Bridging embedded pipelines: some options and recent tests

Pontage au-dessus de pipelines: quelques idées et tests récents

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ABSTRACT: Buried pipelines are located, often, just one to two meters below ground surface leading to significant problems if construction of new infrastructures require pipeline crossings because induced loads cause further soil stresses that can be critical for pipes not specifically designed to support traffic or equipment: in such cases it is necessary to minimize additional stresses to avoid significant pipe deformations and damages. A wide range of methods has been developed and applied over the years in order to reduce soil stresses around the pipe but sometimes the solutions are too sophisticated, expensive or time consuming; recently, innovative approaches look towards modern construction materials such as high-strength polyvinyl-alcohol geogrids. The paper presents the results of the instrumented field full scale test performed on a buried pipeline subjected to extra static & dynamic loads, demonstrating that proper installation of high tensile geogrid works as mitigation measure against additional soil stresses and pipe ovalization at the crossing point.

RÉSUMÉ: Les conduites enterrées sont souvent enfuîtes entre un et deux mètres sous la surface du sol. Cela cause des problèmes lors de la construction de nouvelles infrastructures pouvant circuler sur celles-ci. Ainsi, les nouvelles surcharges (principalement en raison de la nouvelle structure et du traffic provoquent des actions supplémentaires qui sont directement transmises par le sol aux conduites. Il est alors nécessaire de réduire l'effet de ces contraintes supplémentaires transmis par le sol pour éviter l'ovalisation et l'endommagement des tubes. Au fil des années, plusieurs solutions ont été développées, mais laplus part de ces méthodes sont artificielles, chères ou trop longues à réaliser. Des approches innovatrices sont orientées vers des matériaux de construction modernes, comme par exemple les géogrilles à haute résistance. Le document présente les résultats de certains essais instrumentés in situ, effectués, à l'échelle de 1: 1, sur une conduite enterrée et soumise à des charges statiques et dynamiques. L'installation correcte de la géogrille permet de réduire de manière efficace les contraintes transmise par le sol aux tubes.

KEYWORDS: Buried pipeline, pipeline crossing, surface load, induced soil stress, high tensile geogrid, pipe ovalization, pipe deflection

1 INTRODUCTION

Existing buried pipelines usually are not specifically designed for extra loads imposed by new crossings, therefore their structural and serviceability calculations are required when a new infrastructure is built on top of them (for example a new road generating traffic loads that induce extra stresses on the pipe).

If the pipe is not able to support the additional loads, it is necessary to provide mitigation measures to reduce the soil stresses that reach the pipe in order to avoid its ovalization.

1 .1 *Scope of work and engineering philosophy*

Generally, the traditional adopted methods to bridge the existing pipeline are, among the others (Figure 1): jump overs, increasing pipeline depth at crossing point (a); concrete or steel slabs, reducing soil peak pressure on pipe (b); culverts, protecting the pipeline from any additional external loads (c).

The target is to develop an easy to install, low-cost and light bridging method to reduce the additional soil stresses on the buried pipeline by placing a geogrid between the pipe and the ground in order to transfer the extra load into internal action of the geogrid (Figure 2). Geogrids are geosynthetic materials commonly used to reinforce the soils below roads or structures and to sustain the external loads; they are strong in tension and they can work as sheets of parallel cables. Recently, they have been used in standard flexible pavement sections to reinforce the base course to support vehicular traffic (Turan and El Naggar, 2013).

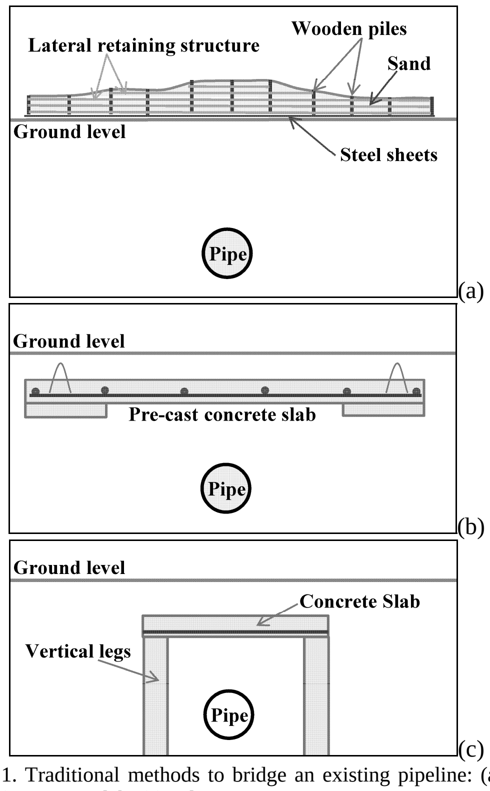


Figure 1. Traditional methods to bridge an existing pipeline: (a) jump over; (b) concrete slab; (c) culvert.

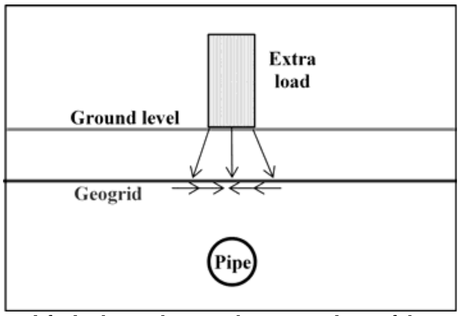


Figure 2. Simplified scheme showing the proposed use of the geogrid.

The overall behavior of the soil-geogrid system can be investigated by considering the transmission of the external loads from the soil to the geogrid which is allowed to sag in order to transfer the vertical soil stresses into internal actions. Starting from general cable theorem and equilibrium considerations for a geogrid in a pull-out failure mode, the operating tensile force and the minimum anchorage length of the geogrid can be derived, optimizing the more influencing design parameters in order to select the best layout configuration and set the geogrid span inside an acceptable and practical range of approximately 10 – 15 m by means of sensitivity analyses and finite element model analyses (Napolitano et al., 2016). The adhesion of the soil-geogrid system is defined by the bonding coefficient which depends, basically, on the interface between the soil and the geogrid and on the geometrical characteristics of the geogrid itself: many expressions are available in literature (Jewell, 1984, 1991, 1996) and for practical applications they are also provided by Vendors (e.g. Huesker Synthetic GmbH, 2005).

2 FULL FIELD SCALE TEST

2 .1 *Soil characterization*

To characterize stratigraphy and mechanical properties of the in-situ soils (useful for geogrid sensitivity analysis and layout assessment), field and laboratory test have been conducted:
- drilled boreholes, conducted for the field test area prior to the construction of test section;
- field determination of soil unit weight;
- standard and modified proctor compaction test;
- granulometric analysis;
- Atterberg limits test.

The soil stratigraphy results in a top layer of disturbed soil and a layer of sandy gravel interbedded by clayey-silt/clay; the soil mechanical properties were determined on the basis of previous experiences for the same area of study.

Stratigraphic and mechanical properties of the in-situ soils are summarized in Table 1.

Table 1. Stratigraphy and geotechnical properties of the soil

h (m)	Soil type	γ (kN/m^3)	c (kPa)	ϕ (°)	E (MPa)
0.0-1.0	Distur-bed soil	16.0	0.0	16	1
1.0-3.6	Sandy gravel	17.0	0.0	26	20

2 .2 *Configurations, instrumentation and loading conditions*

The full scale test was carried out on ND 12” steel pipe, 6 m long, 10 mm thick. The trench is 1.65 m deep and the top of pipe is located at 1.1 m below ground level; the pipe has been installed according to IPLOCA (Onshore Pipelines, the Road to Success, 2nd Edition 2011) technical standards for construction.

Selected geogrid is Huesker Fortrac R400/30-30 MPT, whose Ultimate Tensile Strength (UTS) amounts to 400 kN/m and the short-term tensile stiffness is approximately 8000 kN/m (Figure 3) Mesh size of 30x30 mm has been select to achieve a high coefficient of interaction with the surrounding soil.

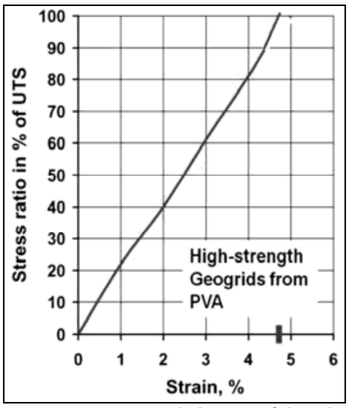


Figure 3. Short-term stress/strain behavior of the adopted geogrid.

Two main tests were carried out: a “control case” has been performed without the geogrid to record the set of measures; a “geogrid configuration case” has been performed using the geogrid (Figure 4). Geogrid dimensions are 12 m x 6 m; a free space (void) was left below the geogrid just above the pipe axis. Its depth was about 0.2 m and its width was about 0.60 m (two times the pipe diameter) in order to allow sagging (deflection) of the geogrid under future loading of the system; a geotextile is used on the top of the geogrid to avoid soil particle migration through the grid filling the void and obstructing the free space area; geogrid anchoring was provided by embedding the geogrid to the left and to the right as shown in Figure 4 in a simplified way.

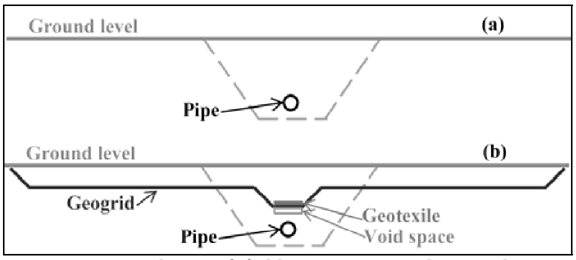
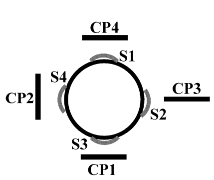


Figure 4. Layout scheme of field test: (a) control case; (b) geogrid configuration case.

The instrumentation consists of four pressure cells (CP1 – CP4) to measure vertical and horizontal normal soil stresses around the pipe and four strain gauges (S1 – S4) to measure the ovalization of the pipe (Figure 5). The geogrid has been equipped with fiber optical cables for strain measurements but unfortunately they failed; therefore strain data are not available. Markers were placed at the ends of geogrid anchoring lengths over the soil surface to register their possible movement (pulling out of geogrid).



CP1	15 cm below pipe; vertical soil stress
CP2	11 cm lateral pipe; horiz. soil stress
CP3	11 cm lateral pipe; vertical soil stress
CP4	10 cm above pipe; vertical soil stress

Figure 5. Layout of soil-pipe-geogrid strumentation system.

Three loading conditions have been carried out:
- no extra load, i.e. only the soil above the pipe;

- static extra load condition, by means of six precast concrete blocks, 1 m^3 and 25 kN each block, placed in correspondence of the middle section of the pipe and generating an average pressure of 75 kPa, Figure 6 (a);
- dynamic extra load condition, by means of an excavator (200 kN) moving orthogonally and parallel to pipe axis, Figure 6 (b).

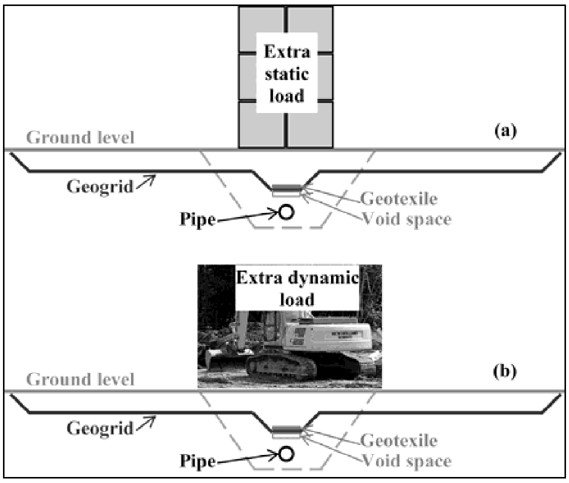


Figure 6. Scheme of loading tests: (a) extra static load condition; (b) extra dynamic load condition.

2 .3 *Row values*

Figure 7 shows the soil stress time history measured by CPs during the field test both for control case and geogrid case (no extra load, extra static load and extra dynamic load). Figure 8 shows the row values (in terms of micro epsilon, $\mu\varepsilon$) recorded by the four strain gauges placed at the pipe.

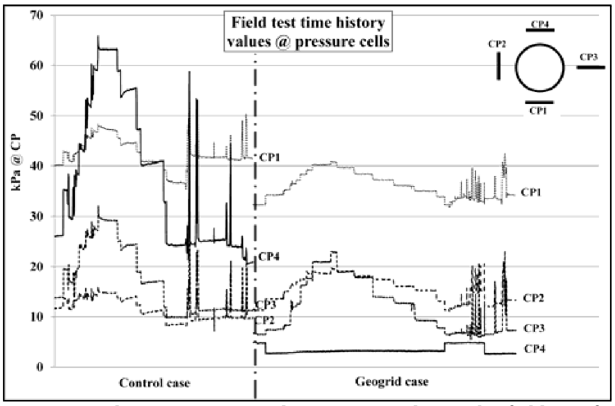


Figure 7. Soil stresses registered at CP1-CP4 during the field test for both configurations.

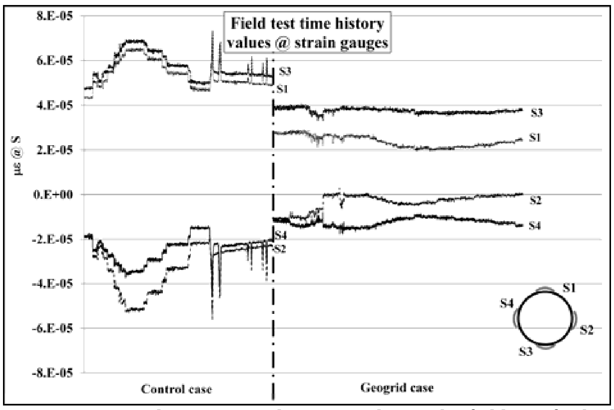


Figure 8. Row values registered at S1-S4 during the field test for both configurations.

No movement of the markers at the ends of the geogrid was observed, i.e. no pullout occurred (sufficient anchorage length).

3 ELABORATION OF RESULTS AND DISCUSSION

3 .1 *Soil stresses around the pipe*

Figure 9, Figure 10 and Figure 11 show, more in detail, the measured stresses for the three different loading conditions of the two configurations. Highlighted points are used to compare the results: the values corresponding to "no extra load condition" and "static extra load condition" are the average values when all the six blocks are placed in, while the values corresponding to "dynamic extra load condition" are the maxima registered during the passage of the excavator.

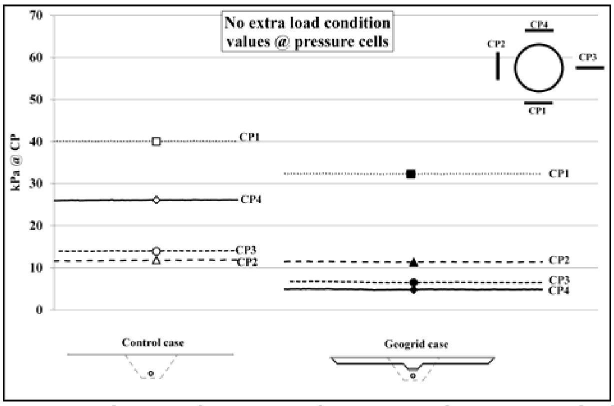


Figure 9. Soil stress values registered at CP1-CP4 during no extra load condition.

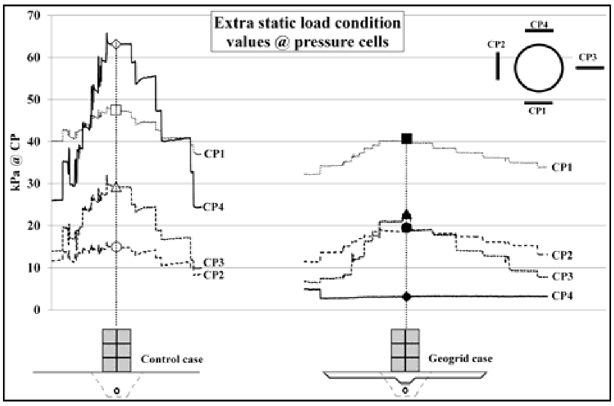


Figure 10. Soil stress values registered at CP1-CP4 during extra static load condition.

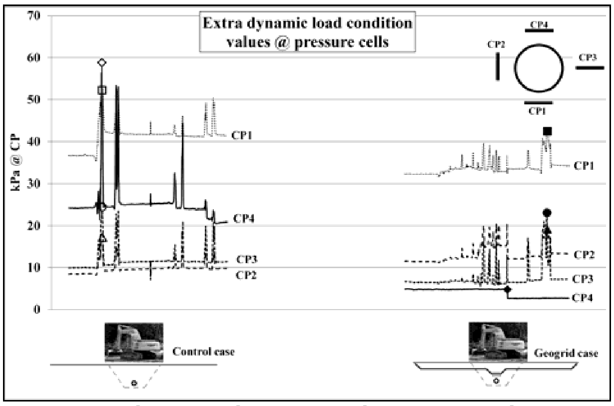


Figure 11. Soil stress values registered at CP1-CP4 during extra dynamic loading condition.

Selected points in previous graphs are summarized in Figure 12 that compares the soil stresses (kPa) measured around the pipe for the two tests. It can be observed that the use of the geogrid:

- strongly reduces the vertical stress on the top of the pipe measured by CP4 (50% to 120% reduction in vertical stress);
- reduces up to 20% the vertical stress at the bottom (CP1) and laterally of the pipe (CP3);
- slightly increases the horizontal stress at the mid height of the trench (CP2); this effect is very small (less than 8%) and it can be considered positive since it induces confining effect on the pipe.

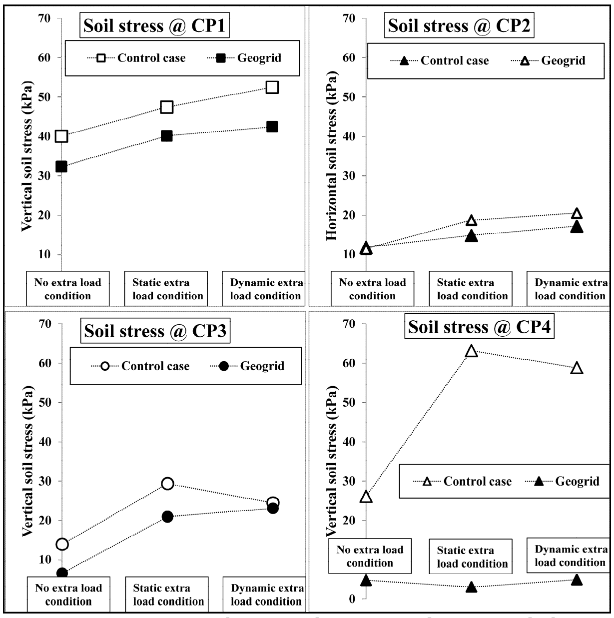


Figure 12. Comparison between the stress values around the pipe measured by CP1-CP4 during field tests.

3 .2 *Pipe ovalization (deformation)*

Looking at Figure 8, it can be noticed that the use of geogrid regularizes the time history trend and cuts the peak values.

More in detail, the graphs of Figure 13 compare the maximum values measured by strain gauges placed at the top and the bottom of the pipe (S1 and S3, respectively) and laterally of the pipe (S2 and S4). It can be observed that the difference between "extra load conditions" (both static and dynamic) and "no extra load condition" is reduced with the use of the geogrid in respect to the case without geogrid, i.e. the effect of the geogrid is keeping the pipe in a nearby undisturbed condition. In other words, the global ovalization effect that exists around the pipe when only the soil is present (no extra load) is reduced with the use of geogrid, hence pipe ovalization (deformation) is globally reduced.

4 CONCLUSIONS

An easy to install, low-cost and light bridging method to protect existing buried pipelines against additional surface loads above them (e.g. when crossings are required) has been proposed, adopting a geogrid installation between the ground surface and the pipe order to transfer additional extra loads into internal action of the geogrid itself.

The selection of geogrid type and system layout (inclusive of the artificial void above the pipe) results from sensitivity and numerical analyses that are not reported in this paper.

Considering two system configurations (only buried pipe and buried pipe plus geogrid plus void), field full scale tests have been performed on 12" steel pipe, applying extra static and dynamic loads.

The results obtained show that high tensile low-strain (high tensile modulus) geogrid can be successfully used to reduce the overall stress induced on the buried pipelines by additional loads, avoiding pipe ovalization.

In order to facilitate construction practices and generalize the results, the solution shall be further investigated for large diameter pipelines and geogrid anchor length reduction.

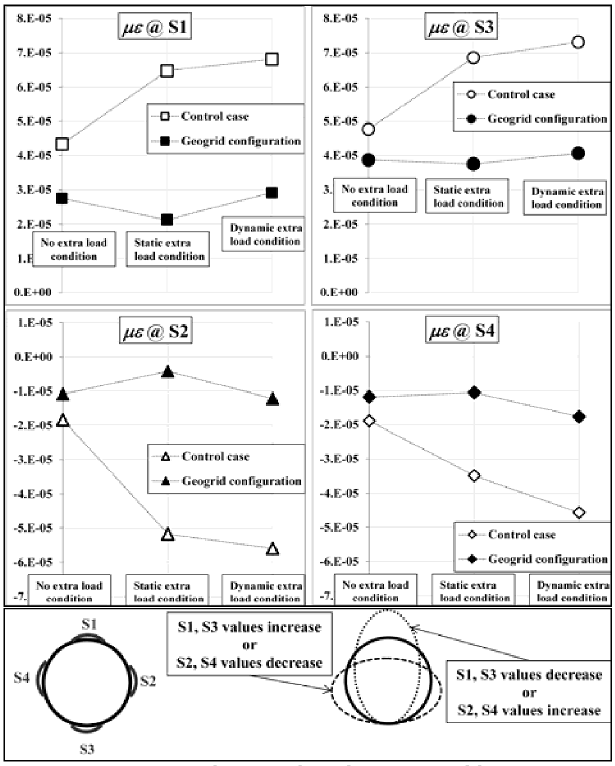


Figure 13. Comparison between the values measured by strain gauges S1-S4 placed on the pipe for control case and geogrid configuration case.

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