"USE OF SOIL FROM GHAZIPUR LANDFILL FOR ROAD EMBANKMENT CONSTRUCTION"

Project

Submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

Mr. Saurabh Rawat

(Assistant Professor)

By

***Aakriti Chauhan* (131661)**

***Prakhyat Khandelwal* (131675)**

***Shreyansh Singh* (131707)**

to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT, SOLAN – 173234

HIMACHAL PRADESH, INDIA

May-2017

CERTIFICATE

We hereby certify that the work which is being presented in the report titled **"USE OF SOIL FROM GHAZIPUR LANDFILL FOR ROAD EMBANKMENT CONSTRUCTION"** in partial fulfilment of the requirements for the award of the Degree of **Bachelor of Technology** and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat, is an authentic record of work carried out by **Ms. Aakriti Chauhan (131661)**, **Mr. Prakhyat Khandelwal (131675)** and **Mr. Shreyansh Singh (131707)** over a period from August 2016 to May 2017 under the supervision of Mr. Saurabh Rawat, Assistant Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date:

Signature of Supervisors:

Prof. Ashok Kumar Gupta	Mr. Saurabh Rawat	External Examiner
Head of Department	Assistant Professor	
Department of Civil Engineering	Department of Civil Engineering	
JUIT Waknaghat	JUIT Waknaghat	

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to everyone who helped us in completing this report for our final B.Tech project on the topic "*USE OF SOIL FROM GHAZIPUR LANDFILL FOR ROAD EMBANKMENT CONSTRUCTION"*. We would like to thank our project guide **Mr. Sauarbh Rawat** for providing all the support and guidance we needed in successful completion of our project. We would also like to express our sincere thanks to **Mr. Abhilash Shukla,** Project Coordinator, Civil Engineering Department, JUIT, Waknaghat, for providing us with an opportunity to undertake this project.

A special thanks to **Mr. Jaswinder Deswal** and **Mr. Itesh Singh**, Technical and Laboratory, Civil Engineering Department, JUIT, Waknaghat, for providing us with all the facilities and experimental setups in the lab.

We are also grateful to **Prof. Ashok Kumar Gupta** (Head of Department, Civil Engineering, JUIT, Waknaghat) for all his support and favors.

We would also like to thank **Mr. Pradeep Khandelwal**, Chief Engineer- East Delhi Municipal Corporation for providing us with the much needed information and materials required. Furthermore, we would like to acknowledge the crucial role of **Mr. Rajesh Pandey**, Member-National Highway Authority of India.

We would like to thank our family and friends for their constant support provided to us during the course of the project.

Signatures of students:

Aakriti Chauhan	Prakhyat Khandelwal	Shreyansh Singh
(131661)	(131675)	(131707)

ABSTRACT

The Municipal Solid Waste (MSW) is a heterogeneous material which cannot be used in road embankments as such. It has large size plastics, clothes and even boulder size C&D waste. The material is much different than soil and use of MSW in embankments may result in long term settlements and ultimately lead to failure of road built over it.

MSW needs to be segregated/separated for use in embankment construction. Physical and chemical characteristics of municipal solid waste are very important to know the presence of different toxic metals and their possibility of polluting the underground water resources. MSW was tested for geotechnical characteristics viz. grain size analysis, compaction characteristics, shear strength, consolidation and permeability characteristics.

The results of direct shear tests (cohesion and angle of friction) were used for slope stability analysis and the results of consolidation were used for settlement analysis.

The design of embankments with MSW is similar to that of earthen embankments. The MSW embankment is designed as a composite structure with MSW in the core and a cover of good earth on either side.

Finite Element Method is used for solving problems of deformation and stability in two-dimensional geometry. Various softwares based on finite element method have been designed specifically for consolidation, stability and deformation analysis. Different models were made using the finite element modelling software to investigate the feasibility of use of Municipal Solid Waste in road embankments. Settlement and stability analysis was carried out to determine the strength parameters.

Once the feasibility is determined, test tracks can be prepared to test the application of the material in road embankments construction.

Keywords: MSW soil (municipal solid waste soil), geotechnical, chemical characteristics, numerical modelling, Finite Element Method, settlement.

List of Figures

List of Tables

List of Abbreviations

MSW	*Municipal Solid Waste*
C&D	*Construction and Demolition*
MDD	*Maximun Dry Density*
OMC	*Optimum Moisture Content*
DST	*Direct Shear Test*
CRRI	*Central Road Research Institute*
FEM	*Finite Element Method*

List of Symbols

c	cohesion
ϕ	angle of internal friction
γ	unit weight

CONTENTS

Page no.

Chapter 1

Introduction

1.1 General

Rapid growth of population, industrialization and urbanization during the last few decades has resulted in generation of huge quantity of municipal solid wastes (MSW) in different cities. Different constituents of this waste dump includes; food and vegetable remains, packing materials, paper, remains of used fuels, wood, metals, plastics, glass, ceramics, cloth etc. Construction and demolition (C&D) wastes are also dumped which consists of bricks, concrete, steel etc. Further, waste from the markets, small industries and non-infectious hospital waste is also dumped. The waste is dumped directly onto grounds without any segregation. Large open grounds and open excavations are often used as unregulated dumps for disposal of a variety of wastes. Landfills are mainly used as unlined open dumps for municipal and industrial wastes

The huge dumps lying at these landfills are affecting the health, hygiene, sanitation and aesthetics of the surrounding areas. These places have become habitat for bacteria, rats, flies and mosquitoes, all posing threat to human health and causing numerous human diseases. If these wastes are not properly treated, they can prove to be dangerous and environmentally hazardous.. Large scale infrastructural development is being carried out in the country considering the huge surge in industrial and consumer good production. Several thousand kilometers of roads are built in the form of National Highway Development Program (NHDP) and Pradhan Mantri Gram SadakYojana (PMGSY) program. This requires huge quantities of road construction materials for both construction and maintenance of roads. Use of local soil and conventional aggregates needs to be reduced as it affects our environment and is disastrous for future. Also, the conventional soil and good quality aggregates are depleting very quickly, especially in urban areas and have to be brought from large distances, increasing the cost of the project tremendously.

Environmental pollution has been threatening the modern world due to excessive growth in developing countries. Main sources for MSW generation are human settlements, small industries and commercial activities. Wastes from clinics and hospitals also find its way to MSW. These wastes on getting mixed with MSW, are a potential threat for human health as well as the environment. Due to low finances available for waste disposal and lack of training to the manpower, open dumping has become the most common practice among the developing countries. This causes deterioration of the natural resources such as groundwater and soil. Heavy metals cause contamination of soil and also affects human health and soil productivity adversely (Smith et al.,1996). The soil quality and fertility has also been damaged due to presence of metals due to increased environmental pollution from agricultural, municipal and industrial sources (Adriano, 1986). The pollutants, in the first place disturb the normal metabolism and growth of plants and also causes injurious effects (Ahmed et al., 1986). Pollutants act as an external agent in affecting the physico-chemical properties of soil (Papageorgiou, 2006). Developing countries are unable to upgrade their disposal facilities due to lack of financial aids, therefore, the environment becomes more prone to get affected by the hazards of dumping (Hazra and Goel, 2009). The material is much different from soil, it has (a) High organic content (b) Low density (c) High water absorption. The use of MSW may result in long term settlements and may result in failure of Road built over it. Compaction in the field is another problem due to presence of heterogenic characteristics of MSW i.e. presence of plastics, papers, clothes etc.

1.2 Landfill

Landfill has become the most common method of solid waste disposal currently being used throughout the world. The technical requirements, environmental and socio-economic aspects are simpler than other known techniques of waste disposal. Other processes like incineration and biological composting are complex and require proper knowledge and setups, therefore landfilling is extensively used for solid waste disposal all around the world. Landfilling is considered as the cheapest method for safe disposal of solid waste. Landfilling does not require any high-technological equipment or machineries to operate however, if the underlying principles of constructing landfills are properly considered and carried out, the cost may be increased (M.I. Ab. Malekand M.G. Shaaban, 2008)

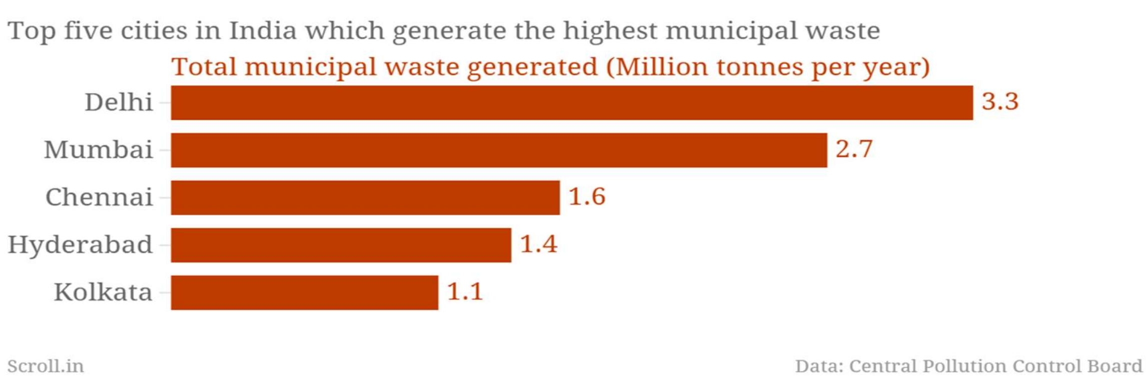


Figure 1.1 Waste generation in major cities (After CPCB)

1.3 Landfill Processes

Physical, chemical and biological processes are discussed in this section. Of the three types, biological processes are most significant, but the physical and chemical processes also greatly influence the landfill properties.

1.3.1 Physical

The significant physical reactions occur due to one of the following processes: compression, dissolution and sorption.

Compaction is the ongoing phenomenon that comprises of processes of compression and size reduction till wastes are in place. This continues due to the self weight of the wastes and over burden of cover soil. Some consolidation may be attributed to sifting of soil and other fines. The end result is however, the settling of the completed fill.

Water acts as a medium for dissolution and transportation of soluble substance and unreacted material respectively, and thus the amount of water that enters the landfill is important for physical reactions.

In a typical landfill, the variety of components and particle sizes of waste determines the condition for extensive adsorption. Adsorption results in the immobilization of living and non-living substances that may cause problems to external environment and therefore, adsorption is one of the more important processes. It plays an important role in containment of viruses and pathogens.

Absorption takes place in significant large parts and immobilizes dissolved pollutants. Most of the absorption is attributed to the cellulosic content and all absorbent material becomes saturated.

1.3.2 Chemical

One of the major chemical reactions that take place in a landfill is oxidation. The extent of oxidation is however limited to the amount of oxygen that was available in the landfill when the landfill was made. Ferrous metals are the components that are most affected by the oxidation processes.

The second major chemical reaction involves the presence of organic acids and carbon dioxide which are synthesized in the biological processes. These reactions are most commonly acid-metal reactions. These end result of such reactions are metallic ions and salts in liquid contents. The carbon dioxide that is dissolved in water results in deterioration of the quality of water, especially in presence of magnesium and calcium.

1.3.3 Biological

There are two reasons as to why biological reactions are important. One is that the organic fraction is rendered biologically stable and does not constitute for potential source of nuisance. Secondly, the mass and volume of organic fraction is substantially reduced due to conversion of carbonaceous and proteinaceous matter into gas. The organic fraction of MSW constitutes the wide variety of materials that are broken down biologically or in the other words are biodegradable. This includes garbage, paper and paper products and natural fibres. Biological decomposition takes place either aerobically or anaerobically.

1.3.2.1 Aerobic Decomposition

Aerobic decomposition occurs directly after the waste is buried and is the greater part of the decomposition. Aerobic decomposition continues till all the oxygen trapped in the landfill is removed. The duration is comparatively brief and depends on degree of compaction. Microbes active during this phase include obligate as well as some facultative aerobes. 'Ash, carbon dioxide and water' are the end products of aerobic decomposition, therefore the adverse environmental impact is minimal.

1.3.2.2 Anaerobic Decomposition

Due to depleting oxygen supply in a landfill, biodegradable organic matter eventually is subjected to anaerobic decomposition. This anaerobic decomposition is similar to anaerobic digestion of sewage sludge. Both facultative and obligate anaerobes are responsible for anaerobic decomposition. The breakdown products exert adverse impact on the environment if they are not managed properly. The products are classified as volatile organic acids and gases. Most of the acids are short chain fatty acid type. When reacting with other substances, they serve as substrate for methane producing microbes. The two principal gases formed are methane and carbon dioxide. Gases formed in trace amounts include hydrogen sulphide, hydrogen and nitrogen.

1.3.3 Environmental Factors

Environmental factors affect all biological activities and thus greatly influence the nature, rate and extent of biological decomposition. The nature of decomposition product is determined by the nature of biological decomposition.

Principal factors to influence biological decomposition are microbial nutrient content, temperature, moisture, and degree of resistance of the waste to microbial attacks. Moisture is a limiting factor at moisture content levels of 55% to 60% or lower, because then the microbial activity is inhibited. The activity of most microbes increases with increase in temperature until a level of 40^{o}C is reached.

1.4 Ghazipur Landfill

Ghazipur Landfill site lies in East of Delhi; it is operational since the year 1984 and falls under the classification of Uncontrolled Solid Waste Disposal Facility. Because of unavailability of land within Delhi for the end purpose of land filling, the then of Delhi had decided to execute a pilot project at Ghazipur Landfill Site to explore the feasibility of landfill reclamation and reuse. The whole site covers an area of 29.62 Hectare and accommodates a volume of over 12.00 million tonnes of waste. Average height of waste is about 40 meters. Ghazipur Landfill overshot its limit in 2002, but due to absence of alternative sites, it continues to be used beyond its capacity.

Waste Characterization Study was undertaken to evaluate the characteristics of the waste lying at the landfill site on 13 locations. A total of 30 samples were collected by augurs at heights varying from 0 meter to 30 meters from the ground level. From the Waste Characterization Study, the following conclusions have been derived:

a) It turns out that the waste is not appropriate for the purpose of compost due to low organic contents (below 35%), low C/N ratio and due to presence of heavy metals.

b) The waste cannot be used as a fuel due to low calorific value (below 2500 kcal/kg).

c) As 50 % of the particle size are below 10mm and the concentration of heavy metals is within acceptable range (as per Schedule II of Hazardous Waste Rules, 2008: Management, Handling and Trans boundary Movement), it can be used as a material for road construction and for daily soil cover in sanitary landfills.

d) Average moisture content is 25.3 % and hence it can be assumed that in the process of segregation soil would lose 10% weight due to drying of moisture.

The average waste coming to the facility is about 2000 tons and the total height of landfill has reached about 30-35m. Oldest waste lies at the bottom and fresh waste (approximately 6 months old) lies within the upper layers (2m). Waste was brought and dumped over the site throughout and not in a phased manner. The site is completely filled and there is absolutely no space available on site. There is a lot of leachate being generated at site, leachate pools are visible with frequent bubbling. The drain surrounding the landfill disposes off the untreated leachate into the MCD drain near the facility. The drains used for disposing off the leachate are not permanent. There is foul odour in the site and birds like crows, eagles, etc and stray animals are crowding the landfill. There was also a huge quantity of construction and demolition waste on the site.

Figure 1.2 Satellite image of Ghazipur landfill

(Source: http://thekachraproject.in/indias-monstrous-dumping-sites-and-its-impacts-will-scare-you/)

1.5 Soil Procurement and Segregation

1.5.1 Collection of raw garbage

Raw garbage (municipal solid waste) was collected from Ghazipur landfill, East Delhi. This waste was collected on the basis of age, depth and pre-identified locations. The biodegradability of this soil depends on the location and depth of soil and also affects the physical, geotechnical and chemical properties of soil

1.5.2 Segregation and composition analysis

Segregation and composition analysis of MSW samples were carried out to know the proportion of different size of heterogeneous materials and its composition. The analysis would help to arrive at suitable material to be used for embankment construction.
Composition analysis of different fraction was carried out to know the amount of different constituents viz. soil, plastics, metals, textiles, papers etc in the heterogeneous mix. This would help to identify a particular fraction for use in the embankment construction.

Figure 1.3 Constituents of MSW

The garbage collected was first dried before the process of segregation. To develop the segregation methodology, raw garbage was segregated in different sieve sizes starting from 80 mm to passing 4mm. The samples segregated in different sieves would give an insight regarding the possible selection of material for embankment construction. The high pressure blower removes all the large size papers, plastics, clothes and the heaver larger size C&D aggregates including large size brick bats are retained on 80mm sieve, and out of the segregated soil-

(a) About 65-79% of the material passes through 80 mm sieve with substantial amount of plastics, paper & cloths and

(b) About 44-48% of the MSW passes through 16mm sieve with minimum plastics.

Figure 1.4(a) Process of collection

Figure 1.4(b) Process of segregation

Figure 1.5(a) Sieved sample (80mm)

Figure 1.5(b) Sieved Sample (16mm)

1.6 Organization of Thesis

The project report is presented in five chapters. Brief description about each chapter is given below.

Chapter 1: Introduction

This chapter gives an introduction of landfill, its processes and the waste soil present in it. It highlights the importance of use of materials from landfill for construction purposes. It also describes the process of collection and segregation of MSW and the procurement of landfill soil thereafter.

Chapter 2: Literature Review

This chapter presents a brief review of relevant literature of the work carried out by various investigators. All the literature related to landfill soil and its properties is summarized. The need for detailed investigation to understand the suitability and use of this soil is identified. In addition to this, the research work done on the numerical modeling using PLAXIS 2D has also been discussed in this chapter. This chapter also helps us derive the objectives of the work.

Chapter 3: Methodology

This chapter describes the various experiments done on the soil to study its geotechnical and chemical properties. The modelling of embankment (through finite element method) using the landfill soil in different layers has been carried out. The various models are studied in detail to optimize the use of soil in construction.

Chapter 4: Results and Discussions

The results of the geotechnical and chemical properties of the soil have been presented and discussed in this chapter. Various models have been analyzed using PLAXIS 2D and suitable application of this soil in embankment has been identified.

Chapter 5: Conclusions

This chapter presents an overall summary of the work carried out and brings out the salient conclusions. The potential application of landfill soil in embankment construction is highlighted. In addition to this, future scope of the work has also been highlighted.

CHAPTER 2
LITERATURE REVIEW

2.1 General

This chapter summarizes the literature of the work carried out by various investigators. It gives a brief description about landfill, the landfill soil properties and numerical modelling through finite element method (FEM).Various research scholars have presented their work on the MSW soil properties and their effect on the strength and stability in construction works. The work done using PLAXIS 2D to develop embankment models has also been discussed.

2.2 Landfill Studies

Urbanization and large scale industrialization have led to huge amounts of generation of solid waste by the expanding population of the urban areas in the country (Karishnamurti and Naidu, 2003). Landfills are the most common method of waste disposal and occupy large disposal area, also creating environmental problems. Large scale infrastructural development is being carried out in the country which increases the demand of road construction materials. The accumulated Municipal Solid Waste (MSW) in landfill is seen as a potential source of material for utilisation in construction. Use of materials like tyres, rubber, glass etc has already gained popularity in highway engineering (Swearingen et al. 1992). The potential use of decomposed MSW soil is also being studied. Extensive road networks which are under construction make use of the local soil and conventional aggregates for road construction. It not only depletes the conventional soil and good quality aggregates, but also has adverse effects on the environment. It is, therefore, very important to adopt waste management techniques and programs that are sustainable (Kurian et al. 2003). In this connection National Highway Authority of India (NHAI) approached CSIR-Central Road Research Institute, New Delhi to carry out a detailed investigation to check the possible use of this material as an embankment fill in highway construction. Municipal corporations have prioritized their services regarding Municipal Solid Waste Management in most of the countries (Ali et al. 2013). Landfill mining is being carried out with the objective of conservation and rehabilitation of landfills, elimination of toxic contaminants and reuse of materials from landfills (Shual and Hillel, 1958; Savage et al., 1993). The soil from landfills can be reused if the contaminated soil does not exceed the contaminant levels. Therefore, sufficient information should be collected to determine the type of soil in the landfill and its characteristics.

Various field test evaluations and studies have shown that about 60-65% of the samples recovered from the dumpsites of about 10 year old landfills was soil fraction with high percentage of fine particles (Kurian et al. 2003). Use of this fraction of MSW soil for construction purposes will not only reduce burden on the conventional soil, but will also help in the rehabilitation of dumpsites.

2.3 Landfill soil parameters

Laboratory and field studies have to be performed to provide an insight on the mechanical properties on municipal solid waste (MSW). It is important to check for properties like specific gravity, unit weight, particle size analysis, moisture content, compaction, permeability, consolidation and direct shear tests. Presence of organic matter, leachate and heavy metals in the soil may affect the properties of this soil and may also lead to the contamination of both soil and groundwater. Production of biogas and leachates in the MSW soil contribute to the pollution of air, water and soil due to numerous biochemical reactions (Harshani et al. 2015).

The stability of landfill will be governed by the physical properties and strength parameters of MSW. For the analysis of landfill soil, laboratory investigation of its geotechnical properties is needed. Geotechnical properties of MSW are difficult to determine because of the heterogeneity and variation in the distribution of particle sizes. Also, the mechanical properties of the MSW get affected because the organic content and water present in the soil as affect the process of biodegradation (Rakesh Kumar Pandey and R.P.Tiwari 2015). It has been suggested by several researchers that there is increase in the rate of settlement and decrease in the stability during the process of biodegradation (Sowers 1973; Oweis and Khera 1976; Leckie and Pacey 1979; Charles and Burland 1982; Kurzeme and Walker 1985). Furthermore, the available studies indicates that the unit weight of wet and degraded waste is significantly greater than the unit weight of waste from relatively dry landfills because of leachate generation(E. Kavazanjian 2001).

From the composition of MSW, it is observed that particles like paper, rubber present in the soil contribute to the higher friction angle and lower cohesion under freshly prepared condition. However, as the MSW degrades the particle size reduces due to decompostion and a more cohesive nature is produced. Increased cohesive nature is also observed due to leachate generation in the MSW soil (Krishna R. Reddy 2011). The soil is considered to have higher strength due to pseudo-cohesion and particle flocculation caused due to leachate. In addition to this the particles present in the MSW soil act as fibers giving better bonding and further increasing the strength (Krishna et al. 2016). According to Machado et al. (2002, 2008), presence of large amount of degradable organic material tends to reduce the shear strength of the fresh waste samples, however, as the decomposition process continues, the MSW fiber content increases and tends to increase the MSW shear strength.

The literature on the investigation of MSW properties is growing extensively. However, development of appropriate constitutive models is possible only if there is an internationally agreed classification and testing guidelines (Dixon et al. 2004).

2.4 Numerical Modelling of landfill soil

Numerical modelling by finite element analysis techniques has created a powerful alternative to the assist the working of geotechnical engineers. Commercial softwares like PLAXIS, GEOSLOPE, GEO5, etc make use of the finite element method (FEM) for soil analysis. Slope stability analysis based on finite element method is preferred because through FEM, complete interaction of the embankment foundation can be simulated since a smaller element will produce a more accurate and detailed solution (Sabahat A. Khan, Syed M. Abbas 2014).

PLAXIS has been developed specifically for the analysis of settlement and deformation of the soil and its stability in geotechnical engineering projects such as excavations, road constructions, foundations, embankments etc.PLAXIS is a two dimensional geotechnical software that uses the soil properties and elastic-plastic parameters as inputs for analysis. PLAXIS analysis is based on a fine elemental mesh with nodal elements (Khabbaz et al. 2007).

Asmaa G. Salih and Heba A. Ahmed in their work "*The Effective Contribution Of Software Applications in Various Disciplines Of Civil Engineering*" states that PLAXIS provides the user with robust calculation procedures and user-friendly input /output facilities, preferred for dynamic analysis. Bahatin Gunduz in his study "*Analysis Of Settlements Of Test Embankments During 50 Years-A Comparison Between Field Measurements And Numerical Analysis*" states that modelling of soil layers is done by selecting either 6-node or 15-node triangular elements. The 15-node triangle is preferred as it has a fourth order interpolation for displacements and twelve stress points in comparison to the 6-node triangle which has a second order interpolation and only three stress points.

Only half of the embankment is analyzed since the test embankment is considered symmetric. Analysis of all the construction work is important, so that the mitigating strategies/ techniques can be implemented accordingly to avoid problems associated with soil. The test embankment are analyzed by using soil in different layers, therefore, different models must be considered (PK Aseeja 2016).

The FEM approach used for modelling does not consider the effect of biodegradation on the MSW soil properties. Theoretical modelling is required to incorporate the effect of decomposition and to study the consequent effect on settlement of soil. One such method is the Composite Compression Model for MSW which considers all three mechanisms for compression : applied load, mechanical creep, and biological decomposition (Marques et al. 2003).

2.5 Summary of Literature Review

- Municipal Solid Waste (MSW) lowers the specific gravity due to presence of organic matter.
- Lowers the maximum dry density (MDD) with higher optimum moisture content(OMC).
- There may be contamination of soil due to increased concentration of heavy metals and groundwater contamination as leachate generated causes water pollution.
- It is difficult to draw conclusions regarding shear parameters because of the pseudo cohesion generated due to leachate and also because of the mixed matrix (where MSW constituents may act as fibres thereby increasing strength).
- Numerical modelling involving the use of PLAXIS, which is based on the finite element method to compute consolidation analysis and slope stability.
- Theoretical modelling is required for settlement calculations to incorporate the effect of biodegradation on the MSW soil properties.

2.6 Objectives

The objective of this project is to determine the application of MSW in road embankment construction. Based on the literature review, the following objectives have been derived:

- Testing of geotechnical parameters of the MSW soil.
- Investigation of heavy metal constituents by chemical analysis.
- Numerical modelling of embankment from determined properties of MSW.

Chapter 3
Methodology

3.1 General

The primary goal of this research is to develop guidelines and technical specifications so as to check the possibility of utilization of soil from Ghazipur landfill in road embankment construction. The use of this soil in construction is based on the study of geotechnical and chemical characteristics of landfill soil and numerical modelling using PLAXIS 2D. PLAXIS 2D solves problems of deformation and settlement, and carries out stability analysis in two-dimensional geometry. It consists of advanced constitutive models for the purpose of study of nonlinear, time dependent and anisotropic behaviour of soils.

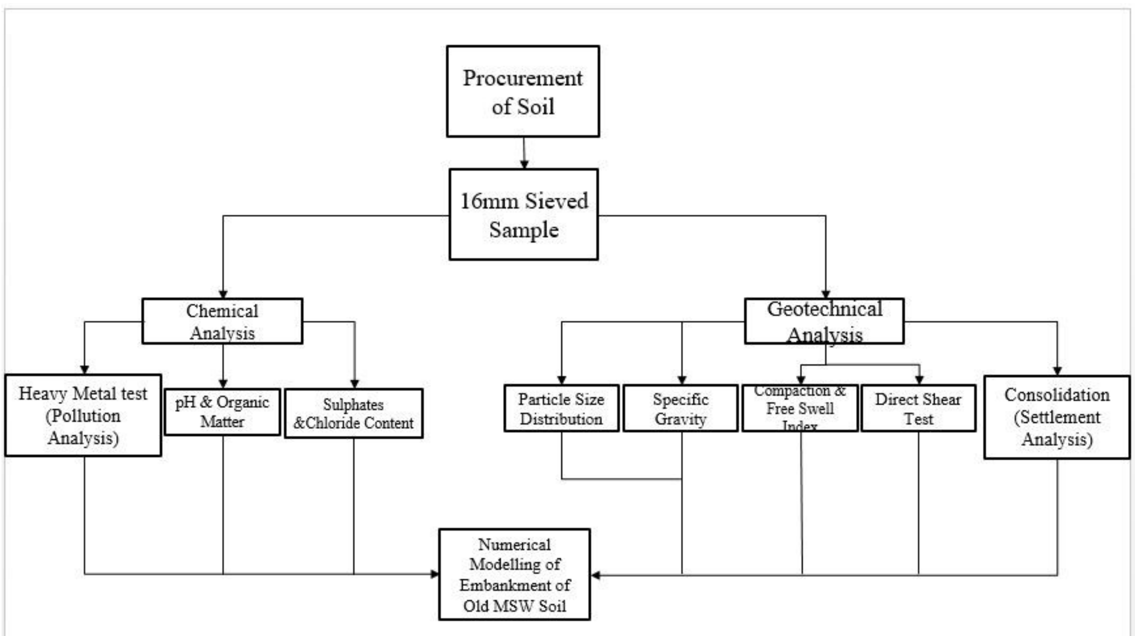


Figure 3.1 Work Plan

3.2 Soil Procurement

The sample that we are testing was directly obtained from the **CSIR-Central Road Research Institute, New Delhi** after proper composition analysis and segregation process. The soil sample sieved through 16mm sieve size was collected and further tested.

3.3 Geotechnical characterization

The soil sample collected from CRRI was investigated for its geotechnical characteristics viz. grain size analysis, compaction characteristics, shear strength, consolidation and permeability characteristics. The following geotechnical investigations are carried out-

1. Particle Size Distribution
2. Specific gravity
3. Atterberg limits
4. Compaction
5. Direct shear test
6. Consolidation
7. Permeability
8. Free Swell Index

The various test procedures have been described below:

1. Particle Size Distribution- Soil gradation (sieve analysis) is the distribution of particle sizes expressed as a percent of the total dry weight. Soil that passes through 4.75mm I.S. Sieve and is retained on 75micron I.S. Sieve can be directly dry sieved according to IS: 2720 (Part 4) – 1985 (Reaffirmed-2006**).** Dry sieve analysis is carried out on particles that are coarser than 75 micron. Dried sample is taken and passed through a set of sieves of decreasing size. The weight retained and passed is measured in each sieve. The cumulative percentage quantities passing each given sieve size i.e. finer than the sieve sizes are then determined. The distribution curve represents the resulting data with grain size along x-axis (log scale) and percentage finer than (i.e. percentage passing) along y-axis.

Figure 3.2 Sieve Analysis

Size distribution curve forms a particle-size distribution curve (which is also known as grading curve) from which useful information such as grading characteristics, (which indicates the uniformity and range in grain-size distribution) and percentage (or fractions) of gravel, sand, silt and clay-size.

2. Specific Gravity- IS : 2720 (Part III/Sec 1) – 1980 lays down the procedure of test for determination of specific gravity of soils which is important in finding out the degree of saturation and unit weight of moist soils which are further needed in soil engineering for solving pressure, settlement and stability problems. This test is used for fine grained soils and coarse grained passing 4.25mm. The test can be done with the help of pycnometer or density bottle.

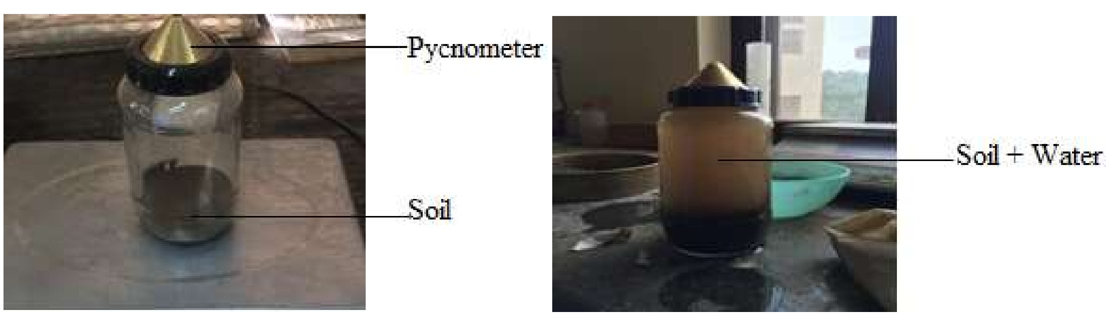


Figure 3.3 Pycnometer

3. **Atterberg Limits:** The atterberg limits were calculated to determine the plastic characteristics of the MSW soil. It is important to find out plastic characteristics of soil used for construction as water present in the soil may change the state of the soil system. These properties affect the fine grained and silty soils. The liquid limit was determined in accordance to the IS: 2720 (Part 5) 1985 (Casagrande Apparatus Standard). The plastic limit and plasticity index of the soil were not applicable as the soil was coarse grained.

4. **Compaction**- The purpose of a laboratory compaction test is to determine the appropriate amount of water to be mixed, and the resulting degree of denseness which is obtained from compaction at optimum moisture content (OMC). The light weight compaction is carried out for cohesive soils but is not preferred to the study of the compaction characteristics of clean sands or gravels as they displace easily when struck with rammer hence we use heavy compaction in case of sands. Some cohesionless soils may compact satisfactorily in the standard test although in many cases the maximum density is not as great as can be achieved readily in the field under available compaction methods.

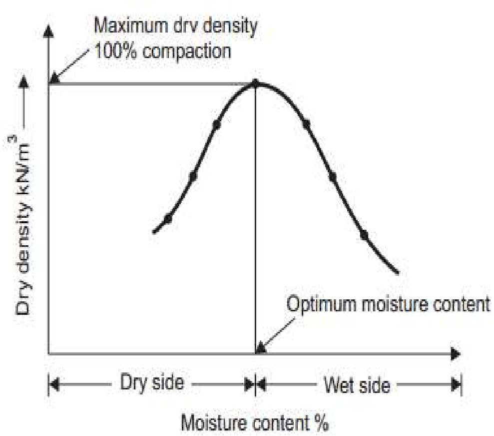
This test is carried out in accordance with the specifications in IS: 2720 (Part 8) – 1983.For light weight compaction, mould of 1000 cm^3 is used and the moist soil is compacted into the mould, in five layers of approximately equal mass, each layer being given 25 blows from the 4.9kg rammer dropped from a height of 450 mm above the soil. For courser grained soils, large size mould of 2250 cm^3 mould should be used in which soil is compacted in five layers, each layer being given 55 blows of the 4.9kg rammer.

Figure 3.4 Compaction Test

The dry densities obtained in a series of determinations shall be plotted against the corresponding moisture contents. The dry density in g/cm^3 corresponding to the maximum point on the moisture content v/s dry density curve shall be defined as the maximum dry density.

Factors affecting Compaction

Effect of increasing water content: On adding water to the soil which have low moisture contents, the particles come closer on application of compacting forces and the voids are reduced which results in increase in its dry density. This increase continues till the stage where water films start developing around the soil particles and water hinders the close packing of the soil grains resulting in decrease of the dry unit weight. The **maximum dry density (MDD)** occurs at an **optimum moisture content (OMC)** and can be obtained from the plot between dry density and moisture content.



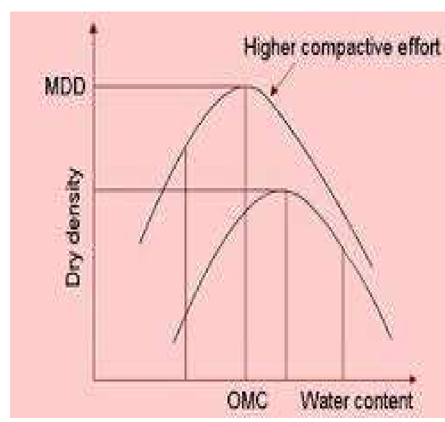


Figure 3.5(a) Compaction Curve *Figure 3.5(b) Effect of compactive effort*

(Source: http://nptel.ac.in/courses/105103097/web/chap10final/s2.htm)

Effect of increasing compactive effort: A greater compactive effort will reduce the optimum moisture content and increase the maximum dry density. The effect is more when soil is compacted at water content less than the optimum moisture content. From the compaction curve, we observe that the compaction curve is not a unique soil characteristic, but it largely depends on the compactive effort. For this reason, it is important to specify the method of compaction used (light or heavy) when determining values of MDD and OMC.

5. **Direct Shear Test**- IS: 2720 (Part 13) - 1986 deals with the method for direct shear test of soils.The controlled strain type of direct shear test provides accurate results and is, therefore, recommended.

Cohesive soils may be compacted to the required density and moisture content into the shear box by using the fixing screws to place the two-halves of the shear box together whereas cohesionless soils may be tamped in the shear box itself with the base plate and grid plate in place at the bottom of the box.

The load dial readings obtained are used to calculate loads. The loads so obtained divided by the corrected cross-sectional area of the specimen gives the shear stress.The test results are plotted in form of a graph in which the applied normal stress is plotted as abscissa and the maximum shear stress is plotted as ordinate. The angle made by the resulting straight line with the horizontal axis shall be reported as the angle of shearing resistance and the intercept which the straight line makes with the vertical axis as the cohesion intercept.

Figure 3.6(a) Direct Shear Apparatus

Figure 3.6(b) Shear box

6. Consolidation- Consolidation test is carried out as per IS: 2720-Part 15 in an Oedometer for a specimen of 60 mm diameter and 20 mm thickness under double drainage conditions. Remoulded samples of MSW (passing 4.75 mm sieve) are prepared at Maximum Dry Density and OMC. Samples were saturated for 24 hours at an initial seating stress of 0.025kN/m^2 for 24 hours. The specimen was then consolidated under initial stress of 5kN/m^{2}and settlement dial gauge reading was recorded at 0, 0.25, 1, 2.25, 4, 6.25, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144, 169, 196, 225, 256, 289, 324, 361, 400, 500, 600, and 1440 minutes or until equilibrium is reached. The procedure was repeated for different normal stress viz. 9.8, 19.6, 39.2, 79, 157, 314, and 628kN/m^{2}and for each normal stress time settlement reading was recorded up to 24 hours. The coefficient of compression and consolidation are calculated to check the compressibility and settlement of soil.

Figure 3.7(a) Soil sample for Consolidation *Figure 3.7(b) Oedometer setup*

7. Permeability- Indian Standard method of test for soils for permeability is described in IS: 2720 (Part 17) which describes the method for the laboratory determination of the coefficient of permeability of soils. The knowledge of the permeability is important in many engineering works involving flow of water through soils such as drainage of excavations, embankments and subgrades and assessing seepage through the body of earth dams or computing losses from canals. Both constant head (mostly for granular soils) and falling head tests (for most of the soil) are used for laboratory determination of permeability. The moisture content used for compaction should be the optimum moisture content or the field moisture.

In a falling head test, the specimen to be tested is connected to selected stand-pipe through the top inlet. The bottom outlet is then opened and the time interval required for the water level to fall from a known initial head to the final head is recorded. The stand-pipe is filled with water again and the test is repeated till three successive observations made give nearly same time interval.

At temperature T, the permeability k_T is calculated as $k_T = 2.303 \frac{aL}{A(t_r - t_i)} \log\left(\frac{h1}{h2}\right)$,

For a constant head test, the specimen is connected through the top inlet to the constant head water reservoir. The bottom outlet is then opened to obtain the steady state of flow so that the quantity of flow is measured for a particular time period and this procedure is repeated thrice. The permeability k_T at temperature T is calculated as: $k_T = \frac{Q}{AiT}$

Figure 3.8 Setup for Permeability

8. **Free Swell Index-** IS 2720-40 (1977) describes the methods of test for soils wherein Part 40 lays down the procedure for determination of free swell index of soil. Free swell is the increase in the volume of a soil on submergence in water, without any external constraints. There is possibility of damage to structures due to swelling of expansive clays, therefore, it must be identified before construction.

The soil specimens were poured into two glass graduated cylinders of 100 ml capacity each, one cylinder filled with kerosene oil and the other one filled with distilled up to the 100 ml mark. The entrapped air is removed by gentle shaking or stirring the solution and the soil in both the cylinders were allowed to settle thereafter. Sufficient time (not less than 24 h) was allowed for the soil sample to attain equilibrium state of volume. The final volume of soils in each of the cylinders was noted. The level of the soil in the kerosene graduated cylinder was read as the original volume, as kerosene is a non-polar liquid that does not cause swelling of the soil. The level of the soil in the distilled water cylinder was read as the free swell level.The free swell index of the soil was calculated as follows:

$$\text{Free swell index, percent} = \frac{V_d - V_k}{V_k} * 100$$

where V_d= the volume of soil specimen in the cylinder containing distilled water, and V_k = the volume of soil specimen in the cylinder containing kerosene.

Free Swell Index ranges below 20% for low expansive soils while greater than 50% for highly expansive soils.

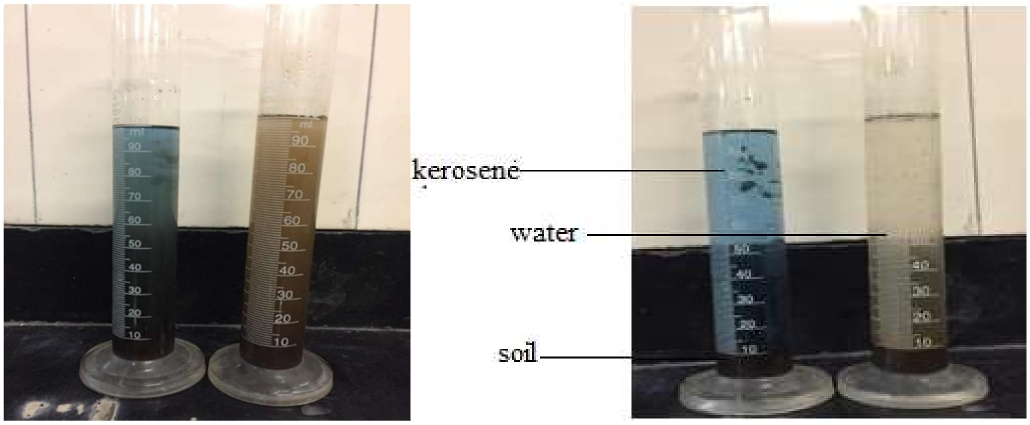


Figure 3.9 Volume change for Free Swell Index measurement (after 24 hours)

3.4 Chemical Characterization

The chemical characteristics of municipal solid waste are very important to know the presence of different toxic metals and their possibility of polluting the underground water resources.

1. pH
2. Sulphates
3. Organic content
4. Heavy metals

1. pH- IS : 2720 (Part 26) – 1987 gives the procedure for determining pH of soil. The acidic or alkaline characteristics of a soil sample are quantitatively expressed in terms of the hydrogen ion-activity commonly designated as pH.

pH = - 1 log[H^+], wherein H^+ is the hydrogen ion-concentration in moles/litre.

Indicator Paper Method-20 g of soil from the representative soil sample was taken and mixed with 50 ml of distilled water. It was stirred for 10 min continuously and allowed to stand for an hour. 20 ml of the clear solution was then pipetted out into a clean test tube. The leaf of the indicator paper or a strip was dipped into this solution. The colour of the moistened indicator paper was compared with those provided with the indicator paper. The comparison of the colour of the solution prepared with the standard chart provided the pH value.

Several factors that affect the pH are soil-water ratio, soluble salts concentration, carbon dioxide pressure, exchangeable cations and temperature. With the dilution of soil suspension, its pH increases. Increase in salt concentration in general decreases the pH. With increase in temperature, pH decreases.

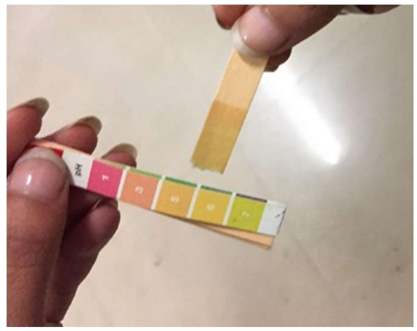


Figure 3.10 pH indicator

2. Sulphates-IS: 2720 (Part XXVII)-1977 deals with the method for the determination of total soluble sulphates in soils. Certain salts (like Sodium sulphate) are easily change their moisture contents under the influence of climatic changes, which causes enormous volume changes during the process of hydration and dehydration, which may influence the engineering properties of soils.

This method depends upon preparation of an aqueous extract of the soil and determination of the sulphate content of this extract by the precipitation of sulphate as barium sulphate, filtering off the precipitate and weighing it.

$$\text{Sulphates (as } SO_4\text{), percent by mass} = 41.15\frac{W2}{W1}$$

where W_1 = mass in g of the precipitate, and W_2 = mass in g of the soil contained in the solution taken for precipitation.

3. Organic Content- Organic matter is an undesirable constituent of the soil from the engineering point of view since it causes swelling or shrinkage of the soil when the moisture content or the applied load changes. The estimation of organic matter, therefore, forms an important part of soil examination. It has been described in IS: 2720 (Part XXII) -1972.

4. Heavy Metal Testing- Chemical characteristics of municipal solid waste are very important to know the presence of different toxic metals and their possibility of polluting the underground water resources. Soil testing for metal contaminants is crucial for the assessment of the environmental and human health hazards caused due to increased concentrations of heavy metals in soils.

Latest technologies such as HDXRF(High Definition X Ray Fluorescence) technology, ICP-OES(Inductively Couples Plasma Optical Emission Spectrometer) can be used for analysis. The testing was performed as per the specifications which uses *Direct Air-Acetylene Flame Method* for heavy metal analysis. In this process, a sample is aspirated into a light beam directed through a flame, and onto the detector. The light absorbed by the element for atomization is measured. This method can be used for determination of arsenic, cadmium, cobalt, zinc, nickel, chromium, iron, lead, copper etc.

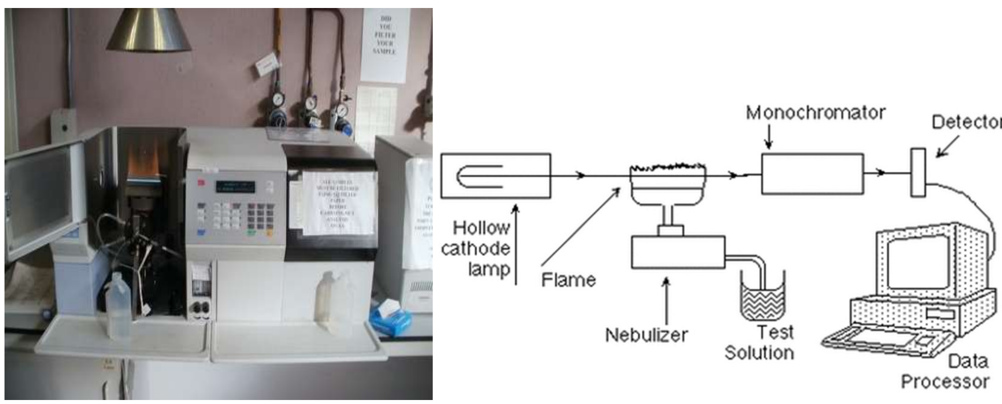


Figure 3.11 Flame Atomic Absorption Spectrometer
(Source: http://chemicalinstrumentation.weebly.com/flame-aas.html)

3.5 Numerical Modelling

PLAXIS is a software package targeted to solve geoengineering problems. PLAXIS 2D solves problems of deformation and stability in two-dimensional geometry. It includes advanced constitutive models for the study of nonlinear, time dependent and anisotropic behaviour of soils. Furthermore, it has special procedures incorporated to deal with hydrostatic and non-hydrostatic pore water pressures. It is based on the finite element method and has been designed specifically to carry out deformation, consolidation and stability analysis. Working of the software is based on the following procedure: generation of complex finite element model, computation of results based on numerical procedures and calculations, detailed graphical presentation of computational results.

Important features of PLAXIS 2D are as follows:

- **Geometry models**: the input of soil data, structures, construction stages and loads is done based on convenient CAD drawings and modelling.
- **Automatic mesh generation**: PLAXIS results in automatic generation of unstructured finite elements.
- **User defined models**: PLAXIS enables users to include self-programmed soil models in analysis.
- **Consolidation analysis**: Automatic time stepping procedures for consolidation analysis and computation of decay of excess pore water pressure with time.
- **Stability analysis**: PLAXIS can be used to compute factor of stability using phi-c reduction method.
- **Preview option**: this option is available to check preview models and calculation settings in graphical 2D environment.
- **Presentation of results**: the PLAXIS postprocessor displays results of stresses, displacements,forces etc with the help of enhanced graphical features and output tables.

3.6 Embankment construction using PLAXIS

3.6.1 Geometry model

Figure 3.12 shows a typical cross section of a road embankment. The embankment is 10m high. The problem is symmetric, therefore only one half of the embankment is modelled. The embankment is composed of the soil obtained from the landfill. The calculated properties of the soil is used. The subsoil is 8m and consists of sand. The phreatic level is assumed to coincide with base of the clay layer.

The embankment shown in figure is analysed with a plain strain model. The 15 node element was utilized for this model. The units for length, force and time used were m, kN and day respectively. A total width of 40m is considered for calculations. The geometry line option may be used for construction of the whole geometry. The subgrade deformations were assumed to be zero and were not included in the model. The standard fixities were used to define the boundary conditions. The geometry model is shown in figure 3.12.

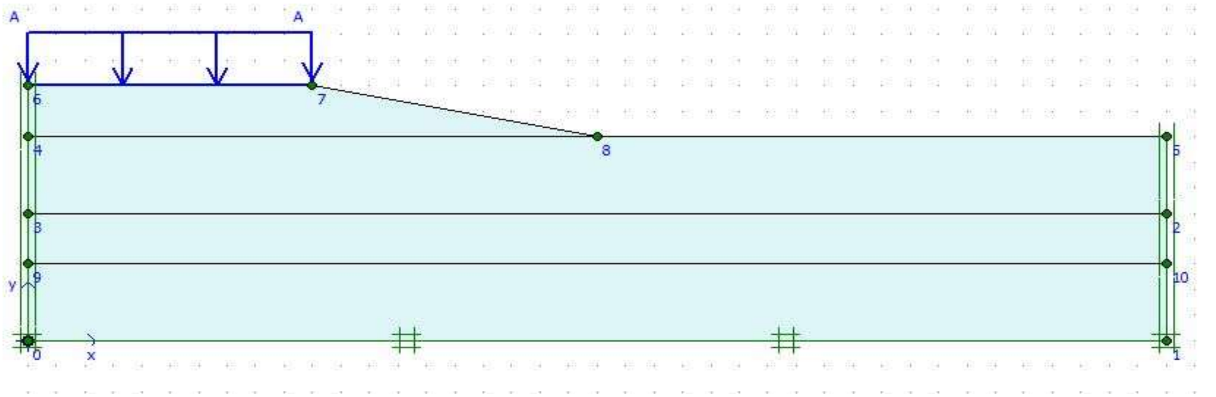


Figure 3.12 Geometry model

3.6.1 Material sets and Mesh generation

The properties used for various soil layers are given in the above table. Different material sets were created containing the data as mentioned in the table. This type of behaviour leads to increased pore pressures during the construction of the embankment. The clusters (layers) were assigned the respective material set.

After the input of the required data, a simple finite element mesh was generated. The *medium coarseness* setting was used for mesh generation. The mesh was generated by clicking on the *generate mesh* button.

Table 3.1 Material Properties used for Analysis

Parameters	**Values after paper (Zaleh, 2014)**	**Values in the current study**
Material Property	Sand	MSW Soil
Material model	MC (Mohr-Coulomb)	MC (Mohr-Coulomb)
Type of behavior	Drained	Drained
Soil unit weight above phreatic level (kN/m^3)	17	13.78
Soil unit weight below phreatic level (kN/m^3)	20	17.33
Young's Modulus (kN/m^2)	163.79	198.57
Cohesion (kN/m^2)	0.2	10
Friction angle (°)	64	31
Dilatency angle (°)	34	1

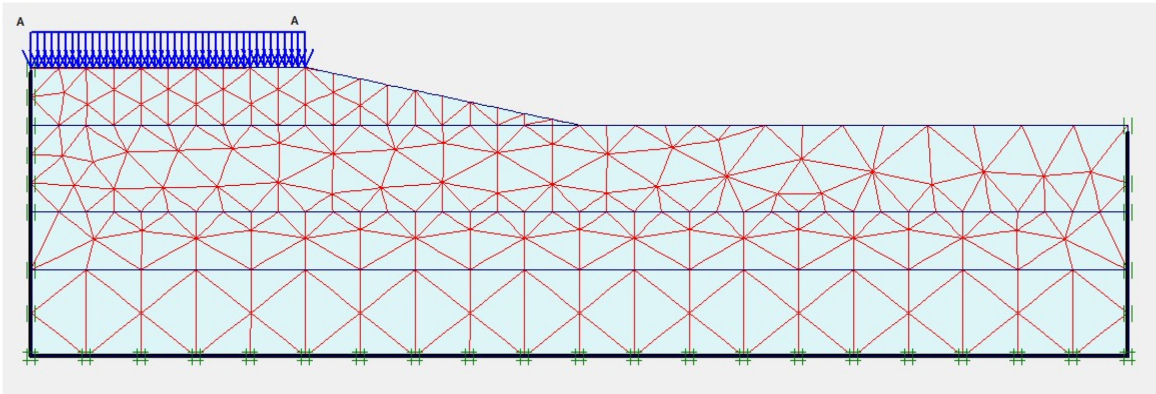


Figure 3.13 2D Mesh Generation

3.6.3 Various Models

Different models were analysed to check the best alternative of using the MSW in road embankments. These models were then analysed using the consolidation, plastic and phi/c reduction methods on PLAXIS 2D.

Table 3.2 Soil Models for Analysis

Model no.	**Model description**
1	All layers as MSW soil layers
2	All layers as Sand layers
3	The top layer as MSW soil and the rest of the three layers as sand layers
4	The second from top layer as MSW soil and the rest of the layers as Sand
5	The second layer from bottom as MSW soil layer and rest of them as Sand
6	The bottom layer as MSW soil and the other three as Sand layers

Chapter 4
Results and Discussions

4.1 General

It is important to know the various geotechnical and chemical properties of MSW to determine the presence of hazarodus wastes and the possibility of these wastes polluting the underground water sources. The materials were investigated for various geotechnical and chemical characteristics viz. grain size analysis, compaction characteristics, shear strength, consolidation and permeability properties, organic content and heavy metal concentrations. Their results are summarized below.

4.2 Test Results

4.2.1 Grain size analysis*:* Dry sieve analysis was performed to determine the variation in grain size characteristics. The soil had more than 50% particles larger than 0.075mm and had a good representation of particles of all sizes ranging from 0.075mm to 4.75mm. The soil is coarse grained sand and percentage fineness is greater than 5%. The Uniformity Coefficient came out to be 10.9 and the Coefficient of gradation came out to be 1.21. Hence, we concluded that the MSW sample constituted **well graded sand with silt (SW-SM).**

The soil particle size lies in the range of sand, possibly due to ongoing decomposition of materials in landfill.

Table 4.1 Results of Grain Size Analysis

S. No.	Grain Size	Percentage (%)
1.	Gravel	9.7
2.	Sand	85
3.	Silt	5.3

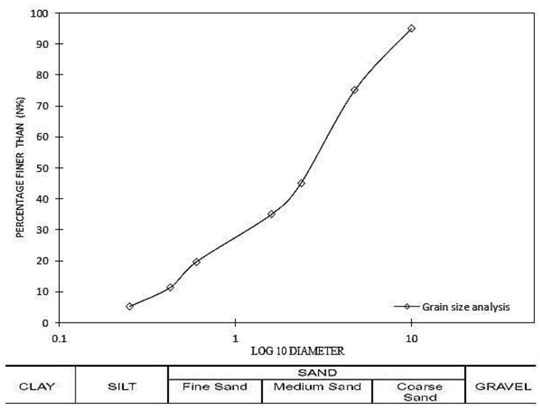


Figure 4.1 Grain Size Distribution

4.2.2 Specific Gravity: The specific gravity test for the soil sample to be used was found out using pycnometer and later checked by using density bottle. The specific gravity of MSW soil came out to be **2.13** using pycnometer indicating the presence of organic content in this soil.

The soil was tending towards organic nature due to the decomposition of organic matter such as plant and animal residues, sewage sludge, carbon compounds, soil nutrients, microbes etc.

Organic nature of this soil would cause low bulk density, high water holding capacity and low load-bearing strength of soil, hence it was necessary to be calculated.

Table 4.2 Specific Gravity Test Results

Method Used	Pycnometer	Density Bottle
Results	2.13	2.15

4.2.3 Atterberg Limits: The plasticity characteristics of the MSW soil were determined as per IS: 2720 (Part 5) – 1985. The results indicated that it was non-plastic in nature. However, the liquid limit of the sample came out to be 30% indicating its medium plasticity characteristics because of absorption of water by organic content present in the MSW soil.

4.2.4 Compaction: *Modified Proctor Test* was carried out on the soil since it contained large sized particles (sand) which required higher compactive effort for breaking into smaller particles, filling up the voids and causing proper compaction. The test resulted in a **maximum dry density** of **21.1 kN/m^3** at an **optimum moisture content** of **20%.**

Maximum dry unit weights may range from around 10kN/m^{3}for organic soils to about 23kN/m^3 for well graduated, granular material containing just enough fines to fill small voids.

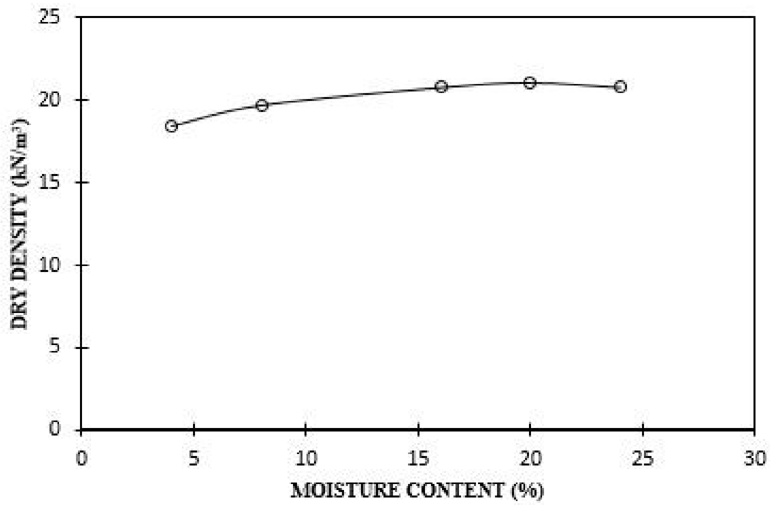


Figure 4.2 Modified Proctor Test

Table 4.3 Proctor Test Results

Method Used	**Standard Proctor Test**	**Modified Proctor Test**
Maximum Dry Density (kN/m^3)	13.9	21.1
Optimum Moisture Content (%)	26	20

4.2.5 Direct Shear Test: Shear strength of a soil is defined as the maximum resistance offered by the soil to shearing stresses. Shear strength parameters were calculated by conducting Direct Shear Test on the soil specimen. The test showed that the respective values for cohesion and angle of internal friction came out to be:

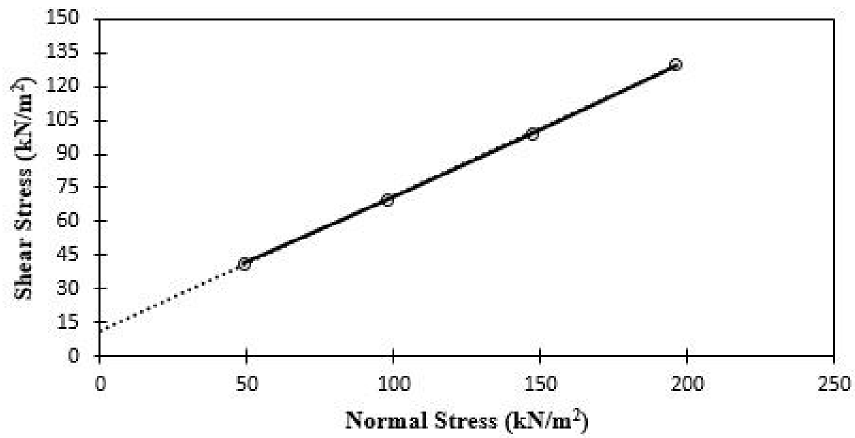


Figure 4.3 Direct Shear Test

Table 4.4 Shear Strength Parameters

Cohesion (*c*)	10 (kN/m^2)
Angle of Internal Friction (ϕ)	31 ^{o}

The test is quicker and easier to conduct; however, there might be variations in the shear parameters as it is difficult to draw conclusions regarding shear parameters because of the pseudo cohesion generated due to leachate and also because of the mixed matrix (where MSW constituents may act as fibres thereby increasing strength).

4.2.6 Permeability: The property of soils to permit the flow of fluid through its interconnected voids is called permeability. The falling head permeability test was conducted on the sample in accordance to the IS 2720-17 (1986) specifications. This test is recommended for soils with coefficient of permeability in the range 10^{-3} to 10^{-7} cm/s.

The coefficient of permeability of the sample was found to be 4.47 x 10^{-5} cm/s which indicates the low permeability of soil (can be classified as semi pervious soil according to U.S.Bureau of Reclamation).

4.2.7 Consolidation: The oedometer test was performed to calculate the coefficient of consolidation.

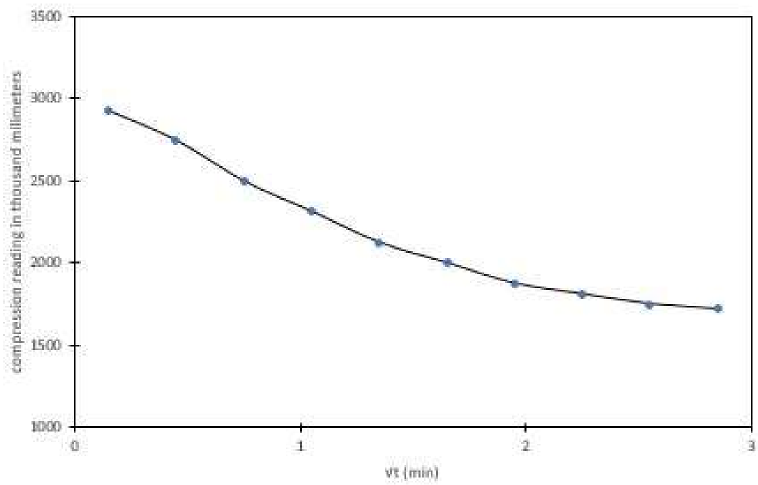


Figure 4.4 Consolidation Graph

The graph between dial gauge readings and square root of time is plotted.

The value for coefficient of consolidation came out to be 0.179 x 10^{-6} m^2/sec after calculating t_{90} (i.e. the time required for 90% consolidation) from the square root of time fitting method.

4.2.8 Free Swell Index: Free swell is the increase in volume of a soil, when submerged completely into water, without any external constraints. Free Soil Index came out to be **18%** for this soil which indicates very low change in volume of soil under effect of water

The possibility of damage to structures due to swelling is low since it comes under the range of low expansive soil (<20%). Change in volume of soil may also be caused due to presence of soluble salts in the soil hence the quantity of important salts such as sulphates, chlorides may be carried out separately.

4.2.9 pH: pH of soil sample was tested by preparing an aqueous solution of soil and checking by pH indicator method. The pH came out in the range of **6-6.5**.

The soil is slightly acidic in nature, which may be due to the nature of waste disposed, industrial discharge, low soil-water ratio, soluble salts concentration, carbon dioxide pressure etc. It is important to study the acidity of soil as very highly acidic soil affects the soil properties adversely. It may cause excess leaching and increased mobility of heavy metals hence it becomes important to know the nature of soil prior to the heavy metal analysis

4.2.10 Sulphates: The test was conducted on aqueous solution of soil by calculating the amount of precipitates of barium sulphate formed due to presence of sulphates. The quantity of sulphates came out to be **5334 mg/Kg** which is well within the limits according to the IARI manual for soil (<10000mg/Kg).

Sulphate determination is important because it may cause volume changes during the process of hydration and dehydration causing settlement problem in embankments or cracks in pavements due to differential settlement.

4.2.11 Organic content: The organic matter came out to be **3.50%** for the soil sample.

The estimation of organic matter is an important part of soil examination as Organic matter is an undesirable constituent of soil from engineering point of view since it causes swelling or shrinkage of the soil when moisture content or applied load changes, (MSW soil being composed of decomposing organic waste). However, the soil was found to be having low organic content.

4.2.12 Heavy Metal Test: This test was conducted on the MSW soil sample by Environ Tech Laboratories, Mohali, which is an NABL accredited lab. The results were given after a test period of one week. The analysis was carried out by Direct Air Acetylene Flame Method.

Soil testing for metal contaminants is crucial for the assessment of environmental and human health hazards associated with heavy metals in soils. The soil used in embankments might get washed due to rain water or leaching and may reach water surfaces causing environmental problems. Based on the leachate results, MSW was found to be a non hazardous material as the concentration of heavy metals was well within permissible limits given by the HSW rules,2016.

Table 4.5 Heavy Metal Concentrations

S. No.	Metal	Result (mg/Kg)	Permissible Limit
1	**Cadmium**	**2.27**	50
2	**Lead**	**120**	5000
3	**Nickel**	**44.47**	5000
4	**copper**	**419**	5000
5	**Arsenic**	**4.13**	50

4.3 Numerical Modelling

4.3.1 Slope Stability of Embankment

4.3.1.1 Factor of safety from PLAXIS 2D

The PLAXIS 2D shows that model 4 (Second layer filled with MSW soil and the rest of the layers having sand) gave the minimum factor of safety of. For all other models *(model 3, model 5 and model 6)* having MSW soil in different layers was found to be 9.79, 10.937, 10.441 respectively. When the embankment was filled with MSW soil, the factor of safety was calculated as 9.76, whereas when sand was used to fill the embankment, the factor of safety came out to be 10.51. The minimum value of factor of safety specified by IRC is 1.25. Thus, the models are well within limits.

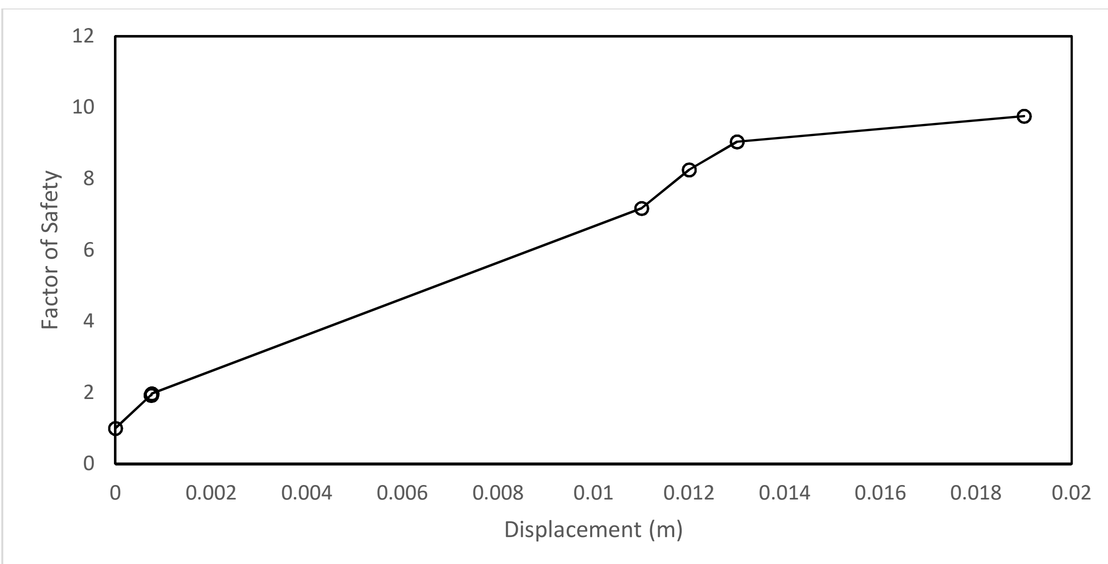


Figure 4.5 Model 1

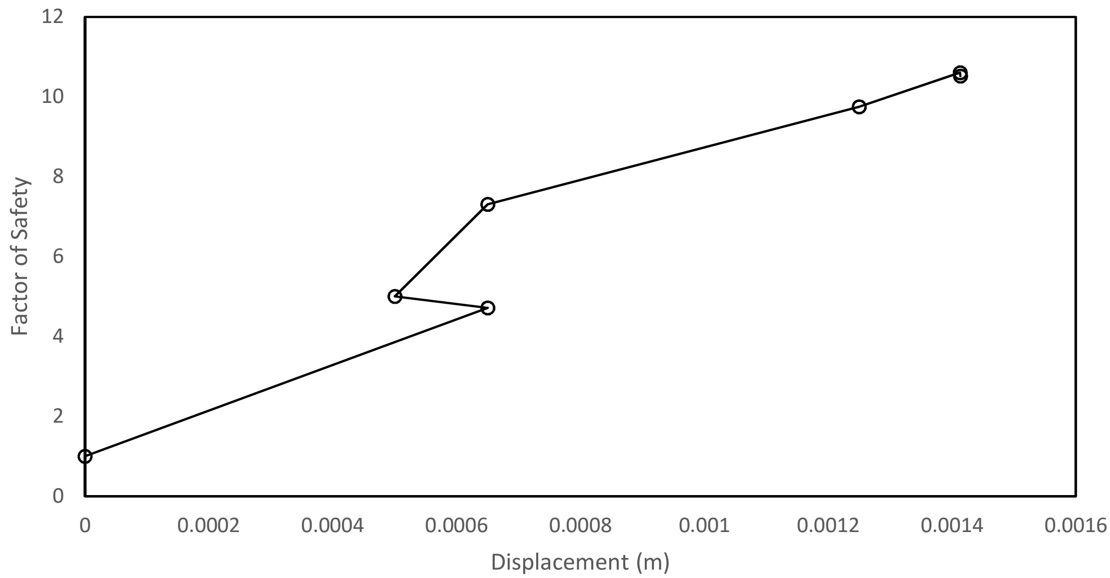


Figure 4.6 Model 2

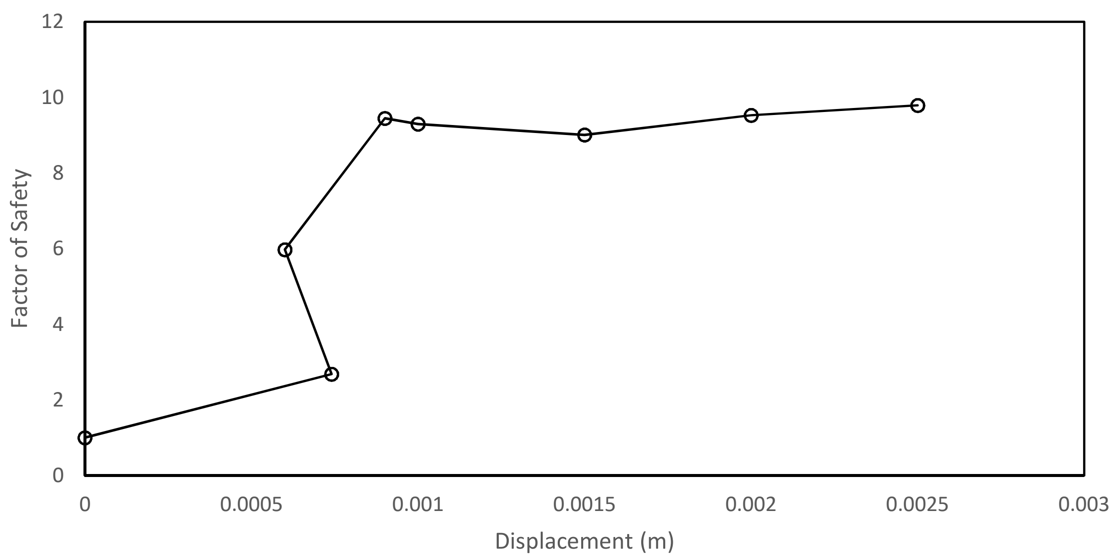


Figure 4.7 Model 3

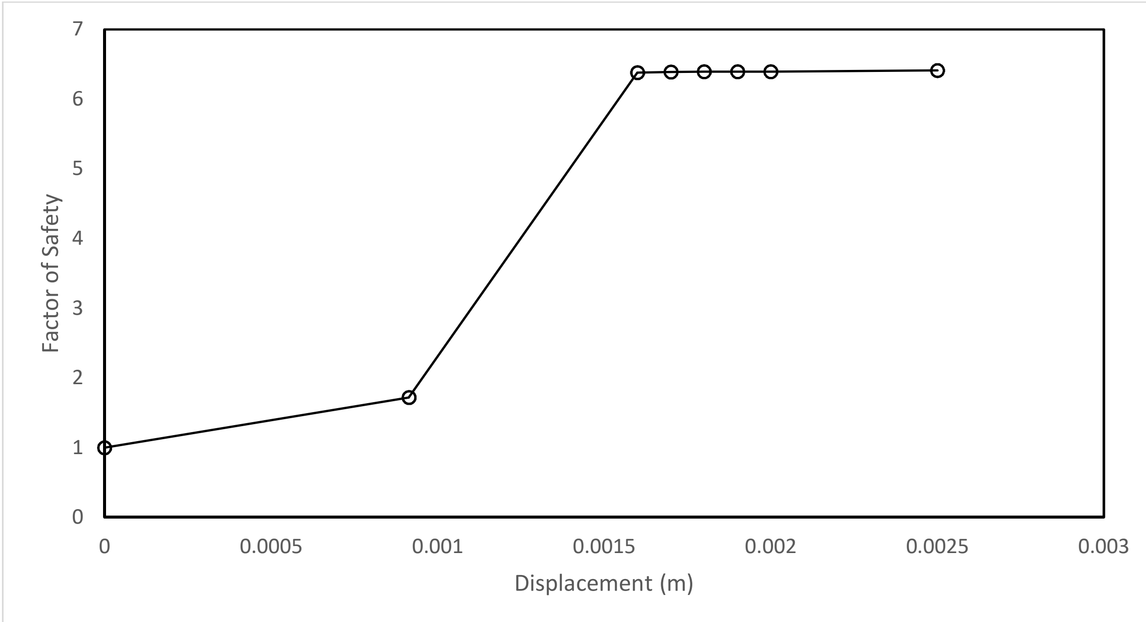


Figure 4.8 Model 4

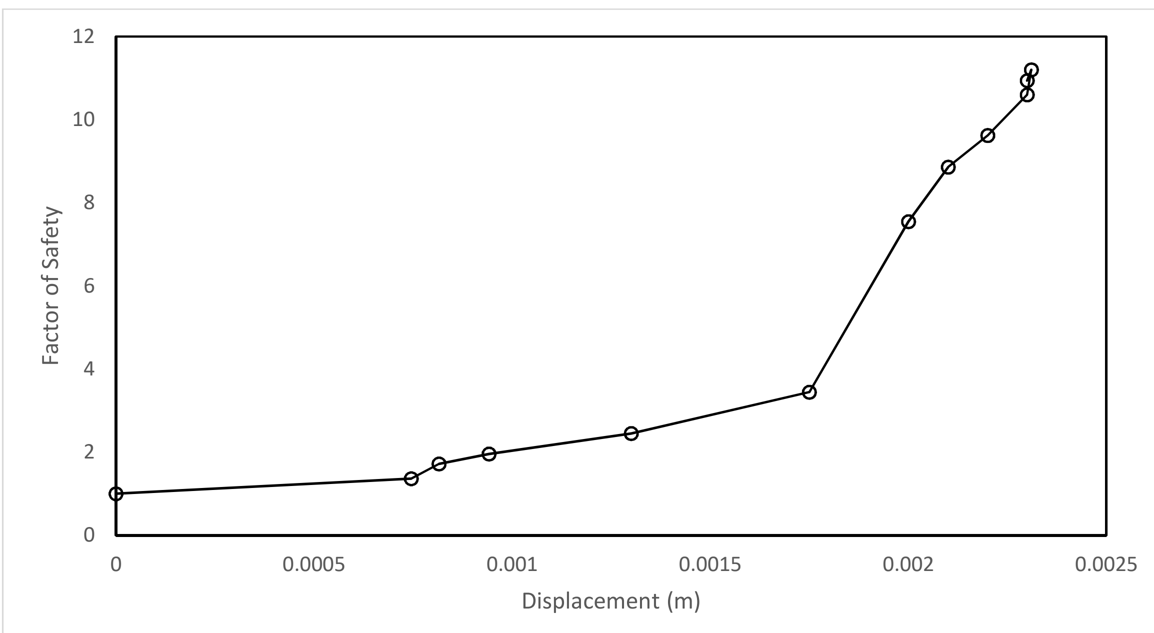


Figure 4.9 Model 5

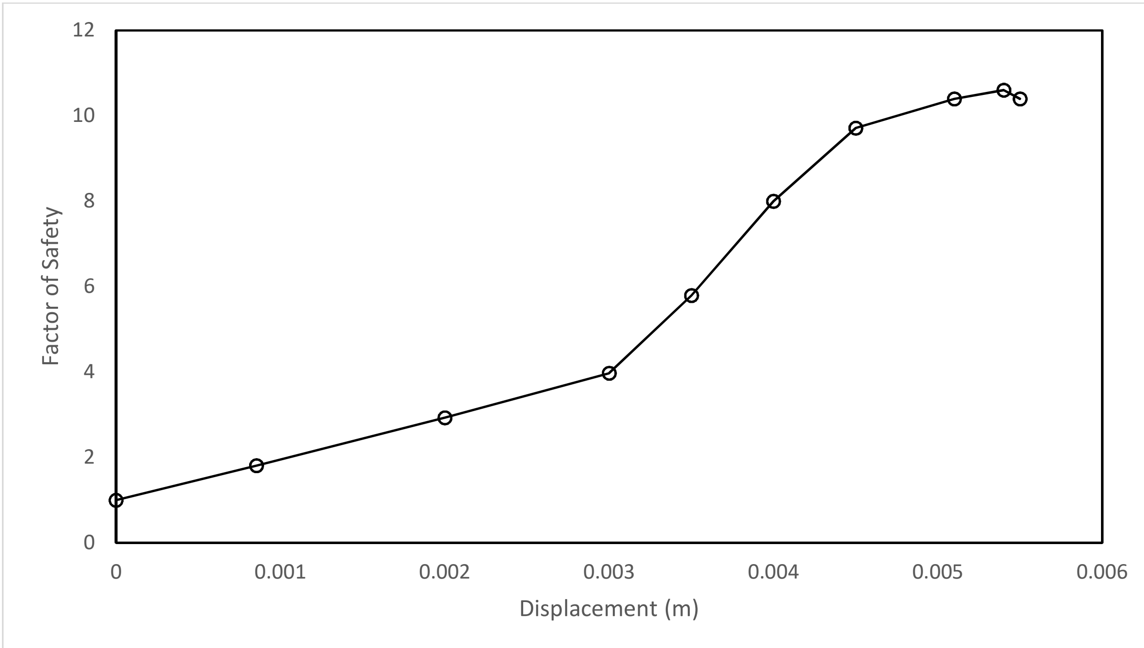


Figure 4.10 Model 6

Table 4.6 Factor of Safety for various models

Model	Factor of Safety
1	9.76
2	10.51
3	9.79
4	6.39
5	10.94
6	10.44

4.3.1.2 Failure mechanism of embankment

From the analysis of various models of embankments using FEM routine PLAXIS 2D, it was observed that the embankments undergo a log-spiral slip surface failure. Although a variation was seen in these slip surfaces in the models using MSW soil in different layers of the embankment fill. It was seen that the failure pattern intersects the crest at right angle (90°) and passes through the toe of the embankment. It was also observed that at the toe of the embankment there was maximum deformation and the soil was bulging out of the embankment.

The analysis also helped in showcasing the plastic points, the points where there was a permanent deformation. It was observed that major percentage of plastic points was located around the slip surface of the embankment model. Tension points were used to determine the points of deformation due to tension.

The plastic points and slip surfaces for various models are shown below.

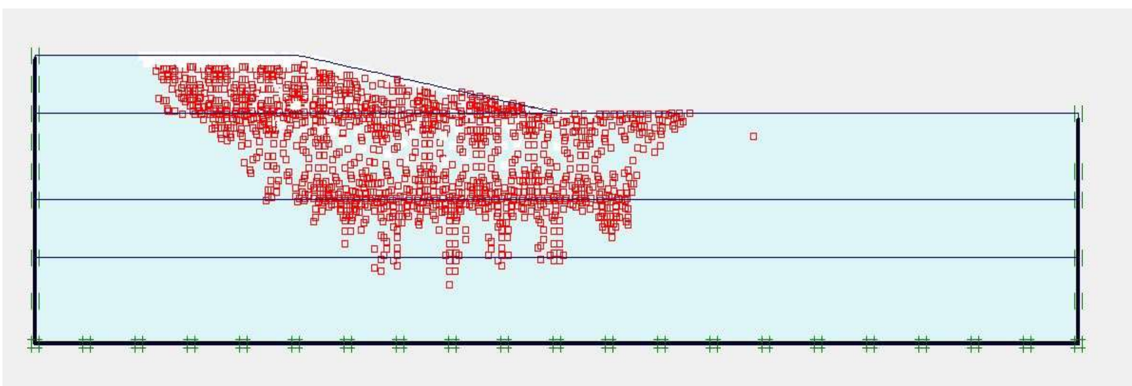


Figure 4.11(a) Plastic points for Model 1

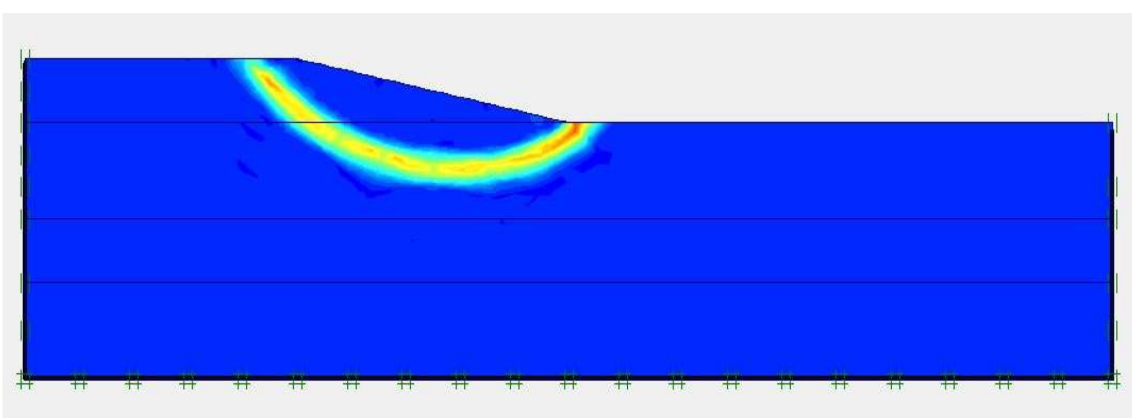


Figure 4.11(b) Slip Surface for Model 1

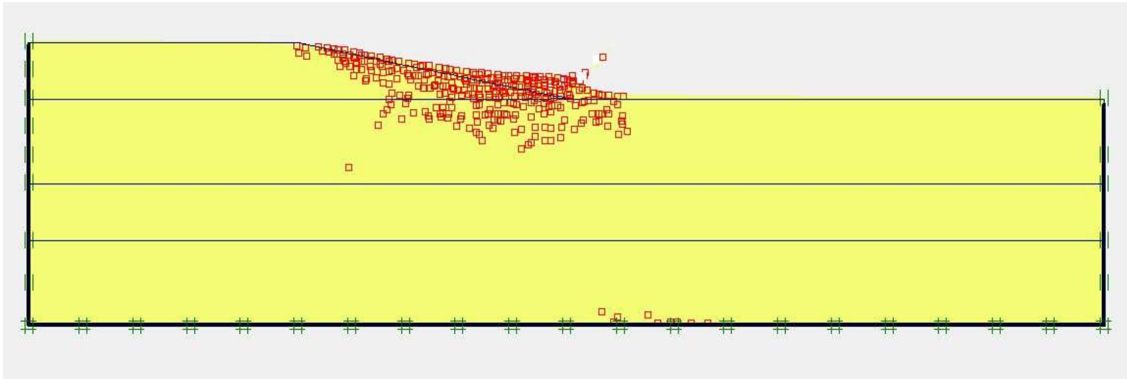


Figure 4.12(a) Plastic points for Model 2

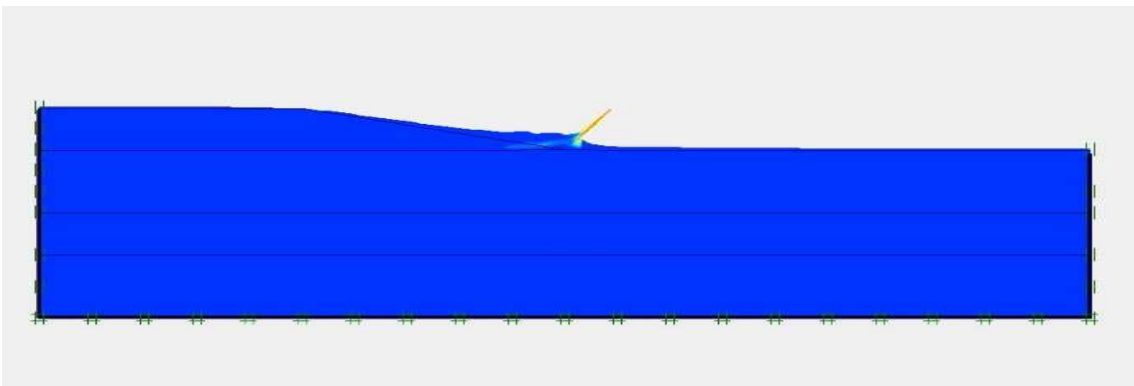


Figure 4.12(b) Slip Surface for Model 2

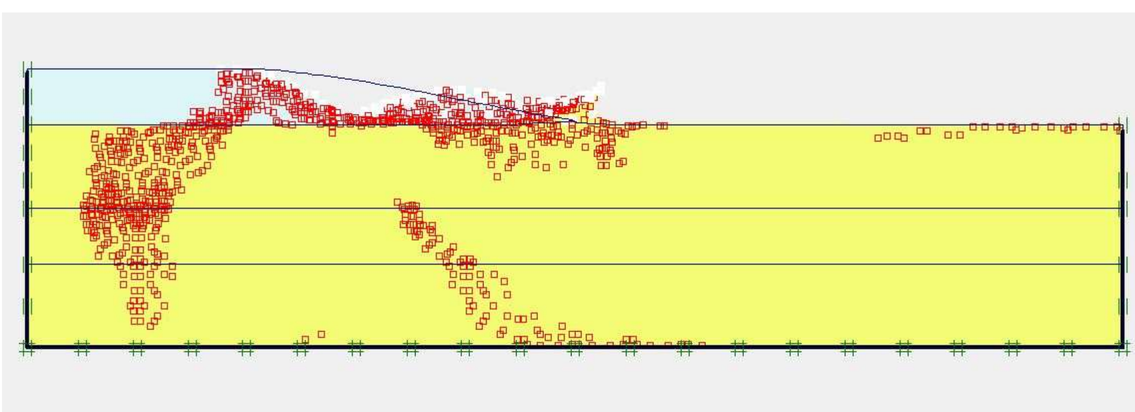


Figure 4.13(a) Plastic points for Model 3

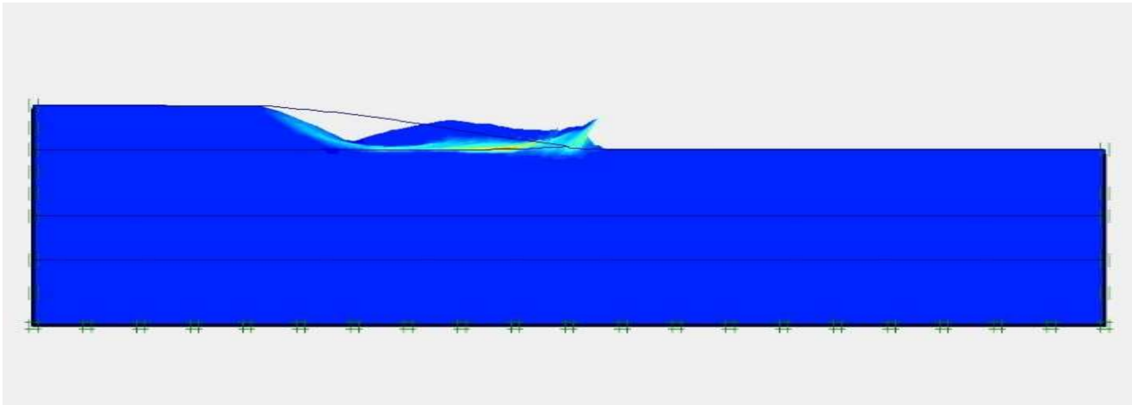


Figure 4.13(b) Slip Surface for Model 3

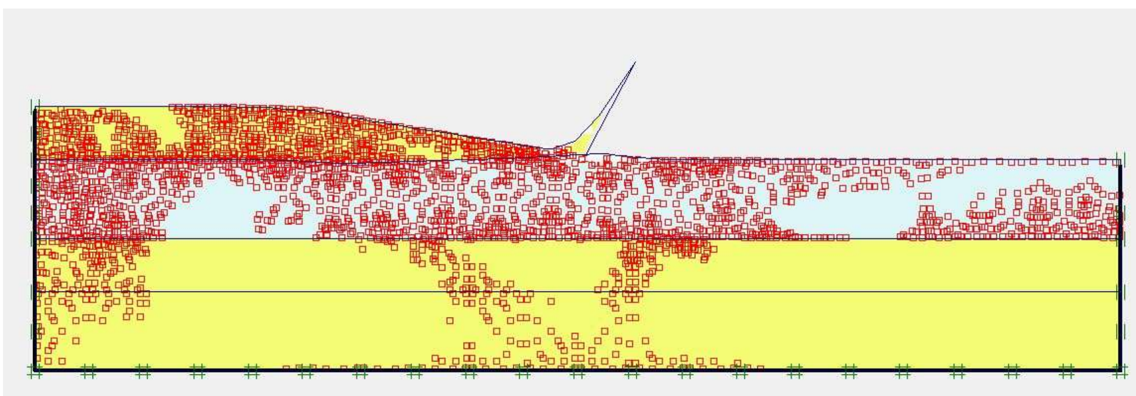


Figure 4.14(a) Plastic Points for Model 4

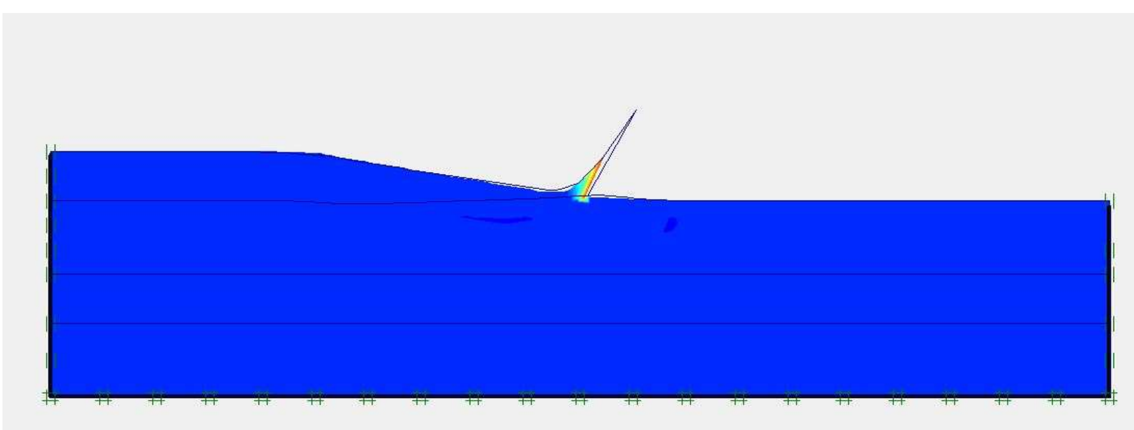


Figure 4.14(b) Slip Surface for Model 4

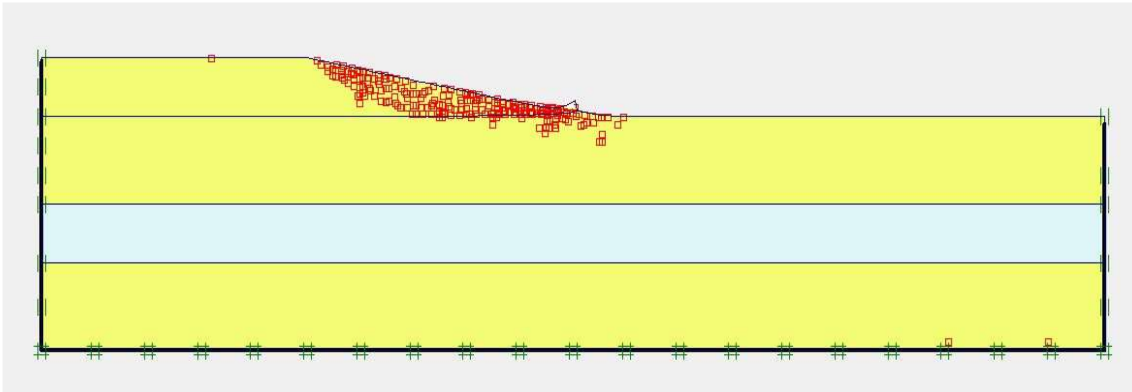


Figure 4.15(a) Plastic Points for Model 5

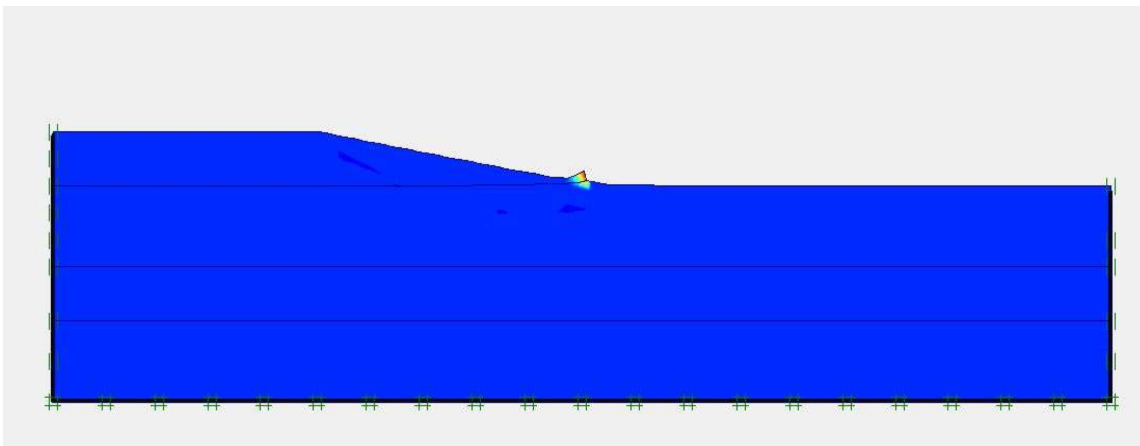


Figure 4.15(b) Slip Surface for Model 5

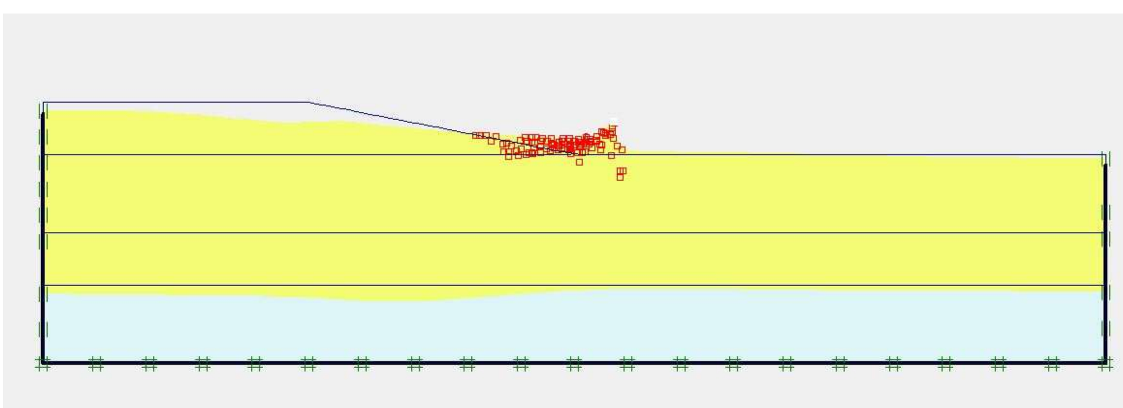


Figure 4.16(a) Plastic Points for Model 6

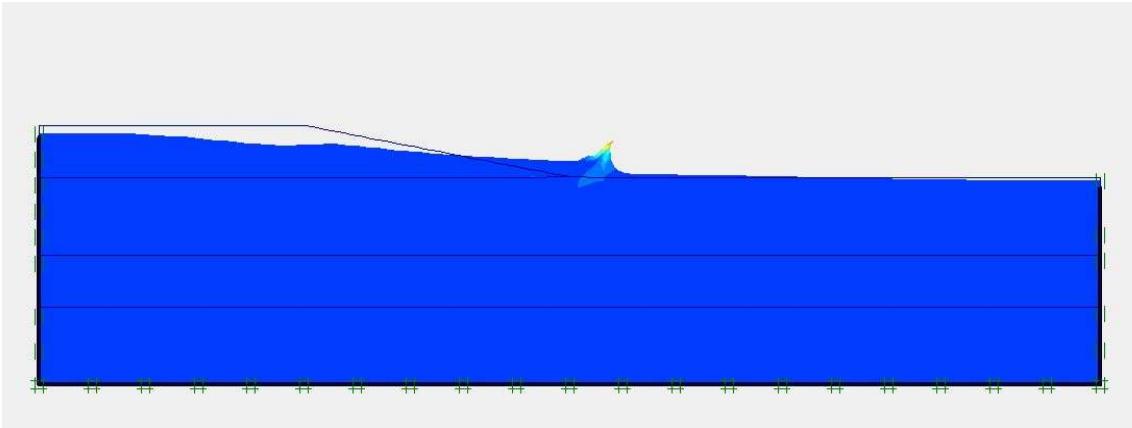


Figure 4.16(b) Slip Surface for Model 6

4.3.2 Settlement Analysis

From PLAXIS 2D, it was determined that the setllement of each model was within tolerable limits provided by the ***Indian Road Congress (IRC).*** Upon investigation of various models, it was found out that the maximum settlement of 19.28mm occurred in *model 2*. The minimum settlement of 18.67mm occurred in *model 4*. The IRC states that a maximum of 300mm settlement is tolerable in case of earthen embankments. The values of maximum displacements came out to be less than the permissible values.

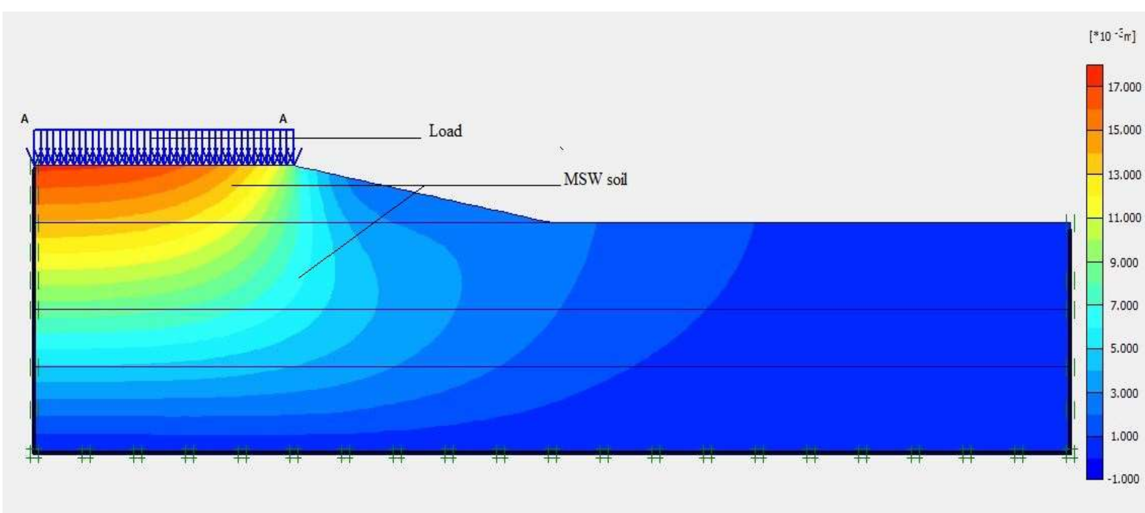


Figure 4.17 Settlements in Model 1

The figure 4.17 demonstrates the settlement variation of finite element model of the embankment. It can be seen that the major deformations occur below the points of application of load. The maximum settlement observed was 17.34 mm.

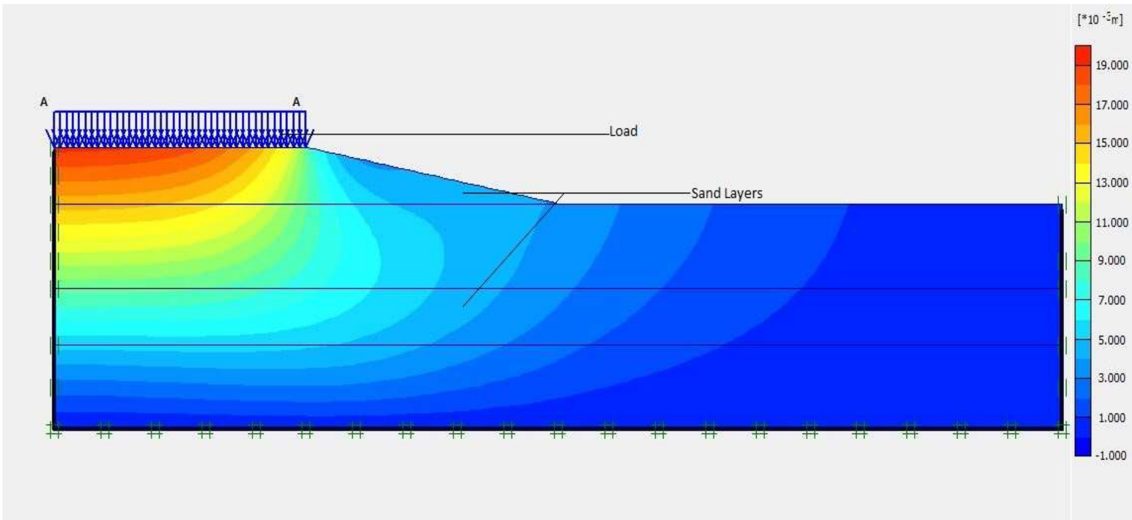


Figure 4.18 Settlements in model 2

The figure 4.18 demonstrates the settlement variation of finite element model of the embankment. It can be seen that the major deformations occur below the points of application of load. The maximum settlement observed was 19.28 mm.

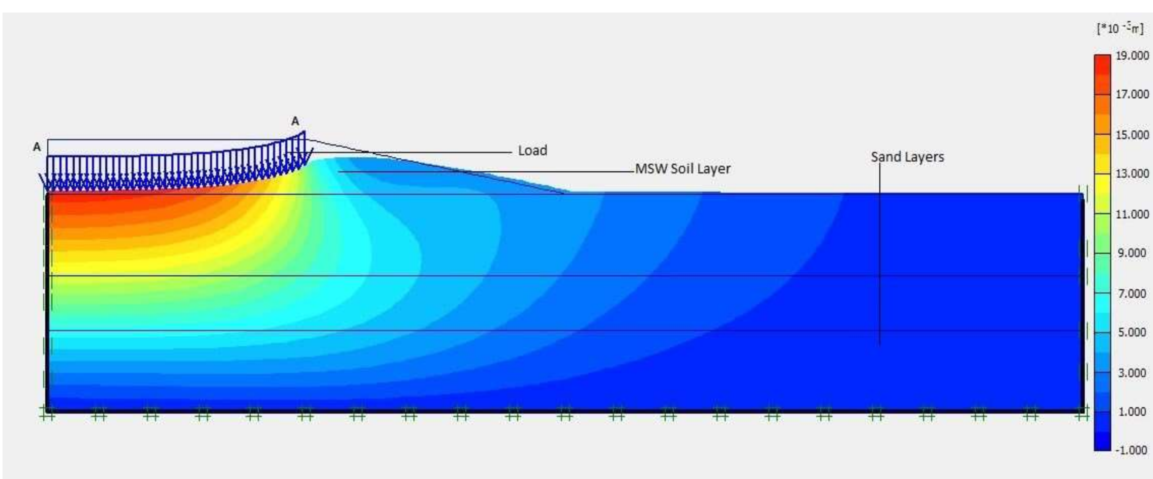


Figure 4.19 Settlements in model 3

The figure 4.19 demonstrates the settlement variation of finite element model of the embankment. It can be seen that the major deformations occur below the points of application of load. The maximum settlement observed was 18.93 mm. It was also observed that the soil started to bulge out near the toe of the embankment.

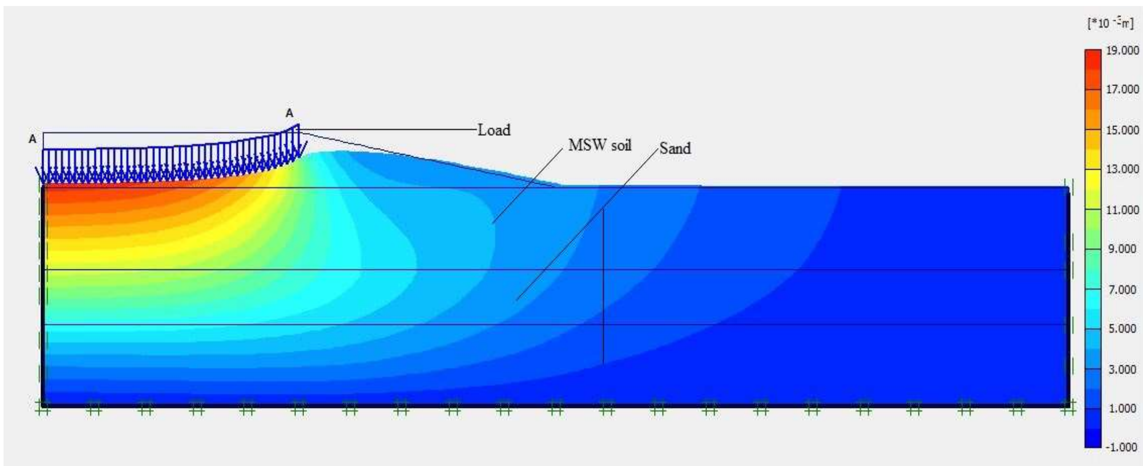


Figure 4.20 Setllements in model 4

The figure 4.20 demonstrates the settlement variation of finite element model of the embankment. It can be seen that the major deformations occur below the points of application of load. The maximum settlement observed was 18.67 mm. It was also observed that the soil started to bulge out near the toe of the embankment.

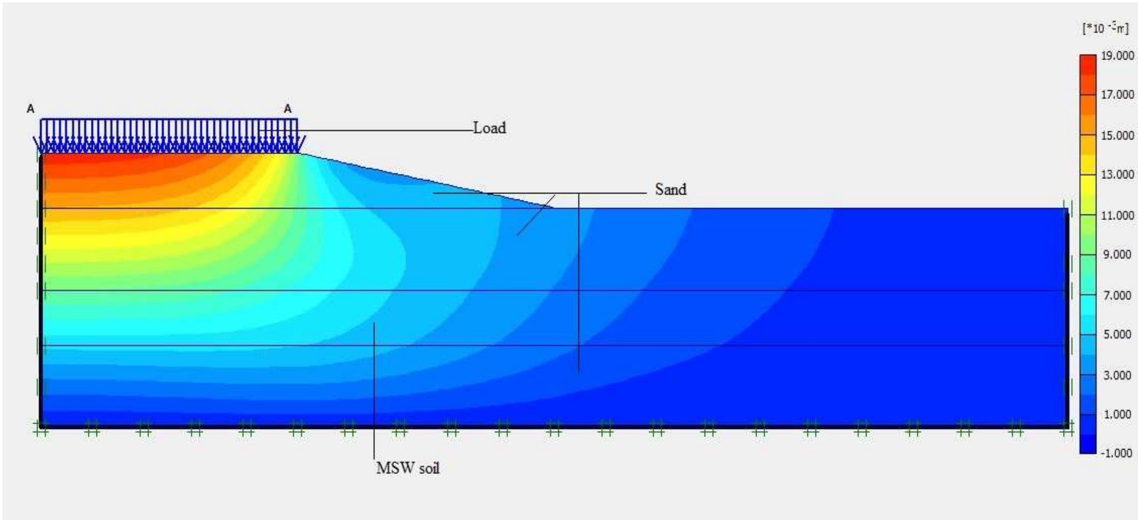


Figure 4.21 Settlements in model 5

The figure 4.21 demonstrates the settlement variation of finite element model of the embankment. It can be seen that the major deformations occur below the points of application of load. The maximum settlement observed was 18.78 mm.

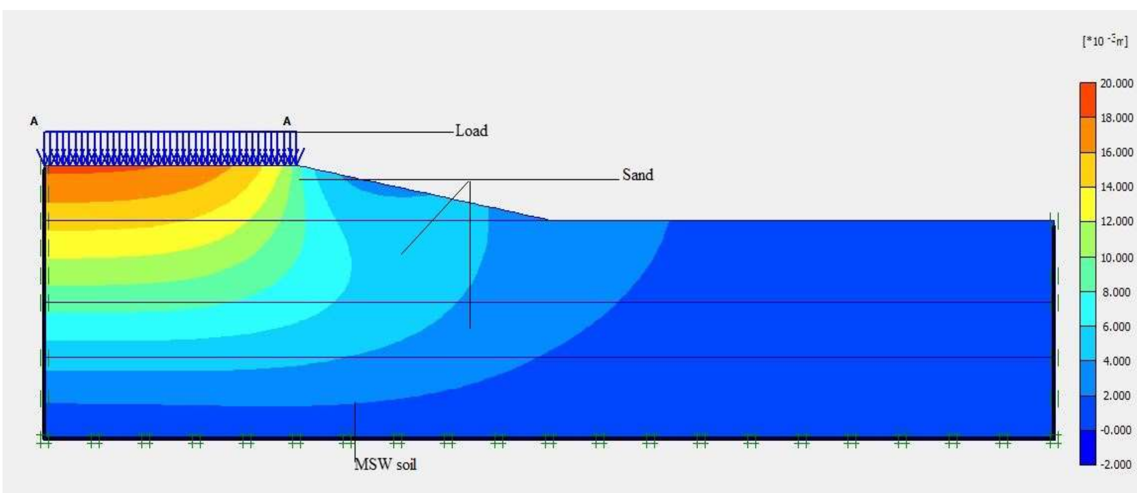


Figure 4.22 Settlements in model 6

The figure 4.22 demonstrates the settlement variation of finite element model of the embankment. It can be seen that the major deformations occur below the points of application of load. The maximum settlement observed was 18.93 mm.

4.3.3 Settlement Due to Consolidation

The settlements can occur due to consolidation of either the embankment itself or the subsoil. It is important to determine the settlements cause by consolidation of the fill material. All models were consolidated for the design period of 15years. The maximum settlement of 17.29mm was calculated in model 1. The minimum settlement of 10mm was determined from model 5. The following figure depicts the settlement distribution due to consolidation over the design period.

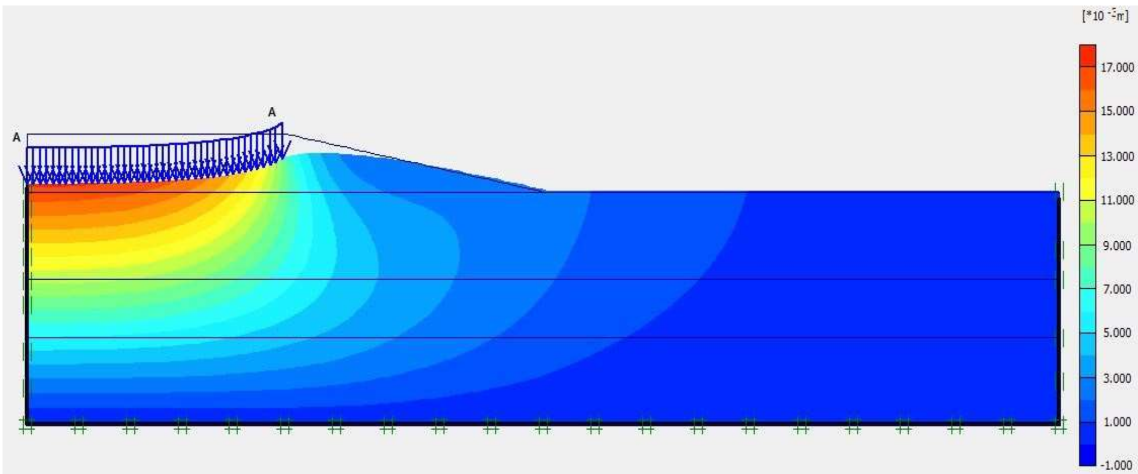


Figure 4.23 Settlements due to consolidation for model 1

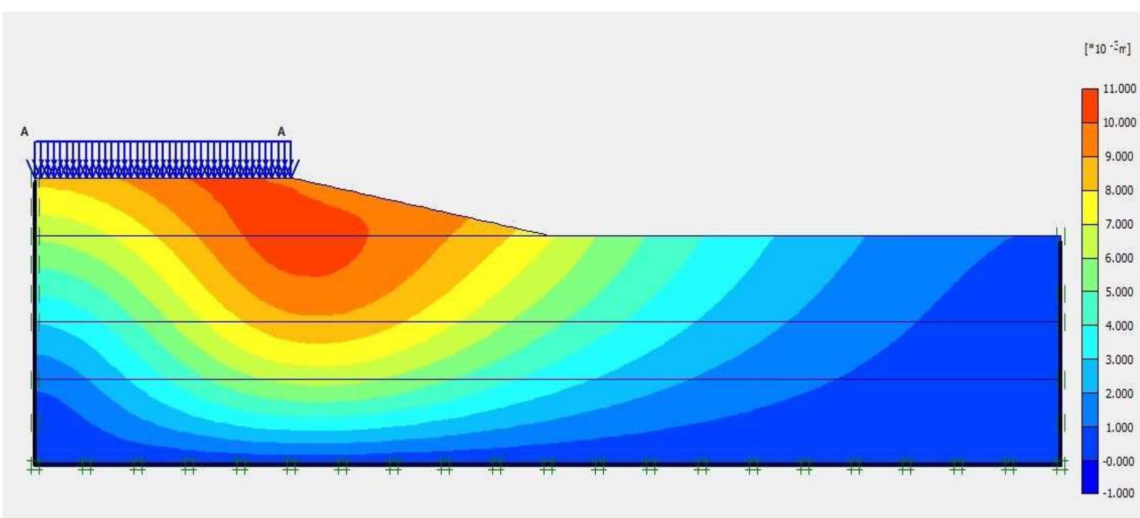


Figure 4.24 Settlements due to consolidation for model 2

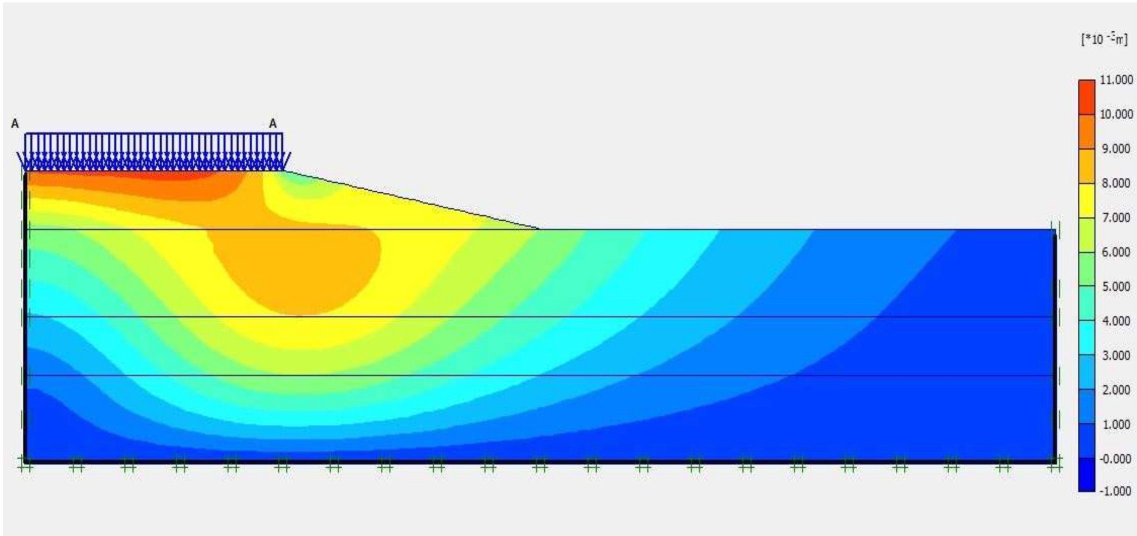


Figure 4.25 Settlements due to consolidation for model 3

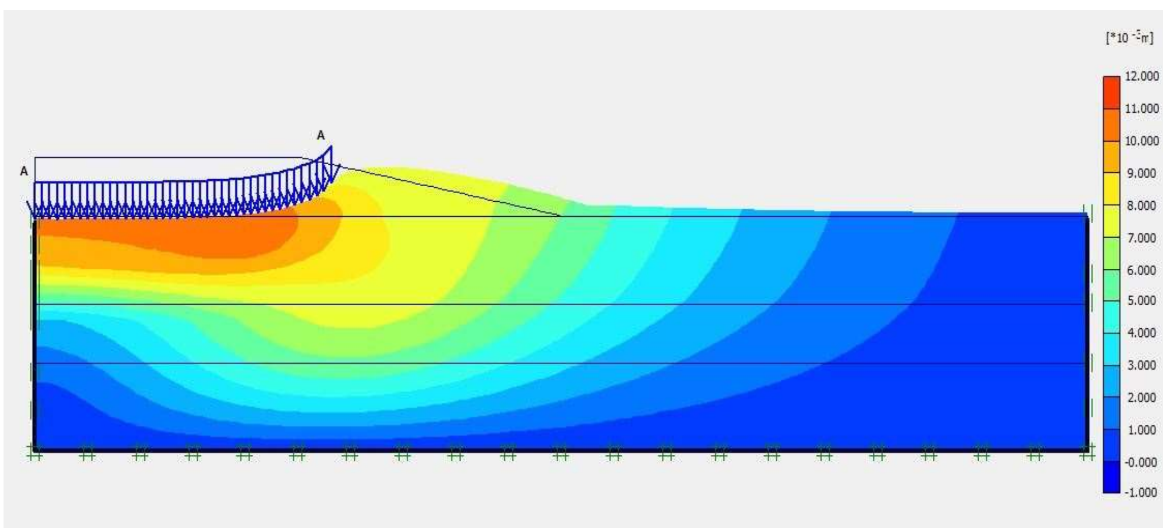


Figure 4.26 Settlements due to consolidation for model 4

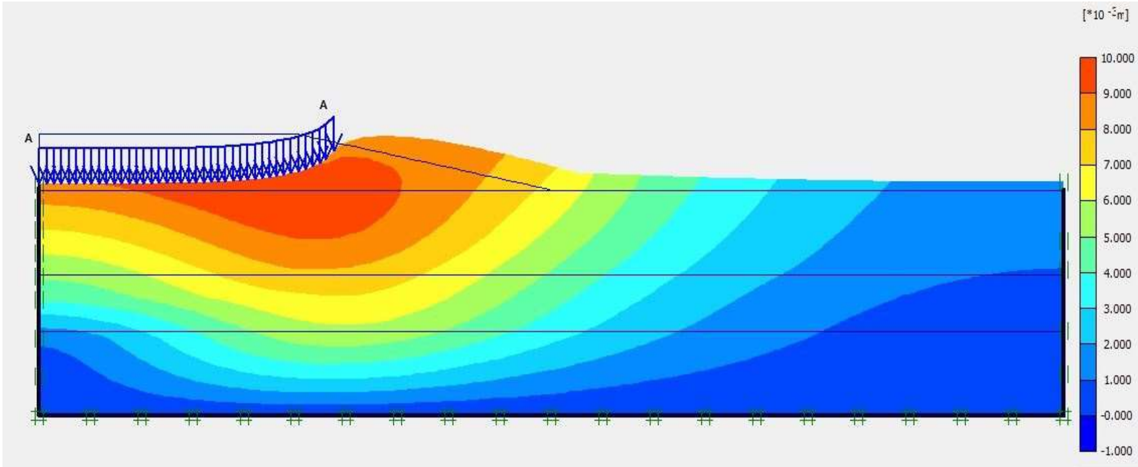


Figure 4.27 Settlements due to consolidation for model 5

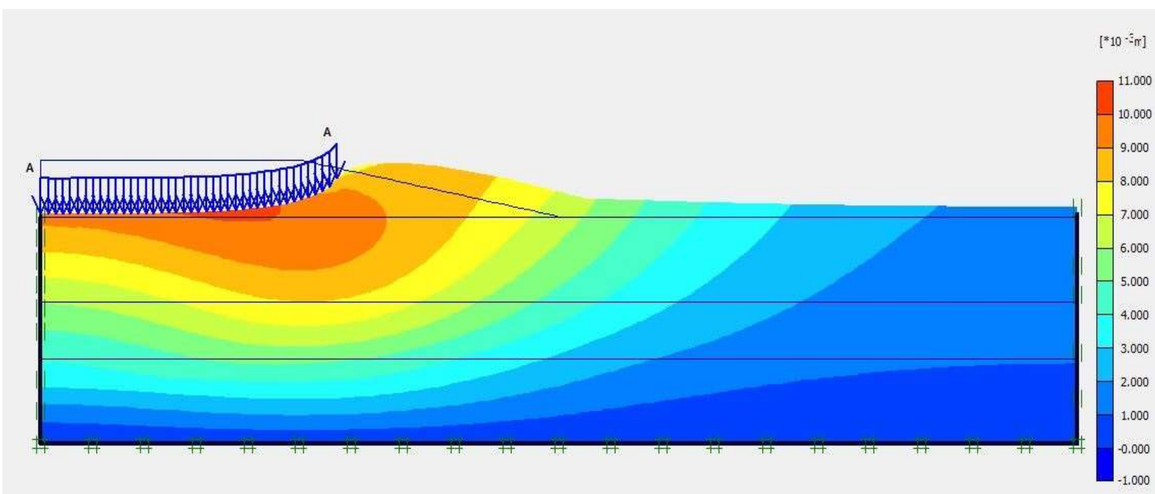


Figure 4.28 Settlements due to consolidation for model 6

These settlements are much less than the tolerable settlements of 300mm specified by IRC. However, these settlements must be uniform and should occur slowly over a period of time.

4.4 Validation of Numerical Modelling

The theoretical model given by Marques was used to calculate the settlement of the embankment fill of MSW. The model incorporates instantaneous response to load, mechanical creep and biological decomposition. Accordingly strain was expressed as:

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}_p + \boldsymbol{\varepsilon}_c + \boldsymbol{\varepsilon}_b$$

Where, $\boldsymbol{\varepsilon}$ = strain due to all three mechanism, $\boldsymbol{\varepsilon}_p$ strain resulting from load response, $\boldsymbol{\varepsilon}_c$ is time dependent strain due to mechanical creep and $\boldsymbol{\varepsilon}_b$ is the time dependent strain due to biological decomposition.

The overall settlement is given by the equation :

$$\Delta H = \sum_{i=1}^{N} H_i \left[\boldsymbol{\varepsilon}_{pi} + \boldsymbol{\varepsilon}_{ci}(t) + \boldsymbol{\varepsilon}_{bi}(t)\right]$$

The equations for calculations of these strains are give by:

$$\boldsymbol{\varepsilon}_{pi} = C'_c log\left(\frac{\left(\frac{1}{2}\right)\gamma_i H_i + \sum_{j=i+1}^{N}\Delta\sigma_{ij}}{\left(\frac{1}{2}\right)\gamma_i H_i}\right)$$

$$\boldsymbol{\varepsilon}_{ci}(t) = b\left[\frac{1}{2}\gamma_i H_i\left(1 - e^{-c(t-t_i)}\right) + \sum_{j=i+1}^{N}\Delta\sigma_{ij}\left(1 - e^{-c(t-t_i)}\right)\right]$$

$$\boldsymbol{\varepsilon}_{bi}(t) = E_{DG}\left(1 - e^{-d(t-t_j)}\right)$$

Values for all the constants have been taken from the paper Marques (2003).

The settlement calculated theoretically was 73.4mm. The IRC states that the maximum allowable settlement is in the range of 300-600mm.

The difference in settlements calculated theoretically and using finite element modeling was due the inclusion of the biological degradation factor that the finite element model does not take into account. This difference is in the range of allowable settlements and hence it can be concluded that the MSW can be used as an embankment fill material provided that the settlements in the embankment are calculated theoretically using the Marques model.

Chapter 5

Conclusions

5.1 General

MSW soil from Ghazipur landfill, East Delhi has been studied in detail for checking the feasibility of the application of this soil in construction. The MSW soil was collected, segregated and characterized for geotechnical and chemical properties. Various design cross sections were analyzed with the objective of optimizing use of MSW soil.

5.2 Conclusions

Major conclusions drawn from the above study have been summarized below:

1. The specific gravity of MSW soil is found to be approximately 2 which signifies the organic nature of soil. This can be accounted for decomposition of organic wastes such as plant animal residues, minerals, carbon compounds, household wastes etc. Hence, it can be concluded that the soil is fresh and has not been completely decomposed.

2. The soil studied for construction of embankment is non plastic, non swelling coarse grained soil, classified as SW-SM (i.e. well graded sand with silt).

3. The MSW soil represents a $c - \phi$ soil with values for both cohesion and angle of shearing resistance. The particle distribution curve defines the particle range as silty sands (formed due to decomposition of waste material) whereas the cohesive nature of soil may be due to the apparent cohesion that is produced due to leachate generation. Fibre action of particles such as rubber, glass etc may also have resulted in increased strength parameters.

4. Chemical analysis indicates that the MSW soil is non hazardous and can be used in construction without any adverse effect on the environment. The concentrations of heavy metals in the MSW soil are well within the permissible range.

5. The Permeability of MSW soil indicates that it is semi pervious and lies in the range of silts. The low value of permeability observed may be because of presence of plastics, and rubber in the MSW mix which obstructs the flow of water through the mix.

6. The value of coefficient of consolidation (C_v) is 0.179 x 10^{-6} m^2/sec which is similar to that of silty soils.

7. From the finite element modelling, it can be concluded that the maximum settlement is less than the specified limit as per IRC. The maximum settlement of 34.58mm is obtained for Model 1(i.e. when only MSW soil is used in all the layers). This indicates that the use of MSW soil in embankment construction is feasible.

8. The strength reduction analysis resulted in a minimum factor of safety as 6.39. The minimum factor of safety as prescribed by the IRC is 1.25. Thus, it can be concluded that the embankment made using MSW soil is stable.

9. From the analysis of failure mechanism of the embankment, it is determined that due to plastic deformation, a log spiral slip surface is obtained that intersects the crest at 90° and passes through the toe of the embankment. Maximum deformation was observed just under the loading surface, accompanied by bulging out of the surface near the toe.

10. The model with the second from top layer as MSW soil and all the other layers as sand gives the mininum deformation and settlement (18.67mm), hence making Model 4 the most optimum configuration for embankment construction.

11. Validation of the numerical modelling was done by comparing the results with the theoretical model given by Marques. The settlements for MSW soil model, using PLAXIS 2D as well as Marques' theoretical model were both within the permissible range.

12. The Composite Compression Model for MSW given by Marques considers three mechanisms for compression : applied load, mechanical creep, and biological decomposition while the FEM approach does not consider the biodegradability of the MSW, hence it is important to calculate the settlements theoretically.

Based on the above conclusion, MSW soil can be called a feasible fill material for road embankments. For further investigation, a test track may be prepared and investigated upon for better clarity on the feasibility of this material. Proper safety precautions must be taken into account.

5.3 Scope of future work

In the current study the suitability of MSW soil for embankment construction has been demonstrated. However, to enable field applications the following research work is desirable.

1. The thickness of the soil layer, when being used in the subgrade of the embankment, can be varied. The depth at which the MSW soil gives the most suitable results can be optimized.

2. The MSW soil can also be used with the local available soil in proper mixing proportions so as to obtain desirable results.

3. Though the modelling validates the use of MSW soil in embankment construction, proper field testing and test track experimentation should be carried out for a certain period of time, before recommending its use in large scale projects.

4. The degree of biodegradability of the MSW soil may vary with depths and age. Therefore, proper durability studies are required to make use of the MSW in embankment construction.

References

1. Alhassan, M. (2012). “Effect of municipal solid waste on geotechnical properties of soils.” *International Journal of Environmental Science, Management and Engineering Research*, *1*(5), 204-210.

2. Ali, S. M., Pervaiz, A., Afzal, B., Hamid, N., & Yasmin, A. (2014). “Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city.” *Journal of King Saud University-Science*, *26*(1), 59-65.

3. Aseeja, P. K. (2016). "Modelling Consolidation Behavior of Embankment Using Plaxis." *International Journal of Scientific & Engineering Research*,7(4), 70-75.

4. Ashour, M., & Ardalan, M. H. (2010). “*Road Embankment and Slope Stabilization*” No. UTCA Report 09305.

5. Barbier et al.(2014). “Soil control of trace metals concentrations in landfills: a case study of the largest landfill in Europe, Malagrotta, Rome.” *Journal of Geochemical Exploration* , doi: 10.1016/j.gexplo.2014.04.001

6. Balasubramaniam, A. S., Cai, H., Zhu, D., Surarak, C., & Oh, E. Y. N. (2010). “Settlement of embankments in soft soils.” *Geotechnical Engineering*, *41*(1), 61.

7. Chik, Z., and T. Islam.(2011). "Study of chemical effects on soil compaction characterizations through electrical conductivity." *Int. J. Electrochem. Sci* 6 : 6733-6740.

8. CSIR - Central Road Research Institute(2016). "Utilization of Municipal Solid Waste(MSW) in Road Embankment." http://www.crridom.gov.in/content/utilization-municipal-solid-waste-msw-road-embankment

9. Dixon, N., & Jones, D. R. V. (2005). “Engineering properties of municipal solid waste.” *Geotextiles and Geomembranes*, *23*(3), 205-233.

10. Dr. Krishna M. K, Chaitra B.R, Jyoti Kumari(2016). **“**Effect of Municipal Solid Waste Leachate on the Quality of Soil.”

11. El-Fadel, M., & Khoury, R. (2000). “Modeling settlement in MSW landfills: a critical review.” *Critical reviews in environmental science and technology*, *30*(3), 327-361.

12. Gündüz, B. (2008). “Analysis of settlements of test embankments during 50 years-a comparison between field measurements and numerical analysis.”

13. Habibnezhad, Z. (2014). “Stability Analysis of Embankments Founded on Clay: a comparison between LEM & 2D/3D FEM.”

14. Harshani, H. M. D., Nawagamuwa, U. P., & Senanayake, A. (2015). “Evaluation of cover soil properties of solid waste dumpsites in Colombo District, Sri Lanka.” *Journal of the National Science Foundation of Sri Lanka*, *43*(2).

15. Hyun Il, P., Borinara, P., & Hong, K. D. (2011). “Geotechnical considerations for end-use of old municipal solid waste landfills.” *International Journal of Environmental Research*, *5*(3), 573-584.

16. IS: 2720 Part 3/Section 2 (1980), “Indian Standard for determination of Specific gravity (fine, medium and coarse grained soil)”, Bureau of Indian Standards Publications, New Delhi.

17. IS: 2720 Part 4 (1975), “Indian Standard for grain size analysis”, Bureau of Indian Standards Publications, New Delhi.

18. IS: 2720 PART VII-(1980) (Reaffirmed on 2011), “Indian Standard for Compaction Test-(Light Weight/Standard Proctor Compaction)”, Bureau of Indian Standards Publications, New Delhi.

19. IS: 2720 Part 40 (1977), “Methods of test for soils: Determination of free swell index of soils”, Bureau of Indian Standards Publications, New Delhi.

20. IS: 2720 Part 26 (1987), “Methods of test for soils: Determination of pH value”, Bureau of Indian Standards Publications, New Delhi.

21. IS: 2720 Part 17 (1986), “Methods of test for soils: Laboratory determination of permeability”, Bureau of Indian Standards Publications, New Delhi.

22. Jain, P., Kim, H., & Townsend, T. G. (2005). “Heavy metal content in soil reclaimed from a municipal solid waste landfill.” *Waste management*, *25*(1), 25-35.

23. Karstunen, M., Wiltafsky, C., Krenn, H., Scharinger, F., & Schweiger, H. F. (2006). “Modelling the behaviour of an embankment on soft clay with different constitutive

models." *International journal for numerical and analytical methods in geomechanics*, *30*(10), 953-982.

24. Kavazanjian, E. (2001). "Mechanical properties of municipal solid waste." In *Proceedings Sardinia* ,1(8), 415-424.

25. Khabbaz, H., Fatahi, B., & Nucifora, C. (2012). "Finite element methods against limit equilibrium approaches for slope stability analysis." In *11th Australia-New Zealand Conference on Geomechanics-Ground Engineering in a Changing World*. Geomechanical Society and New Zealand Geotechnical Society.

26. Khan, S. A., & Abbas, S. M. (2014). "Numerical modelling of highway embankment by different ground improvement techniques."

27. Krishna, M., Chaitra, B. and Kumari, J. (2016). "Effect of Municipal Solid Waste Leachate on the Quality of Soil." International Journal of Engineering Science Invention,Vol. 5(No.6), ISSN (Online): 2319 – 6734

28. Krook, J., Svensson, N., & Eklund, M. (2012). "Landfill mining: a critical review of two decades of research." *Waste management*, *32*(3), 513-520.

29. Kurian, J., Esakku, S., Palanivelu, K., & Selvam, A. (2003, October). "Studies on landfill mining at solid waste dumpsites in India." In *Proceedings Sardinia* (Vol. 3, pp. 248-255).

30. Ling, H. I., Leshchinsky, D., Mohri, Y., & Kawabata, T. (1998). "Estimation of municipal solid waste landfill settlement." *Journal of Geotechnical and Geoenvironmental Engineering*, *124*(1), 21-28.

31. Machado, S. L., Karimpour-Fard, M., Shariatmadari, N., Carvalho, M. F., & do Nascimento, J. C. (2010). "Evaluation of the geotechnical properties of MSW in two Brazilian landfills." *Waste Management*, *30*(12), 2579-2591.

32. Marques, A. C. M., Filz, G. M., & Vilar, O. M. (2003). "Composite compressibility model for municipal solid waste." *Journal of Geotechnical and Geoenvironmental Engineering*, *129*(4), 372-378.

33. McCauley, A., Jones, C., & Jacobsen, J. (2009). “Commercial fertilizers and soil amendments.” *Nutrient Management-A self-study course from MSU extension continuing education series*, 449-510.

34. Parth, V., Murthy, N. N., & Saxena, P. R. (2011). “Assessment of heavy metal contamination in soil around hazardous waste disposal sites in Hyderabad city (India): natural and anthropogenic implications.” *Journal of Environmental research and management*, *2*(2), 027-034.

35. Plaxis, B. V. (2002). “Plaxis 2D–version 8 manual.” Balkema Publisher, Rotterdam

36. Rakesh Kumar Pandey and R.P.Tiwari(2015). Physical Characterization and Geotechnical Properties of Municipal Solid Waste.

37. Rawat, S., & Gupta, A. K. (2016). “Analysis of a Nailed Soil Slope Using Limit Equilibrium and Finite Element Methods.” *International Journal of Geosynthetics and Ground Engineering*, *2*(4), 34.

38. Reddy, K. R., Hettiarachchi, H., Parakalla, N. S., Gangathulasi, J., & Bogner, J. E. (2009). “Geotechnical properties of fresh municipal solid waste at Orchard Hills Landfill, USA.” *Waste Management*, *29*(2), 952-959.

39. Roychoudhury, S. and Roychoudhury, S. (2014). *For Clean India to work, country needs to solve its waste disposal problem*. [online] Scroll.in.<http://scroll.in/article/682335/for-clean-india-to-work-country-needs-to-solve-its-waste-disposal-problem>(12 Oct. 2016).

40. Salih, A. G., & Ahmed, H. A. (2014). “The Effective Contribution Of Software Applications In Various Disciplines Of Civil Engineering.” *International Journal of Civil Engineering and Technology*, *5*(12), 316-333.

41. Sivakumar Babu, G. L., Reddy, K. R., Chouskey, S. K., & Kulkarni, H. S. (2009). “Prediction of long-term municipal solid waste landfill settlement using constitutive model.” *Practice periodical of hazardous, toxic, and radioactive waste management*, *14*(2), 139-150.

42. Stoltz, G., Gourc, J. P., & Oxarango, L. (2010). “Characterisation of the physico-mechanical parameters of MSW.” *Waste Management*, *30*(8), 1439-1449.

43. Soon, Y. K., & Hendershot, W. H. (2007). Soil chemical analyses. *Soil Sampling and Methods of Analysis. Canadian Society of Soil Science, Boca Raton, FL*, 128-332.

44. Times, L. (2016). *New Delhi's 'trash mountain'*. [online] latimes.com.<http://www.latimes.com/world/la-fg-adv-india-trash-mountain-pictures-photogallery.html>(12 Oct. 2016).

45. Times of India, (2016). Ghazipur waste to be used for NH widening.

46. Tiwari, M. K., Bajpai, S., & Dewangan, U. K. (2015). “An analytical study of heavy metal concentration in soil of an industrial region of Chhattisgarh, central India.” *International Journal of Scientific and Research Publications*, *5*(7), 1-8.

47. Tripathi, A., and D. R. Misra. (2012). "A study of physico-chemical properties and heavy metals in contaminated soils of municipal waste dumpsites at Allahabad, India." *International Journal of Environmental Sciences,* 2(4), 2024.

48. Wall, D. K., & Zeiss, C. (1995). “Municipal landfill biodegradation and settlement.” *Journal of environmental engineering*, *121*(3), 214-224.

49. Zekkos, Dimitrios, et al.(2010). "Physical characterization of municipal solid waste for geotechnical purposes." *Journal of Geotechnical and Geoenvironmental Engineering,* ASCE, 136.9: 1231-1241.

ANNEXURES

Annexure A: Particle Size Distribution

Sieve Size(mm)	Mass Retained(Kg)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Finer Than (%)
4.75	0.13	9.7	9.7	90.3
2.35	0.04	3	12.7	87.3
1.6	0.31	23.3	36	64
0.6	0.36	27	63	37
0.425	0.14	10.5	73.5	26.5
0.25	0.09	6.8	80.3	19.7
0.15	0.11	8.3	88.6	11.4
0.075	0.08	6.1	94.7	5.3
Base	0.07	5.3	100	0

Annexure B: Specific Gravity

a) Density Bottle

Weight of empty bottle with stopper (M_1)	33.4g
Weight of bottle and dry soil (M_2)	83.4g
Weight of bottle, dry soil and water (M_3)	110.3g
Weight of bottle and water (M_4)	83.5g

Specific Gravity, $G = (M_2 - M_1) / [(M_2 - M_1) – (M_3 – M_4)]$

$= 83.4 – 33.4 / [(83.4 – 33.4) – (110.3 – 83.5)]$

$= 2.15$

b) Pycnometer

Weight of Empty Pycnometer (W_1)	447.0 g
Weight of Pycnometer + Soil (W_2)	647.0 g
Weight of Pycnometer + Soil + Water (W_3)	1347.0 g
Weight of Pycnometer + Water (W_4)	1240.5 g
Weight of soil used (W_S)	200 g

Specific Gravity, $G = (W_2 - W_1) / [(W_2 - W_1) – (W_3 – W_4)]$

$=(647-447)/ [(647-447)-(1347-1240.5)]$

$= 2.13$

Annexure C: Compaction

Moisture Content (%)	Soil Mass (g)	Density (g/cm^3)	Dry Density (g/cm^3)
4	4315	1.92	1.84
8	4792	2.13	1.97
16	5454	2.42	2.08
20	5699	2.53	**2.11**
24	5741	2.55	2.05

Annexure D: Direct Shear Test

Normal Stress (kN/m^2)	**Shear Stress (kN/m^2)**
49.05	41.20
98.1	69.65
147.15	99.08
196.2	129.49

Slope	0.5968
Angle of Internal Friction	30.9 ^{o}
Cohesion	10 (kN/m^2)

Annexure E: Permeability

Time t = 16.36 min

Initial head h_1= 9

Final head h_2= 78.5 cm

Coefficient of permeability K_p= 4.47 x 10^{-5} cm/s

Annexure F: Free Swell Index

Readings	Soil in Kerosene (g)	Soil in Distilled Water (g)
Initial reading	10	10
Final reading(after 24 hrs)	11	9

Free Swell Index = 18%

Annexure G: Mesh Deformation

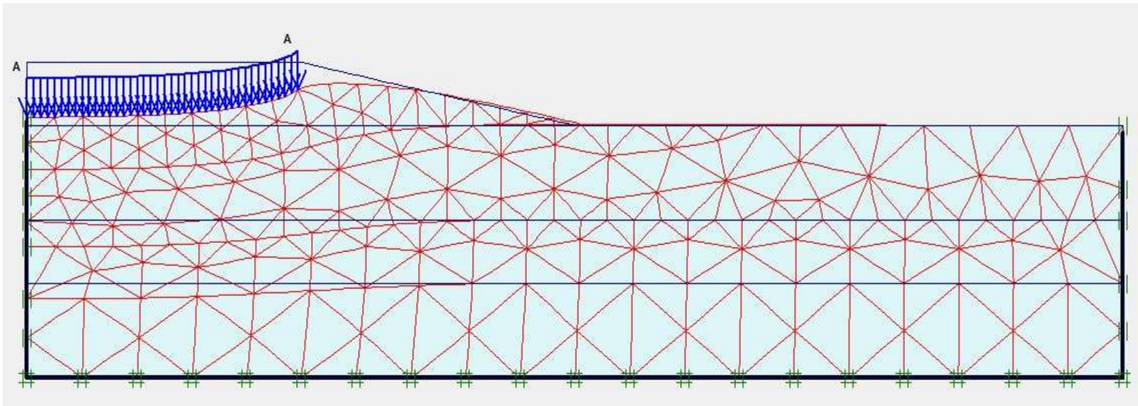


Figure 1 Model 1

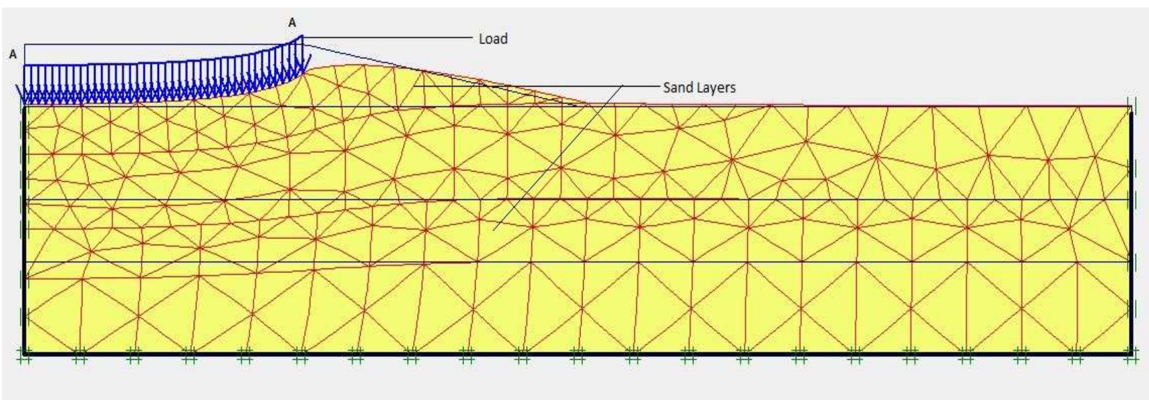


Figure 2 Model 2

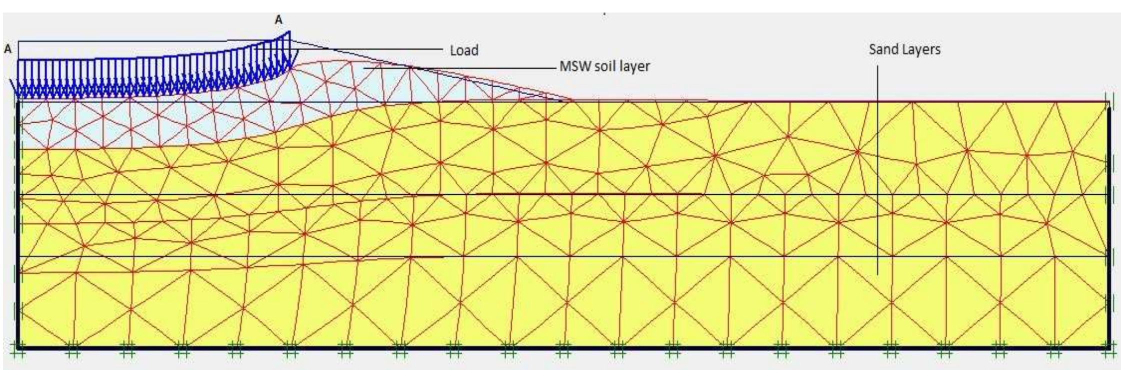


Figure 3 Model 3

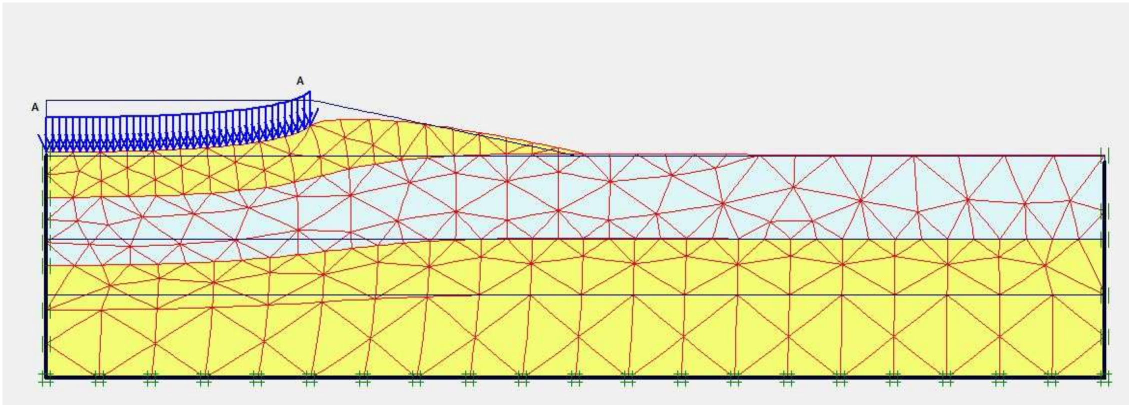


Figure 4 Model 4

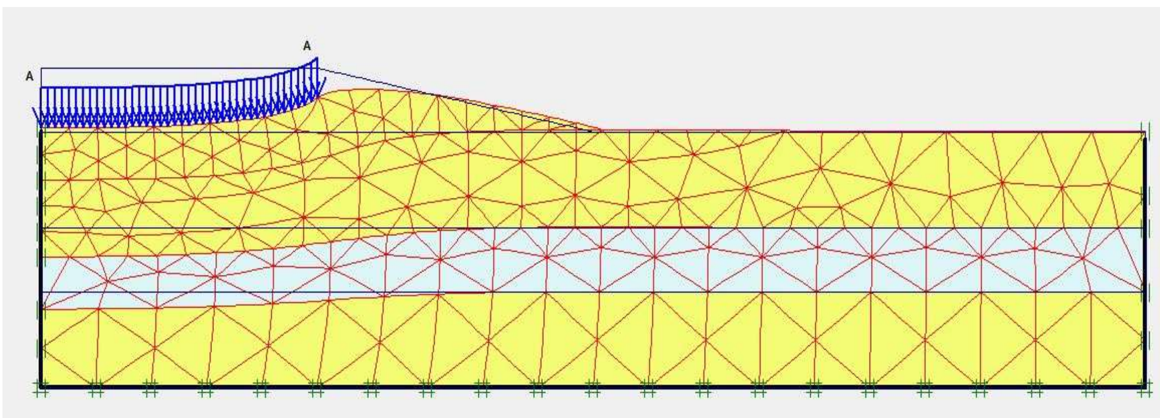


Figure 5 Model 5

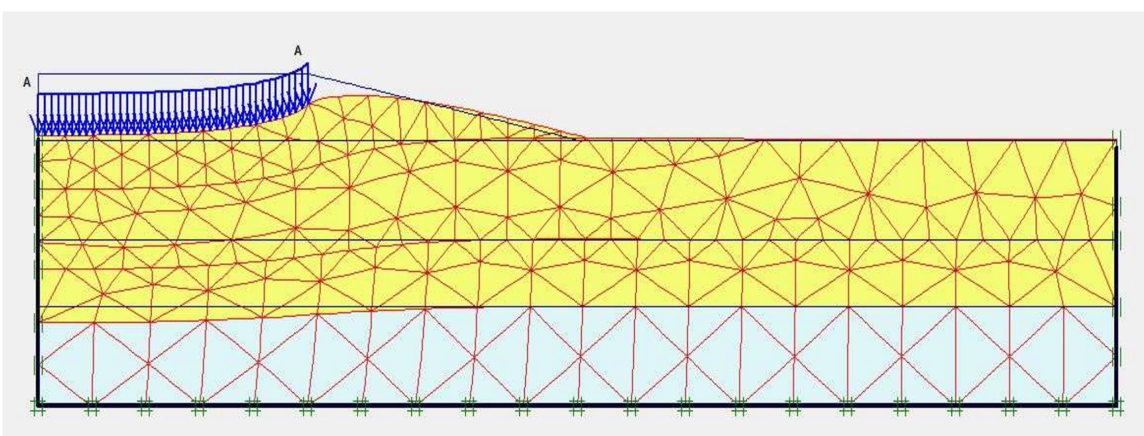


Figure 6 Model 6