Deformation Measurements in the Bored-Pile Wall Combe Chopin

1. Introduction

Between the tunnels Raimeux and La Roche St.-Jean the Transjurane (highway through the Jura range of mountains) crosses the slope at Combe Chopin, partly by way of a bridge. During construction of a maintenance road a shallow slide parallel to the slope occurred along the transition surface separating the rock and the soil at a depth of around 6 m. The slope was stabilised by means of an anchored bored-pile wall, which had to be built in an active slide. Thus there existed the danger of overloading the bored-pile wall during its construction as a result of the forces exerted by the sliding mass. Therefore in this case the construction process was adapted to these special conditions. In sections, firstly the anchor holes were drilled, the anchors installed and grouted, then the piles were installed, the pile cap was constructed and then the anchors were prestressed.

By means of deformation measurements in the bored-pile wall, the computational models used together with the observed behaviour of the bored-pile wall were checked with regard to displacements and loading both under construction and in operation.

In the following the instrumentation is described and some initial measurement results for a pile are presented.

Fig. 1: The slope at Combe Chopin before construction of the bored-pile wall

2. Requirements placed on the Measuring System

- The task is to measure continuously the strains and displacements along the piles to be monitored in the direction of loading on both sides of the pile.
- In order to obtain the loading (axial forces and bending moments) from the deformation measurements in the pile, high accuracy of measurement within +/- 3/1000 mm per metre is required. A change of stress of 1 MPa with a Young’s modulus of 30,000 MPa results in a strain of only 30/1000 mm/m.
- One has to be able to measure the displacements and strains in the horizontal direction with high precision (within a few one-tenths of a mm).
- The measuring system has to be conceived in such a way that the displacements and strains can be measured over a long period of time, i.e. over several decades.
3. Instrumentation of the Bored-Pile Wall with TRIVEC

The instrumentation was carried out using the TRIVEC measuring system. It consists basically of measuring tubes that are embedded in the pile and of the portable measuring equipment. The measuring tubes of diameter 60 mm are in the form of a telescopic system with an extremely accurate inner cone-shaped measuring stop. The shape of the measuring stop allows the measuring instrument to be statically determined and firmly fixed between two consecutive measuring markers 1 metre apart, with a high reproducibility. To align the TRIVEC instrument during inclination measurements the telescopic tube is fitted with an orientation bolt.

![Fig. 2: TRIVEC measuring tube](image)

The 1 metre long TRIVEC measuring instrument has a sphere-shaped measuring head at the upper and lower ends. During the measuring process the measuring heads of the instrument are positioned at the cone-shaped stops of the markers by pulling on the cable or the measuring rod. At this point the distance between two consecutive measuring markers and the inclination with respect to the direction of gravity are measured with high precision by means of the sensors in the instrument and the measured values are stored in the field computer.

![Fig. 3: TRIVEC measuring equipment](image)

![Fig. 4: Diagram showing the TRIVEC measuring equipment in the pile](image)
In order to compensate as far as possible for systematic and random errors in the measuring procedure the measurements are carried out at each level in two diametrically opposite positions. The measurements are performed twice at each step of 1 metre, when lowering and raising the TRIVEC instrument. The complete measuring equipment is calibrated before and after each series of measurements. From this the zero value and the factors for the two inclinometers and the displacement transducer are determined. These values are taken into account in the evaluation of the individual measurements. By means of the numerical comparison of the subsequent measurements with the initial measurement the displacements and deformations of the instrumented piles are determined and afterwards the measuring results are output both graphically and numerically.

The measuring tubes were installed in the reinforcement of the piles partly on site and in the factory producing the reinforcing cages and fixed in position provisionally using steel bands. In order to prevent any damage during transportation of the reinforcing cages and when concreting the piles, here steel tubes were used instead of the usual plastic measuring tubes. The provisional cap at the top of the measuring tube allows an extension of the measuring tubes. Thus the measuring profiles could be extended into the pile cap.

Fig. 5: Pile reinforcement with the TRIVEC measuring tubes

Fig. 6: Diagram showing the cross section through the instrumented pile
The instrumented reinforcement cages were placed and concreted in the same way as the non-instrumented cages.

Fig. 7: Placement of the pile reinforcement with the TRIVEC measuring tubes

4. Measuring Results for Pile No. 16

Altogether two TRIVEC measuring tubes were placed in each of 8 piles. The 8 instrumented piles are distributed over the whole length of the wall. The zero readings were carried out about 2 weeks after concreting the piles. At the same time in addition to the TRIVEC measurements the temperature profile in the pile was measured. The temperature measurement allows deformations due to temperature to be compensated. A further measurement was usually carried out before the anchors were prestressed over the whole length of the measuring tube (in the pile and the pile cap that had in the meantime been constructed) and a further one again some days later, after the anchors were prestressed in the corresponding section.

The first two measurements showed on the one hand the shrinkage of the concrete and the shortening due to the cooling down of the pile. On the basis of the inclinometer readings it can also be observed whether the pile is already being subjected to forces arising from a possible active slide.
Fig. 8: Differential vertical displacements

The introduction of the anchor force is clearly manifested in the form of differential vertical deformations. The tube positioned on the upslope side showed small but definite shortening in comparison to the initial readings of maximum 0.05 mm/m and the downslope measuring tube exhibited lengthening of maximum 0.045 mm/m.

Since only very small horizontal displacements were observed, it may be assumed that in this case up to the present time no substantial horizontal loading of the pile has taken place.

Fig. 9: Horizontal displacements
5. Closing Remarks

The instrumentation of the bored-pile wall Combe Chopin, which was commissioned by the Department of Civil Engineering Works of Canton Berne and was supervised by the consulting engineers GVH Tramelan, clearly showed that the behaviour of structures like the instrumented bored-pile wall can be checked by means of instruments and monitored over a long period of time. The measurements correspond in principle to measurements on a test beam in the laboratory. In the present case the axial force and bending moments can be determined on the basis of these measurements. These measurements serve as the input for the numerical modelling of the anchored bored-pile wall. The high accuracy of measurement of the selected measuring instruments is absolutely essential for the given task. Similar instrumentation has been used in recent years in various diaphragm walls (e.g. in Port Suez and Port Said) as well as for vertical and horizontal pile load tests.

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