Cut and Cover at Landrückentunnel North

R. Pöttler
Kling Consult, Krumbach, Germany

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SYNOPSIS The paper deals with a tunnel structure which has been designed in a very economic way, taking account of best estimate ground parameters and high sophisticated numerical models for simulating the reinforced concrete behaviour. Some changes were made during construction of the tunnel, to speed up the construction procedure. During the backfill of the tunnel higher displacements than calculated occured.

INTRODUCTION

In the course of the new railway line Hanover - Würzburg of the German Federal Railway Cooperation the longest railway tunnel of Germany, the 10,8 km long Landrücken tunnel was built. Starting from the north portal, due to very difficult geological conditions, 200 m of the tunnel were decided to be built according to the cut and cover method. The bad soil conditions were expected in the bench and heading area of the tunnel, whereas in the invert area weathered rock mass was predicted. Calculations of costs have highlighted, that a cut and cover tunnel even with an overburden of about 22 m would save money compared to a conventionally driven tunnel.

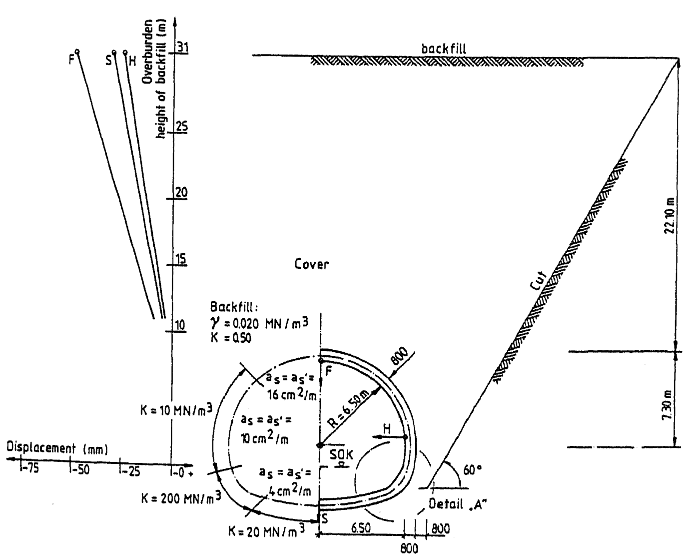

Figure 1: Dimensions, numerical model, geotechnical parameters and calculated displacements

DESIGN

Due to the great overburden and the poor ground conditions and in addition for an economic dimensioning of the structure an extensive soil and rock investigation program was performed. As results of these investigations the soil and rock experts defined the best estimate parameters for the structure as shown in Fig. 1:

- Modulus of subgrade reaction
  - invert area centre K = 20 MN/m^3
  - transition zone invert-bench K = 200 MN/m^3
  - bench area K = 10 MN/m^3
- Specific weight of back fill g = 0,020 MN/m^3
- lateral pressure coefficient K = 0,5

Taking these parameters and the shape of the tunnel shown in Fig. 1 a very economic design was performed. The calculations were done using a beam element model which was supported by the rock- and soil mass in those areas, where the structure deformed towards the ground. The beam element model used (Pöttler and Swoboda, 1986) takes account of the real material behaviour of the reinforced concrete, specially of the cracks and of the tension stiffening effect of the reinforcement.

The key parameters of the structure are the following (Fig. 1):

- concrete grade B 45 acc DIN 1045 (1988) thickness of the structure 800 mm
- Steel grade St IV acc DIN 1045 (1988) amount see Fig. 1

The small amount of steel in the invert area was accepted as no special German standard existed according to which a higher amount of reinforcement was to be placed. The small amount of steel and the "thickness" of the structure the project manager were happy of.

To check the coincidence of assumed and real boundary conditions and material behaviour geotechnical measurements during the backfill have been performed. The calculated deformations should be compared to the actual deformations giving an indication of the exactness of the used boundary conditions and the safety of the structure. In Fig. 1 the calculated roof settlements (F), invert settlements (S) and horizontal divergencies (H) as a function of the height of the backfill is shown.

CHANGES IN THE COURSE OF CONSTRUCTION

For easier processing of the concrete two major changes were made

- the shape of the transition zone invert-bench was changed: compare detail "A" of Fig. 1 and 2.
- the fill concrete and the structural concrete in the invert area was placed in one step (Fig. 2). To make sure that the originally assumed structural behaviour of the invert occurs an artificial crack in the middle of the invert was arranged.

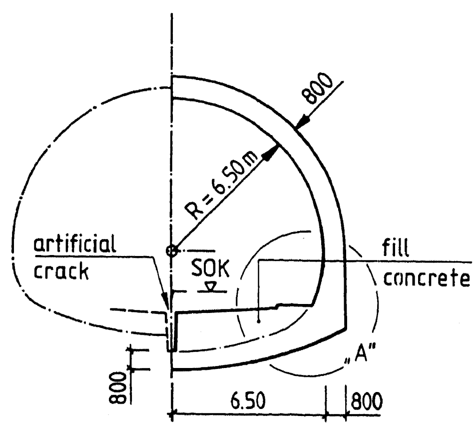

Figure 2: Changes during construction

Unfortunatly after construction of the tunnel and before starting of the backfill rainy days smoothed the final high stressed rock parts at the transition zone. After a few sunny days the rock mass looked as before. No additional measures where thought to be necessary.

BACKFILL

Backfill started as usually: layer by layer were compacted to that amount, which was requested by the structural design. After the backfill has reached a height of about 9 m over the tunnel roof, backfill was stopped by the supervision manager for the following reasons:

- The deformations occuring were two times higher than the calculated one (dotted lines in Fig. 3).
- Cracks in the roof occured (Fig. 4).
- The artificial crack in the invert widened considerably.

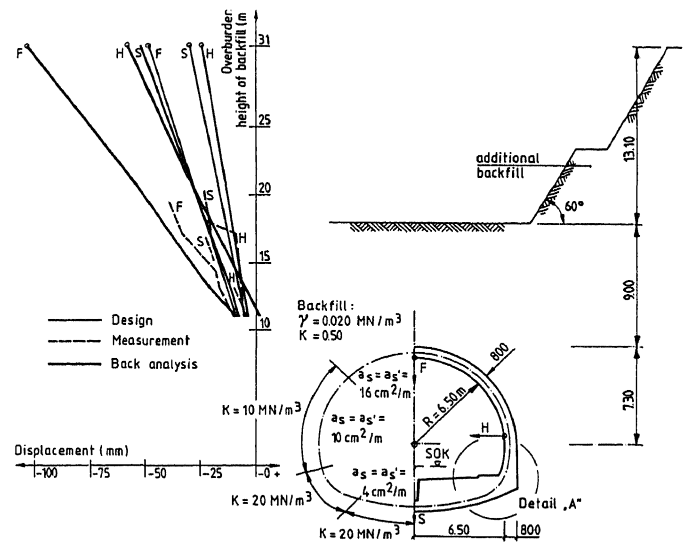

Figure 3: Measured displacements and results of back analyses.

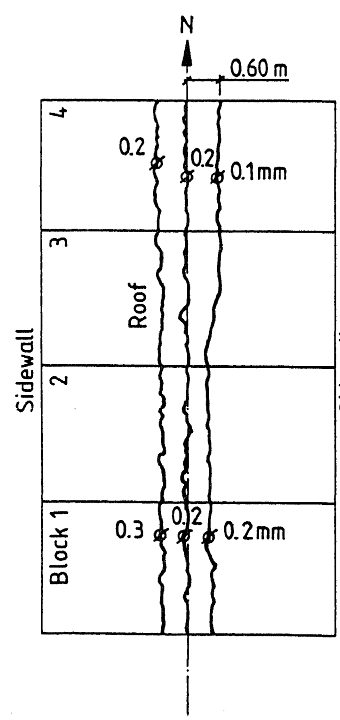

Figure 4: Cracks in the roof area of the tunnel. Top view of construction block 1 to 4

QUESTIONS AND ANSWERS

The following questions arised

- What are the reasons for the great difference between calculated and real deformations of the structure?
- Is the structure still save?
- What happened in the roof?
- What happened in the invert?
- Is it possible to progress the with the backfill?

To answer these questions extensive parameter studies and backanalyses were performed. The following parameters have been varied:

- Modulus of elasticity of concrete.
- Material behaviour of reinforced concrete.
- Modulus of subgrade reaction in the invert, transition zone and bench area.
- Coefficient of lateral pressure
- Specific weight of backfill
- System line of the structure in the invert area, taking account of the real shape of the structure.

The following answers have been obtained:

The overall deformation behaviour of the structure is governed by the moduli of subgrade reaction, all other parameters are negligible. The most realistic soil/rock parameters are shown in Fig. 3, the modulus of subgrade reaction at the transition zone being only 1/10 of the design parameter!

For answering the question "Is the structure still save" the details in the roof and in the invert were analysed. The cracks in the roof area (Fig. 4) have been considered to be "normal" cracks for reinforced concrete. The width of the crack is about 0,2 mm. But the stresses and strains in the roof area have been found to be at the limit of the usability.

In the invert calculations using the Finite Element Method showed, that the artificial crack didn't work as assumed. Whereas there was no rotation in the thick concrete area left and right of the crack, the whole rotation and deformation of the invert took place in the centre of the invert (Fig. 5). At the artifical crack the amount of steel is to small to act as reinforced concrete section. For different excentricities e of the axial force N in the invert the factors of safety according DIN 1045 (1988) for unreinforced concrete sections and the values of the rotation have been calculated. The measured values of the rotation are between 2.10^{-3}rad and 6.10^{-3}rad giving a factor of safety between about 3 and 6. Thus the stability of the structure could be proved.

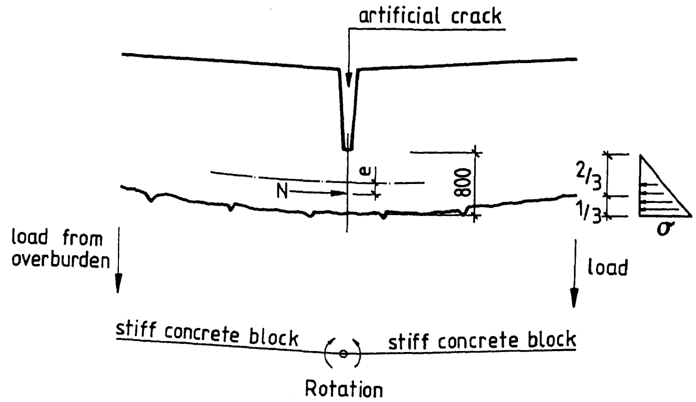

Figure 5: Detail of the invert arch and its structural behaviour.

RESUMEE

The following conclusions can be drawn from this case study.

- When things went wrong, always more than "1" fact is the reason why. In the present case these reasons are
  - overestimation of ground/rock conditions
  - changes during construction
  - design using high sophisticated computer models, instead of conservative ones thus having no "additional" factors of safety for construction changes.

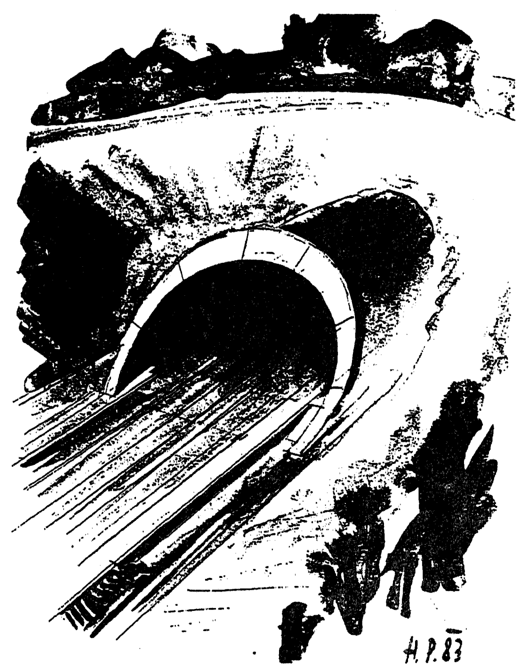

Figure 6: Artist Impression of finished tunnel

- The structural engineer should check ground and rock parameters, given to him from experts on their reliability.

- Parametric studies taking account of a variation of ground parameters are necessary. Not only best estimate parameters but also worst credible parameters are to be investigated.

- Use of engineering judgement is a benefit for the structure: e. g. Even if there are no local codes to us a certain amount of reinforcement in the specific country, look abroad.

- Geotechnical measurement are a very useful tool for controlling the structural behaviour.

- Never make changes during construction, pressed by the construction company without checking this change numerically and very seriously. Money which is saved for the construction company may be lost by the owner in a higher degree afterwards.

CONCLUSION

The tunnel described is in operation since 1987 (Fig. 6). No further problems occured. As less back fill than originally designed was placed the owner saved money and time. The backfill from the landscape point of view now is even better than the original designed landscape.

REFERENCES

Pöttler, R. and Swoboda, G.A. (1987): "Non-linear Beam Element for R/C structures", Communications in Applied Numerical Methods: 397 - 406

DIN 1045 (1988):"Beton und Stahlbeton, Bemessung und Ausführung", Edition Juli 1988 (Code of practice: Concrete and reinforced concrete). Beuth Verlag Berlin.