CHAPTER 3 – MATERIALS AND METHODOLOGY

3.1. General

This chapter presents the overview of materials, planning, apparatus, and experimental methodology followed in the study to achieve the research goals on incremental loading consolidation with conventional and modified cosnolidometer and voltage-coupled surcharge loading consolidation. Initially, a laboratory-based experimental programme was planned to conduct consolidation tests using incremental surcharge loading as well as constant surcharge loading consolidation techniques with conventional and modified oedometer on four different geomaterial samples namely marine soil, black cotton soil, red mud, and Varanasi local soil. Later, the voltage-coupled constant surcharge loading and voltage-coupled constant-rate-strain loading consolidation were carried out with a modified oedometer on marine soil and black cotton soil. The test results such as compression index and coefficient of consolidation are compared among the existing technique and indigenously consolidation methods. The methodology adopted in the study presents stepwise and each step in the methodology is elaborated on in the subsequent sections.

3.2. Material and Methodology

3.2.1. Geomaterial

In the present study, samples of geomaterials namely Marine soil, black cotton soil, red mud, and local soil were collected from four distinct locations in India - Mumbai, Jhansi, Renukoot (Hindalco Industries Ltd, Renukoot), and Varanasi respectively. Subsequently, the collected geomaterials were dried in an oven and sieved through a 425-micron sieve to eliminate extraneous foreign particles and were tested for geotechnical properties.

3.2.2. Geotechnical properties

The samples of geomaterials were subjected to multiple laboratory tests as per ASTM testing standards to ascertain their fundamental geotechnical characteristics. The methodology utilized for the testing is explicated, and the outcomes are summarized in Table 3.1.

3.2.2.1. Specific gravity test

The specific gravity of soil solids is a parameter that quantifies the density of solids to gas-free distilled water. It is the ratio of the mass of a given volume of soil solids to the mass of the same volume of water. The determination of specific gravity is a crucial aspect of soil testing and is conducted according to the ASTM D854 (2010) standard. This test involves using specialized equipment such as a pycnometer, sieve, weighing balance, drying oven, desiccator, entrapped air removal apparatus, and vacuum system to obtain accurate measurements of the soil sample's density. These tools are indispensable for ensuring that the specific gravity test is carried out in compliance with geotechnical standards and that precise results are obtained.

Equation 3.1 shown below is the formula for the calculation of the specific gravity of geomaterials using a pycnometer, which is a device that measures the volume of a solid or liquid by displacement of a fluid.

$$G_S = \frac{(M2 - M1)}{(M2 - M1) - (M3 - M4)} \quad \text{(Eq. 3.1)}$$

In this equation, M1 is the mass of the empty pycnometer, M2 is the mass of the pycnometer filled with water, M3 is the mass of the pycnometer filled with a known volume of dry soil, and M4 is the mass of the pycnometer filled with the same volume of water as the soil sample. Based on these calculations Figure 3.1 shows the trend of specific gravity of different geomaterials.

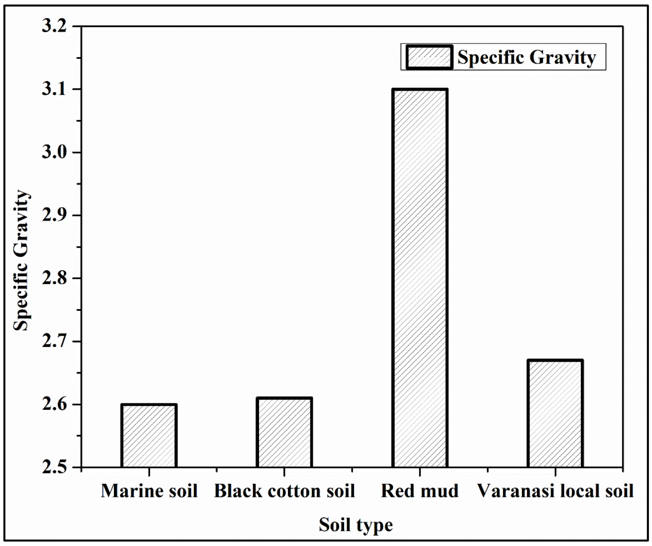

Figure 3.1 Specific gravity of geomaterials

3.2.2.2. Grain size distribution

The grain size distribution test is a technique utilized to determine the percentage of various particle sizes present in a dry soil sample. The test involves a combination of dry sieve and hydrometer analysis. The dry sieve analysis is intended to determine the coarser particle sizes that are above 0.075 mm, while the hydrometer analysis is conducted to determine the finer particle sizes that are below 0.075 mm. This testing method follows the guidelines of ASTM D2487-07 standard. Based on the test results obtained the percentage of sand, silt and clay was calculated and mentioned in Figure 3.2 (a) and (b).

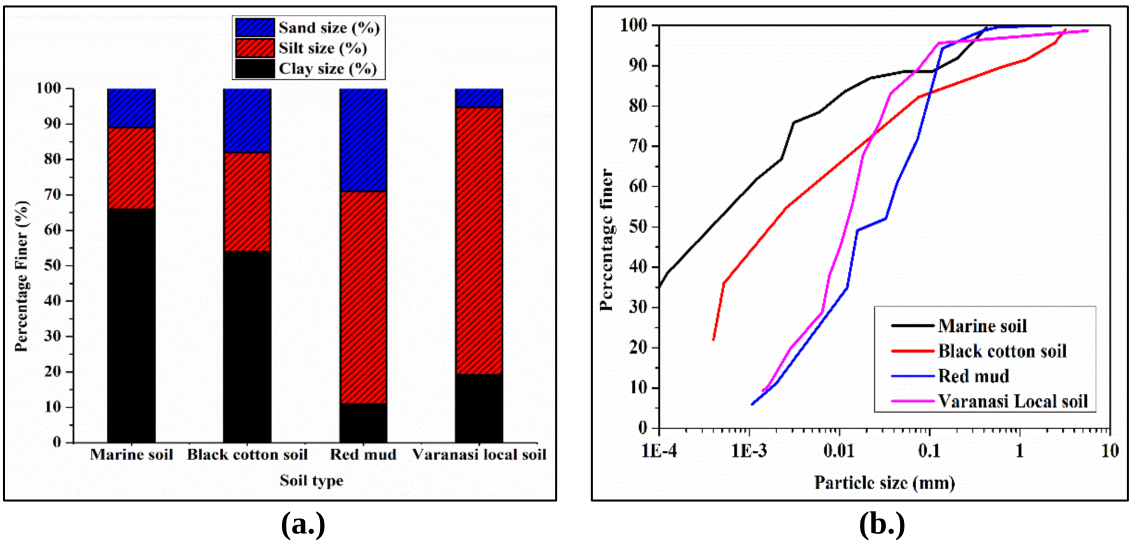

Figure 3.2 (a) Sand, silt, and clay percentage; (b) Grain size distribution curve for geomaterials based on Grain size analysis

For the dry sieve analysis, the required apparatus includes a mechanical sieve shaker, standard sieves, a drying oven, a sample splitter, and a pan. These apparatuses are used to separate and measure the particles based on size. The hydrometer analysis requires the use of a drying oven, stirring apparatus, two glass containers, a dispersing agent, a stopwatch, and distilled water. The hydrometer measures the soil particle sizes based on the specific gravity of the soil-water mixture. The grain size distribution test provides a detailed analysis of the soil's particle size distribution, which is useful for determining the soil's engineering properties such as shear strength, permeability, and compressibility.

3.2.2.3. Atterberg limit test

The Atterberg’s limits test is a widely-used laboratory procedure that helps determine the liquid limit, plastic limit, and plasticity index of soil samples. The test is carried out following the ASTM D854 (2010) standard. The soil sample is air-dried and crushed to pass through a 2.00 mm sieve. Next, the soil sample is mixed with water to form a plastic state and is allowed to rest for a specified period. During this resting period, the water penetrates the soil particles and causes them to absorb moisture.

To determine the liquid limit, a portion of the soil sample is taken and placed in a cup-like device called a liquid limit apparatus. This apparatus is then raised and dropped a specific number of times, and the cup is repeatedly struck by a standardized tool called a grooving tool. The number of drops corresponding to 25 blows required to close a groove of standard dimensions cut into the soil sample is recorded as the liquid limit. The liquid limit trend for different geomaterials is mentioned in Figure 3.3

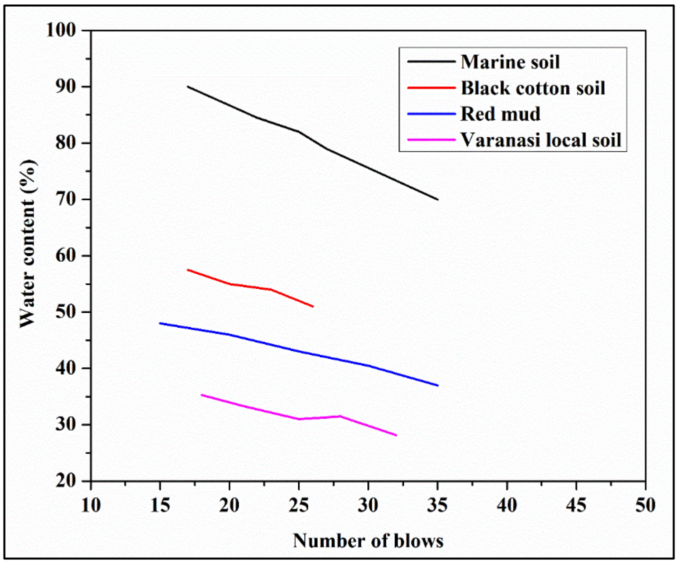

Figure 3.3 Liquid limit trend for different geomaterials

To determine the plastic limit, a portion of the soil sample is taken and placed on a glass plate. A small amount of water is added, and the soil is kneaded until it reaches a plastic state. The soil is then rolled into a thread of 3 mm diameter and laid on the glass plate. The thread is then bent in a U-shape. The number of times the thread can be bent without breaking is recorded as the plastic limit.

The plasticity index is then calculated by subtracting the plastic limit from the liquid limit. This index provides information about the soil's ability to undergo plastic deformation without cracking. The results of the Atterberg limit test are useful for designing and constructing structures on the soil. The plasticity index, in particular, helps engineers understand how the soil will behave under load and helps them determine the suitability of the soil for specific construction purposes.

3.2.2.4. Compaction test

The compaction test is a standard laboratory test performed on soils to determine the relationship between water content and the dry unit weight. The test is conducted following the standard. The equipment used to perform the test includes a compaction mould, a rammer, a weighing balance, a drying oven, and mixing tools.

The test procedure involves the passing of soil through a 4.5 mm sieve and then mixed with a known amount of water to obtain the desired water content. The next step is to compact the soil sample using the compaction mould and rammer. The compaction mould is filled with the soil sample in three equal layers, and each layer is compacted with 25 blows from the rammer. The rammer has a controlled weight and falls from a controlled height, which ensures a consistent compaction effort.

After the compaction is complete, the weight of the compacted soil in the mould is measured using a weighing balance. The mould is then disassembled, and the soil sample is removed and weighed separately to determine its moisture content.

The final step is to determine the dry unit weight of the soil. The soil sample is placed in a drying oven at a temperature of 110 ± 5 °C until it is completely dry. The weight of the dry soil sample is measured, and the volume of the compaction mould is calculated to determine the dry unit weight.

The data obtained from the test is used to plot a compaction curve, which shows the relationship between the water content and the dry unit weight of the soil as shown in Figure 3.4. The information on MDD and OMC values is crucial for the remoulding of soil samples for consolidation testing.

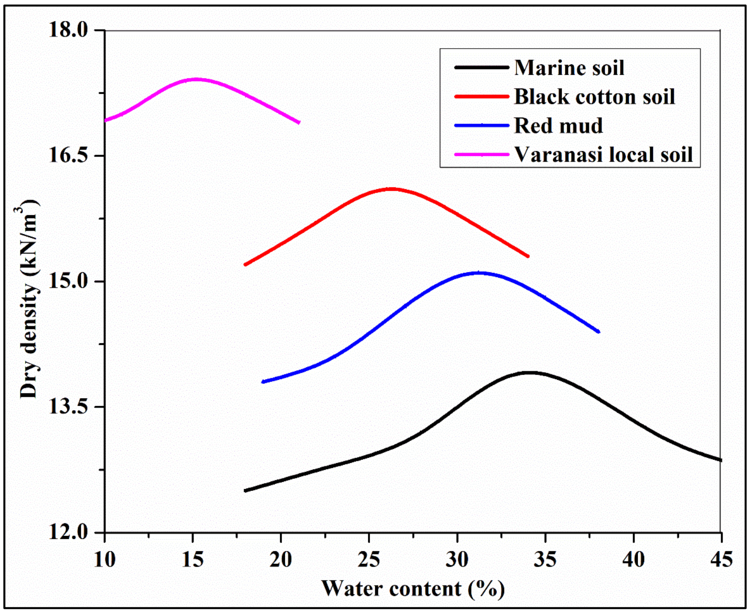

Figure 3.4 Compaction curve for geomaterials used

3.2.2.5. pH test

The pH value test is performed by the soil-water mixture allowed to settle, and a small amount of the supernatant liquid is taken and tested for pH. This is done in accordance with ASTM D4972-19 using a calibrated pH meter, which is immersed in the soil-water mixture. Alternatively, pH test strips or a pH indicator solution may be used.

The results of the pH test provide valuable information about the soil's chemical properties. The solubility of soil minerals and the mobility of ions in the soil is influenced by the soil's pH level. The information on pH is important for understanding the soil's buffering capacity during electrokinetic testing. Furthermore, the measure of pH is a critical factor that affects the effective duration of electrokinetic consolidation.

Table 3.1 Geotechnical properties of geomaterials.

Properties	Standard code/ Procedure used	Marine soil	Black cotton soil	Red mud	Varanasi Local soil
Specific gravity	ASTM D854 (2010)	2.60	2.61	3.10	2.67
Clay size (%)	ASTM D2487-17e1 (2007)	66.0	54.0	11.0	19.2
Silt size (%)		23.0	28.0	60.0	75.5
Sand size (%)		11.0	18.0	29.0	5.3
Liquid Limit (%)	ASTM D4318-10 (2010)	82.0	57.5	43.0	31.0
Plastic Limit (%)		46.0	31.5	31.3	18.6
Plasticity Index		36.0	26.0	11.7	12.4
Classification	ASTM D2487-17e1 (2007)	CH	CH	ML	CL
pH	ASTMD4972-01 (2001)	8.1	7.44	9.9	7.8
Optimum Moisture Content (OMC) (%)	ASTM D698-12e2 (2012)	33.5	26.0	31.2	14.6
Maximum Dry Density (MDD) (kN/m^3)		13.9	16.1	15.1	17.4
Organic content (%)	ASTM D2974 (2014)	6.34	5.21	traces	1.26

Note: CH (high plasticity clay), CL (low plasticity clay) and ML (low plasticity silt)

3.3. Experimental programme

To execute the proposed research the detailed methodology has been planned and discussed subsequently. The following are some of the important points:

i. The specimens used in the study for consolidation testing were either reconstituted or remoulded form as per the type of soil. Reconstituted samples are prepared through a slurry consolidating technique as per the specifically designed methodology. Whereas, remoulded samples were prepared as per the MDD and OMC values of soils.

ii. The specimens that are to be tested are sand-witched between two saturated filter papers, perforated electrode discs, and porous stones, at the top and bottom to facilitate the pore water pressure (PWP) dissipation during the electrokinetic consolidation process. These electrodes are conductive metal electrodes with the cathode at the top of the specimen and the anode at the bottom.

iii. The proposed modified consolidometer ring is made up of either Teflon-coated stainless steel or polycarbonate material to possess insulation characteristics during the application of DC voltage.

iv. Two openings are positioned at the mid-height of the consolidation ring to place sensors to monitor the data of voltage and temperature in real-time. The loading pad is placed at the top of the assembly to provide uniform distribution of load.

v. The base plate consists of three openings one for electrical wiring, the other two for saturation of pore water pressure line and for an acrylic block having provision for an air vent and PWP sensor. The entire assembly is placed over a single gang consolidation assembly along with a Linear Variable Displacement Transducer (LVDT) positioned on top of the loading pad.

3.3.1. Test Plan

The experimental work thesis employs the test plan illustrated in Figures 3.5 and 3.6, supplemented by the details outlined in Table 3.2. This structured approach guides the systematic execution of experiments, encompassing methodologies, variables, and data collection procedures.

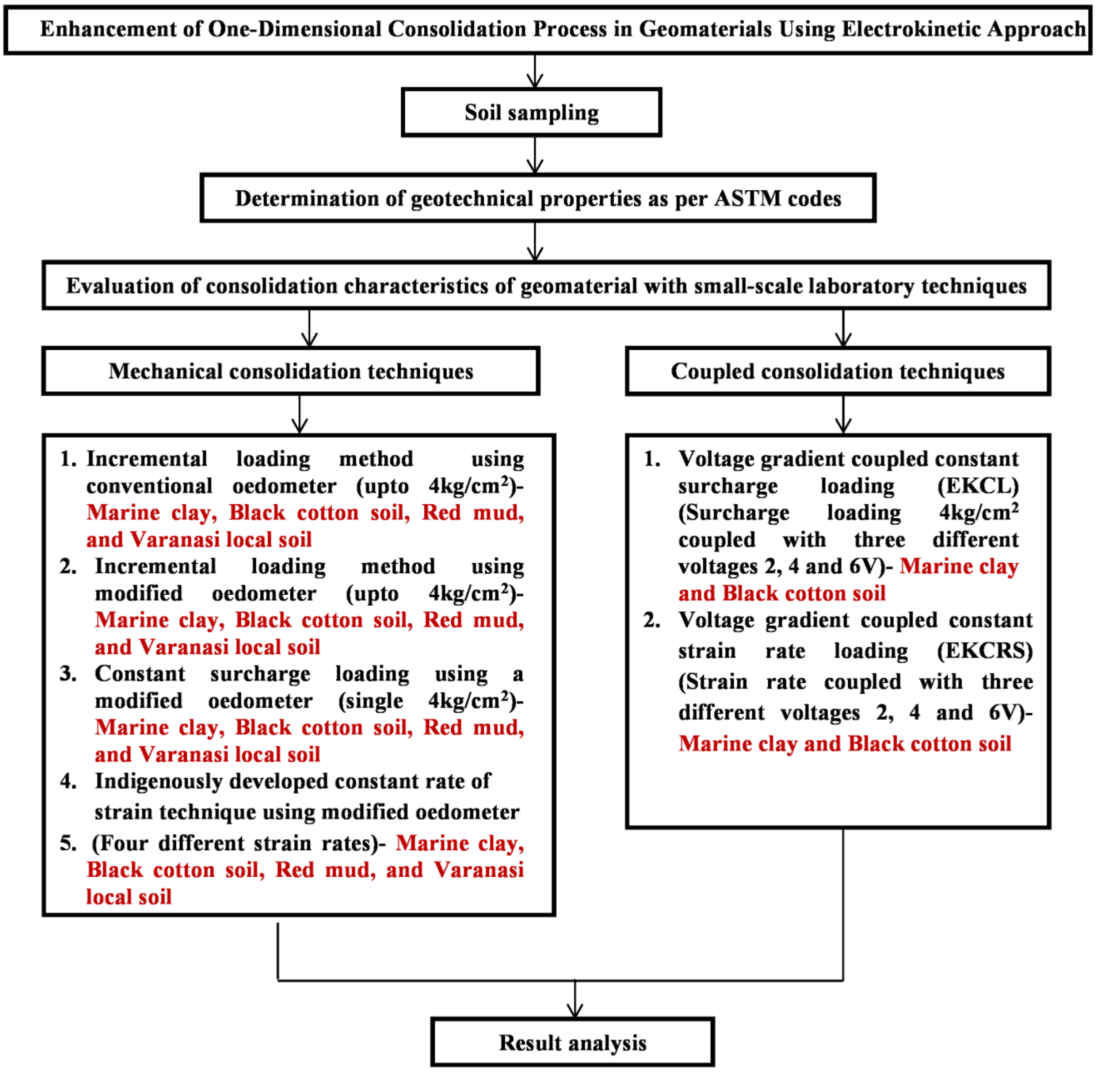

Figure 3.5 Flow chart for overall experimental frame work

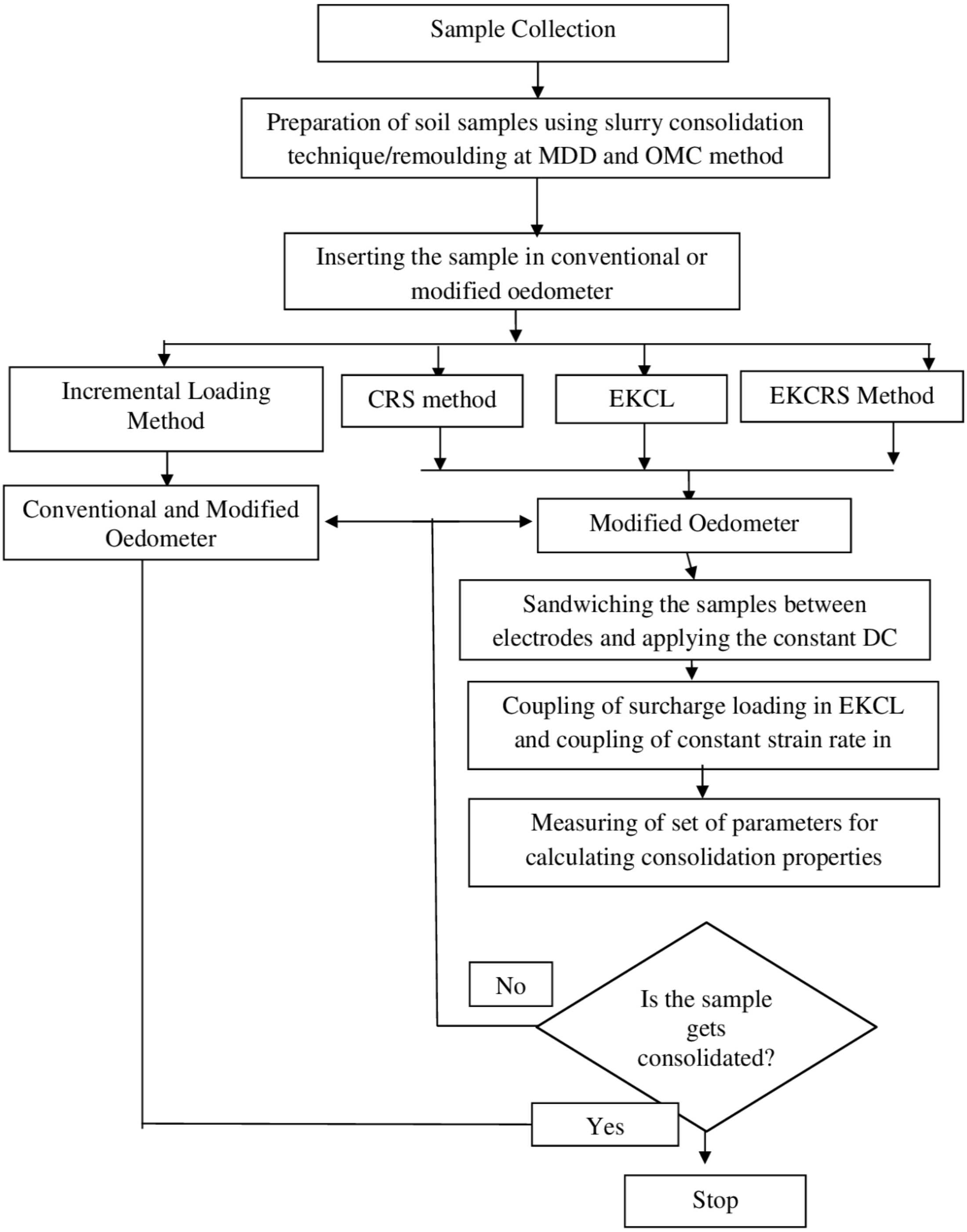

Figure 3.6 Sequential methodology of the proposed research

Table 3.2 Details of the laboratory experimental programme for electrokinetic coupled loading

Testing Parameters → / Test Combination ↓	$\sigma_{v,\,max}$ at end (kg/cm^2)	Strain rate (mm/min) *	Strain rate (%/min)	ΔΦ (V_0)	ΔΦ/L (V/cm)
1. Marine soil					
Using both conventional and modified consolidation cell					
ILMS-C	Up to 4.0	-		-	-
ILMS-M	Up to 4.0	-		-	-
Using modified consolidation cell					
CLMS-M	4.0	-		-	-
EKCLMS1	4.0	-		2	0.5
EKCLMS2	4.0	-		4	1.0
EKCLMS3	4.0	-		6	1.5
CRSMS1	8.0	0.002	0.005	-	-
CRSMS2	8.0	0.005	0.0125	-	-
EKCRSMS1	4.0	0.005	0.0125	2	0.5
EKCRSMS2	4.0	0.005	0.0125	4	1.0
EKCRSMS3	4.0	0.005	0.0125	6	1.5
2. Black cotton soil					
Using both conventional and modified consolidation cell					
ILBCS-C	Up to 4.0	-	-		-
ILBCS-M	Up to 4.0				-
Using modified consolidation cell					
CLBCS-M	4.0	-		-	-
EKCLBCS1	4.0	-		2	0.5
EKCLBCS2	4.0	-		4	1.0
EKCLBCS3	4.0	-		6	1.5
CRSBCS1	8.0	0.0025	0.00625	-	-
CRSBCS2	8.0	0.0075	0.01875	-	-
EKCRSBCS1	4.0	0.0075	0.01875	2	0.5
EKCRSBCS2	4.0	0.0075	0.01875	4	1.0
EKCRSBCS3	4.0	0.0075	0.01875	6	1.5
3. Red mud					
Using both conventional and modified consolidation cell					
ILRM-C	Up to 4.0	-	-	-	-
ILRM-M	Up to 4.0	-	-	-	-
Using modified consolidation cell					
CLRM-M	4.0	-	-	-	-
EKCLRM2	4.0	-	-	4	1.0
CRSRM1	8.0	0.1	0.25	-	-
CRSRM2	8.0	0.5	1.25	-	-
EKCRSRM2	4.0	0.25	0.625	4	1.0
4. Varanasi local soil					
Using both conventional and modified consolidation cell					
ILLS-C	Up to 4.0	-	-	-	-
ILLS-M	Up to 4.0	-	-	-	-
CLLS-M	4.0	-	-	-	-

Note- * When initial height of specimen is 40mm.

3.3.2. Sample preparation

In the present research, the slurry consolidation technique has been followed for Marine soils and black cotton soil. The slurries were prepared by mixing approximately 800 grams of oven-dried soil passed through a 4.75 mm sieve is thoroughly soaked with an amount of distilled water equivalent to 1.25 times the liquid limit value for 6 hours and then mixed homogeneously to ensure better workability and uniform consistency. This was followed by pouring Marine soil slurry into the perforated CBR mould wrapped with filter paper on the inner surface, top and bottom of the mould and was placed under a loading frame for self-consolidation for 12 hours duration. Later, two consecutive surcharge loads of 25 kPa were applied after self-consolidation at 12 hours intervals. After 48 hours of loading, the soil samples were extracted using a sample extruder into a modified and conventional consolidation cell having inside grease coating. The homogeneity of the soil specimens at various locations of cylindrical mould was carefully verified with their moisture content and the void ratios as indicators of consistent consolidation behavior throughout the specimen (McConnachie, 1974; Penumadu et al., 1998; Bhuria and Sachan, 2014; Tajuddin et al., 2014; Liu et al., 2017). The assembled cell was then placed on the conventional consolidation loading unit for EKCL and in the case of EKCRS the cell is placed on the triaxial base, with a layer of filter paper and a porous stone placed inside. The air was then removed through de-airing.

In preparing the red mud and Varanasi local soil samples, the back pressure (BP) technique was employed. The soil was initially remoulded at the optimum moisture content (OMC) and maximum dry density (MDD) in the consolidation cell and was placed on the consolidation assembly. Back pressure was then applied using a water reservoir to saturate the sample, and an axial strain equivalent to a seating load of 0.005 kg/cm^2 axial stress was applied to prevent heaving. The various stages involved in the sample preparation are depicted in Figure 3.7.

(a) In-site and laboratory dried Marine soil **(b) Pulverised and Sieved sample through 4mm sieve** **(c) Base plate of modified cylindrical mould**

(d) Modified mould setup **(e.) CBR Loading Frame used for loading sample.** **(f.) Hydraulic extractor for sample extraction**

Figure 3.7 Images related to sample preparation

In this study, a series of consolidation tests as shown in Table 3.2 were planned with the existing and proposed techniques such as (a) IL consolidation using conventional and modified consolidation cells up to surcharge loading of 4 kg/cm^2 with load increment of 1.0, (IL-C; IL-M), (b) CL consolidation with a constant surcharge loading of 4 kg/cm^2 using modified consolidation cell (CL-M), (c) indigenously developed CRS consolidation run at suitable strain rates for different soil meeting the criteria of pore pressure ratio up to the axial load of 6.26 kN equivalent to 8 kg/cm^2 using modified consolidation cells were conducted on Marine soil, black cotton soil, red mud and Varanasi local soil. Later on, voltage gradient coupled constant loading (EKCL) consolidation with a constant surcharge load of 4 kg/cm^2 at 2, 4, and 6V and voltage gradient coupled constant strain rate loading (EKCRS) consolidation run at the suitable strain rates corresponding to the type of soil at 2, 4, and 6V up to an axial load of 3.12 kN equivalent to 4 kg/cm^2 using a modified consolidation cell were conducted on Marine soil, black cotton soil, red mud, and Varanasi local soil. During the consolidation tests, the parameters such as deformation, settlement, pore pressure, axial stress, voltage and current were continuously monitored in real-time with a data acquisition system as per the loading conditions. The void ratio, bulk and dry densities, average moisture content and pH values were also measured after the completion of the test. The test results obtained using the proposed apparatus are compared with those obtained from the standard apparatus and techniques, ensuring the validity and reliability of the proposed apparatus.

3.3.3 Sensors and their 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 least count of 0.1 kN 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 the 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 a 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.

3.4 Mechanical consolidation methodology

3.4.1 IL and CL consolidation technique

The current chapter presents the conventional consolidation technique used to determine consolidation characteristics. Additionally, it also presents the impact of different-sized consolidation rings under two distinct loading conditions incremental surcharge loading (IL) and constant surcharge loading (CL). A description of the procedure adopted during the consolidation testing are discussed below:

i. ***LVDT Calibration - Before Placement of Soil Sample***

Before placing the soil sample into the consolidation loading assembly, it is necessary to calibrate the Linear Variable Differential Transformer (LVDT). The LVDT is a transducer used to measure the deformation of the soil specimen during consolidation testing. The LVDT should be calibrated to ensure accurate measurement of deformation readings before the test.

ii. ***Porous Disc Preparation - Saturating with a Vacuum Pump***

A porous disc is used to ensure that water flows uniformly through the soil specimen during the consolidation test. To prepare the porous disc, it is important to saturate it with a vacuum pump. This process removes air bubbles and reduces the disc's affinity for water, ensuring consistent water flow through the soil specimen.

iii. ***Soil Sample Housing - Assembling the Test Setup***

The soil sample is housed in a ring, along with the porous discs and filter paper, which are placed at the top and bottom of the specimen. The loading pad and collar are then placed over the sample and secured with fasteners. This assembly is then placed on the consolidation loading assembly.

iv. ***Balancing the Lever Arm with a Counterweight***

Once the sample is housed, the lever arm of the consolidation loading assembly must be balanced with a counterweight to ensure that the loading is applied evenly to the soil specimen.

v. ***LVDT Adjustment and Zero Reading***

Before applying the load, the LVDT is adjusted and zeroed on top of the consolidation assembly to ensure that the deformation readings are accurate.

vi. ***Seating Load Application and Inundation***

A seating load of 0.005 kg/cm^2 is applied to the soil sample, followed by immediate inundation with water. This process ensures that the water enters the soil specimen uniformly.

vii. ***Quick Loading to Prevent Swelling***

To prevent swelling, quick loading is performed with a change in deformation reading. This ensures that the soil specimen remains compact during the test.

viii. ***Consolidation Loading for CL Test***

In the case of the CL (constant load) consolidation test, a single loading is applied after the application of the seating load. The loading is applied until the change in soil specimen height is nearly a constant value.

ix. ***Consolidation Loading for IL Test***

On the other hand, in the IL (incremental load) consolidation test, a load increment ratio (LIR) of one is applied by doubling the total axial stress every 24 hours to obtain values equivalent to 0.25, 0.50, 1.0, 2.0, and 4.0 kg/cm^2. Before each load increment is applied, the change in height of the specimen is recorded.

x. ***Final Procedures for both tests***

Once the consolidation loading test is completed, the soil sample is carefully removed from the loading frame and unmounted. The sample is then weighed with the ring and kept in an oven for drying to determine its water content, final void ratio, and dry density.

3.4.2. CRS consolidation technique

Constant rate strain consolidation (CRS) is a widely used alternate technique in geotechnical engineering to determine the time-dependent settlement behaviour of soils under a constant strain rate.

i. ***Calibration of LVDT, Load Cell, and Pore Pressure Sensor***

To ensure accurate measurements during the constant rate strain consolidation test, the LVDT, load cell, and pore pressure sensor must be calibrated. The LVDT is calibrated with a slip gauge, the load cell with a proving ring, and the pore pressure sensor with a pore pressure arrangement of the triaxial assembly which is connected to the data acquisition system (DAQ).

ii. ***Sample Housing***

The oedometer with soil sample is housed over the triaxial loading assembly with the load cell and LVDT at the top and the pore pressure sensor at the base of the sample.

iii. ***Contact and Wiring Connection***

A minimal strain rate equivalent to 0.005 kg/cm^2 is applied to ensure proper contact of the sample with sensor and wiring connections.

iv. ***Commencement of Experiment***

The required strain rate is applied using the triaxial digital arrangement, and the DAQ is turned on and checked for zero adjustments reading of the LVDT, load cell, and pore pressure.

v. ***Application of Constant Strain Rate***

A required constant strain rate in mm/min based on the type of soil is applied simultaneously on the sample until the axial load value is 3.12 kN.

vi. ***Automated Data Collection***

The DAQ provides automated collection and storage of various data during the process at a fixed interval with an RS-232 interface.

vii. ***Unloading of Sample***

With the progress of the test, the increased axial load reaches the value of 3.12 kN. The experiment is stopped, and the sample is unloaded at the same rate of strain followed during loading.

viii. ***Pore Pressure Ratio (PPR)***

The pore pressure ratio (PPR) is observed at high loading conditions during the test. If the PPR value lies in the range of 0.03-0.15, then the strain rate is assumed to be suitable for evaluating the consolidation characteristics in soil.

ix. ***Dismantling of Oedometer Arrangement and Sample Extraction***

After unloading, the oedometer arrangement is dismantled, and the porous stones are removed. The sample is then extruded from the oedometer with a hydraulic extractor and weighed for density and moisture content range.

x. ***Sample Weight and Drying***

On completion of the test, the soil sample is carefully removed from the loading frame, and the sample is unmounted. The sample is weighed with the ring and kept in a drying oven for water content, final void ratio, and dry density of the sample.

3.5. Voltage Coupled loading consolidation techniques (EKCL and EKCRS consolidation)

To study the consolidation parameters such as compression index (c_c), coefficient of consolidation (c_v), settlement time to reach 90% consolidation etc. using rapid consolidation methods a series of consolidation tests were conducted on soils with a modified consolidation ring using EKCL technique by placing constant load 4 kg/cm^2 coupled with 2, 4 and 6V and EKCRS technique run at constant rate-strain rates coupled with 2, 4 and 6V.

During the consolidation process, the voltage change due to the presence of the soil sample is measured by inserting three voltage probes at different depths; and for examining the pore pressure behaviour pore pressure sensors are also placed at different depths and connected to DAQ system. The settlement parameters are calculated based on deformation in soil and drainage that occurred at the cathode. The void ratio, bulk and dry densities, average moisture content and pH values were also measured after the completion of the test. The sequential methodology adopted in conducting EKCL and EKCRS is discussed below.

3.5.1. Electrokinetic Constant Surcharge Loading (*EKCL)* consolidation procedure

Following are the operational steps involved in conducting the EKCL method.

i. ***Calibration of LVDT***

The linear variable displacement transducer (LVDT) is calibrated before placing the sample with a slip gauge and Data Acquisition system (DAQ).

ii. ***Balancing the lever arm***

The lever arm is balanced with a counterweight setup after housing the sample over the consolidation loading assembly.

iii. ***Measuring axial settlement***

LVDT is placed over the loading pad to measure the axial settlement with different loading conditions.

iv. ***Measuring current with current sensor***

A current sensor is used to measure the current throughout the sample during the process of EK consolidation through electrodes connected with wiring.

v. ***Measuring mid voltage with voltage sensor***

Voltage sensor is used to measure the voltage at the mid-section of the sample.

vi. ***Application of surcharge***

A 0.005 kg/cm^2 seating load is placed over the sample through a lever arrangement with a load distribution ratio equal to 1:10 on the loading assembly to make proper sample adjustment.

vii. ***Turning on the setup***

At the time of the commencement of the experiment, the DC supply and DAQ are turned on, and the LVDT, voltage, and current readings are checked for zero adjustments. Constant voltage and load are applied simultaneously.

viii. ***Automated data collection***

The DAQ provides an automated collection and storage of various data during the process at a fixed interval with RS-232 interface.

ix. ***Analysis of results***

The analysis of the results shows that the current and voltage decrease with time due to increased resistance and the dissipation of pore water. The deformation increases with time and then becomes constant after a certain time.

x. ***Gas generation***

Gas generated throughout the electrolysis process is visible at the top and bottom in the form of bubbles.

xi. ***Continuation of test***

The test is continued till deformation, voltage, and current become constant for 24 hours. Then the DC supply is turned off.

xii. ***Unloading process***

Later, the surcharge is removed for the unloading process, and swelling in the soil is observed with LVDT.

xiii. ***Oedometer removal***

After unloading, the oedometer is removed carefully.

xiv. ***Monitoring pH***

The pH of water collected at the cathode front and anode is monitored, showing the acidic pH range at the anode and the basic pH range at the cathode.

xv. ***Extruding the sample***

Dismantle the oedometer arrangement, remove the electrodes, and porous stones, and then extrude the sample from the oedometer with a hydraulic extractor and weigh the sample for the density and moisture content range.

xvi. ***Collecting soil samples***

Soil samples are collected from the top, mid, and bottom for pH parameters and microfabric studies.

3.5.2. Electrokinetic constant-rate-strain loading (EKCRS) consolidation technique

The sequential operational procedure involved in EKCRS consolidation is briefed in the following section. In this method, some of the operational steps are similar to CRS and EKCL techniques.

i. ***Calibration of instruments***

LVDT with slip gauge, Load cell with proving ring and Pore pressure sensor with pressure arrangement of triaxial assembly and Data Acquisition system (DAQ) were calibrated before the experiment.

ii. ***Sample housing:***

The sample was placed over the Triaxial loading assembly with the load cell and LVDT at the top and the pore pressure sensor at the base of the sample.

iii. ***Applying a minimal strain rate***

A minimal strain rate equivalent to 0.005 kg/cm^2 was applied to ensure proper contact of the sample and wiring connections.

iv. ***Current measurement***

A current sensor was used to measure the current throughout the sample during the EK consolidation process through electrodes connected with wiring.

v. ***Voltage measurement***

Voltage sensor was used to measure the voltage at the mid-section of the sample on application of constant voltage with DC supply.

vi. ***Experiment commencement***

The required strain rate was applied with the DC supply and DAQ were turned on and checked for zero adjustments reading of LVDT, voltage, and current reading for electro-hydro-mechanical coupled loading at a constant voltage (2, 4, and 6V) and a constant strain rate of 0.005 mm/min applied on the sample.

vii. ***Data acquisition***

The DAQ provided automated collection and storage of various data during the process at a fixed interval with RS-232 interface.

viii. ***Analysis of results***

The analysis of results showed that the current and voltage kept increasing with the strain rate application, but due to increased axial load, initially, swelling occurred due to gas generation, and negative pore pressure was observed.

ix. ***Stop experiment***

With the progress of the test, the increased axial load reached the value of 3.12 kN, and the experiment was stopped. The sample was then unloaded, and the DC supply was switched off.

x. ***Pore pressure ratio (PPR)***

PPR was observed at high loading conditions during the test. If the PPR value lies in the range of 0.03-0.15, then the strain rate and voltage combination are assumed to be suitable for the soil.

xi. ***Gas generation***

Throughout the test, gas generated during the electrolysis process was visible at the top and bottom in the form of bubbles.

xii. ***Removal of oedometer***

After unloading, the oedometer was removed carefully from the testing assembly and soil samples are tested for post-experimental parameters.

xiii. ***pH monitoring***

The pH of the soil sample collected at the cathode front and anode was monitored, showing the acidic pH range at the anode and the basic pH range at the cathode.

xiv. ***Sample extraction***

The oedometer arrangement was dismantled, and the electrodes and porous stones were removed. The sample was then extruded from the oedometer with a hydraulic extractor and weighed for the density and moisture content range.

xv. ***Soil sample collection***

Soil samples were collected from the top, mid, and bottom for pH parameters and microfabric studies.

3.6. Summary

In this chapter, a comprehensive account of the geomaterials used in the study is provided, along with an in-depth exploration of their physical and geotechnical properties. Various consolidation methodologies, both with and without the application of electric gradients, are thoroughly discussed. The consolidation setups employed for the experiments are described, including conventional methods and setups specially developed for this research. The subsequent chapters delve into the design and fabrication of the experimental setup, outlining the specific procedures followed and detailing the outcomes and findings of the study.