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Performance analysis of HDPE Corrugated Pipes vs. Concrete Tubes at haul road truck crossings for mining company in Minas Gerais, Brazil

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ABSTRACT
As in the world's largest mining companies, Brazil's largest mining companies use haul road trucks to transport the minerals exploited, to increase productivity and reduce the direct and indirect costs of the beneficiaries. Due to the importance of these, it is necessary to maintain the access roads in ideal conditions for transportation of the ore, especially in adverse climatic periods. Due to the constant enlargements, due to excavations in mine, it is necessary to realize a drainage system, to capture and to lead the precipitate, avoiding the degradation and the necessity of constant maintenance. For the construction of these drainage systems, buried pipes are usually used because of their ease and speed of construction. The present work aims to present a comparative performance of the application of loads between the two main types of pipe used for gravity driving, HDPE corrugated pipes and precast concrete pipes. For the analysis, the software of finite elements was used to evaluate the behavior of the different systems, in front of the two scenarios evaluated, below 9m of soil and submitted to haul road trucks. This evaluation allowed to sustain and approve the use of HDPE pipes in an important mining project in Minas Gerais.

1. INTRODUCTION

The largest mines in Brazil use trucks of to remove large amounts of material in their mining operations, seeking high production and reduction in costs per ton of ore. These trucks have a large load capacity and can exceed 600 tons when fully loaded. Due to the great importance that these trucks represent for the profitability of the mining operation, it is necessary to keep the mining roads stable even in adverse climatic periods. The main challenge addressed in the present work was to find an alternative to conventional reinforced concrete pipes for use in sewers that, having extremely small length, very high weight, high percentage of loss due to damage, complicated handling and installation, paralyzed the transit of these giant trucks for prolonged periods generating large losses mainly in times of rain.

Specifically in the drainage part, the main problem of the maintenance team was to look for options to build sewers as quickly as possible and with high resistance to vertical and horizontal stresses, replacing reinforced concrete pipes that, with more than 2.50m of cover ground, extremely small length, very high weight, high percentage of loss due to damage, complicated handling and installation, generated constant traffic stoppages for haul road trucks due to the closure of roads for prolonged onerous periods that generated loss of efficiency in the mining operation. Within this context, the use of corrugated HDPE pipes was considered as the best option for this type of problems due to high durability, high abrasion resistance, ease of installation and, mainly, because they are “flexible”.

Safety and economy in pipes buried at great depths can be more easily achieved with the reduction of geo-static stresses due to the arc effect of the soil. The pioneering investigation of Marston & Anderson (1913) showed that the tensions that reach a buried structure are affected by the characteristics of the landfill, the geometry of the excavation ditch, the condition of installation and, mainly, by the rigidity of the buried tube. Subsequently, the greatest advance in buried pipes was generated by the research of Spangler (1950) that demonstrated the important role of relative deformation between the soil prism on the structure and the ground outside the deformation prism. The author describes that the geo-static stresses at the top of the buried tube significantly reduce when the vertical deformations of the soil at the crest of the tube are greater than the deformation on the ground adjacent to the projection of the tube, causing a radical alteration in the distribution of tension in the tube, which is attributed to the positive arc phenomenon of Terzaghi. This type of phenomenon can be achieved with the use of a more flexible tube or by the technique of the induced trench, in which a more compressible material is positioned at the top of a rigid buried structure (Figure 1).

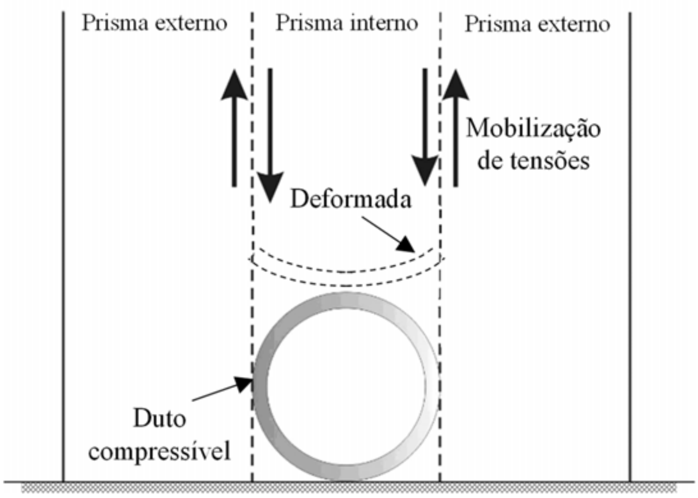

Figure 1. Positive arc phenomenon in flexible tubes.

The present work shows applications of corrugated flexible HDPE pipes buried for mining operation purposes. This article deals with application stories, as well as analysis and project considerations on the use of pipes and their influence on redistribution and stress reduction due to the positive soil arc phenomenon. And provide a performance comparison of the application of loads between the two main types of pipe used for gravity driving, HDPE corrugated pipes and precast concrete pipes.

2. THE SOIL-PIPE SYSTEM

The soil-pipe system follows the same case as foundations, where interaction analyzes are made between the foundation element (piles, radier) and the soil. Marston and some researchers have developed a theory for distributing loads on a grounded rigid pipe. Later, in works developed with Spangler, studies for flexible pipes were developed (Moser, 2001; Moser e Folkman, 2008).

The stress distribution is based on the mobilization of shear stress on the ditch sidewalls caused by soil movement due to its compaction. For flexible pipes, the ground column tends to move downwards, creating an arc condition. In rigid pipes an opposite condition occurs, creating a carriage relief on the pipe.

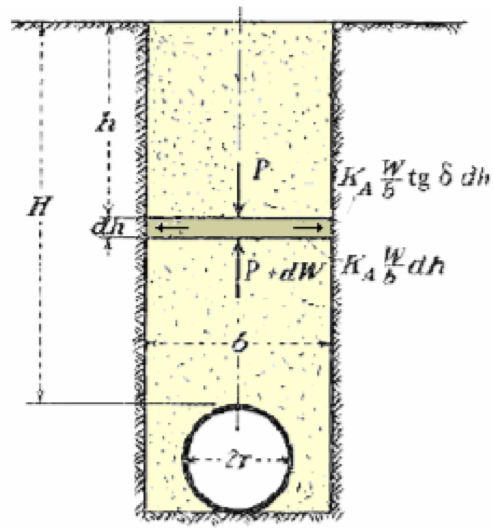

Figure 2. Marston theory for load distribution (Tschebitarioff, 1978).

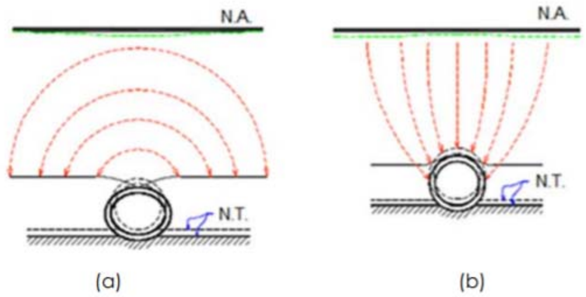

Figure 3. Flow of ground pressures (a) positive arc effect (b) negative arc effect (El Debs, 2008).

3. CALCULATION METHODOLOGY

To verify the soil-pipe interaction, numerical analyzes using the finite element method (FEM) were used. This work presents, therefore, the analysis made to the available filling material, a residual sand of the iron process, and as such characteristics, without compaction effect, were included along with the loads of the giant trucks in the formulas of the AASHTO LRFD and later in the PLAXIS V8 and SLOPE software. In order to verify the resistance of the HDPE soil-pipe assembly in this application and present it as a viable alternative to traditional concrete pipes.

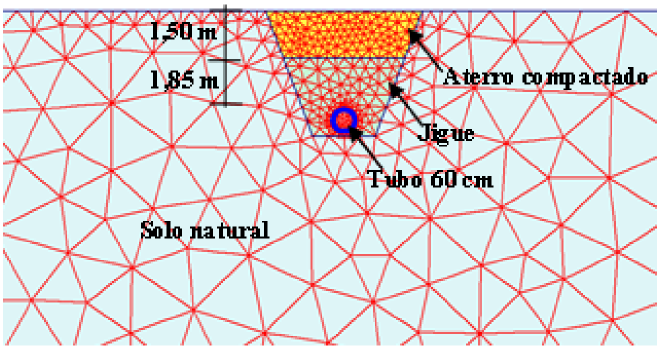

Figure 4. Variables adopted for pipe stress analysis.

4. THE PROBLEM

The described work was carried out in the city of Belo Horizonte (Minas Gerais / Brazil), where HDPE pipes were used to build sewers on high-capacity truck tracks. High capacity trucks consist of ore transport vehicles that have high storage capacity and, consequently, very high weight that would not allow traffic on traditional roads. For this reason, these trucks are called “haul road”. These trucks, with a capacity of more than 240m³ of ore, are 7.70 m high and can have loads of up to 620 tons when fully loaded (Figure 5). The sewers where the trucks pass presented different fill heights, being quite high, which also generated high tensions on the buried pipes.

Figure 5. Haul Road Truck CAT 793D.

In the mining sector, the infrastructure and maintenance processes are dynamic and unpredictable, due to the rapid action that should be taken when there is damage in access due to rain or landslides, and they are moderately predictable when accesses must be generated daily due to constant changes of the extraction points. All with the purpose of keeping the roads (haul roads) in an adequate state of traffic for haul road trucks. Meeting the minimum requirements of these trucks is not simple due to their height and high weight. Each traffic stoppage of these trucks due to road maintenance or, the simple reduction of speed due to inadequate drainage of access means millions of dollars per year in losses for the mining company.

Specifically, in the drainage systems, mining engineers in those areas had two major problems: (a) They used the typical spike-bell reinforced concrete pipes 1.00m long and up to 1,500mm in diameter to build their sewers. With these materials, these works were especially delayed due to the high time consumed by handling such tubes, aggravated by the minimum length they possess; (b) The installation process was carried out with heavy equipment and support personnel that necessarily had to enter the dug trenches to complete the installation of the concrete pipes. This process generated conflict with the safety area of the mine because, in need of deep ditches to receive the concrete pipes of 1.50m in diameter, that service qualified as “work in confined space” and the workers could not enter without a lateral confinement or shoring previously installed and less with mechanical equipment lifting heavy tubes on or next to them.

5. SUGGESTED SOLUTION

Having ruled out typical solutions such as field-mounted corrugated steel pipes, due to the delay in the installation process and limited hydraulic efficiency by internal corrugations, or as plain HDPE pipes with SRD classification, due to the high handling weight and need for Being soldiers in the field (which caused more problems if we compare them with concrete pipes), the mine operations area accepted as a final solution the double-wall pipes in HDPE type ADS N-12 due to their low weight: 36 kg / m for diameter of 1,050mm and 68 Kg / m for 1,500mm, its large length of 6,00m per bar and its high hydraulic efficiency, durability and abrasion resistance, being manufactured in HDPE with smooth interior. Images of the pipes in the factory and work are presented in Figure 6.

Figure 6. Manufacture and disposal on site of corrugated pipes.

Aware that corrugated pipes have been successfully used when they were installed in compliance with ASTM recommendations on roads and railways, and that calculation methodologies such as AASHTO assume the use of homogeneous soils installed with controlled compaction processes, were analyzed in combination with the technical team of the mine, all the critical conditions that would limit the performance of this technology. The two main ones were: (a) the materials available for filling the ditches were clays, fine sands resulting from the cyclone process, thick sands called "jigue" and a combination with larger diameter material called "itabirito". None of them classified as CLASS 1 in accordance with ASTM D2321; (b) limited possibility of entering ditches dug with the support equipment, which consequently meant, no possibility of placing compaction equipment that would allow compaction levels to be achieved in the normal PROCTOR energy recommended by AASHTO.

After conducting characterization tests in the laboratory, it was defined to use the material called “Jigue”. That material could be classified as CLASS 2 in accordance with ASTM D2321 and allowed to reach high densities simply by being thrown into the ditch. With the characterization of the material, it was possible to apply section 12 of the AASHTO procedure for calculation of bridges called LRFD (Load Resistance Factor Design) to determine the initial thickness of the filling fill to be placed at least over the HDPE pipes so that they can support the more than 600 tons of "off road" trucks without suffering internal stresses that exceed the maximum permissible high density polyethylene nor exceed 5% of maximum deformation limited by the manufacturer to maintain the tightness of the spike-type joints Bell. Thus, the vertical limit deformation of 5% should be respected to maintain the operational conditions of the pipes. Figure 4 illustrates the deformation criteria adopted in this project.

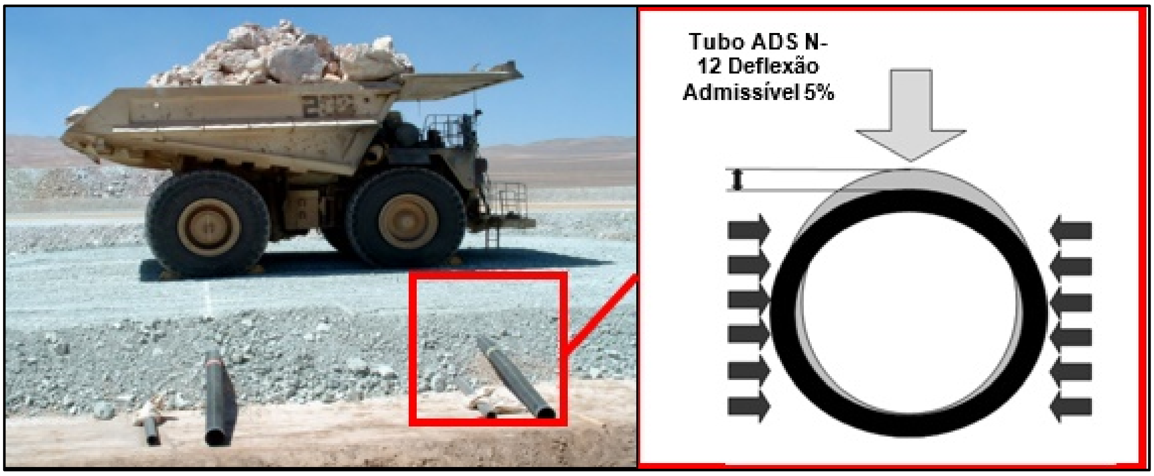

Figure 7. Deformation limits considered in the calculations.

In this specific project, 42" (1,050mm) inner diameter tubes were used. The minimum filling thickness placed on the crest of the pipes was calculated at 1.85m, highlighting that the AASHTO LRFD method (2012) considers fixed parameters for materials classified according to ASTM D2321 and with known or verifiable levels of compaction. With that, complementary analyzes using a finite element model using the PLAXIS V8 software were necessary to verify if the pressure transmitted to the pipes by the haul road generated a deformation of less than 5% using the values of the "jigue" material obtained in the laboratory. The properties of the 1,050 mm (42") HDPE tube used in the analyzes are presented in Figure 8.

Propiedad	**Norma**	**Valor**
Rigidity ate 5% deformation	ASTM D2412-11	140 kN/m²
Vertical deformation	ASTM D2412-11	40% (without damage)
Impact	ASTM D2444-99	130 Joules with 6 hits

Figure 8. The properties of the 1,050 mm (42")

With the soil-pipe set sized using material available in the mine, construction of an initial test stretch of approximately 36.00m in length was initiated to verify the calculations made and verify that the second challenge could be overcome, that is, install the pipes without entering the excavated ditch.

6. PIPING INSTALLATION

The installation began with the excavation of the trench and the placement of a "jigue" bed of approximately 15.00cm (Figure 5) as a leveling layer for corrugated HDPE pipes. Subsequently, the first 6.00m pipe bar was positioned and mechanically fixed with the same "jigue" placed on it. The second bar was embedded in the first one already fixed with "jigue", with the use of a backhoe and polyester belts. The installation process proved to be simpler than imagined, with experienced backhoe operators, HDPE corrugated pipes were installed without the presence of support personnel inside the drainage ditch as required by the customer. Care was taken to install the filling material of the ditch in litters and "compacting" with the "shovel" of the backhoe to try to accommodate and densify as much as possible the "jigue" inside the ditch and mainly on the sides of the pipe of HDPE.

It is important to emphasize that the use of known calculation methodologies allowed us to propose the use of pipes in an application outside the conventional road or rail standard with good performance. However, it is important to indicate that conventional methodologies do not contemplate the positive arc phenomenon when using flexible pipes. Therefore, the topic below compares the methodologies with and without a positive arc effect that allow us to understand why the use of pipes presents a superior performance than rigid concrete structures.

Figure 9. Installation of pipe sections without manual assistance as required by mine safety.

Figure 10. Piping connection and end of work in full operation.

7. POSITIVE ARCH EFFECT WITH USE OF FLEXIBLE PIPES

The influence of tube stiffness was studied with the use of the finite element method. In this work, these analyzes were performed using the commercial software PLAXIS V8. In the software, a buried tube was simulated considering the tube installed over 15 cm of "jigue" and below 1.85 m of the same material calculated according to AASHTO LRFD. On this last material, an additional filler of 1.5 m was considered, totaling a coverage height of 3.35 m. This 1.5m coverage thickness increase was used to compensate for variations in the dimensions and geometry of the project. As this would generate greater tensions applied to the pipe, the analysis would be on the side of safety.

On the landfill it was applied to the "haul road" truck load using an equivalent load distributed generating 800 kPa of tension.

Figure 12 shows the vertical stresses that reach the crest of the buried tube for both the flexible tube case (Figure 12a) and the case of a rigid tube (Figure 12b). The maximum tension that arrives at the crest of the flexible pipe is 15 kPa, while for the rigid tube the tension is more than double, reaching values close to 40 kPa. It is evident that, for the flexible pipe, the vertical tension in the crest is greater than the tension applied to the rigid tube, which is attributed to the arc effect of the ground. It is further evidence that the positive arc effect can also significantly decrease the values of lateral tensions in the tube, as presented in Figure 13.

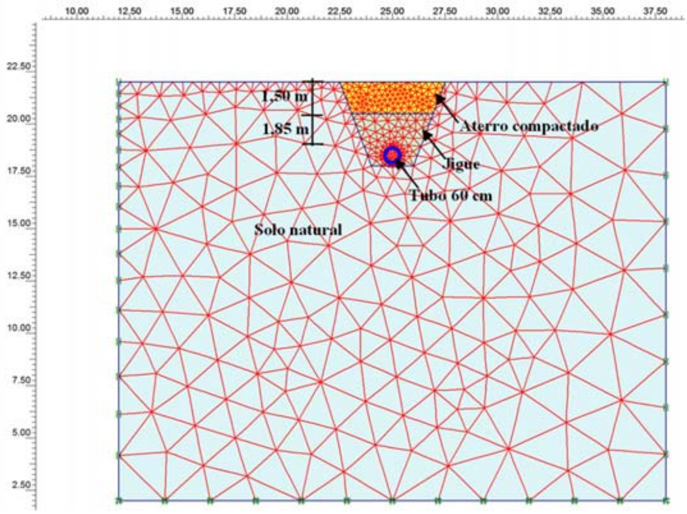

Figure 11. Mesh adopted for application of the finite element method (FEM).

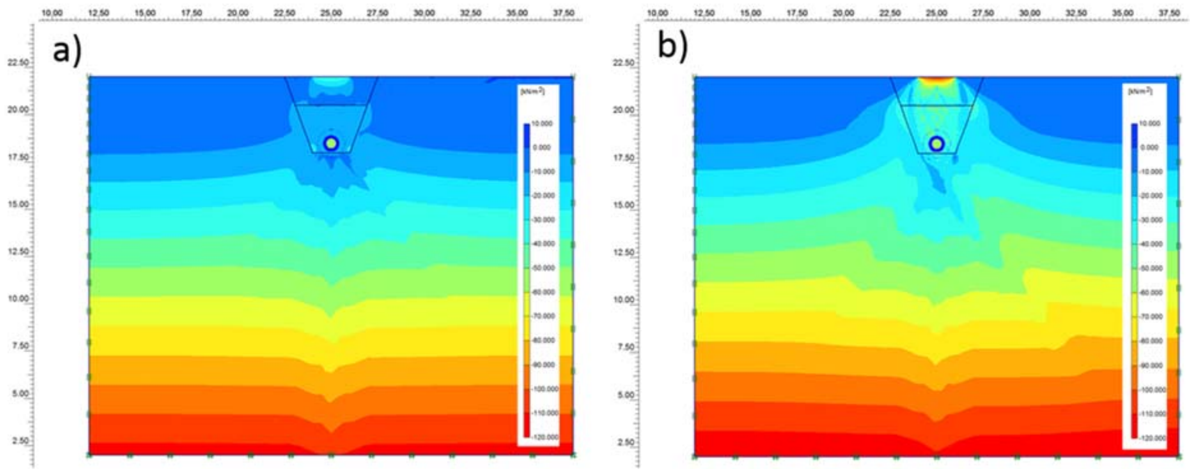

Figure 12. Distribution of vertical stresses in pipes: (a) flexible; (b) rigid.

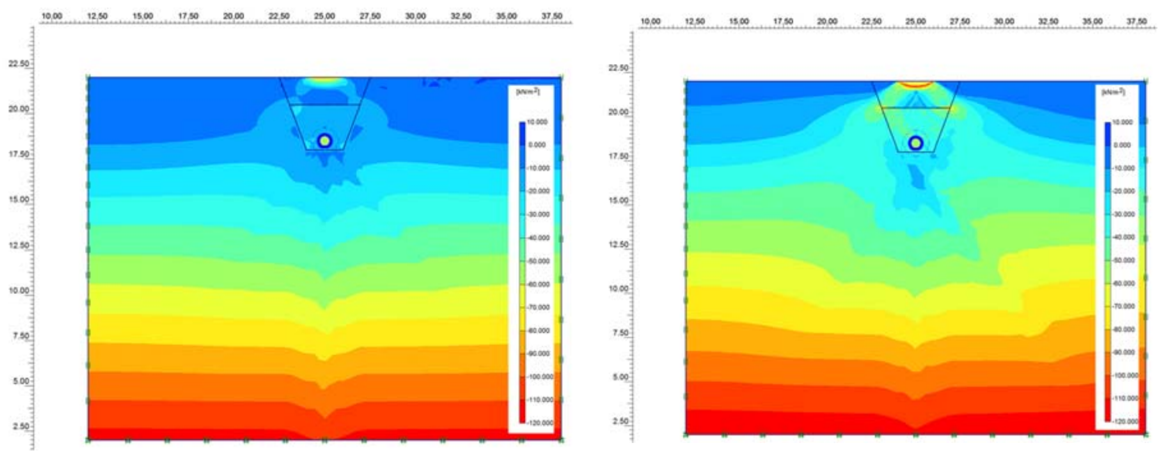

Figure 13. Distribution of horizontal stresses in pipes: (a) flexible; (b) rigid.

8. CONCLUSION

This multipurpose work that the use of geosynthetic tubes (pipes) of great diameters is presented as a technique that enables the quick and efficient construction of rigid pipes in the mining, by allowing an easy disposition within the areas and significantly streamlining the construction process. the drainage lines. Working with broader, lighter and more flexible bars makes the installation work much more practical and avoids the standstill of large transport equipment for mining activities. Within this context of technical efficiency, it has been shown in this design that the use of flexible tubes can drive the Terzaghi positive arc effect resulting in lower stresses than those which are generally rigid. The numerical results show that the reduction of horizontal and vertical tensions can be significant reaching up to 60%.

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