The use of geocomposite as compressible layer to reduce vertical stress on buried structures

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ABSTRACT: This work presents results of laboratory tests and parametric analyses using the Finite Element Method to evaluate the behavior of a geocomposite when used as compressible layer of the induced trench method to reduce vertical earth stress on buried structures. Three laboratory tests were carried out using a reinforced metallic box varying the position of the flexible layer. Sand was used as fill material. The analyses showed that this geocomposite, which is traditionally applied in drainage works, presented excellent behavior, providing stress reduction up to 85%. The experimental results, confirmed by the numeric analyses, showed that the inclusion must be located as near as possible to the top of the buried structure. The numerical analyses showed that the calculated stresses were in good agreement with monitored results, so the finite element method can be considered a useful tool to predict the performance of buried structures.

1 INTRODUCTION

Buried conduits are widely used in road constructions as subterranean passages and drainage gallery. Frequently, these structures are constructed under positive projecting embankment conditions and are covered, later on, with a thin layer of earth fill material. In these cases, loads due to the self weight of the soil and the overload due to the crossing of vehicles on the ground surface, can lead to much higher stress increase on the buried structure. Such increases occur on account of a stress redistribution caused by the difference of rigidity between the conduit and the surrounding soil. This phenomenon is named arching.

The arching can be divided into two categories, active (or positive) when the stress in a certain zone over the structure suffers reduction, and passive (or negative) when there is stress increase (Costa 2005). The positive arching occurs when the conduit shows less rigidity than the one showed by the adjacent soil. When the opposite happens, it characterizes the negative arching.

An alternative to the positive projecting embankment installation is the installation of these conduits in deep trenches so that the overload applied on the surface by the traffic of vehicles does not propagate to the structure. However, this alternative brings high costs of excavation and earth fill.

Although there are many conventional techniques for the installation of conduits, constructive methods that allow arching control to obtain stress reduction over the buried element, seem to be quite interesting.

It is possible to induce the trench condition with the purpose of giving the projecting conduit the inherent advantages of the conduits installed in trenches (Viana & Bueno, 1998).

This process elaborated by Marston in the beginning of last century, identified as induced trench method, consists basically of incorporating a compressible layer inside of the embankment in a region situated above the conduit. As the embankment is done, the most compressible zone (central prism) is more compressed than the adjacent zones (lateral prisms) generating displacement between these two areas. These displacements induce upward shear stresses on the sides of the internal prism, causing stress reduction on pipe due to positive arching.

The induced trench method allows the installation of the conduits in depths which are closer to the surface, so as to obtain a better economy in relation to earthwork.

Although ingenious and very easy to execute, the use of the induced trench was not as extensive as was expected, mainly because the compressible material used in the first examples of application was of vegetal origin and showed serious possibilities of degradation. With the advent of the geosynthetics, the induced trench method has the possibility of returning to an elevated position, because materials such as the draining geocomposites, of excellent dimensional control, resistant to degradation and of compressibility that meets the design necessities, can easily be found in the market.

Although scarcely used in geotechnical area, the induced trench method appears as an alternative to reducing vertical stress over buried pipes. Table 1 presents a summary of the main published works related to the induced trench method found in literature.

Table 1**.** Induced trench method published works.

Author	Fill Material	Compressible Layer	Stress Reduction
Sladen & Oswell's 1988	Silty clay	baled straw and polystyrene	60% to 80%
Vaslestad et al. 1993	Rockfill and silty clay	EPS	52% to 78%
Machado et al. 1996	Sandy clay	Not specified	Up to 48%
Viana & Bueno 1998	Compact sand	Loose sand	Up to 60%
Melotti 2002	Sand	Rice straw	44% to 86%

It can be noticed that the induced trench method, although showing a lack of experimental results, seems to be an excellent alternative to stress reduction over buried structures. There is a need of mastering this technique in order to define reliable parameters to safely design buried conduits.

The presented results indicate that there must be cautiousness on the choice of the composition material of the compressible layer. The option for low quality material may lead to undesirable stress concentration that might result in malfunctioning or even disruption of the conduit.

Due to this, this paper has the objective of studying the efficiency of a draining geocomposite as a compressible element of the induced trench method. Some laboratory tests and parametric analyses (using the Finite Element Method) were performed in order to evaluate the system behavior for different distances between the inclusion and the buried structure.

2 MATERIALS AND METHODS

The laboratory tests were carried out using a metallic reinforced box designed by Costa (2005). The internal dimensions of the reinforced box were 560 mm x 1400 mm in plan, and 560 mm in height. An external view of the reinforced box is showed in Figure 1.

Figure 1. External view of the reinforced box (Plácido 2006).

The models were built using pure and dry sand as fill material. The sand was pluviated through air under controlled condition to give a relative density of 75%.

The distributed load was applied over the model using a reinforced PVC inflatable bag with dimensions of 1400 mm in length x 560 mm in width. The load was applied in three steps: 50 kPa, 100 kPa and 150 kPa.

A geocomposite, which is traditionally applied in drainage works, was used as compressible layer. This geocomposite has a drainage core of looped polypropylene filaments, and is covered with a nonwoven polyester geotextile on both sides.

Three tests were performed using 15 mm thick geocomposite specimens with 200 mm in width and 560 mm in length, transversally positioned at the centre of the test box. To evaluate the influence of the inclusion position in the induced trench method behaviour, each test was carried out using three different heights from the bottom of the box: 100 mm, 200 mm, and 300 mm. The test program performed is shown in Table 2.

Table 2**.** Performed test program.

Test Nº	Distance between the base of the box and the geocomposite (mm)	Geocomposite width (mm)
1	100	200
2	200	200
3	300	200

Parametric analyses using the Finite Element Method (FEM) were also performed. These additional analyses were carried out using the geotechnical software Plaxis®. The simulations were performed considering the same geometry of the laboratory tests.

The geocomposite and soil parameters used in parametric analyses were taken from Plácido (2006), and can be seen in Table 3.

Table 3. Soil and geocomposite properties used in the numerical models.

Para meter	Sand	Geocomposite	Units
Material model	Mohr-Coulomb	Linear Elastic	---
Natural unit weight	16.7	0.051	kN/m^3
Saturated unit weight	20.0	1.000	kN/m^3
Young's Modulus	3.52 x 10^4	130.0	kN/m^2
Poisson's Ratio	0.34	0.100	---
Cohesion	1	---	kN/m^2
Friction Angle	33	---	°
Dilatancy Angle	4	---	°

3 RESULTS AND DISCUSSION

Figures 2, 3 and 4 show the relative vertical stress distribution in a horizontal plane situated over the base of the test box, for tests 1, 2 and 3, respectively. The relative stress is calculated dividing the vertical stress registered in laboratory tests (σ_{VR}) by the theoretical vertical stress ($\sigma_{VT} = \gamma$ x h). The red line represents the laboratory test result, and the blue line represents the Finite Element Method (FEM) analysis result.

Figure 2 shows the laboratory tests and FEM analysis results for test nº 1.

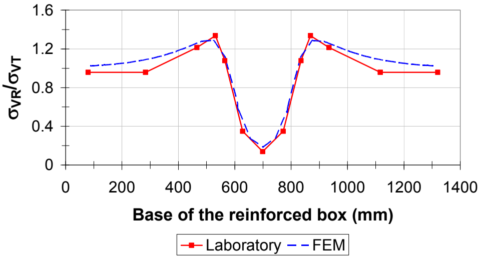

Figure 2. Stress distribution for test nº 1.

It is clearly noticeable that the use of a compressible layer induces a positive arching in the soil, leading to large stress reduction over the buried structure. However, a stress increase occurs in a region situated at the side of the compressible inclusion. As can be seen, the laboratory test nº 1 showed a relative stress of 0.15 in the region situated at the middle of the test box (below the geocomposite inclusion). This relative stress represents a stress reduction of 85%. In the two regions located at both sides of the inclusion (530 mm and 870 mm, approximately), the relative stress was about 1.35, representing a stress increase of 35%. The same behavior occurred for FEM analysis. The numerical simulation showed stress reduction up to 81% at the central region of the model, and a stress increase of 30% at both sides of the compressible layer.

Figure 3 shows the laboratory tests and FEM analysis results for test nº 2.

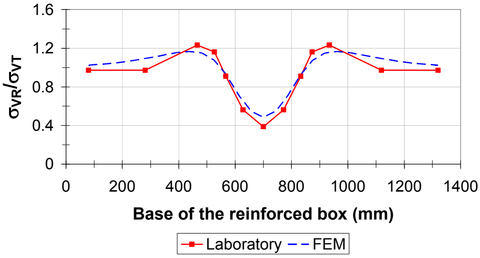

Figure 3. Stress distribution for test nº 2.

As can be seen, the laboratory test nº 2 showed a relative stress of 0.4 in the region situated at the middle of the test box (below the geocomposite inclusion). This relative stress represents a stress reduction of 60%. In the two regions located at both sides of the inclusion (470 mm and 930 mm, approximately), the relative stress was about 1.23, representing a stress increase of 23%. The same behavior occurred for FEM analysis. The numerical simulation showed stress reduction up to 50% in the central region of the model, and a stress increase of 17% in both sides of the compressible layer.

Figure 4 shows the laboratory tests and FEM analysis results for test nº 3.

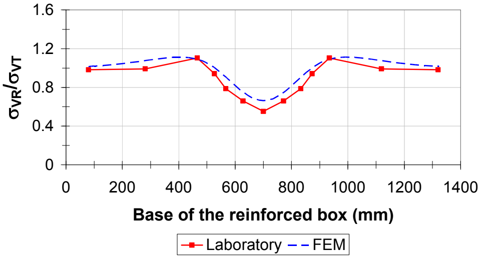

Figure 4. Stress distribution for test nº 3.

As can be seen, the laboratory test nº 3 showed a relative stress of 0.55 in the region situated at the middle of the test box (below the geocomposite inclusion). This relative stress represents a stress reduction of 45%. In the two regions located at both sides of the inclusion (470 mm and 930 mm, approximately), the relative stress was about 1.10, representing a stress increase of 10%. The same behavior occurred for FEM analysis. The numerical simulation showed stress reduction up to 35% in the central region of the model, and a stress increase of 10% in both sides of the compressible layer.

Figures 2, 3 and 4, showed that the geocomposite presents an excellent behaviour when used as compressible layer of the induced trench method. The results showed stress reduction up to 85% in a region located below the inclusion. As can be seen, the best system behaviour was observed for test nº 1, and the worst for test nº 3. This fact indicates that the compressible layer must be located as near as possible to the top of the buried structure.

The numerical analyses showed that the stresses predicted by numerical simulations were in good agreement with the monitored results. The predicted values, in the region below the inclusion, were about 15% lower than monitored results.

The analyses showed that the finite element method is a useful tool to predict the behavior of buried structures that use the induced trench method.

Another important parameter to be considered in buried pipe design is the height of soil cover. According to Watkins (1975), much attention should be given to shallow conduits installations. According to the author, under some circumstances in which the height of cover above the conduit is low, the existence of elevated weights over the surface can generate joint failure or pipe wall buckling. Furthermore, the author mentions that, as a general rule, it is possible to use a minimum height of cover equal to 1/8th of the conduit diameter for pipelines constructed under highways, and equal to 1/4th of the conduit diameter for pipelines constructed under railways, being that, for both cases, a minimum of 30 cm height of cover must be used.

4 CONCLUSIONS

The main conclusions from the use of a geocomposite as a compressible layer to reduce vertical stress on buried structures are as follow:

- The geocomposite, which is traditionally used in drainage works, showed excellent behaviour when used as compressible layer of the induced trench method, providing stress reduction up to 85% over the top of the buried structure;
- Satisfactory stress reductions were observed in the region located below the inclusion;
- The analyses showed that the inclusion must be located as near as possible to the top of the conduit;
- The numerical analyses showed that the calculated stresses were in good agreement with monitored results, so the finite element method can be considered a useful tool to predict the performance of buried structures.

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