TEST PROCEDURE FOR DEGREE OF SATURATION OF GRANULAR MATERIAL

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SUMMARY: This paper describes a quick method to determine the degree of saturation of granular materials. The results can be used to evaluate the preliminary susceptibility of heap and dump leaches and waste dumps to static and dynamic liquefaction under irrigation for recovery of mineral and/or environmental conditions, such as intense rainfall.

KEY WORDS: degree of saturation, permeability, irrigation, leach pad, leach dump, waste dump.

1. INTRODUCTION

In ore leaching and waste dump operations, the degree of saturation of the material is controlled by a number of factors such as: long term irrigation processes, infiltration of water due to intense rainfall events, ice and snow melt, and material permeability.

Sassa (1985) stated that under collapse conditions, excess pore water pressure is developed when the degree of saturation of granular material is at least 85%. Thus, a leach pad or waste dump with poor internal drainage can show saturation levels high enough to allow static or dynamic liquefaction failure.

Yoshimi et al. (1989) indicated that the dynamic liquefaction resistance at 70% saturation is about three times that at full saturation (100%). In addition, one cannot expect greater strength gains by further reduction (below 70%) of the degree of saturation.

Based on the above statements, it is important to know the degree of saturation in leach heaps, leach dumps, and waste dumps for the preliminary evaluation of the susceptibility of these materials to static liquefaction and/or earthquake induced liquefaction. Based on those results, a rigorous analysis may be required, which involves the study of other issues associated with the occurrence of liquefaction.

2. DEGREE OF SATURATION MEASUREMENT

For the determination of degree of saturation of granular material, Vector developed a simple portable device, where a defined flow rate is applied to a material column to simulate irrigation and/or rainfall effects on a heap or waste dump. In addition, information on retained moisture within the matrix can be measured at various post event times. This equipment provides a fast and easy method to determine degree of saturation in the laboratory and in the field, which can be used to estimate saturation.

2.1 Testing Equipment Description

Figure 1 shows a schematic of the testing device designed by Vector. The apparatus can easily be fabricated for use in both the field (i.e., at a mine site) and in the laboratory. The equipment has the following dimensions: 20.9 cm in diameter and 70.5 cm height. These dimensions assure proper testing of materials up to a maximum particle dimension of 4 centimeters and the apparatus can easily be fabricated to accommodate larger materials.

The flow rate is controlled by emitters feeding the system with a predefined flow rate. The applied flow rate depends on leach pad operations (irrigation rates) and design storm events. For our testing program, process solution was not used due to the implied handling risks associated with these materials. Thus, tap water was selected. However, under properly controlled conditions leaching, solutions could be utilized.

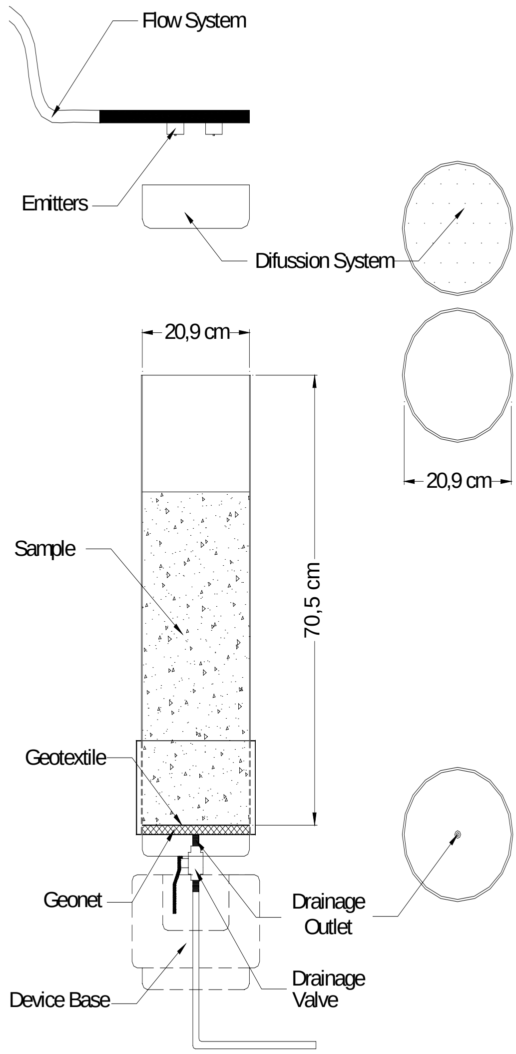

Figure 1. Schematic of column testing device

The material sample recipient is made of a rigid material (such as metal or plastic). A geotextile fabric was placed at the bottom of the device over the top of a geonet to avoid fine particles migration from the sample and to provide a porous base. In the base a hole was drilled to allow liquid to flow out of the testing apparatus through a plastic hose with a valve.

2.2 Testing Procedure

Prior to placing the sample in the equipment, the geosynthetic materials were hydrated to determine the amount of water retained. The average amount of water retained was used in the calculations, so as not to affect the measurements of water retained by material being tested.

The material to be analyzed is placed in layers and compacted to a predetermined density. It is important to indicate that in leach pad operations, the ore density and the coefficient of permeability are parameters that are typically dependent on depth; i.e., higher heaps have higher density and lower ore coefficient of permeability at depth. Thus, a series of tests at known densities can be used to profile the heap or dump.

The system weight is recorded before and after material placement, to determine total weight of the sample placed in the device and to verify the target density.

Water is applied through a tube with emitters at the top of the equipment. The water passes through a diffuser as shown in the Figure 1. The bottom of the diffuser contains small holes to distribute flow evenly over the surface of the material.

The test is run for a period of approximately 12 to 24 hours to ensure the sample is uniformly wetted and the inflow and outflow is in a steady state. To complete the test the feeding system is removed and the drainage valve is closed, simultaneously. The whole system (device plus sample) is then weighed. The drainage valve is re-open to allow the sample to drain freely over a 24-hour period, after which the system is re-weighed. Finally, the sample's average moisture content is determined by performing moisture content checks at different heights within the column. The 24 hour period can be extended for slow draining material, and the weighing process performed at various time intervals to provide a relationship between saturation and drainage time.

Calculations to determine the degree of saturation (S_w) of the material are performed for times t_0 (simulating irrigation and/or rainfall infiltration) and t_{24} (24 hours after stopping irrigation) as described above.

3. RESULTS

The test results below were carried out on ore provided by Minera Barrick Misquichilca S.A., which operates the

Pierina Gold mine in Huaraz, Peru. This mine is a valley fill heap leach operation with a design capacity of approximately 110 metric tonnes and a maximum depth of 130 meters. Two samples of ore were supplied with different nominal sizes. Index characteristics of the ore samples are presented in the following table:

Table 1. Tested Samples Characteristics

Sample	Classification (UCSS)	Passing No. 200 Sieve	Gs
minus 1"	GC	14.3%	2.75
minus 1/2"	GC	15.7%	2.73

The samples were remolded with three different dry unit weights: 16.2, 16.7 and 17.2 kN/m^3, and an application of 8 lt/hr/m^2 was applied to the samples, which represents the design irrigation rate for this facility. The different dry unit weights represent different densities within the heap at varying depths. The 16.2 kN/m^3 density represents the density of the ore poured into the mold without compaction, while the other two samples were compacted to specific densities. The average density at the surface of the heap based on *in-situ* measurements was 16.6 kN/m^3.

The degree of saturation was determined after completing tests t_0 and t_{24}. Results of the tests are presented in the following table and in the Figure 2:

Table 2. Degree of Saturation for 8 lt/hr/m^2

Sample	Time	Degree of Saturation (%)		
		$_d$=16.2	$_d$=16.7	$_d$=17.2
minus 1"	t_0	54.1	52.5	49.7
	t_{24}	37.6	37.4	37.8
minus 1/2"	t_0	76.9	65.2	60.5
	t_{24}	42.0	43.6	45.2

The results indicate that the minus 1/2" ore shows higher degree of saturation at both t_0 and t_{24}, than the minus 1" sample which is to be expected since there is more surface within the matrix. There appears to be a trend of decreased degree of saturation with an increase in density during irrigation and/or rainfall infiltration, which was more evident in the 1/2" material. The highest degree of saturation occurred with the minus 1/2" ore and is 76.9 percent at a unit weight of 16.2 kN/m^3. However, no significant variation in the degree of saturation was observed for the 24-hour drain down test.

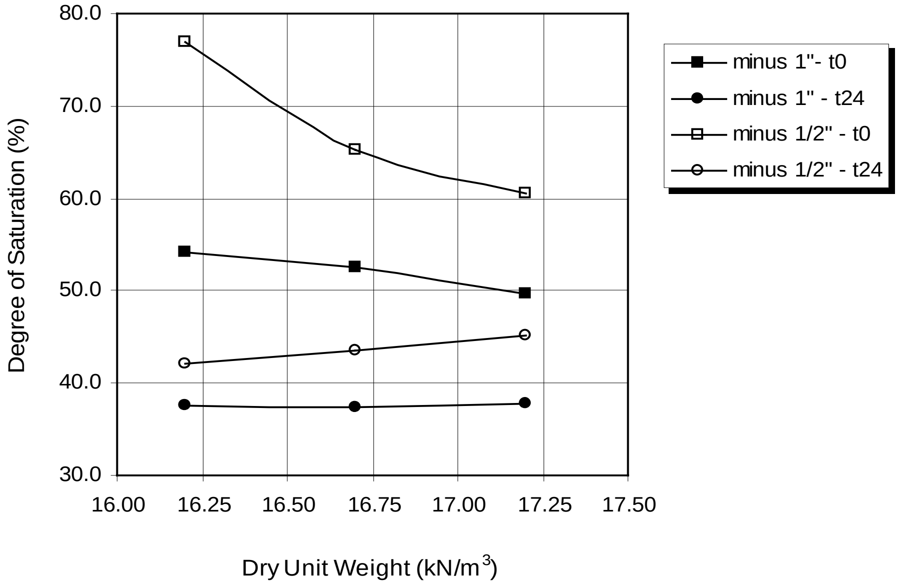

Figure 2. Results from Degree of Saturation Tests.

In addition to looking at the effects of irrigation on the degree of saturation, the combined effects of irrigation and the design storm event on the degree of saturation was studied. The irrigation rate plus the design storm event for Pierina is approximately 18 lt/hr/m^2, which is considered the worst case scenario for analysis of liquefaction. Typically, this type of flow rate is only experienced in localized areas of a leach pad, which are under irrigation, and only during the peak of an intense storm event. Because of time constraints, a single unit weight (16.7 kN/m^3) was used in the analysis of irrigation plus the design storm event. This value represents the near surface density of ore in the heap. The obtained results are shown in the Table 3. The highest degree of saturation occurred with the minus 1/2” ore and is 68.3 percent.

Table 3. Degree of Saturation for 18 lt/hr/m^2

Sample	Time	Degree of Saturation
minus 1”	0h	56.4
	24h	35.5
minus 1/2”	0h	68.3
	24h	42.8

The results also show that for approximately double the flow rate, the degree of saturation during irrigation plus the design storm event only experienced a slight incremental increase of 3 to 4%. The 24-hour draw down degree of saturation remained almost constant, as would be expected.

4. PRELIMINARY EVALUATION

A preliminary and qualitative evaluation of a leaching facility or waste dump stability can be evaluated based on the degree of saturation. This test is one indicator of the potential for static or dynamic liquefaction to occur in a leaching facility or a waste dump.

When the degree of saturation of the granular material is less than 85 percent during irrigation and/or storm event the development of excess pore water pressure necessary to trigger static liquefaction are not to be expected. A rigorous evaluation should be included when the results are near or above 85 percent, which examines of other factors associated to collapse conditions.

For the case of the Pierina leach pad, the above data indicates that during irrigation and/or the maximum storm event, degree of saturation is less than 85 percent (less than 68.3% for actual conditions within heap). Again, this is a favorable condition under which excess pore water pressure can not develop, causing static liquefaction.

The degree of saturation can also be used in the preliminary and qualitative evaluation of leach facilities and waste dumps susceptibility to dynamic liquefaction. Conversely, when the degree of saturation of the granular material is less than 70 percent during irrigation and/or rainfall, an increase of the dynamic liquefaction resistance can be expected, up to three times that at full saturation. In the case of dynamic liquefaction when the degree of saturation is near or above 70 percent, a more rigorous analysis needs to be performed. Similar to static liquefaction, the more rigorous evaluations for dynamic liquefaction take into account other factors associated with the development of liquefaction.

The data above indicates that during the design earthquake in the Pierina mine area, the general degree of saturation of ore within the upper 20 meters of the heap under irrigation and/or rainfall is less than 68.3 percent. There is no known case of dynamic liquefaction in granular material below 20 meters due to confining pressure. Therefore, the development of excess pore water pressure is unlikely to occur during the design seismic event. In addition, to this screening test for the susceptibility of the heap to liquefaction a more rigorous evaluation was performed, which verified the heap was not prone to catastrophic liquefaction.

5. CONCLUSIONS

The degree of saturation in leach facilities and waste dumps can be determined by means of this simple test equipment. A design flow rate is applied to the sample, which is equivalent to irrigation and/or the design storm event.

For this paper, tests were carried out on two different ore sizes from the Pierina Gold mine in Peru. The samples were remolded by using three different densities, simulating different depths within the heap. The ore was subjected to a predefined flow rate, which was equivalent to the design irrigation rate. The flow rate was increased to consider the additional effect of the design storm event during irrigation.

Based on the degree of saturation test, preliminary calculations can be performed to evaluate the susceptibility of granular material to static and/or dynamic liquefaction. When the degree of saturation obtained by simulating irrigation and/or the maximum storm event is lower than 85 percent, static liquefaction is very improbable. In the case of dynamic liquefaction when the degree of saturation below 70 percent, liquefaction resistance triples. Where saturation levels exceed these thresholds, the more rigorous analyses are suggested. The more rigorous evaluations take into account other factors associated with the development of static or dynamic liquefaction.

Based on the ore samples provided by Pierina, this heap leach facility is not considered susceptible to static and dynamic liquefaction failure modes.

In the future, further tests will be performed using different ores samples from operating mines and varying different parameters to help built a database and develop other useful applications from this test, such as general guidelines for maximum irrigation rates for leach facilities.

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