Risk Reduction Strategy
Employed for the
Copenhagen Metro

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International Conference
Reducing Risk in Tunnel Design
and Construction
Basel, December 1998
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ABSTRACT

Tunnelling and underground construction works in the congested area of an ancient city centre impose risk to all parties involved as well as to those not directly involved in the project. This paper describes the risk reduction strategy employed for the development and construction of the Copenhagen Metro. It is acknowledged that identification of risks and potential risk reduction measures should be made at the conceptual design stage of a project. A description is given of the process involved in identifying the risk and the risk management established to control the risk throughout the project development from the early stage of design through detailed design to construction works.

In conclusion risk assessment have been used throughout the project development to identify significant hazards and potential risk reduction measures. Whenever possible these have been implemented to reduce all health and safety technical and commercial risks to manageable levels.

1 INTRODUCTION

Front page articles in the news from the Heathrow Express tunnel collapse in October 1994, the Munich Metro tunnel collapse in September 1994, the Los Angeles Red Line sink hole in Hollywood Boulevard in July 1995 and the flooding of the Storebælt tunnel in October 1991 and the TBM fire in June 1994 focused the public and in particular potential tunnel clients attention on the inherent risk associated with underground works construction.

Working since 1994 as the Client's adviser for the development of a 5 billion DKK (700 million ECU) metro system including 16 km of tunnels under the ancient city centre of Copenhagen COWI advised the Client to implement a risk management strategy in the early design stages of the system development. The strategy included a hazard identification in the early design stage followed throughout the design stages by risk assessments of the construction activities.

Following a short description of the project this paper describes the establishment of the construction risk policy and the risk assessments performed in the early design stages and during the tender evaluation process for the civil works contractor. The paper also describes the risk reduction measures identified during the course of the risk assessment and consequently implemented in the contract documents.

The purpose of the paper is to provide an overview of the risk reduction strategy employed. Details of the methods used are described in Eskesen (1997) and Kampmann (1998).
The risk assessment work continues during construction of the Metro. Although the experience with this work now covers approximately two years, this experience is not described in the present paper. It is envisaged to report hereon when significant parts of the work have been completed.

The Copenhagen Metro is being developed by Ørestadsselskabet I/S, a partnership between the Copenhagen Municipality and the Danish State Ministry of Finance formed in 1993 for the purpose of implementing the Metro system. Ørestadsselskabet chose the strategy to hire consultants to provide project management, preliminary designs, contract documents and construction management and contractors to implement detailed design and construction. COWI is in charge of project management, preliminary design of civil works and preparation of tender documents for Civil Works Contract as well as in charge of the construction management. The contractor for the civil works contract is COMET, an international joint venture between Tarmac UK, SAE International France, Bachy Soletanche UK, Ilbau Austria, NCC Rasmussen & Schiotz Denmark, and Astaldi Italy.

2 THE METRO SYSTEM

The Copenhagen Metro is a new mass transit system that will connect the central part of Copenhagen with a new township with travel times of about 7 minutes, as shown in Figure 1.

![Figure 1 Alignment of Metro (the thin lines indicate later extensions)](image)

The first phase of construction comprises 14 km of double track with 13 stations, of which 8 km and 8 stations will be underground. Second and third construction phases will add a further 8 km of line and 10 stations to the system, mainly at surface level. The first phase of the system is planned to start operation in the year 2001, and the second and third phases are scheduled to follow 2 and 4 years later.
2.1 Existing conditions

The geological stratification of the project area may generally be described as follows, from ground level downwards:

- Recent deposits of fill and topsoil generally 2-6m thickness, in places up to 10m
- Quaternary, glacial deposits of tills (clay, sand and gravel) plus meltwater sand and gravel (8-15m thickness).
- Copenhagen Limestone (35-50m thickness) divided into 3 stratigraphical sub-units: Upper, Middle and Lower. The limestone contains flint beds up to 25%.

The tunnels and the base of the deep underground stations are in general located in the Upper and Middle Copenhagen Limestone strata.

The tunnel alignment passes below the central part of the City of Copenhagen, where many sensitive buildings may be affected by even minor changes in the foundation conditions, caused by either ground settlements or groundwater lowering. The construction of the Metro could, therefore, effect both the stability of buildings and lead to the formation of cracks resulting in structural damage, unless adequate precautions are taken during the design and execution of the works.

Within the construction area, there are buildings spanning a wide age range, from the medieval period to modern times. Many of the 17th and 18th century buildings are founded on timber piles, which cannot tolerate any lowering of the groundwater table. Rot and fungus tend to attack the tops of timber piles if these are exposed above the protective effects of the groundwater. Other old buildings are founded on a layer of stone laid directly on fill. This type of foundation is highly sensitive to settlement and to changes in the groundwater conditions.

2.2 Tunnels

During the design development, comparative studies were made between TBM, NATM and Cut & Cover tunnelling methods, all of which are considered technically feasible for the conditions in Copenhagen.

For the greater part of the tunnel alignment TBM bored tunnels were selected, because of their minimum impact on the environment, high degree of construction safety and cost effectiveness for the actual length of the tunnels, see Figure 2.

NATM tunnelling has been limited to lengths where non-circular cross sections are required for excavation in the limestone for the emergency shafts, and for excavation an underground cross-over cavern, TBM launch chambers, two bifurcation chambers, and cross passages, refer Figure 2.
Cut & Cover tunnelling was limited, too, because of the disturbance it causes to the surface structures, and high construction cost. This method is used only where the cover is insufficient for bored tunnelling.

2.3 Underground stations

The underground station design proposals considered during development of the project covered a wide range extending from 25m wide underground caverns, through the traditional London Underground type small cavern station, to a variety of cut and cover layouts, including stations with two track levels.

The proposed construction method utilises cut and cover construction techniques for the deep station excavation. This method, combined with small diameter single track tunnels, allows the highest possible level of the station platform, in most cases only 18m below street level.

The architectural requirements of the station space have a major impact on the structures. The three main requirements are:

- undisturbed overview of the full passenger area (no concealed areas)
- daylight at platform level
- minimalistic design

All deep underground stations have the architectural layout as illustrated in Figure 3.
2.4 Tender Process and Contract Basis

The tendering and contracting process was based on EU Council Directive 93/38/EEC following the principle of tendering after negotiations. The objective of the evaluation process was to determine which tender was the economically most advantageous to the Employer. The tenders were evaluated on listed criteria, which were subdivided into the following groups: project, construction, organisation and cost.

The tender documents issued to the pre-qualified Tenderers included a Project Outline indicating a possible solution fulfilling the functional requirements in the tender documents. The Tenderers were not obliged to follow this Project Outline.

The tender evaluation process was performed in stages. Each stage consisted of an evaluation and short-listing of the tenders to eliminate the lower ranked tenders. At each stage the Tenderers not on the short list to the next stage were informed about the weak points in their bids (price, quality, organisation etc.) noted by the Employer, and they were given the opportunity to change their tender within a certain deadline.

At the last stage the remaining Tenderers were requested to state their final offer, improving on the technical quality and financial aspects raised by the Employer during negotiations. The Employer then selected the economically most advantageous tender without further negotiations. The Tenderers were informed, in advance, of the tender assessment process and the evaluation criteria, prior to submitting their bids.

The contract is a design and construct contract on a lump sum basis.
3 CONSTRUCTION RISK POLICY

Management of construction risks was identified as an essential task early in the project. A construction risk policy was therefore established, indicating scope, risk objectives, and risk management strategy.

The types of risk covered are:

1. Risk to the health and safety of workers and third party people, including personal injury and, in the extreme, loss of life,
2. Risk to third party property, specifically normal buildings, cultural heritage buildings and infrastructure,
3. Risks to the environment including pollution, and damage to flora and fauna,
4. Risk to the Employer in delay to the completion
5. Risk to the Employer of financial loss.

The general objective of the construction risk policy is to reduce all risks covered to a level as low as reasonably practicable, i.e. the ALARP principle. Emphasis is given to minimising overall risk by reducing the likelihood of occurrence of accidents with large consequences, e.g. with several fatalities.

For each type of risk, specific minimum risk objectives are defined in addition to the general ALARP requirement. For example, the general public should be exposed only to an additional risk from construction of the Metro which is small compared to the risk they are exposed to as users of buildings, cars, bicycles, public transport and when walking in the adjacent streets.

The risk management strategy adopted according to this construction risk policy is to carry out construction risk assessments at each stage of design and construction in accordance with the information available and the decisions to be taken at each stage.

4 EARLY DESIGN STAGE RISK ASSESSMENT

During the early design stage, a qualitative risk assessment of the construction activities expected to be included in the project was carried out covering all types of risk covered by the Construction Risk Policy.

The main purposes of this work were to raise the awareness of all concerned to the major risks involved in the construction, to provide the basis for input regarding management of construction risk in the Tender Documents and to prepare the Client and the project team for the risk aspects prior to the contract negotiations.

The assessment was operated as a top down study. The process of identification relied upon a review of world-wide operational experience of similar projects drawn from the literature with written submissions from partner companies, and discussions with qualified and experienced staff from the project team and other organisations around the world. Keeping in mind that this was a top down assessment, some 40 individual hazards were identified and grouped under the following headings:
It is a general requirement to all risk assessment work that it shall be completed in sufficient time that any risk reduction measure identified can be implemented.

7 CONCLUSION

On the basis of the experience with construction risk assessment for the Copenhagen Metro the following can be concluded:

1. The establishment of a construction risk policy at an early stage in a project enables an uniform attitude and awareness towards risk to be established

2. It is recommended to identify risk and candidate risk reduction measures as early as possible in the project development. During the early design stage there are several parameters which can be adjusted to reduce the risks, whereas in the later design stages several decisions have been frozen, often the alignment and the tunnelling method, and the numbers of parameters in play to reduce the risk are less global and more limited in their effect.

3. The risk assessments was performed as round table discussions with expert judgements. It provided a useful forum for discussion and understanding the risks issues and it assisted in maintaining an awareness of the risk issues by the project team throughout the project development and implementation.

4. The risk assessment carried out during tender evaluation provided an important contribution both to the selection of the Contractor and in the development of the final Contract during the negotiations.

5. Requirements to the Contractor's risk assessment work were included in the Tender Documents and further detailed during contract negotiations. It is thus ensured that construction risk assessment is used as a tool from the early design stage to completion of construction.

8 REFERENCES


