6.1 GENERAL

This thesis presented a detailed examination of strength and mechanical properties of municipal solid waste and investigated the deformation behavior of reclaimed land, particularly those facilities equipped for rapid stabilization, recovery of landfill gas to mitigate greenhouse gas emissions and to generate power. Four research objectives were identified as:

(i) Establish nature and degree of alteration of the Atterberg’s Limits (namely Liquid Limit, Plastic Limit and Plasticity Index) with leachate type and leachate concentration.

(ii) Examine the significance of using intact versus recompacted samples in characterizing the stress-deformation behaviour of MSW.

(iii) Characterize MSW shear strength and Young’s modulus of elasticity from interpretation of triaxial test results and determine the parameters of a non-linear constitutive model as applied to MSW.

(iv) Measure the evolution of compressibility behaviour of MSW with degradation and investigate the mechanism of secondary compression in waste.

A comprehensive research plan was formulated and carried out, which broadly consisted of a review of the literature, field investigation and experimentation.

An exhaustive review of the literature was carried out to understand the existing state of practical and theoretical knowledge and to identify significant knowledge gaps. This review focused primarily on the shear strength and elastic properties of waste which are required to address stability and serviceability issues.
in a reclaimed land. Various sampling methods and the types of waste samples tested were also explored.

It has been observed from this review of literature that, often the samples for testing has been prepared by recompaction of waste obtained from excavation pits or from auger cutting obtained from boreholes. It is very likely that such recompaction of waste might possibly disturb the structure of waste matrix and the orientation and entanglement of tensile/reinforcing elements in the waste matrix. It was hypothesized that such rearrangement of waste constituents in recompacted samples might exhibit stress-strain behaviour which may be different from intact samples of waste.

6.2 SUMMARY OF PRESENT WORK

Atterberg’s Limit of MSW landfill samples were determined by preparing a synthetic leachate with chemical composition most representatives as possible as that observed in real leachate. It is observed that with an increase in concentration of contaminants, liquid limit shows an increasing trend but plastic limit does not follow a definite trend.

Consolidated undrained (CU) triaxial tests with pore pressure measurements were conducted on intact as well as recompacted samples of waste in order to evaluate stress-strain behaviour. The data were presented in terms of stress paths in q-p’ space and the shear strength parameters were interpreted from effective stress paths followed during shearing. The pattern of stress paths exhibited by these samples is typical of cross-anisotropic soils which exhibit a coupling between volumetric and distortional effects under undrained loading. Although, intact and
recompacted samples yielded similar shear strength parameters, their pre-failure response was different. This observation is quite significant from the viewpoint of evaluating serviceability conditions within a reclaimed land and supports the use of intact samples for establishing deformation characteristics of MSW.

The shear strength parameters estimated from stress paths drawn in q-p’ space, are comparable with published values. From evaluation of numerous triaxial test results, both from published literature as well as those conducted as part of this research program, it was observed that the stress deformation behaviour of MSW can be approximated by a non-linear elastic constitutive model (such as an hyperbolic model), within a limiting value of strains(0-20%) typically considered by researchers for interpretation of test data. Such an argument is supported by the fact that MSW shows large pre-failure deformation. The parameters of this model (\(K, n\) and \(R_f\)) were obtained through a statistical analysis of the data from over 50 triaxial tests carried out as part of this research and taken from the published literature. Considering the wide variability in sample composition, age, unit weight and confinement used in these tests: the estimated values of \(K, n\) and \(R_f\) were specified by an upper and a lower bound value using 90% confidence limit. The suggested upper and lower values of \(K, n\) and \(R_f\) are 58 and 36; 0.88 and 0.61; and 0.82 and 0.64 respectively.

The degradation of waste over time is expected to bring changes in its mechanical properties potentially leading to stability and or serviceability concerns. There is a little information in the literature at this time regarding the evolution of mechanical behaviour of waste with time and increased degree of degradation. The result from a long-term degradation test conducted using the dual-purpose compression cell revealed that \(K_0\) is not influenced by degradation and may be considered a constant with a value in the order of 0.4. The constrained modulus,
however, appears to exhibit a slight decrease with degradation when compared with corresponding values obtained from short-term tests conducted in this study. The compressibility indices were observed to undergo significant change due to degradation, and therefore, the use of a single compressibility index may provide unrealistic estimates of settlement in landfills.

A significant finding is that the data gathered from the long term compression/degradation test tend to confirm that the mechanism of secondary compression in MSW involves an episodic process of void formation due to degradation with subsequent collapse of these voids and rearrangement of the material structure with consequent settlement.

6.3 CONCLUSION

The leachate can alter the Atterberg’s limits of cohesive soils. All the leachate contaminated cohesive samples showed an increase in liquid limit and plasticity index values. The increase in liquid limit ($W_L$) and plasticity index ($I_P$) of the cohesive soil is attributed due to change in nature of pore fluid which is shown by increase in clay content of the soil. The disintegrated clay particles from the aggregates due to acidic or alkaline leachate in the pore media tends to increase in specific surface area of soil which leads to high adsorption of water that changes the limit values.

Shear strength parameters of cohesive soils are affected by leachate contamination. For specimens tested at the Proctor density, effective cohesion increases and effective friction angle decreases due to increase in leachate
concentration. The increase in clay content of cohesive soil after interaction with the leachate has increase the cohesion and hence the friction angle decreases.

Chemical characteristics of soil are altered depending upon the leachate constituents or the concentration of individual components. The pH of soil is marginally altered due to leachate. The increase in cation exchange capacity of soil may also be attributed due to marginal increase in pH value of soil with leachate. The increase in electrical conductivity, calcium, sulphate and iron content is due to leachate characteristics.

The change in chemical characteristics of cohesive soil may be detrimental to foundation concrete in real field conditions. For example, the increase in pH of soil may influence the corrosion of reinforcement. Also sulphate content of soil increases with increase in leachate concentration. This may have effect on the buried concrete leading to foundation problems. The preceding results present the short-term effect of leachate contamination on the Atterberg’s limits, shear strength parameters and chemical characteristics of cohesive soils.

The use of contaminated soil for road construction is possible from an engineering point of view by using suitable stabilization technique. The stabilization and solidification technique uses additives or processes to chemically bind and immobilize contaminants to ensure no environmental pollution.

The work presented in this thesis has enhanced the fundamental understanding of the mechanical behaviour of waste, particularly relating to pre-failure deformation and serviceability issues. The specific contributions of the proposed research are:
(i) It is observed that the leachate has significant effect on the liquid limit of the soil. The liquid limit of the soil increases with increase in percentage of leachate added.

(ii) This study has confirmed that the recompacted samples of waste may be used to obtain reasonable estimates for the shear strength parameters of municipal solid waste. This finding is particularly significant in light of challenges inherent in collecting large intact samples of waste.

(iii) An approach based upon effective stress paths obtained from shearing of samples in a CU triaxial test is proposed for estimating the shear strength parameters of waste which also establishes the fact that the mechanical behavior of saturated MSW samples can be explained using the principle of effective stress.

(iv) It is proposed that a hyperbolic elastic response curve is an appropriate constitutive model for the stress-deformation behaviour of municipal solid waste. This finding has practical significance in terms of ability to easily predict deformation of landfills, particularly given that this constitutive model is incorporated into various widely available numerical modeling software packages. Upper and lower bound values are established for required input parameters for the hyperbolic model.

(v) A constant value of $K_0=0.4$ is proposed for municipal solid waste regardless of age or applied stress.

(vi) Test data confirm that the mechanism of secondary compression in waste involves an episodic process of void formation and growth during degradation followed by collapse of voids and rearrangement of the internal structure of the waste and consequent reduction in the void ratio.
6.4 SCOPE FOR FURTHER RESEARCH

Waste mechanics will continue to evolve at least for foreseeable future as new research comes into and the database of its mechanical properties builds up. Some of the issues pertaining to serviceability still require in-depth study. The following research recommendations are made or put forth:

(i) There is need to develop a systematic framework for interpretation of mechanical properties of solid waste.

(ii) Further long-term degradation studies are required to verify compressibility behaviour of MSW as observed in this study.

(iii) The mechanism of secondary compression as observed and understood in this study needs further verification.

(iv) A systematic experimental study is required to understand the effect of accelerated degradation on shear strength of waste.

(v) The role of tensile reinforcing constituents in mobilizing shear strength need to be explored further using a three dimensional numerical tool.