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Performance of HDPE Pipes Under High Loads

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Abstract. In mining facilities, the system responsible for capturing, collecting and conducting solutions from seepage, leached solutions or acid rock drainage (ARD), is of utmost important. Such a system is generally composed of granular material drains, flexible high-density polyethylene (HDPE) pipes and geosynthetics (e.g. geotextiles or geomembranes). Increased production rates, combined with limited availability of areas within mining facilities, has led to designing structures such as tailings dams, heap leach pads and waste dumps of over 200 m height. Therefore, understanding the behavior of drainage pipes in these structures, where they are subjected to high confinement pressures, is critically important. In the present study, results of five laboratory large-scale compression tests are presented. The tests were designed to analyze pipe behavior under high confinement pressures, simulating the effect of a 200 m (3.6 MPa) fill above the pipe crown. The tests were carried out using the configuration of a typical collection system, composed of compacted foundation soil, a geomembrane and a HDPE double wall corrugated pipe of 10 cm (4") diameter, surrounded by granular material. The main objective of the study was to analyze the structural integrity of the pipes under high loads when placing different granular materials, identifying their influence on the pipe performance. Granular materials with different gradings curves, densities, and geological origins were used for testing.

Keywords. HDPE pipe, pipe deflection, drainage system, tailings, heap leach, waste dump, geotechnical laboratory testing, large-scale testing.

1. Introduction

The increase in production rates, combined with the limited availability of areas because of space within mining facilities, have led to designing tailings dams, heap leach pads and waste dumps with heights of over 200 m. These types of facilities usually have a drainage system in their base, composed of granular materials, geosynthetics barriers (GBR), geotextiles and HDPE pipes. The drainage system and other types of buried structures within these facilities are not inspected as frequently as above-ground structures, and it is a common practice not to even inspect them after construction. Figure 1 presents the scale of this type of superstructures.

One the most important components of the drainage system is the granular material. It has the function of capturing and guiding the flow to the drainage system pipes, controlling the increase of pore pressure and the piezometric level at the base of the structure, capturing the seepage, or recovering leach solutions that present an economic

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value. The granular material also has the indirect function of giving confinement and protection to the pipes, geomembranes and geotextiles, against the discharge of ore material, and the traffic of high tonnage mining equipment. Thus, understanding the behavior of these elements that are subjected to high confinement pressures is critically important.

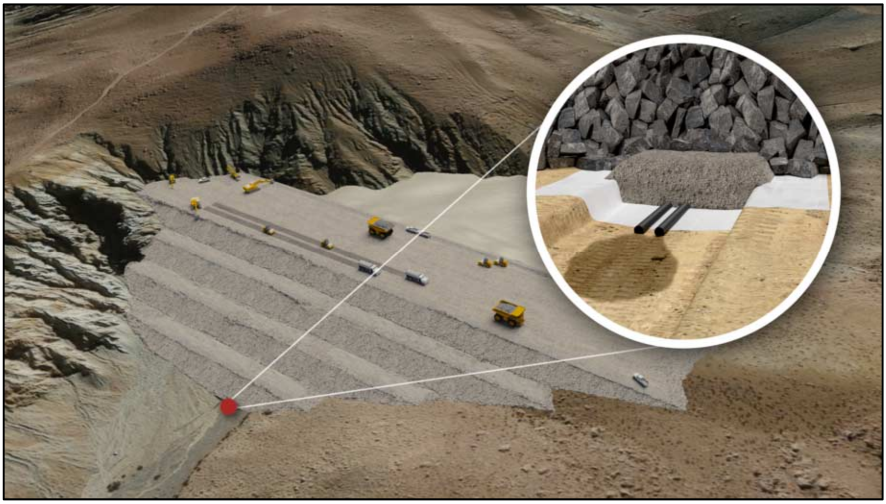


Figure 1. Sketch of the drainage system location in a mining structure.

The objective of this study is to present the results of large-scale compression tests in laboratory, designed specifically for analyzing the performance of HDPE pipes under high confinement pressures, in contact with different granular materials.

2. Large Scale Compression Tests

2.1. HDPE pipe characteristics

The flexible 10 cm (4”) diameter HDPE pipes that were tested have a double-wall consisting of a flat internal wall and a corrugated external wall.

2.2. Test device and setup

The test and its components have been specifically designed by the author for the assays presented in this article, with special attention to represent as accurately as possible the configuration, scale, construction sequence, conditions and solicitations that this kind of pipes will be exposed in the field. Currently, there are no standardized assays or methodologies to replicate these conditions in laboratory.

The loading plan consisted of 8 stages, each one increasing the applied load up to an equivalent fill of 200 m height. For each stage, the load was applied for 10 minutes. In stage 8, the load was applied for 24 hours and then the cylinder was unloaded. After unloading, Soils 3 and 4 were loaded again to an equivalent fill of 400 m height. The test using Soil 5 was only loaded to an equivalent fill height of 54 m.

The complete procedure for setting up the test is shown in Figure 2. Further details of the test are presented in reference 8.

Figure 2. Test preparation sequence.

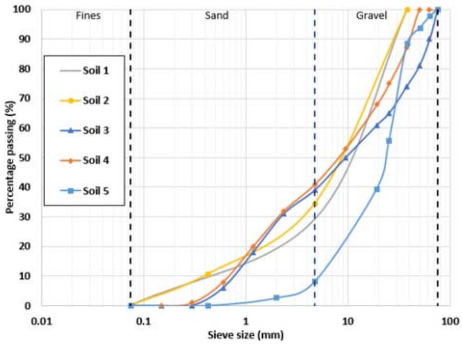
2.3. Characterization of the Granular Materials

Five tests were performed using five granular materials with different grading curves, different initial density and different geological origin. Common design criteria consider that if the soil particle size is too coarse and angular, it can puncture the geomembrane liner, but if it is too fine, means that it has a low permeability which could affect the drainage system. These verifications are not presented in this study.

Figure 3 shows the cylinder filled with the five soils. Soil 5 was the least compacted of all soils tested, and with higher gravel content and lower sand content. The other soils tested had sand percentages varying between 29 to 41%.

Figure 4 shows the particle size distribution of the five soils used, their grading curves, relative density, and initial moist density before testing.

Figure 3. Images of the five granular materials tested.



Sieve	Size (mm)	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
3"	76.2	-	-	100	-	100
2 ½"	63.5	-	-	90	-	98
2"	50.8	-	-	81	100	94
1 ½"	38.1	100	100	74	87	88
1"	25.4	-	-	65	75	56
¾"	19.1	-	-	61	68	39
#4	4.76	29	35	39	41	8
#200	0.075	0	0	0	0	0
Cu		37.74	27.7	23.9	18.8	5.18
Cc		6.49	2.21	0.51	0.62	1.15
Gravel (%)		71	66	61	59	92
Sand (%)		29	35	39	41	8
Fines (%)		0	0	0	0	0
Initial Density (kN/m³)		18.0	16.4	18.8	18.7	13.5
Initial Relative Density (%)		35.0	32.0	65.0	65.0	2.0

Figure 4. Grading curves and geotechnical properties of the five soils used for testing.

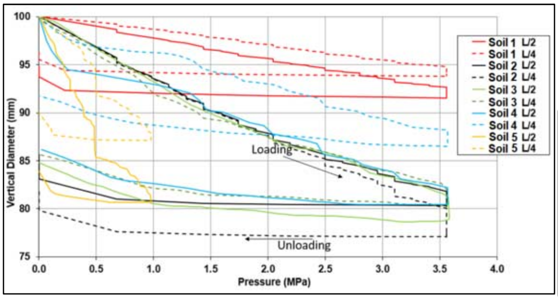
2.4. Test Results and Discussion

Results show that the main cause of pipe damage is the induced deformations rather than the load applied to the tested system. The pipes that presented more damage were those surrounded by soils in a looser state, or whose granulometry allowed greater deformation. On the contrary, compact soils or those that admitted less deformation, resulted in less pipe damage, what proves the "soil-pipe interaction" effect. In fact, the tests performed with "Soil 1" presented the least pipe damage.

The deformation mechanism of the pipes observed in all the tests is mainly due to ring deflection (see Figure 5), which manifests proportionally to the load or deformation according to each type of soil. Also, ring compression was observed in the side walls of the pipes. None of the pipes collapsed during the development of the tests. Figure 5 shows also the effect of the load inside the HDPE pipes.

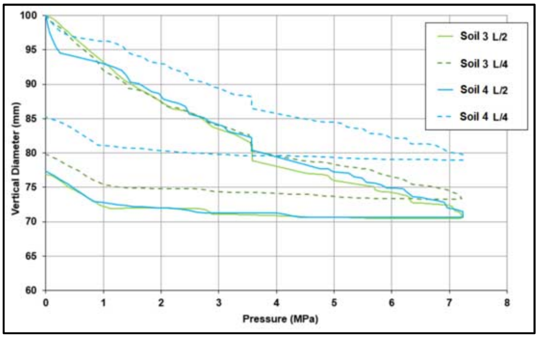
Figure 5. Left image: Typical lateral deformation observed inside the pipes during the tests. Center image: Typical deformation observed inside the pipes after the 400 m height fill test. Right image: Literature failure mechanisms (Ref. [7]).

The largest vertical deformations occurred in pipes tested with "Soil 2" and "Soil 3", but these values are in the same order as those from "Soil 4" and "Soil 5", which is about 20% of vertical deformation. For pressures lower than 1 MPa, the test with "Soil 5" (lowest relative density) had the biggest vertical deformation (proportionally). Test results are presented in Figure 6, which shows a graph with the reduction of the vertical internal diameter of each pipe tested. The deformation of the pipes was measured at L/4 (dashed line) and L/2 of the pipe (solid line), where "L" is the length of the tested pipe and the diameter of the steel cylinder (100 cm).



Material	Max. Vertical deformation (%)	Initial density (kN/m³)	Initial Relative Density (%)	Equivalent fill height (m)
Soil 1	8.4	18.0	35	200
Soil 2	23.0	16.4	32	200
Soil 3	21.1	18.8	65	200
Soil 4	19.5	18.7	65	200
Soil 5	19.3	13.5	2	54

Figure 6. Vertical Internal Diameter of the HDPE pipes vs pressure.



Material	Max. Vertical deformation (%)	Initial density (kN/m³)	Initial Relative Density (%)	Equivalent fill height (m)
Soil3	29.6	18.8	65	400
Soil4	29.4	18.7	65	400

Figure 7. Results for an equivalent 400-meter-high fill on Soils 3 and 4 (after an unload and reload cycle).

The integrity of the pipes with "Soil 3" and "Soil 4" was evaluated using a higher load cycle, to an equivalent of a 400 m height of fill. The pipes did not collapse, and the maximum vertical deformation was nearly 30%, as it can be observed in Figure 7. Both pipes present similar deformations, which is expected considering the soils have similar characteristics (i.e., gravel and sand content, and relative density before testing).

As it can be observed in Figure 6, after reaching 3.6 MPa (equivalent to a 200 m fill height) and maintaining the pressure, the pipes continued to deform. On reaching this pressure, the load was maintained for 24 hours and then unloaded. It also can be observed that the measurements at L/2 of the pipe were higher for all soils except "Soil 2". When maintaining a constant load of 3.6 MPa for 24 hours, after 15 hours the deformations stabilized, as it can be seen in Figure 8.

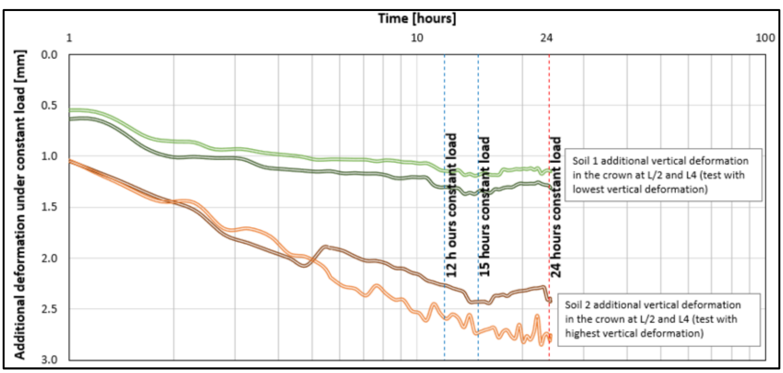


Figure 8. Additional vertical deformation due to constant load (of 3.6 MPa) for 24 hours.

The integrity of the pipes after the tests can be observed in Figure 9 and Figure 10. “Soil 3” and “Soil 4” presented the largest damage to the pipes, but none of them collapsed. On the other hand, the pipe in “Soil 5” (subject to a lower load) kept a good integrity. It was observed that gravel particles were incrusted in the corrugation of the pipes.

After removing the cylinder from the load frame, an arching effect could be observed by the difference in rigidity between foundation soil and the pipe. The foundation soil right below the pipe was slightly compacted, compared to the foundation soil by the sides of the pipe.

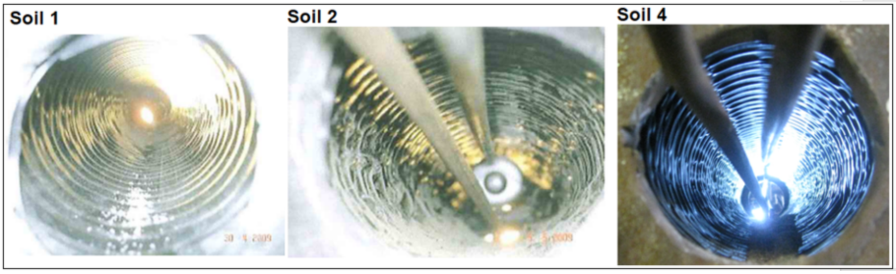


Figure 9. Vertical Internal Diameter after final loading stage (200 m).

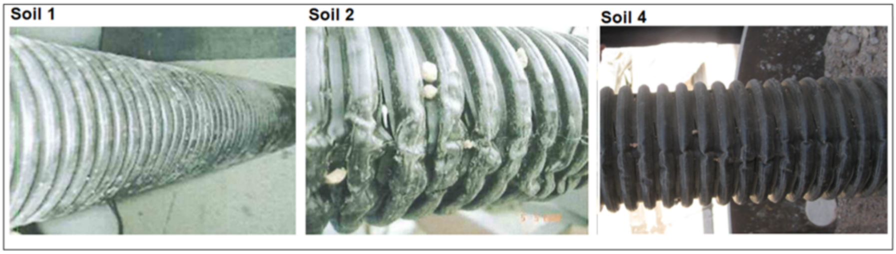


Figure 10. Pipe integrity after the testing.

All tests presented particle crushing effect in the top side of the granular soil, probably as a result of the steel lid placement. Particle crushing was not visually identified in the granular material, in the middle and bottom part of the cylinder. Figure 11 shows gravel particles crushed in the top after completion of the tests. Particle size distribution variation was evaluated with sieve analysis pre and post-testing. Results indicate that for “Soil 3”, sand content increased 8% and gravel content was reduced by 8% as well.

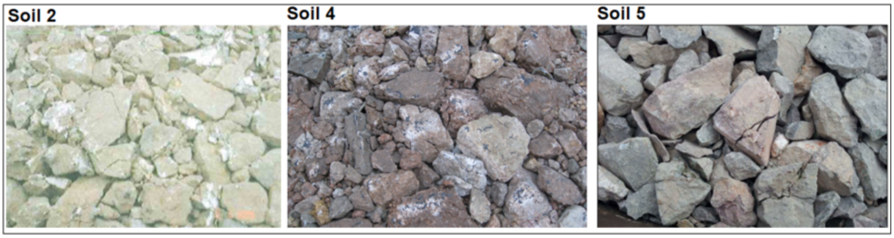


Figure 11. Particle crushing effect. Note that the fresh particles that surround the fractured particles allow the comparison of the effect.

3 Conclusions

The design of the drainage system for large dams, leach pads and waste dumps is very important, especially considering that this type of facilities are increasing higher (much higher). Currently, there are no laboratory tests or standardized methodologies to simulate the conditions of the entire drainage system to verify its structural long-term behavior under high pressures. Among the elements that integrate this system, probably drainage pipes are one of the least geotechnically investigated elements.

New issues related to the drainage system appear due to the large dimensions of the structures, such as the availability of adequate borrow materials at a reasonable cost, the uncertainty related to particle breakage in the long term, the influence of the high hydraulic gradients on the internal (in)stability of certain types of soil or filters, the impossibility of replacing any damaged or not adequately operative component, or at least, the monitoring of all these risk factors. It seems reasonable to accept that avoiding the collapse of the pipes is critical to have a perdurable system.

Due to the mentioned issues, the authors designed a series of tests considering a typical configuration of a drainage system, including all its components inside a large-scale test cylinder. The intent was to simulate high vertical loads equivalent to 400 m height of filling, considering steps according to the construction bench heights and including the time to stabilize the deformations. The results presented here are valid only for the pipes, diameters and materials that have been tested and cannot be extrapolated to other cases.

The following main conclusions can be obtained from the present study:

- The behavior of this type of pipes must be analyzed together with the characteristics of the surrounding soil, in terms of its granulometry, degree of compaction, relative density and particle hardness, proving that the soil-pipe interaction is a key issue to be understood.
- The creep (deformation over time) phenomenon on different materials at high confinement pressures should be carefully studied, not only in this case. It is highly recommended to incorporate this phenomenon into the different standardized and commonly used geotechnical tests, even in granular soils.

Finally, it is also recommended to assess the impact of the test-scale in the results, especially the size of the pipes. In terms of monitoring, it is recommended to implement instrumentation inside the drainage system to enable access and registration points (where feasible) and the inspection inside the pipes using robots or fiber optics, among others to check their deformations and structural conditions.

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