Groundwater management in central Copenhagen for the construction of the fixed link across the Øresund

Gestion des eaux souterraines au centre de Copenhague dans le cadre du projet liaison permanent à travers le Sund

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ABSTRACT: This paper presents groundwater management and control applied in the construction of the landworks in central Copenhagen for the fixed link to Sweden. The paper describes handling of environmental groundwater issues by the use of a 3-D groundwater model for the entire Copenhagen area based upon 3-D interpretated geology extracted from a large database. Furthermore, the paper describes the groundwater management interplay between the design- and construction phases. The management and control programme has included a major monitoring programme with reporting to the municipalities.

RESUMÈ: Cette note présente le systéme de gestion des eaux souterraines utilisé dans le cadre des excavations pour les constructions à terre pour la liaison pérmanente avec la Suède. La note concerne le manipulation des sujets environmemetaux des eaux souterraines par l'utilisation d'un modèle informatisée en 3-D. Ce modèle est basé sur un modèle geologique interprête en 3-D et etabli à partir d'une base des données de forage complet de la metropole de Copenhague. En plus la note décrit l'interaction des eaux souterraines entre les phases de la concéption et de la construction. Le programme de gestion et du contrôle a compris une grand programme de surveillance avec réportage aux autorités municipales.

1. INTRODUCTION

In march 1991 the Swedish and the Danish governments agreed to establish a fixed link across the Øresund between Copenhagen in Denmark and Malmö in Sweden. This agreement was followed up by the Danish decision to construct landworks comprising 2 railway alignments and a motorway extension. A 12 km. passenger track from the Central Station of Copenhagen to Copenhagen Airport at the coast and a 4.2 km freight track through the southern parts of Copenhagen are to be built. The motorway consists of an 8.6 km extension of the existing motorway to the coast.

The landworks are constructed by A/S Øresundsforbindelsen (ASØ), which is a state-owned limited liability company. The construction works began in 1993 with a total investment of approximately USD 800 million. The Danish landworks are expected to open in 1998 and the entire Link in the year 2000.

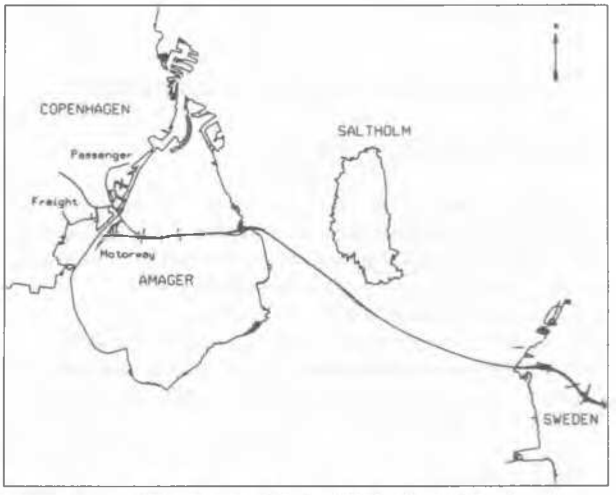

Figure 1. The Øresund Link with the Danish landworks.

The passing of the act was preceded by almost 6 months of intense public debate, which focused very much on environmental issues. Based on this debate and the experience gained from large projects, the Act contains environmental guarantees for both the operational and the construction phase, including groundwater conditions.

2. THE GENERAL ENVIRONMENTAL POLICY

The Construction Act contains an Article describing the environmental requirements which apply to the Øresund Link. The Article reads:

- Final characteristics of the Fixed Link and landworks shall be executed with due consideration to what is ecologically motivated, technically feasible and financially reasonable in order to prevent any detrimental effects on the environment.
- Quality objectives shall be stipulated for the environmental effects of the works on the Baltic and the Øresund as well as on land, which, together with a monitoring and a control programme, are to be approved by the Ministry of Transport after consultation with the Ministry of Environment before starting the works.

ASØ decided to be certified both for environmental management according to BS7750 and for quality management according to ISO 9001. All ASØ's Contracts, be they with Contractors, Consultants or other Suppliers, stipulate compliance with a general environmental management system prepared on the basis of BS7750. Based on the this general system, detailed environmental action plans have been prepared for all Contracts.

Two of the overall environmental groundwater action plans prescribed by ASØ state that during groundwater lowering, the present withdrawal of groundwater shall be maintained to the greatest extent possible and the water quality in the harbour may not deteriorate significantly.

This has resulted in the following general instructions to the contractors:

- the groundwater lowering shall be kept to a minimum of what is necessary according to constructions
- discharge of groundwater must not result in contamination of sea, lakes and ponds, streams or groundwater

In order to guarantee that these objectives can be fullfilled, each contractor is to prepare an action plan before commencing work, describing the handling of groundwater lowering including methods of lowering and place of discharge.

As a tool for the groundwater management and for general control of soil conditions and relations/reporting to the municipalties, the contractors have been contractly instructed to record all borehole data in a standard digital form and to report the resulting data monthly to the central database (BRegister):

- amount of discharged fresh and saline groundwater
- water level measuremets
- chemical analyses

3. DEVELOPMENT OF A 3-D GROUNDWATER MODEL

3.1 *Geology of central Copenhagen*

The geology of central Copenhagen comprises soil infill and glacial till in thicknesses from 0.5 to 8 meters. Sand lenses are in some areas found in the glacial till and in some areas sand strata are found directly overlying the limestone. The limestone is found at depths between 4 and 12 m below ground surface, cf. the longitudinal section shown in figure 2. One major fault in the prequaternary are of major importance for the hydrological conditions in central Copenhagen. The fault is shown in figure 4.

3.2 *Borehole database.*

In 1988 a large relational database, called BRegister, was developed for storage of geological, geotechnical and soil related environmental data. The database consists of over 5000 borings all over Copenhagen coming mainly from geological and environmental investigations carried out by public institutions and private companies. The borehole data is backed by geophysical data from borehole logging and site investigations. Figure 3 shows the intensity of borehole data in central Copenhagen.

In order to monitor and protect the notable water supply in central Copenhagen, a 3-D geological model was developed in 1990 based on information from the BRegister database. Digital mapping of both the quaternary deposits and the prequaternary surface was carried out. The mapping was carried out in scales from 1:500 to 1:25.000 according to the density of data information. The quaternary sediments were divided into approximately 20 units such as: lower meltwater gravel unit, upper sand till unit, fill unit etc. The extent and distribution as well as the elevation of the upper and lower

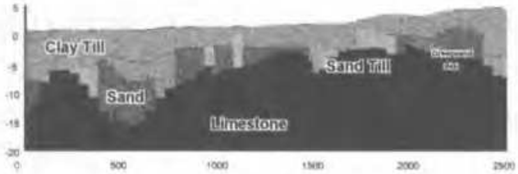

Figure 2 Typical longitudinal profile of central Copenhagen.

Figure 3 Intensity of borehole data in central Copenhagen.

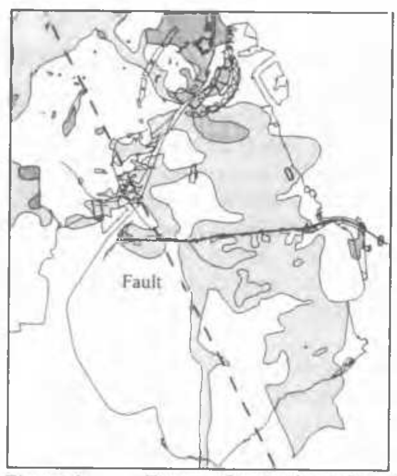

Figure 4 Extent of upper boundary level of sand layer resting directly on the Prequaternary.

surfaces of each unit have been mapped and entered into the computer as a 3-D geological model using the modelling tool SHE (Systeme Hydrologie Européne) which is a finite difference model tool. In figure 2, the extent of sand directly overlying the prequaternary surface is shown.

The hydrogeological model was established by adding hydrogeological parameters to each unit of geology, by implementation of transmissivities of the prequaternary, by implementation of hydraulic heads and by adding recharge, controlled by the character of the ground surface and by implementation of water supplies. In table 1 the parameters added to fill , quaternary units and prequaternary are listed.

In Copenhagen the groundwater conditions are affected by leakages to the main sewage pipes and therefore the sewage pipes have been implemented as a drain function in the model in order to complete the model calibration.

Table 1 List of hydrogeological parameters added to fill, quaternary deposits and prequatenary.

Geological Layer	Horizontal permeability k_H 10^{-7} m/s	Vertical permeability k_V 10^{-7} m/s	Specific storagecoeff. S, 10^{-5} m^{-1}	Porosity n (%)
Fill, clay	1	0.5	4	30
Fill, sand	800	100	3	20
Peat	60	60	3	60
Silt, meltwater	60	60	3	20
Sand, meltwater	800	100	3	20
Gravel,upper meltwater	5000	1000	3	15
Gravel, lower meltwater	800	100	3	15
Clay till	1	0.5	2	30
Sand till, upper	10	3	3	20
Sand till, lower	50	8	3	20
Till, varying	20	10	3	20
Till, local	20	0.5	3	15
Limestone w. glauconite	1	0.5	2	15
Limestone, lower	1	0.5	2	15
Limestone, upper,	variable	variable	2	15

4. THE PROJECT BACKGROUND (DESIGN)

For the final design of the two railway links and the passenger link, one of the main design criteria has been that the noise from cars and trains should be reduced to what was technically feasible and economically reasonable. At the same time the permanently discharged groundwater should be minimized. This lead to the general environmental dilemma illustrated in figure 3.

The design phase of the two railway links and the motorway link has therefore been divided into phases where each phase has included several environmental and economical evaluations. The environmental groundwater impact from temporary and permanent dewatering at different vertical alignments has been evaluated by the use of the 3-D groundwater model. Furthermore, the amount of discharged temporary and permanent groundwater has been calculated by the use of the model. Figure 4 illustrates the areas where the alignments are situated below groundwater level, and figure 5 illustrates where the alignments have been elevated 1-2 m due to general environmental evaluations, including the results from the 3-D simulations.
The discharge results from the 3-D simulations with the two different alignments are shown in table 2.

5. GROUNDWATER MANAGEMENT (CONSTRUCTION).

The main purpose of the groundwater management programme in the construction phase has been to ensure that the objectives given in the construction act could be fulfilled.

As described in section 2, all information relevant to soil and groundwater conditions has been implemented in the BRegister database. This procedure has made the following possible in the construction phase:

- to make an running revision of the geology and groundwater situation available for the contractors on request
- to compare and revise the hydrogeological model for more accurate 3-D groundwater modelling if necessary

Figure 5 Basic design problem

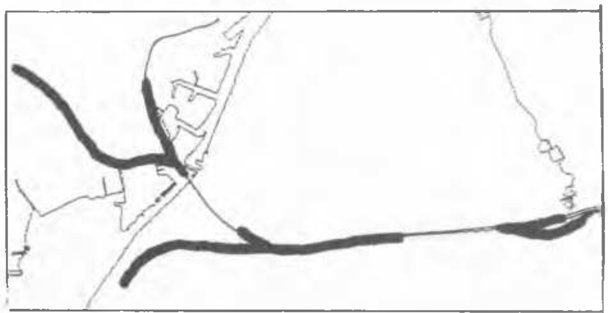

Figure 6 Areas where the vertical alignments are situated below groundwater level.

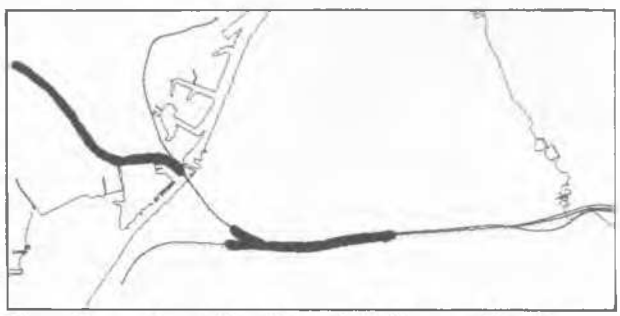

Figure 7 Areas where the vertical alignments have been elevated 1-2 m.

Table 2. Calculated discharges at two alternative vertical alignments.

Location	Alternative 1 (1000 m^3/year)	Alternative 2 (1000 m^3/year)	Reduction (%)
Copenhagen Construction phase	320	220	30
Amager West Construction phase	1900	1600	20
Copenhagen Operational phase	700	440	35
Amager West Operational phase	1650	1350	20

- to analyse changes in the hydraulic head at critical spots
- reporting of environmental soil and groundwater problems

On the basis of the dewatering time schedules from each contractor, prognoses of the groundwater situation have been made continuously throughout the construction period. Figure 6 and 7 illustrates forecasts of simulated lowering of the water table in central Copenhagen and Amager based upon implementation of the dewatering action plans received from the contractors.

Furthermore, the model made it possible to forecast the

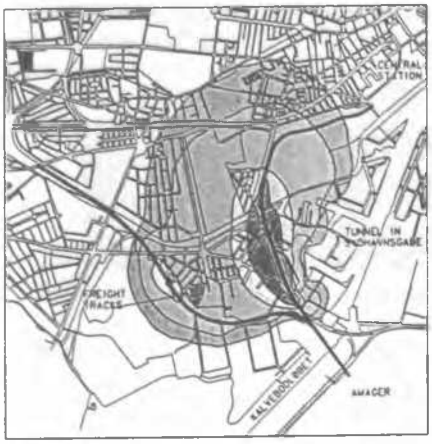

Figure 8 Prognosis of lowering in Copenhagen.

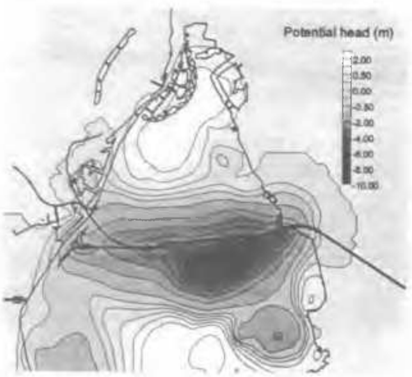

Figure 9 Prognosis of hydraulic head at Amager.

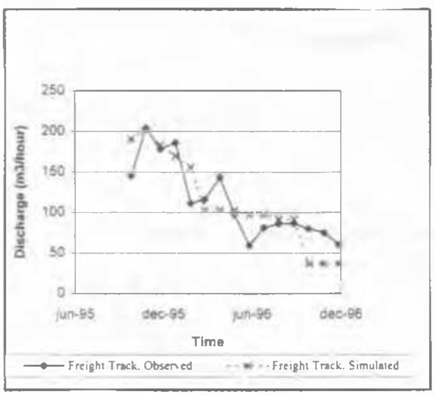

Figure 10 Simulated and observed volume of discharged groundwater per hour for the freight track.

discharge per hour through the entire construction period. This has been especially useful controlling the total nitrogene outlet to the harbour. Figure 8 illustrates the calculated discharge per hour together with the later observed discharged values for the freight track in southern Copenhagen.

On basis of the above described simulations a "groundwater budget" for each contract was introduced, in order to control the amount of discharged water. The introduction of this budget has contributed to a greater consciousness about the environmental problems by dewatering and in general optimum dewaterings have been achieved.

6. CONCLUSION.

Groundwater management at large urban construction projects have been more and more common not at least due to deeper foundation levels and larger excavations in general.

Numerical 3-D groundwater models have been used for many years, but the introduction of the models as a general groundwater management tool in the design phase as well in the construction phase has proved to be useful for general handling of environmental problems.

Furthermore, this project has reveiled that a groundwater model based upon a very detailed study of geology is a must in order to obtain the neccessary agreement between simulated and observed phenomena and to obtain the right geotechnical design- and construction basis.

7. REFERENCES

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