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Backanalysis of an instrumented reinforced abutment on soft soil

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ABSTRACT: This work presents a numerical analysis of reinforced abutments built in highway works in the state of Santa Catarina, Brazil. The abutments are 5.80 m high and were reinforced with eight layers of uniaxial geogrids that were oriented with the strongest direction aligned with the highway axis. To accelerate the consolidation of the foundation soil, geodrains were installed in a square pattern with 1.30 m spacing. For a better knowledge of the soft-soil proprieties, several types of field and laboratory tests were performed, including consolidation, triaxial, field vane shear, piezocone and dilatometer tests. Because of the proximity of an existing concrete bridge structure, the abutments were instrumented with inclinometers, vibrating wire piezometers, Casagrande piezometers, settlement plates and a full-profile settlement gauge. To the numerical predictions, the computer code PLAXIS 7.2 was used. The parametric study yielded to satisfactory comparisons between predicted and observed performances of the abutments and helped to identify design aspects that might be optimised had this type of analysis been performed in advance.

1 INTRODUCTION

Large and sometimes rather deep soft soil deposits are often found in the Brazilian territory. These occurrences may pose difficult engineering problems to be solved when highways and other types of embankments have to be built on such soils. Some types of techniques for the improvement of softsoil deposits have been developed during the last decades. When the construction of an embankment on a soft soil can not be avoided, geosynthetic reinforcement associated with pre-fabricated vertical drains can be used to increase embankment stability and to accelerate consolidation settlements. In addition, numerical tools can be utilized for the prediction of the embankment behaviour. A numerical method that has been frequently used is the Finite Element Method, and today several commercial codes are available for analyses. Field instrumentation can also be used to monitor the embankment behaviour with time and measurements can be compared with numerical predictions to backanalyse the embankment performance.

2 DESCRIPTION OF THE PROJECT

The abutments studied are part of the duplication of the BR-101 highway, in the state of Santa Catarina, in South of Brazil. The abutments are 5.80 m high and were reinforced with eight layers of uniaxials geogrids with 200 kN/m tensile strength, 30 m long, at 0.40 m spacing along the vertical. The reinforcements were oriented with the strongest direction aligned with the highway axis. Geodrains were installed in a square pattern with 1.30 m spacing. At the face of the abutment whose performance is reported in this paper there is a 18.5 m wide fill, that is the berm used to construct the old highway embankment (Figure 1). The foundation soil is composed of a clay layer overlying a layer of sand and another layer of clay (Figure 1).

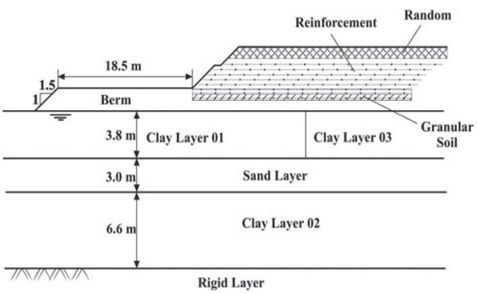

Figure 1. Geometry of the problem.

A sand blanket, 0.4 m thick, was executed before the installation of the reinforcement layers. All the reinforcements were buried in sand, while the rest of the embankment height was constructed using a fill material consisting of a random mixture of materials (rockfill elements and fine grained materials).

The abutment whose results are discussed in this paper is that at the south of the bridge. This abutment was chosen because of the greater number of instruments installed in it.

3 FIELD INSTRUMENTATION

Due to the proximity of an existing concrete bridge, the abutments were instrumented with inclinometers, vibrating wire piezometers, Casagrande piezometers, settlement plates and a full profile settlement gauge (horizontal inclinometer) to monitor its behaviour during and after construction. Figure 2 presents the location of the instruments.

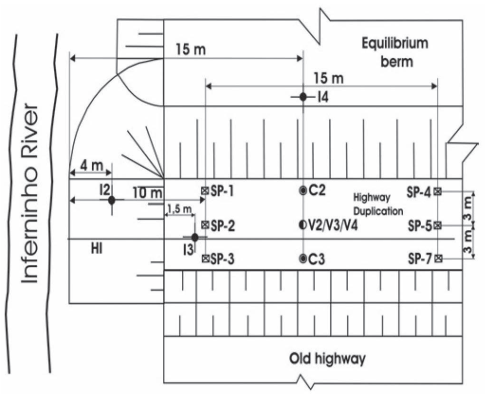

Figure 2. Location of the instruments in the south abutment.
SP: Settlement plate
HI: Horizontal inclinometer (full profile settlement gauge)
I: Inclinometer
C: Casagrande piezometer
V: Vibrating wire piezometers

4 FIELD AND LABORATORY TESTS PERFORMED

For a better knowledge of the soft soil proprieties, several types of field and laboratory tests were performed, including consolidation, triaxial, field vane shear, piezocone and dilatometer tests. The results of these tests were used as initial input values of some parameters in the numerical analyses. Based on the results of the field instrumentation, some of these initial values had to be calibrated to achieve a better comparison between predicted and measured values.

5 NUMERICAL TOOL AND PARAMETERS USED

For the predictions of displacements and strains the Finite Elements code PLAXIS 7.2 was used. This program analyses geotechnical problems under plane strain conditions with a variety of soil constitutive models. Two models were chosen to simulate soil behaviour: the *soft-soil model* was used for the soft clays in the abutment foundation and the *Hardening-soil model* was used to simulate the embankment material. Tables 1 and 2 show the soil parameters required by these models for the calculations related to the abutment performance.

Table 1. Clay soils parameters.

Soil Property	Clay 01	Clay 02	Clay 03
λ^*	0.12	0.12	0.26
κ^*	0.04	0.05	0.095
c (°)	3	3	3
ϕ (°)	27	27	27
ψ (°)	0	0	0

Table 2. Fill and sandy soils parameters.

Soil Property	Fill	Random	Sand Layer
γ_{dry} (kN/m^3)	18.5	20	15
γ_{wet} (kN/m^3)	20	22	16
c (°)	1	1	1
ϕ (°)	33	33	33

Additional information on the case-history and methodology employed in the analyses can be found in Fahel (2003) and Araujo (2004).

6 RESULTS OBTAINED

Numerical simulations (Araujo 2004) of the performance of the instrumented embankment were performed and the results compared to the measurements obtained from the geotechnical instrumentation. The following items show the comparisons between numerical predictions and field instrumentation data in terms of settlements of the abutment, horizontal displacements measured in inclinometer I3, close to the embankment crest (Fig. 2), and poropressure increments in piezometer V2 (Fig. 2).

6.1 *Vertical settlements along the abutment axis*

Firstly, numerical simulations of the abutment performance were made with and without the reinforcement layers. Figure 3 depicts the comparisons between such predictions with respect to the settlement profile along the abutment axis 53 days after the abutment construction has started. These results show

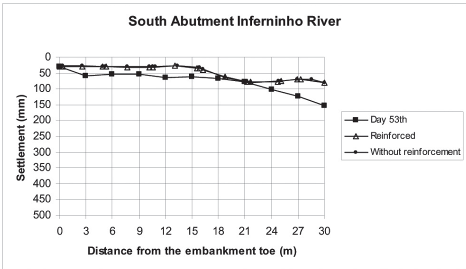

Figure 3. Comparisons between vertical displacements after 53 days of monitoring.

that the presence of the reinforcements would have negligible effect on the settlements of the abutment. These behaviour was confirmed by comparisons between predicted and observed settlements after 110 days of monitoring, as shown in Figure 4. The predicted settlements compare well with measurements, but again the presence of the reinforcement layers had negligible effect on the development of settlements along the abutment axis.

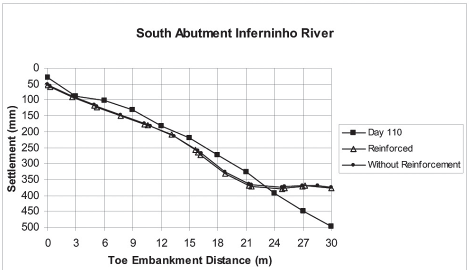

Figure 4. Comparisons between vertical displacements after 110 days of monitoring.

6.2 *Horizontal Displacements*

Figures 5 and 6 show comparisons between predicted and observed horizontal displacements in inclinometer I3 (Fig. 2) after 88 and 121 days of monitoring, respectively.

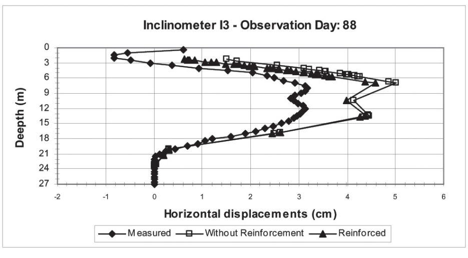

Figure 5. Comparison between horizontal displacements after 88 days of monitoring.

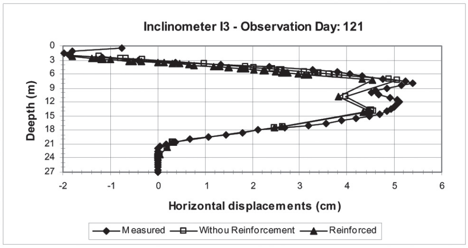

Figure 6. Comparison between horizontal displacements after 121 days of monitoring.

The patterns of variation of horizontal displacements through depth are similar in both cases. The numerical analysis was able to pick the reduction of horizontal displacement in the region of the sand layer in the foundation. The comparisons between numerical predictions with and without reinforcements show that the presence of the reinforcements slightly reduced the horizontal displacements. This may have important practical implications when the abutment is built after the bridge and its foundations have been executed. Some rather significant deviations between predicted and observed horizontal displacements can be observed in Figure 5. However, predictions and measurements after 121 of monitoring compared well, as shown in Figure 6.

Other works in the literature have also reported differences between predicted and observed horizontal displacements using the finite element method. In a very well documented case-history, Calvelo & Finno (2004) did not obtain accurate predictions of horizontal displacements. Other examples of deviation between predictions and observations can be found in Ortigão (1980) and Bergado et al. (2002). The results obtained in the present and in other works in the literature highlight the complexity still involved in the predictions of horizontal displacements by numerical methods.

6.3 *Excess poropressure*

Figure 7 shows that the numerical analysis predicted the maximum porepressure increments rather accurately in piezometer V2. However, the rate of porepressure dissipation predicted was greater than that observed in the field.

Differences between measured and predicted excess porepressures can be associated to the following factors:

- Partial clogging of the vertical drains, which at this stage is difficult to quantify;
- Variation of soft soil coefficient of permeability around the vertical drain due to smear;
- Misbehaviour of the piezometer;
- Variations of the horizontal coefficient of consolidation with time (Arulrajah et al., 2003),

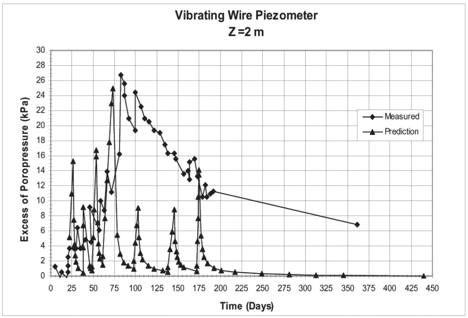

Figure 7. Comparison between predicted and measured poropressure increments with time in piezometer V2.

which is not taken into account by the computer code employed.

7 CONCLUSIONS

This paper presented a numerical simulation of an instrumented reinforced abutment on soft soil using the finite element method. The main conclusions obtained are summarised as follows:

- The models used in the numerical analyses showed satisfactory accuracy for the predictions of displacements and maximum porepressures;
- When comparing measured and predicted increments of poropressures, it was noted that the predicted value of the maximum increment was very close to the measured one, but the dissipation rate was faster in the numerical analysis. This may be attributed to some limitations of the numerical tool employed;
- Bearing in mind the complexity of the problem and some level of uncertainty on some soil parameters and project data, the numerical analysis proved to be an important tool for the prediction of the abutment performance. It also allowed to verify that the designers of the work were over-conservative regarding the number and characteristics of the reinforcement used.

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