

CHAPTER 4- DESIGN, FABRICATION AND ASSEMBLY OF A MODIFIED CONSOLIDATION APPARATUS

4.1. Introduction

This chapter discusses the requirements for the design and fabrication of indigenously developed consolidation testing systems such as constant-rate-strain (CRS) loading consolidation, electrokinetic constant surcharge loading (EKCL), and electrokinetic constant-rate-strain (EKCRS) loading. Details of modifications required to use the conventional oedometer cell for performing the CRS test are also described.

4.2. Consolidation Loading Assembly

The IL, CL, and EKCL consolidation are stress-controlled loading techniques that are developed using a conventional incremental loading frame with modifications as per the requirements, as shown in figure 4.1 and 4.2. In this process, the soil sample is restrained laterally and drained axially while being subjected to constant or incremental stress. The pore pressure is assumed to dissipate based on the interpretation of the time deformation under constant total stress. The stress application continues until the excess pore water pressures are largely dissipated. This interpretation is based on the assumption that the soil is 100% saturated. The changes in the specimen height are measured and the data is used to evaluate the consolidation parameters.

The CRS and EKCRS consolidation are strain-controlled phenomenon that are performed using an existing triaxial assembly in the laboratory with modifications as per the requirements. In this process, the soil sample is confined axially between two parallel and rigid platens and laterally, such that the cross-sectional area remains constant. Drainage is

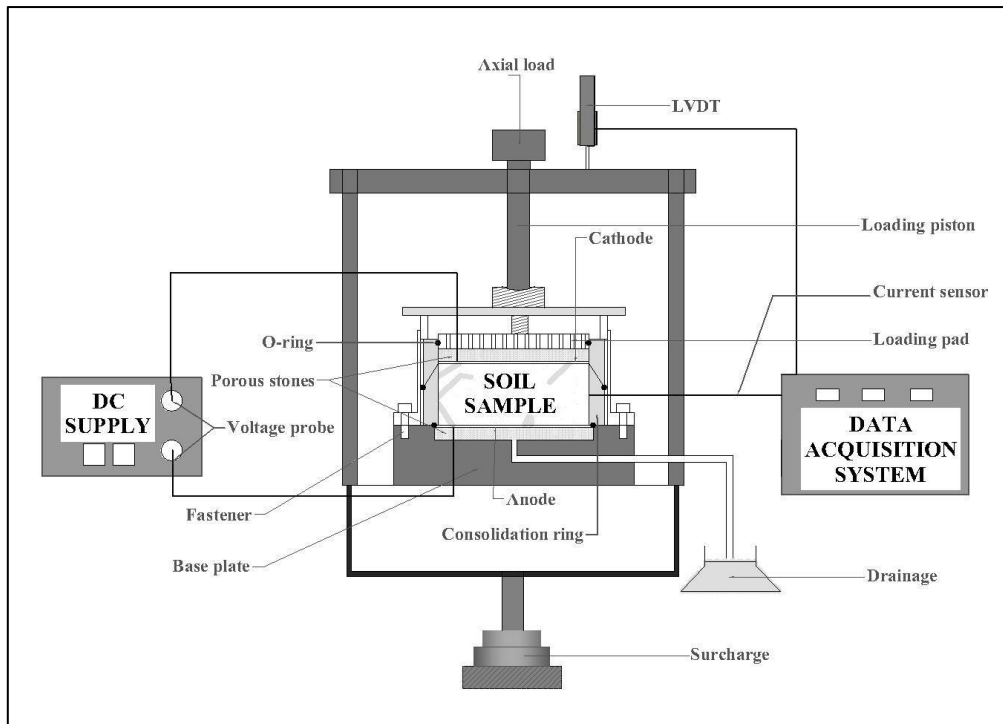
provided along one boundary (usually the top), and the fluid pressure is measured at the other sealed boundary (usually the base).

4.2. Brief Description of EKCL and EKCRS Systems

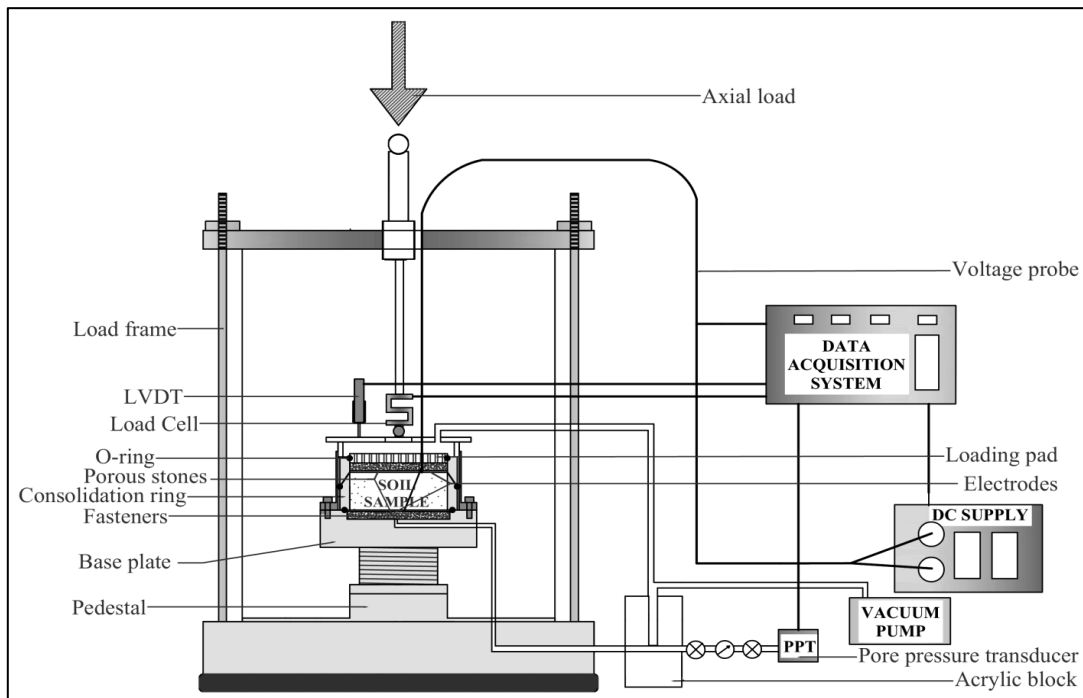
A system for electrokinetic constant surcharge loading (EKCL) soil consolidation, comprising a modified consolidometer ring for accommodating a soil sample that is to be consolidated. Wherein, the soil sample is sandwiched between two saturated filter papers, electrode discs and porous stones for enhancing the movement of water and facilitating the dissipation of pore water pressure (PWP). It is having the provision for providing at least two electrode discs preferably a cathode and anode for enhancing the movement of charged soil particles and water. Further, two porous stones are placed on the top and bottom of the consolidometer ring to allow free flow of water through the soil sample during the electrokinetic consolidation process. A vacuum pump is associated with the filter paper and porous stones and acrylic block for de-airing the porous stones and removing the excess amount of gas generated at the front of electrode discs throughout the electrokinetic process. The sensors for sensing a set of parameters generate respective signals and a data acquisition (DAQ) unit is connected to the sensors for measuring the set of parameters upon receiving the generated signals. The sensors include a linear variable displacement transducer (LVDT), pore water pressure (PWP) sensor, temperature sensor, voltage and current sensor and the set of parameters includes deformation, load, pore pressure, temperature, voltage and current respectively. The pore water pressure sensor (PWP) is a pore pressure transducer (PPT) that measures the pore pressure at the anode due to the combined effect of electrokinetic and hydraulic gradient and LVDT is connected to the consolidometer ring for measuring the soil consolidation (deformation) upon the employment of surcharge/mechanical load and electrode discs (electric gradient) on the soil sample.

Similarly, an electrokinetic constant rate-of-strain (EKCRS) consolidometer with a modified base plate and continuous controlled-strain axial compression has been designed for expediting the rapid consolidation process. It is capable of dissipating pore water pressure faster and is completely suitable for highly compressible soils, tailings and sludge. The EKCRS system has the feature of continuous monitoring of experimental data in real-time and saves time in acquiring the consolidation parameters. The EKCRS consolidometer, comprising of a base plate with a soil sample, a consolidation ring and a collar for proper positioning of the sample. The vacuum pump is for de-airing of the porous stones and for permitting the liberation of gas generated during an electrokinetic phenomenon, the block has a provision for an air vent and a water pressure sensor for the pore water pressure measurement. This system consists of two transducers for measuring pore pressure, one load cell for measuring an axial load, a vacuum pump, one loading pad, two porous stones, two electrodes and two sensors. The base plate has three openings for electrical wiring, a back pressure line for saturation of the soil sample, and an acrylic block and positions the consolidation ring with a provision of pore water pressure measurement, the transducers measure an axial deformation and pore water pressure respectively due to application of the constant strain rate. The sensors monitor voltage, current and temperature during the consolidation test. The EKCRS consolidometer includes a monitoring unit for online monitoring and controlling of parameters related to the soil sample and a data acquisition unit for automated recording and storage of the parameters and an axial load is applied at a constant strain rate.

The details of the EKCL and EKCRS apparatus modified in the present study are briefly illustrated in Figure 4.1 and 4.2.



(a) EKCL Consolidation Testing System



(b) EKCRS Consolidation Testing System

Figure 4.1 Schematic diagrams of EK consolidation testing systems

4.2.1. Loading device

The loading device is used for the application of constant axial loads (IL) or axial strain (CRS) to a soil specimen which is an essential component of consolidation testing

assembly. It must meet several technical requirements to ensure that the test results accurately reflect the behaviour of the soil under the specified loading conditions, without generating significant disturbances that could affect the test results. Figures 4.2 and 4.3 show the photographs of loading systems used in the present study.

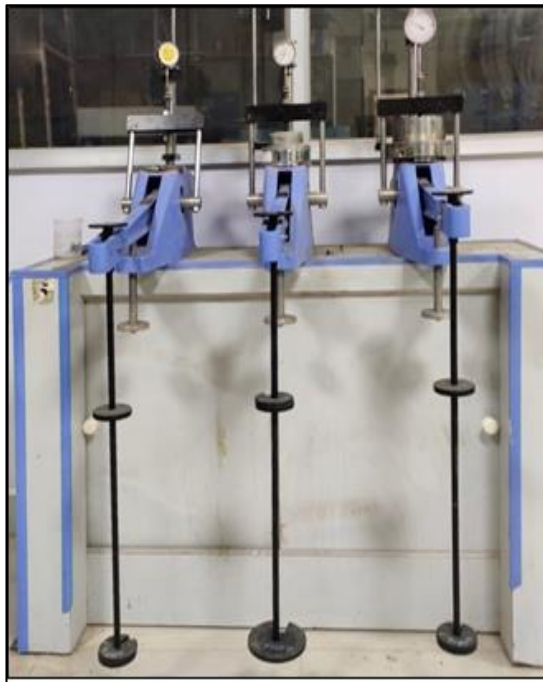


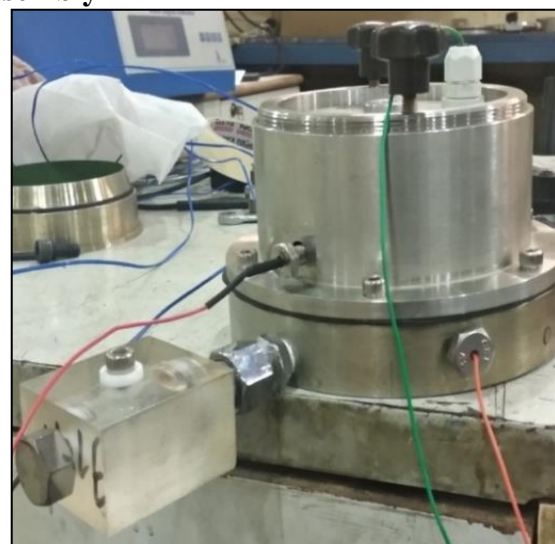
Figure 4.2 IL, CL and EKCL loading assembly



Figure 4.3 CRS and EKCRS loading assembly



(a) Assembly EKCL Oedometer



(b) EKCL Oedometer



(c) Individual components of EKCL Oedometer



(d) Consolidation made up with polycarbonate



(e) Metal consolidation cell with collar

Figure 4.4 Images of different loading assemblies used in EKCL

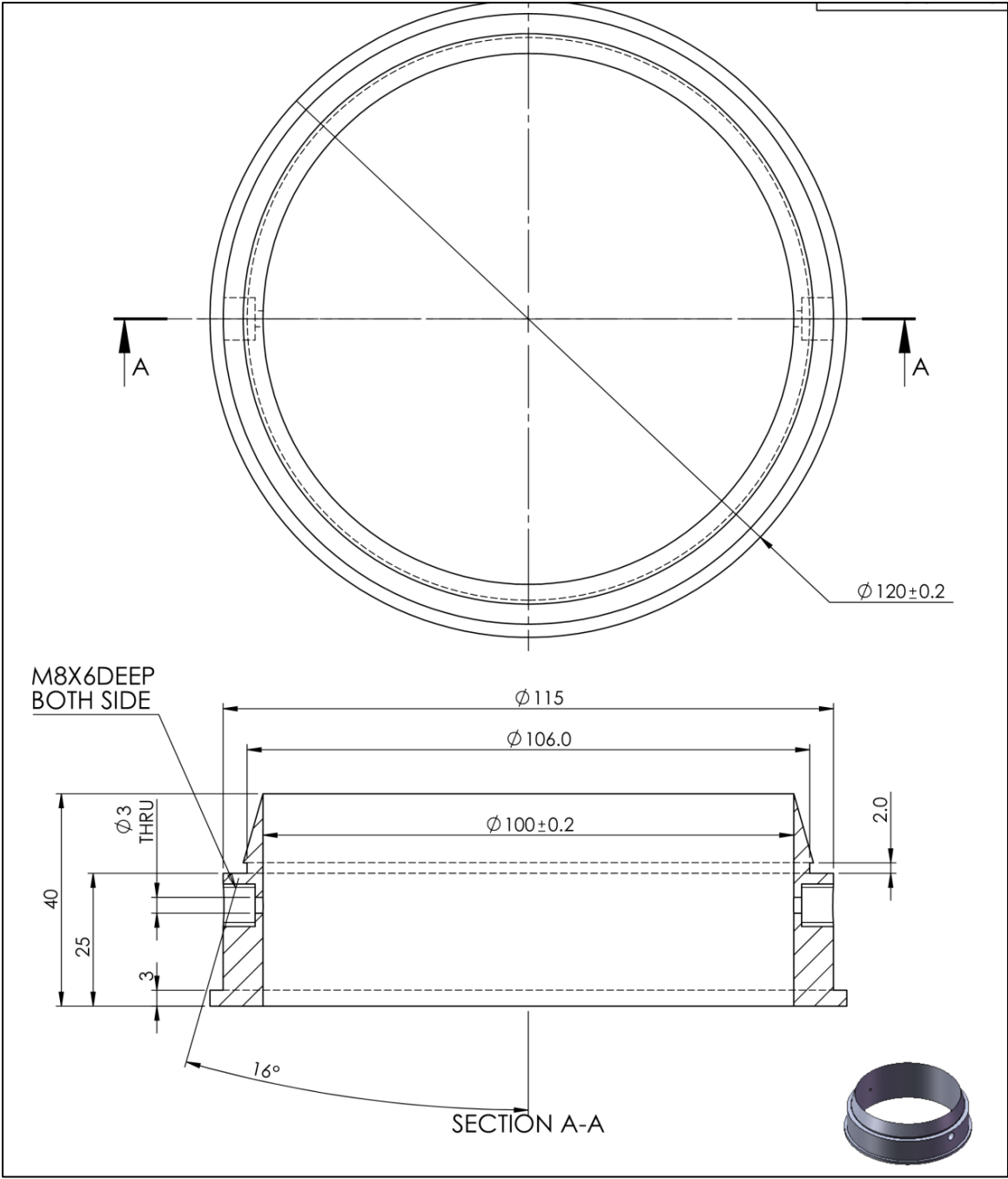
4.2.2. Consolidometer ring

The primary purpose of the consolidation ring is to hold a soil specimen within a confinement ring attached to a rigid base. A conventional consolidometer made of stainless steel with a height of 2 cm and diameter of 6 cm was used for performing conventional incremental loading (IL-C) tests. A modified consolidometer made of stainless steel (for IL-M and CL-M) or Polycarbonate (for EKCL and EKCRS) with a height of 4 cm and diameter of 10 cm was used for performing loading requirements and to accommodate soil specimens with a diameter-to-height ratio ranging from 2.5 to 4.0. The aspect ratio should be carefully considered for higher or lower aspect ratio, as it can significantly affect the

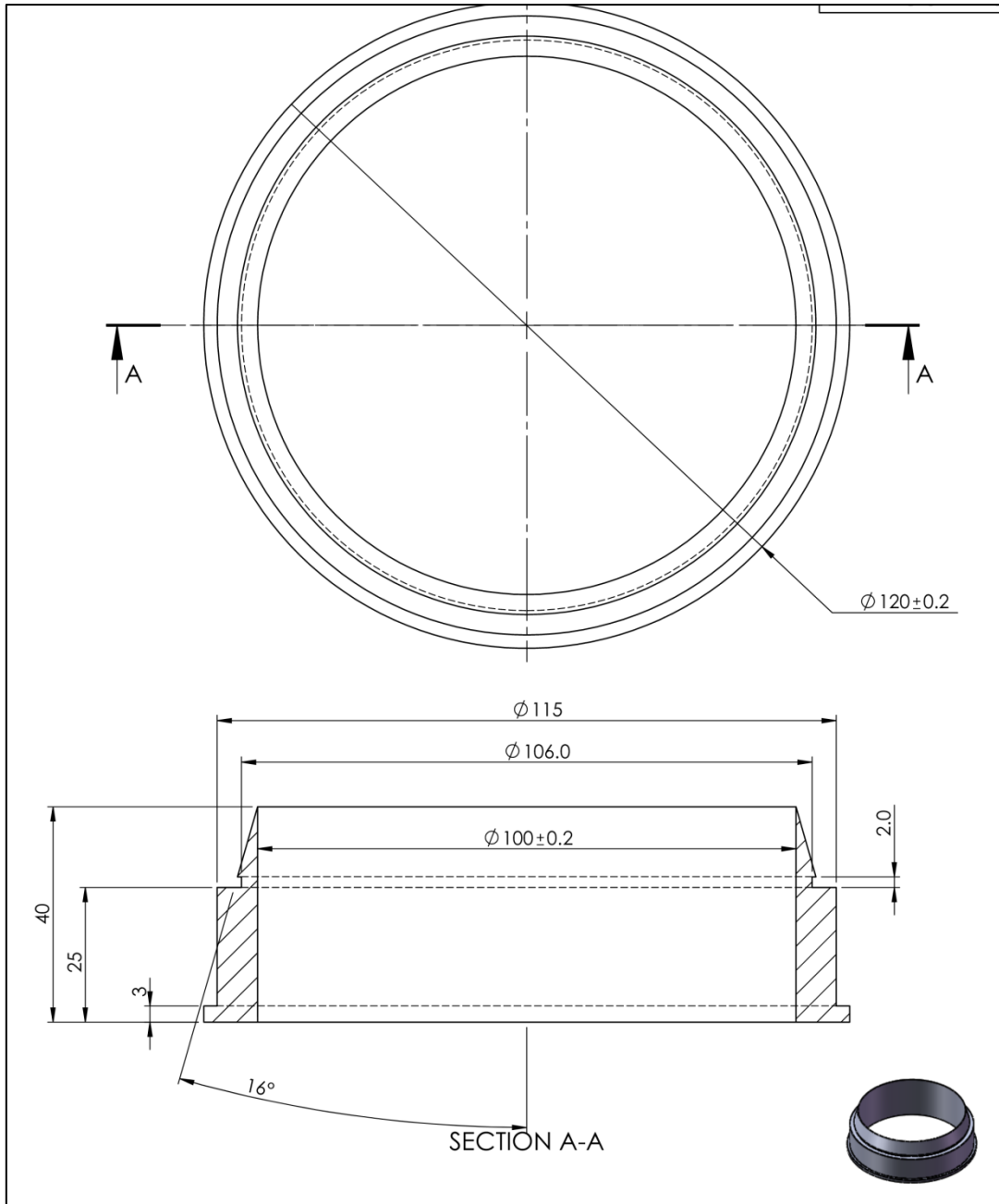
interpretation and applicability of consolidation test results. For instance, a higher aspect ratio may lead to a longer consolidation time due to increased path length for pore water to travel. On the other hand, a lower aspect ratio may result in faster consolidation but could lead to potential edge effects.

The inside diameter of the ring shall be fabricated to a tolerance of at least 0.1% of the diameter. The consolidometer shall also provide a means of submerging the specimen in water, for transmitting the concentric axial load as strain to the porous disks, and for measuring the axial deformation of the specimen. A major modification was performed for electrokinetic coupled consolidation ring with an opening for mid-voltage measurement. In this study, three different types of consolidometer rings were used.

This also involves the provision of incorporating saturated porous disks on both faces of the specimen and applying back pressure to it. The top platen should be rigid enough to distribute the load evenly across the top stone. To prevent corrosion from soil or other components, any submerged parts of the consolidometer must be made from non-corrosive materials. Additionally, the bottom of the confinement ring must create a leak-proof seal (with O-rings and vacuum grease) on the rigid base and be able to withstand internal pressures of up to 800 kPa (equivalent to 8 kg/cm²). The consolidometer must be designed to avoid trapping air at the base of the specimen during the placement of the confinement ring. The axial loading and back pressure maintenance systems may be integrated into one unit, and a typical schematic drawing with all dimensions in mm is shown in Figure 4.5(a) and (b)



(a) Consolidation ring used for electrokinetic coupled (EKCL and EKCRS) loading



(b) Consolidation ring used for mechanical (IL-M and CL-M) loading

Figure 4.5 Different consolidation rings used

4.2.3. Base plate

The base plate of the experimental setup includes three distinct openings, each serving a specific purpose in the electrokinetic coupled consolidation process. The first opening facilitates the application of direct current (DC) voltage for electrical measurements. The second opening is intended for attaching an acrylic block to facilitate the discharge of fluids and gases generated during the test, along with the inclusion of a pore pressure sensor to

measure changes in fluid pressure. Finally, the third opening is used for back pressure saturation of the soil specimen. In the case of mechanical loading, only single opening is required for the connection of pore pressure sensor. The schematic diagram of base plate used for the different consolidation types is mentioned in Figure 4.6 with all dimensions in mm.

These features of the base plate are essential components of the experimental setup for conducting geotechnical tests, particularly for evaluating the mechanical behavior of soil under different loading conditions. The ability to apply electrical measurements, discharge fluids and gases, and measure fluid pressure is crucial in obtaining accurate data on soil behavior during testing. Moreover, the inclusion of back pressure saturation ensures that the soil specimen is fully saturated with fluid, which is an essential condition for accurately measuring its mechanical properties.

Overall, the base plate with its three openings is a critical component of the experimental setup, enabling to accurately evaluate the properties and behavior of soils under varying conditions.

measures the pressure changes within the soil specimen during testing. The schematic diagram of acrylic block used is mentioned in Figure 4.7 with all dimensions in mm.

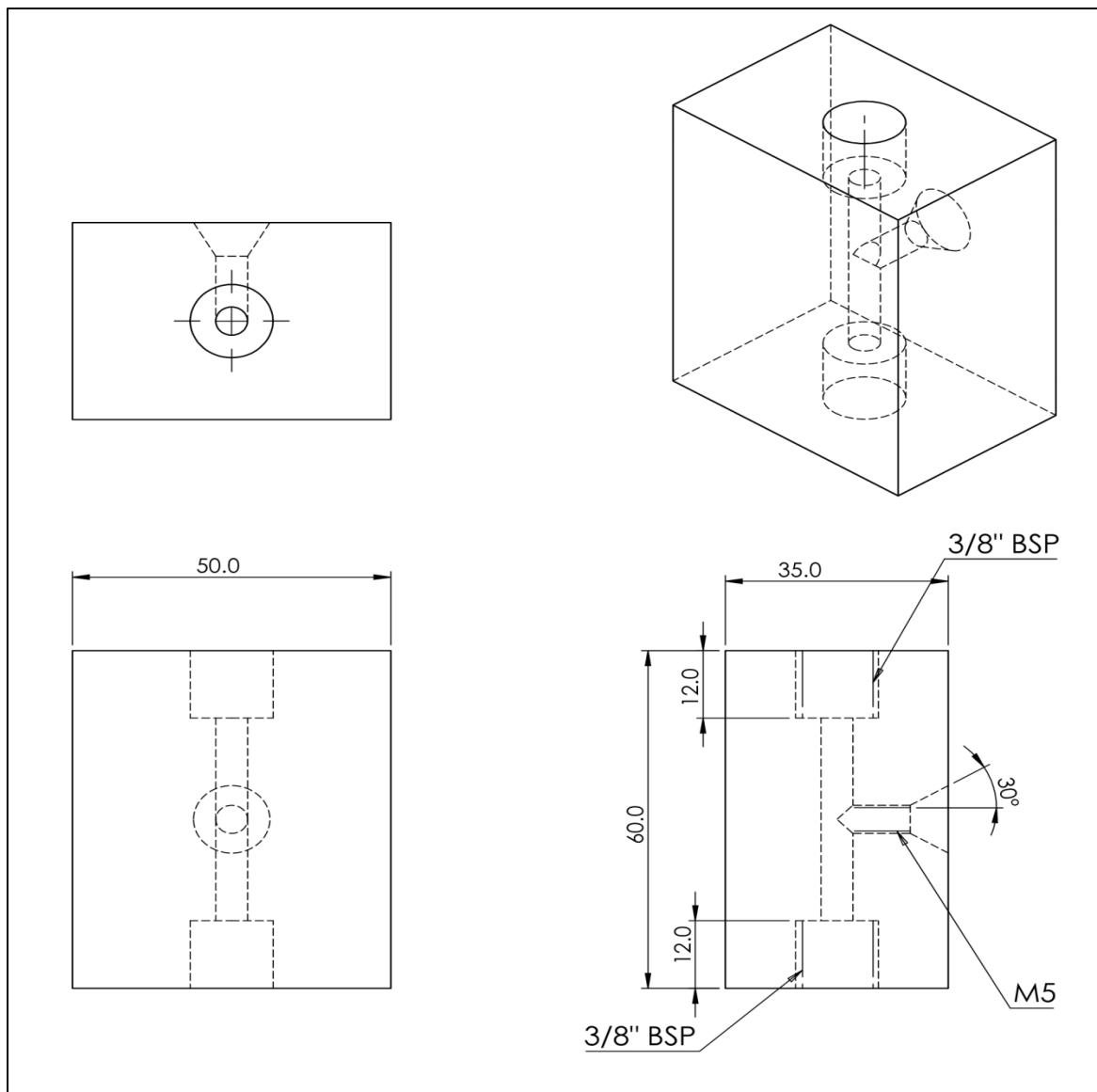


Figure 4.7 Acrylic block used for electrokinetic coupled consolidation loading

4.2.5. Collar

The collar is a cylindrical sleeve typically made of stainless steel (mechanical loading) and polycarbonate (coupled electrokinetic loading) material to apply confining pressure on the soil specimen which is placed on top of the soil specimen in the consolidation cell. The purpose of the collar is to ensure that the soil specimen is subjected to uniform pressure

from all sides during the test. The schematic diagram of the collar is mentioned below in Figure 4.8.

The collar is an important component of the consolidation assembly because it helps to simulate the in-situ conditions. Without the collar, the soil specimen could expand laterally, which would lead to inaccurate test results. Additionally, the collar helps to prevent the soil specimen from being damaged during the test by providing a strong, stable boundary around it.

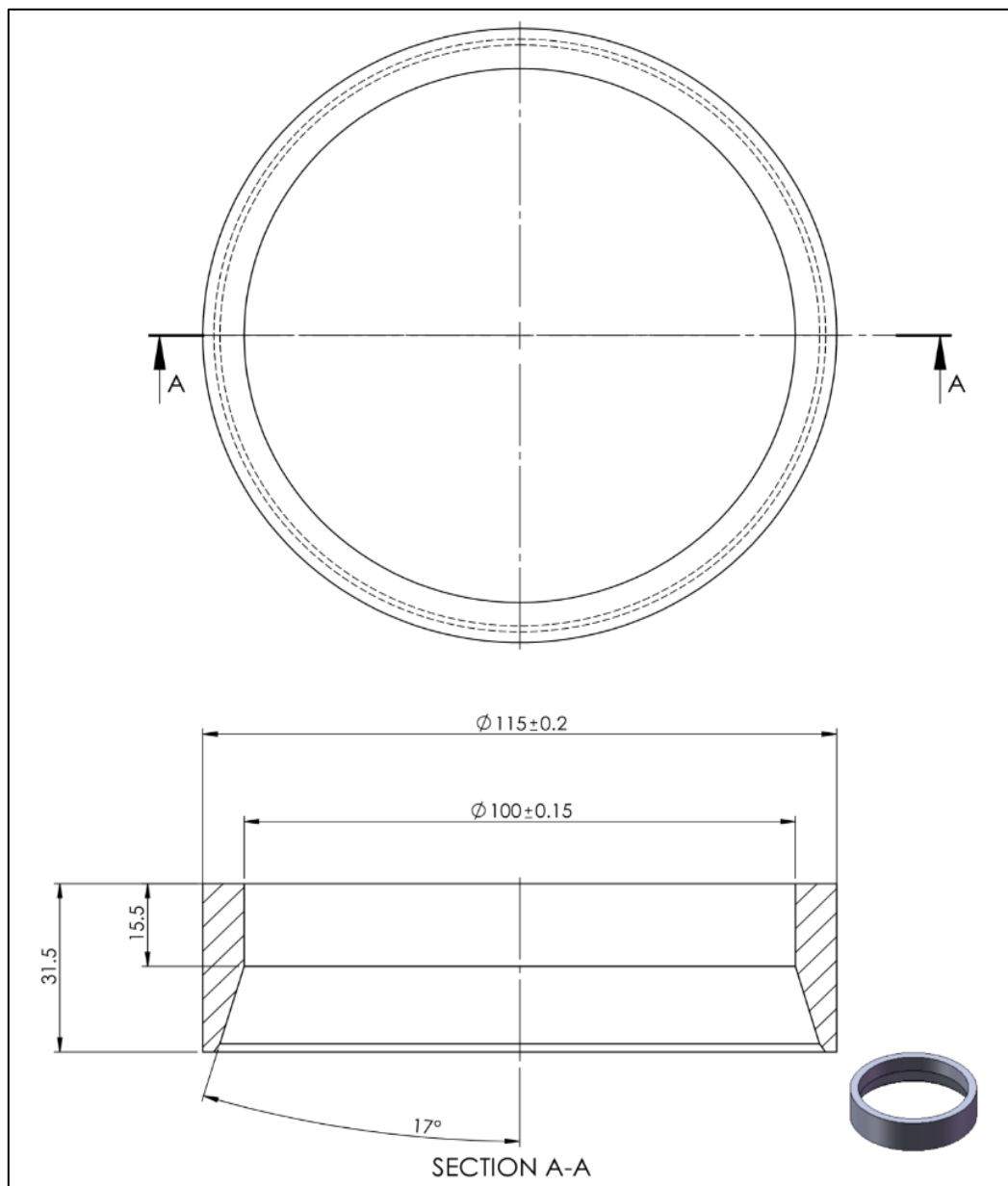


Figure 4.8 Schematic diagram of collar with all dimensions in mm.

4.2.6. Water jacket

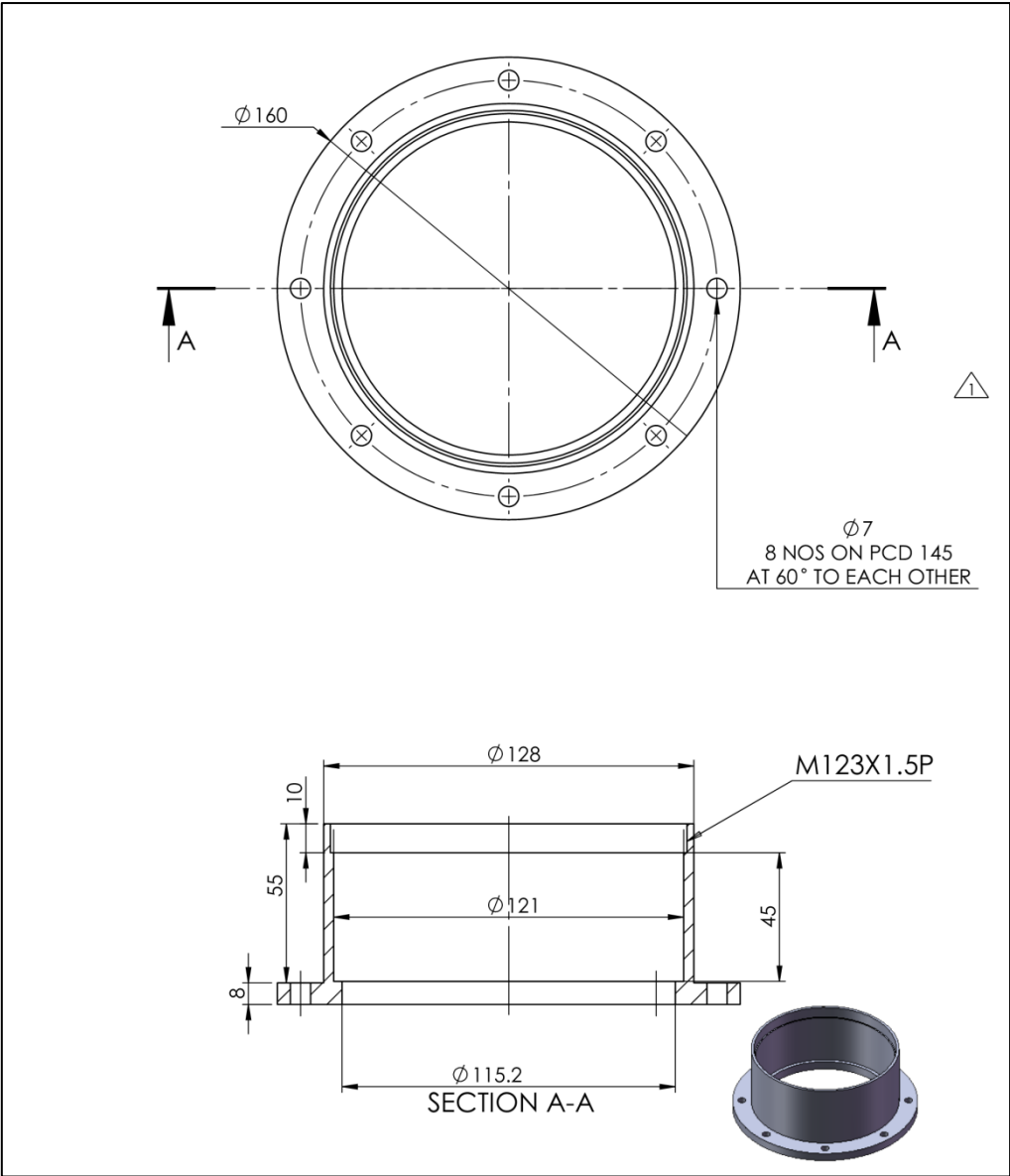
A water jacket is a device made of stainless steel used in soil consolidation tests to apply uniform confining pressure to a soil specimen. The primary function of the water jacket is to provide lateral support to the soil sample and prevent it from expanding laterally during the application of the load. The schematic diagram is mentioned in Figure 4.9 with all dimensions in mm.

The confining pressure applied by the water jacket serves two main functions:

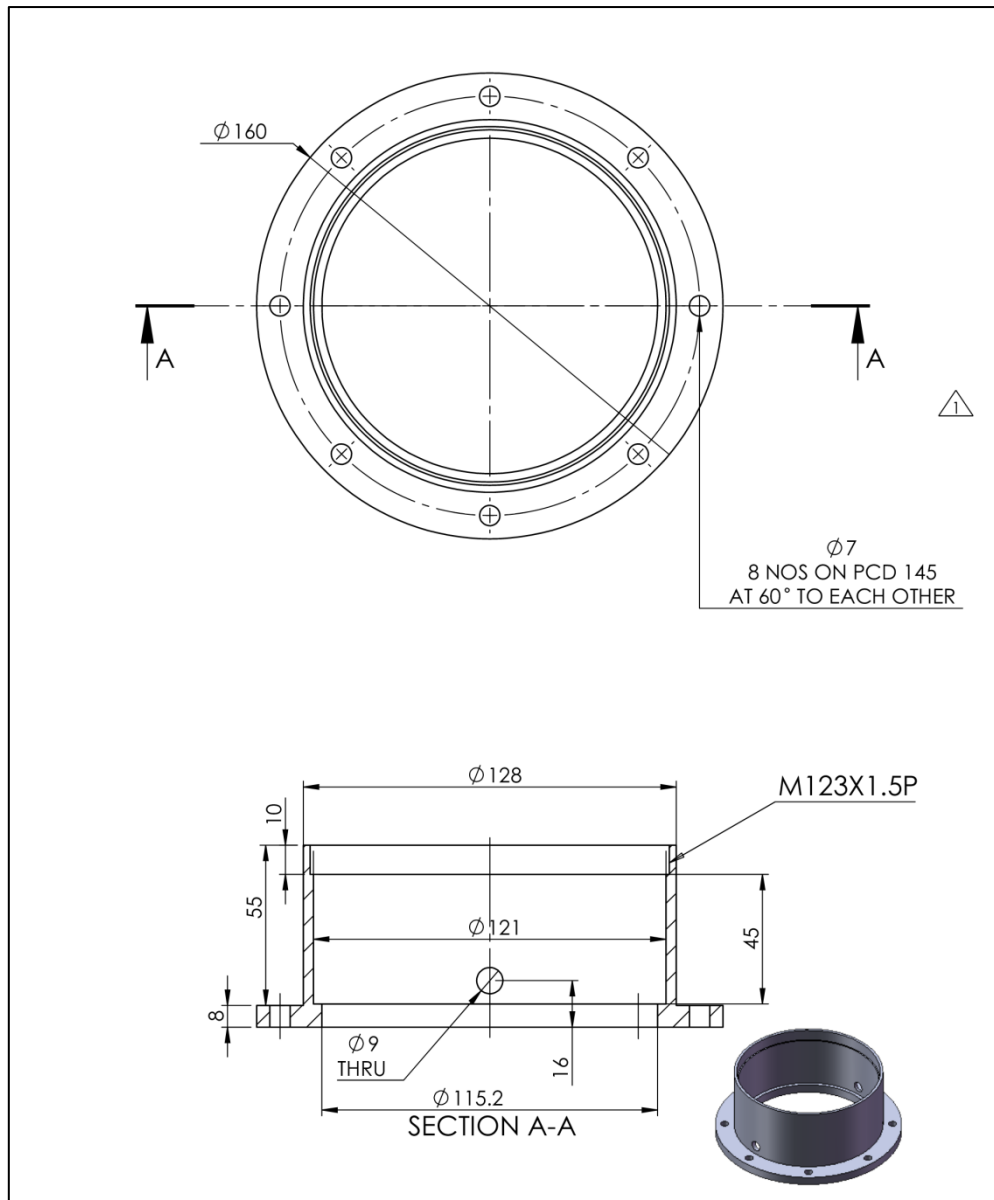
1. It prevents the soil sample from expanding laterally during the application of the load, which ensures that the vertical deformation of the sample can be accurately measured.
2. It creates a uniform stress condition around the soil specimen, which ensures that the test results are representative of the soil's behavior under similar conditions in the field.

The water jacket also helps to maintain the temperature of the soil specimen during the test. Since the consolidation process generates heat, the water jacket helps to dissipate the heat and prevent any temperature-related issues in the test results.

In summary, the function of the water jacket in soil consolidation setup is to provide uniform confining pressure to the soil sample, prevent lateral expansion of the sample during the application of the load, create a uniform stress condition, and maintain the temperature of the soil specimen.



(a) Water jacket used for mechanical consolidation.



(b) Water jacket used for coupled electrokinetic loading

Figure 4.9 Different water jackets used for consolidation

4.2.7. Loading pad

The main function of the loading pad is to distribute the load uniformly over the soil sample, prevent localized deformation of the soil, and ensure that the deformation of the soil is uniform and controlled. By providing a uniform load distribution, the loading pad helps to ensure accurate measurement of the soil's consolidation behaviour.

The loading pad is typically made of a rigid material such as stainless steel and is designed to fit the size and shape of the consolidation cell. This loading pad consists of multiple

openings that allow pore pressure dissipation. In the case of electrokinetic coupled loading, one additional opening was given for the provision of wiring. The schematic diagram of the loading pad is mentioned in figure 4.10. with all dimensions in mm.

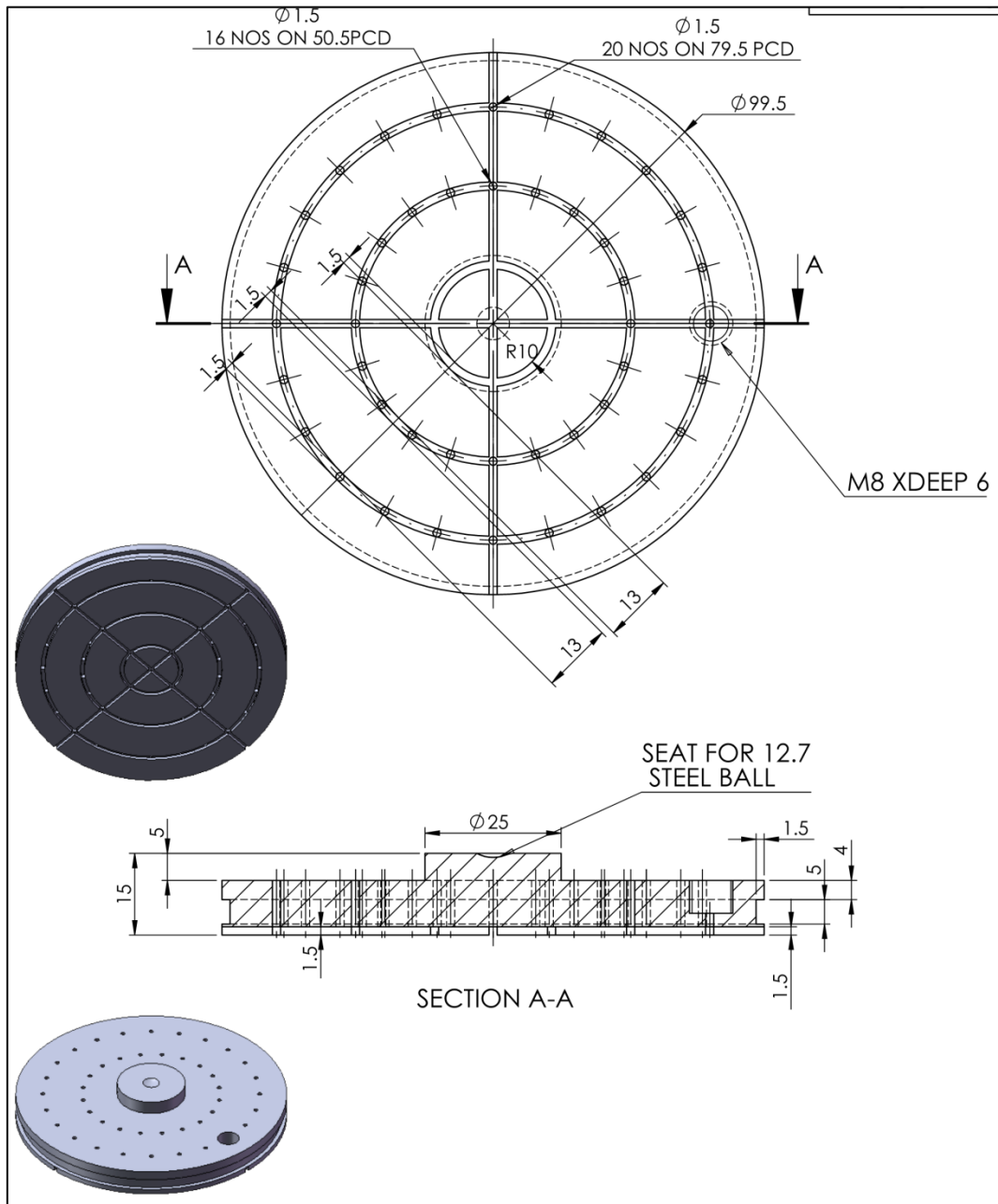


Figure 4.10 Loading pad used for consolidation

4.2.8. Porous stones

A porous stone is a crucial component of a soil consolidation test setup that is used to allow water to flow through the soil specimen during the consolidation process. The primary function of the porous stone is to facilitate the flow of water and prevent any trapped air in

the soil sample, which can interfere with the consolidation process. For the study, two different-sized porous stones were used at the top and bottom of the soil specimen as mentioned in Figure 4.11.

During the consolidation test, water is expelled from the soil specimen as the load is applied, and the volume of water expelled is measured. This process is known as pore water pressure dissipation, and it is a critical component of the soil's consolidation behavior.

The porous stone serves as a drainage path for the water expelled from the soil sample, allowing it to flow out of the soil specimen and into the drainage system and serves to prevent any trapped air in the soil sample. If air is trapped in the soil, it can create a barrier to water flow and interfere with the consolidation process. The porous stone allows any trapped air to escape, ensuring that the water can flow freely through the soil specimen.

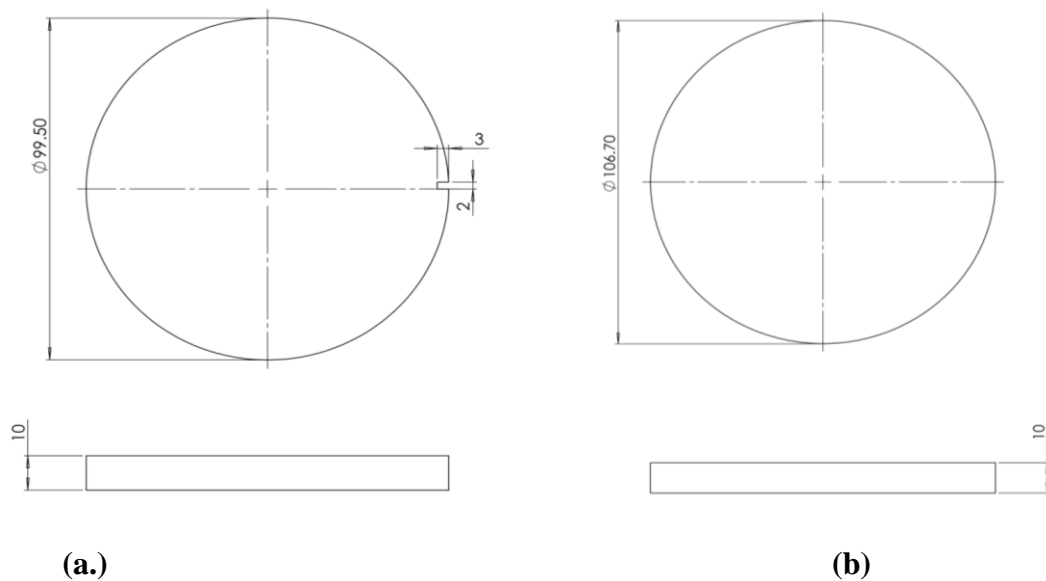


Figure 4.11 Porous stones for top and bottom used for consolidation with dimensions in mm.

4.2.9. Electrodes

For the current study, copper electrodes are the most suitable for developing potential differences in electrokinetic coupled consolidation. The two diameters, thickness, and area

of the electrodes used in the present study were 9.4 cm, 0.2 cm, and 69.36 cm² respectively as shown in Figure 4.12. To ensure proper pore water collection at the electrode end, multiple holes of 1 mm diameter were made, and a layer of saturated filter paper was placed over the electrodes at the top and bottom to prevent clogging of the holes. During the experiment, electrolysis reactions occur, leading to the production of oxygen gas at the anode front, which is utilized by copper at the cathode front to form copper oxide.

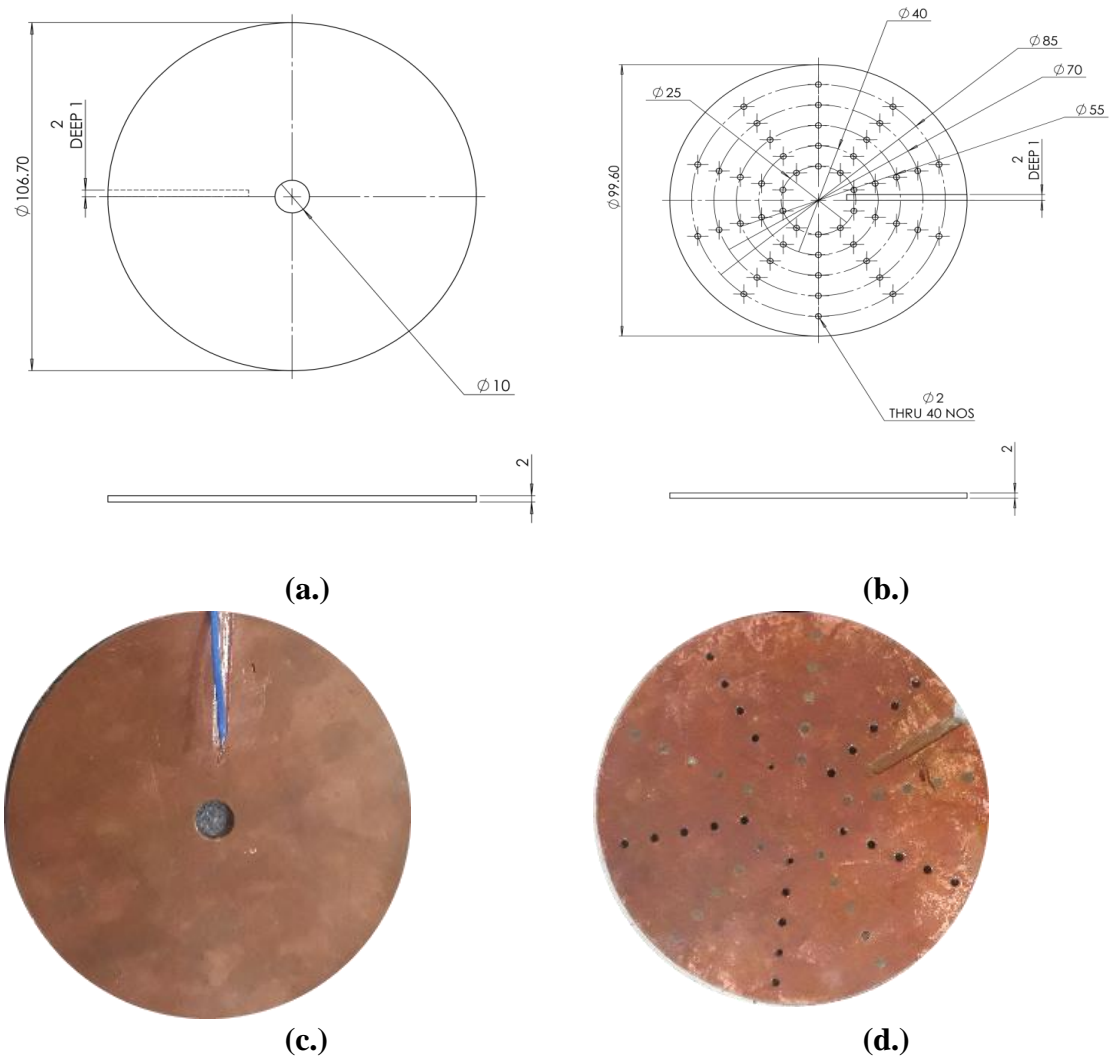


Figure 4.12 Electrodes as anode and cathode

4.2.10. Threaded ring

The threaded ring is used to confine the consolidation ring and collar in the vertical direction on the base plate to prevent movement on load application. The schematic diagram of this ring is shown in Figure 4.13 with dimensions mentioned in mm.

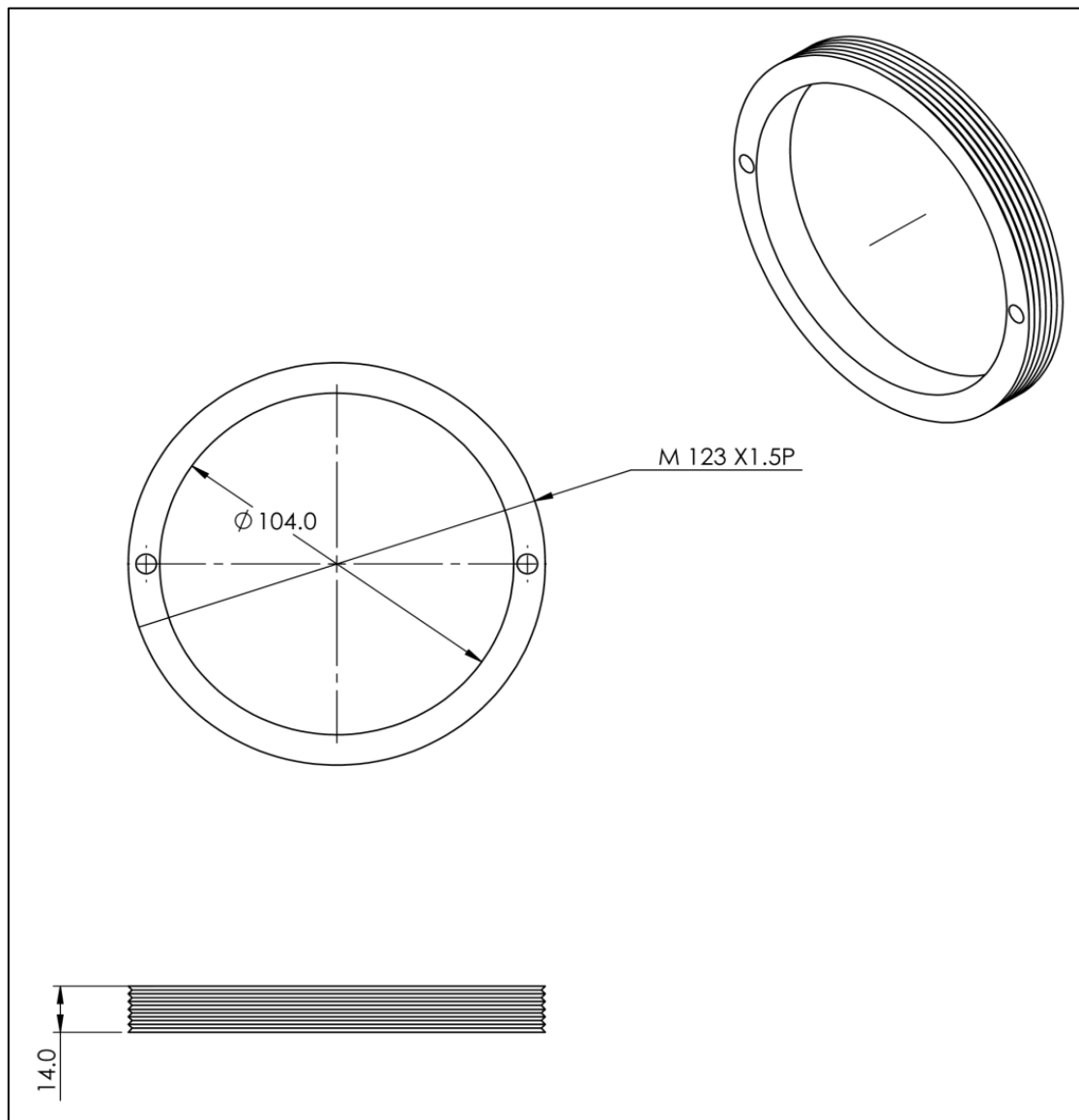


Figure 4.13 Schematic diagram of the threaded ring.

4.3. Schematic Diagrams of Indigenously Developed Consolidation Systems

Figures 4.14 and 4.15 shows the detailed schematic diagrams of modified consolidation cells used in study.

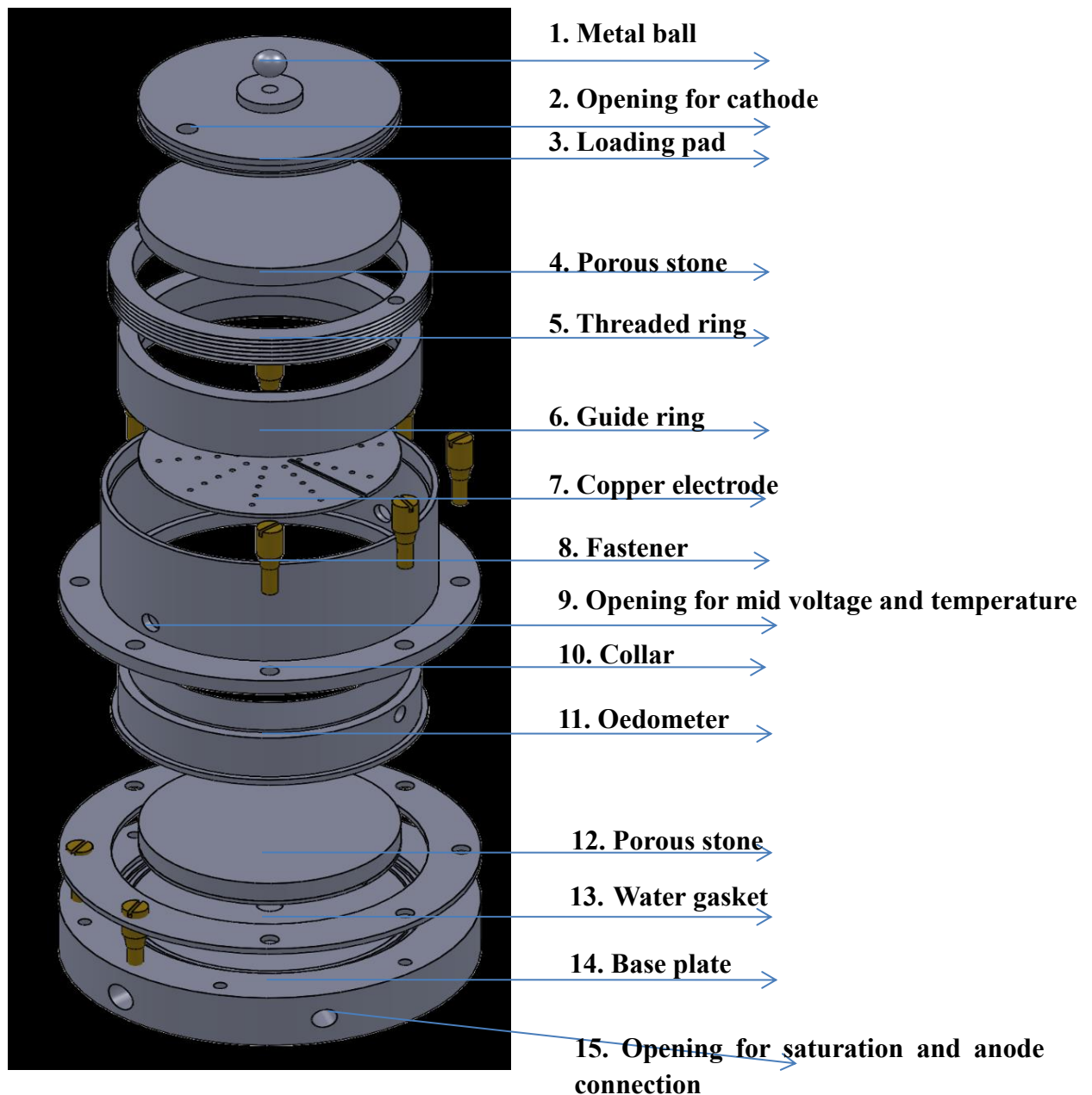


Figure 4.14 Schematic of modified consolidometer indicating each part of the system

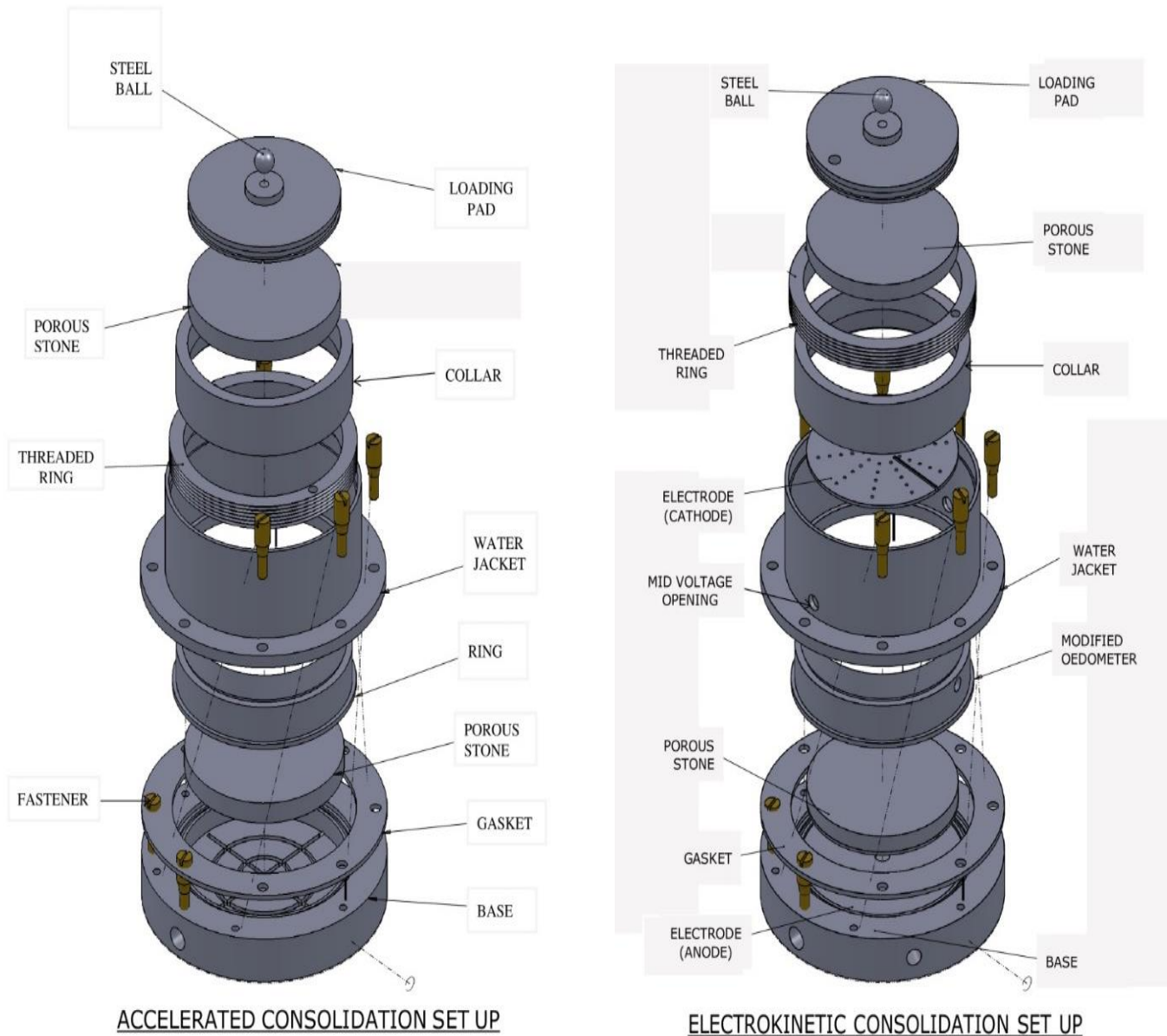


Figure 4.15 Comparative Schematic of consolidation assembly arrangement

4.4. Data Acquisition System (DAQ)

The Data Acquisition System (DAQ) is a device that is designed to collect, store, and manage data automatically during an experiment. The DAQ is equipped with an RS-232 interface, which allows for the transfer of data from the device to a computer. The device operates by acquiring data at regular intervals and storing it for later analysis. The DAQ is an essential component in laboratory experiments as it provides an accurate and efficient means of collecting data. Table 4.16 provides a visual representation of the DAQ apparatus.



Figure 4.16 Data Acquisition system (DAQ)

4.5. DC Power supply

The constant DC power supply is an electrical apparatus that has the capability to generate and maintain a consistent voltage level. This device provides a stable electrical potential for the flow of charges in a single direction. The design of the constant DC power supply is shown in Figure 4.17 and it is essential in ensuring reliable and consistent performance during the experiment. The maintenance of a constant voltage level throughout the experiment is crucial in obtaining accurate and reliable results, and the constant DC power supply enables this by providing a stable electrical source.



Figure 4.17 DC power supply apparatus

4.6. Sensors and its Calibration

In this study, various sensors were utilized to collect data on axial deformation, axial load, pore water pressure, voltage, and current for evaluating consolidation parameters. A 10 kN capacity S-type load cell with a 0.1 kN least count was utilized to measure the axial reaction of the soil upon the application of the desired strain rate. A pore water pressure sensor with a range of 0-25 bar and least count of 0.01 bar was used to measure the pore water pressure at the bottom of the sample. The axial displacement/deformation was continuously monitored using a linear variable differential transducer (LVDT) with a range of 0-25 mm and least count of 0.001 mm.

The load cell, LVDT, and pore water pressure sensors were calibrated using a proving ring, slip gauge, and triaxial pressure system. The load cell was calibrated by applying a constant strain rate on the triaxial loading frame and comparing the corresponding axial load trend with the S-type load cell and the proving ring. The accuracy of the data obtained was within 0.1%. The two-point calibration technique was used for calibrating the LVDT by assigning two initial values and verifying the mid-values with different slip gauge blocks. The triaxial pressure controller system was utilized for calibrating the pore pressure sensor.

4.7. Summary

In summary, the chapter introduces a new and innovative approaches to conduct the IL, CL, CRS, EKCL and EKCRS consolidation tests using a modified consolidation apparatus. This method offers several distinct advantages, including simplification of the consolidation test procedure, reduction in costs, and increased accessibility for teaching and research laboratories. The proposed modification has the potential to significantly impact future research in geotechnical engineering by facilitating more extensive and diverse studies. By streamlining the modified consolidation test procedure and optimizing

resource utilization, the modified apparatus reduces complexities and financial burdens, making consolidation testing more feasible. The enhanced accessibility and cost-effectiveness of the proposed method may lead to an increase in CRS and electrokinetic coupled consolidation testing and related research, allowing researchers to explore a broader range of geotechnical phenomena. Ultimately, this chapter highlights the practical significance of the modified consolidation apparatus in advancing geotechnical engineering research and opening up new avenues of exploration in these fields.