CHAPTER 7 - SUMMARY AND RECOMMENDATIONS FOR THE FUTURE STUDY

7.1 Summary and Conclusions

In the present research, modified consolidation systems were developed and performed satisfactorily during the consolidation tests on geomaterial samples. A series of laboratory experiments were performed to explore the mechanism for one-dimensional consolidation on a conventional (60 mm dia and 20 mm height) and modified consolidation ring (100 mm dia and 40 mm height) in an axial direction the tests were carried out in two stages performing IL, CL and CRS consolidation with and without voltage gradient of 2, 4 and 6V application. The parameters studied from all the test data are deformation, void ratio, pore pressure, pore pressure ratio, voltage, current, pH, moisture content and energy consumption. Experimental data are compared, analyzed, and further validated. Based on the test results, the following conclusions can be made:

1. The CRS test results were compared and validated very well with the consolidation test results of the incremental loading technique using both conventional and modified consolidation rings. The CRS technique is faster and more accurate in completing the consolidation process than the conventional incremental loading technique. However, in high plastic soils such as marine and black cotton soils, the CRS tests with modified consolidation cell time duration took slightly longer in comparison to low plastic soils red mud and Varanasi local soil at their corresponding strain rates respectively.
2. Amongst all the test combinations, the time for completion of the electro-mechanical loading consolidation (EKCL and EKCRS) test was found to be less

than the conventional consolidation tests (IL, CL) with a modified oedometer due to an accelerated dissipation of pore water pressure observed at the base of the sample even at higher strain rates as compared to simple CRS consolidation test.

3. The maximum settlement was observed for the applied voltage gradient of 1V/cm. This proves to be a notable impact in voltage-coupled loading due to ions' transport, including diffusion, electromigration, and electro-osmotic flux advection.
4. In electro-mechanical coupled consolidation, voltage loss was observed at mid-height of the sample due to soil–electrode contact resulting in power loss. This voltage loss is attributed to electrode corrosion, gas generation and heating. The effective voltage at the midpoint of the sample was around 70-80% of the applied voltage. The voltage loss can be accounted for by the complex mechanism involved from the precipitation of metal hydroxides near the cathode and the desorption of metal ions at the anode during the test.
5. The voltage variation with time plays a vital role in both EKCL and EKCRS loading conditions. Electrochemical reactions due to an increase in applied voltage from 2, 4 and 6 V intensity increase the volume of water drained as proved by the change in moisture content and void ratio data. This additional effect of constant gradient response resulted in early dissipation of pore water through the sample which was confirmed from the moisture content value obtained before and after the test.
6. The current variation with time revealed that for constant voltage gradient (0.5, 1.0 and 1.5 V/cm) application, the maximum current was observed at the beginning of the consolidation test. However, with the progress of the test, the current decreases steadily with time and this decrease in current can be attributed to the reduced electrical conductivity of the soil.

7. In mechanical consolidation (IL, CL and CRS), a negligible amount of moisture content variation was observed at different pre-and post-test locations. In the case of electro-mechanical coupled loading consolidation (EKCL and EKCRS), the moisture content drop near the cathode was smaller due to the drainage frontier compared to the anode location, which indicates the water flow from the anode towards the cathode as expected from the technique.
8. Based on the EKCRS tests performed on geomaterials, it is proved that the consolidation parameters viz. compression index (c_c), coefficient of volume compressibility (m_v) and the coefficient of consolidation (c_v) are found to be very much higher due to the maximum value of the final settlement for a given time of consideration when compared with the CRS on a particular strain rate application.
9. The maximum settlement was observed more in EKCL and EKCRS consolidation techniques than in the conventional mechanical loading consolidation (IL-C and IL-M) processes. This is due to the faster rate of dissipation of excess pore water pressure resulting in the additional settlement because of the electrolysis/dissociation of pore water molecules between electrodes.
10. In coupled loading consolidation, with the increase in time-stressed corrosion and electroosmotic passivation takes, which reduces contact between soil and electrode interface and causes crack formation that destructs the drainage channel within the soil for water movement and further increases the resistance to flow of water.
11. Amongst EK consolidation tests, the energy consumption was found to be significantly lower in the EKCRS test compared to EKCL tests. The advantage of test run at high strain rates in EKCRS completes the consolidation process at early hours compared to EKCL and CRS test, thus ultimately minimizing the energy consumption.

In summary, electrokinetic consolidation proved to be a promising technology to improve the consolidation characteristics of fine-grained soils.

7.2 Contributions of the Study

The research focuses on the consolidation characteristics of geomaterial, specifically on fine-grained soils that pose significant challenges to geotechnical engineering due to their high compressibility and low shear strength. Traditional hydraulic methods such as pre-loading and vacuum pressure may not be effective and can be time-consuming. Therefore, the study aims to establish a laboratory consolidation technique that confirms electrokinetic standards, which can be utilized for the effective management and utilization of these materials in construction practices. The laboratory technique involves applying an electrical potential gradient coupled with constant stress and constant strain to the soil, leading to fundamental changes in its electro-hydro-mechanical (EHM) behaviour. To develop this technique, extensive research on soil samples is necessary, which can provide a better understanding of the soil behaviour on a smaller scale and can be replicated in field conditions as required. This technique can be used to address the consolidation of problematic, soft-grained soils in geotechnical engineering, and can also aid in the reclamation of abandoned land masses.

7.3 Limitations of the Study

The main limitation encountered during the CRS is tests run at lower rate of strain thus taking a long time to complete the consolidation process. This hindrance is minimized with the coupled electrokinetic CRS and allows the apparatus to run at higher strain rates also. The EKCRS device is more advantageous over CRS but there is a possibility of blockage of flow due to the generation of gas during the EK process. This limitation can be overcome effectively by attaching a vacuum pump as well by knowing the supportive data such as the zeta potential of clay, amount of clay content etc.

7.4 Recommendations for future study

Based on research findings obtained from the present dissertation, the following issues can be explored in future research:

1. To develop a large-scale pilot test apparatus for the comparison and validation of results obtained through laboratory test and its implication in field test
2. To develop a large strain consolidation for EK coupled with constant surcharge loading and constant strain rate loading.
3. To understand the unknown effect of some design parameters on coupled EK consolidation which are influenced by the changes in soil properties like zeta potential which need to be considered to determine the efficiency of the process.
4. Further research can be studied on polarity reversal and intermittent current technique for the optimization of power associated with the test.
5. Parameters like pore pressure and density changes with depth can also be further investigated, if possible, with proper techniques
6. The EKCRS consolidation method will also be investigated from the point of view electrokinetic stabilization of soft soils helps in field applications.