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ASPECTS AND CONCERNS RELATED TO OIL PIPELINES IN SOFT SOILS

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ABSTRACT

Oil and gas pipelines are linear structures that cross the most diverse geomorphological structures, including mountainous regions, with associated mass movements risks and coastal, lagoon or even river plains, with the possibility of the presence of unconsolidated soft soils, with the possibility of occurrence of settlements due to its own weight or various overloads.

Oil pipelines, when installed in areas with unconsolidated soft soils, represent the possibility of risks when there are constructions that result in transverse or longitudinal overloads, as these promote the increase of tensions to the soil, with the consequent consolidation of the unconsolidated layers. These deformations, when vertical, lead to displacement of the pipeline, where it loses support and receives overload from the soil over it. This loss of support can lead to excess stress in the pipeline structure. When there are longitudinal overloads far from the pipeline, lateral displacements of the pipeline may occur, also resulting in increased stress. Another situation, when there are longitudinal excavations to the pipeline in areas of soft soil, there may also be lack of definition and movement of the soil, generating displacements and increased tensions.

In this way, whenever there is interference with new roads, railways, that cross transversally or that are longitudinal to the pipeline, specific geotechnical investigations are necessary for the definition of the geological-geotechnical foundation models so that the adequate engineering solutions can be evaluated to avoid compaction and displacement of soft soils and ensure the integrity of the pipelines.

Brazilian experiences at road crossings with existing pipelines show the need to implement special protection and support devices. There have been historical cases of high deformations that have been observed in embankments on soft soils with existing pipelines.

The objective of the article is to present geotechnical risk situations in pipelines in soft soils, the expected behaviors and possible technical solutions to mitigate these risks, with the presentation of cases of protection works successfully executed in pipelines in southern Brazil.

Keywords: Pipelines, Soft Soil.

1. INTRODUCTION

The population growth of cities close to pipelines leads to an increase in demand for new highways, duplications, changes to existing routes and the adaptation of traffic capacity.

In many cases, these new interferences occur at points where existing pipelines, both transmission and distribution, were built and designed without forethought to absorb dynamic and static loads arising from traffic and landfills. In these cases, a geotechnical assessment of these interferences must be carried out, with a view to defining the need or not for additional protection over existing pipelines. The assessment is mainly geotechnical, as it involves foundations, paving, embankments and excavations. A possible failure in this assessment may increase the risk of damage to the pipelines, whether due to actions by third parties (touching the pipelines), mechanical impacts, localized deformations or vertical and horizontal displacements of the pipeline, which can generate increased stress.

In order to meet the demands of the growth of transport routes and at the same time guarantee the integrity of the pipelines, special protection works can be built, after a correct technical assessment of the new intersection. Throughout the article, geotechnical assessment methodologies for new interferences are described, including geotechnical investigations and data necessary for the assessment of soil-pipe interaction under the effects of overloads and embankments. Possible pipeline protection solutions are presented, as well as recommended mechanical and geotechnical instrumentation, also used to prevent third-party actions.

2. TRADITIONAL PIPELINE CONSTRUCTION AND ASSEMBLY

All materials and methods that have been used in the work must be stated clearly. Subtitles should be used when necessary.

The definition of the pipeline route follows several criteria, including serving consumer centers, the presence of preservation areas, parks, areas of population growth, etc. Along the route, the pipelines are installed over the most diverse types of geotechnical materials and physical stresses. Pipelines pass, for example, through slopes with colluvial deposits that may undergo seasonal displacement; they cross existing highways, whose embankments are generally consolidated; by regions with soft soils with low support capacity and also by rivers, reservoirs, etc. (Figure 1). During the design and construction stages, future duplications, new highways, etc., must be considered, however, long-term planning is not always available or does not offer minimum data for the necessary protections to be carried out even during implementation. of the duct range. The crossings are designed and built in accordance with the Petrobras N-2177 standard – Onshore Pipeline Crossing and Crossing Project. This standard presents, for each type of intersection or crossing, the minimum coverage, types of duct protection and signage. In cases not included in the implementation, the solutions presented in the aforementioned standard may not meet subsequent requests, arising from new interferences.

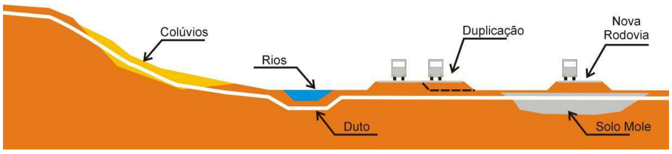

FIGURE 1: EXISTING CROSSINGS AND NEW INTERFERENCES.

3. SOIL-TO-PIPE INTERACTION EFFECTS

At points where the pipeline is subject to parallel soil movement, it is expected that, through the effect of friction between the soil and the pipeline, increased stresses will occur in the pipeline wall, which may be tensile or compressive. In the case shown in Figure 2, where the pipeline is located in an area with ground movement, due to a landslide, tensile stresses are expected in the upper part of the slope and compressive stresses in the lower part.

These tensions develop due to the soil-pipe friction effect. If the pipeline is subject to perpendicular displacements of the ground, as in a pipeline installed on a mid-slope, the increase in tension is mainly due to the effect of soil pressure, as shown in Figure 3. The effect of soil-pipe friction also occurs , but is less influential. At points where loading occurs vertically, such as in areas subject to settlement in the soil foundation (Figure 4), the pipeline may suffer localized or global deformation.

In the latter case, the duct works like a beam and its deformation necessarily adds stress to the duct wall, mainly at the "embedded" points and at the point with the greatest deformation (arrow). The weight of the soil in the trench on the pipeline can generate these deformations if the pipeline foundation does not have good support capacity.

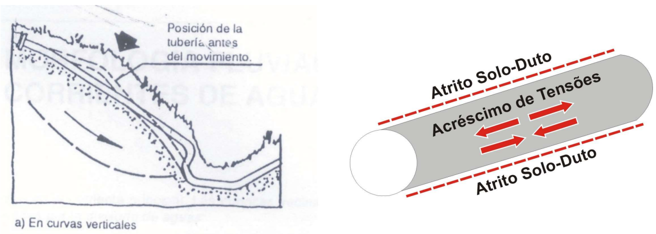

FIGURE 2: PARALELL SOIL MOVEMENTS IN PIPELINES.

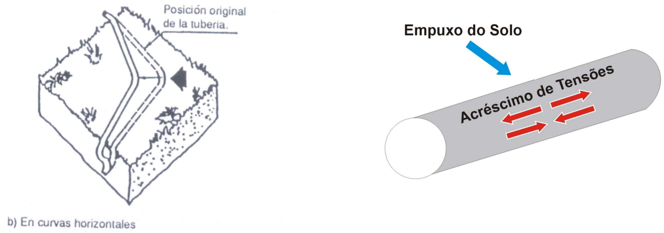

FIGURE 3: PERPENDICULAR SOIL MOVEMENTS IN PIPELINES.

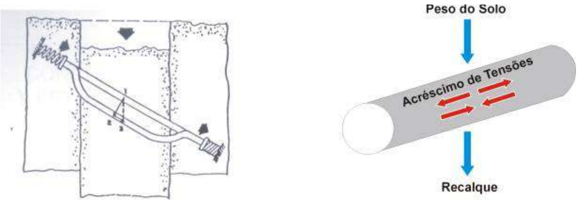

FIGURE 4: VERTICAL SOIL MOVEMENTS IN PIPELINES.

These effects can be observed in typical situations of new highways, duplications, etc. Figure 5 shows the schematic of a highway duplication, whose embankment extends beyond the limit of the jacket tube. If the foundation is competent, the pipe may suffer, depending on the magnitude of static and dynamic loads, local deformation (ovalization).

In a similar situation (Figure 6), but with the pipeline laid on soil with low support capacity (for example, soft soil, peat), it suffers from settlement (s: settlement) and global deformation of the pipeline, which can generate considerable increases of tensions.

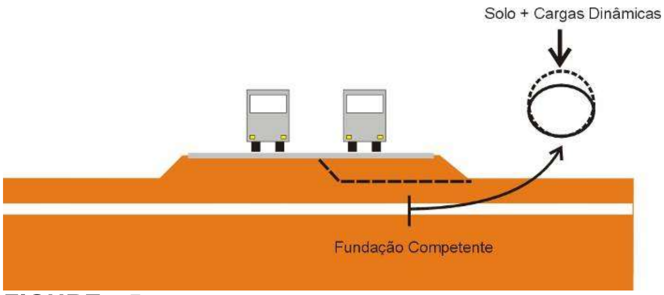

FIGURE 5: ROAD EMBAKMENT ADVANCING OVER UNPROTECTED PIPELINE ON COMPETENT FOUNDATION.

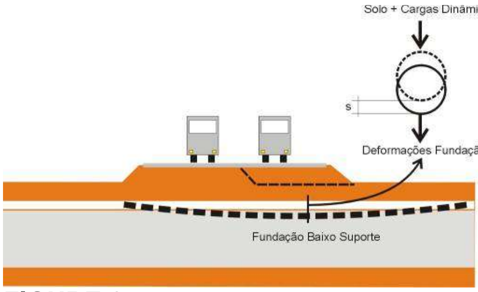

FIGURE 6: ROAD EMBAKMENT ADVANCING OVER UNPROTECTED PIPELINE ON LOW CAPACITY FOUNDATION.

If the pipe is installed parallel to the duplication, in low-resistance soil (Figure 7), the effect occurs laterally, with deformation being observed in this direction. This deformation can also generate significant increases in stress. Figure 8 shows a real case of a pipeline deformed by the action of an embankment built laterally to the strip.

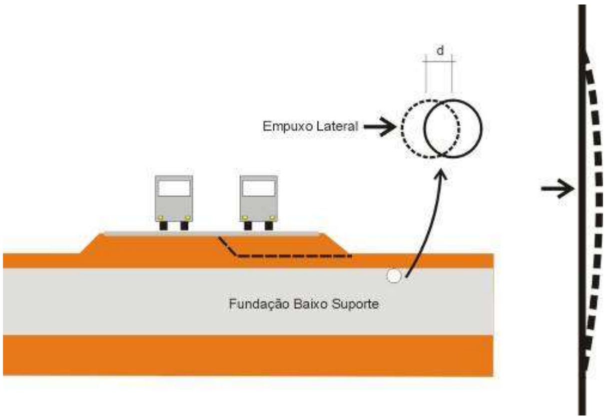

FIGURE 7: ROAD EMBAKMENT ADVANCING OVER UNPROTECTED PIPELINE ON LOW CAPACITY FOUNDATION – LATERALL DISPLACEMENT.

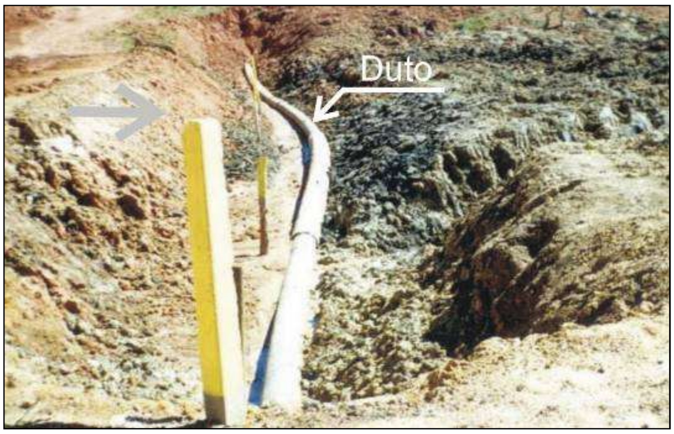

FIGURE 8: REAL CASE OF UNPROTECTED PIPELINE ON LOW CAPACITY FOUNDATION – LATERALL DISPLACEMENT.

In a more complex situation, simultaneous effects may occur. If the pipeline is installed in a colluvial deposit, which is not very resistant in nature (Figure 9), and a road embankment is built over it: deformations are expected below the body of the embankment and also stresses at the top and bottom of the slope by the displacement of the colluvial mass, which can be influenced by landfill overload.

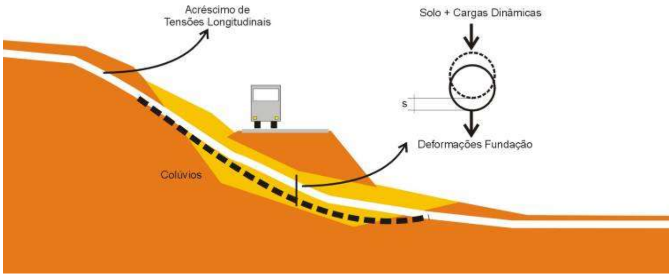

FIGURE 9: COMBINED EFFECTS IN PIPELINES IN COLLUVIUM DEPOSITS AND NEW EMBANKMENT ROADS.

4. NEW PIPELINE CROSSINGS DESIGN

4.1 Geotechnical Investigation and Parameters for Evaluation

Before defining any type of investigation, it is important to visit the site of future interference by technicians from the parties involved. The geotechnical engineer must carry out a general assessment of the area, in order to obtain preliminary information to define an investigation plan, which may be simpler or more complex, if the interference is in areas with suspected soft soil. It is recommended that percussion surveys be carried out using the SPT test – Standard Penetration Test, standardized by NBR 6484, at the point of future crossing, requiring at least three holes. Care with the actual position of the ducts is mandatory to avoid damage to the coating.

These probes must reach a material with good resistance, in general, with NSPT greater than 30 blows. The interpretation of the drilling holes will allow sketching the subsoil at the crossing, identifying the layers and their resistance, soil types and water table. If the subsoil has layers of low-resistance and high-compressibility material, it is recommended to take undisturbed soil samples (preserving the characteristics of the sample's place of origin), both above the pipe level and below.

These samples must be carefully taken to laboratories for testing. Samples can be obtained in blocks or using thin-walled Shelby-type samplers (special for collecting soft soils). Figure 10 shows an example of the location of SPT surveys and sample collection points.

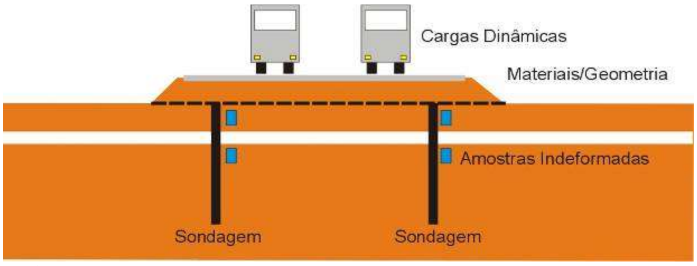

FIGURE 10: RECOMMENDED GEOTECHNICAL INVESTIGATION IN NEW EMBANKMENTS.

In general, soil characterization tests (granulometry, Atterberg limits), odometric tests and/or triaxial tests are carried out on the samples obtained to obtain soil deformability parameters. In addition to information about the subsoil in which the duct is installed, it is necessary to obtain the geometry of the interference. In the case of road landfills, for example, it is necessary to know the expected height above the pipeline, the types of materials to be used (clay, rockfill) and the traffic loads.

4.2 Geotechnical Parameters for Evaluation and Analysis

From the geotechnical information presented above, it is possible to determine the vertical stresses that act on the duct and at the level of the lower generator. The settlement that will occur at the lower level of the duct is also determined (Figure 11). This analysis must be complemented with the mechanical evaluation of the pipeline, in which the maximum allowable deformation level of the pipe must be evaluated, which must be compatible with the deformations calculated by the geotechnical evaluation.

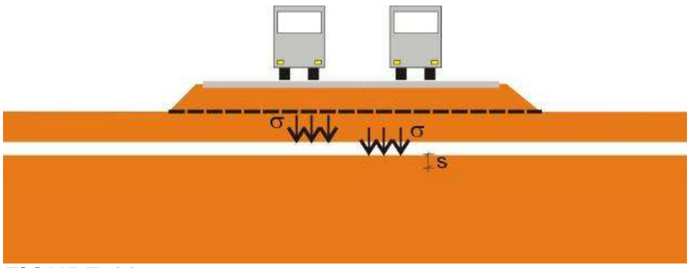

FIGURE 11: PARAMETERS OF INTEREST FOR EVALUATING NEW CROSSINGS.

4.3 Typical Situations of New Crossings and Planned Protections

Case 1: the foundation conditions are favorable and the loads arising from the interference are of small magnitude. This situation, theoretically, will not require any additional protection, and it is recommended, if possible, to implement the requirements of N-2177, both for signage and ground coverage. It is worth noting that all third-party work must be monitored by the pipeline operator's technicians (Figure 12).

Case 2: the foundation conditions are favorable and the loads arising from the interference are considerable or the construction method of interference can cause surface deformations (for example, use of a compactor roller). In this case, it is recommended to use some temporary or permanent load dissipation element, depending on each case. Wooden stowage, steel sheets or even woven geotextile blankets or geogrids can be used, which increase the support capacity and distribute loads (Figure 13).

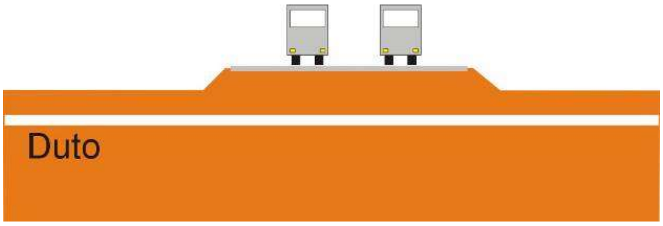

FIGURE 12: FAVORABLE SITUATION AT NEW INTERSECTIONS – CASE 1.

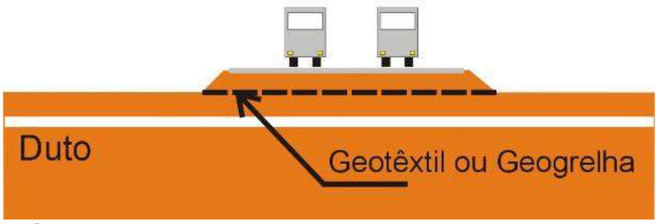

FIGURE 13: INTERMEDIATE SOILS CONDITIONS AT NEW INTERSECTIONS – CASE 2.

Case 3: the foundation conditions are not favorable (except soft soils) and the loads arising from the interference are considerable. In this case, a reinforced concrete slab can be constructed, appropriately dimensioned, in order to distribute the loads (Figure 14).

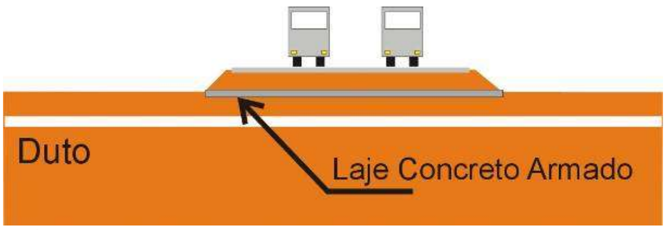

FIGURE 14: UNFAVORABLE SOILS CONDITIONS AT NEW INTERSECTIONS – CASE 3.

Case 4: foundation conditions are not favorable and soft soils occur; the charges arising from interference are considerable. In this case, a reinforced concrete slab supported on piles, appropriately dimensioned, can be built in order to distribute the loads to layers with adequate resistance (NSPT greater than 30 blows). It is worth noting that excavated piles should preferably be used, as they produce less soil displacement nearby. Driven piles can cause displacement of nearby pipelines. These works require a specific project and the piles must be located at a considerable distance from the pipelines, in order to minimize risks. The execution must only be released after viewing and confirming the real position and elevation of the crossing ducts (Figure 15).

FIGURE 15: MOST CRITICAL UNFAVORABLE SOILS CONDITIONS AND HIGH LOADS AT NEW INTERSECTIONS – CASE 4.

4.4 Instrumentation and Monitoring at New Crossings

For Cases 3 and 4, which are more unfavorable, it is recommended to instrument the pipeline for monitoring before, during and after the completion of the new crossing.

Figure 16 presents an example of recommended instrumentation. At points where there will be no landfills, a clamp can be installed with a reference point on the duct, for topographic monitoring of displacements. Figure 17 shows photos of cable ties used for this purpose. Other sections can be instrumented with strain gauges to monitor stresses in the pipe wall.

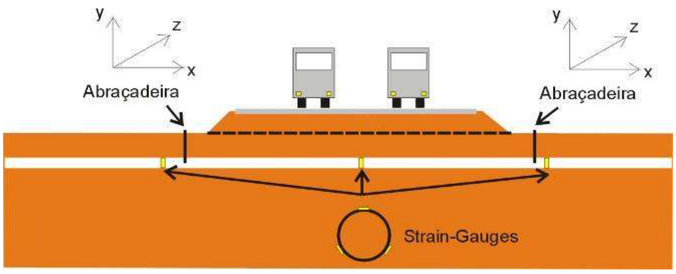

FIGURE 16: PROPOSED INSTRUMENTATION AT NEW INTERSECTIONS.

FIGURE 17: PROPOSED PIPE COORDINATES CONTROLS AND INSTRUMENTATION AT NEW INTERSECTIONS.

5. REAL CASE STUDY

A Brazilian Southern Gas Pipeline had a new crossing at a point not expected to receive traffic loads. It turned out that the SC-474 highway (Figure 18) had a route defined by a dirt road and this route, a few years after the completion of the gas pipeline implementation, was modified. In order to adapt traffic speeds on the highway, a tangent section was incorporated into the highway, causing a new crossing over the existing pipeline. It should be noted that the gas pipeline was adequately protected on the existing local road and this change was not foreseen during the construction of the pipeline. In fact, this adjustment of the highway layout occurred during the highway paving process.

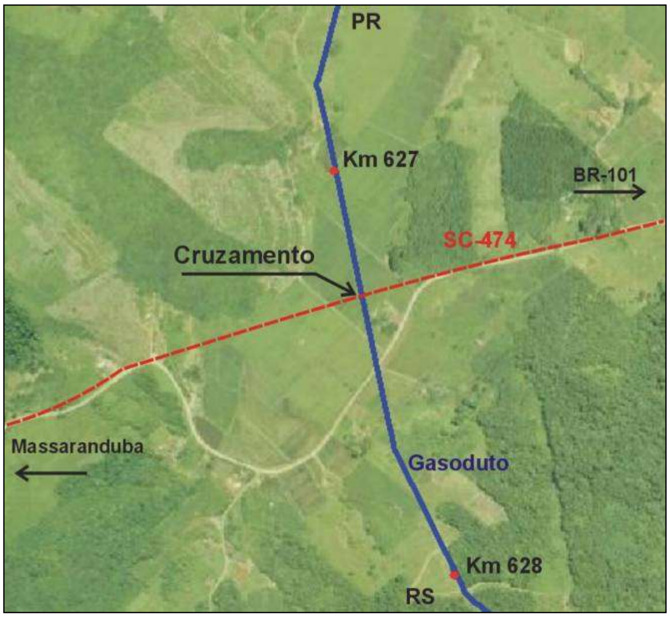

FIGURE 18: GENERAL VIEW OF NEW ROAD – SC-474 OVER EXISTING GAS PIPELINE.

The parties involved maintained contact with a view to defining the type of crossing. SPT type surveys were then carried out at the point of the new intersection, which identified the presence of a layer of soft soil, with low support capacity, approximately 4.6m thick. The procedure specified by the highway Designer and Contractor was to remove and replace 3 meters of the soft soil layer, executing the embankment with 3 meters, as indicated in Figure 19.

FIGURE 19: TYPICAL CONSTRUCTION PROCESS OF THE ROAD NEARBY THE EXISTING PIPELINE.

5.1 Study of Alternatives

Therefore, the parties involved jointly discussed alternatives to carry out the crossing in order to guarantee the integrity of the gas pipeline. Three alternatives were analyzed:

Alternative 1: the replacement of soft soil would be stopped 30 meters from the gas pipeline. In the 60-meter section above the pipeline, the landfill and traffic loads would be dissipated using a geogrid and non-woven geotextile set at the base of the landfill (Figure 20). Despite being the most economical alternative, it was discarded, as differential settlements could occur, damaging the conditions of the roadway and even with the distribution of landfill loads, it was not possible to guarantee that the pipeline would not suffer deformations.

FIGURE 20: ALTERNATIVE 1.

Alternative 2: the replacement of soft soil would be stopped 18 meters from the gas pipeline. In the 36 meter section over the pipeline, the landfill and traffic loads would be dissipated using a set of geogrid and non-woven geotextile supported on piles with capitals at the base of the landfill (Figure 21). This alternative presented an intermediate cost and was discarded. The higher cost than alternative 1 was caused by the high density of piles that would be necessary to guarantee the minimum load on the pipeline.

FIGURE 21: ALTERNATIVE 2.

Alternative 3: consisted of executing two juxtaposed pile curtains, 5 meters away from the duct. Crown blocks would be built on top of the piles to support prefabricated prestressed beams. Pre-modified shapes would be mounted on the beams to create the slab. Any differential settlements in the transition would be reduced by approach slabs. The soft soil replacement would be carried out up to the pile curtain, which would confine the soil around the pipeline (Figure 22). This was the alternative chosen and implemented, because even though it had a higher relative cost, it guaranteed that the duct would not suffer deformations and would be long-lasting.

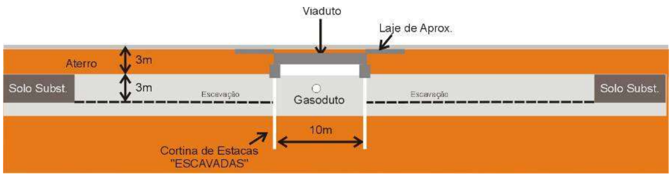

FIGURE 20: ALTERNATIVE 3 – ADOPTED.

5.2 Execution of Protection Works

FIGURE 21: BORED PILES EXECUION**.**

FIGURE 22: SOFT SOIL EXCAVATION CLOSE TO BORED PILE WALL.

FIGURE 23: SOFT SOIL EXCAVATION CLOSE TO BORED PILE WALL.

FIGURE 24: VIADUCT BEAMS INTALLATION.

FIGURE 25: PROTECTION WITH VIADUCT OVER BORED PILES CONCLUDED.

6. CONCLUSION

In short, it can be concluded that cases in which new interferences arise and which need to be evaluated by operators' engineers and technicians are not rare. Inadequate assessments increase the risk of damage to installed ducts.

For each specific case, as much information as possible must be obtained about the underground conditions and the loads arising from the interference.

A complementary assessment by mechanical engineers is necessary, who have greater competence in evaluating allowable loads and deformations in the pipelines.

No matter how unfavorable the new crossing may be, there are technical engineering solutions that guarantee the integrity of the installed pipelines. The work described in this article is a classic example of successful protection of pipelines laid in soft soil.

REFERENCES

[1] Oliveira, H. R., 2005, *Pipeline Integrity Management: Proposed Approach to Geotechnical Risk in Gas Transmission.* M.Sc. thesis, Santa Catarina Federal University, Florianópolis, SC. [In Portuguese]

[2] INGENIERA Y GEOTECNIA LTDA, 1991, "Manual de Protección Geotecnica y Ambiental", 2nd Edición, Nuevas Ediciones, Bogota, Colombia, pp. 4-17. [In Spanish]