler project interfaces will require less detailed project requirements. … These types of project parts are ideal for design and built contracts, where the Employer can exploit that the different tendering contractors will have different skills and experiences in the use of different construction methods." In general, the public spaces within the stations and the station surface areas are exposed to the public and fall within the former category whereas underground works, such as tunnels, shafts and main station structures, not exposed to the public, fall within the latter category.

The existing metro was tendered as a design and build contract based on functional requirements. During the design process the Employer ended up providing greater input than expected to the contractor’s design of elements exposed to the public, i.e. mainly the station finishes which were part of the civil works contract, compared to how the civil works contract was actually tendered. Further, the interface between station civil works and the above station surface areas, which was designed after or simultaneously with the contractor’s design of the underground stations, proved to be very complex and required great effort in the design coordination and adjustments to the civil works station structures.

On the basis of these lessons learned, it was, for the Cityringen project, the Employer’s intention to take control over certain project parts or design elements. Considerations were given on how to split the works into different contracts and to which detail the various contracts should be tendered, i.e. to which detail the project requirements, including requirements to interfaces between the different contracts, should be developed prior to tender.

Based on many considerations and ongoing discussions between the Employer and the consultants in parallel with the design work, it was decided to tender stations in the following contracts, of which the Employer decided to carry out the Detailed Design of the two latter ones:

- Civil works
- Architectural finishes
- Station surface areas (more contracts)

The overall decision was to tender civil works in two almost equal size design and construction contracts, namely the Civil Works North Contract and the Civil Works South Contract. Contracts were for the station parts decided to be tendered with detailed requirements to layout and geometry of public spaces and with well-developed and well-defined interfaces to the architectural finishes within the stations and to the station surface areas, for which reason the design of these project parts was advanced to a sufficient detailing in parallel with the Tender Design of the civil works. Other project parts of the civil works contracts, such as tunnels and shafts were tendered with fewer requirements to layout and geometry.

Architectural finishes scope includes in general for all station spaces exposed to the public, floors and paving, wall claddings, doors, security gates, handrails and balustrades, skylights, signage, station furniture and other visible design elements. Architectural finishes will be designed simultaneously with the
civil works contractor’s design to ensure that the two designs are coordinated. The works will be tendered as a general contract, and the successful contractor will be nominated as subcontractor to both civil works contracts. It is the intention hereby to let the civil works contractor take responsibility for all construction interfaces between civil works and the architectural finishes.

Station surface areas scope includes in general all works at the surface above the stations including sub base and paving, surface drainage systems, surface area furniture, surface lighting and planting. Station areas have many interfaces to the surrounding urban environment which require coordination with the local Municipalities. Station surface areas will also be designed simultaneously with the civil works contractor’s design to ensure that the two designs are coordinated. Station surface areas will be tendered in general contracts to be carried out after completion of the civil works.

6.0 Tendering station civil works

The basic idea of tendering station civil works as design and build contracts with fixed layout and geometry is to ensure that the Employer retains control over spaces fully or occasionally exposed to the public. For this purpose the following station spaces were defined:

- Public spaces
- Emergency escape spaces
- Space for bicycle basements
- Civil works spaces
- Transportation system spaces
- Employer’s spaces

Figure 5 Example of geometry and setting out drawing, concourse level of Nuuks Plads station.

Stations main geometry, including station position, main levels and layout and geometry of public spaces, emergency escape spaces, spaces for bicycle basements and station elements at surface level were...
defined by the Employer, whereas the contractors would retain some flexibility in defining layout and geometry for the remaining types of spaces in order to suit their own technical solutions and systems. In order to be able to do so, station layouts and interfaces between contracts were developed, coordinated and described to great detail during Tender Design, although final interface agreements are still subject to coordination between the parties involved, leaving some room for manoeuvre for the Detailed Design.

In order to take full control over the spaces mentioned, the Employer also needed to take the responsibility that the station layouts and geometry fulfil all requirements necessary to obtain all required approvals in relation hereto. This meant that the Employer’s consultant carried out detailed passenger flow analysis and emergency egress calculations to ensure the required capacity of access ways as well as emergency escape routes.

Requirements were defined in "Cityringen Common Basis" (CCB), a common document for transportation system and civil works contracts, and "Civil Works Project Basis" (PB) text documents and drawings valid for the civil works contracts only. In order to provide the tendering contractors with a possible solution a "Project Outline" (PO), description and drawings were issued as well. Further "Project Information" (PI) documents and drawings were issued for information to the tendering contractors providing amongst other information on other project parts to which the main contracts would have a contract limit.

An example of a typical concourse level layout from a geometry and setting out drawing is shown on figure 5. From the figure it can be seen how layouts and geometry of concourse level public spaces, emergency escape spaces and spaces for bicycle basements are fixed, whereas technical areas are not defined in detail providing the contractor some flexibility for his design. Similar plans were provided for all other stations and for all other station levels such as roof levels, technical levels, intermediate levels, platform levels and below platform levels.

The very detailed requirements to station geometry and setting out resulted in a very large drawing production during the Tender Design phase. The total numbers of station drawings issued for the two civil works contracts were 552, excluding M&E installations, split as indicated in table 1 below. Of the 552 drawings, 248 drawings will form basis for the contracts, whereas the remaining 304 drawings were provided to the contractor for information in order to provide him with a good basis for developing his most optimal Bid Design.

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Table 1 Tender drawings issued for Cityringen stations, civil works**
(*drawings which will form part of contract, **drawings for M&E installations are not included).

References

