Assessment of Alkali-Induced Heaving in Soil and its Stabilisation using Additives through Electrokinetics

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by

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Chapter 7

CONCLUSIONS AND FUTURE SCOPE

7.1 Summary and Conclusion

The heaving in soil due to alkali contamination has been observed widely in several industries in India and countries across the world. Understanding the alteration in geotechnical properties of soil after alkali interaction has been a challenging task for researchers. In the past, several extensive studies have been carried out to understand the effects of different concentrations of alkali on heaving as well as other geotechnical properties of soil. The primary objective of this is to study and understand the effects of different concentrations of alkali on heaving as well as the geotechnical properties of soil. An attempt has also been made to utilize industrial waste and chemical stabilizers to control the alkali-induced heaving and to improve the geotechnical properties of soil. The ultimate aim is to suggest proper methods to control the alkali-induced heaving as well as improving the geotechnical properties of heaved soil caused due to alkali with the help of laboratory-based investigations. For this, the research has been divided into three phases. Each phase involves a separate parametric analysis of various factors apart from the impact of different concentrations of alkali contamination. The first phase includes an indicative assessment of the effects of different alkali concentrations on heaving and other geotechnical behaviour of soil. It also includes an electrokinetic analysis of alkali-induced heaving in large-scale rectangular and circular models. The second phase of the research work involves the utilization of different percentages of GGBFS and alccofine to control the alkali-induced heaving and to improve the geotechnical properties of soil. The third phase employs the bench-scale electrokinetic tests to evaluate the efficiency of different percentages of EICP and different combinations of sodium silicate and calcium chloride as well as sodium carbonate and calcium chloride to improve the geotechnical properties of alkali heaved soil. The different combinations of these chemicals are also used to control the heaving in soil due to alkali inundation. Details of experimental investigations carried out, results obtained along with the analysis of the results have already been presented in detail in different chapters of the thesis. Based on the results discussed in chapters, the major conclusion of the study can be summarised as follows:

- Alkali contamination adversely affects the heaving behaviour as well as other geotechnical properties such as specific gravity, Atterberg limits, compaction characteristics, unconfined compressive strength and shear strength parameters of soil.

- The mineralogical study evidenced that the new compounds formed after alkali interaction leads to an increase in soil heaving whereas the microstructural changes show the weathering and deteriorating effect due to alkali interaction resulting a decrement in the strength of the soil. The increase in alkali-induced heaving in soil and alterations in geotechnical properties of soil is proportional to the concentration of alkali.

- In the large-scale electrokinetic model, the maximum heaving value of 5.42% was observed in the case of the circular electrokinetic model as compared to the rectangular electrokinetic model in which the heaving value of soil was observed to be 4.39%. Finally, it was observed that the heaving of soil due to alkali interaction was found to be consistent. The maximum heaving pressure observed in the circular EK models about 370 kN/m^2 and the heaving pressure in the rectangular EK model was 184.36 kN/m^2 respectively.

- More uniform and consistent values of heaving, heaving pressure, EO flow, voltage and temperature were observed in the case of the circular electrokinetic model due to uniform ingression of alkali solution as compared to the rectangular model.

- A considerable decrease in the unconfined compressive strength and shear strength parameters of soil due to alkali interaction was observed in both large-scale electrokinetic models. The decrement was more prominent in the case of the circular electrokinetic model.

- The oedometer test results shows that the maximum reduction in heaving was observed with the addition of 20% GGBFS and 20% alccofine. The higher reduction in heaving is not due to just the replacement of soil with GGBFS and alccofine but mainly due to the cementation of soil particles by the formation of pozzolanic compound.

- The UCS test results confirm that the unconfined compressive strength of both soils increases with the increase in GGBFS content and increased in curing period whereas the maximum unconfined compressive strength value of uninteracted soil and alkali-interacted soil is achieved at 20% and 25% alccofine respectively.

- UU triaxial tests have also been done to analyse the variation in shear strength parameter in stabilising the un-interacted and alkali interacted soil with the addition of 20% GGBFS and alcofine at different curing periods. The major findings of this test were that the addition of 20% GGBFS caused an increase in both cohesion and angle of internal friction. However, with the increase in the curing period, cohesion increased but a marginal change in the angle of internal friction was observed.

- An electrokinetic stabilisation approach to simulate the field treatment of alkali-interacted soil was found to be successful when GGBFS and alccofine were allowed to migrate through alkali-interacted soil in the form of slurry.

- The mineralogical and microstructural study of GGBFS and alccofine stabilised soil confirms the formation of cementitious compounds after the pozzolanic reaction between soil and these stabilisers in the presence of alkali. The formation of CSH gel forms a denser and more compact packaging between soil particles, leading to an increase in the strength of the soil and a reduction in alkali-induced heaving.

- Chemical stabilizers accompanied with EK technique has been used to stabilise the alkali interacted soil. EICP solution was used as a bio-inspired chemical technique, whereas sodium carbonate and sodium silicate with calcium chloride solution was used as chemical stabilizers. Remarkable recovery in strength and stiffness of alkali interacted soil was observed with the use of these stabilizers.

- The utilization of EICP solution and combination of sodium carbonate and calcium chloride solution with EK technique results in calcite precipitation in the voids of soil matrix. The formation of calcite precipitation in the voids of clay particles forms a package between clay particles, thus generating cementation or bond between clay particles which facilities a dense soil matrix and brings the soil particle together leading to an increase in strength and reduction in alkali-induced heaving of soil.

- The maximum value of calcite precipitation in alkali interacted soil treated with EICP solution was observed at about 6.3% for molar combination C2 whereas the maximum calcite precipitation of about 8.4% was observed in alkali interacted soil treated with the combination M5 of sodium carbonate and calcium chloride solution.

- The maximum unconfined compressive strength of alkali interacted soil increases from 103 kPa to 331.82 kPa after EK-EICP treatment while the unconfined compressive strength value of alkali interacted soil increased up to 489.45 kPa with the addition of sodium carbonate and calcium chloride solution.

- The addition of EICP and the combination of sodium carbonate and calcium chloride solution also increases the cohesion value from 17 kPa to 67.12 kPa and 84.32 kPa respectively and the angle of internal friction angle from 24.3^o to 33.50^o and 27.32^o respectively, after calcite precipitation in the voids of treated soil.

- The alkali-induced heaving in soil reduces from 5.25% to 2% after EK-EICP treatment and from 5.25% to 1.2% with the addition of sodium carbonate and calcium chloride through EK treatment.

- The formation of calcite precipitation in the voids of soil after EK treatment with these stabilizers was also visible in the SEM image of treated soil. The new peaks of calcium carbonate were also observed in XRD analysis of treated soil.

- The ingression of calcium chloride and different concentrations of sodium silicate solution through EK technique increase the unconfined compressive strength value of alkali interacted soil increases from 103 kPa to 464.37 kPa and the cohesion and angle of internal friction increase from 17 kPa to 77.93 kPa and 24.3^o to 28.13^o respectively after EK treatment.

- The addition of different concentrations of sodium silicate solution with calcium chloride solution also reduces the heaving in soil due to alkali interaction. The heaving in soil decreases from 5.25% to 0.95% after mixing sodium silicate solution.

- The mineralogical and microstructural study also shows the development of CSH and CAH gel in voids of alkali interacted soil after EK treatment which results in an improvement in geotechnical properties of alkali interacted soil.

7.2 Limitations and Scope for Future Work

7.2.1 Limitations

In the present research, an attempt has been made to study the effect of alkali solution on heaving as well as other engineering properties of soil. A new approach EK technique has also been employed to analyse alkali-induced heaving in the soil in a large-scale model to simulate the field conditions. It also includes the evaluation of the efficiency of pozzolanic waste materials to reduce the alkali-induced heaving as well as to improve the mechanical properties of soil. Despite these, chemical stabilizers have also been used to stabilise the alkali-interacted soil through a bench-scale model equipped with electrokinetic setup. Using EK technique facilitates the flow of the chemicals through the contaminated soils and makes stabilization process faster. However, the present research is only a laboratory-based study and it requires detailed research to validate the results with field conditions. There is a lack of information about the differential settlement and deformation in structure due to heaving in foundation soil after alkali interaction. For this, a pilot scale, as well as a field study, is required to investigate the behaviour of structures built on or in the alkali-induced heaving soil in detail. Further, the pozzolanic waste materials and chemical stabilizer should be examined in the field to control the alkali-induced heaving in soil.

7.2.2 Scope for Future Work

The scope of the present study for future work is summarized as follows:

- Studies are also required to identify the use of other waste materials to control the alkali-induced heaving and to improve their long-term performance in terms of strength, endurance and environmental assessment.

- The discussed EK equipped technique for stabilization of alkali interacted soil can be analysed for the built-up areas beneath the structures.
- The efficiency of pozzolanic waste materials and chemical stabilizers should be examined in the field to control the alkali induced heaving in the soil.
- Analytical simulations can also be performed to check for the accuracy and reliability of the results.