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ScienceDirect
Procedia Engineering 172 (2017) 1129 – 1136
Procedia Engineering
www.elsevier.com/locate/procedia

Modern Building Materials, Structures and Techniques, MBMST 2016

Full-scale Testing of Ground Anchors in Neogene Clay

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Abstract

The research campaign aimed on the better understanding of behavior of prestressed soil anchors in neogene clay, including conduction of variety of in-situ (CPT, PMT) and laboratory (Triaxial test, Simple shear test an Oedometric test) ground investigation methods, has been done during 2012 – 2015 in Czech Republic. The stress – strain diagrams and distribution of axial force along the anchor free length and anchor bond length was determined, based on the data obtained from variety types of sensors placed onto the tendon and into the gravity and post-grouted part of the grout body. On the basis of this information the software application for prediction of the anchor pull-out force and stress-strain diagram was developed, calibrated and verified. The application for purposes of conduction of prestressing tests and test reports elaboration was programmed also. Research activities leading to development of the pair of forenamed software are described in paper.

*Keywords:*Rock anchors; Geotechnical measurement; Full - scale load testing; Monitoring; Software development.

1. Introduction

Grouted ground anchor is a structural component used to transmit tension force from the structure to the subgrade. Ground anchors are typically used as a supports of retaining structures of excavations or for slopes stabilisation. They are also used against the uplift or overturning of structures. The research project focused on better understanding and improvement of design process of those members was conducted by research group gathering the members involved in the field of realization (STRIX Chomutov,a.s.) design (SG-GEOPROJEKT, spol.

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doi:10.1016/j.proeng.2017.02.170

s.r.o.) and research (Brno University of Technology, Faculty of Civil Engineering) in years 2012 - 2015. Financial support for the research activities has been obtained from the Ministry of Industry and Trade of the Czech Republic.

The crucial part of the research was conduction of the full-scale load testing program performed at the experimental site located in Brno, Czech Republic (130 km north of Vienna). The various aspects of this extended load test campaign were reviewed, e.g. soil investigation, anchor and measurement system installation methods [1], [2] [3] [4], recording an interpretation of load tests [5] [6], monitoring [7] variety of design methods [8] [9] and design assumptions [10] [11] etc. Moreover attention was paid to the experience with ground anchors of several Czech special foundation contractors in sense of building up a database of test records conducted on sites in last ten years. The statistical analysis based on data from those tests has been performed [12] [13] [14]. In addition, anchoring techniques like a SBMA [15], which use is recently not common in Czech Republic now, have been tested and the results have been analyzed.

On the basis of a set of load tests, detailed analysis of geological and geotechnical conditions and technological aspects, an application system has been developed. The system can be applied in the design and assessment of geotechnical structures and in a complete set of project preparation, implementation work and monitoring of special geotechnical structures. The application system for the design of ground anchors is meant to enable relevant, safe and economical design and geotechnical assessment of the structural elements of buildings, which often makes up 50% of the price of work and deliveries of special geotechnical structures.

2. Ground Investigation

The research activities associated to full-scale testing were divided into the two phases. The detailed geotechnical site investigation was performed before installation of the "Phase I" Anchors. The CPT tests have been performed and evaluated [16]. The samples for the physical and index properties of the soil laboratory determination has been taken from boreholes. The PMT pressuremeter tests have been performed in those boreholes also. The oedometric tests, triaxial tests, and simple shear tests have been performed on the samples of the soil for the purpose of determination of the mechanical and deformation properties of the soil. The soil has been classified as a Cl – Clay according to the EN ISO 14 688 [17]. The consistency of the upper layer (0.0 m – 2.0 m) was stiff. In the lower layers the consistency has changed into firm. The thin-face calcium carbonate strata have been present in the samples. The aim of all those tests performance was to obtain input values for first estimate of the ultimate anchor capacity in the Neogene clay, which soil is the typical subsoil in Brno area.

3. Full-scale testing

After initial survey, it was proposed by the project team to set up work at full-scale testing in the Arboretum belonging to the Mendel University in Brno, Czech Republic. Seven pressure grouted [18] (6 of them using Selective and Repeatable Injection IRS method, and 1 of them using Global and Unique Injection IGU), strands anchors were installed and tested on the arboretum site during two seasons 2013 and 2014. All boreholes for anchors have been drilled vertically. The rotary drilling without casing has been used to drill the boreholes. Diameter of the borehole was d = 180 mm. Relatively high value of the borehole diameter was chosen due to avoiding the damage of installed sensors. The crane has been used to insert the anchors into the drills due to the same reason. Tested anchors characteristics are summarized in Table 1.

Table 1.Tested anchors description.

ID		No. of strands φ 15,7 / 1860	Type of anchor	Extension length L_e [m]	Tendon Free length L_{tf} [m]	Tendon bond length L_{tb}[m]	Total length [m]
Phase I (2013)	I-A1	6	Standard	2,0	5,0	6,0	13,0
	I-A2	6	Standard	2,0	5,0	6,0	13,0
	I-B	5	Standard	2,0	5,0	8,0	15,0

Phase II (2014)	II-B	5	Standard	2,0	5,0	8,0	15,0
	II-C1	7	Standard	2,0	5,0	10,0	17,0
	II-C2	7	Standard	2,0	5,0	10,0	17,0
	III		SBMA	2,0		2 x 3,0	

The research activities associated to full-scale testing were divided into the two phases, as stated above. The first reason for phasing work was to evaluate the design assumptions and estimates and take the conclusions into account in the next phase. The second reason was the evaluation of functionality of selected types of sensors. The short description of sensors used is in next paragraph.

3.1. Measurement system

One of the adjacent goals of the research was to test the feasibility of installation of variety of sensor types for purpose of measurement of desired magnitudes. Simple description of selected sensors that were used is in Table 2.

Table 2.Tested sensors description.

Measured magnitude	Used type of sensor	Principle of measurement	Position of the sensor
Displacement	LVDT	Linear variable differential transformer	Anchor head
	Potentiometric rotary sensor	Potentiometer	Anchor head
Strain	Foil resistance strain gauge	Change in electrical resistance	Tendon, grout
	Vibrating wire strain transducer	Change in the frequency of oscillation of the string	Tendon, grout
Force	Load cell	Resistance strain gauge	Anchor head
Stress	Magneto-elastic torque sensor	Change in the magnetic field around the tendon	Tendon

Basic monitoring consisted of measurement of displacement of the tendon and of prestressing force. The load cell SISGEO 0L219V18000 has been used for the force measuring, and pair of LVDT transducer for the displacement measuring.

Advanced monitoring techniques have been used for purpose of the quasi-continual measuring of the force in the whole length of the tendon. The Foil resistance strain gauges HOTTINGER 1-LY-3 /350 have been fasten to the strands in the anchor bond length L_{tb}. The Magneto-elastic torque sensors INSET have been installed in the anchor free length L_{tf} and also in the anchor bond length L_{tb} [19]. The vibrating wire Strain gauges SISGEO 0VK4200VC00, GEOKON 4200 / 42002 and foil resistance strain gauges HOTTINGER 1-LY-3 /350 have been placed in the pressure and gravity grouted parts of the grout body for the purpose of measurement of the strain in the grout. Figure 1 shows the installed foil resistance strain gauge with water protection and the vibrating transducer fixed to the tendon.

a *b*

Fig. 1. (a) the foil strain resistance gauge stuck on the tendon; (b) the Vibrating wire strain transducer fixed to the tendon.

3.2. Investigation tests

All anchors have been tested according to the pr EN ISO 22477-5 [20]. The investigation test using cyclic load test procedure TM1 has been conducted (after reaching the maxim level of the prestressing force in every cycle, the force was kept constant, and the displacement of the tendon was measured and registered in specified times).

The load bearing steel frame was designed and fabricated for distributing the reaction from stressing force into the pair of steel pads. The stiffeners were added to the frame profiles to increase lateral buckling resistance [21]. The bridge has been placed over the tested anchor, on what the LVDT transducers has been fastened. So the displacement measurement has not been affected by the deformation of the bearing frame. Figure 2 shows setting up the hydraulic jack and measurement devices prior the start of investigation test.

a *b*

Fig. 2. (a) the investigation test setting up; (b) bridge for the independent measurement of the tendon displacement.

3.3. Data from monitoring

The similar process of behavior under loading and failure mode of tested anchors was observed on all tested members. After reaching the ultimate resistance (maximum value of prestressing force), the sudden decrease of prestressing force occurred. It was accompanied by the eye visible displacement of grout body out of the ground. After the anchor was fully unloaded, the prestressing force was increased again. The level of 50 % - 55 % of previous maximum value of prestressing force was achieved by this operation. The protrusion of grout body out of the ground was observed again, when this level of force was tried to be kept by the hydraulic jack piston lift. The record of measured prestressing force and tendon displacement from test conducted on anchor II-B, where the above described phenomena are recorded, is shown in fig. 3.

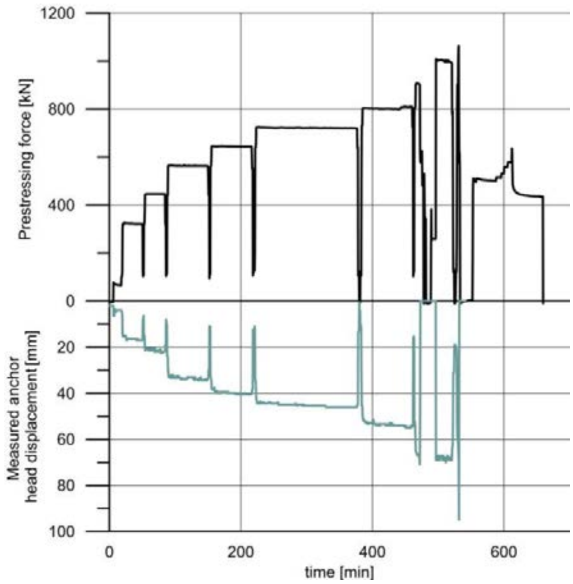

Fig. 3. The loading procedure test record of anchor II-B.

4. Results

All experiences, that the authors acquired from work and its results described in previous chapters has been capitalized in last phase of the project, which consisted of creation of the efficient and practically usable application system, as stated in Introduction. It was achieved by writing the two software applications, which simple description is in next paragraphs.

4.1. Software application for ground anchors design based on load-transfer functions

Determination of the ground anchors ultimate carrying capacity is mostly conducted using various empirical and semi-empirical methods [22] [10] [11] etc. These procedures are usually successful but highly simplified. Wide range of empirical factors is required, which knowledge is limited only for certain types of soil. One of the major simplification of these methods is an assumption that the bond stress on the soil – grout interface is mobilized uniformly along the whole fixed length. The result of these methods is mostly only ultimate carrying capacity with no additional information about the displacement required to mobilize this ultimate force. An innovative approach incorporating load transfer functions [23] is therefore proposed. A load transfer function (t-z curve) is the dependence of shear stress mobilized on the surface of a member on the vertical displacement of a corresponding member. The load transfer function is frequently adopted for determination of the load – settlement curve of vertically loaded piles [24]. However its use for ground anchors is rare. The important feature of the proposed approach is the possibility to determine t-z curves as a combination of standard laboratory tests results (e. g. direct shear test) and certain assumption of shear stress mobilization in radial direction [25]. The program application incorporating this assumption was created. The newly developed algorithm also includes several other features: e. g. axial stiffness change due to the occurrence of tensile cracks in the grout material, radial stress increase due to the post-grouting (cylindrical cavity expansion theory [26] is therefore adopted) followed by its decrease caused by the grout consolidation [27] [28] [29] etc. Back analysis of three ground anchors using this application was described in [30]. Use of the newly developed application is demonstrated on fig. 4 where the measured and predicted load-displacement curves for the II-B anchor are compared.

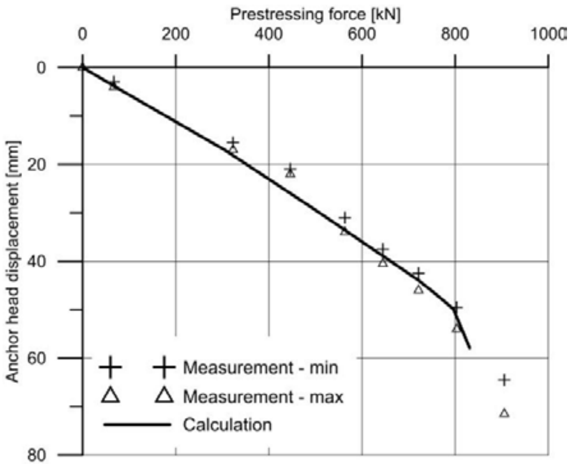

Fig. 4. Measured and predicted dependence between the prestressing force and anchor head displacement for anchor II-B.

4.2. Software application for ground anchors testing

Each ground anchor has to be tested in a way of prestressing. The aim of the test is to prove accomplishment of acceptance criteria, which has been defined to demonstrate the capacity and serviceability of tested anchor. The recommendations for testing of anchors in Europe are changing recently. The new recommendations [20] demand new style of test records. The finding was done, based on the evaluation of records from past years elaborated by local contractors, that none of them satisfies those new code demands. This situation, which the contractors relatively easily could deal with, was judged, with some reason, difficult and inconvenient for them by the research team. The software utility has been developed for purpose of keeping the test records suitable to those demands. The utility facilitates and automates also the process of deriving the acceptance criteria values [31]. The bonus of records worked up using proposed application for future research is the fact, that records are stored in digital files. Those files can be relatively easily processed in sense of extend the database of test records for future analyses. The interactive template of record consists of those components:

- The text fields for recording the key information identifying the concrete test (e. g. the site reference, location reference, date of the test execution etc.). For the purpose of mark the anchor in terms of working time (short-term, long-term) the drop down menu is available. The values typed in cells, where user specifies geometrical and mechanical properties of the anchor tendon and anchor bond, serves as input values for determination of the apparent free length of the anchor L_{app}, as same as the values of prestressing force levels P_P and P_a .

- The next part of the record has the form of a table, into which the measured deformation of the anchor tendon is written. Those values are used as inputs for the graphs plotting. In the last row of this table the creep coefficient α_1 is calculated based on the last four recorded values of deformation. The least square method is used for determination of this coefficient, where R^2 indicates, how well the measured data fit the statistical model with linear trend.
- The graphs, that are automatically drawn, serve for purpose of documentation the load test process and for deriving the desired acceptance criteria and results of test: 1) Record of loading procedure in time; 2) Anchor head displacement vs. logarithm of time; 3) Anchor head displacement vs. load; 4) Variation of α with the applied maintained load (the graph serves for determination of pull-out resistance in case of investigation test).
- At the end of the template user can see values determined from input data and drop down menu for test result input (OK/not OK).

5. Conclusions

After detailed ground investigation, seven full-scale investigation tests on prestressed ground anchors in neogene clay were conducted. The applicability of variety of sensors for measurement of desired magnitudes (Displacement, Force, Stress and Strain) on different cross sections of anchor was tested. All installed sensors were evaluated to be satisfactory for purpose of monitoring the behavior of anchor during prestressing. The results of basic and advanced monitoring gave the detailed description of stress-strain behavior of tested elements. It proved the strong decreasing of the prestressing force, after reaching the critical mobilized skin friction. The stabile residual value of prestressing force was in range of 50 % - 55 % of its peak value. The considerable difference between the ultimate and residual force proved the progressive debonding (decreasing of the shear stress along the bond of the anchor). Distribution of axial force in the tendon and in the grout along the anchor length was also received from measurement.

The new program application was created, which was calibrated and evaluated on basis of data from measurement described above. The main advantage of this application is its ability to predict the stress-strain diagram of the anchor and distribution of axial force and of shear stress along the anchor fixed length, instead of just give the estimate of the pull-out resistance.

The finding was done, that none of existing test records templates used by local contractors satisfies new code requirements on those records. Thus the second application was programmed, which facilitates and automates the conduction of anchor testing and elaboration of the test records.

Acknowledgements

This research was financially supported by the research project of Ministry of Industry and Trade of the Czech Republic No. FR-TI4/329.

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