Parametric Study on Dynamic Characterization of Homogeneous and Stratified Soil-Ash Deposit under Low-Strain and High-Strain Conditions

Thesis submitted in partial fulfillment

for the Award of Degree

Doctor of Philosophy

by

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18061002 ***June 2023***

CHAPTER- XI

CONCLUSIONS AND FUTURE SCOPE

11.1 SUMMARY AND CONCLUSIONS

In this study, a detailed investigation has been carried out on the homogeneous and stratified soil-ash deposit. The objective of the study was to utilize the homogeneous and stratified soil-ash deposit as a pavement material. To fulfill this prime objective, a series of chemical, geotechnical, strength characterization, static and dynamic characterization, and maximum shear modulus characterization tests were conducted on the homogeneous and stratified soil-ash deposit. The shear strength characteristics and failure behaviour of the considered materials were determined in the laboratory through a series of static triaxial tests under different controlled loading conditions. The dynamic properties and maximum shear modulus characteristics of the homogeneous and stratified soil-ash deposit were determined in the laboratory through a series of cyclic triaxial and bender element tests respectively considering different influencing parameters (relative compaction, shear strain, loading frequency, effective confining pressure). The details of the materials, apparatus used, methodology, and detailed testing plan have been discussed in the previous chapters. Also, the influence of asymmetricity in the shape of the hysteresis loop during large shearing strain has been assessed. The shear modulus obtained from the cyclic triaxial test has been incorporated with the maximum shear modulus to determine the normalized shear modulus of the present considered materials. The suitability of the stratified soil-ash arrangements in the application of pavement engineering has also been analyzed. The experimental investigations and results of the laboratory tests have been discussed in detailed in chapter IV-X of the thesis. Based on the results discussed in the previous chapters, the major conclusions of the study can be summarized as follows:

11.1.1 Chemical Analysis Test Results

- The fly ash exhibits glassy spherical shaped particles popularly known as cenospheres and plerospheres. Whereas the local soil shows particles of shape flaky, angular, and thin chipped form.
- Al, Si, and O are present in fly ash at their highest levels, whereas, Al, Si, O, Mg, and K are present at their highest levels in local soil.
- The major peaks of Quartz, Alumina, Hematite, and Titanium dioxide has been observed in fly ash.
- In the case of local soil, along with Quartz, the Stilpnomelane, Muscovite, Leucite, Gupeiite, and Biotite were observed.
- The combination of Al_2O_3, SiO_2, and Fe_2O_3 contributes around more than 95% of the chemical constituents in the fly ash, hence classified as class F fly ash.
- The fly ash shows acidic behaviour while basic nature has been observed in the local soil.

11.1.2 Geotechnical Characterization Test Results

- The fly ash contains a higher fraction of sand (61.52%) size particles followed by silt (33.19%) and clay (5.29%). Similarly, the local soil is composed of maximum silt (81.77%) size particles followed by clay (16.11%) and sand (2.12%).

- As per Unified Soil Classification System, the fly ash is classified as well graded silty sand and local soil is classified as silt of intermediate plasticity.
- The fly ash needs higher percentage of water to behave as liquid materials as compared to that of the local soil.
- The local soil shows the high degree of compactness for a lower percentage of water content whereas fly ash requires a higher amount of water to achieve the maximum degree of compactness. The local soil has higher maximum dry density than that of the fly ash.
- Due to the presence of the higher percentage of clay size particles, the local soil has very low permeability than that of the fly ash that is suitable to entrap the harmful leachates from the fly ash.
- The California Bearing Ratio of fly ash is higher followed by stratified soil-ash and local soil for both the unsoaked and soaked conditions.

11.1.3 Shear Strength Characteristics

- The shear strength parameters such as cohesion (c) and friction angle (ϕ) obtained from the UU tests reveal overestimated values, and nearly all the samples performed well. However, the strength parameters (effective cohesion (c') and effective friction angle (ϕ')) change significantly when samples get saturated under CU and CD conditions.
- Regardless of the drainage circumstances, there are no significant changes in the FA and 2-layered samples, although LS exhibits a decrease in strength parameters with saturation.
- The shear failures are only visible in the case of UU circumstances for FA and LS, but the pattern of failure switches from shear to bulging with saturation and layering.

- The equivalent modulus (E_{eq}) for multi-layered soil-ash deposit was mathematically formulated, and it was compared with the experimentally measured modulus of the two-layered specimens, leading to the conclusion that the weighted harmonic mean approach is the most appropriate for the current investigation.
- This thorough investigation of the shear strength properties of the homogeneous and stratified soil-ash deposits, aids in choosing the appropriate soil replacement while also enhancing the shear strength and bearing capacity.

11.1.4 Dynamic Shear Modulus and Liquefaction Assessment

- The stratified soil-ash system shows higher dynamic shear modulus than that of the fly ash and local soil for the shear strain 0.3% & 0.6% and beyond 0.6% it shows comparable shear modulus with that of the homogeneous one.
- The local soil exhibits high energy per unit volume needed for liquefaction followed by stratified soil-ash and fly ash system.
- The energy required for liquefaction is dependent on all the considered parameters whereas it is independent of the cycle needed to liquefy.
- The local soil and stratified soil-ash deposits are greatly influenced by the change in loading frequency whereas fly ash was least affected by the frequency of loading.
- The shear modulus versus shear strain variation of the present materials were comparable with the sand having higher fine content (or categorized as SP).
- The stratified soil-ash deposit shows significant improvement in the cyclic strength and can be recommended for the application in the seismic area where shear strain is restricted up to medium strain range.

11.1.5 Damping Characteristics

- The damping ratio of fly ash estimated from the symmetrical method (SHL) approach shows a similar trend, as in the case of the asymmetrical approach (ASHL), and shows the maximum damping ratio at around 1% of shear strain.
- The specimen prepared under high density and the specimen subjected to high confinement shows low damping ratio. Whereas, specimen tested under high frequency shows high damping behavior.
- The SHL approach is suitable for low strain conditions because, under large strain conditions, it underestimates the damping ratio of soils.
- Among all the approaches, the ASHL approach gives a higher damping ratio followed by the ASTM and then the SHL approach for fly ash, local soil, and stratified soil-ash samples.
- The influence of cycle position is not remarkable for low shear strain, but for the high strain, the difference in the A_L is profound.
- The ASHL approach can be adopted for estimating the damping ratio using any cycle position data because this approach shows a minimum variation than that of the others.
- The maximum damping ratio of stratified deposit is always falling in between the damping ratio of local soil and fly ash. This is due to the combined interaction between fly ash and local soil.
- The peak of damping ratio of the fly ash varies between 0.6-0.9% of shear strain, however, the local soil shows a peak in between 0.8-1.2% of shear strain. On the other hand, the stratified soil exhibits a wide range of damping ratio's peak variation, i.e., in the range of 0.6-1% of shear strain.

11.1.6 Maximum Shear Modulus and Correlation Studies

- The peak-to-peak method has been incorporated for the estimation of travel time of the wave from the transmitter to the receiver.
- The maximum shear modulus (G_{max}) is directly proportional to the confining pressure and frequency of the input wave.
- The rate increase is G_{max} was very high till 3-4 kHz of input wave frequency and then decreases with the increase in frequency.
- The hyperbolic models were best fitted with the G/G_{max} and damping ratio (D) of the present study. These models can be implemented to predict the stiffness properties of homogeneous and stratified soil-ash deposit at low and high shear strain.
- The excess pore pressure ratio model has also been established with the energy ratio till liquefaction failure with upper and lower boundary limits. That will help in the prediction of liquefaction failure of homogeneous and stratified soil-ash deposit based on the strain energy stored.

11.1.7 Performance of Stratified Soil-Ash Deposit as a Pavement Material

- The stratified soil-ash provides economical flexible pavement than that of the local soil under all the considered loading conditions.
- Among all the reinforcement used, the biaxial geogrid shows promising strength improvement that has been witnessed through CBR values.
- The unreinforced stratified soil-ash deposit observed high thickness reduction with the inclusion of reinforcement especially under low traffic condition and vice-versa.

- The stratified soil-ash arrangements can be successfully implemented in low rainfall areas, whereas for high rainfall areas some ground improvement or reinforcements are required for the sustainable applications.

11.2 LIMITATIONS AND SCOPE FOR FUTURE WORK

11.2.1 Limitations

The issue of coal ash production as a whole is too complex to be solved in a single move. Also, it is very challenging to cover every aspect of the application in a single study because of the limited resources and time constraint. The present study precisely focuses on the ash contributing a higher fraction of coal ash, i.e., fly ash and its combination with local soils. The present study is limited to the strength and dynamic characteristics of the homogeneous and stratified soil-ash deposit for a shorter period of time, which need to be explored for long term strength testing. In the same way, the concentration of heavy metals in the leachates formation was not covered in this study. Moreover, this study involves small size reconstituted cylindrical specimen that should be investigated under large scale model testing in the laboratory as well as in the field to make the study more realistic. The engineering properties of the coal ash are highly dependent on the coal used for burning, therefore this study needs to be verified with the ash sample produced throughout the year. This study is limited to ash collected from a single thermal power plant, hence similar type of studies on the ash produced at other thermal power plants may assist in the standard codal provisions, which will ease the application of coal ash in the homogeneous and stratified form in the field of Civil Engineering.

11.2.2 Scope for Future Work

The limitations addressed in the above section open a wide scope for future work. The future scope of the present study has been discussed below:

- The present study focuses only on the homogeneous and two layered soil-ash arrangements that can be further extended to three layered or multi layered deposits for static and dynamic investigation.
- The whole experimental investigations were carried out with a maximum size of a cylindrical sample having 50 mm diameter and 100 mm height. Therefore, large scale model testing is required in order to make the study more realistic.
- The complete testing of triaxial specimen was done either under small-strain or large strain condition. Hence, for better prediction of the modulus reduction curve, the performance of these samples must be investigated under medium strain range using Resonant column apparatus also.
- For stratified soil-ash deposit, the pore pressure sensor was employed at the bottom as like homogeneous one, but for accurate measurement of the pore pressure this sensor should be installed in the middle of the specimen.
- Additional ground improvement techniques can be used to enhance the strength that will increase its wide applicability.
- The stratified soil-ash behaviour has been examined only for the dry and saturated condition that need to be explored under the unsaturated condition because any of this situation can be encountered in the field depending upon the weather conditions.