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A Novel Construction Method for Buried Pipes using Geosynthetics

B. S. Bueno[1], P. M. F. Viana [2] and J. G. Zornberg [3]

[1]Department of Geotechnical Engineering, School of Engineering at Sao Carlos, University of Sao Paulo, Av. Trabalhador SaoCarlense 400, Centro, 13.566-590 – Sao Carlos - SP- Brazil, PH 55-16-3373-9505; FAX 55-16-3373-9509; email: bsbueno@sc.usp.br
[2]University of Goias, Brazil, paulo.viana@ueg.br
[3]The University of Texas at Austin, Civil Engineering Department, 1 University Station, C1792 Austin, TX 78712-0280, email: zornberg@mail.utexas.edu

Abstract

This paper describes preliminary results of a novel construction method developed to reduce the vertical stresses on buried pipes. The method, named Geovala (*vala* means trench in Portuguese), involves the use of geosynthetic reinforcement layers placed within the soil mass, above the crown of the buried pipe. The main objective is to redistribute the vertical stresses acting on top of the pipe to the lateral surrounding soil. The construction methodology involves not only trench installation but also of construction of protecting structures. An experimental testing program was conducted to evaluate this system. The results obtained from tests conducted in both small- and large-scale facilities show that vertical stresses acting on top of the pipe can be significantly reduced by using geosynthetic reinforcement. The variables governing the design include the layout of the geosynthetics (length and position of the reinforcement in relation to the top of the structure), the soil type, the soil density, and the stiffness of the geosynthetic inclusion. It is expected that implementation of this construction technique will allow the use of more flexible pipes as well as their placement at more shallow depths. This can lead to significant cost savings in projects involving pipes in civil and environmental applications.

Introduction

Buried pipes are part of modern life as they transport basic needs of the population (water, gas, electricity). They are used also in sewer systems and other industrial liquid disposal applications.

Since the second half of the last century, a better understanding of soil-pipe interaction has led to the use of more flexible pipes. However, flexible pipes require a more rigorous design and a more rigorous quality control during installation. Flexible pipe are less expensive and lighter than rigid pipes and perform very well if installed in a well compacted medium.

This change in design paradigm has led to new developments in materials, manufacturing processes, joining, etc.. Such advances were unfortunately not followed by similar developments in suitable parameters for pipe installation.

Considering current practice and the variety of pipe products commercially available, cost can only be reduced if more flexible pipes or more shallow installation are used. Consequently, further cost reduction requires new trends in installation.

This paper describes preliminary results of a novel construction method developed to reduce the vertical stresses on buried pipes. The method, named Geovala (*vala* means trench in Portuguese), involves the use of geosynthetic reinforcement layers placed within the soil mass and above the crown of the buried pipe. The main objective is to redistribute the vertical stresses acting on top of the pipe to the lateral surrounding soil, therefore allowing the use of very flexible pipes or shallower installation.

The construction methodology involves not only trench installation but also projecting pipes. An experimental testing program was conducted to evaluate the effect of geosynthetic reinforcements on vertical stresses acting on top of the pipe. Results are evaluated from tests conducted in both small- and large-scale facilities.

The Construction method

Buried pipes can be classified according to the manner of their installation as follows: (i) in trench, and (ii) projecting pipes. In the first case, pipes are installed in narrow trenches excavated in the natural ground which are filled with compacted soil after pipe installation. On the second case, projecting pipes are installed under compacted embankments and can be classified as negative and positive projecting pipes. A positive projecting pipe is installed such that its top projects over the natural ground surface, while negative projecting pipes are placed within shallow trenches, excavated in the natural ground, which is then covered by a compacted embankment. The crown of negative projecting pipes is always below the ground level.

Figure 1 shows trench installation using the Geovala method. As can be seen, the trench installation requires the over-excavation of the trench that is wider than the pipe trench. The pipe rests at the bottom of the narrow trench, which is filled with compacted soil. Geosynthetic reinforcement is placed on the bottom of the over-excavated trench which is then backfilled with compacted soil. The main difference with a conventional trench installation is the over-excavated trench used for placement of the reinforcement.

The geosynthetic should be placed without slack or folds. Due to the vertical deformation that occurs once vertical loads are applied the geosynthetic behaves as a tensioned membrane fixed at the edges and loaded in its central portion. Two situations may then occur:

a) The geosynthetic deforms vertically but does not touch the top of the pipe. In this case the narrow trench can or cannot be filled with soil. In this case, a perfect void is created. If the geosynthetic is well anchored at the sides of the over-excavated trench, the vertical load is entirely supported by membrane action. No vertical load reaches the crown of the pipe. This is an extreme case that can only be considered in practice if the walls of the trench are rigid and do not subside or collapse due to the applied loads;

b) The trench is filled with loose soil. In this case, although the reinforcement still deforms and sustains part of the vertical load, as it rests on the top of the loose backfill soil it transmits part of the vertical load to the top of the pipe. To free the pipe from vertical load, a small gap below the geosynthetic has to be left empty (or filled with a highly compressible material) to allow its free deformation. As for the case described above, since the reinforcement does not touch the trench backfill, no vertical load is transmitted to the pipe.

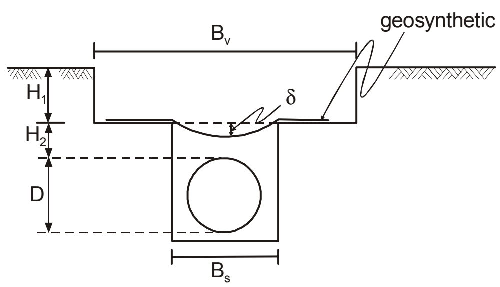

Figure 1. Trench installation according to Geovala method.

Figure 2 shows projecting pipe installations, i.e., negative projecting pipe and positive projecting pipe. Installation of a negative projecting pipe is similar to the trench approach. The main difference is that the geosynthetic rest on the soil surface in the negative projecting condition and is covered by an embankment. Consequently this case can be thought of as an over-excavated trench of infinite width.

The positive projecting installation according to the Geovala method requires the use of a channel section which is installed over the top of the pipe during the building of the embankment. This auxiliary piece has been named geocalha (calha means channel section). This channel section can be made of metal, plastic or wood. With the geocalha concept one is creating a kind of shallow trench that will remain empty in order to allow for free geosynthetic deformation (i.e., as the geosynthetic deforms it does not touch the bottom of the geocalha). The same effect of a geocalha can be obtained by simply excavating in the embankment, over the top of the pipe, a very shallow trench which is then covered by the geosynthetic. Under vertical stresses the geosynthetic deforms inducing stress transference from the top of the geocalha to the lateral surrounding soil. This is a modern approach to the classical induced trench used by Marston and his followers. Obviously, the classical induced trench method can be obtained using a compressible geosynthetic cushion, such as compressible geocomposites or EPS. The use of geosynthetic in any case is an improvement of the classic induced trench method.

In any type of installation (wide trenches, projecting pipes, situations where trench walls are not stable, etc.) this modern induced trench method using the geocalha can be used.

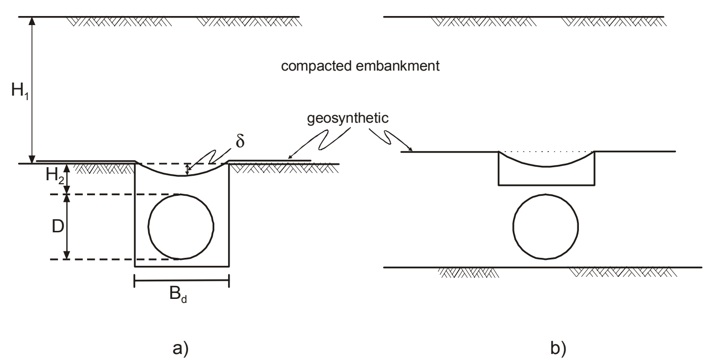

Figure 2. Projecting pipe installation using the Geovala method: a) negative projecting pipe; b) positive projecting pipe.

Vertical Stress Acting on Top of the Pipe

In a general case, the vertical stresses, σ_V, are induced by the self-weight of the soil layer above the pipe and external loadings. The vertical stress is resisted by three components as follows:

- A portion of the vertical stress is transferred by positive arching from the internal soil prism (soil block that acts on pipe span) to the surrounding soil, σ_A.

- A portion of the vertical stress is transferred by the geosynthetic membrane action, σ_M.

- A portion of the vertical stress is transferred to the top of the pipe, σ_C.

Therefore,

$$\sigma_V = \sigma_A + \sigma_M + \sigma_C \qquad [1]$$

The value of σ_A can be calculated using Marston's theory of vertical load on buried pipes (Bulson, 1985) or other appropriate formulation available in the literature. The value of σ_B can be calculated using Giroud´s theory of geosynthetic surpassing voids (Giroud et al., 1990) for the case where the geosynthetic touches the bottom of the void. For the cases where the deformed geosynthetic does not touch the soil above the pipe $\sigma_B = 0$.

Since the value of σ_V can easily be estimated, σ_C can be computed as follows:

$$\sigma_C = \sigma_V - (\sigma_A + \sigma_B) \qquad [2]$$

Experimental Work

An experimental program was carried out at the University of Sao Paulo - Sao Carlos using a small test tank (1500 mm x 700 mm x 500 mm). In addition, tests are being performed using large scale test facility (1820mm long x 1420 mm wide x 1800 mm high). Both structures are rigid.

A rectangular trapdoor located at the center of the small test tank is used to induce vertical movement representative of those occurring in a buried structure. A total pressure cell is fixed to the center of the trapdoor to register the acting vertical stress.

The opening resulting when the trapdoor is lowered, at the center of the test tank, simulates a void or a trench with rigid walls. If a geosynthetic is used to bridge the void it is possible to register its deformed shape.

A uniform surcharge is applied on the soil surface using an air bag to simulate additional stresses representative of high embankments or live loads.

Two soils are being used in this experimental program: a sand (soil A) and a fine sand with 15% of clay (soil B). Two nonwoven geotextiles were used (50 and 130 g/m^2) and the number of reinforced layers varied from 1 to 3. Table 1 summarizes the main characteristics of the testing program. Figure 3 shows the vertical displacement registered at the center of the trapdoor during a series of tests conducted using a geosynthetic bridging the void. The vertical dashed line in Figure 3 separates the displacements that occurred during construction (zone 1) from those that occurred during surcharging (zone 2). The vertical displacements of the geosynthetic that occurred during placement of soil layer are those for applied loads below 4kPa. As can be seen in this figure, most vertical displacements occurred during construction.

The large scale test facility can be filled with compacted soil to allow trench installation to be carried out using Geovala approach. It can be used also to install positive and negative projecting pipes. With this test box, compaction loads can be registered at any time during pipe installation.

Table 1. Experimental Design

Test	Soil	Reinforcement	
		g/m^2	Number of Layers
11	A	130	1
12	A	130	2
13	A	130	3
21	B	50	1
22	B	50	2
23	B	50	3

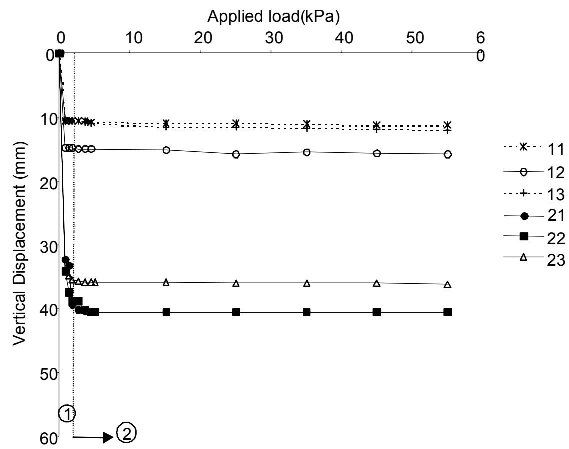

Figure 3. Vertical displacement of geosynthetic bridging the trapdoor opening during construction and surcharging.

Figure 4 shows a set of data obtained from trench tests carried out using this large scale test box. The narrow trench was left empty. The vertical stresses shown in this figure were monitored over the geosynthetic (200mm above the top of the pipe) using a total pressure cell. For comparison purposes the results from a conventional trench installation are also shown in Figure 4. Soil B and three nonwoven geotextiles with initial rigidity, J_t, of 15, 27 and 57 kN/m were used. The pipe had a diameter of 400mm and the over-excavated trench was 600 mm wide (i.e., anchorage length of the geosynthetic was 100mm).

The results in Figure 4 show that the measured vertical stresses for a conventional shallow trench installation are similar to the applied stress. However, in all the tests conducted using the Geovala approach the registered vertical stress was smaller the applied stress. Also, measured stress increases with increasing geotextile stiffness.

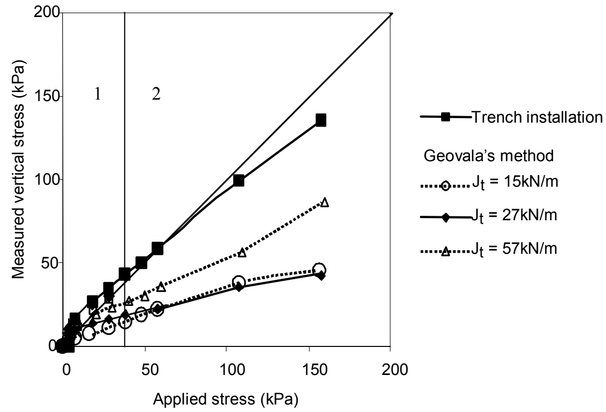

Figure 4- Vertical stress over the pipe during construction (1) and surcharging (2).

Final Remarks

A new installation method for buried pipes was developed. The preliminary test results show that the use of geosynthetics can reduce vertical stresses over buried pipes.

Large scale tests are in progress to better quantify the beneficial effects of geosynthetic reinforcements.

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