Geosynthetics for the protection of buried pressurised pipes against mechanical damages caused by excavating tools

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ABSTRACT: The transportation of gas through pipes is of utmost importance for any modern society. The network of pipelines in large cities or industrial plants are subjected to accidental damages and vandalism actions and the consequences of leakage or explosions of such pipes can be very serious, commonly implicating losses of human lives and significant material damages. One common type of damage to a buried pipe is that caused by an excavating or perforating tool, and serious consequences of such events have been reported in the literature. This paper investigates the use of geosynthetics to protect buried pipes against damages caused by excavating tools. To assess the influence of the presence of the geosynthetic protective layer, model scale tests were performed on an instrumented steel pipe buried in dense sand. A wedge like tool was forced to penetrate in the sand mass and the effects of such penetration on the pipe behaviour were assessed. Geosynthetics were installed at different locations in the sand mass to protect the pipe under different arrangements. The results obtained showed that the presence of the geosynthetic protective layer in the soil caused a significant increase on the force required for tool penetration and reductions on the pipe strains in comparison to the situation without the protective layer. The results obtained show the potential for the use of geosynthetics as protective layers for buried pressurised.

1 INTRODUCTION

Nowadays the need to keep up with the development of urban, industrial and even rural areas, has demanded the construction of wide networks, with several tracks of underground buried pipes in those areas. The products transported by these pipelines range from water and sewage to more dangerous materials, like gas. In those areas, the occurrence of accidents involving these structures is not rare. One of the main causes of accidents is the unawareness of existence of these buried pipes. A research developed in Europe revealed that the most common causes of the accidents with buried pipes that transported petroleum products and crude oil, involved excavation machines and agricultural equipments. In 69% of the cases, neither the operator of the machine had knowledge of the existence of the pipe, nor the gas or oil company operator had of the construction works taking place (CONCAWE 2002). Most of the accidents with pipelines are originated from damages caused by impacts of excavating tools (CONCAWE 2002, NTSB 1999, 2000, 2004 and 2007, Tupa and Palmeira 2007). These accidents, especially the ones that involve pressurized pipes, usually lead to explosions or fires and bring serious consequences to the environment and the society, usually involving fatal victims.

In order to contribute with solutions that lessen the consequences of this accident type, Tupa and Palmeira (2007) showed the efficiency of the use of geosynthetics to minimize the effects of explosions of buried pipe. Also with that same objective, the present work studied the use the geosynthetics as a protective layer, avoiding or minimizing damages in buried pipes caused by impacts from the action of excavating tools. To assess the influence of the presence of the geosynthetic protective layer, model scale tests were carried out using an instrumented steel pipe buried in dense sand.

2 EQUIPMENT AND METHODOLOGY

Tests were conducted in a rigid steel box (800mm long, 500mm wide and 600mm high), shown in Figure 1. The box frontal face was made of acrylic. In this box, the sand mass was prepared using the sand rain technique to obtain a dense and uniform soil mass. The soil used in the tests was an uniform medium sand, with particle diameters ranging from 0.5mm to 2.2mm and coefficient of uniformity of 2.30.

An instrumented steel pipe (75mm in diameter and 1.5mm thick) was buried in the dense sand.

The penetrating object was simulated by a rigid steel plate 100mm high and 20mm thick and with a length approximately equal to the rigid box width, yielding to plane strain testing conditions. The penetrating plate was driven in the soil by the action of a hydraulic cylinder, which reacted against a reaction frame. The load applied by the cylinder and the displacement of the tool were measured by a load cell and by displacement transducers, respectively. Figure 1 presents schematically the test setup.

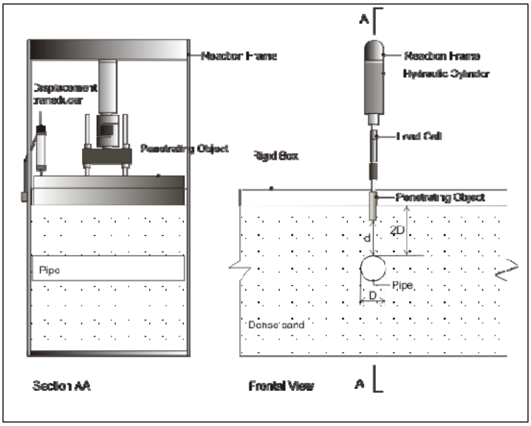


Figure 1. Scheme of the model tests.

The pipe was instrumented with electric strain-gauges installed at different locations along the pipe perimeter. The strain-gauges allowed the measurement of strains in the pipe during the penetration of the plate into the soil.

In order to assess the total pressure increments caused by the penetrating plate during the tests, total pressure cells were installed at different locations in the soil mass around the pipe.

A woven geotextile and a geogrid were used to reinforce the soil mass. The woven geotextile is a polyester material, with 550 kN/m tensile stiffness. The geogrid was also manufactured with polyester, with 20mm wide square apertures and a tensile stiffness equal to 200 kN/m. Three types of reinforcement arrangements were employed: (i) horizontal layer; (ii) inverted U; and (iii) enveloped. These arrangements are shown in Figure 2. A horizontal reinforcement layer was installed above the pipe in the first and simplest arrangement. Tests with the horizontal reinforcement layer at depths (z_r) of 35.5mm (half the pipe diameter D) and 75mm (pipe diameter D) were carried out to assess the influence of the depth of installation of the reinforcement. In the tests with reinforcement layer at depth (z_r) of 35.5mm only the geogrid was used. An inverted "U" arrangement was also employed aiming to increase the anchorage of the extremities of the geosynthetic layer. The third arrangement was as a layer enveloping completely the pipe (Fig. 2).

Additional information on the test equipment and methodology are reported by Andrade (2009) and Palmeira and Andrade (2009).

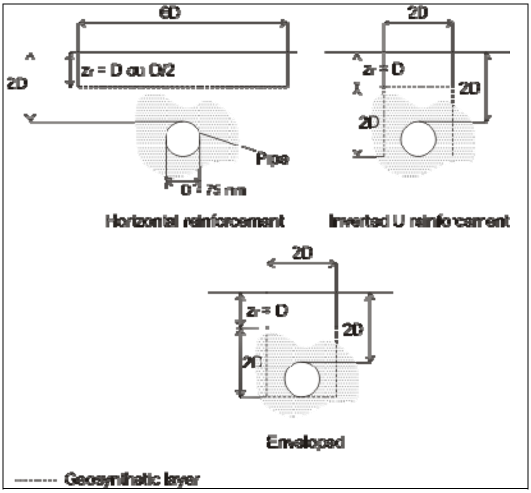


Figure 2. Reinforcement arrangements tested.

3 RESULTS AND ANALYSES

3.1 Influence of the presence of the reinforcement on the resistance against object penetration

One of the objectives of this study was to evaluate the increase on the resistance against plate penetration in the sand mass.

Figures 3(a) to (c) show the results of load (P) applied to the penetrating plate against the distance (d) between the top of the buried pipe and the plate tip for tests with and without the presence of a geosynthetic reinforcement layer at a depth equal to the pipe diameter (75mm). In Figure 3(a), the results of the test with a geogrid reinforcement layer installed at a depth z_r = 37.5mm (D/2 in Fig. 2) are also presented. In Figure 3 the codes RP and RP* stand for the conditions where the depth of the upper horizontal part of the reinforcement layers is D and D/2 respectively.

Figure 3(a) shows the results of the tests using a horizontal geosynthetic layer. For z_r = 75mm (D in Fig. 2), no significant differences between the results with and without reinforcement are noticed from the beginning of the test (d = 150 mm) until the moment that the plate tip was approximately 100 mm from the pipe (d = 100 mm). After that, the smaller the distance between the plate and the reinforcement the greater the force needed for the penetration of the plate in the soil mass in comparison to the situation without the reinforcement layer. At the end of the tests, it was observed that the load level required for plate penetration in reinforced tests was approximately 2.5 times higher than those values in the unreinforced tests. For the test with a geogrid reinforcement layer installed at a depth z_r = 37.5mm (D/2) the influence of the reinforcement is noted earlier in the test, when the distance between plate tip and reinforcement layer reaches 18mm, but at the end of the test the results are similar for both situations (z_r = D or D/2).

Figure 3(b) shows the results of the tests with the inverted U arrangement. For this arrangement it can be observed that, at the end of the tests, the force required for plate penetration in the reinforced ground was up to 5.5 times greater than that for the unreinforced ground, depending on the reinforcement type considered. The performance of the geogrid layer was slightly better than that of the geotextile during most of the test, but the final perforating load of the former was slightly lower, with a sudden drop on the value of d and with a regaining of strength at the later stages of the test, immediately after the plate tip has reached the upper horizontal part of the reinforcement layer (RP, in Fig. 3b).

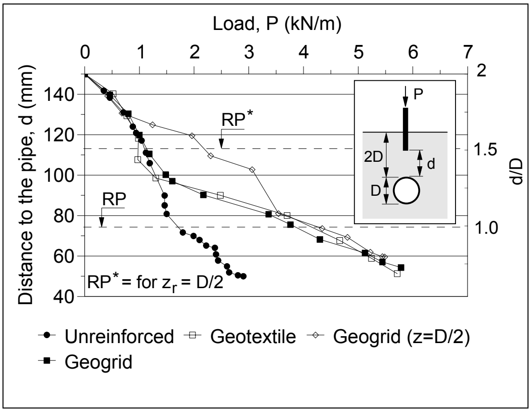
The results obtained in the tests with the enveloped arrangement are represented in the Figure 3(c). This arrangement was the one that presented the best performance. In this case, the final load at maximum penetration for the reinforced cases was up to 9.3 times greater than that of the unreinforced soil mass. The benefits of the use of the geogrid where smaller than that of the geotextile, due to the possibility of passage of sand grains through the geogrid apertures, which influenced the mobilisation of bearing forces at the grid transverse members.

3.2 *Influence of the presence of the reinforcement on the strains in the pipe*

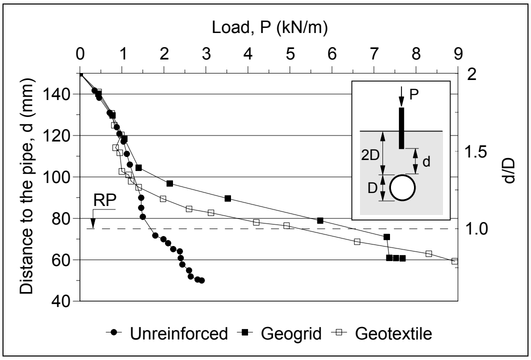
Figure 4 presents the maximum strains suffered by the buried pipe, at points where the strain-gauges were installed (along the external perimeter), for a plate load equal to the value reached at the end of the test without reinforcement. The convention for strain signs is that compressive strains are negative and tensile strains are positive.

In most of the cases, the largest pipe strains occurred in the test without reinforcement, mainly at the pipe crest and bottom.

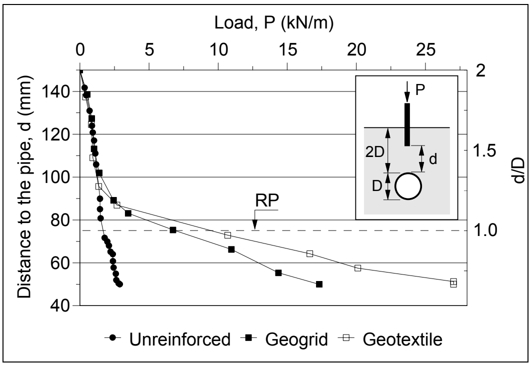
In addition, despite the plate load for the enveloped arrangement test having been 9.3 times greater than that of the unreinforced case, it was observed that the strains in the pipe for the enveloped arrangement were still smaller than those measured in the unreinforced test (Palmeira and Andrade 2009).



(a) Horizontal layer

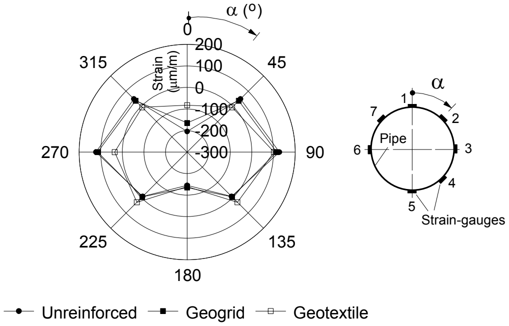


(b) Inverted U

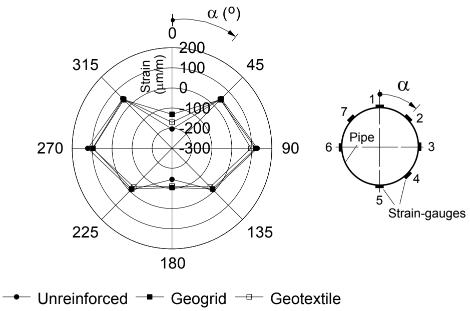


(c) Enveloped

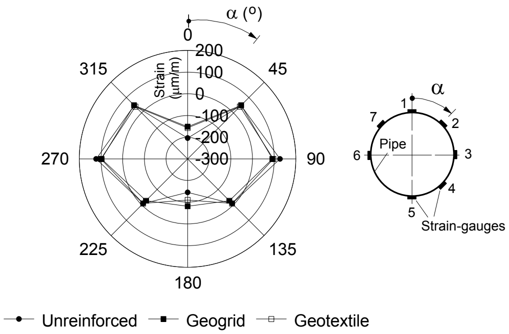
Figure 3. Vertical plate load versus plate distance to the pipe.



(a) Horizontal layer



(b) Inverted U



(c) Enveloped

Figure 4. Distributions of pipe strains along the pipe perimeter for a plate load equal to the maximum value obtained in the unreinforced test.

4 CONCLUSIONS

Based on the results obtained in the testing program, it is possible to draw the following conclusions:

- In all the tests, the presence of the geosynthetic increased the load necessary for the penetration of the plate in the sand mass. The enveloped arrangement was the one that presented the largest resistance against plate penetration, particularly for the test with the geotextile;
- The presence of the reinforcement also reduced the strains in the pipe, particularly for the envelope arrangement;
- In the field, the need for larger loads for the penetration of a excavation tool provides better protection to the pipe. In addition, the possible exhumation of the reinforcement layer after tool extraction may help an unadvised machine operator to realize the existence of a buried piping at the site.

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REFERENCES

Andrade, H.K.P.A. (2009). Protection of Buried Pipes against Mechanical Damage Using Geosynthetic Reinforcement. MSc. Thesis, Graduate Programme of Geotechnics, University of Brasília, Brazil, 99 p. (in Portuguese).

CONCAWE, 2002. Western European Cross-country Oil Pipelines - 30 Year Performance Statistics. Report n^0. 1/02. Brussels: CONCAWE, 48 p.

NSTB. 1999. Rupture and fire, Natural gas, Indianapolis, Indiana, July 21, 1997. Pipeline Accident Brief PAB/99-02, National Transportation Safety Board, Washington, DC, USA.

NTSB, 2000. Natural Gas Pipeline Rupture and Subsequent Explosion in St. Cloud, Minnesota, December 11, 1998. Pipeline Accident Report NTSB/PAR-00/01, National Transportation Safety Board, Washington, DC, USA.

NSTB. 2004. Rupture, explosion, and fire, Wilmington, Delaware, July 2, 2003. Pipeline Accident Brief NTSB/PAB-04/01. National Transportation Safety Board, Washington, DC, USA, 7 p.

NSTB. 2007. Pipeline break, explosion, and fire, Bergenfield, New Jersey, December 13, 2005. Pipeline Accident Brief NTSB/PAR-07/01, National Transportation Safety Board, Washington, DC, USA, 13 p.

Palmeira, E. M. & Andrade, H. K. P. A., 2009. Protection of buried pipes against accidental damages using geosynthetics. Submitted for publication in Geosynthetics International.

Tupa, N. & Palmeira, E.M., 2007. Geosynthetic reinforcement for the reduction of the effects of explosions of internally pressurised pipes. Geotextiles and Geomembranes 25(2), p. 109-127.