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Taming of large diameter triaxial setup

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Abstract. Triaxial tests are essential to estimate the shear strength properties of the soil or rock. Normally triaxial tests are carried out on samples of 38 mm diameter and 76 mm height. Granular materials, predominantly used in base/sub-base construction of pavements or in railways have size range of 60-75 mm. Determination of shear strength parameters of those materials can be made possible only through triaxial tests on large diameter samples. This paper describes a large diameter cyclic triaxial testing facility set up in the Geotechnical Engineering lab of Indian Institute of Science. This setup consists of 100 kN capacity dynamic loading frame, which facilitates testing of samples of up to 300 mm diameter and 600 mm height. The loading ram can be actuated up to a maximum frequency of 10 Hz, with maximum amplitude of 100 mm. The setup is capable of carrying out static as well as dynamic triaxial tests under isotropic, anisotropic conditions with a maximum confining pressure of 1 MPa. Working with this setup is a difficult task because of the size of the sample. In this paper, a detailed discussion on the various problems encountered during the initial testing using the equipment, the ideas and solutions adopted to solve them are presented. Pilot experiments on granular sub-base material of 53 mm down size are also presented.

Keywords: triaxial test; laboratory study; cyclic test; large scale testing; installation.

1. Introduction

Triaxial tests are very widely used for obtaining the stress-strain response of soils and rocks and are normally carried out on samples of 38 mm diameter and 76 mm height. Granular materials used in the construction of pavements normally range in 60-75 mm size. For rural roads, Indian Roads Congress (IRC: 2004) specifies size of aggregates in the range of 26.5-75 mm based on the grading. To determine the mechanical properties and stress-strain response of these aggregates, a triaxial set-up which can test large size specimens is essential.

Triaxial tests on large diameter specimens were started in late 1960's for testing prototype rockfill materials, generally used in rockfill dams. Later large diameter triaxial testing was extended to ballast, road aggregates and soils. Experimental work carried out by Marshal (1967), Marachi *et al.* (1972), Indraratna *et al.* (1993) are few among the studies that describe large diameter triaxial testing. Monotonic or repeated or cyclic triaxial tests on ballast were carried out by researchers like Raymond and Williams (1978), Bathurst and Karpurapu (1993), Suiker *et al.* (2005), Aursudkij (2007) and Indraratna *et al.* (2010) to evaluate the stress-strain response of ballast. Unlike the

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ballast which comprises more or less of same sized particles, the base/sub-base course layer in pavement comprises of graded aggregates bounded with non-plastic fines. Since the pavement base/sub-base is non-plastic and at the same time free draining, many challenges are involved in its preparation and testing.

This paper describes a large diameter cyclic triaxial testing facility, set up in the Geotechnical Engineering Laboratory of Indian Institute of Science. Major issues in conjunction with the preparation and testing of samples of 300 mm diameter and 600 mm height using graded sub-base aggregates are also discussed. Pilot experiments to obtain the stress-strain response of the granular sub-base material under static condition at three confining pressures of 50 kPa, 150 kPa and 200kPa are presented.

2. Experimental set-up

The cyclic triaxial test set up described in this paper is designed to be used with a triaxial cell with a maximum working pressure of 1000 kPa for specimens with diameter range of 38-300 mm. It is provided with a 100 kN load frame fitted with a cyclic actuator which can apply cyclic loading up to 10 Hz frequency. Photograph of the cyclic triaxial testing facility is shown in Fig. 1. The basic system consists of the following components:

a) 100 kN capacity load frame with cyclic actuator
b) Hydraulic power pack for the load frame
c) Dynamic control system for data acquisition and control

Fig. 1 Cyclic triaxial set up in the Geotechnical Engineering Laboratory of Indian Institute of Science

d) 1000 cc/2 MPa advanced pressure and volume controller
e) Pneumatic regulator for cell pressure
f) Triaxial cell

The hydraulic load frame is powered by a hydraulic power unit. The triaxial cell comprises of a cell base, an access ring, a cell top and a ram. The cell base has ports for measurement of cell pressure, back pressure and pore pressure. The access ring has a large diameter port for dynamic cell pressure and eleven spare ports for LVDT transducers. The cell top has ports for de-airing the cell, pneumatic cell pressure application and a connection to the top extension cap. The details of the accessories of the triaxial cell are shown in Fig. 2.

There are two load cells, one of 100 kN capacity and the other of 10 kN capacity which enable testing of small and large samples. The load cells are of submersible type and are within the triaxial cell. The frame is also equipped with an external load cell of 100 kN capacity. The top beam of the load frame can be raised and lowered by loosening the bolts using torque wrench. This facilitates testing of small and large diameter samples. The maximum axial displacement is 100 mm. The maximum pressure output of the pneumatic regulator for application of cell pressure is 1000 kPa. The back pressure application is made using a digital volume controller.

A two-part split mould is provided for preparing the samples. Triaxial specimens are prepared within a split mould on top of the pedestal. Samples are enclosed within the membrane and sealed by O-rings/clamps at both the ends to have a water tight seal. Porous stones and filter paper circles are placed on top of the pedestal and on top of the prepared specimen to prevent clogging of holes by the fines present in the sample. Once the sample is prepared, the top plate is placed in position and the membrane is clamped to the top plate using O-rings/clamps followed by the removal of the split mould. There are two attachments provided to the top cap, one that facilitates the static testing

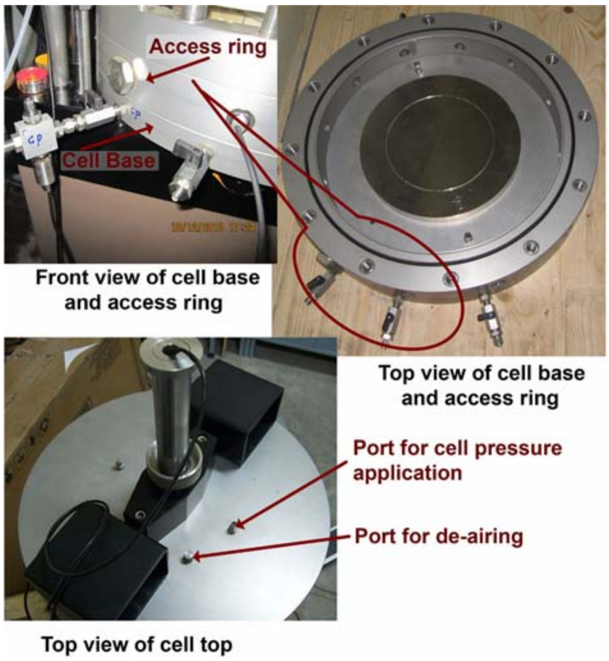

Fig. 2 Parts of the triaxial cell

Fig. 3 Triaxial sample of 300 mm diameter and 600 mm height with LVDT's for local axial and radial strain measurements

and other that facilitates the cyclic testing. Either of these can be used based on the type of testing. This is followed by lowering of cell on top of the prepared specimen. The whole assembly is then moved to the load frame.

Transducers are available for accurate measurement of pore pressures, local axial and radial strains. Two local axial strain indicators and one local radial strain indicator are available. The local axial strain indicators are attached to the specimen diametrically opposite to each other and the local radial strain indicator is attached at the centre of the axial strain indicators. Triaxial sample of 300 mm diameter and 600 mm height with LVDTs attached for local axial and radial strain measurements is shown in Fig. 3. The local LVDTs (both axial and radial) can measure deformations up to 20 mm and are attached to the surface of the specimen before the placement of the cell. The confinement to the triaxial sample is provided through air-water interface where water is pressurised by the air. Hence, pressurised air is made to enter the cell from top and the cell pressure transducer block is attached to the base of the triaxial cell. The back pressure is applied through the top of the specimen and pore pressure is measured at the bottom of the cell. The transducers for measurement of back pressure and pore pressure are connected to the cell base.

3. Initial problems

Preparation and testing of large diameter triaxial specimens of 300 mm diameter and 600 mm height using aggregates is a difficult task because it involves the preparation of a large size homogeneous sample and protecting it against leakage during the test. The installation of the equipment and initial

Fig. 4 Manual and mechanical lifting of the triaxial samples

test phase encountered lot of problems. This section discusses the problems faced in the initial stages of using the set-up and the solutions adopted for the same. Results of some pilot tests conducted using this set-up are also discussed.

The triaxial cell for testing 300 mm diameter samples has a dead weight of 100 kg and with sample in position has a weight of around 200 kg. Initially, lifting, moving and placing of the triaxial cell on to the load frame was done manually which was laborious. To solve this issue a hydraulic hand operated boom was devised to facilitate lifting (maximum lift of 2 m). A rolling platform was also designed on top of the existing fork-lift to enable easy mounting of the prepared specimens to the load frame. Initially the cell base is placed on the floor and sample is prepared on the pedestal within the split mould. After that the cell base (with the sample within split mould) is shifted to the rolling platform fitted to the forklift using the boom. Once the sample preparation is completed, the same boom is used to raise the triaxial cell over the sample and place it on the pedestal for fixing. Fig. 4 shows the photograph of triaxial cell being lifted manually and mechanically.

Preparation of large diameter cohesionless triaxial specimens can be done only with the aid of split moulds, because the effect of gravity itself may cause the sample to collapse. One-part split mould was supplied with the set-up, which was found to be unfit for the task because it was impossible to detach the mould after the sample preparation, without the sample getting disturbed.. Hence a two-part split mould was procured, which was successfully employed for the sample preparation. Fig. 5 shows the photograph of the one- part and two-part split moulds used for sample

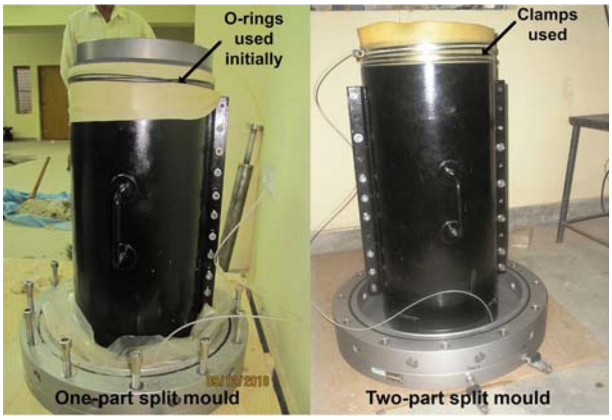

Fig. 5 One-part split mould and two-part split mould used in the experiments

preparation.

In triaxial testing, it is extremely important to make the sample leak proof in order to get accurate results. Because of the size and type of the sample, the O-rings were not sufficient to make the sample water-tight. During the preparation of sample, water was leaking out of the sample from bottom end even while great care was taken to seal the sample with O-rings. Hence special clamps were designed and fabricated to tightly seal the samples to the pedestal. These clamps were made of thin steel sheet and covered polythene tube so as to prevent the latex membrane from getting punctured by the used of clamps. Total four clamps, two at the top and two at the bottom were used to seal the sample. The O-rings and the specially designed clamps are shown in Fig. 5.

The porous stones used for testing are of 300 mm diameter and 6 mm thickness. During all trial tests, the porous stones were found to be broken after the completion of test. These porous stones are slender and brittle circular discs made of pumice stone and were found to be not suitable for aggregate testing because they are subjected to impact loads during compaction and testing of aggregates. Hence perforated plexiglass discs of size identical to that of the porous stones are fabricated to replace the porous stones. Fig. 6 shows the porous stone (before and after the test) and the custom made plexiglass disc.

The membrane used for enclosing the sample should be flexible and at the same time should not get punctured during the tests. Aggregates used in tests have sharp edges and corners, which pierce the membrane at high confining pressures applied. Initially for the preparation of 300 mm diameter triaxial samples, 0.6 mm thick latex membranes supplied along with the equipment were used. But these membranes were getting punctured during the test. Literature suggests the use of neoprene membranes for testing ballast and aggregates (e.g., Indraratna *et al.* 2010). Hence a 2 mm thick black neoprene membrane was molded specifically for this purpose and was used in few tests. It was observed that though the neoprene membrane could offer resistance to puncture, it is stiffer and the membrane exerts extra confining pressure on the specimen, thereby increasing the load bearing resistance of the specimen. Also, the neoprene membrane being less flexible compared to the latex membrane, it offered resistance to the free deformation of the sample. Hence the idea of using neoprene membranes to enclose the samples was discarded and it was decided to use thicker latex membranes. Latex membranes of 2 mm thickness were custom ordered and procured. Trial tests using 2 mm thick latex membranes were relatively successful with lesser issues of membrane

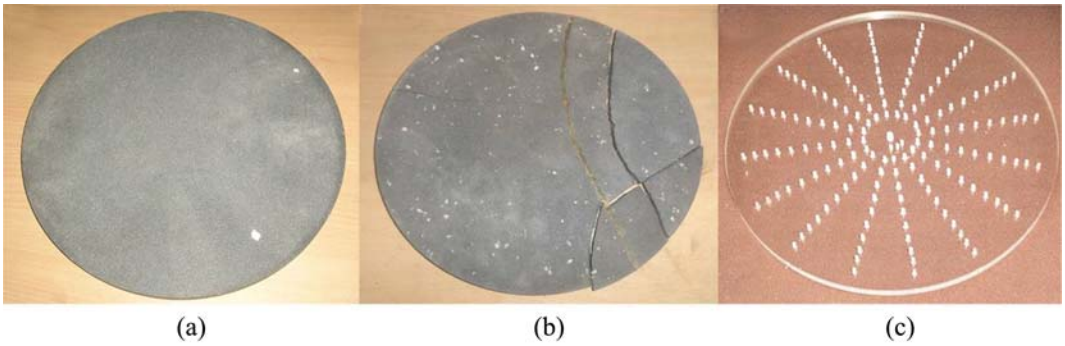

Fig. 6 Porous stone (a) Porous stone before test (b) Porous stone after test and (c) Custom made Perspex plate

puncture. After the preparation of sample and removal of split mould, wherever the aggregates showed signs of piercing into the membrane, those areas were patched up with extra pieces cut from same 2 mm thick latex membrane using glue A bi-cycle puncture kit as suggested by Aursudkij, 2007 was kept handy to seal punctures in the membrane, if any, after the sample preparation. With all these modifications and precautions, few trial tests could be completed successfully without any issues of leakage or membrane puncture. Sample preparation and testing is relatively simplified and pilot tests were carried out on the set-up, the details of which are described in next section.

4. Pilot tests

4.1 Materials used

For the pilot tests graded aggregates are used.. The material selected is such that it conforms to Grading II for granular sub-base design as given by Ministry of Rural Development, Specifications for rural roads, 2004. Aggregates of different sizes and quarry dust were mixed in specific proportions to obtain the graded aggregate conforming to Grading II. The grain size distribution curve of the chosen granular material is shown in Fig. 7. Particle size to triaxial specimen size issues were addressed by several researchers (Marachi *et al.* 1972 and Indraratna *et al.* 1993) and the term *Sample Size Ratio* was introduced. In triaxial testing, sample size ratio is defined as the diameter of the triaxial specimen divided by the maximum particle dimension. ASTM D4767 recommends a minimum sample size ratio of six for undrained triaxial testing. In the present study, the maximum particle size is around 45 mm, which would correspond to a sample size ratio of 6.7.

Since fines are there in the selected granular material, compaction and placement of the material itself was a difficult task. If the sample is dry it is appropriate to use vibration technique for sample preparation. Charles and Watts (1980), Indraratna *et al.* (1993), Anderson and Fair (2008), Arei *et al.* (2010) have used vibration technique for preparation of large diameter ballast/rockfill samples. Sevi *et al.* (2009) used shake table for the preparation of ballast specimens for large diameter triaxial testing. Suiker (2005) used layered compaction technique (using standard proctor hammer) for preparation of ballast or sub-ballast specimens for triaxial testing. The granular sub-base material used in the present study is a free- draining material. Hence, determination of optimum moisture

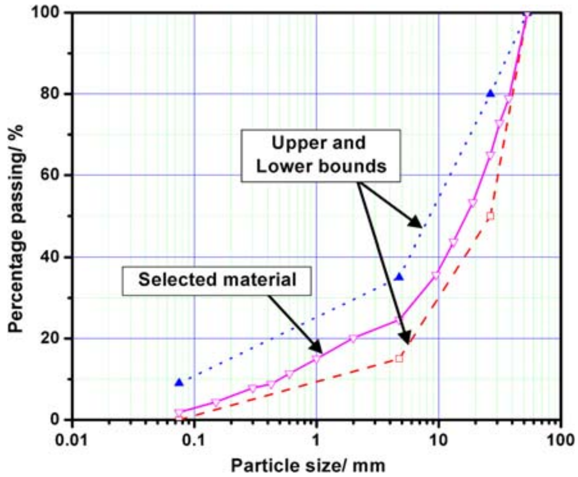

Fig. 7 Grain size distribution curve of the selected granular material

content using proctor method is difficult. The size of the granular material used in the tests is 53 mm down. ASTM D 4253, 2000 outlines a procedure for the determination of maximum unit weight of large size granular materials by using large mould (28 cm diameter and 25 cm height). This procedure was attempted for two trial mixes of granular sub-bases. The average water content of the compacted granular material so determined is 5% at a maximum wet density of 23 kN/m^3. In both the cases, water got segregated from the aggregates. Hence vibratory test was performed at a low water content of 3.1%, which yielded a maximum wet density of 22.58 kN/m^3. Manual compaction was also carried out on the granular material in the same mould at standard compaction effort using a rammer of 4.7 kg falling from a height of 450 mm at a water content of 3.1%. The wet density so attained (21.72 kN/m^3) is close to that attained using vibratory table method at lower water content. Hence, for preparation of samples, manual compaction was adopted and the water content was kept as 3.1%.

4.2 Sample preparation and testing

The triaxial specimen of 300 mm diameter and 600 mm height is prepared by the compaction of the granular material inside the split mould placed around the cell base. After placing the porous plate on the cell base, the 2 mm thick latex membrane is fitted to the triaxial cell base pedestal using clamps. The split mould is placed over the cell base and the membrane is stretched such that it fits the inner side of the split mould. Once the membrane is fully stretched it is held tightly to the walls of the split mould using clamps. Then the granular material is placed in layers and compacted. To achieve the maximum density (at standard compaction effort), if the sample is compacted in 5 layers, each layer is to be given 245 blows (using a rammer of 4.7 kg falling from a height of 450 mm). For the pilot tests, 1/4th of he standard compaction effort is used for sample preparation because it was seen from the trials that the variation in the density with variation in compactive effort for the aggregates is not substantial as it is for soils. Accordingly the sample is prepared in 5 layers and 62 blows are applied to each layer using the rammer mentioned above at a water content of 3.1%. The bulk unit weight achieved at 1/4th standard compaction effort is 19.70 kN/m^3. A

Fig. 8 Sample prepared within the membrane

Fig. 9 Triaxial cell with sample inside

photograph of the sample prepared within the membrane is shown in Fig. 8. Once the specimen is prepared, the surface is levelled and the porous disc is placed. After placing the top cap on the porous plate the membrane is fitted to the top plate using clamps.

The triaxial cell base with the sample in the split mould is shifted to the rolling platform using boom arrangement and then the split mould is removed. After that the sample is examined carefully for any puncture in the membrane. Any puncture in the membrane was sealed using a puncture kit and then the triaxial cell is lowered on to the sample using the boom. The triaxial cell is shifted to the loading platform. The ram is lowered so that it is in contact with the triaxial cell. Unconsolidated undrained tests are carried out at three confining pressures of 50 kPa, 150 kPa and 200 kPa. The confinement effect is provided through air-water interface. The level of water in the cell (surrounding the sample) before testing and after testing is checked to ensure that there is no puncture in the membrane during testing. Also the water content of the sample is verified after the test and observed to be unchanged. The triaxial cell with sample inside is shown in Fig. 9.

4.3 Experimental results and discussions

The experiments were carried out at a strain rate of 0.5 mm/min. The stress-strain plots for the graded aggregate at three confining pressures 50, 150 and 200 kPa are shown in Fig. 10. As the confining pressure is increased the peak deviatoric stress of the sample also increased as expected Fig. 11 shows the Mohr circles plotted for the granular sub-base at three different confining pressures, from which the cohesion and friction angle of the material are estimated as 40 kPa and 43.53° respectively. The p-q plot for the sub-base material is shown in Fig. 12.

The pore pressure variation in the sample is shown in Fig. 13. Pore pressure does not have much

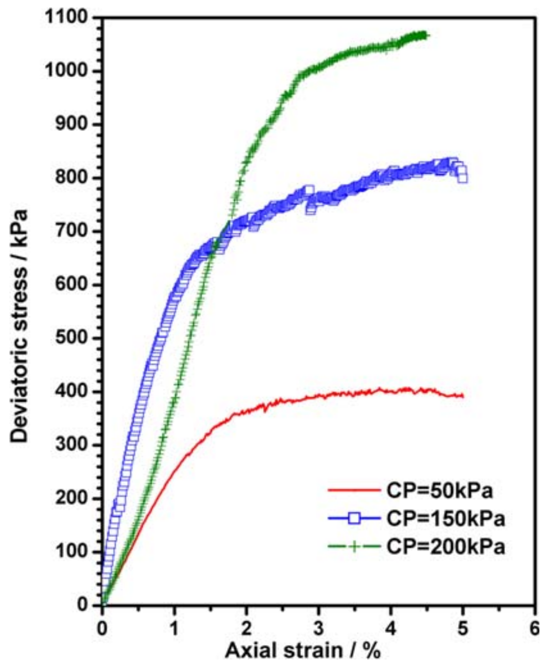

Fig. 10 Deviatoric stress vs axial strain plot for granular sub-base material at three confining pressures (50 kPa 150 kPa and 200 kPa)

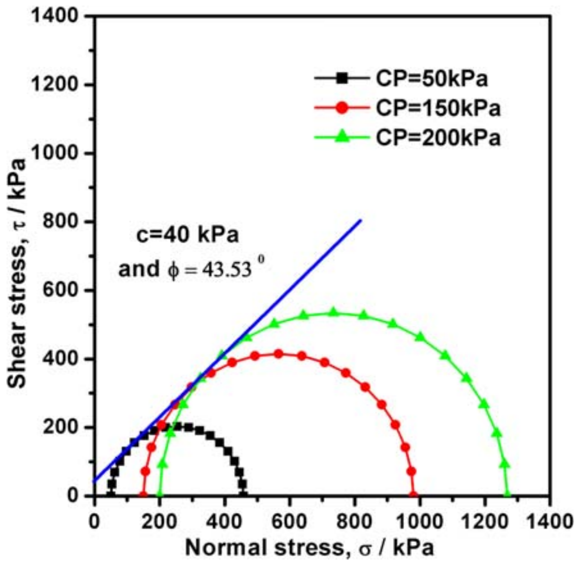

Fig. 11 Mohr circle for granular sub-base at three confining pressures of 50 kPa 150 kPa and 200 kPa

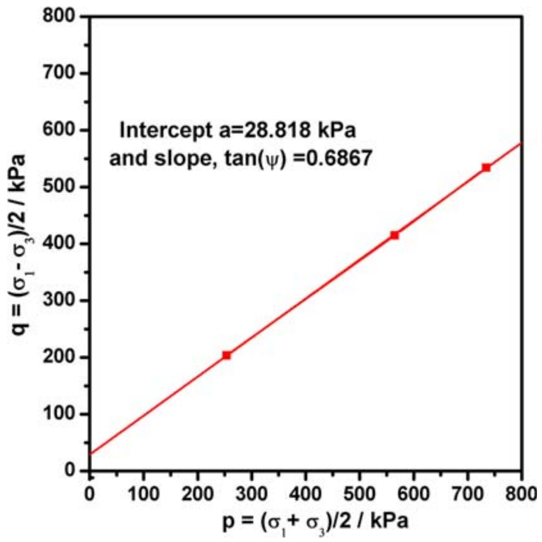

Fig. 12 Stress path corresponding to peak deviator stress at three confining pressures

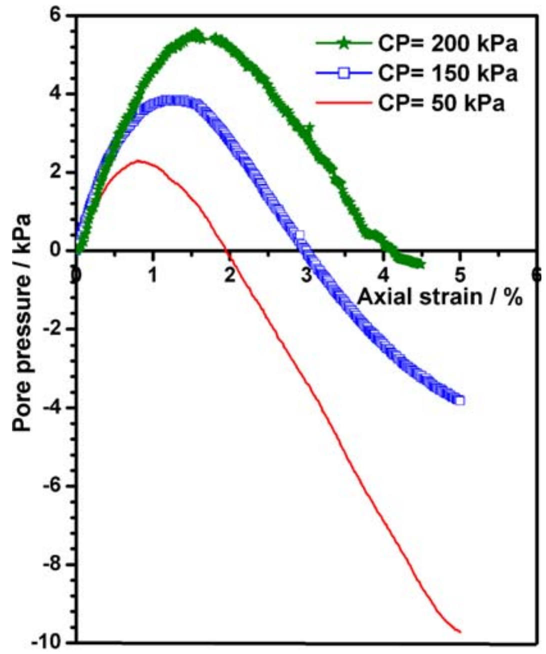

Fig. 13 Variation of pore pressure with respect to axial strain at different confining pressures

Table 1 Results obtained from unconsolidated undrained tests

Confining Pressure, kPa	50	150	200
Peak deviatoric stress, kPa	407.22	829.95	1068.20
Axial strain at (σ_1-σ_3)max, %	4.25	4.85	4.44
σ_1/σ_3 (maximum)	9.38	6.61	5.34

significance in these tests because the sample is not completely saturated and consolidated. But the pore pressures were measured during the tests to understand the response of the sample to the applied deviatoric stress. Any unusual increase or drop in the pore pressure would alert possible leakage inwards or outwards as observed in few trial tests. The pore pressure variation seems to be normal in the pilot tests and the increase in confining pressure resulted in the increase of pore pressure. The maximum pore pressure measured was about 6 kPa at a confining pressure of 200 kPa. At any specific confining pressure, with the increase in deviatoric stress, the pore pressure increased initially and started to drop after a specific axial strain. The strain at which the peak pore pressure was observed increased with confining pressure. The drop in pore pressure at higher deviatoric stress could be due to the increase in suction of the air voids in the sample.

Table 1 summarizes the results from the triaxial tests at three confining pressures. The peak deviatoric stress and the corresponding axial strain and the stress ratio (s_1/s_3) are given in the table The stress ratio is observed to decrease with the increasing confining pressure, as expected in triaxial tests.

5. Conclusions

This paper describes problems encountered while commissioning the large diameter cyclic triaxial testing equipment at Indian Institute of Science, Bangalore. Several issues like sample preparation and its transportation to the test set-up, leakage of water from the sample base, puncture of the membrane due to coarse aggregates, breakage of porous stones while testing are discussed in detail and the solutions and strategies adopted to solve all these issues are described. Finally, successful testing using the set-up and typical results are presented.

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