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Evaluation of the behaviour of pipes buried in geosynthetic reinforced ground

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Abstract. This paper aims to present an evaluation of the soil-geosynthetic interaction used for protection and reinforcement of a buried flexible pipe inserted in non-reinforced soils and soils reinforced with geosynthetics subjected to the application of a surface overload. Therefore, tests were carried out in models (scale 1:3.5) and numerical simulations using PLAXIS 2D program. In laboratory tests, a 200 mm diameter PVC pipe was used buried in a non-cohesive soil and different types of geosynthetics. The reinforcement used were four geogrids and a woven geotextile, with tensile stiffness varying between 34 kN/m² and 2000 kN/m². The results of the experimental tests showed beneficial effects regarding the insertion of the reinforcement in the massif with buried pipe. The efficiency of reinforcement depends on the type of arrangement considered and its physical and mechanical properties. Overall, the numerical simulations showed that the predicted results reproduced the patterns of the experimental results, but some significant deviations between predictions and measurements were observed.

1 Introduction

Pipelines play an important role in urban and industrial development, as an effective part of the modern infrastructure for the transport system of essential products for modern societies. However, buried pipelines are subject to static, accidental and relief loads acting on the underground structure, such as loads due to the surrounding soil, overloads, vehicle traffic, accidental damage, etc. Accidents with urban pipelines, caused by the construction of pavements and maintenance services in the adjacent distribution network, have occurred with great frequency in recent years.

Given the importance of protecting buried pipelines in order to preserve the integrity of the structure and prevent accidents, the prospect of using geosynthetics becomes increasingly attractive. Several pipe protection methodologies have been employed in practice and investigated in order to provide a baseline for future buried pipe designs.

The methods developed sought to reduce the impact of surcharges on buried pipes, reducing the vertical stresses and strengthening the foundation soil. In the literature, techniques such as induced trench, compressible cradle and the use of geosynthetics, among others, can be found [5]. Geosynthetics have been used in buried pipe projects and are the

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subject of studies by many researchers [3, 4, 5, 6, 7, 8, 9, 10], which have evaluated the performance of the geosynthetic as well as the soil-pipe system under different aspects.

The aim of this study was to investigate the influence of the presence of reinforcement on the reduction of vertical and horizontal stresses acting on a flexible tube buried in a soil subjected to surface surcharge. The study also investigated the reduction of deformations and deflections experienced by the buried pipe and showed the mechanical performance of the soil-pipe system due to the application of surface surcharge. For that, experimental tests were carried out in the laboratory (in scale 1:3.5) and numerical simulations using Plaxis 2D.

2 Experimental and numerical programme

2.1 Experimental program

The experimental program of the research consisted in carrying out tests in a 1:3.5 scale to evaluate the influence of the presence of foundation soil reinforcement. The tests were carried out in the rigid steel box 1500 mm long, 1000 mm high and 700 mm wide. The box frontal face consisted of a 12 mm thick glass, allowing the visualization of the soil failure mechanism, displacement field of the mass of soil and of the pipe. In the proposed test condition, a 250 mm wide rigid plate, simulating plane strain conditions, applied the vertical surface surcharge.

Figure 1 shows the model test setup and the geometric configurations used for the geosynthetic layers. Three different geometric configurations were used in the reinforced tests. The first installation arrangement consisted of a horizontal reinforcement layer (code HL) at a depth of 200 mm and with a length of 1200 mm (= 6 times the pipe diameter). The second configuration consisted of positioning the reinforcement surrounding the pipeline in an inverted U (code UI) arrangement. Finally, the third condition consisted in the reinforcement enveloping (code ENV) of the tube.

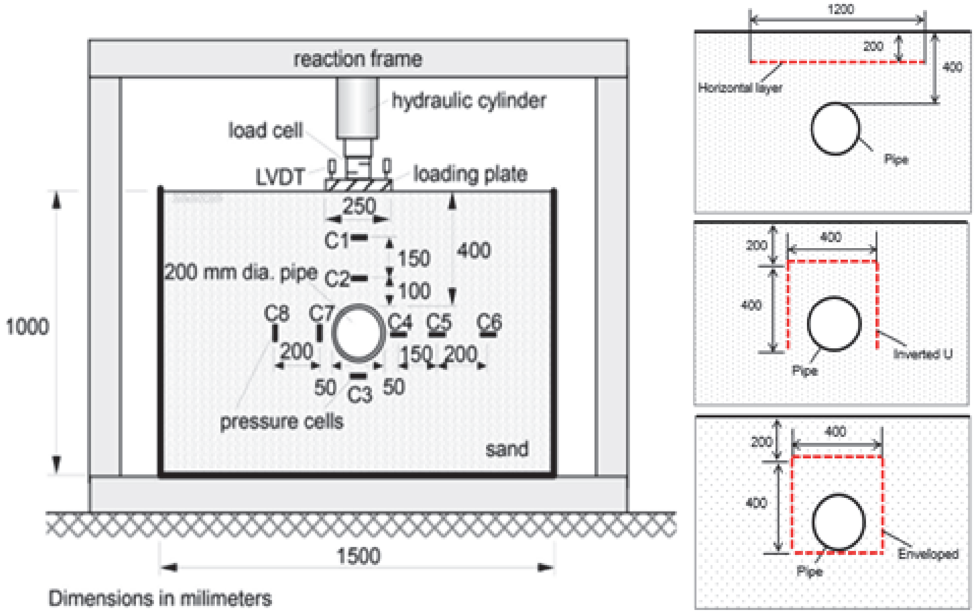

Fig. 1. Experimental tests –Model test setup and reinforcement arrangements tested.

All test were instrumented with pressure cells, load cell and displacement transducers. The readings acquired during the tests made it possible to evaluate the influence of the presence of the reinforcement.

The soil used was a uniform fine to medium quartz sand, classified as SP according to the Unified System of Soil Classification [1]. The sand parameters were determined in direct shear tests, following the recommendations by [2], obtaining soil friction angles between 37° and 46°, depending on the stress level considered.

A PVC tube was used in the study, with an external diameter of 200 mm, a wall thickness of 3.6 mm and a length of 690 mm. Considering the scale factor of 3.5 adopted in this model, the tube would simulate a 700 mm diameter tube under prototype conditions.

Table 1 shows the main characteristic of the five types of reinforcements that were used in the reinforced test. Among the reinforcements, there are four geogrids (code GG), with tensile stiffness values ranging from 34 to 300 kN/m and apertures between 1 x 1 mm to 20 x 20 mm. In addition, a woven geotextile (GT) with a tensile stiffness of 2000 kN/m to assess the influence in using a very stiff reinforcement.

Table 1. Reinforcement properties.

Property	**Reinforcement**				
	GG1	GG2	GG3	GG4	GT
t_{GT} (mm)	0.8	0.4	0.5	0.9	1
Mesh opening (mm)	20x20	1.1x1.1	1.3x1.3	2x2	-
J5% (kN/m)$^{(2,5)}$	300	34.1	90.8	125.8	2000
Tmáx (kN/m)$^{(3)}$	20/13$^{(6)}$	5.1	16.9	10.1	200
$\varepsilon_{máx}$ (%) $^{(4, 5)}$	12	23	25	9	11

Where: (1) PET = polyester, PA = polyamide and HDPE = high density polyethylene; (2) J5% = secant tensile stiffness at 5% strain; (3) Tmax = tensile strength; (4) εmax = maximum tensile strain; (5) As per ASTM D4595 or ASTM D6637, de-pending on type of reinforcement; (6) Left and right values are from machine and cross machine directions, respectively.

2.2 Numerical analyses

Once the experimental program was concluded, a numerical simulation of the test was performed. The numerical analyses were performed with Plaxis 2D using an elastic-perfectly plastic model. Four different models were investigated: (i) without pipe and without reinforcement; (ii) unreinforced test; (iii) reinforced test with a horizontal reinforcement layer; and (iv) reinforced test with geosynthetics in enveloped arrangement. Soil properties determined in the laboratory tests were used as input parameters in the numerical simulation. However, the Young's modulus (E) of the soil for the relative density of 50% employed in tests was back-analysed from results of loading tests (using the same loading plate) on the sand mass (without pipe and without geosynthetics).

3 Results and discussions

3.1 Influence of the reinforcement on the displacements of loading plate

Table 2 shows the plate displacement values for the maximum applied surcharge of 160 kPa, which would correspond to a vertical stress value close to a typical tire pressure under prototype conditions, for all tests. Besides, the table shows the ratio between the displacements in reinforced (δ) and unreinforced (δ_{UNR}) tests. The value obtained in the unreinforced test (22.97 mm) was taken as a reference value. The result of the numerical analyses showed that for a surcharge of 160kPa the displacement of the loading plate was equal to 21.5 mm in the unreinforced case, which is very close to the measured value.

Table 2. Plate displacement in the experimental tests.

Condition of test	**δ (mm)**	**$\delta/\delta u_{NR}$**
NR	22.97	-
GG1-HL	17.09	0.74
GG1-UI	16.15	0.70
GG1-ENV	16.83	0.73
GG2-ENV	16.37	0.71
GG3-ENV	16.21	0.71
GG4-ENV	16.36	0.71
GG4-HL	16.75	0.73
GT	17.43	0.76

In general, the insertion of the reinforcement in the subgrade reduced the loading plate displacements. It can be noted that the geometric arrangement used for geogrid GG1 had little influence on the ratio δ/δ_{UNR}. Geogrid GG4 with horizontal and enveloped arrangements provided reductions in loading plate displacements of 23% and 29%, respectively. The geotextile (GT) reinforcement caused a reduction of 24% in the plate displacement, a value very close to that obtained by the geogrid GG1 with an enveloped arrangement (GG1-ENV). The results show that the tensile stiffness of the reinforcement was a parameter that did not significantly influence the plate settlements, despite the wide range (34.1 kN/m to 2000 kN/m) of tensile stiffness value of the reinforcement tested.

3.2 Stresses around the pipe

The evaluation of the influence of the reinforcement on the stresses generated around the buried pipe was possible due to the presence of pressure cells inserted in the soil (Fig. 1). Despite three different geometric arrangements have been used for reinforcement, the positions of the cells in relation to the pipe were kept constant in all tests. The pressure cells

C1, C2, and C3 were positioned to measure vertical stresses above the top of the pipe and immediately below it, respectively. The vertical and horizontal stresses generated at the sides of the buried pipe were recorded by cells C4 to C8.

The maximum surcharge applied on the soil surface in the all test was equal to 160 kPa. Figure 2 shows the results of the vertical stress measured for the pressure cells C1, C2 e C3.

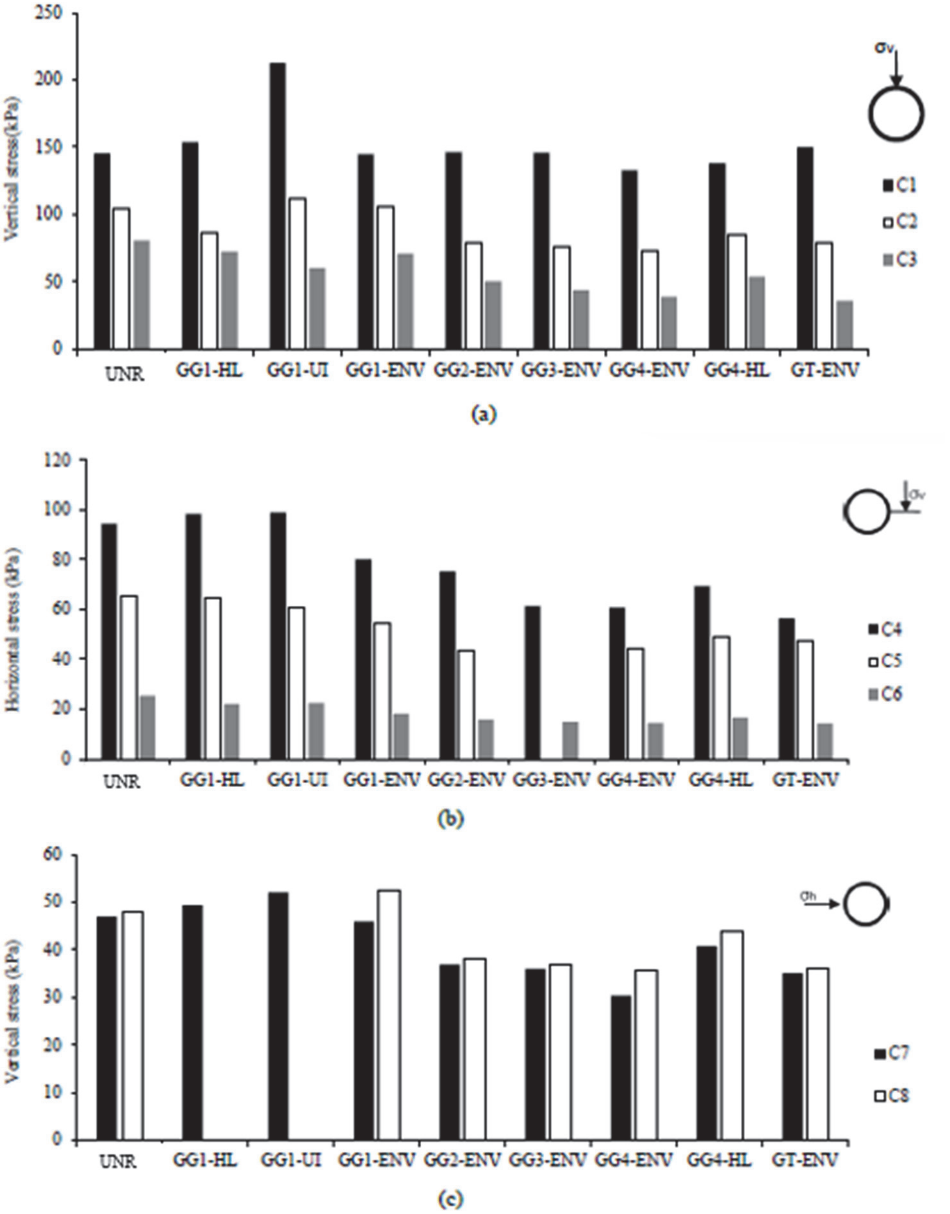

Fig. 2. The vertical stress measured above and below the pipe.

It can be seen that, based on the readings of cell C1, the results with and without reinforcement were similar, with the exception of the tests with the inverted U (GG1-UI). Further analysis showed that pressure cell C1 malfunctioned in this test, which explains the unexpected result shown. In this sense, two relevant aspects regarding the results from pressure cell C1 should be considered. The tensile stiffness of the reinforcement did not influence the stresses in the region of installation of that cell. Note that reinforcement GT the one with the highest tensile stiffness, but the results of the test with this reinforcement were similar to the others. An important aspect is that cell C1 was placed in a region above the reinforcement, regardless of the arrangement considered. Thus, it is justifiable little benefit from the presence of the reinforcement having been observed in this case.

On the other hand, although high vertical stress were measured in the region of cell C2, also due to the proximity of the cell to reinforced area and tube. The results presented in Figure 2a showed a significant reduction in the efforts in the reinforced mass throughout the entire test compared to the unreinforced test, especially in the inverted U and enveloped arrangements. This behaviour was also evidenced by [8]. The presence of geogrids (with the exception of GG1) and geotextile have a beneficial effect on the insertion of the geosynthetics into the soil mass, achieving reductions in the value of vertical tension by up to approximately 29%, depending on what is considered. reinforcement.

Regarding the tensions in the region below the tube, the results obtained by the C3 pressure cell show that the tensions below the pipe are lower compared to the stress C1 and C2. The vertical stress at the end of the test recorded by cell C3 in the unreinforced UNR condition was 80.5 kPa. Furthermore, it was found that insertion of the reinforcement contributed to reducing stress values, but the type of arrangement did not have a significant influence on the results for reinforcement GG1. For geogrids GG2 to GG4 and geotextile GT, the stresses measured by cell C3 varied between 36 kPa and 51 kPa, which represents reductions of up to 55% in relation to the result obtained in the UNR test.

The vertical stress measured in the lateral region of the tube, by cells C4 to C6, presented the lowest tension values, reaching 100 kPa, when closer to the tube corresponding to the installation of C4 (Figure 2b). In all cases, the enveloped arrangement was the most effective in reducing the stresses in the tube. Analogously verified by the results of cells C1 to C3, it can be noted that the reinforcements GG2, GG3, GG4 and GT, when installed in the enveloped arrangement, contributed significantly to the reduction of tensions.

Finally, depending on the results presented by pressure cells C7 and C8 (Figure 2c), it can be concluded that: (i) the horizontal layer configuration did not provide a significant benefit in relation to the test condition without reinforcement; (ii) the enveloped arrangement, on the other hand, proved to be effective in terms of contributing to the reduction of horizontal tensions in the soil; (iii) although the GT reinforcement has a significantly higher tensile stiffness than the geogrids, the results were similar to those obtained with the geogrids GG2, GG3 and GG4; and (iv) the passage of sand grains through the openings of the GG1 geogrid negatively influenced its efficiency in reducing stresses in the mass of soil.

Numerical analyses of the reinforced conditions tested in the laboratory showed that in some regions of the soil there was a good agreement between the measured and predicted stresses in the soil, with a maximum deviation of 20%. However, at certain points the measured stresses were approximately 50% lower than those predicted in the numerical analyses were. Despite the discrepancy between the stress values, the simulations were important to verify that there may be a significant increase in the value of the vertical stresses in the region below the tube, depending on the vertical forces generated during the installation of the tube in the test preparation phase.

Figure 3 presents the ratio between the measured stresses in the reinforced (σ_R) and un-reinforced (σ_{UNR}) soil for the 160 kPa stress, predicted and measured. One can observe the significant discrepancy between results in the region below the tube for the two geogrids. This fact is directly related to the high value of the vertical stress below the tube obtained in the UNR model test (= 93.28 kPa) in comparison with the stress obtained numerically (= 34.88 kPa).

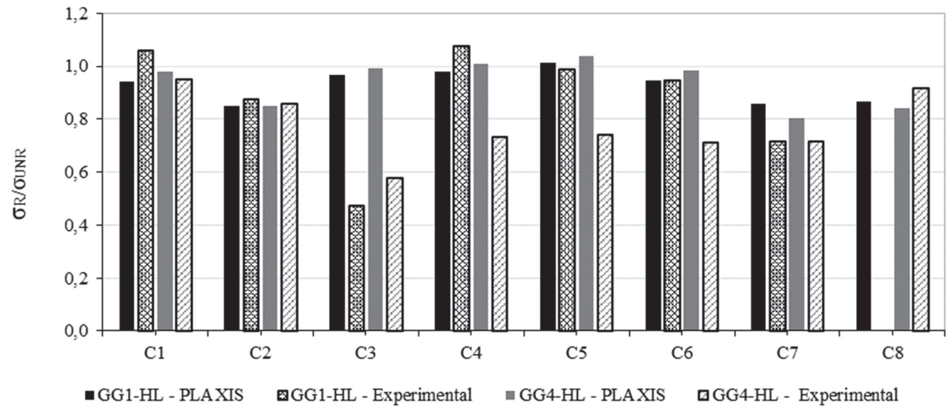

Fig. 3. Vertical stresses obtained through experimental tests and numerical model.

4 Conclusions

In general, the insertion of the reinforcement resulted in beneficial effects, contributing favourably to the alteration of the stress state in the massif. The geometric configuration of the installation and the tensile stiffness of the reinforcement were important parameters in the evaluation of the soil behaviour and, consequently, in the response developed by the soil-duct interaction.

The enveloped arrangement proved to be the most effective in terms of enhancing the benefits of the presence of reinforcement. The tensile stiffness of the reinforcement is an important parameter for the reduction the vertical and horizontal stresses in the soil. However, for the range of tensile stiffness values of the tested reinforcements, the influence of tensile stiffness was not as significant as could be expected in most cases. In addition to the tensile stiffness of the reinforcement, the interaction between the soil and the reinforcement and the flexural stiffness of the reinforcement can also play important roles in the performance of the reinforcement.

A relevant point in the study was that the results suggest that the passage of soil particles through the openings of the geogrid mesh. The geogrid (GG1), with the largest mesh opening (20 x 20 mm) tested, was less efficient than the other tested geogrids. Thus, geogrids with low aperture dimensions for soil and geotextile particle size ratios would be more suitable for this type of application.

However, one can observe the GT woven geotextile, although presenting a tensile stiffness significantly superior to the geogrids; it presented similar results to those obtained for the geogrids GG2, GG3 and GG4. This implies that tensile stiffness is not a predominant factor in this case, the physical properties of the reinforcements such as the opening of the mesh and the interlocking of the grains in the voids of the geogrids contributed to a better performance of the geogrids in relation to the GT reinforcement. Particularly, the GG4 geogrid presented the best performance among the geogrids, considering all the points of soil stress analysis.

In the analysis of the tensions in the soil, it was possible to observe that the presence of the reinforcement contributed to the reduction of the values of the vertical and horizontal tensions of the soil surrounding the tube.

Numerical analyses of the reinforced conditions tested in the laboratory showed that in some regions of the soil there was a good agreement between the measured and predicted soil stresses, with a maximum deviation of 20%. However, at certain points the measured stresses were approximately 50% lower than those predicted in the numerical simulations were. Despite the discrepancy between the stress values, the simulations were important to verify that there may be a significant increase in the value of the vertical stresses in the region below the tube, depending on the vertical efforts generated during the installation of the pipe in the phase of test preparation.

Finally, it is highlighted that the use of geosynthetics together with the installation of underground pipes makes sustainable contributions. It is noteworthy that this geosynthetics installation technique allows the installation of pipes at smaller depths, considering that the reinforcement reduces part of the efforts on the buried structure.

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