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Behaviour of Vertical Ground Anchors

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Behaviour of Vertical Ground Anchors. X ECSMFE, Firenze, May 1991.

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ABSTRACT: This paper is a case story describing the application of permanent ground anchors counterbalancing uplift forces on a large highway underpass structure. The structure, soil conditions, design and installation of anchors are described briefly, and experience from testing and monitoring the anchors is presented. It is concluded that care should be taken in order to evaluate in advance possible critical variations of anchor forces.

RESUMÉ: Cet article décrit l'application des tirants d'ancrage dans le sol, pour équilibrer la souspression d'une nappe phréatique élevée au passage au-dessous d'une autoroute primaire. La constrution, les conditions de sol, le design et l'exécution des tirants d'ancrages est décrit et l'expérience du contrôle est présentée. La conclusion est, que c'est à recommander de prévoir et calculer les variations critiques des forces des tirants d'ancrage par avance.

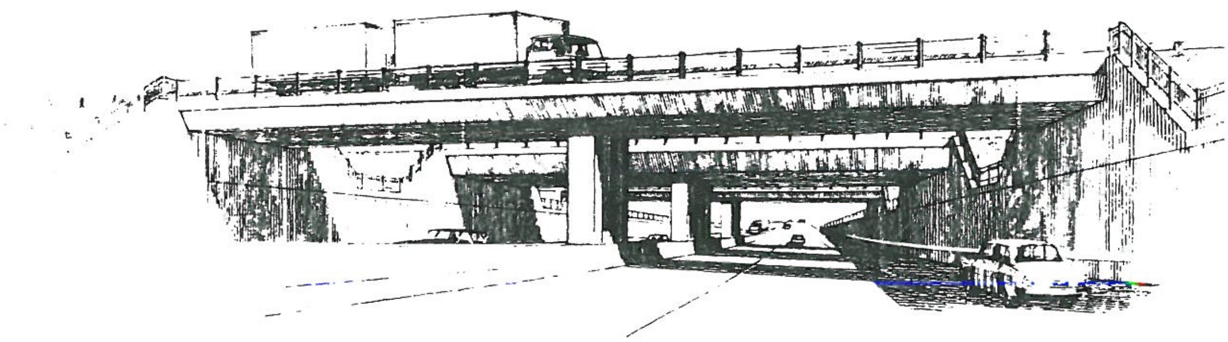

Figure 1. Perspective view of The Trough.

1. THE PROJECT

Part of a newly constructed 23 km six-lane expressway in the Middle East is a 675 m long and 33 m wide underpass structure in reinforced concrete known as "The Trough" (fig. 1). Main contractor on the project was Samsung Construction Co., Ltd., Seoul, Korea. Subcontractor on ground anchor works was Bauer, Schrobenhausen, Germany.

The deeper part of the structure is situated 6-7 m below ground level. To ensure adequate safety against uplift pressure caused by a high ground water table, the structure is equipped with 470 permanent vertical ground anchors (fig. 2).

A deep well dewatering system ensured dry working conditions during excavation, construction works, installation and stressing of anchors. This construction sequence caused large variations of effective vertical stresses in the soil below the structure (fig. 3). One notes in particular the large decrease of stresses caused by the final raise of ground water table (situation 5 to 6).

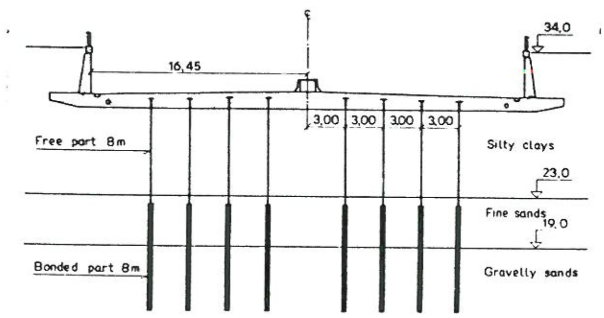

Figure 2. Cross section.

Table 1. Soil properties.

Level m	Classification (Unified)	γ kN/m³	w %	w_L %	I_p %	< 75 μm %	c_u kPa	N_{SPT}
34.0 - 26.0	CH	19-20	25-30	50-70	30-40	90-99	150-250	-
26.0 - 23.0	CL/CH	20-22	15-25	40-60	25-35	60-90	250-400	-
23.0 - 19.0	SM	-	-	NP	NP	10-30	-	30-140
19.0 -	GP/GM/GC	-	-	NP	NP	10-20	-	40-250

2. SOIL CONDITIONS

The area surrounding the structure is flat apart from man-made regulations. Ground level is ∽ +34.0 m and ground water level is ∽ + 33.0 m with seasonal variations of appr. ± 1 m. The subsoil consists of alluvial river sediments, silty clays, fine sands and gravelly sands (fig. 2). Soil properties are given in table 1.

3. DESIGN OF GROUND ANCHORS

Total number of anchors was calculated assuming a working load of 320 kN. A safety factor of 2.5 was specified for the ultimate capacity of the single anchors. Length of free and bonded anchor parts were 8 m each giving a total length of 16 m. Fig. 4 shows cross sections of free and bonded parts of the anchors.

Preliminary design of the anchors was carried out in principle only and detailed design was done on site by the contractor. Specified code for the anchor works was FIP 75 (ref.). This code was during the construction period replaced by FIP 82 on which the contractor's final method statement was based.

4. PRODUCTION AND INSTALLATION

All anchors were assembled and internally grouted over the bonded part under carefully controlled workshop conditions. The anchor holes were drilled with auger through the clay layers and with rotary drill bit using water and compressed air flushing through the sand and gravel layers. Temporary casing was used to the bottom.

After homing the anchor and filling the casing with grout through the filling tube (fig. 4) the casing was withdrawn and using the flushing tube, the top 6 m of grout was replaced by a weaker bentonite/cement grout.

The anchors were left for 12-24 hours of curing after which cracking of the external grout and post-grouting under high pressure was carried out. This procedure was repeated once more and each time, post-grouting was continued until a pumping pressure of 40 bars or a consumption of 100 liters of grout was reached.

Finally, the anchors were tested for acceptance, stressed to lock off load and grouted internally over the free part.

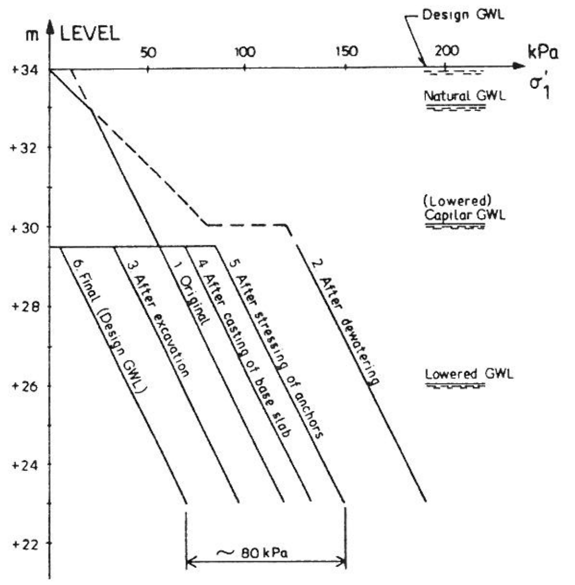

Figure 3. Vertical, effective stresses in the soil during construction.

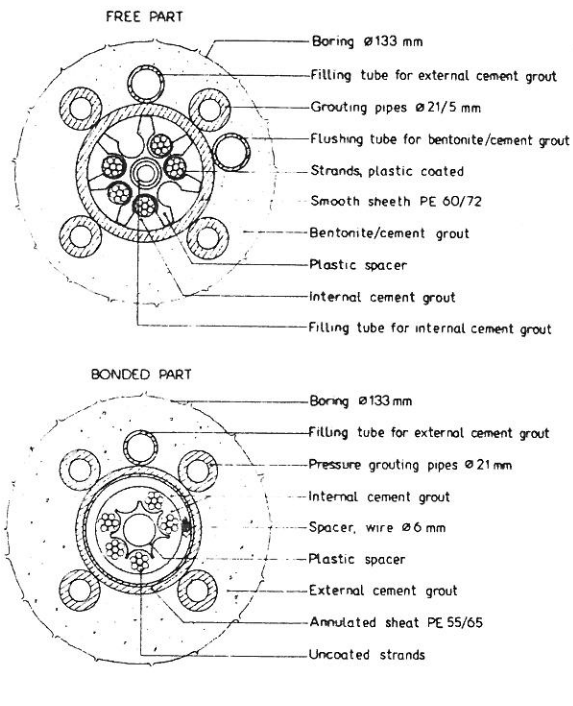

Figure 4. Cross sections of free and bonded parts of anchors.

5. ANCHOR TESTING

5.1 Proving Tests

Prior to finalizing the detailed anchor design, a series of proving tests were performed.

Purpose of the proving tests was to verify the detailed anchor design and to prove the adequacy of construction and installation methods in general. Five anchors with different number of strands and different bonded lengths were installed in order to test grout/ground and strands/grout bonds. Furthermore, single parts of the anchor were tested under workshop conditions. This included testing of grout mixture, corrosion protection, water tightness of connections between smooth and corrugated sheets and of bottom plug etc.

The proving tests caused amendments to a few anchor parts and construction methods, but generally the designed anchor and the way of construction and installation were found to be satisfactory.

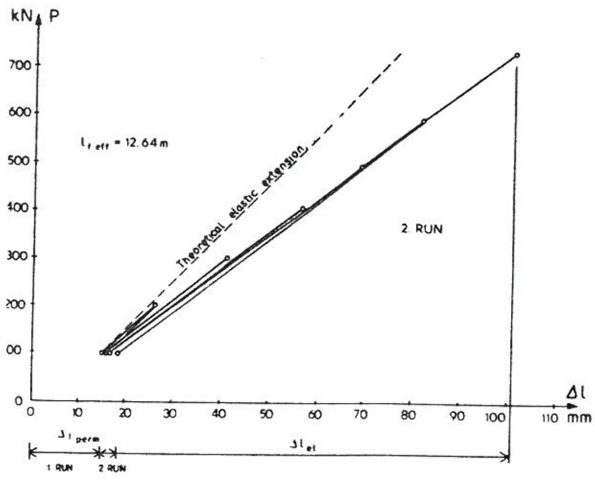

Figure 5. Suitability test. Load holding time t = 15 min.

5.2 Suitability Tests

When the contractors final method statement was approved, suitability tests were carried out on 20 non working anchors distributed evenly over the anchored part of the structure. The purpose of these tests was to verify the suitability and behaviour of the anchors under actual conditions prevailing on site and to provide basic test results from which acceptance criteria for working anchors could be derived.

All suitability test anchors were identical to the working anchors. A typical result of a suitability test is shown in fig. 5 and 6. A distinct seating effect is observed: Permanent deformations during 2nd run (holding time t = 150 min.) are very small compared to 1st run.

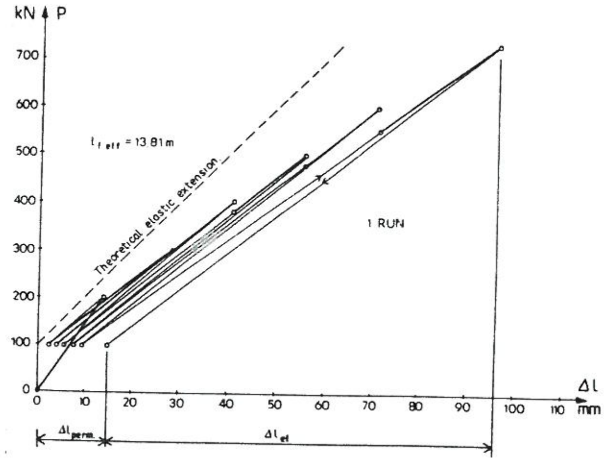

Figure 6. Suitability test. Load holding time t = 150 min.

5.3 Routine Acceptance Tests

Each anchor was subjected to acceptance testing to a proof load of 480 kN (1.5 times designed working load). Acceptance was based on criteria for permanent deformation, creep and effective free length.

Fig. 7 shows creep and permanent deformation of suitability test anchors at 480 kN for a holding time of load of 15 minutes. The agreed acceptance criteria are shown as well.

Only very few anchors had to undergo prolonged testing in order to fulfill the criteria, and in each case this was caused by too much permanent deformation. It was surprising to find that creep of the production anchors was in general much less than found at the suitability test anchors, often less than 0.1 mm. A possible reason for this could be a combined group effect, partly due to pressure grouting from surrounding anchors increasing horizontal stresses and partly due to large grout diameters over the bonded length.

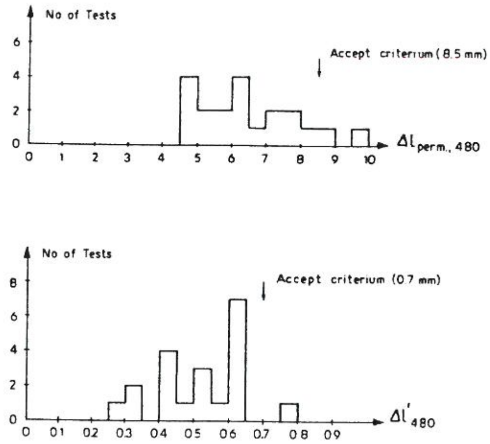

Figure 7. Suitability test results. Permanent deformation and creep at 480 kN. (t = 15 min.).

6. ANCHOR BEHAVIOUR

Hydraulic load cells were installed at 20 anchors for long time monitoring of anchor loads. In fig. 8, the average anchor load is plotted for a period of 6 weeks during which the ground water table was raised to near natural level.

This period was of special interest because raising of ground water was expected to cause significant increase of anchor forces due to large reductions of effective stresses in the soil along the free part of the anchors (fig. 3). Estimates of the magnitude of this load increase were based on oedometer tests carried out on silty clays. Deformation properties of sand layers were unknown and had to be estimated. It was calculated that a raise of grund water to design level would cause an increase of anchor load of approximately 120 kN.

In spite of the uncertainty of this calculation it was decided to take the expected load increase into account by reducing the initial anchor loads slightly. In practice this was done by keeping the load at 350 kN before lock off instead of after. This decision showed succesfull since the average monitored anchor load raised from appr. 286 kN with lowered ground water table to appr. 323 kN 6 weeks later.

However, at this time ground water level was still more than 1.5 m below design level, and based on the gained experience it was calculated that a further raise of ground water to design level will take anchor forces to an average of appr. 345 kN - giving room for remaining creep and relaxation of 25 kN.

It was noted, though, that the actual load increase (with ground water at design level) will amount to only half of the estimated.

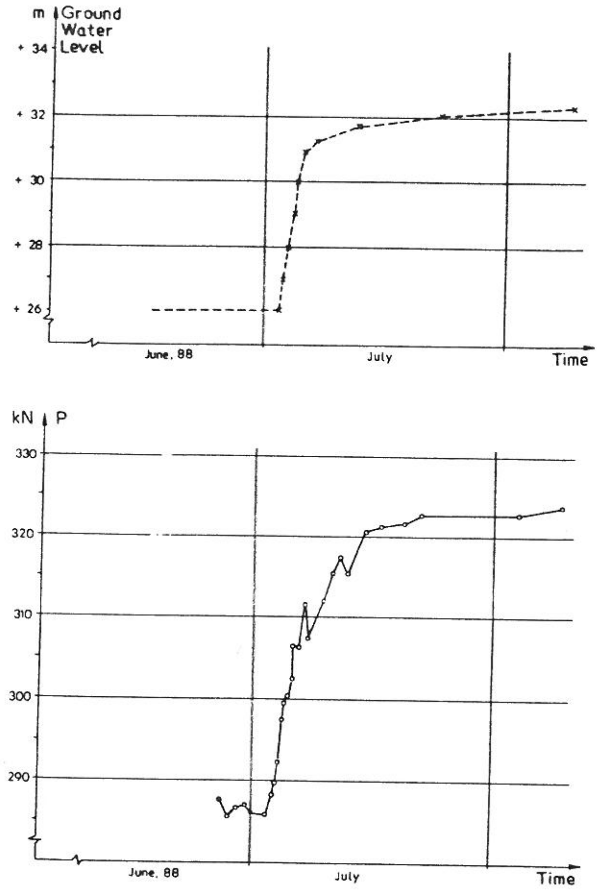

Figure 8. Monitored anchor behaviour during raise of ground water table.

7. CONCLUSION

We find this project to be an example where strict appliance with a good code (FIP 82) reveals its benefits: Smooth coorporation between supervision staff and contractor, systematic test programs and a high quality result.

The described findings from the monitoring of anchor loads emphasize the importance of examining the internal forces of anchored structures when exposed to external events. It also appears that prediction of such internal forces can be rather difficult.

In this case we ended up with almost exactly the intended anchor forces, although luck obviously had something to do with it. It is not difficult to imagine situations where unintended (and unexpected) stressing or relaxation of anchors could become of unacceptable magnitudes.

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