CONSOLIDATION BEHAVIOUR OF COMPACTED SWELLING AND NON-SWELLING FINE-GRAINED SOILS

The state of the soil which is the base for all constructional activities on this earth plays an important role in deciding the performance of the structures constructed over it. From the point of view of all the three major criteria of structures founded on soils namely, Strength, Stiffness and Stability, the subsoil is expected to be in a compacted state. This paves the way for numerous studies on compacted soils. The study of compacted soils becomes all the more important in the present day scenario wherein the lack of good constructional sites is forcing the people to go for using the sites which have been considered since ages as unsuitable for constructional activities. In view of ever-growing demand for the constructional sites, it is inevitable to reclaim the marginal lands after subjecting them to various ground improvement techniques. Compaction is the simplest and more versatile mechanical ground modification process, which engineers prefer to adopt. While the compaction of coarse grained soils do not pose problem to a field engineer, same thing cannot be said about the compaction of fine-grained soils. While the compaction of coarse grained soils is purely a physical problem, the behavior of compacted fine-grained soils is expected to be physio-chemical in nature by virtue of the clay mineralogical composition of such soils.

The contradictory behaviour of kaolinitic and montmorillonitic soils have been brought out and studied with respect to many soil properties in the field of geotechnical engineering such as liquid limit, free swell, volume change, sedimentation, undrained shear strength and the like. On the similar lines, the present experimental work aims at a detailed study of engineering behaviour of compacted fine-grained soils as controlled by their clay mineralogical composition.

The second chapter which follows the introductory remarks to the present work reviews the pertinent and important literature pertaining to the compaction behaviour of swelling & non-swelling soils, consolidation and permeability behaviour of compacted swelling & non-swelling soils. The important out come of this review is that the studies related to the compaction behaviour of swelling and non-swelling
soils and also to the studies related with the consolidation and permeability behaviour of compacted swelling and non-swelling soils are almost nil, and the same has helped in formulating the scope of the present experimental work.

A detailed description of the experimental programme envisaged and meticulously carried out forms the subject matter of the third chapter. This also gives an account of various soils selected for the present experimental work, the selection process involved and preparation of soils prior to the experimental investigation work.

The natural soils used in the present work have been broadly grouped into two categories namely, soils of same low liquid limit group ($w_L = 54\%$) and soils of same high liquid limit group ($w_L = 68\%$). Out of the two soils of same low liquid limit group, one soil is kaolinitic and the other is predominantly montmorillonitic. While one of the three soils forming the soils of same high liquid limit group is a field soil containing montmorillonite as the predominant clay mineral, the second field soil contains both kaolinite and montmorillonite clay minerals in dominant proportions. The third soil of this group is a commercial kaolinite clay mineral (i.e., China Clay). The third category of soils contains two soils with their liquid limits differing by a great margin namely, commercial kaolin ($w_L = 48\%$) and mixture of bentonite & sand ($w_L = 165\%$). Grouping of the selected soils into swelling and non-swelling types has been done with the help of free swell ratio, which is defined as the ratio of equilibrium sediment volume of 10 g of oven dried soil fraction passing 425 μm sieve in distilled water to that in carbon tetra. The results obtained from such tests have been validated with the results from more sophisticated X-ray diffraction analysis.

Compaction characteristics of swelling and non-swelling soils (Fourth chapter) have been studied at two compaction energy levels namely Indian Standard light compaction (akin to standard Proctor compaction) and Indian Standard heavy compaction (akin to modified Proctor compaction). The studies have shown that the compaction characteristics namely optimum moisture content (OMC) and maximum dry density ($\rho_{d,max}$) cannot be related with the liquid limit and plasticity index of soils. Instead, they can be correlated with the plastic limit of soils and the associated dry density. Very good correlations have been shown to exist between optimum moisture contents obtained from light compaction tests with those obtained from heavy compaction tests and also between the maximum dry densities obtained from light & heavy compaction tests. A general correlation has also been shown to exist between
the values of maximum dry unit weights and corresponding values of OMC encompassing all compaction energy levels. The study also has established the dependency of compaction characteristics on the clay mineralogical composition of natural soils. The degree of saturation at OMC has been shown to be a function of dominant clay mineral present in the soil, and its strong dependency on the specific gravity of soil solids has also been established with numerous illustrations.

A detailed study of consolidation behaviour of compacted swelling and non-swelling soils has been done, and the results & discussions are presented in the fifth chapter.

One dimensional consolidation experiments have been carried out corresponding to three placement conditions namely, compacted to $0.95\rho_{d\text{max}}$ on dry side of optimum, compacted at OMC and compacted to $0.95\rho_{d\text{max}}$ on wet side of optimum, where $\rho_{d\text{max}}$ is the maximum dry density of the soils obtained from light compaction test and OMC is the corresponding optimum moisture content.

It is shown that the compacted soils also exhibit characteristic preconsolidation stresses akin to the preconsolidation stresses of over consolidated field soils. The preconsolidation stresses of compacted soils have been shown to be dependent on soil clay mineralogical composition of the soil and also on the placement conditions.

The $e$-$\log \sigma'$ behaviour of compacted soils have been shown to be a function of initial moulding water content, effective consolidation stress level and also the clay mineralogical composition of soils. Even though $\frac{\Delta e}{\Delta \log \sigma'}$ vs $\log \sigma'$ behaviour of compacted soils appears to be independent of clay mineralogical composition of the soil, the values of conventional compression index ($C_c$) of compacted soils have been shown to be strongly dependent on the clay mineralogical composition of soils. The values of conventional compression index of compacted montmorillonitic soils are always higher than those of compacted kaolinitic soils, the liquid limit of both soils being the same, under any placement condition. Unlike the soils undergoing consolidation with liquid limit water content or more as the initial moulding water content, the variation of $c_v$ of compacted soils with effective consolidation stress does not get affected dominantly by the mineralogical composition of the soils.
The over consolidation can be induced in the soils by subjecting them to compaction or to consolidation. A comparative study of consolidation behaviour of soils has been done under the present experimental work considering the compacted soil specimen and also remoulded-reloaded soil specimen, both with the same stress history. The Indian standard light compaction energy has been used to obtain the compacted soil specimens. On the other hand, the remoulded soil specimens have been obtained starting from the initial water content slightly more than the liquid limit water contents of the soils. Such soil samples have been subjected to virgin compression upto preconsolidation stress of optimum compacted soil samples, followed by unloading to a seating stress of 6.25 kPa. These soil samples have been subjected to reloading similar to consolidation loading of compacted soils samples. The comparative study of the consolidation behaviour of compacted and remoulded-reloaded soil samples of identical past stress history indicated that the e-log $\sigma'$ curves of remoulded-reloaded soils always lie above those of compacted soil samples indicating the influence of fabric induced in the soil due to compaction and consolidation process. On an average, the $(\Delta e / \Delta \log \sigma')$ values of remoulded-reloaded soil samples at any given effective consolidation stress level are higher than those of compacted soil samples. The values of conventional compression index of remoulded-reloaded soils have been shown to be always higher than those of same soils in the optimum compacted state and are strongly dependent on the dominant clay minerals present in the soils. The remoulded-reloaded montmorillonitic soils have been shown to always exhibit higher values of conventional compression index than the remoulded-reloaded kaolinitic soils, the liquid limits of both type of soils being the same.

The present study has also shown that the montmorillonitic soils have more compressibility than kaolinitic soils of same liquid limit under compacted state or remoulded-reloaded state.

The study also indicated that the variation of $c_v$ with $\log \sigma'$ in the post-yield region of remoulded-reloaded soils is controlled by the clay mineralogical composition of soils.
Permeability behaviour of compacted fine-grained soils is of immense practical importance. In view of this, some studies on the permeability behaviour of compacted swelling and non-swelling soils have been carried out in the present work. The results of such studies along with the discussions are presented in the sixth chapter.

Variable head permeability tests have been conducted on compacted swelling and non-swelling fine-grained soils with different placement conditions namely, compacted to 0.95 \( \rho_{\text{dmax}} \) on dry side of optimum, compacted at OMC and compacted to 0.95 \( \rho_{\text{dmax}} \) on wet side of optimum. The permeability measurements have been taken at a seating effective consolidation stress of 6.25 kPa during the forward loading process and also at the same stress level before dismantling the soil samples.

The results of the present experimental work indicate that the compacted swelling and non-swelling fine-grained soils follow the Darcy's law beyond characteristic threshold gradient. The coefficient of permeability of the compacted soil has been calculated as the slope of linear portion of the velocity of flow vs hydraulic gradient curve.

The clay mineralogical composition of compacted soils appears to have a controlling influence on the values of their coefficient of permeability.

The compacted soils exhibit maximum values of coefficient of permeability on the dry side of optimum and the least values at or slightly beyond OMC on wet side of optimum. At the same void ratio level, the fabric of the soil appears to control the values of coefficient of permeability of compacted soils. The values of coefficient of permeability obtained from direct measurement have been observed to be much greater than those calculated indirectly from \( c_v \) values.

The important features of the present experimental work on compaction behaviour, consolidation and permeability behaviour of compacted fine-grained swelling and non-swelling soils have been summarised in the seventh chapter.
In total, it can be concluded that the compaction behaviour of fine-grained soils, consolidation and the permeability behaviour of compacted swelling and non-swelling soils are governed by the clay mineralogical composition of the soils, in addition to placement conditions. This emphasises the importance of the effect of clay mineralogy on the engineering behaviour of compacted soils in the field and also the greater responsibility of the geotechnical engineers who are in-charge of the planning and execution of various constructional works related with compacted soils for the satisfactory performance of such projects.