The influence of a designed twin-tube highway-tunnel on the stability of a nearby water-transmission tunnel

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Abstract

A tunnel is not only stabilized by safety measures e.g. steel and concrete. The surrounding underground is part of the construction. The excavation of an underground opening influences the stresses around the tunnel. Therefore twin tube highway-tunnels are excavated in a distance 40 m. When the designed tunnel meets existing underground structures in a smaller distance the impact of the stress changes is to be investigated. For the investigated case where the new tunnel crosses the existing tunnel in a distance of only 7 m the stress changes required extra safety measures for the existing tunnel.

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1. Introduction

The existing water transmission tunnel with a diameter of 4.8 m has been excavated by a tunnel boring machine in competent dolomite chalk stone. Therefore safety measures as shotcrete or anchoring were not supposed to be necessary. The tunnel is operated since 1983 without any problems. The water transmission tunnel contains tubes of 2.5 m diameter out of prestressed concrete for the water transmission.

The designed highway crosses the existing tunnel in a distance of only 7 m. As the two parallel tubes of the highway (width 12 m, height 8.5 m) are located in a horizontal distance of 40 m (axis) the existing tunnel is crossed twice. The highway tunnels and the existing tunnel do not intersect perpendicularly therefore these crossing points are located in a distance of 56 m. The detailed geometric relations can be seen in a map with contour lines (see figure 1). The gradient of the new tunnels is 657 m above see level. For sake of a better understanding of the 3-dimensional situation a 3-dimensional model was built (see figure 2).

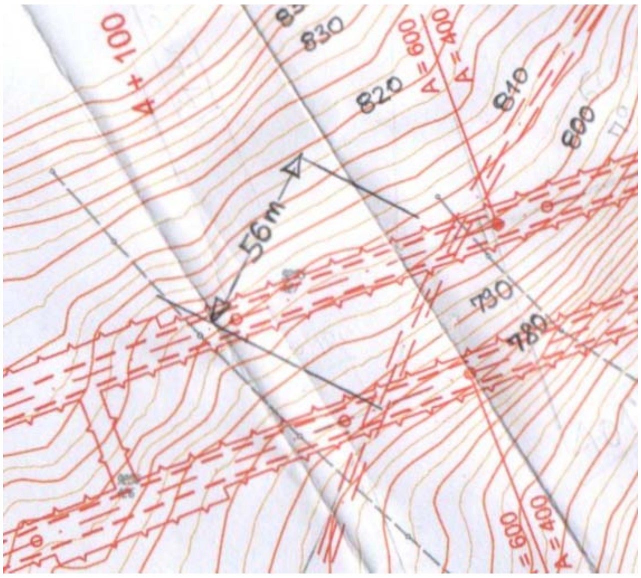


Figure 1: Topographic contour line map with existing tunnel and twin-tube tunnel

2. Calculative procedures

2.1 Modelling of the in-situ situation – simplifications

A finite element mesh to represent the three dimensional situation seems to be very complicated, time consuming and would probably exceed the capacity restrictions of normal computers. For a tunnel with high overburden only a small portion of the load due to overburden can be taken by the lining e.g. the installed safety measures.

Figure 2: 3-D model of tunnel intersections

The greater part of these forces is diverted around the tunnel and taken by the adjacent rock mass. In order to quantify this effect a 3-dimensional modelling is not necessary for the investigation of the diverted forces acting on the existing tunnel. For a tunnel with a width of 10 m the equilibrium of vertical forces reveals that a standard shotcrete lining of 20 cm only can take normal forces due to 40 m overburden thus being loaded up to maximal strength (see fig. 3).

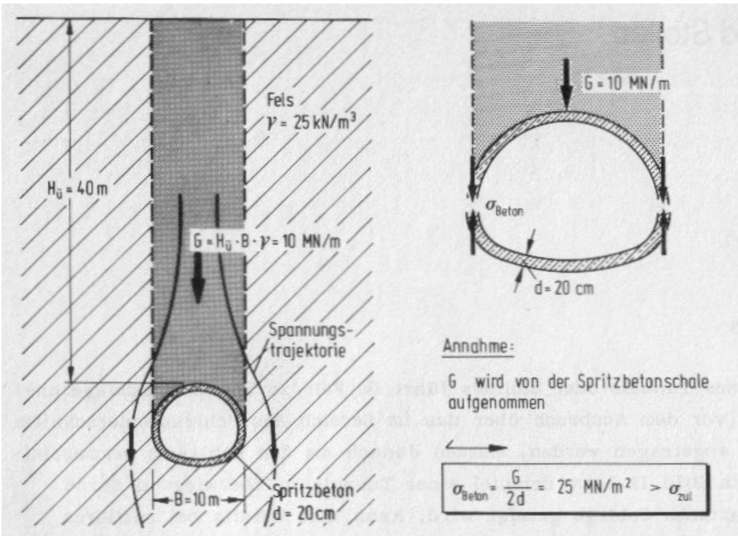


Figure 3: Stress diversion around a tunnel with a width of 10 m sealed by 20 cm shotcrete

As the existing underground opening is unlined the extra loading of the adjacent rock mass requires careful investigation. The overburden above the designed highway tunnel is 120 m thus the greater portion of the vertical forces is diverted around the tunnel. These forces cause stresses diverted to both sides of the tunnels thus yielding stability problems when the existing tunnel is in an unfavourable position. In order to investigate this 2-dimensional finite element calculations were performed.

2.2 Numerical Modelling

The rock mechanical parameters can be taken from t he geological report containing the results of the laboratory tests (see table 1).

Material	properties	Parameters
Self weight	γ	27 k//m³
Young's modulus	E	8 GPa
Poisson's ratio	υ	0.2

Table 1: Mechanical properties for the rock mass

A slab of 60 m height was investigated. The width of 60 m was chosen according to the requirement that the boundary conditions are not affected when simulating the excavation. Roller boundaries were adopted for all nodal points being located in vertical planes w hereas the nodal points at t he basis were fixed. In order to simulate the overburden of 120 m appropriate vertical pressure was adopted as a boundary condition.

At first the stress distribution of the investigated calculative section without any underground openings is investigated. This is well known as the primary state of stresses due to self weight. In a second step the excavation of the existing water transmission tunnel is simulated. Within a third step the excavation of the highway tunnel is simulated not stepwise – vault, bench and floor – but in one step. This simplification is not affecting the results when adopting elastic conditions.

The increase of compression stresses around the water tunnel due to diverting stresses around the highway tunnel was the main item to be investigated. Some preliminary investigations revealed that the investigation could be reduced to 5 different geometric relations between existing tunnel and new tunnel (see fig. 4).

The investigated five geometric properties as to the location of the two tunnels are

1. The centre line of a new tunnel coincides with the centre line of the existing tunnel – the vertical distance being 7 m.

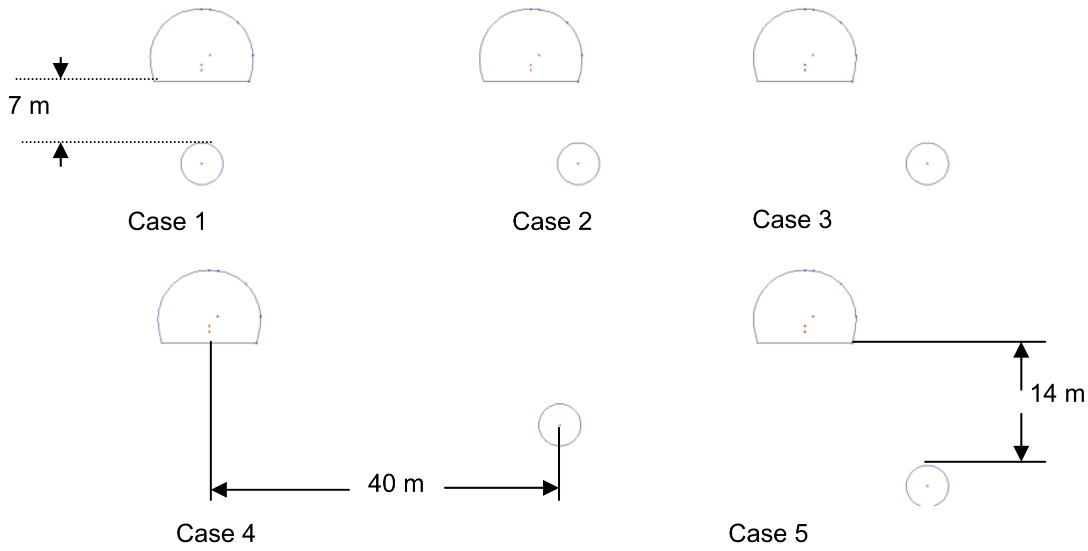


Figure 4: Investigated geometric relations (Case 1 – 5) between underground openings

2. As no. 1, but centre line distance being 6 m.
3. As no. 1 but centre line distance being 14 m.
4. As no. 1 but centre line distance being 40 m.
5. As no. 3 but vertical distance being 14 m.

For the FEM-calculations a material law assuming plain strain conditions is used. All these models and the excavation technique are implemented into the FEM-program SIGMA. SIGMA/W (version 5) is a finite element software product that can be used to perform stress and deformation analyses of earth structures. Its comprehensive formulation makes it possible to analyze both simple and highly complex problems. In coincidence with the available rock mechanical parameters elastic calculations were performed.

2.3 Results

The obtained results were represented in contour lines of stresses. The extra stresses due to excavation of the highway tunnel were plotted. Case no. 1 revealed the expected unloading around the existing tunnel. Case no. 2 yielded an increase of stresses ob both sides of the existing tunnel. This result led to the investigation of the distance between tunnels showing the maximum stress increase in elements above the existing tunnel (case no. 3). In order to investigate an eventual influence of the second highway tunnel to the existing tunnel case no.4 adopting a distance of 40 m was chosen showing no effect. Case no. 5 assuming a greater vertical distance between the excavations revealed no decisive reduction as to the stress increase. It could be shown that the maximum additional stresses in the circumference of the existing tunnel are detected by case no. 3 (see fig. 5).

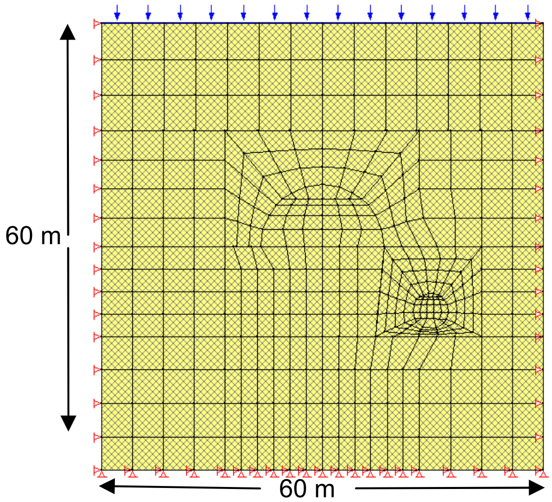
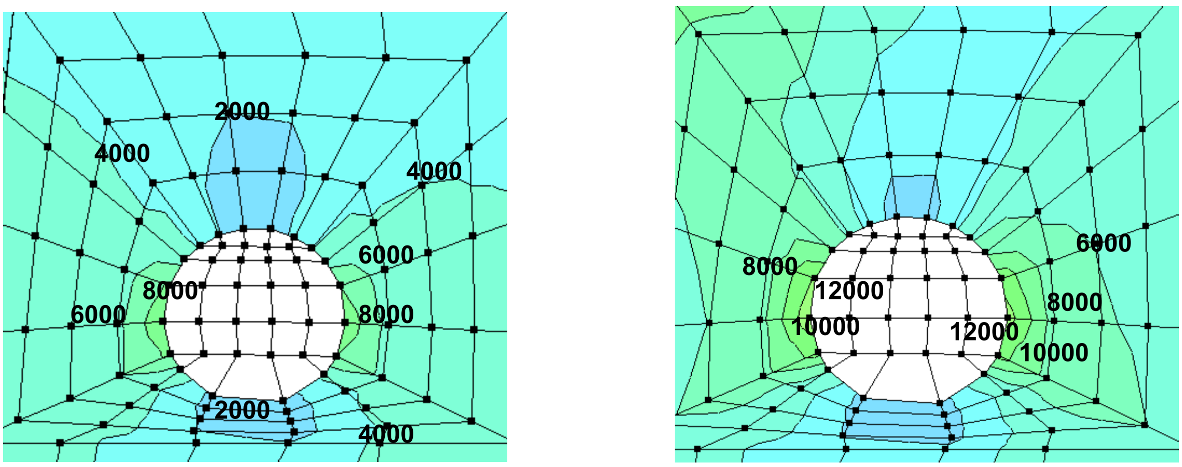


Fig. 5: FEM-mesh, boundary conditions, contours of underground openings

The vertical stresses around the water transmission tunnel before and after excavation of the highway tunnel are plotted in figure 6.



before excavation of new tunnel after excavation of new tunnel

Fig. 6: Contour lines of vertical stresses around water transmission tunnel

The excavation of the highway-tunnel causes a considerable increase of the vertical stresses. This increase is accompanied by an increase of the horizontal stresses around the existing tunnel (see fig. 7).

3. Conclusions

The maximum increase of stresses is calculated for case 3 where the horizontal distance of tunnel axis reaches 14 m (see fig. 4). A greater vertical distance (14 m instead of 7 m) between the underground openings which could be taken into account when designing the highway is of little influence.

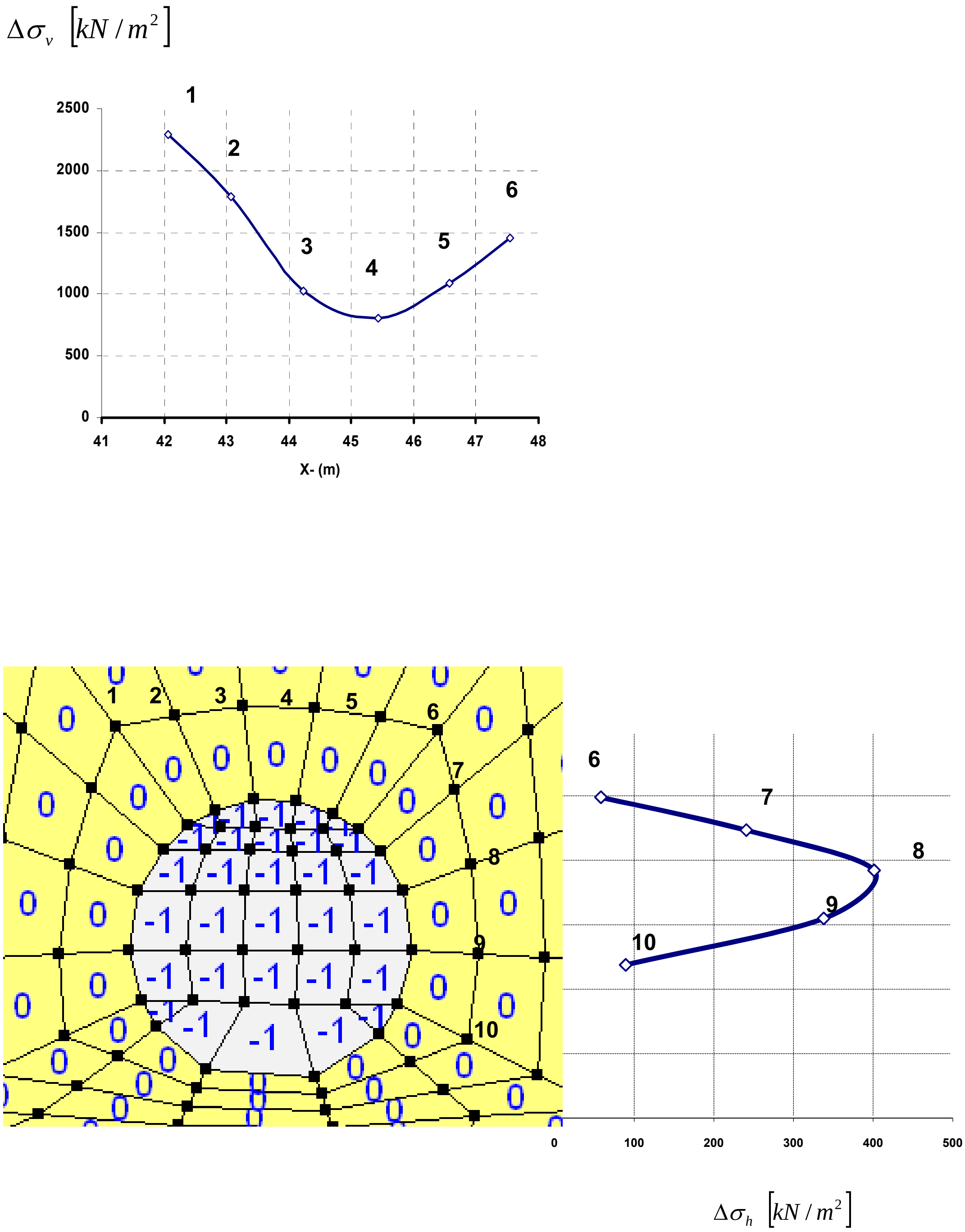
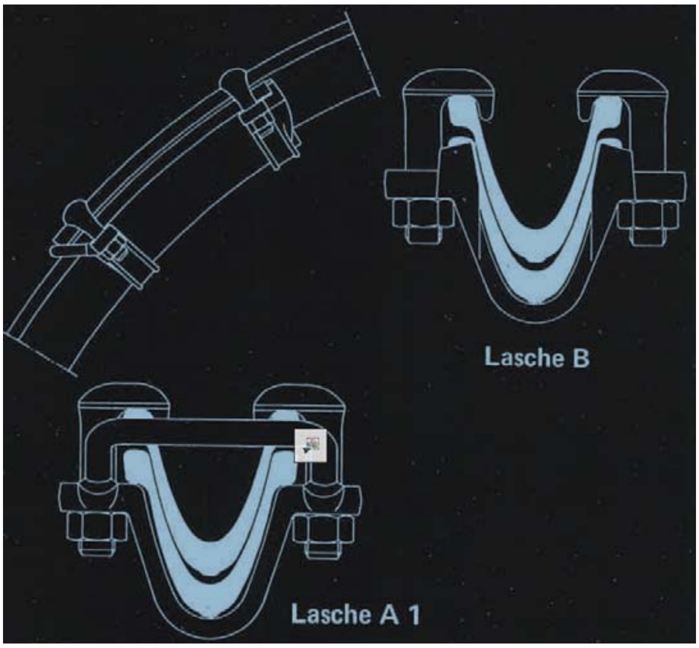


Fig. 7: Additional stresses in the circumference of old tunnel due to excavation of highway tunnel

The resulting stress increase for case no. 3 (see fig. 7) shows that the additi onal vertical stresses above the vault of the existing tunnel are varying bet ween 800 and 2300 kN/m² whereas the increase of the horizontal stresses at the side of the existing tunnel ranges from 100 to 400 kN/m². When adopting the principle that a new construction should not pr oduce negative effects on an existing one the conclusion will be that the existing tunnel is to be equipped with extra safety measures in order to balance the extra stresses being produced by excavation. A rough estimation can be performed using the vessel equation ($F = p \cdot r$) for a mean value of the radial extra stresses (900 kN/m²) a circumference force of $F = 2160$

kN/m can be found. As the water transmission tunnel is permanently operated a shotcrete sealing can not be taken into account. Therefore a support consisting of steel profiles as used in mining industries is preferred.



$$n = \frac{F}{A \cdot \sigma} = \frac{2160}{32.9 \cdot 21} = 3/m$$

Fig. 8: Steel profile GPc_2 of Bergbaustahl company, Hagen/Germany

When being used in tunnelling the curvature is vice vers a as shown in figure 8 thus the shoulder of the profile is oriented towards the rock mass. As to t he problems of transport and handling during installation – material can only be transported to the installation area via 1 km by men - the smallest profile (h = 12.3 cm) was chosen. The GPc_2-28 profile having a cross section of 32.9 cm² thus leads to a support consisting of 3 profiles per meter. When installing this support before excavation of the new tunnel the diverted stresses in the rock mass around the water tunnel can be taken by the steel support. In order to stabilize loosened rock particles steel wire meshed are installed in between.