Uplift Capacity of Reinforced Buried Pipelines on Sand

Priscila Cardoso Santiago, Fernando Saboya Jr., Rodrigo Martins Reis,
Sérgio Tibana
Department of Civil Engineering - State University of Norte Fluminense
Darcy Ribeiro – UENF, Campos, Rio de Janeiro, Brazil

ABSTRACT

The use of buried pipelines in urban areas has experienced impressive growth during the last decades. This has happened mainly because the high demand for basic services has forced the expansion of the pipeline nets which transport gas, oil, communication and electrical cables amongst others. The main reasons for the use of buried pipelines for such services are the low installation costs, low environmental impact and protection of the facilities. However, the success design of buried pipelines is highly dependent on the good knowledge of the soil x pie interaction mechanism and also on the knowledge of the risks involved during their lifetime. This work has as the main aim to study the behavior of buried pipelines regarding their resistance against the uplift and, therefore, to come up with a proposal for a new anchoring system in order to avoiding these upwards movements, using geogrid reinforcement. Therefore, this paper has as the main aim to show results from a study carried out on reduced scale buried pipeline in geotechnical centrifuge, where a special and innovative anchor using geogrid, is proposed. The study was conducted using the UENF geotechnical centrifuge at 10G. Two different relative densities were considered for the sandy backfill (23 and 70%). Also, two different reinforcement widths attached to the pipelines were considered. The pipelines were tested at three different depths. Therefore, a total amount of 24 tests were carried out. For each test using reinforced pipeline an adjacent unreinforced pipeline was also pulled out in order to allow a direct comparison to each other. The results have shown a high efficiency of the proposed anchoring system due to the changing in the failure mechanism avoiding, thus, the soil grain flow around of the pipe. This is particularly significant for pipelines buried at shallow depth in loose soil

RESUMEN

El uso de tuberías enterradas en las zonas urbanas ha experimentado un crecimiento impresionante durante las últimas décadas. Esto ha ocurrido principalmente debido ala gran demanda de servicios básicos que ha obligado a la expansión de las redes de gasoductos de transporte, combustibles, cables eléctricos y de comunicación, entre otros.Las razones principales para el uso de tuberías enterradas son los bajos costos de instalación,el bajo impacto ambiental y protección de estos servicios. Sin embargo, El éxito del proyecto de tuberías enterradas depende en gran medida del dominio y conocimiento de los mecanismos de interacción del suelo y la tubería, también como, de los riesgos durante su vida útil. Este trabajo tiene como principal objetivo estudiar El comportamiento dela stuberías enterradas en lo que concerniente ala resistencia contra las fuerza de izamiento, para proponer un sistema de anclaje con refuerzo de geomalla con el finde evitar el levantamiento de las tuberías. Por lo tanto,este trabajo muestra los resultados Del estudio llevado a cabo em escala reducida em centrifugadora geotécnica de tuberías enterradas, donde fue utilizado un sistema innovador de anclaje mediante geomalla. El estúdio se realizo em la centrífuga geotécnica de la UENF a 10G. Fueron considerados dos densidades diferentes de arenas para El relleno (23y70%). Además fueron considerados dos anchos diferentes de refuerzo unido alas tuberías. Las tuberías fueron enterradas a diferentes profundidades. Por lo tanto, el número total de ensayos fueron de 24. Para cada ensayo de izamiento realizado con la tubería reforzada, también fue ejecutado otro con solamente la tubería, esto con el fin de permitir una comparación directa entre sí. Los resultados han mostrado una alta eficiencia del sistema de anclaje propuesto debido a los cambios en los mecanismos de ruptura, así como, del flujo de granos de arena al rededor de la tubería. Esto es particularmente significativo para las tuberías enterradas a poca profundidad en terrenos sueltos o poco compactados

1. INTRODUCTION

In the last decades several studies have been conducted to investigate the geotechnical and structural behavior of buried pipes. Geotechnical studies have been almost all concerned to type of soils, embedment, backfill compaction, buckling amongst others (Katona, 1988; Phares et al. 1998, Rogers, 1988, Rogers, 1987; Conrad et al. 1998).

Nowadays these studies are mostly directed to a better understanding of the failure mechanisms when these pipes are subject to upward movements (White et al., 2000, Cheuk et al, 2008).

Pipes transport a great variety of products with different characteristics, densities, pressures and temperature. Therefore, the pipe is submitted to efforts which depend on what product is being transported. However, most important pipelines in the world transport basically gas and oil.

These pipelines are generally buried for safety reasons which encompass mechanical and thermal protection. On the other hand, they are light in relation to the weight of the backfill and, thus, are prone to suffer upward movements due to uplift forces that come from temperature gradient or groundwater rising.

There are a group of problems related to the stability of pipelines when subject to uplift forces. For that reason it is interesting to study mechanisms to avoid upward movements by means anchoring system which takes advantage of the bakfill bulk weight.

Following this issue, a study was conducted in the Geotechnical Centrifuge Center at State University of Norte Fluminense, with the purpose of developing a quick and economical system to increase the uplift capacity of buried pipelines. This system uses a geogrid strategically attached to the bottom of the pipe to prevent soil flowing around it which has been identified as the main failure mechanism of the soil-pipe arrangement (Cheuk et al, 2008)

For this study, 32 tests were carried out in the centrifuge at a modified gravity equivalent to 10g, which means that the model was scaled down to the ratio of 1:10.

These instructions have been created using the technical paper template to illustrate the correct format for the preparation of papers. The template is also available in the Submission Details section of the conference website.

2. PHYSICAL MODELLING IN GEOTECHNICAL CENTRIFUGE

Physical modeling is understood as the simulation of an event under controlled conditions. If two physical processes are similar, it is plausible to predict the behavior of the one of them when the behavior of the other is known. Therefore, tests in reduced models under increased gravitational stresses are used to predict the behavior of the prototype with high degree of fidelity.

With respect to tests in reduced models, Langhaar (1951, apud Carneiro, 1993) mentions that results from dimensional analyses indicate that, if same soil used in both model and prototype, the variation of the model size of N scale factor do not cause any variation in stress, whereas displacement, force and torque need to be corrected by N factor.

Geotechnical Centrifuge is a physical modeling tool, available in geotechnical engineering that permits the study of real case using in mostly cases, the same soil as the prototype.

One of the most important aspects to be considered in a centrifuge test is the preservation of the similitude between model and prototype. This similitude must follow a proper law (Table 1).

Accelerated model inside the centrifuge is submitted to an inertial radial acceleration field, and as consequence the gravitational field is increased N times the earth gravity (Schofield, 1980 e Taylor, 1995).

2.1 UENF Geotechnical Centrifuge

UENF geotechnical centrifuge, presented in Figure 1, was designed and manufactured in 1995 by Wyle Laboratories Scientific Services and System Group, headquartered in El Segundo, California, United States. After several meetings and suggestions it was established that a dual basket centrifuge would be more convenient not only due to balance operation system but also to provide room for carrying two tests simultaneously

Table 1. Scale Ratio in Centrifuge Modelling (Schofield,1980).

Parameter	Scale Ratio (Model/Prototype)
Gravity	N
Length	1/N
Density	1
Mass	$1/N^3$
Stress	1
Strain	1
Force	$1/N^2$
Time (diffusion)	$1/N^2$
Time (relaxation)	1

The centrifuge was then designed with dual swing basket having dimensions that can accommodate payload sizes up to 0.9m(W) x 0.9m(L) x 1m (H). A maximum weight of 1 ton can be subjected to accelerations of up to 100g's.

The UENF centrifuge is powered by two DC motors connected to a vertical right angle gearbox which drives the main shaft to a coupling with a ration of 6.307:1. The gearbox is provided with a cooling system oil level and temperature switches.

The DC motor is powered by a DC Motor Drive that converts the 480V alternating voltage to the DC voltage required by the motor, which, in turns, is controlled by a solid state controlling center designed by Sabina Motors Inc.. The power train also incorporates regenerative braking, which is able to bring the centrifuge to a complete stop safely in case on emergency.

Data acquisition and testing control are done using two different systems: a Focal Slip-Ring which support electrical and hydraulic power and the wireless device developed by National Instruments for controlling step motors and actuators.

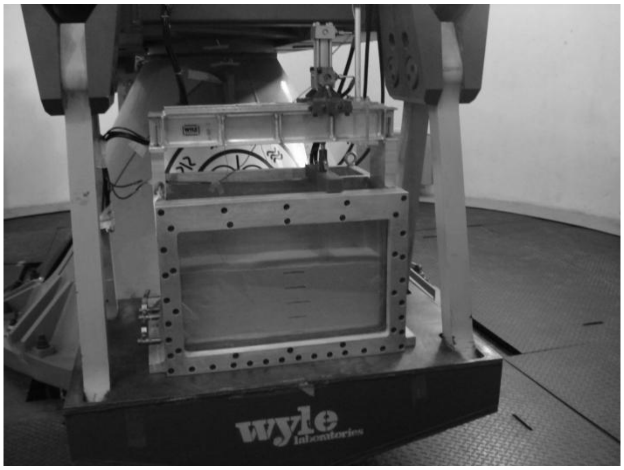

Figure1. Overview of the UENF Geotechnical Centrifuge basket

3. EXPERIMENTAL MODELLING

The pull-out tests were carried out in rigid cylinders made of alloy, embedded in five different burial depths in loose and dense sand.

In each container, it was possible to test two pipes with and without geogrid, simultaneously, as shown in Figure 2.

Two different widths of geogrid were considered, corresponding thus, to two and three times the pipe diameter

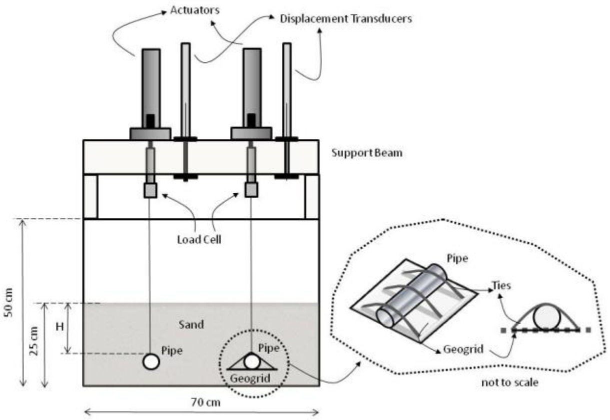

Figure 2. Set up of experimental model in centrifuge

3.1 Materials and Methods

A total of 32 tests were executed at 10 g, aiming to assess the uplift resistance of the proposed anchoring system.

The pipes were pulled out by means a hydraulic actuator at a constant rate of 0,5mm/sec. The pull-out force was measured by a load cell with maximum capacity of 490N. The vertical displacement was measured by displacement transducers.

The sand was tested for two different densities, 70% (dense) and 23 (loose), in order to account for the influence of soil compaction on this newly proposed anchoring system.

The models were constructed in a aerospace aluminum alloy box with dimensions of 70 x 25 x 50 cm. This box possess a transparent front side in order to allow visualization of the model during spinning.. Aluminum alloy rods were used to represent the pipe with 5cm in diameter and 20 cm in length, which corresponds to a scale of 1:10th of the prototype.

Industrial sand from IPT (Institute of Technology Research, São Paulo) was used to construct the soil model, and its main characteristics are depicted in Table 2.

The IPT sand was poured into the strong box by means a sand-rain device which, according to the drop height, can control the required density. This device also permits a good uniformity of the soil throughout the model.

As a whole, five different embedment, two different densities and two different geogrid widths were considered.

It is worth to mention that for each box tested, two pipes were pulled out, with and without geogrid. This was found necessary in order to allow a direct comparison between anchored and unanchored models in the same centrifuge test.

The procedures used for model preparation and pull-out tests were kept essentially the same for all models.

It is somewhat important to mention about geogrid physical scale modeling and how it was considered to work. As presented in Figure 1, the geogrid is coupled to pipe by means ties in three points. These ties, made by nylon, have the function to avoid geogrid to flexure. Thus, the geogrid will not be subject to any flexural strain because the ties will bring the geogrid upward as the pipe move in this direction. The whole system is believed to work in a monolithic way. The main role of the geogrid is to avoid soil to flow around the pipe as it moves upward mobilizing extra soil volume during uplift. In other words, it acts like a flat rigid plate. Therefore no concerns about scale modeling are in fact considered in this work, regarding the geogrid.

Table 2. Physical Properties of IPT Sand

Property	Value
Effective Diameter D10	0,277mm
Specific Weight	2,67 g/cm3
Minimum Void Ratio emin	0,725
Maximum Void Ratio emax	1,063
Shear Strength Angle (peak)	38^0
Critical State Angle	33^0
Dilation Angle (dense)	25^0
Dilation Angle	4.6^0

4. RESULTS

Several tests have been conducted to investigate, not only the uplift resistance of buried pipes, but also the failure mechanism associated to upward displacements (Trautmann et al. 1985; Ng. and Springman 1994; Bransby et al. 2002; White et al. 2001; Chin et al. 2006; Schupp et al. 2006)

Figure 3 shows the uplift resistance for all tests carried out in dense sand. It can clearly be noticed the positive influence of the anchor on the break-out load, even for embedment ratio higher than 3. Uplift resistance of unanchored pipes for embedment ratio about 1.5 is the same as for anchored pipes for embedment ratio of about 0.5, indicating a considerable gain when using anchors, even for geogrid width of 2D.

For dense sand, there is no evident gain when using geogrid width 3D, in comparison to results from narrower geogrid.

For loose sand this gain is much more evident, which represents a great advantage because good compaction of backfill is not a common practice in the field as can be seen in Figure 4.

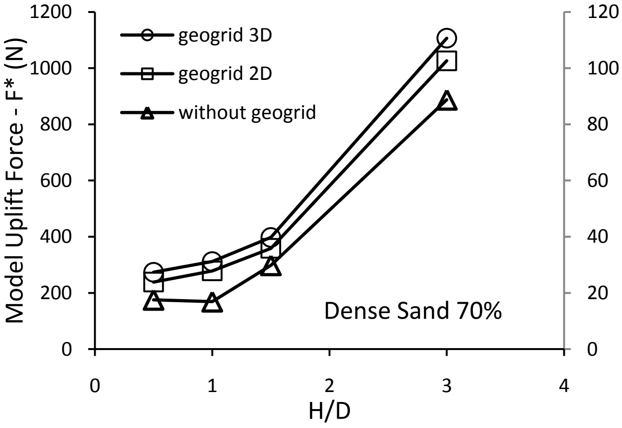

Figure 3. Uplift peak resistance (dense sand)

4.1 Normalized Uplift Resistance

The normalized uplift resistance Nγ can be defined as the following Equation:

$$\frac{F}{HD\gamma L} = N_\gamma \qquad [1]$$

Where F is the measured uplift peak force (discounted the testing and the pipe apparatus weight), D is the pipe diameter, L is the pipe length, H is the burial depth and g is the soil specific weight.

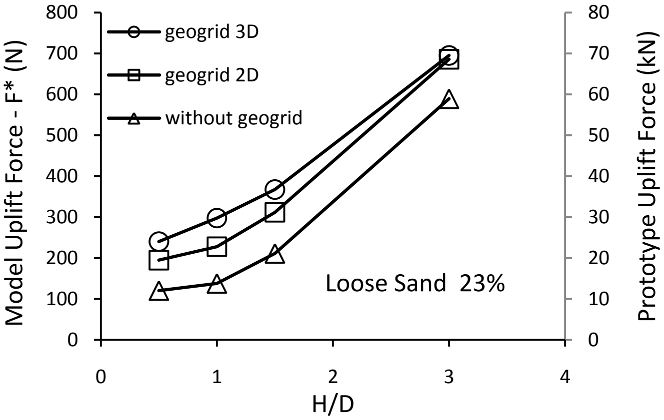

Figure 4. Uplift peak resistance (loose sand)

Considering the N factor for modified gravity as shown in Table1, Nγ obtained in centrifuge tests shown herein, has to be multiplied by 10 in order to define the prototype value of Nγ.

Figures 5 and 6 show the Nγ (Eq. 1) against embedment ratio for dense and loose sand respectively. It can be seen that the use of geogrid considerably improves the normalized resistance for both dense and loose soils. However, this enhancement is more stressed for loose sand at embedment ratio less than 1.5. For embedment ratio about three or higher there is no great difference in the normalized uplift resistance, even for geogrid width of 2D.

This can be attributed for the additional difficulty that soil mass faces to flow around the pipe during uplift.

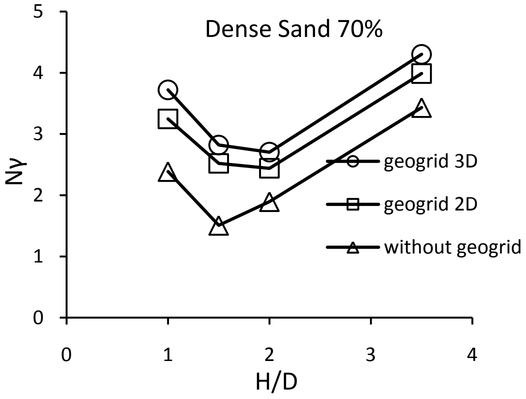

Figure 5. Normalized uplift resistance (dense sand)

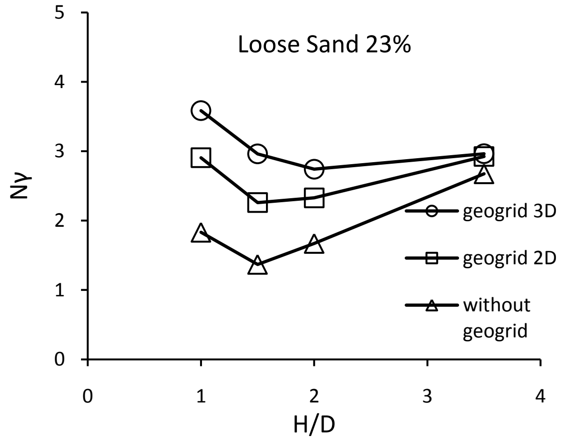

Figure 6. Normalized uplift resistance (loose sand)

It is also interesting to notice that Nγ increases even for unanchored pipe as it becomes shallower. This is understood as the dilation is favored by the low stress level at low embedment ratio

5. FINAL REMARKS

As a proof of its great importance, the behaviour of buried pipeline has been studied elsewhere. However more attention has been paid on the burial depth as the main variable to fight against upward movements. In order to allow the installation of shallow pipeline or else to keep its stability in case of upper soil erosion, it has been proposed a new anchor system using geogrid attached to the bottom of the pipe.

This system has been tested in a geotechnical centrifuge where soil density, geogrid width and embedment were variables to account for their influence on final results.

The tests showed that the system is highly efficient for shallow pipes and has as the main advantage to be set up before the pipe is launched into the pit by the side booms avoiding, thus, any human presence inside the trench.

ACKNOWLEDGEMENTS

The authors are grateful to FAPERJ (Rio de Janeiro Science Foundation) for financing this research. They are also thankful to Brazilian National Science Foundation (CAPES) for the MSc scholarship of the first author.

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