Development and performance of load cell systems for reinforced embankment and reinforced soil wall

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Keywords: reinforced soil walls, reinforced embankments, soft soils, monitoring, load cells

ABSTRACT: This article presents the development and performance of two load cell systems based on the use of strain-gauges to measure tension forces in geosynthetic-type reinforcements. The load cells were applied in two test sites: a test embankment on soft soils and a segmental block face retaining wall. The embankment was built in the city of Florianópolis (Santa Catarina, Brazil) with a view to implementing an expressway where the thickness of very soft soil deposit ranges from 4 to 22m. The other load cell system was applied to a reinforced soil wall built in the city of São José dos Campos (São Paulo, Brazil) on a road connecting the Carvalho Pinto and Presidente Dutra highways. Both load measurement systems were effective for the load measurement reinforcements.

1 INTRODUCTION

In 2002 a test embankment was executed (Magnani, 2006) to support the construction of an expressway in the city of Florianopolis, Brazil, where the very soft clay thickness deposit ranges from 4 to 22 m. Three instrumented test sections with different characteristics (AE1, AE2 and AE3) were built. In two of the sections (AE1 and AE2), emphasis was placed on monitoring the loads acting on reinforcements, resulting in the need to construct specific load cells for the feasibility of the proposed studies.

A reinforced soil wall with segmental block face (Riccio Filho, 2007) was built to link two highways in São José dos Campos (Sao Paulo, Brazil), as there was not enough space for the deployment of a conventional trapezoidal embankment.

In addition to the measurements of the reinforcement tension forces, other measurements were also made and are reported by Magnani and colleagues (2009, 2010) and Riccio Filho & Ehrlich (2009, 2010).

This article presents the conception, design and performance of monitoring systems of tension forces used in each of these cases, referred to here as cases A and B. It also presents a comparative analysis between the systems used.

2 DEVELOPMENT OF THE LOAD CELLS

2.1 *Case A – Embankment work on soft soils*

The load cells used in case A were based by Magnani (2006) on the COPPE experience, according to the concepts originally proposed by Saramago (2002) and Saramago & Ehrlich (2005) with necessary adaptations. These included protection of the load cell to resist factors such as heavy traffic, vibrations resulting from earthmoving equipment (compactor Dynapac CA 25 operating at high frequency) and the presence of saltwater.

Figure 1 illustrates this type of load cell, which was assembled on an instrumented reinforcement (Stabilenka: 200 kN/m x 45 kN/m) band 1.5m long. Each load cell system was composed of two fabric segments 0.25 m wide, added to the 0.10 m of stainless steel instrumented membranes between the two fabric segments. In the field, the load cells were then attached to the reinforcement to form a continuous reinforced material.

Pairs of steel battens connected by bolts were used to attach the instrumented membrane to the geosynthetic.

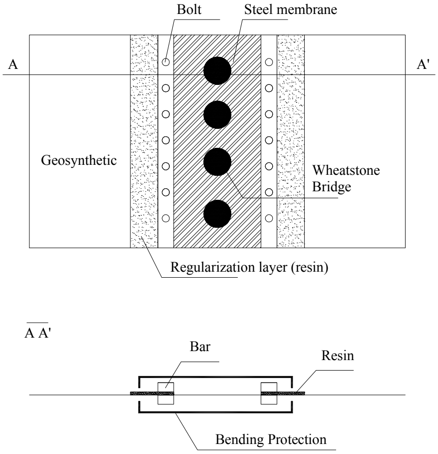

Figure 1. System used to measure loads in reinforcement.

One side of the steel bars had a rough surface formed by powder quartz being pasted onto it to prevent relative movement between the membrane and the geosynthetic. In order to prevent the tearing of the fabric caused by pressure applied in the process of bolting the steel battens an epoxy resin band 50 mm wide involving all the fibres (Figure 1 and Figure 2), was used. The resin used was a liquid Araldite TM epoxy resin Bisphenol A type (GY 260 Vantico), cured at room temperature with curing agent Aradur ™ Polyamino Amide (HY 825 Vantico).

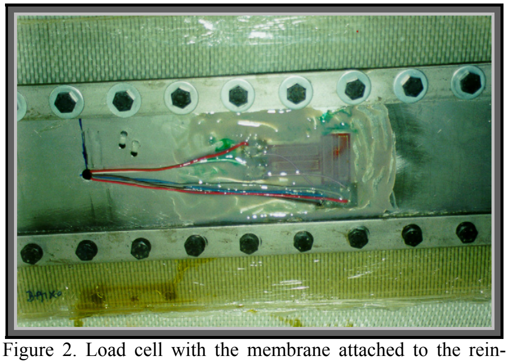

Figure 2. Load cell with the membrane attached to the reinforcement and the sides with resin (Magnani, 2006).

There was also a need to protect the load cells against the presence of saltwater. Several long-term tests were performed to obtain a waterproof fabric that did not deteriorate over time. To solve the problem, a technology used for the instrumentation of oil conduits installed offshore was used whereby vulcanised rubber was directly applied to the electrical circuits (strain-gauges). Figure 3 illustrates the application of the product to the electrical circuits.

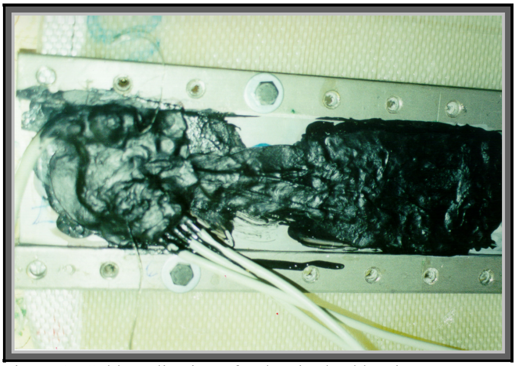

Figure 3. Cold application of vulcanised rubber in a prototype for the sealing of the cell (Magnani, 2006).

The load cells had four independent Wheatstone bridges per load cell, thus allowing the determination of an average tension force per load cell (average of four measurements). The electrical circuit used for each Wheatstone bridge, with eight strain-gauges (28 mm x 8 mm.) of 120 Ω each.

The complete Wheatstone bridges were designed to be self-compensating for bending moments and also self-compensating for the temperature effects. Temperature effect compensation is important, as the temperature during calibration is different from that in service and the electrical circuit itself generates heat.

The load cells were calibrated with appropriate equipment close to the maximum recommended load of 200 kN/m. In order to reduce hysteresis of the glue used in the sensors five load-unload cycles were applied in advance (Potma, 1967). The results in Figure 4 show an excellent linearity between applied loads and load cell responses, with regression coefficients greater than 0.9990. The curves presented correspond to a complete load-unload cycle, showing negligible hysteresis for the present purposes.

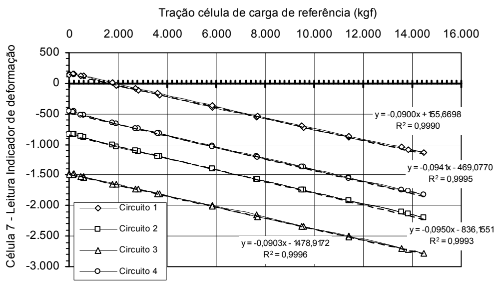

Figure 4. Results of a load-unload cycle for load cell 7 in each of the four Wheatstone bridges (Magnani, 2006).

Comparing the response of the four Wheatstone bridges of each cell, we observed that the slopes of the regression lines were very close, which shows that the electrical and mechanical parts of each of the sensitive parts were properly designed and constructed, as they present the same responses to the same tension forces applied.

This observation also led to the conclusion that the load transfer calibration mechanism was very successful, ensuring a uniform load transfer along the entire length of 1.50 m of the cell.

Figure 5 illustrates the U-shaped mechanical protection against deformations caused by bending moments (see Figure 1). The mechanical protection is composed of folded steel profiles 3.0 mm thick, located on each side of the load cell, and is fixed and supported by bolts (8 mm) in insensitive portions by steel plates 3.3 mm thick. This protection has the purpose of avoiding twists and moments along the largest direction of the cell caused by earthmoving, and preventing mechanical damage owing to traffic of equipment, especially during the first layers.

As shown, the steel battens used for fixing the field geotextile to the load cells were sawn with manual saws just in the projection of the boundaries of sensitive portions. These cuts had the function of separating the sensitive portions of load cells from the connection bands, ensuring the continuity of fibres of load cells' sensitive portions along the entire length of 1.5 m.

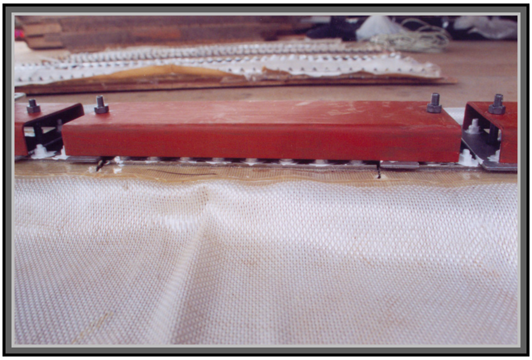

Figure 5. U-shaped mechanical protection against bending moments (Magnani, 2006).

Figure 6 illustrates the load cells sectioned and applied in the field already protected against bending moments. The connection of load cells' fabric extremities to the 1.5 m wide instrumented reinforcement band was performed in the field with the same solution used for the connection of geosynthetic to the steel membranes.

That is, the connection was made by the use of steel battens, powder quartz glued to steel battens, bolts and epoxy resin reinforcements in the geotextile.

Figure 6. Load cells installed in a reinforcement band 1.5m wide (Magnani, 2006).

Figures 7 and 8 illustrate the results of load measurements in reinforcements obtained for the various stages of the embankment loading. As shown, the load cells were able to make measurements in the time required for the full embankment implementation. The results also show consistency in the measured values, i.e. the stresses measured increased as the embankment was heightened. The variation of the reinforcement tension loads with time and height of the embankment may be observed in Figure 9. These measurements were interpreted by Magnani and colleagues (2009).

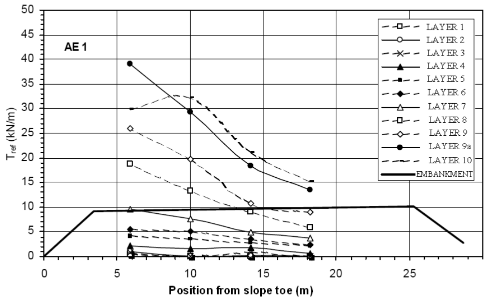

Figure 7. Tensions measured in reinforcements by load cells for section 1 of the experimental embankment (Magnani, 2006).

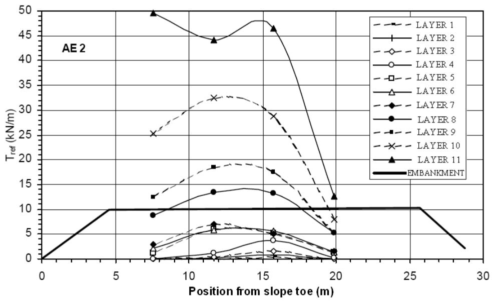

Figure 8. Tensions measured in reinforcements by load cells for section 2 of the experimental embankment (Magnani, 2006).

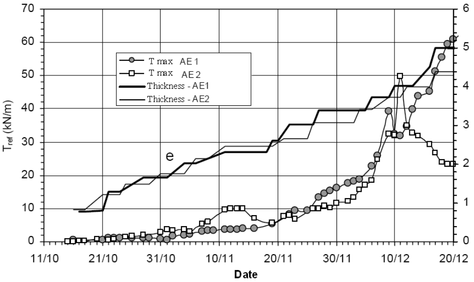

Figure 9. Evolution of loads with time and height of the embankment (Magnani, 2006).

2.2 *Case B – Reinforced soil wall*

Load cells were designed and built (Riccio Filho, 2007; Riccio & Ehrlich, 2009) to measure tension forces in geogrid-type reinforcements (FORTRAC 55/30-20 and 35/20-20) used in a reinforced soil wall. The concept adopted in this case, Figure 10, is different from that employed by Magnani (2006) in Figure 1. The main difference between the two systems is related to the connection between the instrumented element and the geosynthetic to be monitored. Instead of an instrumented membrane like that used in Case A, a system consisting of an instrumented tube and spherical joints (tbs6, THK Co.) was used instead, thus eliminating undesirable twisting and bending efforts.

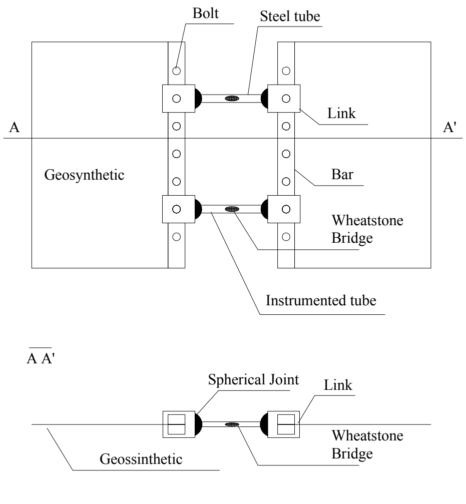

Figure 10. System used to measure loads in reinforcement.

Figure 11 shows a prototype used in the initial studies of the system. The prototype consists of an instrumented tube with spherical joints in the extremities and a connection to the geosynthetic. The tube has a reduced cross-sectional area in its central part to create a small thickness and therefore more deformable region in which, for each cell, a full Wheatstone bridge was assembled with four extensometers of 120 Ω (strain-gauges) with two double 90° rosettes (two extensometers per rosette). The use of double rosettes reduced the strain-gauge glueing work and allowed the use of a small sensitive area.

Figure 11. Prototype of load cell with spherical joints (Riccio Filho, 2007).

The connection of the set illustrated in Figure 11 with the geosynthetic was made by means of battens, a procedure very similar to that used by Magnani (2006). The battens were made of AISI 304 stainless steel 0.5 m long, 0.19 m wide and 0.03 m thick, being initially cleaned with benzene and surfaces covered with a thin layer of slow-curing Araldite glue. Subsequently, a layer of powder quartz was placed on the glue layer, forming sandpaper.

The small size of the load cells and extensometers favoured their thermal stabilisation process. It was found that the reference zero for the readings varied over time and in a nonlinear way. This occurred even with the use of the full Wheatstone bridge. This may be caused by deformation of the steel induced by heat generated by the circuit. Figure 12 illustrates the variations of zero owing to heat generation over time. It could be seen that the variations were negligible after 30 minutes. A procedure that considers the variation in signal during the stabilisation time is presented by Riccio Filho (2007) for readings performed during the stabilisation time.

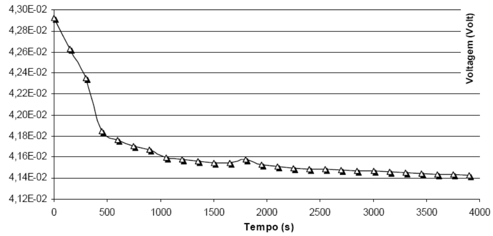

Figure 12. Variation of zero over time owing to heat generated by the electrical circuit (Riccio Filho, 2007).

The use of a circular section (tube) instead of a rectangular section (membrane) increased the inertia moment substantially with respect to bending. The use of spherical joints combined with the adoption of a circular section resulted in a satisfactory performance of the measurement system. The performance is presented in Riccio Filho (2007) as result of tests on prototypes, which show that the set did not make a significant load record when separated from the geosynthetic. The cells received a mechanical protection consisting of a polyurethane tube (PU 80 shore A) 2.5 mm thick to prevent mechanical damage. Protection against moisture comprised heat-shrink material, silicone inside the cell and in the polyurethane-instrumented tube interface, and a heat-shrink layer. The severity of the environment in this case was smaller than that found by Magnani (2006).

The system showed adequate mechanical damage resistance to the stresses induced by compaction equipment of Dynapac CA 25 PD type operating at high vibration frequency and resulting in a vertical force of 378 kN (Riccio & Ehrlich, 2009; Riccio & Ehrlich, 2010).

Each cell was calibrated by three load-unload cycles preceded by ten load-unload cycles to eliminate the glue hysteresis. In both sets of cycles, the cells were stressed up to 4500 N. The results were very good, with regression coefficients always higher than 0.9990. Since the cells are individually calibrated and then mounted in the measurement system, it is possible to add to or remove cells easily from the system in the field. This operation can be done without removing the battens from the geosynthetic.

Figure 13 illustrates the application of the system in a 0.50m reinforcement band (Riccio & Ehrlich, 2009).

Figure 13. Band of instrumented geogrid, 0.50m wide (Riccio & Ehrlich, 2009).

The use of isolated tube-type load cells (Figure 10 and Figure 11) gave flexibility to the system. Cells can also be added to or removed from the set according to the load acting on it. This ensured that if there was a reinforced soil structure higher (or a heavier compaction) than expected, the measurement system would easily fit in the field. At the same time, some instrumented tubes could be saved if the size structure and/or compaction produced a stress lower than that expected.

Typical results obtained by this measurement system are shown in Figure 14, where tension values measured during two months of monitoring can be observed. Throughout this period, all 40 load cells (instrumented tubes) used worked properly, without malfunctioning caused by moisture action or compaction efforts.

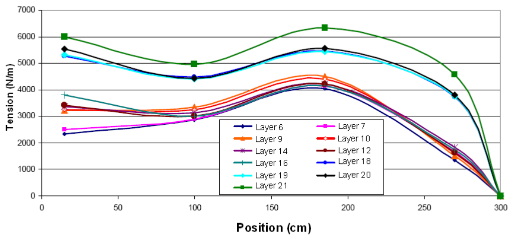

Figure 14. Tensions in an instrumented reinforcement band of 0.50m (Riccio & Ehrlich, 2009).

3 COMPARISON OF SYSTEMS

Both systems achieved the objective for which they were designed and built. Some comparisons can be made:

the system employed in case A required a greater number of operations for its implementation in the field and laboratory and did not have the flexibility for adaptation in the field, unlike the system used in case B;

by having a larger area useful for bonding extensometers, the conception used in case A allows for the implementation of circuits with more sensors, increasing the resistance of each arm of the Wheatstone bridge and reducing both heat generation and time stabilisation of zero reading. Case B's system needs 30min for thermal stabilisation process. Adoption of sensors with greater resistance, 350 Ω, for example, may be need if fast stabilization period would be necessary;

the system used in case B demanded precision machining to manufacture the cells and the connection of spherical joints to the fixing battens. Nevertheless, system B is simple to assemble and have a more reliable operation, it design turns it complete free of bending related problems.

4 CONCLUSIONS

Two different systems for measuring stresses in reinforcements of two instrumented works were presented: a system used on an embankment on soft soils and another used on a reinforced soil wall.

The tension force results measured by both systems show that they were efficient in achieving the measures and were durable. Both systems can be used to measure tension forces in a variety of geosynthetic types.

Both systems showed sufficient strength to withstand forces induced by the heavy compaction operation.

Depending on the type of reinforcement used, it is necessary to use epoxy resin to create a band where the system can be coupled to the geosynthetic.

Heat generation can cause deformation of the metal of the instrumented part. This phenomenon alters the reading zero of the cell and requires time for stabilisation.

ACKNOWLEDGMENT

The authors would like to thank the Brazilian Research Council (CNPq-Pronex Program), State of Rio de Janeiro Research Agency (FAPERJ – Cientistas do Estado Program) and Jose Bonifacio University Foundation (FUJB) for their financial support. Financial assistance was also provided by HUESKER Synthetics Co. The authors also thank Andrade Gutierrez Co., Odebrecht Co., for providing logistic support in the field.

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