Geological Aspects of Swissmetro, a Long Distance High Speed Transport System

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Abstract

The high-capacity passenger subway Swissmetro shall connect all major cities in the northern Alpine foreland of Switzerland. In addition, the neighbouring traffic systems in the European countries shall be included in the Swissmetro concept. In this project, geological, hydrogeological and geotechnical studies have been conducted under particular consideration of technical and civil engineering related conditions and parameters. Some critical geological issues addressed in the study are presented in this paper. The results of the study show that, from a geological and geotechnical point of view, the feasibility of the Swissmetro project is favorable.

1 Introduction

Given the rugged topography, the high population density and an increasing awareness of environmental issues, it is hoped that the high speed underground transport system may provide an overall advantageous solution to Swiss transportation needs. The system will result in improved energy and economy efficiency as well as geographic mobility. The performance will be evaluated based on the trains' velocity, safety concerns and economic profitability. The line segments presented in this paper are elements of the new Swissmetro rail network which is to complement the existing rail transportation system. The network of the Swissmetro encompasses several axes as shown in Figure 1.

The Swissmetro project is based upon several specific technological components which affected the assessment of geological and geotechnical conditions and the layout for civil engineering works:

- The infrastructure, consisting of two parallel tunnels, stations and maintenance caverns will be located entirely underground.
- A partial vacuum in the tunnels will reduce air resistance and energy requirements for propulsion.
- The propulsion system will use linear electric engines fixed to the tunnel wall elements.
- The contact-free magnetic suspension and guiding system will allow for maximum velocities of 400 to 500 km/h.

Geological investigations along the preliminary tunnel routes need to respect certain technical and geological constraints: (1) high curve radii of 10 km both vertically and horizontally; (2) tunnel segments of up to 15 km length; (3) existing underground structures in cities; (4) the system's high sensitivity to differential ground movements; and (5) commonly difficult soil conditions (e.g. Zurich, Lucerne, Basle). As a new element a vertical switch was provided. These new components necessitate the construction of large underground caverns.

2 General Conditions

The assessment of the geological and geotechnical conditions is based on both published and unpublished literature including reports from consulting and governmental investigations, as well as existing geological maps. No additional field work was performed.

From a civil engineering perspective, the following minimal requirements need to be satisfied:

Tunnel:
Two parallel tunnels, water- and airtight, no drainage permitted through tunnel.

- Diameter of inner tunnel: 5 m
- Distance between tunnels: 25 m
- Diameter of connecting galleries: 3 m
- Temperature: ≤ 35 °C

Horizontal alignment:

- Min. horizontal radius (low velocity) 3,000 m
- Min. horizontal radius (high velocity) 10,000 m

Vertical alignment:

- Minimum vertical radius: 10,000 m
- Minimum inclination: ± 0.3 %
- Maximum inclination: ± 1.5 % (high velocity), ± 3.0 % (low velocity)

Intermediate shafts:

- Diameter of inner shaft 16 m

Stations:

- Length of boarding platform 100 m

Vertical switch:

- Total length of the cavern: 770 m
- Maximum height: 16.5 m

3 Geological Aspects of two Swissmetro segments

3.1 Introduction

Figure 2 shows the location of the two Swissmetro sections on a tectonic map of northern Switzerland. The course of these routes was laid out by an interdisciplinary team of civil engineers, traffic engineers and engineering geologists. Further constraints were given by the regional geology and technical requirements. Particular emphasis was given to three aspects along the Basle-Zurich segment, namely hydrogeology, gas and neotectonics. For the section Berne-Zurich, the aspect of crossing Quaternary valley fills was considered.

3.2 Geology

The Swissmetro segments connecting the cities in the northern part of Switzerland lie in a zone displaying a wide spectrum of geological and tectonic elements. The Swissmetro segment connecting the vicinities of Basle and Zurich starts in the Rhinegraben representing a deep-reaching intra-continental rift system. Within this structure the tunnel first cuts through shallow Quaternary fluvial gravels and sands. Towards the eastern boundary, Tertiary deposits prevail. The element to the east of the Rhinegraben border fault is dominated by Jurassic sediments such as marls and various limestones. The last segment crosses mainly Tertiary Molasse sedimentary rocks. It is interrupted by marked erosional features with Quaternary fills and by the eastern-most anticline of the Jura chain. Fortunately a contact of the tunnels with the anhydrities of Trias between Basle and Zurich could be avoided by the choice of the route.

Whereas the Swissmetro route between Berne and Zurich lie entirely within the Molasse Basin of Switzerland. The near subsurface geology in the project area is controlled by Tertiary and Quaternary sediments (mainly of fluvial and glacial origin). The Molasse formations consist of variously composed marls, sandy marls, sandstones, calcareous sandstones and conglomerates. The thickness of the strata varies from centimetres to hundreds of metres.

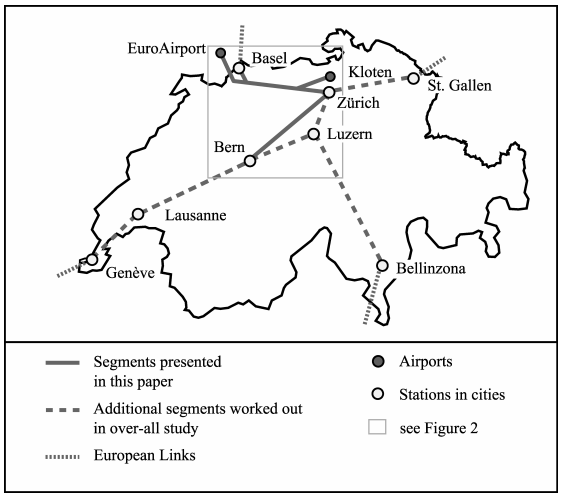

Figure 1. Overview of Swissmetro segments.

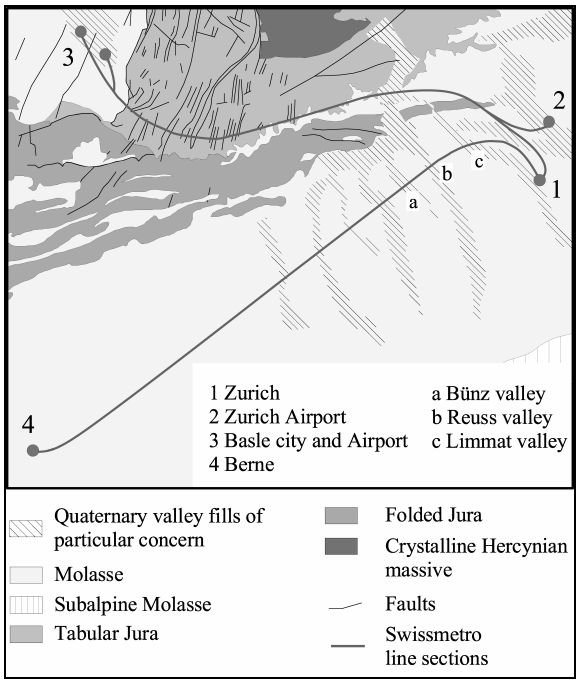

Figure 2. Tectonic map showing two segments of Swissmetro.

3.3 Examples of a geological aspects

Hydrogeological aspects for the section Basle-Zurich:

The hydrogeological setting is predominated by massive rock formations. According to the hydrogeological characterisation, the route Basle-Zurich may be divided into four main types: (1) Fluvial Quaternary valley fills, and (2) Quaternary glacial sediments such as moraines, fluvioglacial deposits and lacustrine sediments. (3) In the Tertiary sediments, groundwater flow is expected to take place mostly within isolated joints and fractures with discharge rates of up to 4 l/s and more. Porous groundwater flow rates are not expected to exceed 1 l/s per tunnel kilometre. Depending on the sedimentary cover the groundwater pressure may reach up to several bars. (4) In the Folded as well as in the Tabular Jurassic sediments groundwater flows in the more permeable horizons, in fissured formations, along faults but preferably in karstic cavities.

The chemical characteristics of the shallow karst groundwater of the Malm carbonates or of the "Hauptrogenstein" generally pose few problems. The flow systems are mainly of local extent and the groundwater's age rarely exceeds a few years. Groundwater at the greater depth of the tunnel's level, for example in the Effinger, the Opalinus or the Lias formation, is expected to display highly increased total dissolved solids contents and highly increased age.

Neotectonics in the area of the Tabular Jura and Rhinegraben (section Basle-Zurich):

Locally increased seismic activity occurs in the Basle-Hochrhine region along the eastern limit of the Rhinegraben (Dinkelberg) and the adjacent areas. The dangers caused by settlements due to dissolution of Triassic evaporites are nearly negligible. The risks posed to a tunnel by these neotectonic activities in a hard rock setting with more than 100 m of overburden are two-fold: (1) The seismic loading induced by an earthquake may cause structural damage. This risk, however, is of minor relevance. (2) Active and irreversible movements in the underground represent a greater threat to the tunnel. They may happen discretely along faults or diffusely over the full width of large fault zones. It

is necessary to analyse in detail the local neotectonic conditions for all critical faults along the Swissmetro route.
The Swissmetro route crosses two important active fault zones in the region east of Basle, the Rhinegraben border fault and a cluster of secondary faults related to the Dinkelberg. The Rhinegraben border fault best typifies the neotectonic activity.
The very complex fault geometry may be traced readily along the surface. In contrast, the definition of local fault systems and their major faults at depth is difficult. The following average total slip rates have been determined over the period from the Quaternary to present (Löw et. al. 1989):

- Rhinegraben: 0.06 - 0.08 mm/y
- Rhinegraben border fault: 0.15 - 0.2 mm/y
- Dinkelberg: 0.06 - 0.2 mm/y

It is necessary to analyse in detail the local neotectonic conditions for all critical faults along the Swissmetro route. This analysis should be based on three types of information: (1) a qualitative and quantitative synthesis of the Quaternary tectonic activity in the investigation area, (2) a qualitative and quantitative description of the present day seismotectonic activity and (3) the results from parametric and deterministic modelling of possible surface deformations at the site. New investigations including observations along fault zones are in progress.

Deep glacial erosion and Quaternary valley fills along the segment Berne-Zurich:
The lithology and general characteristics of the Molasse formations between Berne and Zurich are well known and are rather favourable to tunnel construction. However, crossing the glacially overdeepened valleys with their Quaternary fills presents a true challenge. The valley fills are very heterogeneous, consisting of moraine deposits, lacustrine sediments, and fluvial gravel, sand and silt deposits. During the last glaciation period only some of the valleys were covered by ice. In contrast, nearly all of Switzerland was blanketed by ice during the previous glaciation period.

One of the main objectives for the projection of the Swissmetro route between Berne and Zurich was to bypass as much as possible the unfavourable Quaternary valley fills. In addition the hydrogeological conditions have to be studied with care because the fluvial gravels and sands hold some of the most important groundwater reserves in the Molasse basin of Switzerland. It has, therefore, been attempted to cross the valleys where the fill is made up of terminal moraine deposits. Because of their grain composition and the consolidation induced by the former glacier front they are most predominantly of aquiclude quality. Accordingly any significant negative effects on the groundwater flow systems may be pre-empted.

4 Conclusions

The results of this study show that, from a geological and geotechnical point of view, the feasibility of the Swissmetro project is favourable. The route segment between Basle and Zurich crosses a complex geological setting including a considerable variety of tectonic and lithological elements. Observations from previous tunnel projects in the area have shown that the associated problems may be overcome with appropriate civil engineering methods and techniques. Because of the tightly sealed construction of the Swissmetro tunnel, particular attention needs to be paid to hydraulic overpressures. The high salinity of the groundwater is an additional concern. Although the section Berne - Zurich lies entirely within the relatively favourable Molasse Basin, problems may arise where wide glacial valleys, filled with low consolidated or permeable Quaternary sediments, need to be crossed.

5 References

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