FINITE ELEMENT ANALYSIS OF THE USE OF A GEOCOMPOSITE AS A COMPRESSIBLE LAYER TO REDUCE VERTICAL STRESS ON BURIED STRUCTURES

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Abstract: This work presents results of parametric analyses using the Finite Element Method to evaluate the behaviour of a geocomposite, when used as a compressible layer in the induced trench method, to reduce the earth stress on buried structures. The analyses showed that this geocomposite, which is traditionally applied in drainage works, demonstrates excellent behaviour, providing stress reduction up to 92%. The numeric analyses showed that the compressible layer must be located as near as possible to the culvert crown, and appropriate values of inclusion width must be between 1.5 and 2 times the conduit diameter.

Keywords: Pipeline, stress, geocomposite, arching, finite element, numerical

INTRODUCTION

Buried conduits are widely used in road constructions as subterranean passages and drainage galleries. Frequently, these structures are constructed under raised 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). Positive arching occurs when the conduit shows less rigidity than that displayed by the adjacent soil. When the opposite happens, it characterized by negative arching.

An alternative to the raised 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, construction 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 raised conduit the inherent advantages of the conduits installed in trenches (VIANA and 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 constructed, the most compressible zone (central prism) is more compressed than the adjacent zones (lateral prisms) generating displacement between these two areas, as seen in Figure 1. These displacements induce upward shear stresses on the sides of the internal prism, causing stress reduction on pipe due to positive arching.

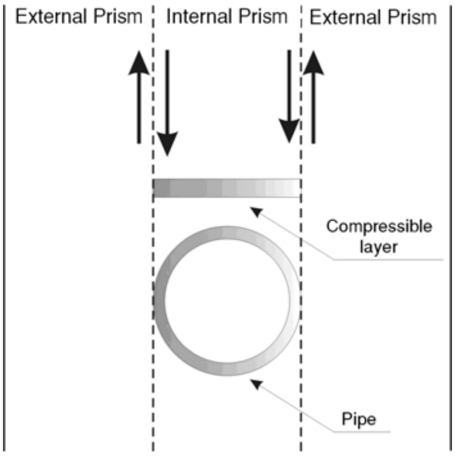

Figure 1. Relative movement caused by the induced trench method.

The induced trench method allows the installation of the conduits at depths that 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 requirements, can easily be found in the market.

Although scarcely used the induced trench method appears as an alternative to reducing vertical stress over buried pipes. Sladen and Oswell's (1988) are among the prominent published works. The authors make a comparison between the trench condition and the raised condition.

Three different installations were made using the induced trench method. One of them was made with a 2.10 m diameter conduit installed under a flexible layer of baled straw, and the other two with a 2.50 m diameter conduit installed under compressible layers of baled straw and polystyrene with density of 15 kg/m^3. The results demonstrate that for both materials used, the stress reduction over the top of the conduit was of about 60 to 80%.

Vaslestad et al. (1993) executed three tests in real scale using EPS to generate the induced trench. The first test was performed with a 1.95 m external diameter concrete pipe and a compressible layer of 2.0 x 0.5 m rectangular section located at 0.5 m over the top of the conduit. Rockfill was used as fill material. In this test a stress reduction of about 72% was obtained over the pipe. On the second test, a 1.74 m external diameter concrete pipe and a compressible layer of 3.0 x 1.0 m rectangular section located at 0.20 m over the top of the conduit generated a stress reduction of 78% over the pipe. The last test was carried out with a rectangular section concrete conduit of 2.0 m width and 2.55 m height. The compressible layer used on this test had a 2.0 x 0.5 m rectangular section located at 0.5 m over the top of the conduit. The fill material used was silty clay, and the stress reduction obtained was of 52%. Vaslestad et al. (1993) give special attention to the importance of the choice of the compressible layer material on the system performance.

Machado et al. (1996) worked on a parametrical study of the induced trench technique using the Finite Element Method. The authors made a study into the influence of the depth, width and position of the inducing layer on the system performance. The best results were achieved for the compressible layers located as near as possible to the top of the conduit, resulting in reduction factor up to 1.9 to vertical stress.

Viana and Bueno (1998), pursuing the induced trench technique improvement, introduced the use of a geosynthetic over the compressible "block" implanted within the embankment. The main objective of this constructive process was to ally the benefits of the trench to the effect of the geosynthetic soil reinforcement. The authors, varying the width and the position of the geosynthetic, obtained stress reduction over the buried structure up to 60%.

Melotti (2002) carried out several studies on a reinforced metallic box varying the dimensions of the flexible layer. The author used rice straw as part of the inducting element, and obtained stress reduction of 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 to master this technique in order to define reliable parameters to safely design buried conduits.

The presented results indicate that there must be caution in 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. Several parametric analyses were made using the Finite Element Method to evaluate the system behaviour when varying the width, the position and the number of layer inclusion.

MATERIALS AND METHODS

The parametric analyses using the Finite Element Method were performed using the geotechnical program Plaxis®.

The simulations were carried out using a 150 mm diameter PVC pipe installed in sandy-clay soil. The soil parameters were taken from Machado et al. (1996). A geocomposite, which is traditionally applied in drainage works, was used as compressible layer. This geocomposite presents 15 mm thickness approximately and it is made of a three-dimensional mesh draining core to which is fixed a nonwoven geotextile on both sides. The geocomposite parameters were taken from Plácido (2006).

The characteristics adopted for the used materials are found in tables 1 and 2.

Table 1. Soil and geocomposite properties used on the constructive models.

Parameter	Sandy-clay Soil	Geocomposite	Units
Type	Soils and interfaces	Soils and interfaces	---
Material model	Mohr-Coulomb	Linear Elastic	---
Type of material behavior	Undrained	Drained	---
Soil unit weight above phreatic level	18.800	0.051	kN/m^3
Soil unit weight below phreatic level	20.000	1.000	kN/m^3
Young's Modulus	12.900 x 10^4	70.5	kN/m^2
Poisson's Ratio	0.300	0.100	---
Cohesion	40.000	---	kN/m^2
Friction Angle	28	---	°
Dilatancy Angle	0	---	°

Table 2. PVC conduit properties.

Parameter	Pipe	Units
Type	Plate	---
EA	3.196 x 104	kN/m
EI	80.690	kNm^2/m
d	0.174	m
w	0.018	kN/m/m
ν	0.38	---

All analyses were done with the conduit located at 1.15 m depth. Then, the height of cover above the top of the conduit was 1 m. It is important to highlight that the analyses were done considering soil stress in two different points: point A (at culvert crown) and point B (at the spring line). Figure 2 shows the typical section used in the performed simulations.

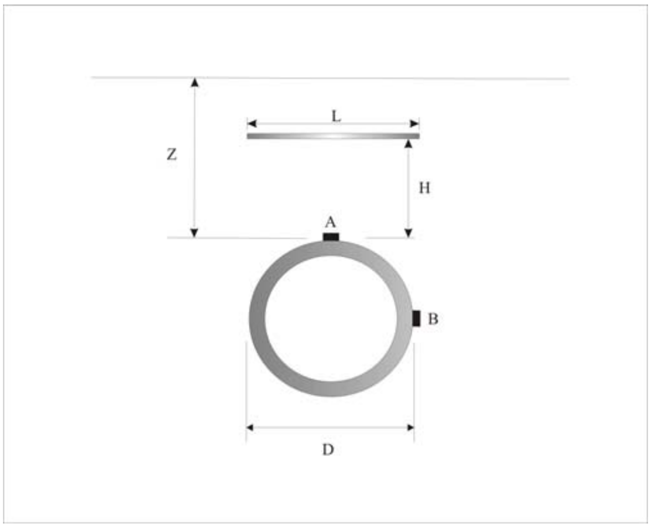

Figure 2. Typical section used in the simulations.

To verify the influence of the inclusion width in the induced trench method performance, simulations were carried out with a fixed distance between the geocomposite and the top of the conduit (H) in 75 mm and varying the inclusion width (L) from 75 mm to 450 mm.

To evaluate the inclusion position in the system behavior, simulations were performed fixing the geocomposite width (L) in 150 mm and varying the distance between the inclusion and the top of the conduit (H) from 47.5 mm to 300 mm.

Just for comparison, one more simulation was done without the presence of the inducing layer. The numerical simulation program can be seen in Table 3.

The simulation sequence was executed considering an overload of 30kN/m^2 to simulate a real situation with a conduct exposed to surface requirements. The Finite Element Method analyses were performed using the staged construction option.

Table 3. Numerical simulation program

Simulation	Position (mm)	Width (mm)
1	75	75
2		150
3		300
4		450
5	37.5	150
6	75	
7	150	
8	225	
9	300	
10	Without geocomposite	

RESULTS AND DISCUSSION

Figures 3 and 4 show the vertical stress distribution in a horizontal plane situated 10 mm over the top of the conduit, for a traditional conduit installation (without the compressible layer) and for different induced trench method configurations.

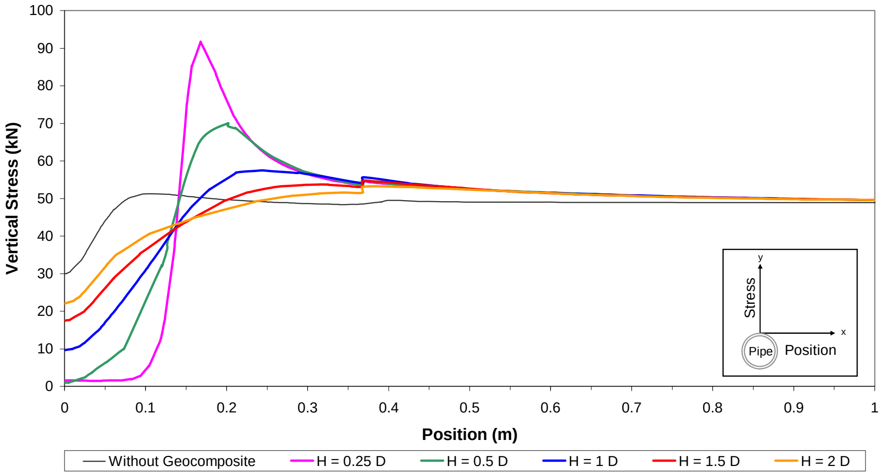

Figure 3. Comparison of results without the inducing layer and with the inducing layer at different heights (point A).

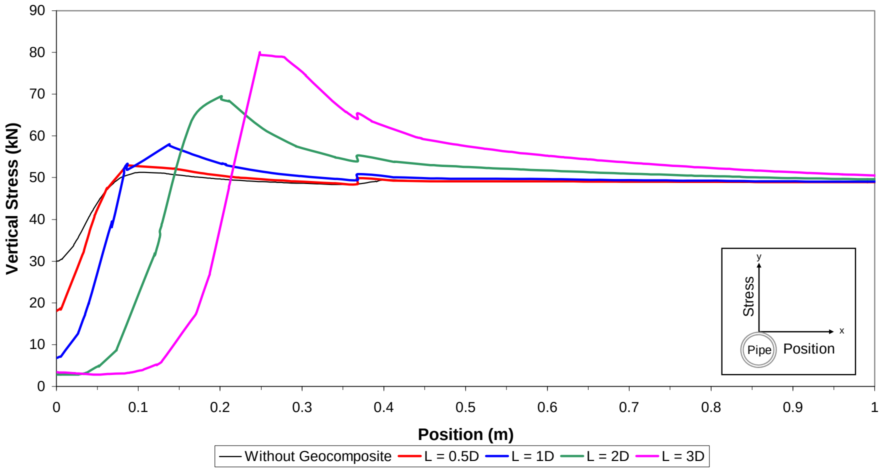

Figure 4. Comparison between results without the inducing layer and with the inducing layer with different inclusion widths (point A).

It is clearly noticeable that the use of a compressible layer induces a positive arching in the soil. It is also perceptible that its use, in the cases shown, may lead to stress reduction up to 92% over the top of the conduit. Moreover, it is also clear that the lack of the inducing layer also results in tension reduction due to the flexibility of the conduit. However, this reduction (about 30%) is lower than those achieved with the use of the geocomposite.

In order to evaluate the influence of the inclusion width in the system behaviour, numerical analyses were performed fixing the distance between the geocomposite and the culvert crown (H) in 75 mm and varying the geocomposite width (L). These results are shown in Figures 5 (point A) and 6 (point B). As seen in Figure 5, larger widths represent larger stress reduction, but only between L/D values from 0.5 to 2. Values of the relation (L/D) higher than 2 show a slight tendency to loss of performance. However, this behaviour is not observed in Figure 6. It can be noticed that in this figure, the bigger the L/D relation is, the higher the system performance is.

Simultaneously analyzing the two sets of curves (figures 5 and 6), it is possible to affirm that an adequate value of the L/D relation to be used in pipe design should be situated between 1.5 and 2.5, since these values showed adequate stress reduction not only for the area above the top of the conduit (point A) but also for the area located in the spring line of the conduit (point B).

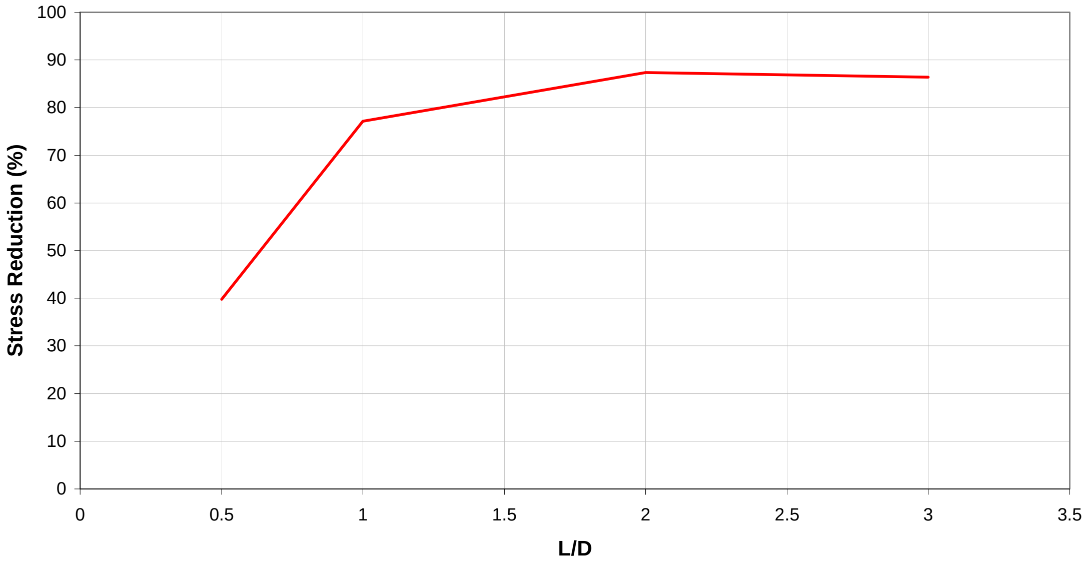

Figure 5. Influence of the inclusion width on the system performance (point A).

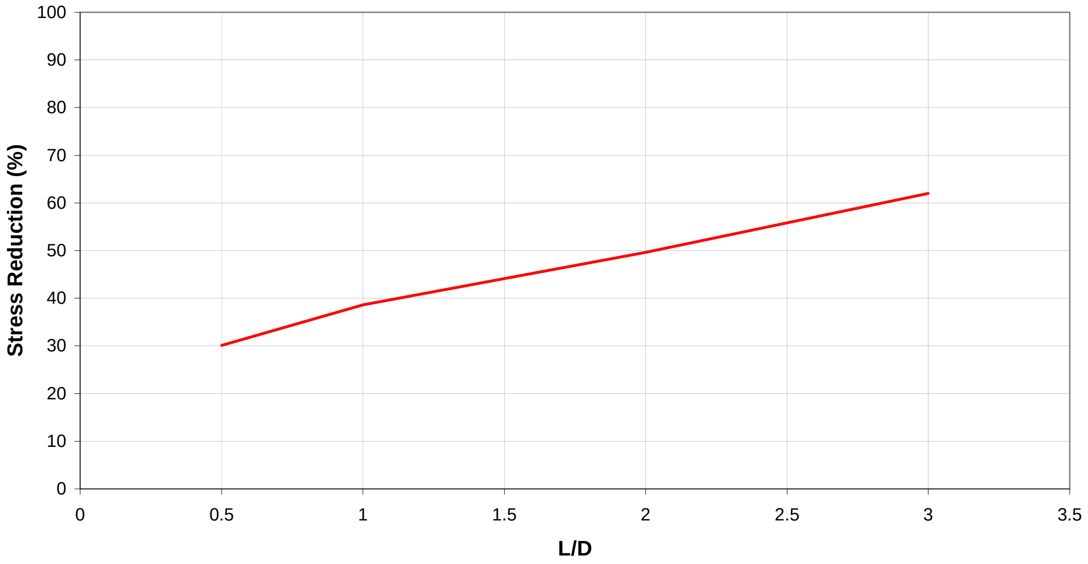

Figure 6. Influence of the inclusion width on the system performance (point B).

A second series of analyses were done to verify the influence of the compressible layer position on the system performance. These results are presented in Figures 7 (point A) and 8 (point B). A geocomposite layer with a 150 mm width was used in this simulation varying the H dimension. It can be noticed that in both points, the best system performance was obtained for inclusions found closest to the top of the conduit, without tendency of stabilizing the curves. This indicates that there is no “best” value for the H/D relation, so the compressible layer must be located as near as possible to the top of the buried structure. However, appropriate values of H/D relation must be situated between 0.25 and 0.5.

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 pipes constructed under highways, and equal to 1/4th of the conduit diameter for pipes constructed under railways, being that, for both cases, a minimum 30 cm height of cover must be used.

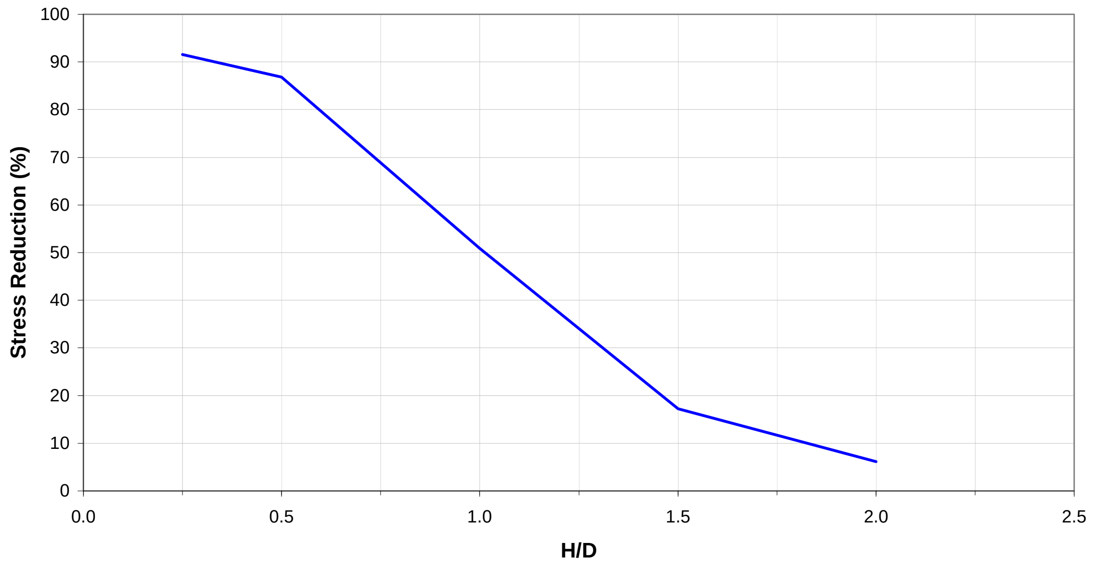

Figure 7. Influence of the inclusion position on the system performance (point A).

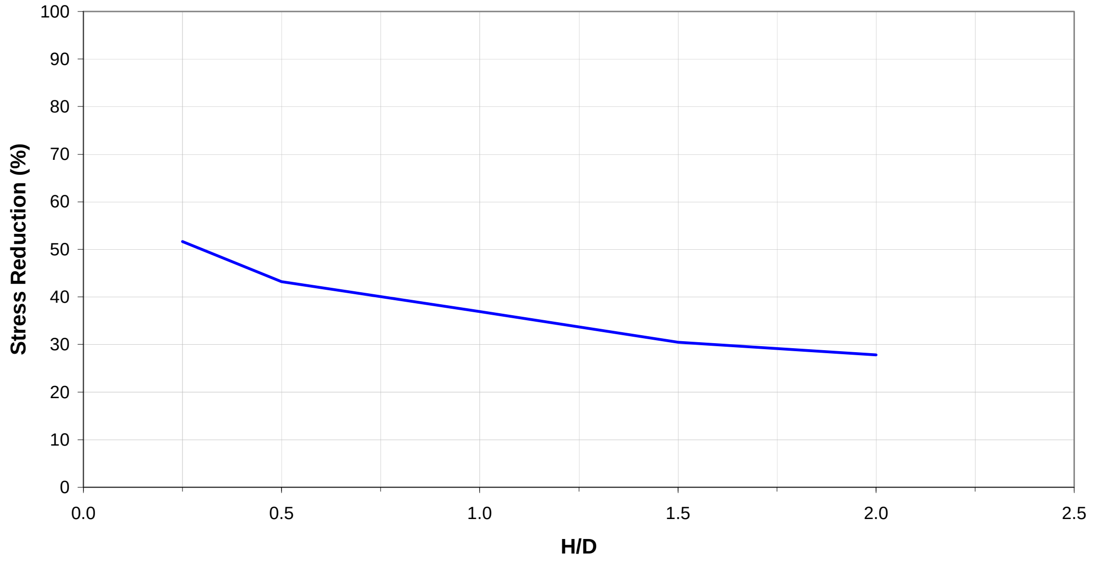

Figure 8. Influence of the inclusion position on the system performance (point B).

CONCLUSIONS

The main conclusions from the finite element analysis of 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 a compressible layer in the induced trench method, providing stress reduction up to 92% over the top of the conduit.
- Satisfactory stress reductions were observed in point A (culvert crown) and point B (spring line of the pipe);
- The analyses showed that the inclusion must be located as near as possible to the top of the conduit. For pipeline design, appropriate values of H/D relation must be placed between 0.25 and 0.5;
- The use of the L/D relation between 1.5 and 2.5 provide stress reduction from 77% to 87% at point A and stress reduction from 45% to 55% at point B.

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