Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 78 (1998)

Artikel: Safe backfilling due to finite element precalculations
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DOI: https://doi.org/10.5169/seals-59061

Safe backfilling due to Finite Element precalculations

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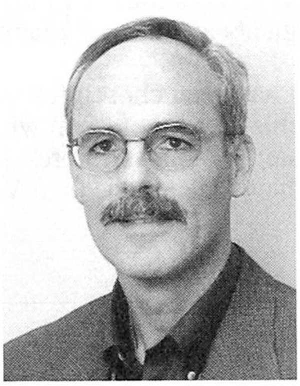

Juerg Matter, born 1952, received his civil engineering degree at the Swiss Federal Institute of Technology in 1976. After earthquake and risk engineering, General Site Manager in Saudi-Arabia he has been working now for over 13 years as a General Project Manager of several highway and railway tunnels.

Summary

The Habsburg tunnel is part of the lately completed National highway A3 from Zurich to Basel. At the southern end of the 1500 m long tunnel, 400 m of the two tubes with two lanes each were built in a foundation trench of up to 25 m depth, using the cut and cover method. The Finite Element calculations have not only been used to solve the statical problems but also to evaluate the backfilling procedure to prevent the arches from asymmetric deformations. To control the deformations during the backfilling phase, an extensive measuring concept with 8 cross sections per tube was developped. In the areas, where the backfilling work complied with the instructions, the measurements showed a very close conformity with the calculated values. In one area with asymmetric backfilling, the measurements showed much higher values.

1. The Project

On october 17, 1996, the last 13 km of the Swiss National Highway A3, from Zurich to Basel, including 3 tunnels, were inaugurated after a total construction time of 10 years.

The Habsburg-Tunnel with two tunnel tubes, each with two lanes, was constructed using five different construction methods. At the southern end, 400 m were built in a foundation trench of up to 25 m depth, using the cut and cover method. The overburden varies between 5 m and 12 m. To reduce transportation of excavation material, the excavated soil was directly used to backfill the already constructed tubes.

The tunnels have an inner diameter of 10.2 m and a reinforced concrete wall thickness of 45 cm. Every week two tunnel elements of 10 m length have been completed. In parallel with at least one month delay, after sealing the concrete surface of the tubes, the elements were continuosly backfilled.

After the second tube's breakthrough with the open shield at the northern end of the foundation trench, the gap between cut and cover and the underground section was closed, the foundation trench was fully backfilled and the surface could be reused as agriculture soil again.

2. The Finite Element Precalculations

2.1 The geometric model

To consider the influence of the backfilling procedure on the behaviour of the concrete arches, a two-dimensional Finite Element Model was established. This model allowed the simulation of a stepwise compression of the backfill layers. By simulating only one of the tubes because of the problem's symmetry, the number of elements and the calculation time was cut in half .

The following figure shows the area that has been chosen for the model. It consists of 611 knots, 1117 triangles and 200 beams. It represents an area of 42 m width and 34 m hight. The earth load above the Finite Elements is simulated as a uniform pressure. The backfilling layers have a thickness of 1 m each. The calculations have been made on a Vax computer using the software Rheo Staub.

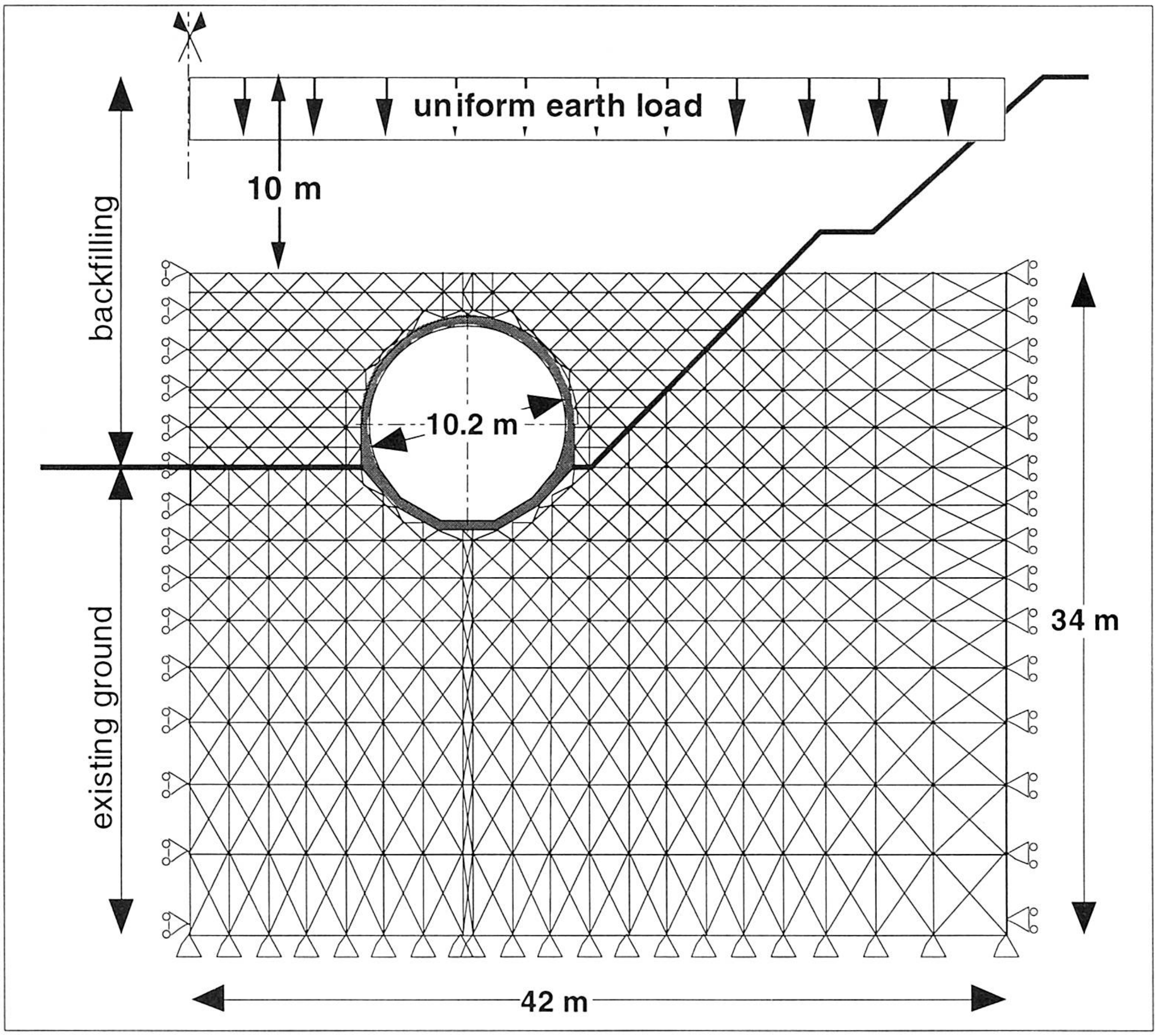

Fig. 1 Cross section through half of the foundation trench with the area of the Finite Element model

2.2 The Assumptions

The following values have been used for the calculations

Soil	young's module of existing soil	300'000 kN/m^2
	unit weight of existing soil	22 kN/m^3
	young's module of the backfill material	50'000 kN/m^2
	unit weight of the backfill material	21 kN/m^3
Reinforced concrete	young's module	33'000 N/mm^2
	compression strength after 28 days	30 N/mm^2
	unit weight	25 kN/m^3

Determinative for the stresses and deformations in the concrete construction is the assumption of the lateral earth pressure. In the calculations the ratio between vertical and lateral earth pressure is defined as λ. The influence of λ on the tunnels stresses is much higher than that of the soils young's module.

During backfilling of another cut and cover tunnel near the international airport of Zurich in 1970 we made pressure measurements around the tunnels surface. We found out that the value of λ varies with the hight of the backfilling. From the bottom up to 2 m over the tunnel roof λ was 1.0 and decreased rapidly to about 0.45 for the rest of the backfilling. Figure 2 shows the shape of the measured curve (4) in relation to the overburden. Curve (2) with a very stiff bedding has been determined from a two lane road tunnel near Zurzach. Instead of a v-shaped foundation trench like the one at the Habsburg tunnel and at the airport, the foundation trench in Zurzach was built with anchored bored piles. In addition the tunnel wall thickness is 30 cm compared to the 40 cm and 45 cm of the other two tunnels. Curve (3) with a constant λ value of 0.43 represents a soft bedding and is therefore very conservative. Because the geometrical and the geological conditions for the Habsburg tunnel were quite similar to the airport tunnel we used curve (1) with a variable λ value for our calculations.

The diagram on the right side in figure 2 shows the influence of the λ value on the bending moment at the tunnel roof.

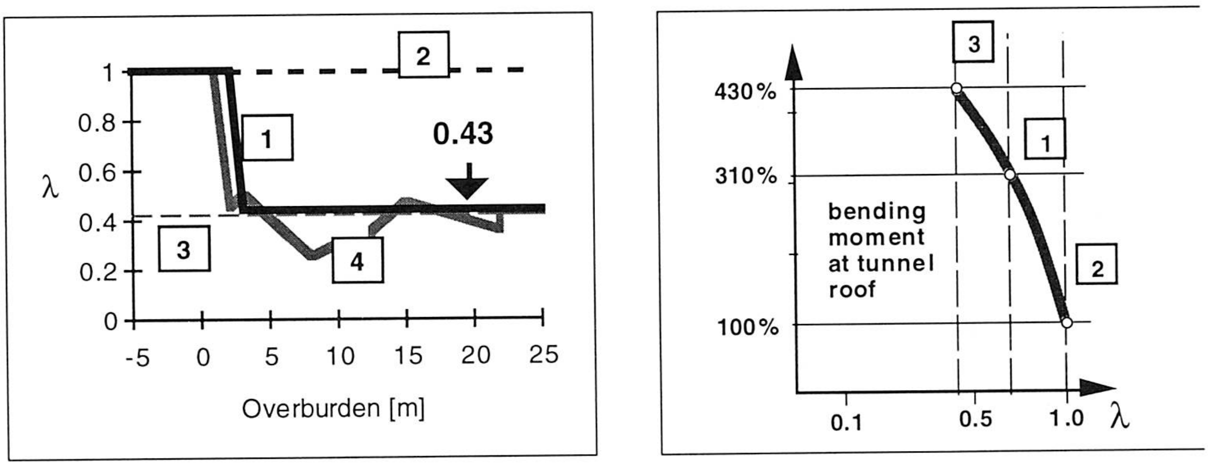

Fig. 2 Different shapes of the lλvalue and its influence on the bending moment at the tunnel roof

3. The backfilling instructions

The calculations showed, that the influence of an asymmetric pressure on the tunnel construction is much higer in the upper half than in the lower half. So we determined strict rules for the contracter's backfilling procedure. The difference permitted between the backfilling surface on the left and the right side of the tunnel decreases from 3 m at the bottom to 50 cm at the top. The maximum thickness of one backfill layer was limited to 50 cm and 50 N/mm^2 were required for the minimum elasticity in the backfill material.

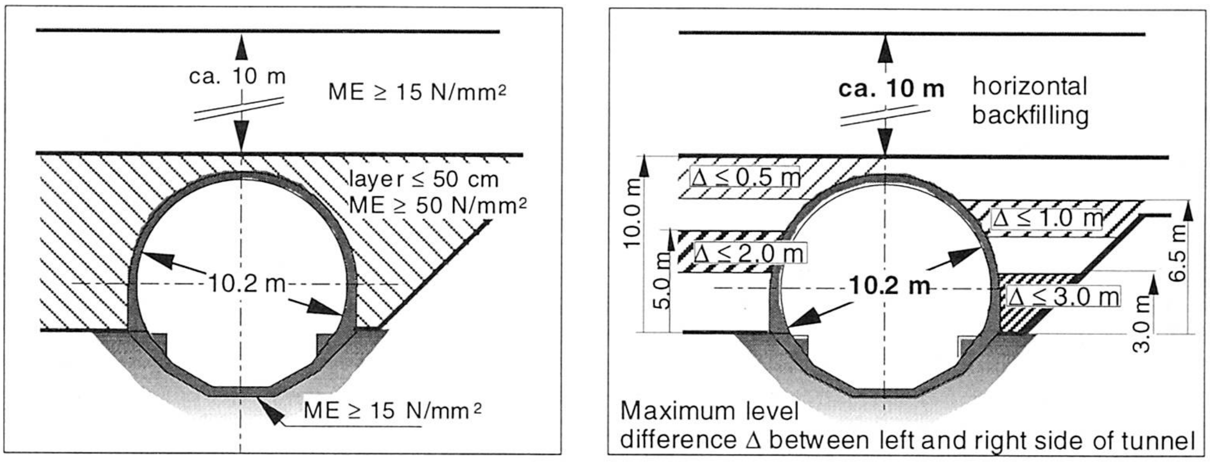

Fig. 3 The backfill instructions for the contractor

4. The measuring concept

To superwise the actual deformations during construction and to verify the calculations, an extensive measuring concept with eight cross sections per tube was developped and realized. The following figure shows the cut and cover section of the Habsburg tunnel with the measuring cross sections.

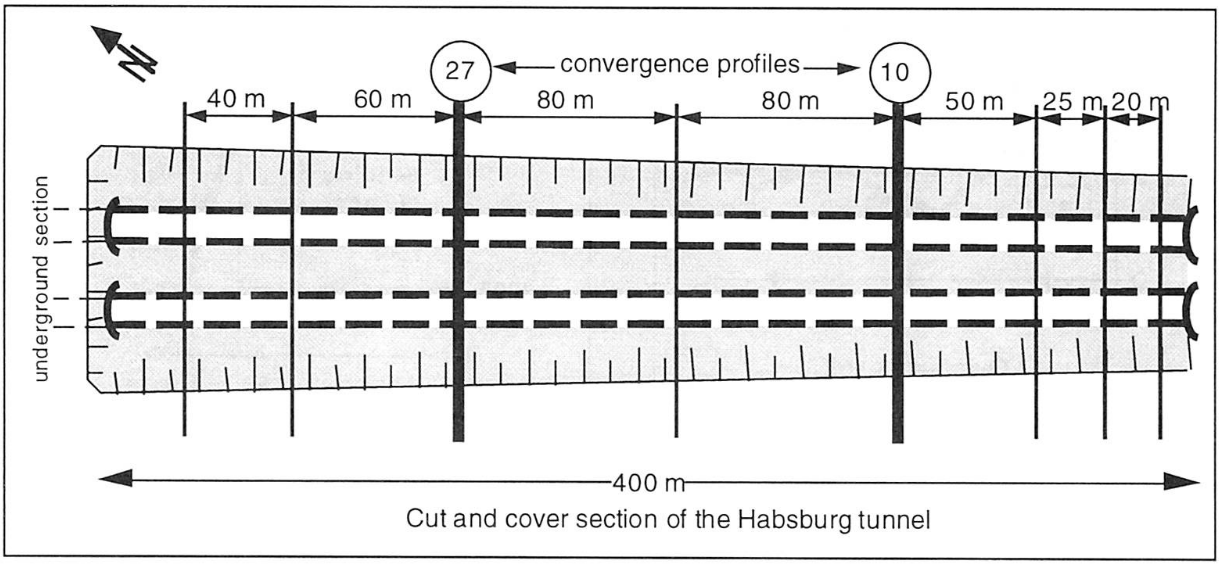

Fig. 4 Situation of the cut and cover section with the measuring cross sections

In six of the eight traces, only vertical deformations at three points have been measured. The two convergence profiles at the tunnel elements 10 and 27 have been monitored in cooperation with the Swiss Federal Instiitute of Technology. The following figure shows the arrangement of the two types of measuring points within the tunnel profile. For the discussion of the results the present paper focuses especially on the two convergence profiles.

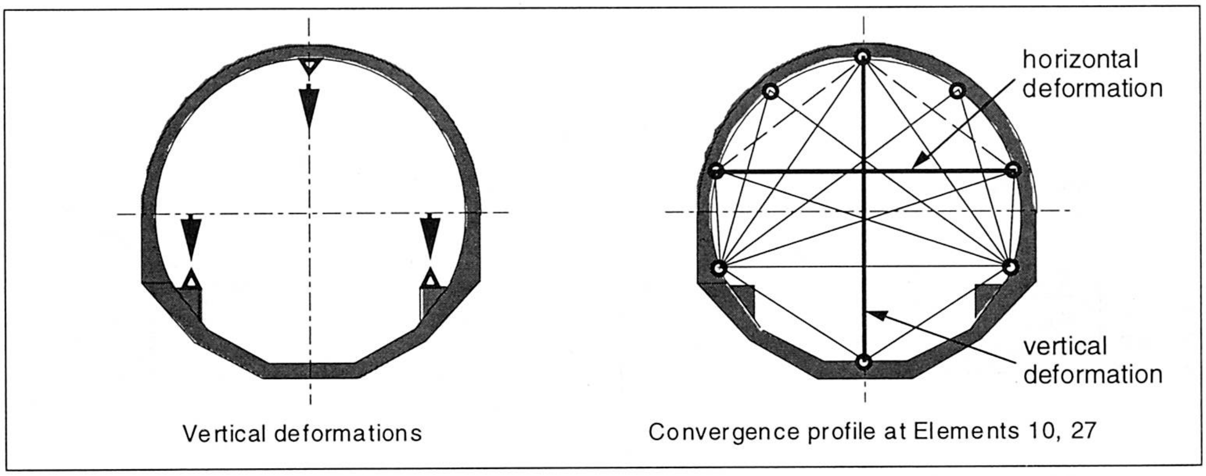

Fig. 5 Cross sections through the tunnel tubes with the measuring points for vertical deformation measurement and convergence profile

5. The results

In the beginning the convergence measurements showed, that the effect of the horizontal pressure of the compressed backfill material on the tunnel construction is less than calculated. This phenomenon corresponds with the expectations. In reality, the horizontal stiffness of the backfillmaterial does not remain constant as assumed in the Finite Element calculations. Up to two meters over the tunnel top the instructions for the backfiiling procedure were followed quite well. Then, in the southern part of the foundation trench, the contractor used the surface above the tunnel tubes as a site to store excavation material. To have easier access to the northern area he left an opening in the middle of the trench and caused by that an asymmetric load (see Fig. 6)

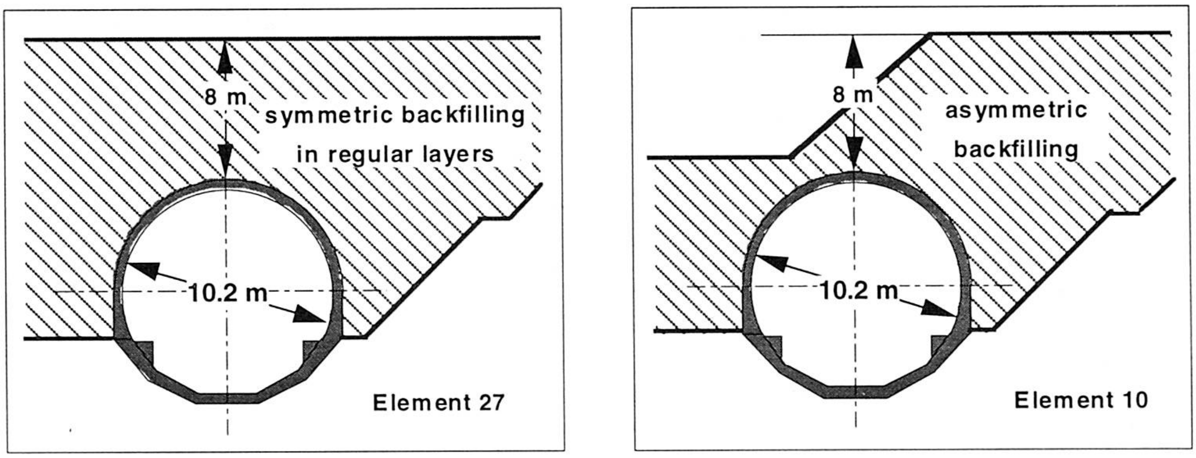

Fig. 6 Correct symmetric backfilling (Element 27) and incorrect backfilling (Element 10)

The following figures 7 and 8 show the difference between the calculated and measured vertical and horizontal deformations at the tunnel elements 10 and 27. Element 10 was backfilled with an asymmetric load, element 27 was correctly backfilled.

At element 27 the comparison between the calculated and the measured deformations shows a close conformity. For the vertical deformation 12 mm instead of 14.4 mm (minus 17 %) and for the horizontal deformation 15 mm instead of 12.6 mm (plus 19 %) were measured.

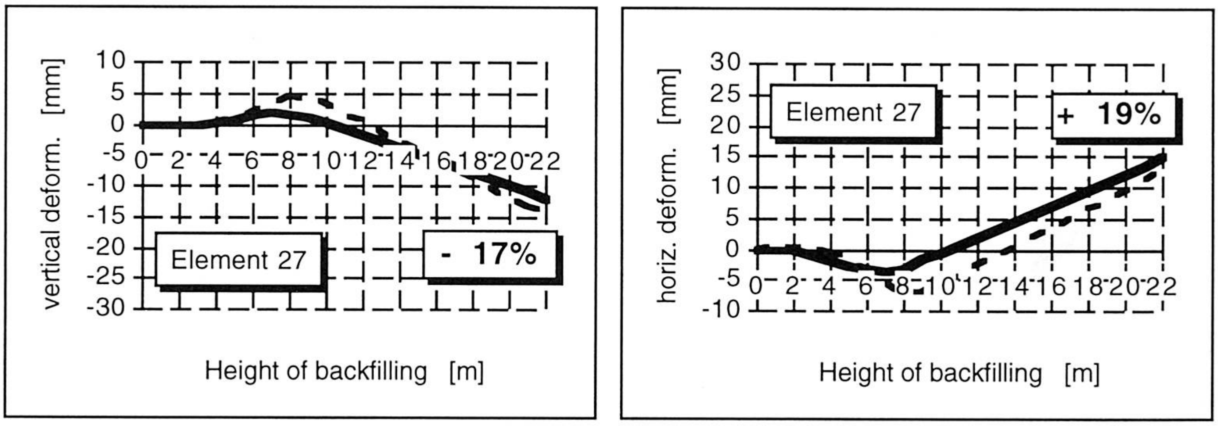

Fig. 7 Difference between calculation (dotted line) and measurement of the vertical and horizontal deformations at element 27

At element 10 the comparison between the calculated and the measured deformations shows a dramatically higher difference. For the vertical deformation 29.5 mm instead of 13.2 mm (plus 125 %) and for the horizontal deformation 30.5 mm instead of 10.2 mm (plus 200 %) were measured !

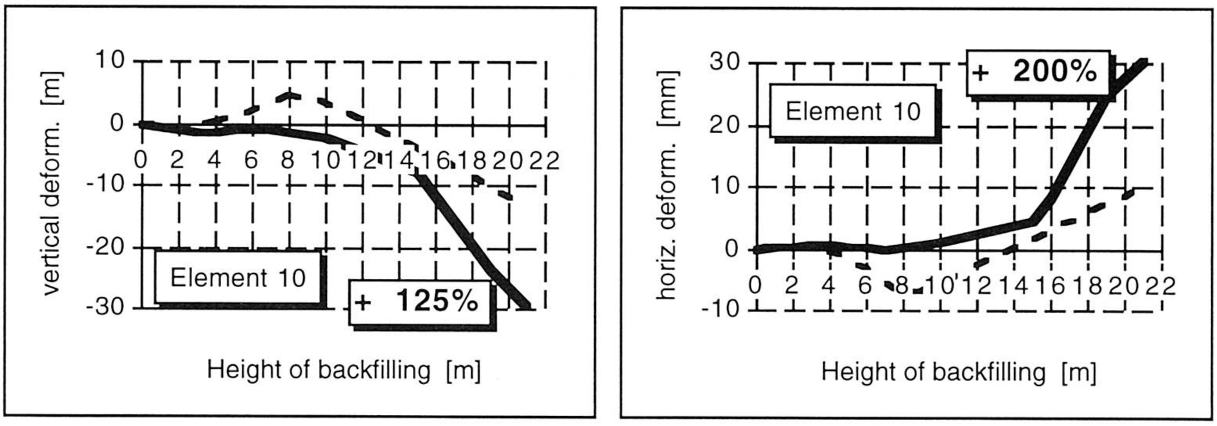

Fig. 8 Difference between calculation (dotted line) and measurement of the vertical and horizontal deformations at element 10

The close conformity of the results of the Finite Element calculations with the measurements in tunnel element 10 demonstrate, that the assumptions concerning the Finite Element model and the λ value for the lateral earth pressure were correct.

On the other hand, the mesurements on element 27 indicate that a strict compliance with the backfilling instructions is indispensable to prevent the tunnel construction from inadmissible stresses and deformations.