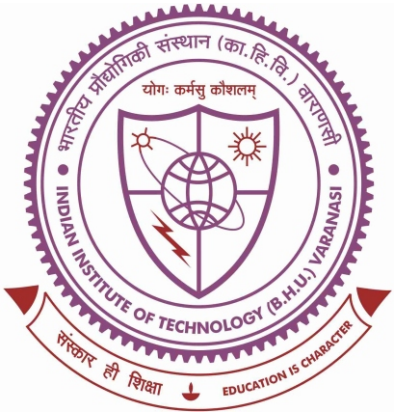
Static & Dynamic Characterization of Unreinforced and Reinforced Municipal Solid Waste (MSW Fines) for Geotechnical Applications



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By

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CHAPTER- VII

CONCLUSIONS AND FUTURE SCOPE

7.1 SUMMARY AND CONCLUSIONS

The study has been conducted on a portion of the degraded municipal solid waste in landfills or open dump sites, i.e., MSW fines (particle size less than 4.75 mm). The objective of the study was to utilize this waste material (MSW fines) which consists of a huge portion of the degraded waste (about 60% in the present study) as a geomaterial in the embankments/backfills. To fulfill this prime objective, a series of physicochemical and geotechnical laboratory tests were conducted on the MSW fines. To have a realistic idea of the behaviour of this material reconstituted samples were tested under static and dynamic loading conditions. The whole research can be divided into two sections. The first section includes the laboratory tests on unreinforced MSW fines, and the second section aims to understand the behaviour of reinforced MSW fines with different fiber content (0.5 to 10%), whereas the fibers included were also part of the waste itself. The dynamic characteristics of the unreinforced and reinforced MSW fines were determined in the laboratory through a series of cyclic triaxial and bender element tests considering different influencing parameters (relative compaction, shear strain, loading frequency, effective confining pressure, fiber content). The details of the materials, apparatus used, methodology, and detailed testing plan have been discussed in the previous chapters. The experimental investigations and results of the laboratory tests have been discussed in detail in chapter IV of the thesis. The data obtained from the detailed experimental program has

been further used to develop some correlations and prediction of the dynamic shear modulus of unreinforced and reinforced MSW fines using machine learning models (Artificial Neural Network (ANN) and Gaussian Process Regression (GPR)). Further, the sensitivity analysis was carried out to check the influence of different considered parameters on the dynamic shear modulus. Based on the results discussed in the previous chapters, the major conclusions of the study can be summarised as follows:

7.1.1 Geotechnical Laboratory Test Results

- The segregation of the collected waste shows that 60% of the waste can be categorized as MSW fines/soil-like material (particle size less than 4.75mm).
- The MSW fines can be categorized as non-plastic silty sands with medium compressibility, medium permeability, good shear strength, and low specific gravity of 2.32 through laboratory geotechnical investigations. The material meets the minimum soil shear strength and bearing capacity requirements.
- The chemical investigation of the MSW fines revealed that a few parameters, such as TDS and leachate colour, are objectionable and must be addressed, whereas TDS, chloride, and sulphate levels are relatively low. The research material contains a few heavy metals (Fe and Ti) that may need to be processed before use in the field. The organic content was found to be 5.9% which also needs to be addressed if settlement in the field exceeds the allowable limits.
- The fiber inclusion (0.5 to 10%) decreases the specific gravity and maximum dry density of the MSW fines. The monotonic strength tests confirm the improvement in the shear strength with FC, with 8% being the optimum content.
- The consolidation study on the reinforced MSW fines shows that the highest settlements were observed during the first phase of the test, which concludes that

out of the two graphical methods used, the square root of time method is more suitable to evaluate the C_v and the values were comparable to the computational method. The infusion of these waste fibers in MSW fines has reduced the overall settlement, although it's difficult to comment on the optimum percentage of FC comparing fiber-reinforced MSW fines (at any FC) with the unreinforced ones shows improvement. The fibers delay the process of consolidation due to the reduction in permeability caused by the heterogeneity and random distribution but can effectively be used to mitigate the piping effect.

- The UU, CU, and CD triaxial tests comparisons between the MSW fines and optimum (FC:8%) fiber-reinforced MSW fines revels the behaviour shift of the material from ductile to elastic. Because of the saturation and undrained conditions in the CU triaxial test, the pressure developed in the pores is unable to be reduced, resulting in a reduction in the internal friction when compared to the UU and CD testing conditions.

7.1.2 Cyclic Triaxial and Bender Element Laboratory Test Results

- The cyclic behaviour of the compacted MSW fines shows that deviator stress reduces with the number of cycles for every case. The excess PWP (pore water pressure) ratio (r_u) gradually increases with cyclic loading cycles until r_u=1 and the mean effective stress becomes zero.
- With the increase in relative compaction, confining pressure, and shear strain the liquefaction susceptibility reduces as the number of cycles to liquefy increases but the effect of frequency was still unclear. The pore pressure development was slower at low frequencies of 0.3 Hz compared to high frequencies of 1Hz.
- The G (dynamic shear modulus) of the MSW fine fractions is extremely sensitive to the increase in confining pressure, However, there are no trends in relative

compaction and shear strain. The degradation in the G and D (damping ratio) values was seen with the increase in shear strain. The effects of the considered parameters on the damping ratio values are still unknown in the current study.

- For fiber-reinforced MSW fines, there was no improvement in the dynamic shear strength (G) of MSW fines. But, the degradation of strength is comparatively low at a higher percentage of FC (8 and 10%). The damping ratio (D) was significantly improved with a higher percentage of FC (8 and 10%).
- Under cyclic loading conditions, the reinforcement of MSW fines with the waste fibers results in a faster accumulation of pore water pressure and can be divided into two stages: straight vertical and steady state.
- The shear wave velocity computed from the bender element test varies linearly with the loading frequency (f) considered up to 2 kHz for every FC but considering different relative compaction (R_c) improvements can be seen at confining pressure (σ_c) of the above 100 kPa.
- The effect of considered R_c was not that clear on the V_s but comparing the lowest (90%) and highest (98%) R_c, the improvements can be seen as the density variations between the considered R_c was very minute.
- The σ_c has no distinguishable effect on the V_s for any FC as the samples were already compacted at MDD and there was no possibility of readjustment of the particles. The σ_c effect can be seen for the samples of MSW fines compacted at lower R_c.
- The optimum fiber content obtained from the study was 1% for any σ_c and f at which the V_s or normalized G_{max} values were higher. The saturated condition reduces the V_s values due to the lag in the time of the shear wave, as the voids are assumed to be filled with water.

7.1.3 Correlations and Prediction Model Study Results

- Based on the experimental test results, the excess pore water pressure (r_u) model for the fiber-reinforced MSW fines was established, which consists of 2 parameters (b_1 and c) and also considers the effect of FC and γ. The predicted model agreed satisfactorily with the experimental data (R^2 values from 0.6 to 0.9) and can be proposed to analyze the r_u accumulation for fiber-reinforced MSW fines.
- A cubic polynomial model (R^2 values from 0.7 to 0.99) was applied to correlate the normalized small strain shear modulus (G_R/G_{UR}) and normalized shear strength (τ_R/τ_{UR}) of the fiber-induced MSW fines.
- A linear regression model was fitted to the data of the dissipated energy and shear strain of the unreinforced MSW fines. A few relationships between the energy dissipated during cyclic loading under different compaction states, effective confining pressure, and frequency were developed. Whereas a nonlinear model was fitted for the fiber-reinforced MSW fines.
- Nonlinear models were fitted for the normalized shear modulus and damping ratio with cyclic shear strain for both the unreinforced and reinforced MSW fines.
- Machine learning models (Artificial Neural Network (ANN) and Gaussian Process Regression (GPR)) were used to predict the dynamic shear modulus of the unreinforced and fiber-reinforced MSW fines. The sensitivity of all the considered parameters was analyzed and confirmed frequency to be the least affecting parameter and shear strain has maximum influence on the dynamic shear modulus of the MSW fines.

7.2 LIMITATIONS AND SCOPE FOR FUTURE WORK

7.2.1 Limitations

The problem of MSW itself is too wide that this whole problem can't be addressed in one single step. This whole study presented in this thesis addresses a very small portion of this big problem. The MSW fines contribute only about 50% of the waste, the rest 50% of non-decomposed waste is still a challenge. Although there are huge possibilities of using MSW fines in bulk quantities as geomaterials, the cost-benefit analysis needs to be considered as excavating, planning, and segregating the waste involves a huge amount of funds. Moreover, for this study only small, reconstituted samples of MSW fines were considered, which does not represent the appropriate behaviour of the material and limits its application in bulk quantities in large projects. This requires some large-scale tests or field implementation and monitoring to have a realistic idea of the long-term behaviour of the material. The chemical characteristics (heavy metals) may not be a great issue for this case, but this is the most specified limitation in the reutilization of the MSW fines, which requires pre-treatment. The pre-treatments and micro-level studies on the MSW fines itself is a huge research area. The study is very site-specific and the properties of the MSW/MSW fines widely depending on the source, so the correlations developed may not work for the same material from another site. Large scale database is required to create a universal model for the specified material.

7.2.2 Scope for Future Work

The limitations addressed in the above section open a wide scope for future work. The following suggestions given below are only from an engineering point of view,

whereas it requires research on social, economic, environmental, cultural, psychological, etc. backgrounds too.

- Field and large-scale model tests are required to have a better perspective of the material under consideration (MSW fines).
- Chemical and geotechnical studies can be conducted to check the effect of binders with MSW fines, as from this study the reinforcing material (waste fibers) does not show remarkable improvements under the cyclic loading conditions.
- Micro-level studies on MSW fines and reinforced or stabilized MSW fines can be done to have a better idea of the internal load transfer mechanism of the material.
- There have been no standard codes or practices to use MSW fines as geomaterials. Studies can be done to formulate some standards so that the material can be used widely.