CHAPTER 6

CONCLUSIONS

From the analysis of results of three phases of experiments that were conducted on six different expansive clays (three natural and three Bentonite) to study the swelling, shrinkage, and load carrying capacity of clays for varying initial density and initial moisture content under swollen and unswollen state and with and without addition of geosynthetic and admixture (sand), the following general conclusions may be drawn.

Effect of Initial Moisture Content and Density on Swelling and Shrinkage Behaviour (Phase I)

1. Even though % swell and swell pressure decrease with increasing moisture content, its effect on the swelling magnitude is significant only when the initial moisture content is lesser than shrinkage limit water content and beyond which the same is insignificant irrespective of soil type and initial density.
2. The % swell and swell pressure increase with initial density only when moisture content is relatively low and on the other side even at higher densities, swelling remains the same when initial moisture content is greater than plastic limit water content. Even
though, both initial moisture content, and density together are responsible for the magnitude of swelling, but still initial moisture content over rides the effect of initial density especially at low water content. These observations are different from findings of earlier researchers.

3. The initial moisture content influences not only the magnitude of shrinkage but also the rate of shrinkage. The vertical, horizontal, and volumetric shrinkage increase with increasing moisture content irrespective of the differences in initial densities. When initial void ratio is closer to the liquid limit void ratio, the volumetric shrinkage remains unchanged.

**Unconfined Compressive Strength and Consolidation in Swollen and Unswollen Condition (Phase II)**

4. Irrespective of the two different conditions (varying IMC – constant density and varying density and constant IMC) under which the compressibility on UCC strength of swollen expansive clays are evaluated, the initial void ratio (unswollen) and water content bear a linear relationship with swollen water content and void ratio.

5. A linear correlation is obtained between unswollen clays and swollen clays with a slope of 0.0615. The swollen clays showed UC strength 50% lesser than the unswollen clays.

6. The compression index values of swollen clays are 30% to 50% higher than the unswollen clays.
7. Normalized water content which is the ratio of swollen water to the liquid limit of soil \( \frac{W_{SW}}{W_{LL}} \) vary between 0.4 to 0.6, which in close agreement with the findings of earlier researchers Parthasarathy (2002), Babu sanker et al. (1990), and Liu et al. (1998). Normalised water content \( \frac{W_{SW}}{W_{LL}} \) is having exponential relationship with normalized strength values \( \frac{q_u(swollen)}{q_u(unswollen)} \), in the form of

\[
\frac{q_u(swollen)}{q_u(unswollen)} = 0.0165 e^{4.3488 \left( \frac{W_{SW}}{W_{LL}} \right)}
\]

Where,

- \( q_u(swollen) \) is swollen unconfined compressed strength in kN/m\(^2\)
- \( q_u(unswollen) \) is unswollen unconfined compressed strength in kN/m\(^2\)
- \( W_{SW} \) is swollen water content in \%
- \( W_{LL} \) is liquid limit water content in \%

**Control of Swell – Shrink Behavior by Geosynthetics (Phase III)**

8. Among different geosynthetic materials used, introduction of geomembrane into the clay system is found to control the swelling of expansive clay significantly compared to other materials. The reduction in % swell is as high as 50% for the case of one layer of geomembrane in clay sample without end confinement. The reduction of % swell is in the order of geomembrane > geogrid > geotextile > geocomposite.

9. For any geosynthetic material, the one which is confined at the edges, is found to control the swelling 30 to 40 % higher than the same material without confinement. In the case of soil + two layers of geomembrane with end confinement, the swell reduction
is 85%. The swell reduction is attributed to the passive resistance mobilised on the geomembrane.

10. Geosynthetic material placed vertically gave the higher swell reduction compared to the same material placed in horizontal direction, especially this is true for the case of geogrid and geocomposite. This may be due to the development of friction between the soil and geogrid for the entire sample height unlike the case of soil with horizontally placed geogrid, where soil below the geogrid gives raise to friction and whereas soil above is allowed to freely swell. Among the materials selected, the amount of shrinkage (both in horizontal and vertical direction) was the least for soil with geomembrane compared to other geosynthetic materials. The % reduction in shrinkage is in the order of geomembrane > geotextile > geocomposite > geogrid.

11. Even though the introduction of geomembrane controlled swell-shrink behaviour of expansive clays better than other geosynthetic materials, load carrying capacity of swollen clays with geomembrane yielded the lowest strength and among the material used, clay with geogrid provided higher capacity at any given settlement.

**Control of Swell – Shrink by Admixtures**

12. The magnitude of shrinkage, both vertical and horizontal, is found to decrease with increasing sand content of clay. The difference in vertical shrinkage at the centre and edge of the dry soil pat is found to decrease with increasing sand content.
Further the time at which the shrinkage comes to a constant value also decreases with increasing coarser fraction.

13. Time-shrinkage curves generally follow a rectangular hyperbolic relationship irrespective of the soil type, amount of coarser fraction and initial moisture content. The time-loss of weight relationship also follows a hyperbolic relationship. The cracks developed during shrinkage is found to decrease with increasing sand content in bentonite.

14. An empirical equation has been developed to predict the time – shrinkage of clays for any liquid limit as

\[ V_{sh} = \frac{t}{7.1551 \times (LL)^{0.7445} + (4482.1 \times (LL)^{0.3209}} \]

Where, \( V_{sh} \) is Vertical shrinkage in mm, \( t \) is time in minutes at which shrinkage is required, ‘LL’ is Liquid limit of soil in %. The applicability of the above equation has been attempted and found to be in good agreement with experimental values.

15. A correlation is also proposed to predict the volumetric shrinkage of expansive soil for any liquid limit (LL) and initial moisture content (IMC) as.

\[ S_{vs} = LL \times (0.6345 \times (IMC)^{-0.4917}) \]

Where, \( S_{vs} \) is volumetric shrinkage in cm\(^3\).

Among the geosynthetic materials used in this study, though geomembrane controlled swell–shrink potential of expansive clays better than other materials, the same did not show any improvement on the load carrying capacity of swollen clays. Whereas use of geogrid in expansive clays not only controlled the swell – shrink magnitude, but also
enhanced the load carrying capacity of swollen clays. Clays with two layer of end confined geogrid controlled swelling almost equal to that of clay with either 50% sand or flyash or quarry dust.

It is hence concluded that, considering the construction difficulties experienced with reference to uniform and effective mixing of admixtures like sand or flyash or quarry dust and also selection optimum dosage in geotechnical projects like embankments, land reclamation etc., geosynthetic material can be effectively used to control the swell-shrink potential of expansive clay, added advantage being enhancement of load carrying capacity.