Bored diaphragm with heavy duty rock anchors

Parois en pieux avec des ancres à haute capacité

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SYNOPSIS A vertical cut of 20 m depth was supported with 45° inclined anchors of high bearing capacity. Owing to the high earth pressure a high concentration of anchors was necessary. Control measurements ensured the good placement of the anchors and the bearing performance of the wall. The latter was found to exhibit very low deflections in accordance to the requirements set.

INTRODUCTION

In the course of the construction of the nuclear power plant Neckarwestheim II a vertical cut with a depth up to 23.5 m was to be supported with - almost - no deformation of the near structures. The ground plan shows that the 175 m long retaining wall is not straight but it has a curved region and a sharp corner (s. Fig. 1).

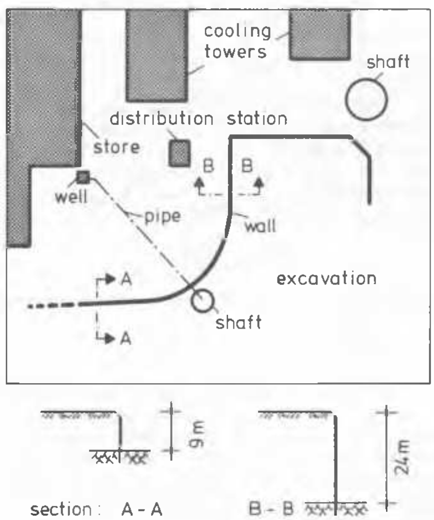

Fig.1 Ground plan and sections of the wall

The site is in a former quarry. The surface of the calcareous rock is covered by 9 to 24 m of silty fill placed without controlled compaction. Into this fill are buried pipes of importance to the working nuclear power plant Neckarwestheim I, which is situated close to the excavation. The design and the construction of the retaining wall were completed within 9 months. The upper rock stratum, a Middle Triassic Limestone with vertical and horizontal joints (s. Fig. 2), has an unconfined compression strength lying between 30 and 150 MN/m^2. The ground water level was lowered to about 20 m beneath surface level. Table 1

Fig. 2 Middle Triassic Limestone at Neckarwestheim

shows the measured parameters of the fill which consists of clayey silt.

In its curved region the retaining wall is crossed by a water-pipe, which has a diameter of 1.92 m. Bracing struts were not possible.

DESIGN

According to the available information the depth to the rock level was up to 23.5 m and the corresponding earth pressure was 2640 kN/m. The latter was to be supported with almost no yield. This earth pressure results from the strength parameters ϕ = 35° and c = 0. A so-called "increased active earth pressure" given by the coefficient

$$K = (K_a + K_o)/2 = 0.475$$

was laid down in order to assure a yield as low as required.

	mean	min.	max.	standard deviation
water content	19,2 %	6,7 %	28,6 %	3,3 %
w_P	17,1 %			2,8 %
I_c	0,88			0,19
clay content	27 %	15 %	39 %	
silt content	51 %	19 %	73 %	
$CaCO_3$ content		2,4 %	10,5 %	
organic content		5,3 %	8,2 %	
C_c	0,038	0,020	0,050	0,011
c [N/cm^2]	2,1	0,9	2,7	0,7
Φ	25,1°	21,8°	27,3°	2°

Table 1 Geotechnical properties of the fill

Initially, a horizontal timber sheeting with several rows of almost horizontal anchors was planned. But it turned out that the anchors did not have sufficient bearing capacity within the soft fill. Even with very long prestressed anchors the retaining wall would yield by creeping. Shaft-like anchor abutments placed into the fill (s. Fig. 3) were also rejected, as they would not guarantee sufficient rigidity. A cross-wise anchoring (s. Fig. 4) was not possible due to the high horizontal forces in the retaining wall.

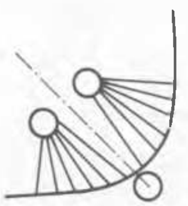

Fig.3 Shaft-like anchor abutments

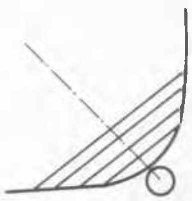

Fig.4 Cross-wise anchoring

Thus, the only feasible solution was to put the anchors into the underlying rock. A high inclination of 45° was chosen for the anchors. A lower inclination was not technically feasible and a steeper one would have invoked too high vertical forces within the wall.

The design was based on the use of rock anchors with safe working load of 1000 kN each. The resulting number of anchors was distributed in several rows. In every row the spacing of the anchors was 1 m. This high density of anchors was increased by the fact that the retaining wall was curved (s. Fig. 5). Starting from a maximum boring deviation of 1° the disposal of the anchor directions was chosen in such a way that mutual intersections of the anchors could be avoided. The no-intersection condition was checked by computer plots. Assuming a maximum directional deviation of 1°, every anchor covers a conus with an apperture of 2°. The intersections of these conuses with several horizontal planes are ellipses. If these ellipses do not seriously intersect each other the anchors are well placed (s. Fig. 6).

The bearing performance of the provided anchors bas been proved by tests. It has been found that a 5 m grouted section was sufficient to

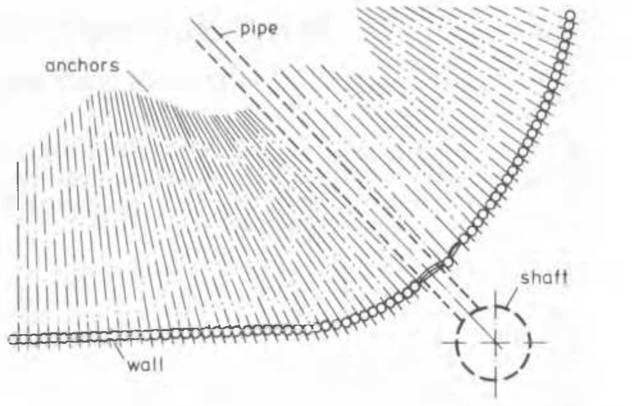

Fig.5 Distribution of anchors in the curved region

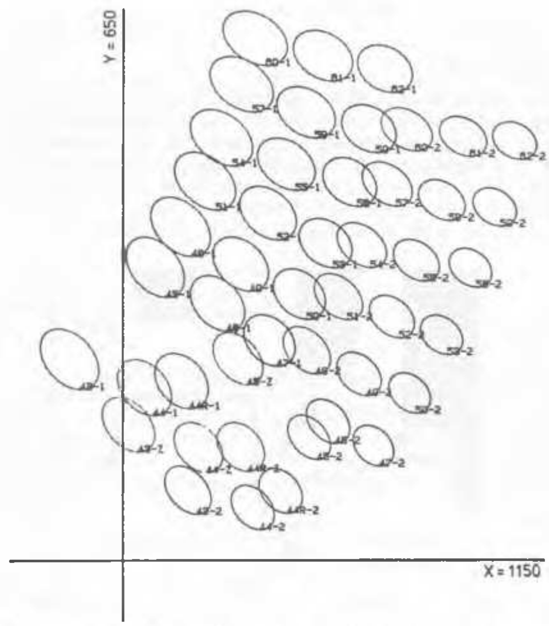

Fig.6 Computer plotted anchor targets

transmit the anchor force into the rock. The overburden weight of the fill was enough to counteract the total uplift force exerted by the anchors.

The tops of the anchors were mounted on heavy horizontal braces made of reinforced concrete. These braces were intended to carry and redistribute the anchor loads in case of a failure of an anchor.

The retaining wall is formed by a series of cast-in-situ piles of 88 cm diameter with a spacing of 1 m. Their point pressure can be carried by the rock. Due to the uncertainty regarding the exact level of the rock surface the piles were required to penetrate 2 m into the rock. The resulting abutment in the rock was also assigned a part of the earth pressure, which resulted from the assumption that the shear strength parameters of this jointed rock are

$$\phi = 50^\circ, \quad c = 0, \quad \gamma = 26.7 \ kN/m^2.$$

The consecutive excavations and stretching of the anchors alter the wall deflection and the earth pressure in the way shown in Fig. 7.

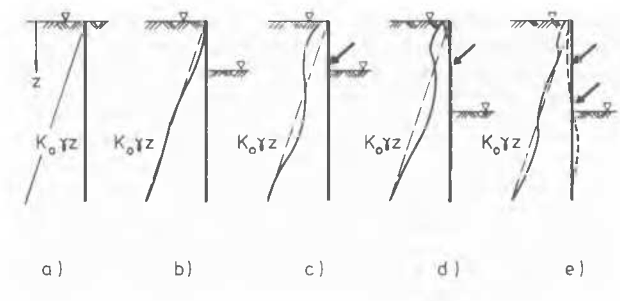

Fig.7 Earth pressure distribution at several stages of the excavation

(a) before excavation the earth pressure increases linearly with depth;
(b) the first stage of excavation causes a yield of the wall. As a consequence, the earth pressure decreases in the upper part;
(c) placing and pre-stressing the first row of anchors moves the wall back. This movement invokes a sort of passive earth pressure;
(d) due to the following excavation the corresponding part of the wall yields, and the earth pressure is reduced;
(e) the stressing of the next anchor row moves the wall back and causes an increase in the earth pressure.

Creep and stress relaxation in the soil make it impossible to obtain an exact prediction of the earth pressure distribution for every stage of the construction. Thus, it was decided to design the wall and the anchors according to the earth pressure distribution given in the recommendation EB 22 of the German committee of braced excavations (EAB), s. Fig. 8. Measurements of forces and displacements were taken to ensure that

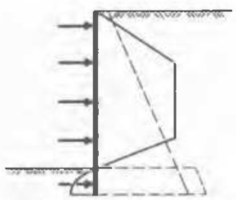

Fig.8 Earth pressure distribution in case of pre-stretched anchors, according to the German recommendation EB 22

the allowed loads were not exceeded. Special measurements were required in order to control the exact borings for the anchors.

CONSTRUCTION AND PERFORMANCE OF THE WALL

The boreholes for the 175 piles were excavated within 12 weeks using three BG 11 drilling machines. It turned out that the rock surface level was up to 6 m higher than expected. As a result, only 4 rows of anchors were placed. The rock was bored with drill bits. 4 piles were equipped with tubes enabling inclinometer measurements. 3 inclinometer tubes were placed into boreholes in the fill, 30 m behind the wall. The anchor boreholes were up to 40 m long and they had a diameter of 133 mm. For every borehole the orientation of the boring carriage was given by the geodesist. As far as was permitted by the ground water (i.e. up to a length of 37 m), the positions of the boreholes could be measured by means of a theodolite and a flashlight equipped with crosswires. The latter was introduced into the hole and its position was measured at several stages. The vertical position of the boreholes was also measured by the following method: A flexible tube filled with water was introduced in steps of 1 m into the boreholes. The hydrostatic pressure in the bottom of this tube could be measured by a piezometer. The curves obtained for borehole No. 93A are shown in Fig. 9. Due to

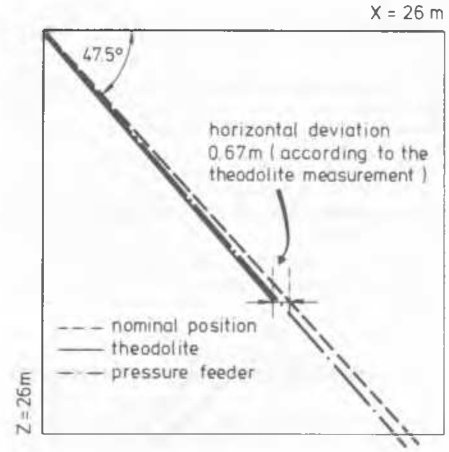

Fig.9 Measurements at the borehole for anchor No. 93A

the gravity effect the actual boreholes are slightly curved downwards. To counteract this effect, the orientation of the upper anchors was changed upwards by ca. 1.5°. In general, a boring accuracy of 1° was achieved.

According to the German Standard DIN 4125, the bearing performance of the anchors has been checked by loadings and unloadings in steps up to 1400 kN and measuring the corresponding displacements. In Fig. 10 typical results are shown. In order to ensure that the measured bearing capacity of the anchors would not be diminished by mutual interaction (so-called group action) two groups consisting of 3 anchors each have been tested by loading all three anchors simultaneously. The group anchors exhibited the same bearing performance as the single anchors.

The pre-stressing of the first anchor row caused a yield backwards of the wall by 43 mm (s. Fig. 11). This motion did not influence the inclinometer tubes placed behind the wall, where no displacement was registrated. A yield in the opposite direction was not observed until the excavation for the third anchor row occurred. The latter was accompanied by a yield of 5 mm. In general, this yield never exceeded 3 $^{o}/oo$ of the total wall height. Except for the window for the crossing pipe , the wall was equipped with 4 anchor rows. As was required, the pipes behind and across the wall have not been damaged.

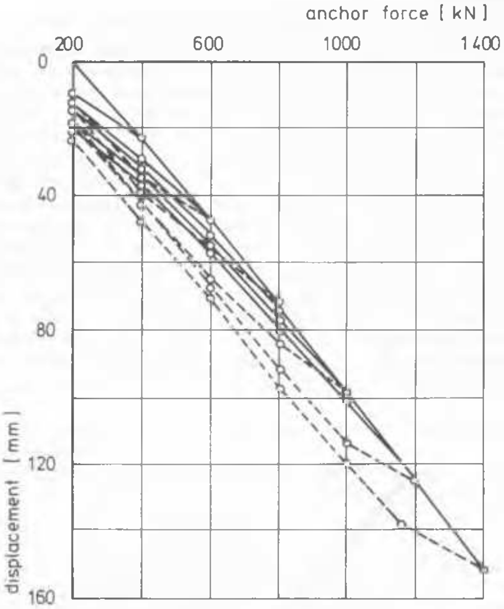

Fig. 10 Results of an anchor qualification test

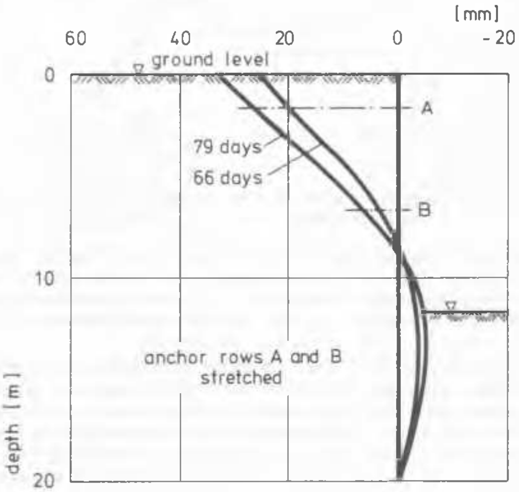

Fig.11 Measured displacements of the wall

CONCLUSIONS

The lateral earth pressure distribution during the excavation and stretching of the anchors is an unsolved problem and still gives rise to discussions. Two main theories prevail: According to one, the lateral pressure increases linearly with depth. The other theory claims that in braced walls a redistribution is possible due to arching in the soil. This redistribution can be counteracted by creep and relaxation of the soil. Because the actual soil behaviour is not known with confidence, the envelope of the lateral pressure distributions according to these two theories was used for the design. As a result, the upper anchors were stretched by forces exceeding the K_o-earth pressure and, therefore, the wall yielded backwards. This was accepted and caused no damage to the protected pipes, but it still gives rise to revise the second theory, which is established in the German recommendation stated above. It seems that if the wall is braced by pre-stressed anchors with sufficiently high stressing forces introduced into an underlying stratum of high strength, the wall deflections can be kept arbitrarily small.

Furthermore, it can be concluded that the present boring techniques achieve a high degree of accuracy enabling the use of a high concentration of anchors. This is of importance, especially in cases where the ground plan of the retaining wall to be anchored exhibits convex edges. In order to check this accuracy, control measurements of the borehole positions are necessary. Due to limitations of existing techniques such measurements are only possible when the boreholes are nearby vertical, not strongly curved and free of groundwater.

ACKNOWLEDGEMENT

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