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Behavior Evaluation of an Anchored Wall

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***Abstract*—**This work presents a study about a retaining structure designed for the duplication of the rail FEPASA on the 74th km between Santos and São Paulo. This structure, an anchored retaining wall, was instrumented in the anchors heads with strain gauges in order to monitor its loads. The load measurements occurred during the performance test, locking and also after the works were concluded. A decrease on anchors loads is noticed at the moment immediately after the locking, during construction and after the works finished. It was observed that a loss of load in the anchors occurred to a maximum of 54%.

***Keywords*—**Anchors, Instrumentation, Retaining wall, Strain gauges.

I. Introduction

THE objective of this work is the processing of data obtained from a geotechnical instrumentation program to analyze the behavior of an anchored wall, built for doubling FEPASA railway at Km 74 between Santos and São Paulo. The instrumentation data consisted of load measurements in thirty-six ground anchors instrumented with load cells installed in the head thereof.

Load readings were taken continuously from the performance test, locking and up to the stabilization of loads, which was the average of six months after the completion of the construction work activities. No measurements were made for monitoring the horizontal displacement of the anchored wall over time.

The analysis of data obtained in field instrumentation presented in this work includes monitoring the load of evolution over time, as well as the comparison of these values with those estimated by the apparent earth pressure diagrams and design procedures proposed by [1], [2] and the Federal Highway Administration [3].

II. Characteristics of Structure Studied

A. Geometry of the Anchored Wall

The retaining structure studied is an anchored wall composed of continuous panels cemented "in situ", usually comprising two ground anchors in each unit, with a height between 1.5m and 2.0m and length of 4.5m. The total length of the anchored wall is 205m approximately, with a maximum height of 18m in the central section decreasing towards the ends, and featuring six expansion joints along its length. The structure has a total of 89 sections, spaced 2.0m, each corresponding to a row of ground anchors, determined by the final level of the anchored wall, ranging from the top level (Level A) to the lower level (Level L), composing a frame of 786 ground anchors in total. Each ground anchor is designated by section number to which it belongs, followed by the letter corresponding to the level at which this is located. Thus, the rod located at the level of the B section 54, is called lifter 54B [4].

Different types of ground anchors used are 10ø8mm and 8ø8mm, with 350 kN working load at levels B, C, D, E, I, J, K and 250 kN at levels A, F, G, H, respectively, all forming an angle of 20° to the horizontal.

The overall lengths are in the range between 13.9 m and 31 m, being anchored stretch of 5 meters and 6 meters.

The bond length consists of short steel wires protected by a plastic paint and arranged around "headline" tubes (PVC perforated tube, surrounded by rubber membrane), using spacers and fastened at the far end of the passive part.

The unbonded length has covered wires one by one by plastic conduit tube (sheath), and the involvement of the entire length of the free section through a PVC pipe, in order to protect this laitance stretch during phase's injection.

B. Instrumentation Design

Ten sections along 70 meters of the central portion of the anchored wall, between sections 34 and 69 were instrumented in order to measure loads in the ground anchors over time, during and after construction of the structure. Each section had a column of between nine to twelve ground anchors maximum, where three ground anchors out of four were instrumented. The central part is of greater height with (18 meters), placed on the highest density of instrumented ground anchors, which are horizontally spaced and every two sections in the same amount in rows vertically.

The geometry of the instrumented section of the anchored wall and the lease of the ground anchors are shown in Fig. 1. Instrumented ground anchors are shown in red color. The instrumentation of the ground anchors was made with load cells installed in the head thereof.

C. Subsoil Features

The landfill Km 74 of the analyzed railway section covers the section between the stakes in 1837 and 1850, and its platform is developed about the elevation 638. The topography presents sharp being the landfill situated hillside, and limiting the left by a steep cut with a drop of about 80 meters, and the right gap by the same proportion. The inclination, both for cutting and for landfill, is variable between 45 ° and 80 °.

The landfill consists of wide silty sand, mica, color brown gray variegated, with rock fragments. Its thickness ranges from 8 to 12 meters in length around 250 meters.

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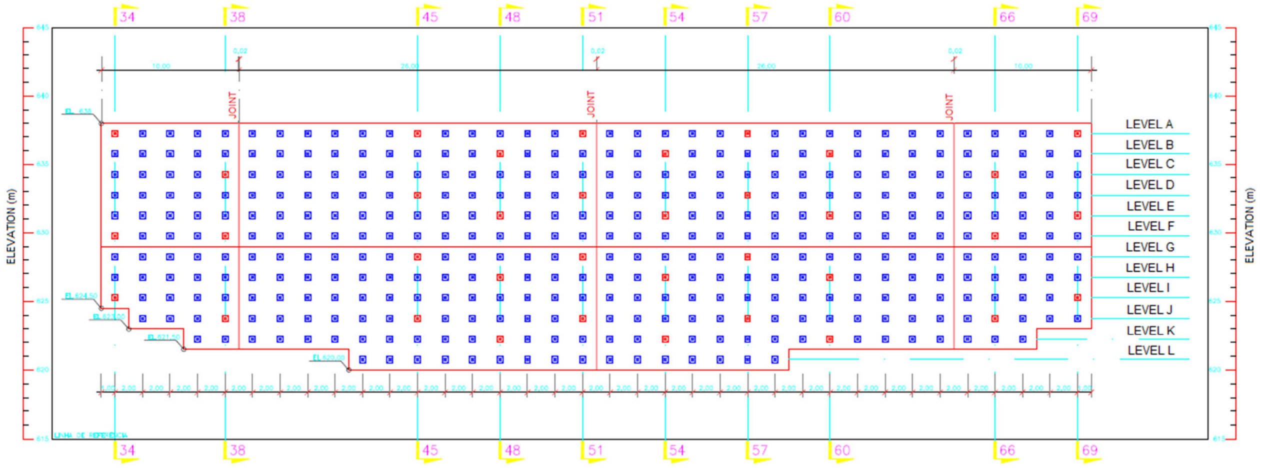

Fig. 1 Geometry of anchored wall

From the geological point of view the construction site is in a region represented by Pre-Cambrian gneiss of medium texture, with schistose bands and interspersed granite bands

The local soil is characterized by yellowish silty sand, variegated, micaceous, with hard-soft varied interbedded rock. These intercalated behaves as boulders, since they are discontinuous, giving the soil a large mass heterogeneity. The thickness of this material is approximately ten meters.

The foundation of the landfill consists of residual soil along its entire length. Beneath this soil layer a soft weathered rock layer with intercalated soil is present, and below this the top amended hard and bedrock.

The surveys performed have not reached the water table, which should exist at great depth (beyond 50 meters).

III. Field Measurements

Loads in instrumented ground anchors were measured by electrical resistance strain gages. It was observed that when the ground anchors have been installed and after curing the laitance, the gages functioned properly.

With the instrumentation data, proceeds to make an analysis of behavior the ground anchors instrumented, according to the characteristics presented by the load-time curve, considering the length of time between the moment of pre tensile ground anchor during the construction process and to six months after the anchored wall construction. In general, the ground anchors had four different types of behavior, not necessarily all at the same time being present in all sections.

Fig. 2 shows the load curve over time of section 51, where types of behaviors identified can be observed.

The behavior of particular ground anchors was characterized by the sharp drop in instant then charged a small or no change of force during the construction period. The ground anchor with major instantaneous drop presented is the 60E corresponding to a value of 120 kN. The behavior of another group of ground anchors is characterized by increased load on the ground anchors during the construction process and finally reached stabilization. The ground anchor with the larger total loss in this group was 60K having a final charge value 240 kN. Another behavior observed in ground anchors was the oscillating load variation from the moment of installation and during the construction period.

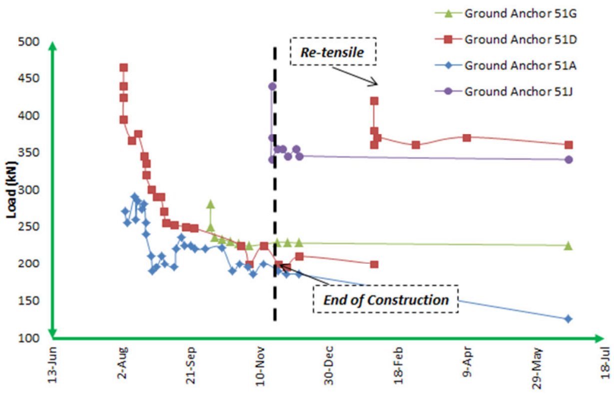

Fig. 2 Types of behavior of the ground anchors (Section 51)

Finally, the stabilization of the load, the most characterized ground anchors of the group was the 51A with a total loss of 145 kN. The final identified behavior in the ground anchors was characterized as sharp drop in instant the charge and during the construction period continued with a sharp fall reaching final values of very low load with respect to its workload. Under the premise of reducing the displacements and increasing the efficiency of ground anchors of that group, it was decided to make a re-tensile in them, which allowed that the final load measurement was very close to the designed load. The ground anchor that presents this behavior with the greatest burden falling before re-tensile was the 57D, after the re-tensile got a minor load 50 kN of workload.

Fig. 3 presents the load curve over time for the instrumented section of ground anchors 45 and Fig. 4 shows the same curve for the section 57. Sections that have been identified where the major and minor losses of load, having in reference to the sum of loads of all the ground anchors instrumented section and not instrumented, for summing said interpolation was required for the ground anchors not instrumented with the measured values of the adjacent ground anchors.

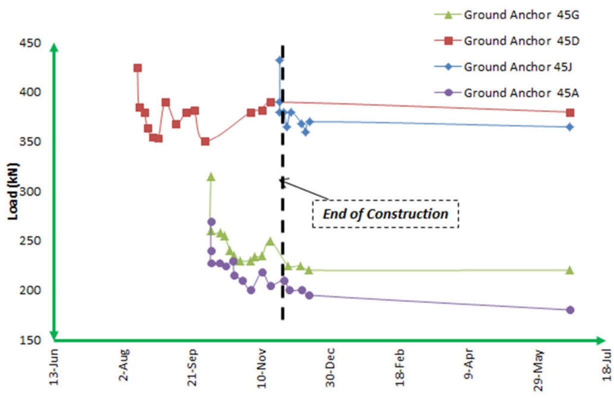

Fig. 3 Curve load vs time of the section 45

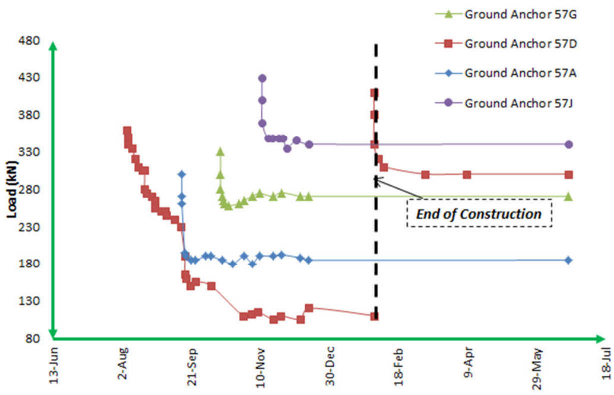

Fig. 4 Curve load vs time of the section 57

Generally, for the ten instrumented sections, larger load losses were made at higher levels, with a final load of approximately 80% of the workload. In lower levels, the end load was very close to the workload, so recorded lower losses took place.

IV. Theoretical Earth Pressures for Comparison

The comparison made in this work involves the measured forces and the forces on the ground anchors estimated according to the procedures described in Ground Anchors and Anchored Systems published by the FHWA. For the calculation of the ground pressure loads on the structure, it used an apparent earth pressure diagram. The land use pressure diagrams refer to papers presented by [1], [2], where semi-empirical diagrams were developed from the point charges measures to internally anchored excavations. The original diagrams of [1], [2] have been modified in recent years, but generally are consistent with the original investigation. The procedures recommended FHWA diagram for a trapezoidal shaped sands depending on the position of the upper and lower risers. Fig. 5 shows the resulting FHWA diagram according to the procedure for single and multiple ground anchors as the diagrams recommended by [1], [2].

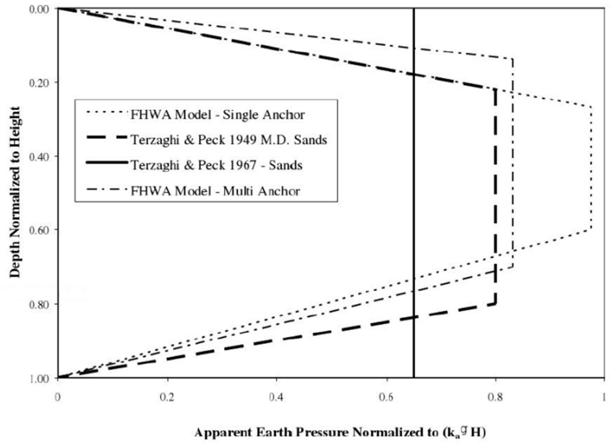

Fig. 5 Apparent earth pressure diagrams [5]

The methodology used for the calculation of the horizontal components of the forces on the risers by the pressure apparent diagrams including uniform overload was the method of tributary areas.

Fig. 6 shows the envelope pressure earth measured to section 57 (corresponding to the lower pressure earth total during the implementation period), and estimated by empirical diagrams proposed by the FHWA and thrusts [1], [2].

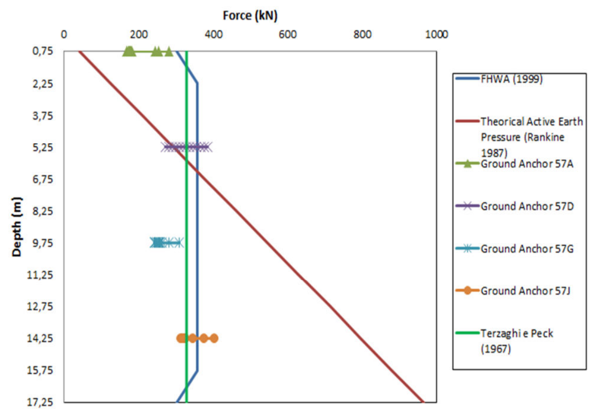

Fig. 6 Load measurements for section 57

The behavior of particular ground anchors was characterized by the sharp drop in instant then charged a small or no change of force during the construction period. The ground anchor with major instantaneous drop presented is the 60E corresponding to a value of 120 kN. The behavior of another group of ground anchors is characterized by increased load on the ground anchors during the construction process and finally reached stabilization. The ground anchor with the larger total loss in this group was 60K having a final charge value 240 kN. Another behavior observed in ground anchors was the oscillating load variation from the moment of installation and during the construction period.

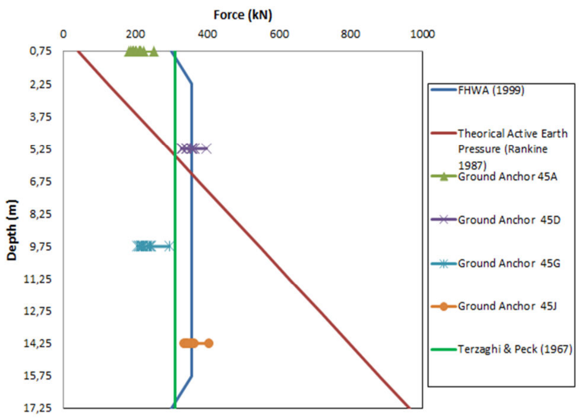

Fig. 7 Load measurements for section 45

The values obtained for the thrust coefficient are shown in Fig. 8. These values are very close to the value of the earth pressure coefficient at rest defined by [6], for this case corresponds to a value of 0.65; The analyzed values field average is 8% lower than the theoretical decrease reaching this value by 15%, which almost corresponds to the active boundary condition for a few sections.

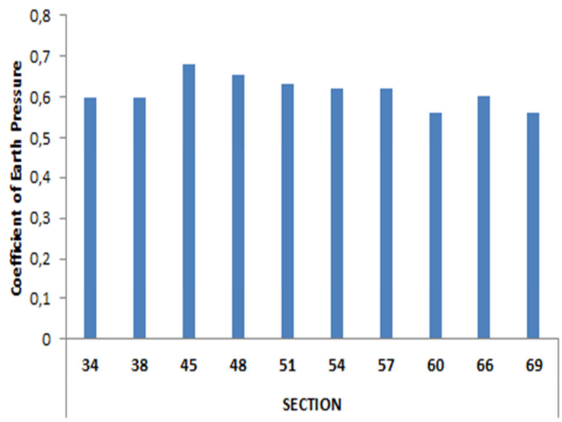

Fig. 8 Analyzed values of the coefficient lateral of earth pressure

Estimating the value of the thrust coefficient for all the sections can be to obtain the value considered to friction angle parameter corresponding to the mobilized friction angle. The values obtained by these analyzes are shown in Fig. 9 for the ten instrumented sections.

It can be seen in Fig. 9 that the analyzed values show great similarity, and in which it was estimated an average of 15 ° for this parameter resistance, the lower the value adopted for all estimates in this study (20°).

With mobilized friction angle values calculated, one can obtain a safety factor for each section obtained by the ratio between the tangent of the friction angle and the tangent of the mobilized friction angle. The results of this analysis are shown in Fig. 10, where can be observed that the estimated average safety factor is 1.5; corresponding to the minimum required by the regulatory provision in Brazil for the works of this type., However, there are individual sections with values below the set minimum, but still higher than the unit.

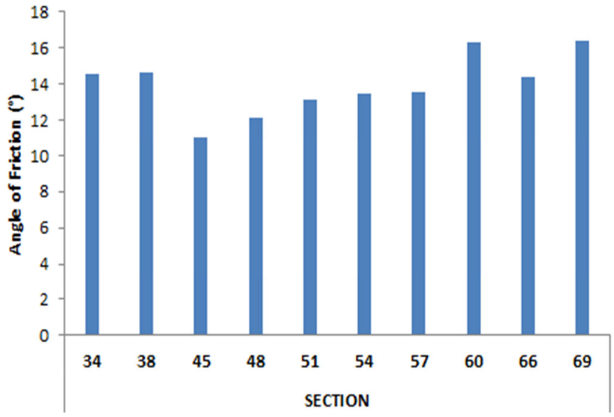

Fig. 9 Analyzed values of the angle of Friction

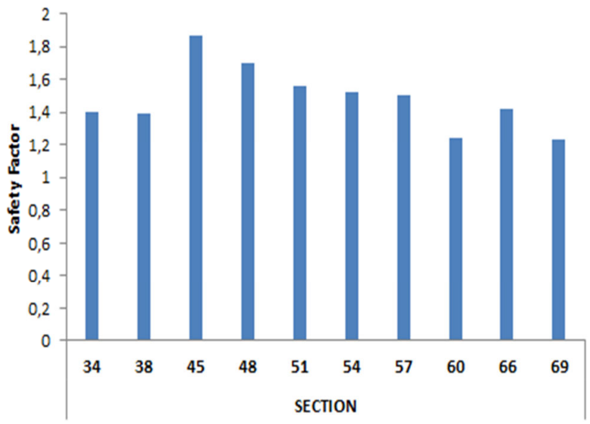

Fig. 10 Safety factors obtained for the ten instrumented sections

V. Conclusions and Suggestions

The following is a summary of conclusions to be made about the field measurements and analyzes above described.

A. Conclusions

- The ground anchor with the higher load drop is the 51A, which reached a value of 54% loss of the installation load and the ground anchor with minor drop load was 34E corresponding to 6.25 % of total loss.
- The ground anchors from the upper levels reported higher losses than the ground anchors of the lower levels, this due to the higher levels are the most exposed to the construction process.
- Loads on field measures were consistent with estimated by trapezoidal diagrams proposed by [1], [2] and modified by the US FHWA.
- The results of this study suggest that the current practice of using the land pressure diagram apparent proposed by the FHWA for curtains anchored project is appropriate and represents a very conservative approach, as in the original diagram proposed by [1], [2] it is also suitable, but are less conservative. The results do not indicate that

any particular method for the development of land surrounding pressure is higher than other design methods.

B. Suggestions

- Include in instrumentation design the equipment needed for measuring horizontal displacements and repressions of the structure studied over time. Study the influence of the displacement speed of the structure stability.
- Simulate dimensionally, through numerical methods, instrumented work to complement the experimental data field.
- Implement ground anchors in more points along the bond length and the unbonded length in order to obtain more detailed charge distribution diagrams.

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