

SIMPLIFIED LIQUEFACTION ANALYSIS FOR LEACH HEAPS AND DUMPS¹

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INTRODUCTION

In heap or dump leaching the degree of saturation of the ore is controlled by a number of factors such as: short- and long-term irrigation rates and patterns, infiltration of water due to intense rainfall events, ice and snow melt, and material properties such as gradation, density and permeability.

It is important to know the degree of saturation in leach heaps for, among other reasons, a preliminary evaluation of the susceptibility to liquefaction. Dynamic (earthquake induced) liquefaction resistance can be three times as high when the degree of saturation is less than about 70% (Yoshimi, et al, 1989). For static liquefaction, it was estimated that the degree of saturation should be at least 85% before the dump is considered vulnerable (Sassa, 1985). Thus, a quick screening for both failure modes can be done with this simple test.

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 leaching and/or rainfall effects on a heap or 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.

Testing Equipment Description

Figure 1 shows a schematic of the testing device. The apparatus can easily be fabricated for use in both the field (i.e., at a mine site) and in the laboratory. These dimensions assure proper testing of materials up to a maximum particle dimension of 4 centimeters. The apparatus can easily be fabricated to accommodate larger

materials and thus most crushing sizes. For run of mine ore, only the matrix can be tested.

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.

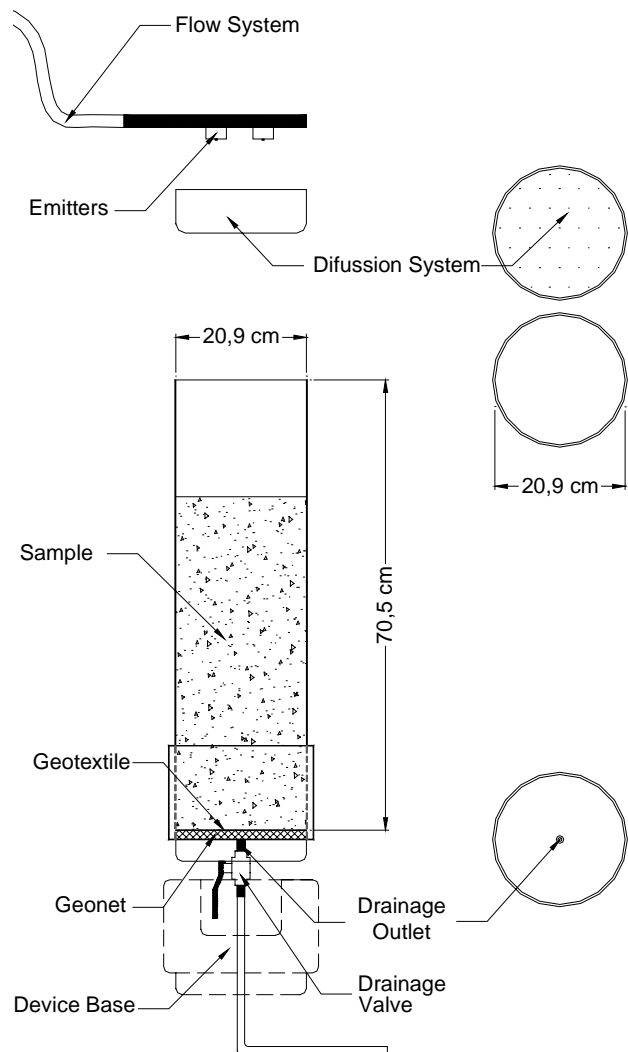


Figure 1. Schematic of column testing device

Testing Procedure

The material 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 densities and lower permeabilities 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 then 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 until the inflow and outflow are 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-opened to allow the sample to drain freely, after which the system is re-weighed. Finally, the sample's average moisture content is determined by performing moisture content checks at different depths within the column.

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).

RESULTS

The test results below were carried out on ore from a gold heap leach operation in Peru. This 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 samples are presented in Table 1.

The samples were remolded with three different dry unit weights: 16.2, 16.7 and 17.2 kN/m³, and an application of 8 lt/hr/m² 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/m³ density represents the density of the ore loosely poured into the mold without compaction and is lower than measured in the heap, even in the uppermost lift. The other two samples were compacted to specific densities, representative of *in situ* densities. The average density at the surface of the heap based on *in situ* measurements was 16.6 kN/m³.

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 degree of saturation was determined after completing tests, at times t_0 and t_{24} . Results of the tests are presented in Table 2 and Figure 2.

Table 2. Degree of Saturation for 8 lt/hr/m²

| Sample | Time | Degree of Saturation (%) | | |
|------------|----------|--------------------------|-----------------|-----------------|
| | | $\gamma_d=16.2$ | $\gamma_d=16.7$ | $\gamma_d=17.2$ |
| 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 |

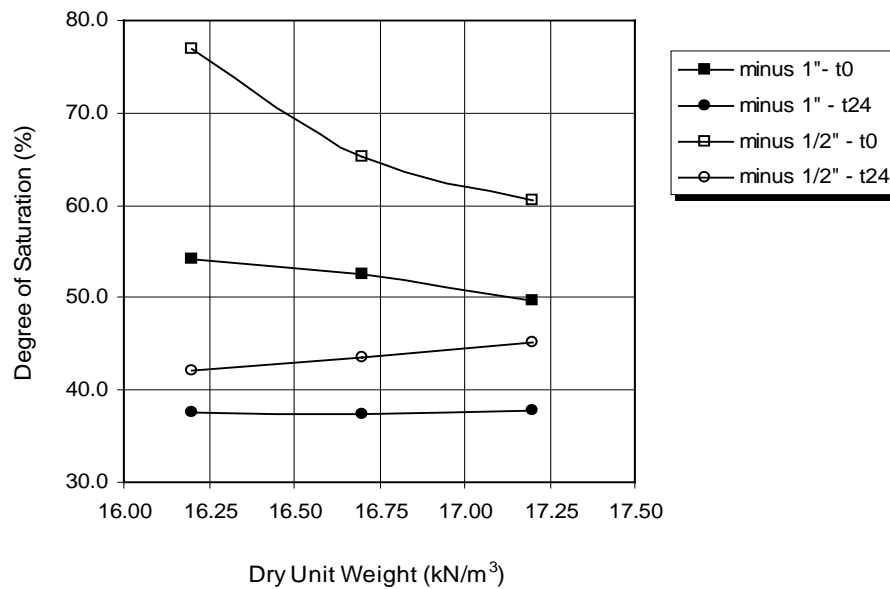


Figure 2. Results from Degree of Saturation Tests.

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 this site is approximately 18 lt/hr/m². This is considered the worst case scenario for analysis of liquefaction as well as other slope failure modes. 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/m³) 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/m²

| 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.

PRELIMINARY LIQUEFACTION 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 a granular material is less than 85 percent, the development of excess pore water pressure necessary to trigger static liquefaction is not to be expected. A rigorous evaluation should be completed (see Dawson, et al, 1998, for methodology) when the results are near or above 85 percent. Such an analysis examines other factors associated with collapse potential and trigger mechanisms. Similar conditions exist for dynamic liquefaction, with the threshold saturation level about 70%.

For this material, the data indicates that during irrigation plus the maximum storm event the degree of saturation is well under 85 percent and just under 70%. This is a favorable condition

under which excess pore water pressure can not develop and indication good resistance to both static and dynamic liquefaction.

CONCLUSIONS

Liquefaction is a potentially catastrophic failure mode. As heap and dump leaching technology expands, and as heap heights increase, there are parallel risks of liquefaction: higher densities resulting from deeper heaps which increases the basal degree of saturation, and the potential consequences of a flowslide failure caused by static liquefaction become increasingly catastrophic. With this method of analysis the authors suggest a simple method by which preliminary screening can be performed on a heap's sensitivity to liquefaction failure.

In the future, further tests will be performed using different ore 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. Ultimately, it is expected that a general relationship between heap height (*in situ* density) and operating saturation levels will be developed, based on general material properties such as grain size and clay content.

Other valuable data which can be generated by this test is the drain down volumes as a function of drainage time, a factor critical in designing pond storage capacity criteria and in planning the rinse phase for dynamic (on/off) pads and in closure of conventional heaps. This data can also be used to estimate metal inventories during operation and lag times between leaching and metal production.

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