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## Applying vacuum in one dimensional and isotropic test carried out in remolded material

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**ABSTRACT:** The technique of soft soils improvement with vacuum consolidation is more and more used, in different places around the world, because it offers a series of advantages compared with other techniques of soft soils improvement, depending of the kind of project. The laboratory tests are important sources of information for projects of soft soils improvement. In this work are presented the procedures and the results of one-dimensional compression test (consolidation press) and isotropic compression test (the triaxial cell), applying vacuum and using remolded material. For made this, was necessary the development of procedure for the applying vacuum in the tests. Difficulties happened during this development, this situation forced to test different techniques until to obtain a satisfactory operation. With the development of the procedures was done a series of tests to know the results that these tests provide. With the results obtained were done analyses for its interpretation. It was proved experimentally that the vacuum works as a loading for the consolidation of soft soils.

**Keywords:** soft soils improvement; vacuum consolidation; laboratory test.

### 1 INTRODUCTION

The vacuum consolidation technique for improvement of soft soils, proposed by W. Kjellman (1952), has been used in different constructions around the world, principally in Oriental countries like Japan, South Korea, Malaysia, Thailand, Vietnam, China and in European countries like France and Germany, as it's studied in works such as Masse et al. (2001) and Chai et al. (2006). In these countries also have been development investigations for the study of this technique in geotechnical laboratories in works such as Chai et al. (2009) and de Rujikaitkamjorn et al. (2008).

In the field, this technique works with the use of vertical drains to bring the vacuum pressure until the layer of soft soil. The connection of vacuum pumps system to vertical drains can be carried out using a system with membrane or drain to drain system.

In Brazil, there is one experience of the use of this technique, which is described in the work of Sandroni, Andrade, Odebrecht, 2012.

The present work studied the use of vacuum in two tests of a conventional geotechnical laboratory:

- Conventional consolidation test (of incremental loading) with odometer in the Bishop's press;
- Isotropic consolidation test, in the triaxial cell, with drainage for one extreme of the sample and pore pressure measurement in the other extreme: This test allows studying the variation of pore pressure along the time, during a process of consolidation.



Figure 1. Sealing during the stage of application of vacuum.

### 2 PROCEDURES OF APPLYING VACUUM

Bonilla (2013) describes all the details and procedures for applying vacuum in laboratory.

#### 2.1 In the one-dimensional compression test

The objective of this test is to know the behavior over time of a sample of soft soil, in odometer in the Bishop's press, in the test of incremental loading, when it is submitted to application of a vacuum pressure.

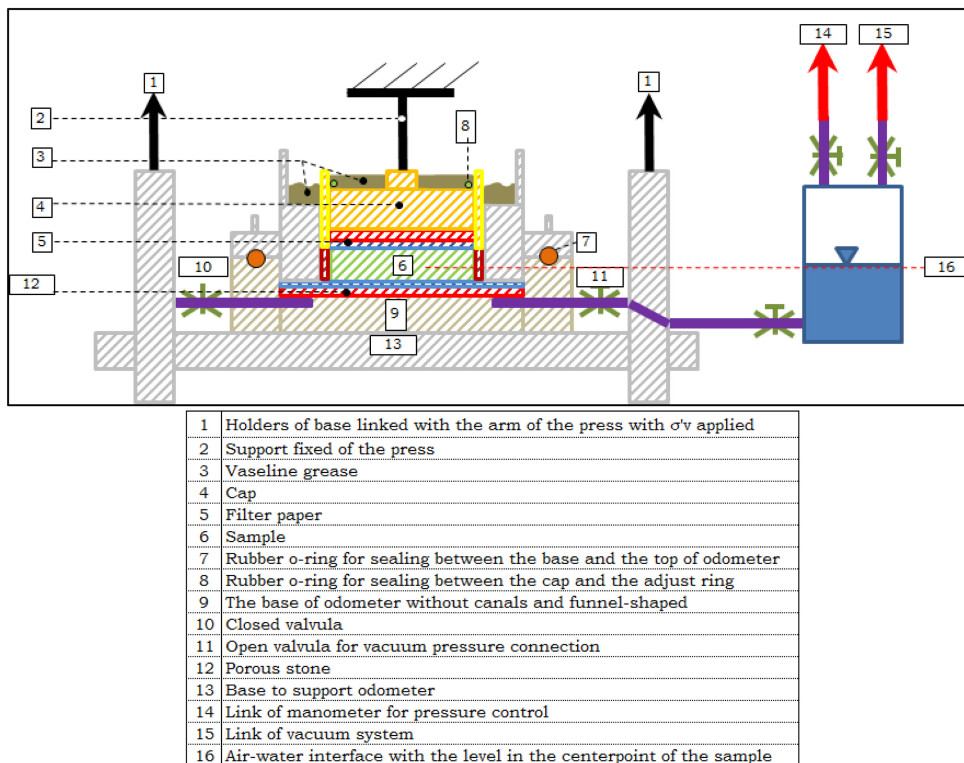


Figure 2. Scheme of odometer used, with the connections to the execution of vacuum consolidation stage.

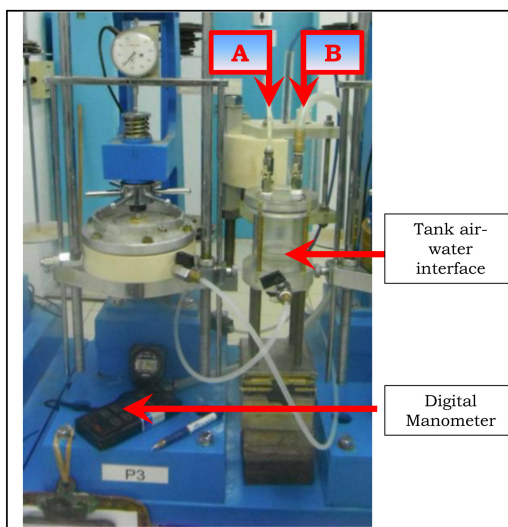


Figure 3. Odometer mounted on the Bishop's press ready to start the stage with vacuum pressure.

Was used grease of Vaseline for sealing the contacts between the cap and odometer top (See Figure 1), in this form was avoiding the air intake and pressure fall.



Figure 4. Cracked and spaced sample from the confinement ring after being submitted to a vacuum pressure.

The Figure 2 presents a detailed diagram of the odometer and the connections made for the vacuum application.

In the Figure 3 are presented the photo of the test already assembled.

It was made a test, with only two stages, the first stage with 3.75 kPa of conventional effective vertical stress with weights, and the second stage with vacuum pressure of 80 kPa. During the application of vacuum pressure was observed that the sample

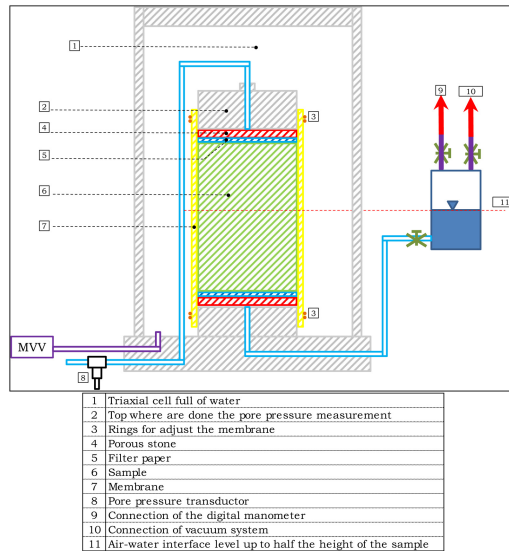


Figure 5. Scheme test set-up in the triaxial cell.

separates from the containment ring (this situation was also observed by Chai 2007) and the formation of cracks and in the sample. The cause of this situation is that the vacuum pressure it's much higher than the initial effective stress in the sample (see Figure 4).

## 2.2 In the isotropic compression test.

This test of isotropic consolidation is done by draining from one of the extremes of the sample (in this work from the bottom) and measuring the pore pressure at the other extreme.

The objective of this test is to know the pore pressure variation along the time for samples of different heights, during a process of consolidation produced when is used vacuum pressure joint with the action of loading for a triaxial confinement stress.

In the Figure 5 is showed the test mounting scheme in the triaxial cell.

## 3 SYSTEM OF VACUUM PRESSURE APPLICATION

In the field, the vacuum pressure is applied to a closed tank that contains an air-water interface. A vacuum pump is connected in the upper part of the tank (air) therefore the vacuum pressure is transmitted to the water of the bottom part that is connected to a system of vertical drains, which are installed in soft clay layer, through pipes or a membrane system (system Menard). In this work it was used an air-water interface in a tank with dimensions appropriate for laboratory tests, see Figure 6).

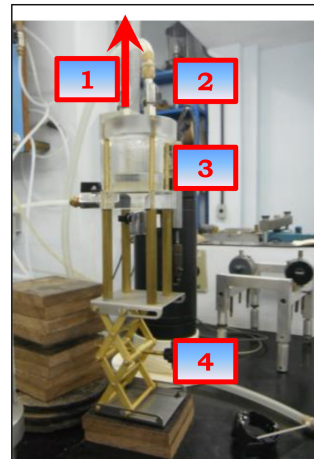


Figure 6. Connections in the tank of the air-water interface.

1. Connection to line of vacuum pressure
2. Connection of the digital manometer
3. Air-water interface
4. Pantographic base to level the air-water interface up to half the height of the sample.

## 4 LABORATORY TEST PROGRAM

### 4.1 One dimensional compression test

Was doing with the stresses showed in the Table 1, two tests, the V-10 with vacuum in the stage 7 and the V-11 without vacuum.

### 4.2 Isotropic compression test.

Table 2 shows a list of the tests done.

Table 1. Stresses used in each of the stages of one test.

Stage	Loading or unloading	Stress applied in the stage (kPa)	Total stress (kPa)
1	Loading	3.76	3.76
2	Loading	6.24	10
3	Loading	10	20
4	Loading	20	40
5	Loading	40	80
6	Loading	80	160
7	Loading	80	240
8	Unloading	-80	160
9	Loading	80	240
10	Loading	240	480
11	Unloading	-240	240
12	Unloading	-160	80

Table 2. Summary of the isotropic consolidation tests.

Item	Test number	Vacuum pressure?	Height sample
1	1BJ	Without vacuum pressure	2.90 cm
2	2BJ	With vacuum pressure	2.97 cm
3	3BJ	Without vacuum pressure	4.53 cm
4	4BJ	With vacuum pressure	4.62 cm
5	5BJ	Without vacuum pressure	6.16 cm
6	6BJ	With vacuum pressure	5.93 cm
7	7BJ	First stage without vacuum Second stage with vacuum	5.95 cm

## 5 CHARACTERIZATION OF THE USED MATERIAL

The used material for these series of tests is from a deposit of very soft soils of Barra da Tijuca, which belongs to a coastal plain of Rio de Janeiro (RJ), known as Baixada de Jacarepagua. The material was collected at a depth of 12.70 m in a campaign to extract samples, done in June 2009, for an embankment project in this region.

This material was remolded adding water to obtain an homogeneous mass and with appropriate consistency for preparing the test samples.

The characterization of this material is summarized in Table:

## 6 TEST RESULTS

### 6.1 One dimensional compression test

In the Figure 7 is showed a comparison of the curves of the strain percentage vs. square root of time, obtained in stage No. 7 done with vacuum pressure in the test 10 and without vacuum in the test 11.

The curve of the stage made with vacuum pressure shows at various times, percentages of deformation lower than the obtained in the curve of the stage made

Table 3. Characterization material used in the test.

Characteristic	Value	Unit
Liquid limit	245.00	%
Plasticity limit	113.50	%
Plasticity index	131.50	%
Organic matter contents	19.80%	%
Specific real mass of grains	2.39	g/cm <sup>3</sup>
Soil particles (%)		
Clay (%)	23.50	%
Silt (%)	47.40	%
Sand (%)	29.10	%

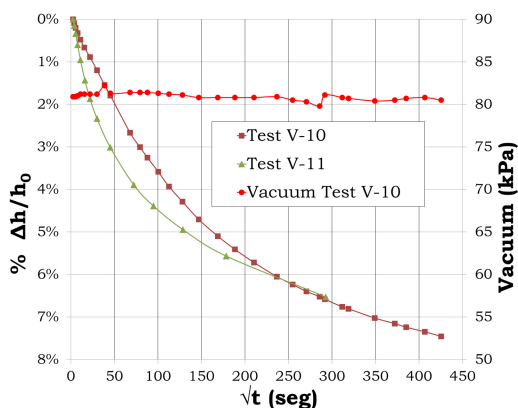


Figure 7. Comparison of curves, strain percentage ( $h_0$  = starting height in the stage) vs. square root of time, obtained in stage 7 of the tests No. 10 and No. 11.

with the same pressure, but with weights (conventional method of surcharge loading), until the two curves come to the some point, in which settlements are similar for the same time. In the phase of the secondary compression where the two curves have a very similar inclination.

In the Figure 8, is showed the curve of  $U(\%)$  Vs.  $T_v$  (percentage of consolidation, vs. time factor) calculated from the results obtained in the seventh stage of the test V-10, done with vacuum pressure. It is evident that the behavior of this stage of consolidation is governed by the one-dimensional consolidation curve.

It is verified experimentally that applying a vacuum pressure produces settlement like the application of loading with weights.

The Figure 9 are showed the curves of void ratio vs. logarithm of vertical effective stress ( $e$  vs.  $\log \sigma'_v$ ) obtained in the test No. V-10 and No. V-11.

It can be seen that the two curves are very similar.

It is evident that the stage 7, made with vacuum pressure has a similar behavior, at the end of stage, to that obtained at the same stage made with conventional loading with weights.

### 6.2 Isotropic compression test.

The Figure 10 presents the curve  $U(\%)$  vs.  $T_v$  calculated with the results obtained in the tests 6BJ. It is

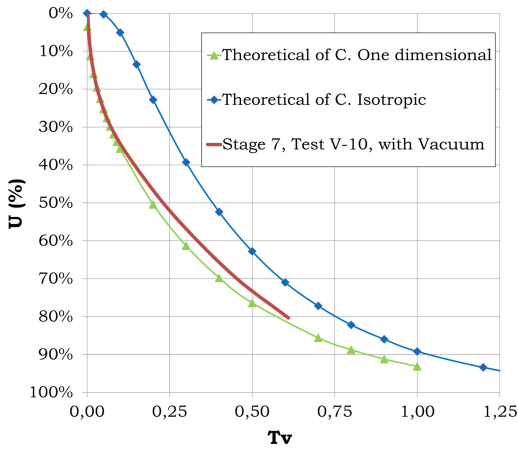


Figure 8. Curve  $U$  (%) vs.  $T_v$  calculated with the results obtained in stage 7 of the test V-10.

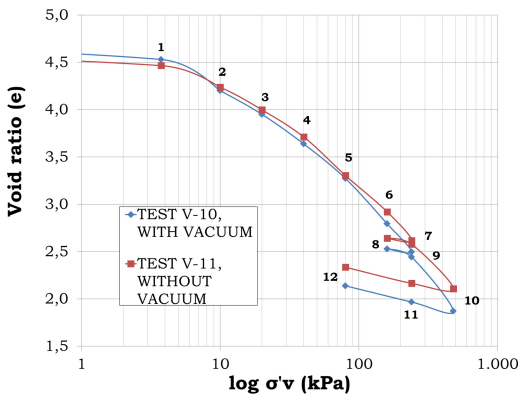


Figure 9. Comparison of the curves  $e$  Vs.  $\log \sigma'v$  obtained in the test No. 10. and No. 11.

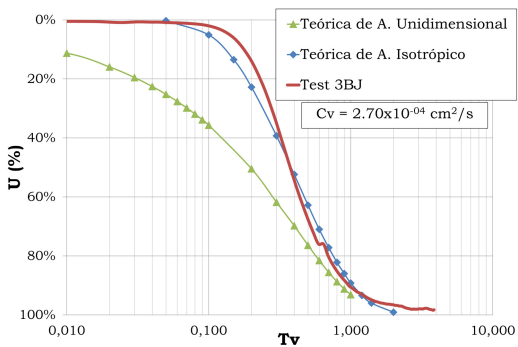


Figure 10. Curve  $U$ (%) vs.  $T_v$  for the calculation of the  $c_v$  of the material tested in the test 6BJ.

evident that the behavior of this consolidation test is governed by the curve of isotropic consolidation.

Similar results were obtained in tests 2BJ and 4BJ.

In the Figure 11, are showed a graph with curves pore pressure (kPa) vs. time (hours) obtained in the test 5BJ, 6BJ and 7BJ.

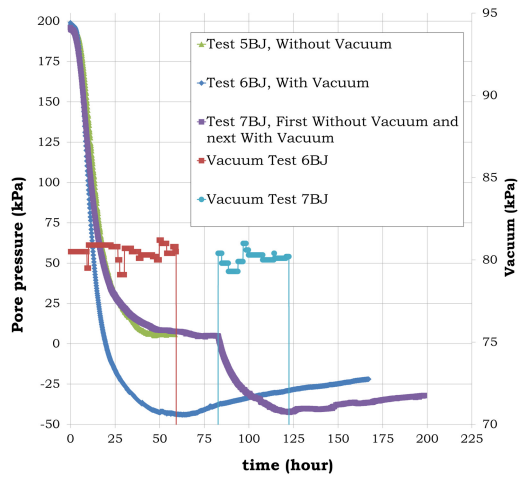


Figure 11. Comparison of the curves Pore pressure (kPa) vs. time (hours) obtained in tests 5BJ, and 6BJ 7BJ done with sample of 5.95 cm of height.

It can be observed that at the beginning the two curves are very similar. After, the curve without vacuum pressure starts to stabilize while the curve of the test with vacuum pressure continues descending until it stabilizes at one pressure of  $-44$  kPa.

In other tests were observed a similar behavior.

The test 7BJ was made in two stages. In first staged one without vacuum pressure, only had the consolidation for the action of the confining pressure (200 kPa). In the second stage was applied vacuum pressure until the pore pressure has stabilized at  $-42$  kPa. The curve of the first stage is very similar to the curve obtained in the test 5BJ and the entire curve obtained by two stages arrives at pressure stabilization very similar to the obtained in the test 6BJ. This test allows to observe a curve of variation of pore pressure only by the action of the vacuum pressure.

## 7 CONCLUSIONS

The use of vacuum pressure in a geotechnical laboratory for the realization of testing of consolidation, presents various challenges for the test mounting. In this paper are described some difficulties encountered and the solutions used to ensure the functionality of the tests.

It is verified experimentally that the vacuum pressure works as a surcharge loading for the soft soils consolidation.

The shape of the curve of the percentage of consolidation (%  $U$ ) vs. time factor ( $T_v$ ) obtained on a stage with vacuum loading, corresponds to the shape of the curve of one-dimensional consolidation.

The shape of the curve of consolidation percentage (%  $U$ ) vs. time factor ( $T_v$ ) obtained in a test using vacuum pressure, corresponds to the shape of the curve of isotropic consolidation.

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