Geotextile Encased Columns (GEC) under bridge approaches as a pressure-relief system: Concept, experience, measurements

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ABSTRACT: Geosynthetic Encased Sand Columns (GEC) have been frequently adopted in geo-engineering practice to improve bearing capacity, reduce settlements and accelerate consolidation in saturated soft cohesive ground. The present paper extends these early views by introducing the use of columns to reduce the magnitude of horizontal earth pressures acting on structures adjacent to compaction fills. The monitoring program of a full-scale bridge abutment on soft soil supported by GECs and geogrid reinforced system is described and field performance was monitored with pressure cells, electrical piezometers, inclinometers and settlement plates. The collected database is interpreted in order to estimate the horizontal earth pressure over bridge border foundation piles.

Keywords: GEC, soft soil, horizontal pressure, bridge approach, monitoring

1 INTRODUCTION

Sand columns have been systematically used in engineering practice as a ground improvement technique designed to transfer superficial applied loads to substratum of higher bearing capacity (Alexiew et al, 2005; Alexiew et al, 2012; Raithel et al, 2005). In very soft soils, the lateral confinement offered by the surrounding ground to the columns may not be sufficient to guarantee the necessary support and, consequently, the columns are encased by Geosynthetic (in this case they are referred as Geosynthetic Encased Columns, GEC). The encasement increases the strength and stiffness of the sand column, providing higher load carrying capacities under lower settlements as extensively demonstrated by both experimental and numerical studies (Raithel and Henne, 2000; Madav et al., 1994; Malarvizhi and Ilamparuthi, 2004; Murugesan & Rajagopal, 2006;Gniel & Bouazza, 2010; Najjar et al, 2010). In addition to improving the load/settlement behavior of the foundation, GECs work as vertical drains, thus reducing the consolidation time of clay deposits under loading.

Although the technique is now well established, no research has been undertaken on the use of encasement columns regarding the induced horizontal earth pressure acting on pile foundations embedded in soft soils. This is a common occurrence during fill and embankment elevation close to piled structures such as bridges, storage tanks and retaining walls. This paper aims providing some insights on this topic by discussing the interaction of a bridge abutment and an 8m high road embankment constructed on soft soil where one of the concerns was the potential increase in horizontal pressure to overload the previously constructed bridge piles.

2 CASE STUDY

For a new high traffic road project in the Brazilian State of Rio Grande do Sul, a solution was conceived to protect an existing bridge foundations constructed prior to an 8m elevation embankment.

A comprehensive site investigation program was carried out to evaluate conditions of the site comprising SPTs, CPTs, vane and 4” Shelby undisturbed soil sampling for triaxial and oedometer tests. A CPTU profile representative of the areas shown in Figure 1, revealing a sedimentary deposit with a 6m to 8m soft clay layer overlain dense sand. Near the surface there is an overconsolidated crust within the depth affected by seasonal variations of the water table. The hydrostatic pore-pressure is in accordance with the regional water level (near the surface), without artesianism indication.

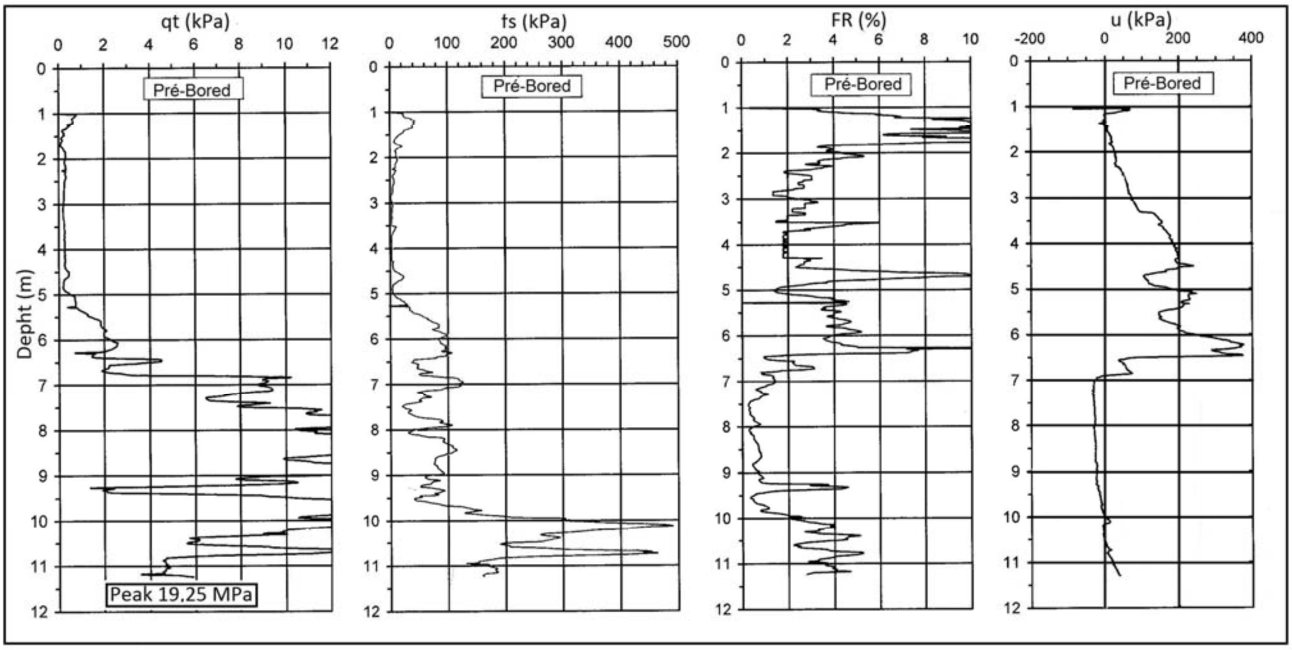

Figure1. Typical CPTU profile.

Given the presence of a soft clay deposit and the proximity of a thick embankment fill close to a bridge, a design solution has been conceived based on the installation of a Geogrid Reinforcement combined to 4 rows of Geosynthetic Encased Columns next to the bridge in addition to 2 rows outside the bridge edge. Sand columns 800mm in diameter and 2.4 m spacing in a triangular pattern were placed in the clay underneath the embankment, corresponding to an area replacement ratio of 0.1. The columns were installed up to full depth of clay soil layer using a casing pipe having an outer diameter equal to the diameter of the column (0.80m). The casing placed by a vibrating hammer prevents the outer wall from collapsing during drilling on soft ground and enables the installation of the geosynthetic, sand filling and final case removal. Rio Guaíba sand which classifies as poorly graded sand according to the Unified Soil Classification System was used to construct the sand columns. The geosynthetic fabric provided lateral support for the sand column and relatively fast drainage of pore water during loading. Tensile strength properties of the geosynthetic, trademark Ringtrac produced by Huesker Synthetic, determined from standardized test procedures are listed in Table 1.

Table 1. Reinforcing tubular geosynthetic properties used in sand column encasement.

Parameter	Norm	Value
Tensile strength, perimeter direction (kN/m)	ISO 10.319	≥ 200
Maximun Strain, perimeter direction (%)	ISO 10.319	≤ 12%
Stiffness modulus at 5% strain, perimeter direction (kN/m)	ISO 10.319	≥ 1.900
Permeability (m/s)	ISO 11058	≥ 2 x 10^{-3}
Nominal diameter (m)		0,8

3 EXPERIMENTAL DATA

A monitoring program was implemented to study the performance of the adopted solution and to validate the analysis approach for horizontal pressure assessment. A set of instrumentation was installed, comprising total pressure cells, electrical piezometers, inclinometers and settlement plates. Pressure cells and piezometers (700kPa range each, provided by Geokon) were installed between the first column row and the piles, 50cm from the edge of the first row of bridge piles, vertically, in three different depths (see Figures 2 and 3).

Inclinometers placed in flexible tubes allowed the force-balanced sensing elements to detect the change in tilt (from absolute vertical) of the probe that houses the sensors. Two inclinometers were installed between the columns with the aim of monitoring the horizontal displacement fields within the soft soil layer, while settlement plates were installed in several different locations on both the treated and untreated areas for recording the evolution of settlement during construction and consolidation. Vibrating wire piezometers were installed in drilled boreholes. Pressure cells were fixed on a structural steel gilder having a H-beam cross section. A discussion regarding the effectiveness of the solution is presented from this monitoring program based on measurements maintained over a period of about 154 days (from 08/08/2013 to 09/01/2014) until the excess pore pressures were dissipated. The embankment was actually built from day 27 to day 91.

Overall settlements were recorded at several locations during construction, being one on the treated encased columns area and the others over the untreated soft clay deposit. Although the settlement plate placed over sand columns was damaged at 6m embankment elevation, some conclusions could be drawn. Maximum ground settlements were of the order of 110mm and 340mm for measurements with and without improvement, respectively. The corresponding improvement factor, defined as the ratio between the final settlement without and with improvement, is about 3.3 which is within the predicted numerical and analytical values (Castro and Sagaseta, 2011). The ratio is known to be a function of the encasement stiffness and tensile strength, the surrounding soil stiffness, area replacement ratio and the applied load.

Horizontal displacement *versus* depth curves measured at the axis perpendicular to the earth fill are show in Figure 4 for a number of load increments recorded during embankment elevation. Inclinometers measured maximum horizontal displacements of about 65mm at a depth around 3.5m (approximately mid depth of the clay layer). Maximum displacements could have been slightly higher, given the fact that measurements were halted just before finalizing construction. Rates of displacements have decreased substantially at final construction stages and were close to stabilization at final readings.

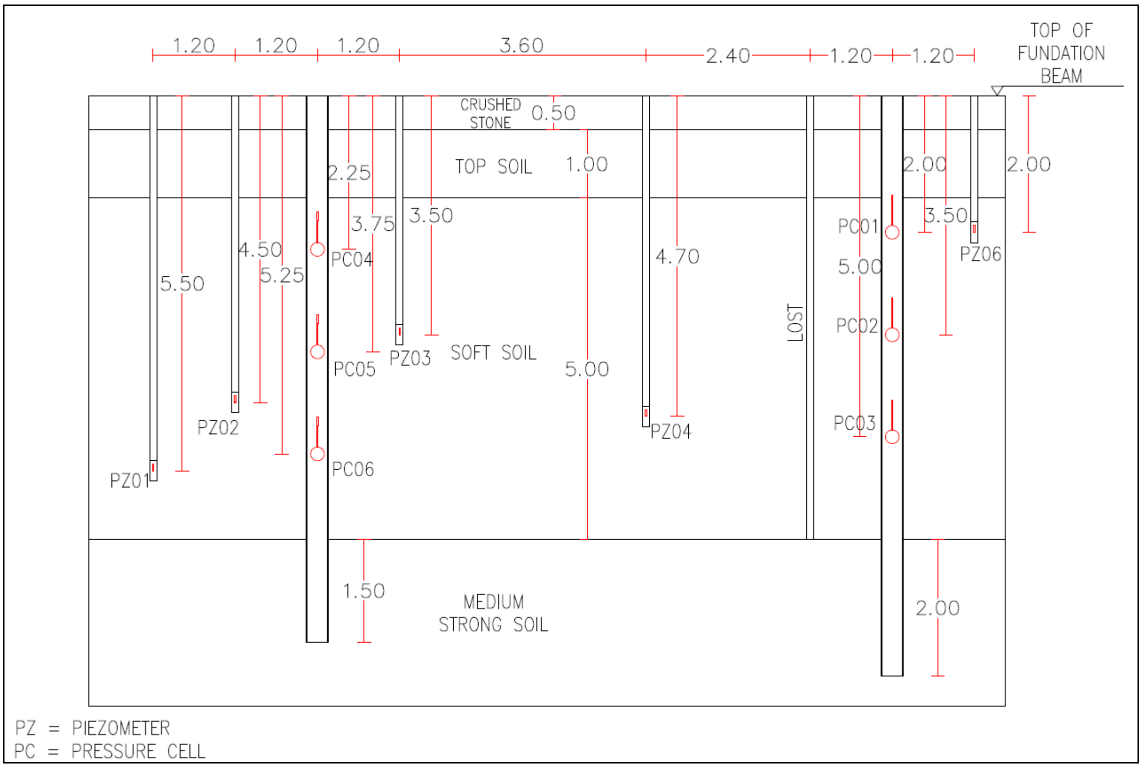

Figure 2. Instrumented cross-section.

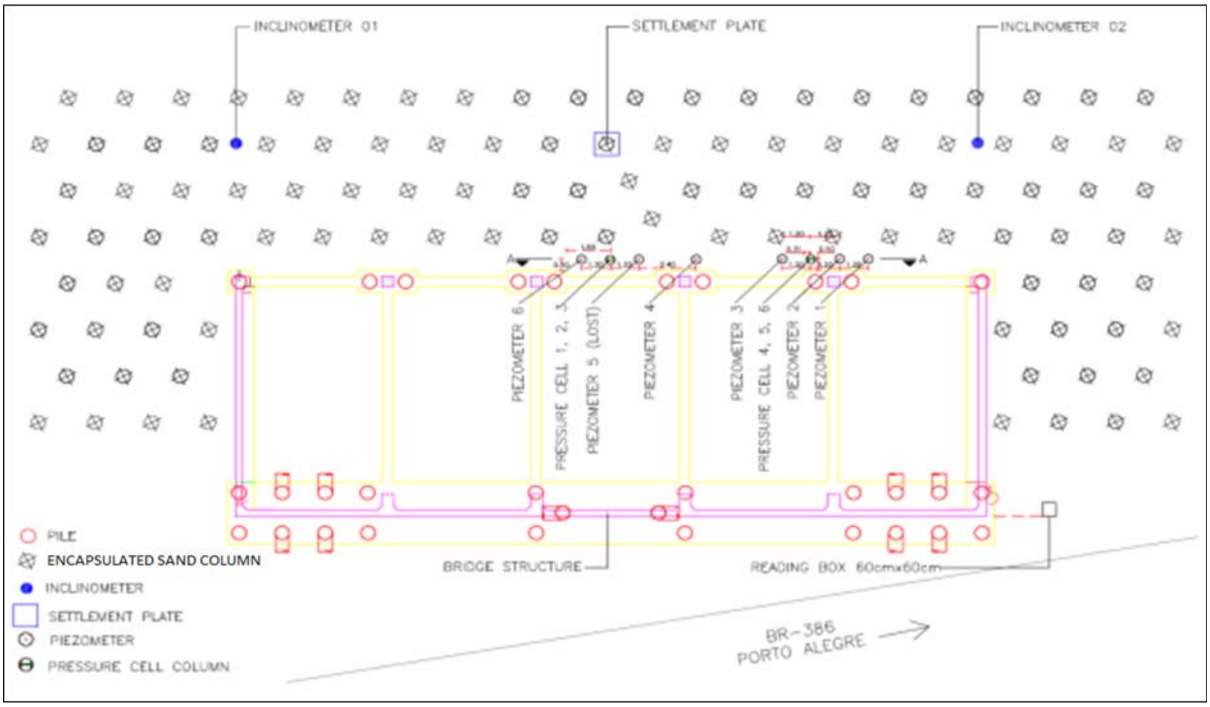

Figure 3. Plan view of the columns and instrumentation location.

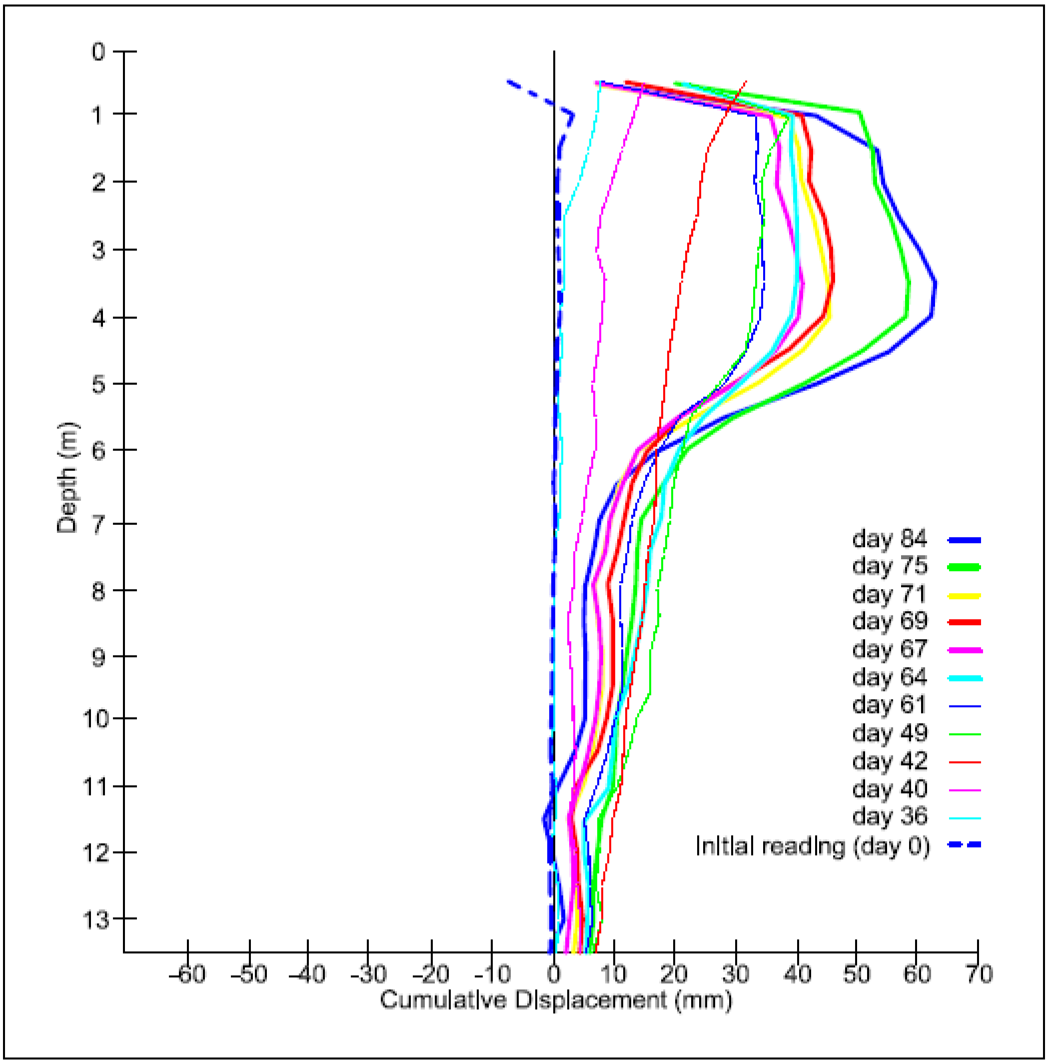

Figure 4. Horizontal cumulative displacement measurements from.

Results from variation of pore-pressure measurements with time are illustrated in Figures 5 and 6 for piezometers placed at different depths below ground level (two piezometer have been damaged during or after installation). Results show a steady increase in pressure with time during construction, followed by pressure decrease due to consolidation. Note that the site was flooded by a 200mm rainfall in 24h and this event was recorded on the pore pressure measurements (day 20). Variations of pore pressures with depth are shown in Figure 5, indicating the steady increase from the hydrostatic pore water value to larger values, generally increasing linearly with depth. Due to the higher stiffness of the encased columns relative to the surrounding soil, the columns concentrate the vertical stresses from the embankment and only a minor part is transferred to the clay layer in this composite system. In this case study, the excess pore pressure Δu relative to increasing surcharge load $\Delta\sigma_v$ yields a ratio of 0.1 to 0.3, as indicated in Figure 6. These data were found to correlate well with the FE analysis carried out in the original design calculations.

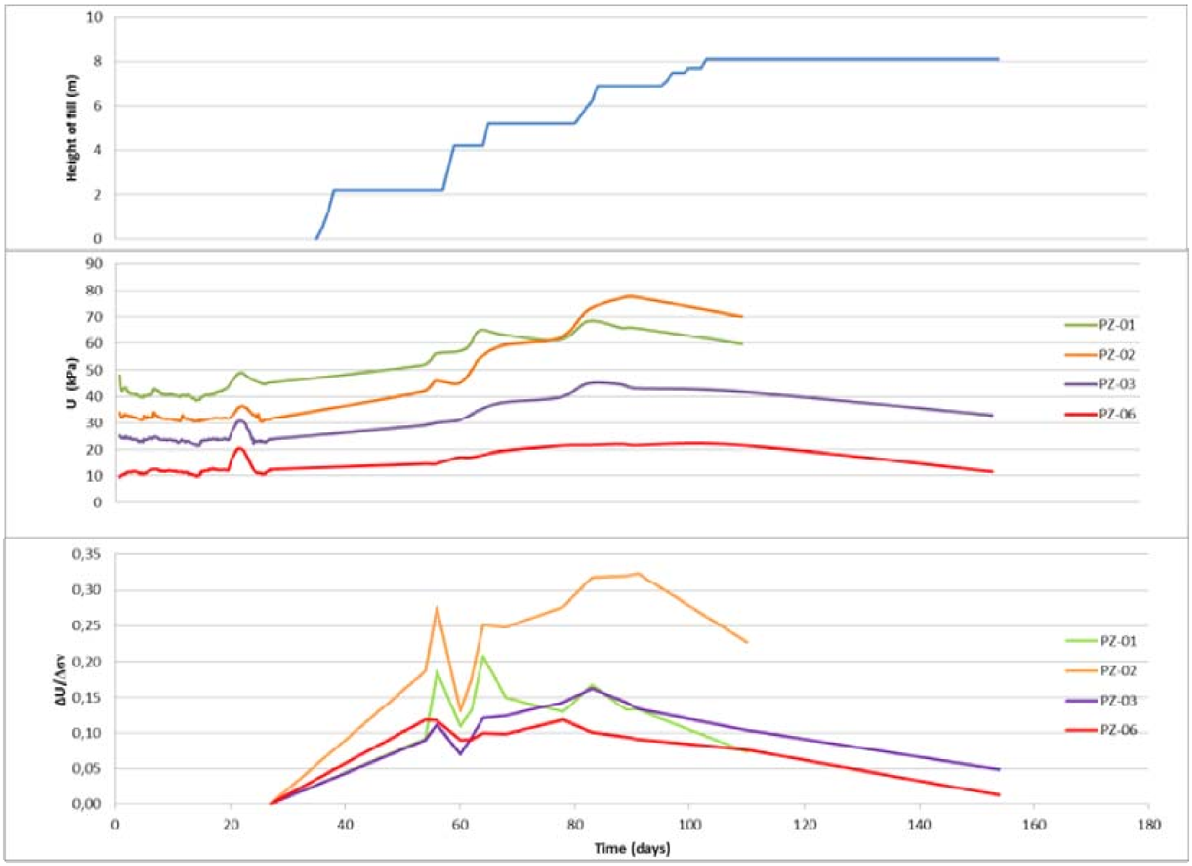

Figure 5. Variation of pore water pressure with time.

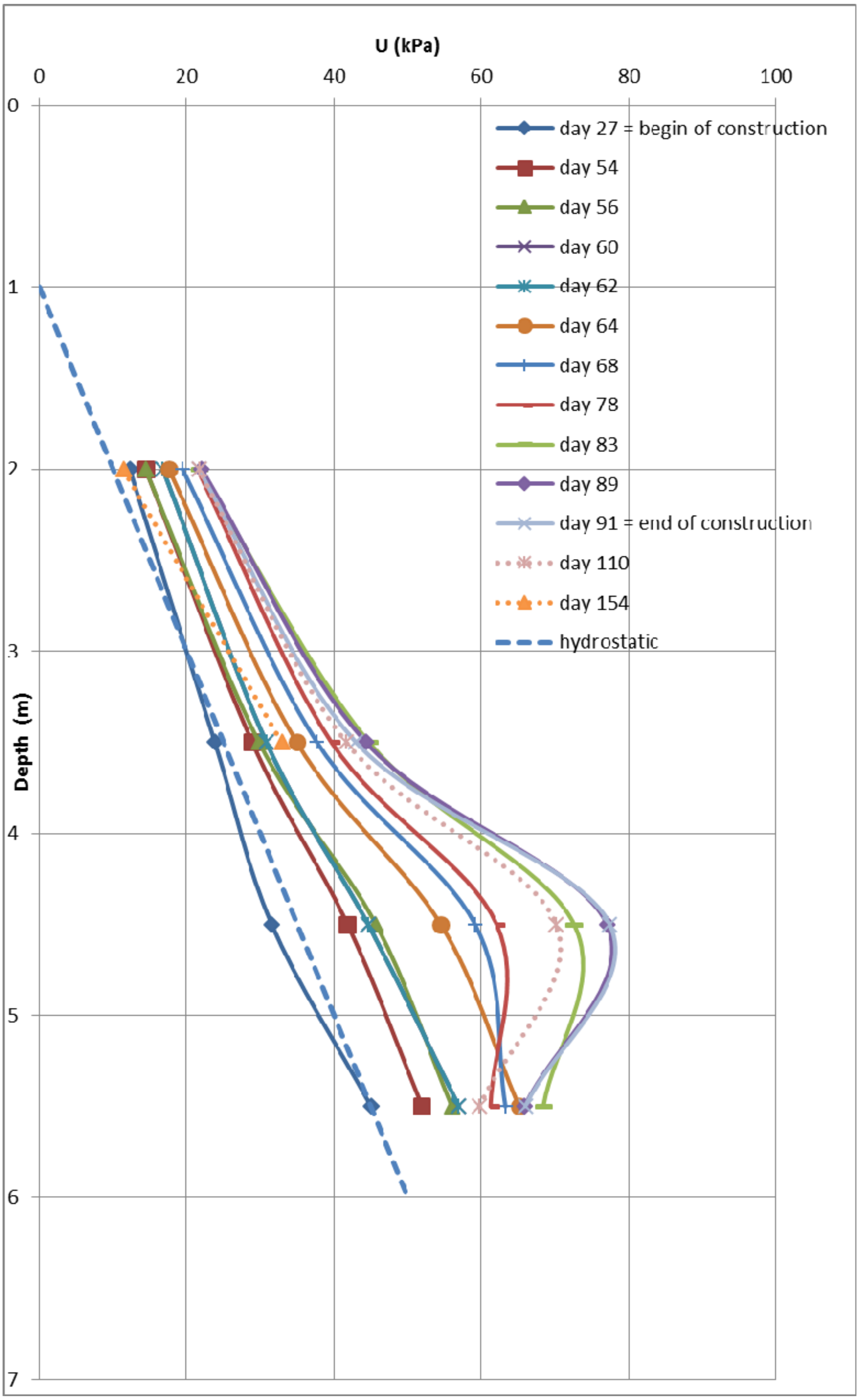

Figure 6. Variation of pore water pressures with depth.

Figure 7 shows the variations in measured earth pressure with increasing surcharge loading. During cell pressure installation, the H-beans were not subjected to any significant movement and the horizontal earth pressure remained at or near the value of at-rest conditions, which for normally consolidated cohesive soils is approximately 1-sinϕ´. Since H beans were prevented from moving or rotating, each stage construction produced an increase in horizontal pressure in the clay layer induced by the horizontal movements recorded by the inclinometers. The evolution measured earth pressure diagrams show two distinct characteristics: at initial loading stages the earth pressure increases linearly with depth whereas at larger loads it increases linearly up to a certain depth (approximately mid depth of the clay layer) and reduces from thereafter.

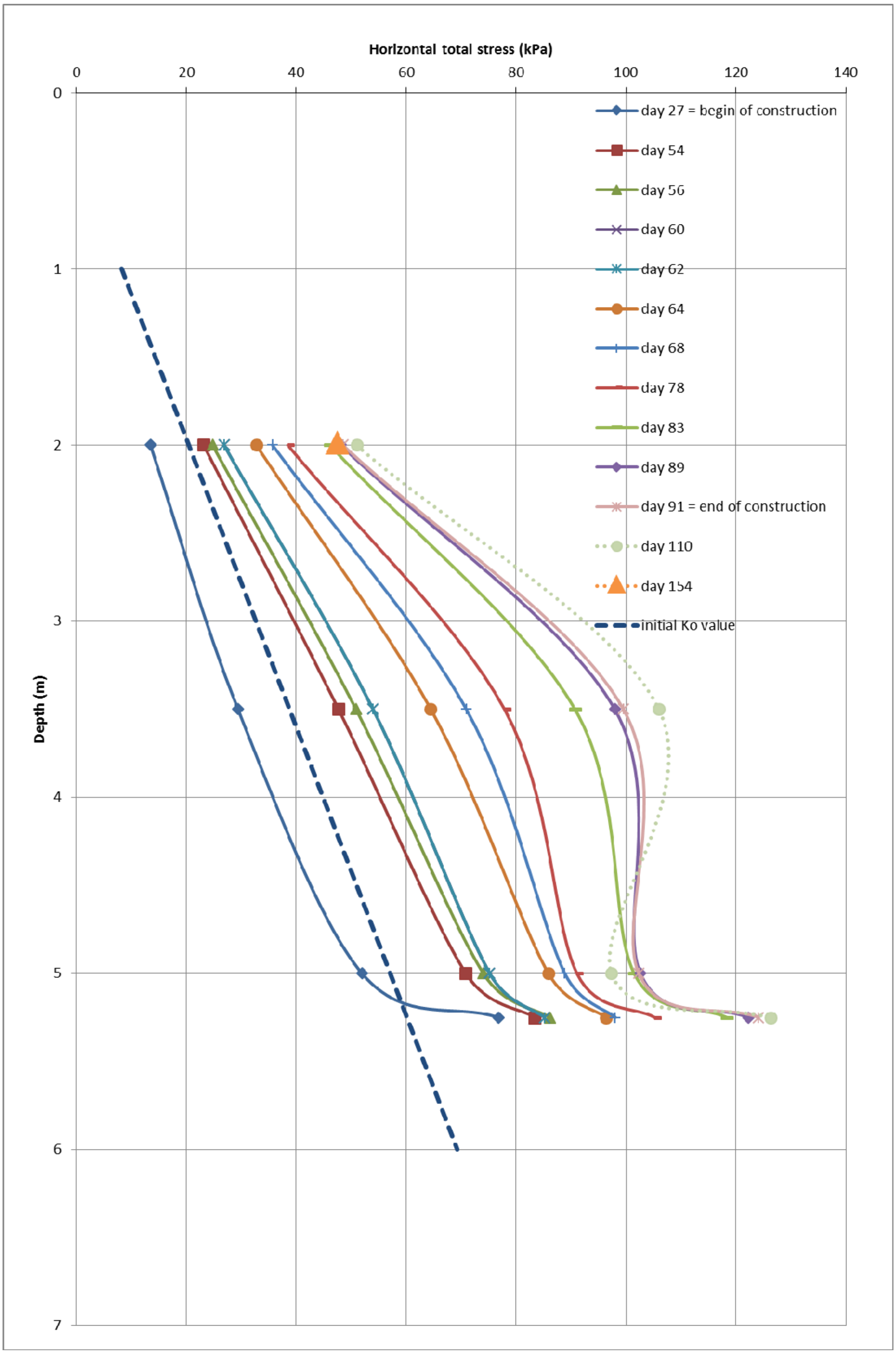

Figure 7. Variation of horizontal total stress with depth.

Measured horizontal pressures progressively increase during embankment elevation under predominantly undrained conditions, as identified from piezometer readings. After completion of earth work construction, drainage takes place and a further and final increase in pressure is observed. At the mid depth of the clay layer, the maximum measured horizontal pressure is 110 kPa, a value as large as large as four times the initial measurement at this depth. However, this measured pressure is about half of what would have been expected for an untreated clay layer, as calculated numerically (not shown in this paper) or from the empirical earth pressure proposed by Tschebotarioff´s theory (Tschebotarioff´s, 1973) for asymmetric loading conditions.

4 CONCLUSIONS

The present paper discusses the use of Geosynthetic Encased Sand Columns installed on soft soils to reduce the magnitude of horizontal earth pressures acting on a bridge structure adjacent to an 8m high compaction fill. Construction work has been comprehensively monitored with pressure cells, electrical piezometers, inclinometers and settlement plates in order to evaluate the load transfer mechanism taking place in the soft clay layer. Sand columns have proven to be useful in providing drainage to reduce the potential for build up of excess pore water pressures in the clay layer, in reducing the magnitude of settlements and in reducing the maximum horizontal earth pressure acting on structures adjacent to compacted fills.

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