PREDICTION OF STABILITY ANALYSIS OF A LANDFILL DESIGNED ON A PROPOSED AREA

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

MASTER OF TECHNOLOGY
in
CIVIL ENGINEERING

(With specialization in Geotechnical Engineering)

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CANDIDATE DECLARATION

I hereby declare that the work presented in this report entitled PREDICTION OF STABILITY ANALYSIS OF A LANDFILL DESIGNED ON A PROPOSED AREA, in the partial fulfilment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science and Technology University, is a work carried out in the said college under the supervision of Dr. Abinash Mahanta, Associate Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati- 13, Assam. Whatever I have presented in this report has not been submitted by me for the award of any other degree or diploma.

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ABSTRACT

The main focus of this study is to predict slope stability analysis in Noonmati-Choonsali area using Grid and Radius Analysis Method of the SlopeW software, evaluating the Factor of Safety (FoS) under dry and wet conditions including seismic loading conditions.

The proposed landfill, covering an area of 110,879.96 m^2, will accommodate a waste generation rate of approximately 1.29 million tonnes annually, with a waste density of 312 kg/m^3, ensuring a waste height of 3.75 meters. The landfill is designed to cater to the waste disposal demands of Guwahati City until the year 2050. Furthermore, the site's topographical advantages—its elevation and proximity to major urban centre ensures operational efficiency and minimize environmental risks such as flooding or contamination of groundwater. This research also adds advantages of the proposed site, ensuring minimal disruption to local ecosystems and communities.

List of Figures

List of Table

Table of Contents

CHAPTER 1

1 INTRODUCTION

1.1 Overview

The management of solid waste has become an increasingly pressing issue, driven by the multifaceted forces of economic development, globalization, urbanization, and industrialization. These transformations have led to a significant increase in the quantity and complexity of the waste generated, posing substantial challenges to environmental and public health. (Manaf et al., 2009) (Vishwanath & Bhargava, 2020). The world is currently undergoing rapid urbanization, with an unprecedented rate of population growth in cities. This influx of people, coupled with changes in lifestyle and the advent of new technologies and industries, has resulted in a radical shift in both the quantity and quality of solid waste produced. (Vishwanath & Bhargava, 2020) These wastes have become more hazardous to the environment, necessitating the implementation of careful disposal practices. Recognizing the critical importance of a clean environment to human health and progress, societies are now more sensitive to the need for effective solid waste management. However, managing urban solid waste is a complex task, often hampered by limited resources and capacity of local authorities. (Vishwanath & Bhargava, 2020) Effective waste management strategies must take into account local waste characteristics, which vary with cultural, climatic, and socioeconomic factors, as well as the institutional capacity of the governing bodies. (Vergara & Tchobanoglous, 2012). Globally, the waste management landscape is becoming increasingly regionalized and formalized, with industrialized nations generally managing waste at a municipal or regional scale.

In India, the per capita waste generation is projected to increase at an annual rate of 1% to 1.33% (Shekdar, 1999). Figure 1 illustrates the projected growth in municipal solid waste from 1997 to 2047 under the BAU scenario. This projection is based on the assumption that daily per capita waste generation in 1995 was 0.456 kg (EPTRI, 1995), with an annual per capita increase of 1.33%. By 1997, the calculated daily per capita waste generation was 0.468 kg.

As shown in Figure 1, the total amount of waste generated by 2047 is expected to exceed 260 million tonnes, representing more than a fivefold increase compared to the current levels. This dramatic rise in solid waste generation will have substantial implications, particularly in terms of the land required for waste disposal and the associated increase in methane emissions.

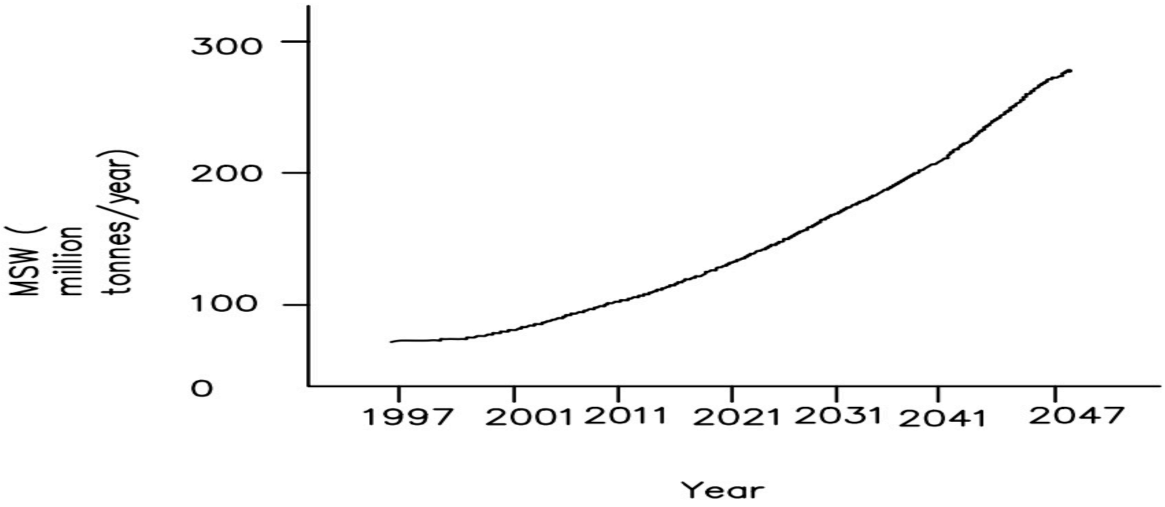


Figure 1: Projected trends in Municipal Waste generation in India by 2047 according to BAU Scenario (Singhal and Pandey, 2001)

Landfills have been a prominent method of waste disposal for centuries, with the earliest known records dating back to the Minoan civilization in Crete, Greece, where municipal solid waste from the capital Knossos was placed in large pits and covered with layers of earth (Allen, 2001). As industrialization progressed, various types of containment facilities were constructed to retain raw materials and waste products, often without proper design considerations or lining to prevent environmental contamination. (Shankar & Muthukumar, 2017)

The concept of designing landfills to protect groundwater and the surrounding environment gained traction in the 1960s and 1970s, leading to the development of "Engineered Landfills" that utilized geosynthetics to contain and isolate waste (Shankar & Muthukumar, 2017). The period from the 1970s to the 1990s saw significant advancements in landfill design, including the use of leachate treatment, recirculation, and bioreactor technology, as well as increased utilization of geosynthetics. (Shankar & Muthukumar, 2017)

The evolution of landfills has been driven by the need to address the environmental degradation and groundwater contamination caused by the decomposition of organic waste and leachate production.

CHAPTER 2

2. Literature Review

Guangyu and Yuan(2009), stated that the overflow of waste in the landfills could contribute to environmental problems such as water pollution, habitat destruction, and soil contamination due to its inorganic nature. The final disposal is being done by considering the wastes as waste and not as a resource.

Fobil et al.,(2005), proposed that sanitary landfills are designed especially to dispose of solid and non-hazardous waste, in which delivered wastes are placed with proper base cover and top cover with soil.

Gallardo et al.,(2012), stated that the base layer of the landfill must be designed with the impermeable layer. The liner protects the groundwater and soil from leachate. The landfill is covered at the top with clay and gravel to prevent leakage of water

Fatta et al.,(1999), concluded sanitary landfills prevent health problems and environmental hazards, but it incurs huge costs. Leachate generated from the waste migrates which contaminate the surface water and groundwater

Sornil and Warangkana(2014), stated that leachate generated due to the chemical and biological reactions between the different types of waste needs proper treatment before it is being disposed of

Mohamed et al.,(2009), stated that leachate generated from landfills consists of heavy metals such as Cu, Cd, Pb, Ni, and Zn which pollute the soils and the groundwater

Kale et al.,(2010), proposed that the factors such as type of waste, rainfall, landfill cover, climate, topography, vegetation, solid waste management and age of dumpsite practices, and dumpsite characteristics affect the leachate generation

Peter et al.,(2000), stated that to design a proper landfill depends on the location, geology, and hydrogeology of the site conditions. Proper landfill investigations regarding the composition of waste, characterization of waste enable to design of a site-specific landfill. Materials such as soils are required at all stages of landfill construction, development, restoration, and operation. The low hydraulic conductivity of natural clays, such as clayey silts, clays, and silty clays, have the potential to make good liners. He found that the hydraulic conductivity parameters which concern the design include particle size distribution, clay content, the degree of compaction (density), moisture content, and compaction method.

Parameswari and Mudgal(2014), stated that the topographical map or production of a digital terrain model should be undertaken to design a landfill. Contour maps are necessary to understand the topography of the terrain.

Wihan and Palm(2009), discussed that it is important to be aware that too wet soil may have too low strength with a greater shrinkage potential, while too dry soil may result in high hydraulic conductivity. The construction and design of a landfill depend on the location, potential environment, ground conditions, impacts, and the hydrogeology and geology of the site. The study states that the waste has to be dumped in a series of cells with optimal size. A maximum period of five years is required to design and construct new layers in the following cells

2.1 Engineered Landfill

An engineered landfill is a scientifically designed waste management facility that ensures safe and environmentally sustainable waste disposal. It consists of a well-structured system that includes impermeable liners to prevent leachate leakage, leachate collection systems, and landfill gas extraction systems to control harmful emissions. Engineered landfills are designed with proper waste compaction, daily covers, and drainage systems to reduce pollution risks. Additionally, they have environmental monitoring systems in place to track groundwater quality, gas emissions, and landfill stability over time.

Waste management is a critical aspect of environmental stewardship, and the distinction between a dumpsite and an engineered landfill is crucial in ensuring the safety and sustainability of waste disposal practices. In the developing world, open dumpsites and controlled landfills are often seen as the norm, with municipal administrators taking pride in the transformation of a dumpsite into a landfill that receives all urban garbage without any methane capture. (Fehr, 2012)

The life cycle of an engineered landfill involves several important stages to ensure environmental safety, effective waste management, and compliance with regulatory standards. These stages include:

a. Careful planning

Planning is the foundation of a successful landfill project. It involves the following key activities:

- Site Selection: Choosing a suitable location for the landfill is crucial. The area must be away from water bodies, residential zones, and areas prone to flooding or earthquakes.
- Environmental Impact Assessment (EIA): A thorough analysis of the environmental impact of the landfill on local ecosystems, wildlife, water sources, and air quality is conducted.
- Stakeholder Engagement: Engaging with local communities, government bodies, and environmental organizations ensures that the project is transparent and considers public concerns.

b. Study of the Landfill

A comprehensive study of the site involves:

- Geological and Hydrological Studies: Understanding the site's soil composition, groundwater flow, and geological stability is essential for preventing contamination of water sources.
- Topographical Studies: Detailed surveys of the land's elevation and drainage patterns help design a landfill that minimizes environmental risks.
- Waste Characterization: Determining the types of waste that will be disposed of in the landfill helps shape the design and containment strategies.

c. Design to Site the Landfill

The design phase ensures that the landfill will contain waste safely over time. This stage includes:

- Liner Systems: The design includes impermeable liners (usually made of clay and synthetic materials) to prevent leachate (contaminated water) from seeping into the ground and polluting groundwater.
- Leachate Collection Systems: Drainage systems are designed to collect leachate, which is treated to prevent contamination.
- Gas Collection Systems: Landfills produce gases like methane and carbon dioxide. A gas collection system is installed to capture these gases, which can be treated or used to generate energy.
- Stormwater Management: Systems are implemented to control stormwater and prevent it from entering the landfill and increasing leachate production.

d. Constant Monitoring, Testing, and Reporting

Once the landfill is operational, continuous monitoring and reporting are essential to ensure the landfill functions correctly and complies with regulations. This stage includes:

- Leachate Monitoring: Regular testing of leachate is done to ensure it is effectively collected and treated. Any abnormalities in the leachate can indicate liner failure or contamination.
- Groundwater Monitoring: Groundwater is regularly tested for contamination to ensure the landfill is not leaking harmful substances.
- Air Quality Monitoring: The surrounding air is monitored to detect any harmful emissions, particularly landfill gases like methane. This helps prevent air pollution and mitigate health risks.
- Landfill Stability Monitoring: The structural stability of the landfill is checked to ensure that the waste is compacted and that there is no risk of landslides or other structural failures.
- Reporting: Continuous reporting to environmental agencies and regulatory bodies is crucial to maintain transparency and ensure the landfill is compliant with environmental laws.

2.2 Important components of an engineered landfill

2.2.1 Leachate

Sanitary landfills have become the predominant means of managing municipal solid waste globally, particularly in developed countries, owing to the relatively low upfront costs associated with this approach (Saleem et al., 2017). However, the generation of leachate, a highly contaminated liquid by product of the decomposition of the waste, poses a significant environmental concern that must be addressed. (Saleem et al., 2017)

Leachate is formed when water, such as rainfall or groundwater, percolates through the solid waste deposited in a landfill. Leachate can mitigate into underlying ground water and soil layers, resulting in contamination. Leachate can contain many different chemicals, depending on what is in the solid waste. If leachate flow is intercepted or impeded by a liner, then it should be removed from the landfill by use of a leachate collection system. Accurate estimation of leachate generation, a crucial aspect of landfill management, is essential for designing appropriate treatment and disposal systems (Manfredi & Christensen, 2008). One widely used tool for evaluating landfill leachate generation is the Hydrologic Evaluation of Landfill Performance model (Kai et al., 2018). The quality of leachate is dictated by the type waste. For MSW, Leachate quality is very much dictated by the type of waste.

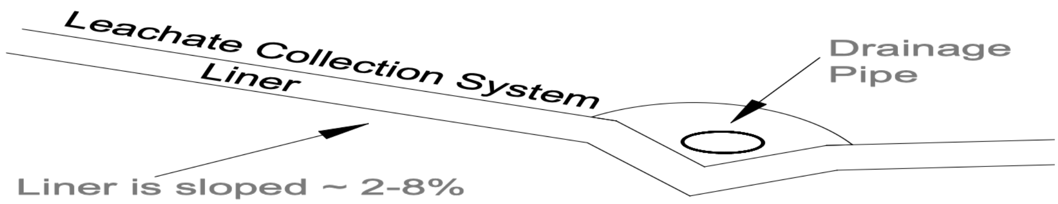


Figure 2:Diagrammatic cross-sectional view of Leachate Collection System

2.2.2 Landfill Gas

Landfill gas, a byproduct of the decomposition of organic matter within landfills, presents both significant environmental challenges and considerable untapped potential as an energy source. This gas, composed primarily of methane, carbon dioxide, and water vapor, is a major contributor to greenhouse gas emissions and can also pose hazards such as odors, toxic fumes, and the risk of explosions. (Amritha & Anilkumar, 2016)

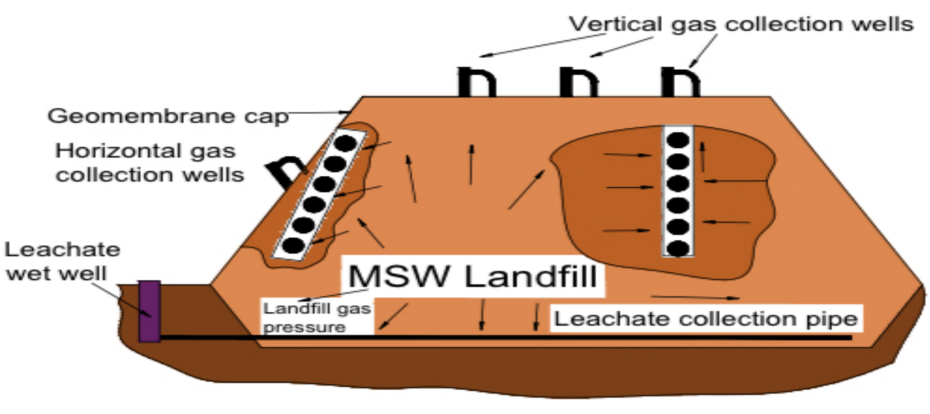


Figure 3:Landfill Gas Generation and Flow

2.2.2.1 Gas Collection

Gas Collection system typically uses Vertical Wells which are installed vertically after the landfill has reached its final grade. The gas comes out through the vertical wells due to the action of pressure, without any wells, gas will find its way to the surface or through bottom posing hazard to both atmosphere and soil. Wells provide path of escape through creating pressure gradient.

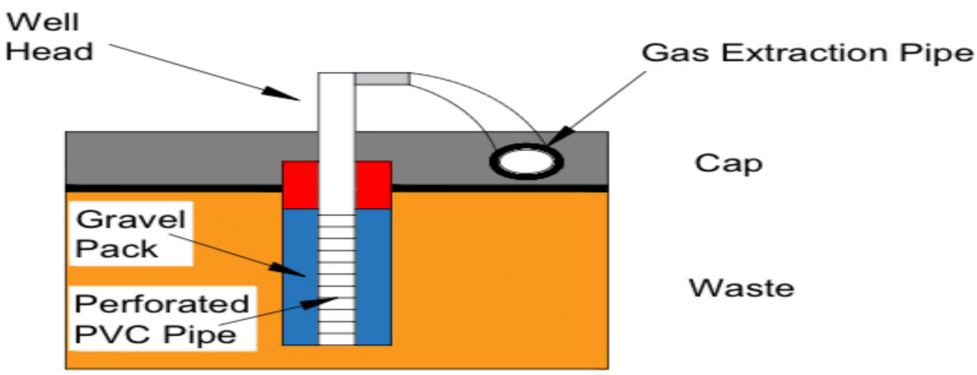


Figure 4:Vertical landfill gas well

2.2.3 Liner System

Liners are Low Permeable barrier layers which keep Leachate from migrating out of the landfill.

Liners are of various types, but typically contains two layers – Compacted soil (clay) and Geomembranes (plastic). The various types of liner system are:

1. Single Liner System: A liner consisting of only Compacted clay or Geomembrane. These are generally used in ponds, lakes etc.
2. Single Composite Liner System: This liner system consists of Compacted clay and geomembrane in immediate contact. Used in non-hazardous waste landfills.
3. Double Composite Liner System: A liner system with low permeability barrier layers which are used in case of Hazardous waste landfills, which consists of primary and secondary leachate collection system as well as primary and secondary composite barrier layers. The secondary leachate collection system is also called the Leakage detection layer

The requirements of Compacted Clay layer:
1. Permeability (hydraulic Conductivity) should be less than 10^{-9}m/s
2. Thickness should be about 100 cm or more
3. At least 3 to 4 layers of compacted clay, each 0.20 to 0.25 m thick, properly bonded.

4. There should be no lumps or clods in compacted clay.
5. No shrinkage or desiccation cracks.
6. Adequate strength.

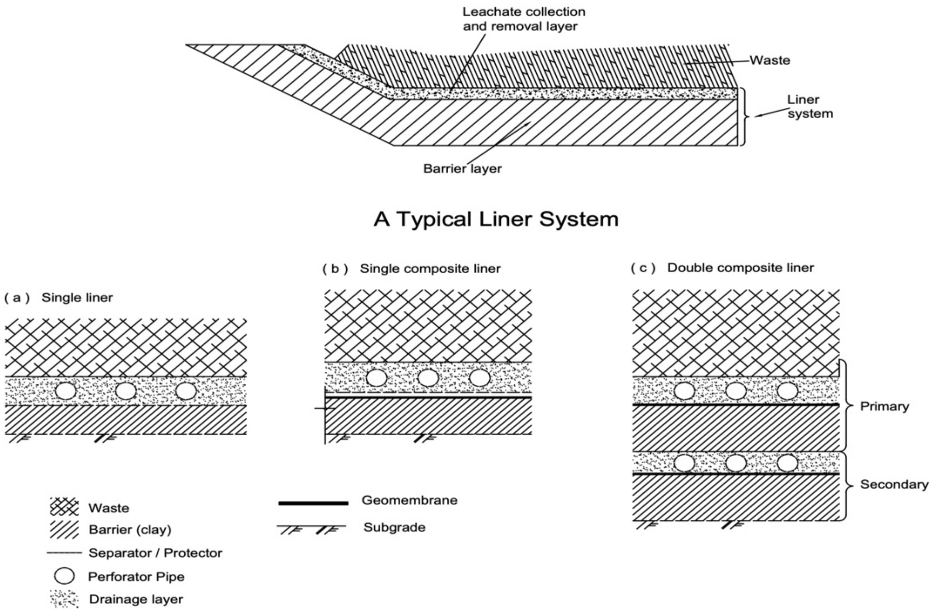


Figure 5:Different types of Liner system

Double Composite Liner system**:**
The Double liner system is generally preferred over single liner system, when:
1. The risk of leachate passing through is high, i.e., for hazardous Wastes over Municipal Solid Wastes.
2. When Water Table is shallow, as the leachate can easily reach and contaminate the water table. In this case, the Secondary Leachate Collection system helps in early determination of leakage.
3. When the sub soil is pervious.
4. When precipitation is high in the region.
5. When a drinking water source (wells or lake) is nearby.
6. When 100% leakage detection is required.

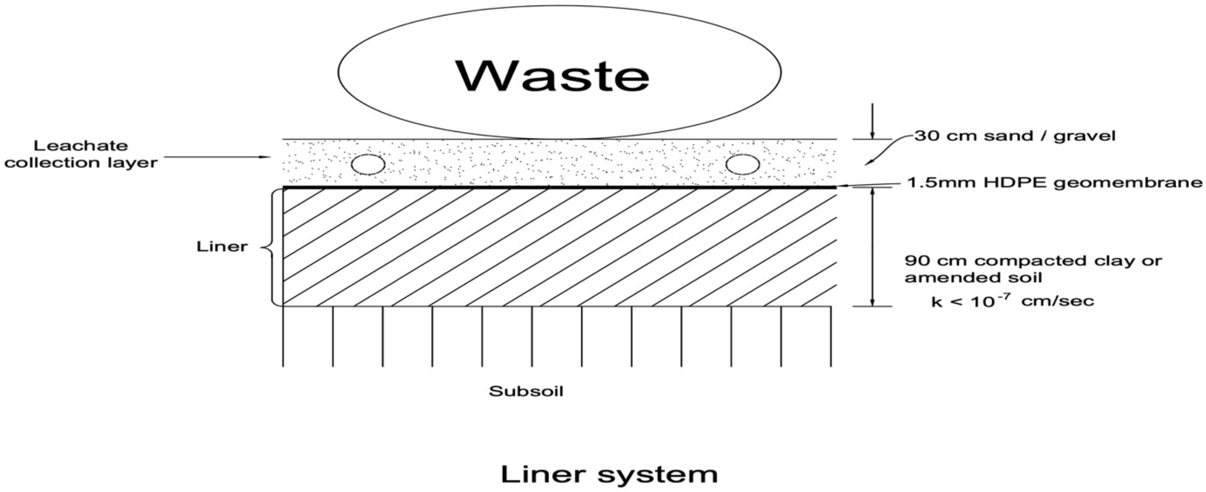


Figure 6:Composite Liner System

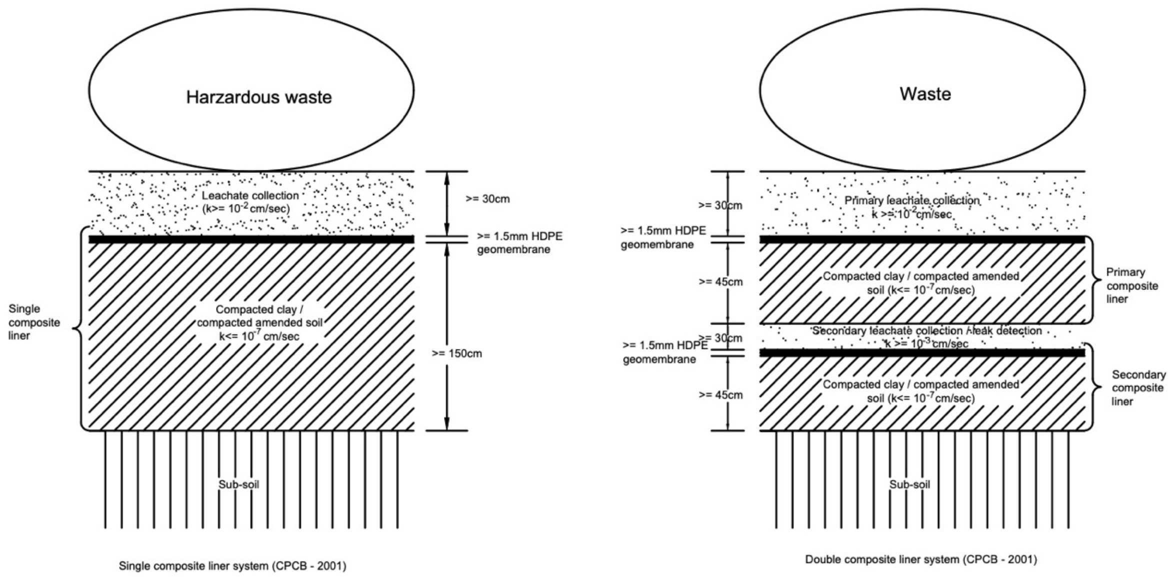


Figure 7:Single and Double Composite Liner System

2.2.4 Geomembrane

A Geomembrane layer is a synthetic barrier made from polymeric A geomembrane liner is a synthetic barrier made from polymeric materials such as High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), or Ethylene Propylene Diene Monomer (EPDM). It is engineered to provide an impermeable barrier against fluid and gas migration.

Functions of Geomembrane Layer:
1. Primary Barrier: It acts as the first layer of defence preventing leachate from seeping into the

surrounding soil and groundwater.
2. Gas Containment: It traps landfill gases such as methane, allowing for controlled collection or flaring.
3. Chemical Resistance: Resists chemical reactions caused by hazardous waste components.
4. Mechanical Protection: Provides durability against tears, punctures, and mechanical stresses from waste deposition.
Significance: The Geomembrane liner is essential because of its high impermeability and long-
term durability, making it a crucial layer in preventing environmental contamination. Its ability to contain both liquids and gases ensures compliance with environmental regulation and promotes sustainable waste management practices.

2.2.5 Compacted Clay Layer (CCL)

A Compacted Clay Layer (CCL) is constructed by compacting layers of natural clay material to achieve low permeability. Its thickness ranges from 0.6m to 1m depending on regulatory requirements.

Functions of Compacted Clay Liner:
1. Secondary Barrier: Serves as a backup in case the geomembrane is punctured or damaged.
2. Leachate Containment: Minimizes leachate migration due to its low permeability.
3. Structural Support: Provides a stable foundation for the waste mass and geomembrane.
4. Chemical Buffering: Absorbs and neutralizes some hazardous chemicals present in the leachate
Significance: The compacted clay liner is critical because of its ability to self-heal minor cracks through swelling properties when exposed to moisture. This property enhances the system's long- term reliability, ensuring continuous environmental protection.

2.2.5.1 Combined Functionality in a Composite Liner System

When geomembrane liners and compacted clay liners are used together, they form a composite liner system with enhanced protection. The geomembrane provides a highly impermeable barrier, while the clay liner offers chemical buffering and backup containment. This combination helps ensure redundant environmental safety, making engineered landfills more reliable and reducing the risk of groundwater contamination and air pollution.
By integrating both liners, modern engineered landfills comply with international waste management standards, ensuring sustainable waste disposal and long-term environmental conservation.

2.3 Importance of Engineered Landfills in Hilly Regions

In the context of waste management, Engineered Landfills have become a crucial part of sustainable waste disposal systems. In hilly regions, their importance is even more pronounced due to the complex interplay between environmental factors, topography and population pressures. These regions present unique challenges, but engineered landfills offer solution that balance effective waste management with environmental protection. A close look at these factors reveals the need for specially designed landfills for the following reasons:

2.3.1 Classification of Plain Land in Hilly regions

One of the most significant challenges in Hilly regions is the scarcity of flat land. In mountainous areas, the availability of large, flat areas suitable for urban development, agriculture or industrial use is limited. The topography of hilly regions is characterised by steep slopes, uneven terrain, and narrow valleys, which make it difficult to find suitable areas for residential, commercial, or industrial development. As a result, the scarcity of plain lands leads to intense competition for the available flat land. These areas are prioritized for high-value activities such as:

a) Residential Development: As urbanisation spreads, there is an increasing demand for housing, flat lands are developed for building homes, which can accommodate growing population in these regions.

b) Commercial and industrial use: Flat lands are also critical for establishing businesses, factories, and infrastructure projects, which require large, level spaces to support heavy machinery, transportation networks, and economic activities.

c) Agriculture: Arable land is essential for farming, and flat lands are typically used for cultivating crops. In regions with steep slopes, agricultural activities may be limited or less productive, making the available flat land even more valuable.

Given these competing demands for land, it becomes clear that hilly regions have limited capacity to accommodate waste disposal facilities in the form of traditional landfills. As a result, innovative solutions are required to utilize the steep hill slopes and transform them into viable sites for engineered landfills.

2.3.2 Utilising Steep Slopes for Landfills: A Necessary Solution

Given the shortage of flat land in hilly regions and the high demand for it for other uses, it is essential that hill slopes be considered for landfill development. The design of engineered landfills on steep slopes involves a thorough understanding of the geotechnical properties of the soil, the seismic risk, and the hydrological conditions.

The design process includes stabilizing the slope to prevent landslides, ensuring that the landfill structure can withstand the pressures of waste accumulation, and implementing advanced technologies to monitor and manage the site over time. Reinforcement techniques, such as the use of soil nails, geogrids, and retaining walls, are essential to ensuring that these landfills do not pose risks to the surrounding environment. In addition, the waste placement and compaction techniques must be carefully planned to minimize settlement and maximize the capacity of the landfill.

In conclusion, engineered landfills in hilly regions are of paramount importance. Not only do they provide an effective and environmentally responsible means of waste disposal, but they also make optimal use of limited flat land by utilizing steep slopes. With proper design, monitoring and management, engineered landfills can help mitigate the environmental impacts of waste while supporting the economic and residential needs of the region.

2.4 Design Philosophy

The Limit State Method (LSM) in the analysis of the Factor of Safety (FoS) in SlopeW software is used to evaluate the stability of slopes by assessing whether the slope meets specific safety criteria under various loading conditions. This method ensures that the design remains safe, economical, and functional throughout its expected life span.

Key Uses of the Limit State Method in SlopeW Analysis:
1. Determining Factor of Safety (FoS): The LSM helps calculate the Factor of Safety by calculating both Ultimate Limit State (ULS) and serviceability limit state (SLS) condition.ULS ensures that the slope does not collapse under extreme conditions like heavy rainfall, earthquakes, or increased loading. SLS ensures that the slope doesn't experience unacceptable deformations or settlements under normal operating conditions.
2. Analysing Failure mechanisms: This method helps identify potential failure surfaces and critical slip surfaces in slopes by evaluating multiple trial surfaces. SlopeW uses the strength reduction technique, adjusting soil shear strength parameters (cohesion c and friction angle φ) to find limiting equilibrium state.
3. Incorporating safety margins: By considering partial factors of safety for different material properties (soil strength, load, and water pressure), the method ensures that design parameters account for uncertainties in material behaviour. This ensures a more reliable design with appropriate safety buffers.
4. Design Optimisation: LSM allows for design optimisation by adjusting slope geometry, reinforcement systems (geotextiles or anchors), and drainage solutions. Engineers can compare different design scenarios to find the most cost effective and safe design.
5. Seismic and environmental conditions: In hilly terrains or engineered landfills, seismic forces can be applied using LSM to assess the slope's stability during earthquakes. Environmental factors such as fluctuating groundwater levels, rainfall infiltration and surface loading can also be included for realistic modelling.
6. Risk and Reliability Analysis: Since LSM involves probabilistic analysis, it helps assess the likelihood of slope failure under varying conditions, providing risk assessments and decision-making support for sustainable designs.

2.4.1 About SlopeW

SlopeW is a geotechnical software used for analysing the stability of slopes, embankments, excavations, and engineered landfills. It uses various limit equilibrium methods such as Bishop's Simplified Method, Grid, and Morgenstern-Price Method to compute the Factor of Safety (FoS) against potential slope failure. The software allows for modelling complex slopes by considering factors like soil properties, loading conditions, water pressure, and seismic forces.

SlopeW is widely used in civil and geotechnical engineering due to its user-friendly interface, versatile analysis methods, and advanced modelling features. It helps design stable landfills, retaining walls, and other earth structures by evaluating critical failure surfaces and determining the most stable configuration.

2.4.2 Grid and Radius Analysis in SlopeW

Grid and Radius Analysis is one of the primary search techniques used in SlopeW to identify the most critical failure surface within a slope. This method systematically searches for potential slip surfaces by generating multiple circular failure surfaces using a grid of centres and radii.

2.4.2.1 How Grid and Radius Analysis Works

1. Grid Generation: A grid of potential centre points is generated within a defined area, typically inside or near the slope. These points represent the centres of the circular slip surfaces to be analysed.
2. Radius Selection: A range of radii is specified for the failure surfaces originating from each centre point. The software draws potential slip surfaces from these points using the defined radii.
3. Slip Surface Calculation: For each generated circular slip surface, the software calculates the Factor of Safety (FoS) using selected limit equilibrium methods. SlopeW evaluates thousands of potential slip surfaces through this method.
4. Critical Surface Identification: The software identifies the critical slip surface, which is the surface with the lowest Factor of Safety, indicating the most likely failure mode.

2.4.3 About ArcGIS

ArcGIS, developed by Esri, is a powerful Geographic Information System (GIS) software widely utilized for spatial analysis, mapping, and geospatial data management. Understanding the basics of ArcGIS is foundational for integrating geospatial technology into landslide susceptibility mapping.

2.4.3.1 Introduction to Key Terms

A. Vector Data

In the realm of ArcGIS, spatial data is categorized into two main types: vector and raster. Vector data represents geographic features using points, lines, and polygons. Points denote specific locations, lines represent linear features, and polygons enclose areas. This format is highly suitable for representing discrete features, such as roads, rivers, or administrative boundaries. Vector data maintains precision in representing the spatial relationships between features.

B. Raster Data

Contrasting with vector data, raster data employs a grid of cells to represent geographic features. Each cell in the grid contains a value, creating a pixelated representation of the landscape. This format is ideal for continuous data, such as elevation or temperature, where values change gradually across space. Raster data is efficient for large-scale mapping and spatial analysis, providing a different perspective on geographic phenomena.

C. Shapefile

A fundamental concept in ArcGIS is the shapefile, a common geospatial vector data format. A shapefile comprises multiple files that collectively store geometric and attribute information. Geometric data includes points, lines, or polygons defining spatial features, while attribute data provides additional information related to these features. Shapefiles are versatile and widely used for storing and sharing geographic information due to their simplicity and compatibility with various GIS applications.

D. Thematic Maps

Thematic maps are graphical representations of spatial data that highlight and illustrate a specific theme, variable, or attribute across a geographic area. The primary purpose of thematic maps is to visually communicate spatial patterns and relationships of a chosen theme, facilitating a better understanding of geographic phenomena.

2.4.4 Types of Slope Instability in Landfill

Slope instability in landfills refers to the failure of waste or soil slopes due to gravitational forces, poor design, or external factors such as rainfall and seismic activity. In engineered landfills, ensuring slope stability is essential to avoid environmental hazards like leachate leakage and gas emissions. The primary types of slope instability encountered in landfills are as follows:

2.4.4.1 Partial Slope Failure

Partial slope failure occurs within the landfill slope itself, typically in localized areas. It results from the accumulation of waste, changes in waste composition, and environmental factors such as heavy rainfall or earthquakes. This type of failure is generally surface-level and may cause localized deformations but does not compromise the entire landfill system.

2.4.4.1.1 Causes:

a. Waste settlement due to decomposition
b. Overloading due to excess waste deposition
c. Inadequate compaction of waste materials.
d. Rainfall Infiltration: Water increases pore pressure, reducing shear strength.
e. Seismic Activity: Earthquakes induce vibrations that destabilise the waste mass.

2.4.4.1.2 Preventive Measures:

a. Proper waste compaction and layering
b. Regular slope stability monitoring
c. Installations of surface drainage systems.

2.4.4.2 Sliding Failure along the Liner System

Sliding failure occurs along the weakest layer within the landfill, usually the interface between the geomembrane liner and the compacted clay liner (CCL). This is considered a deep-seated failure, which can cause large-scale instability, resulting in major environmental risks due to potential leachate leakage and gas release.

2.4.4.2.1 Causes:

a. Shear Failure: Due to inadequate bonding between the liner layers and the waste layer
b. Excessive Stress: From the load of accumulated waste.
c. Seepage forces: Caused by water infiltration an hydraulic pressure.

2.4.4.2.2 Preventive Measures:

a. Using High Friction geomembranes to improve inter layer stability.
b. Ensuring proper compaction of waste and liners.
c. Installing drainage layers to reduce seepage forces.

2.5.4 Factor of Safety (FoS) in Landfill Slope Stability

The Factor of Safety (FoS) is a critical measure used in slope stability analysis for engineered landfills. It represents the ratio of resisting forces (shear strength of the soil/liner) to driving forces (stress caused by waste load, seepage, and external factors like earthquakes.
Recommended FoS values for Engineered Landfills:

- **Under Static Condition (Normal Operation): FoS ≥ 1.5**

This value ensures long term stability under normal loading conditions, including the self-weight of waste, compaction equipment and leachate build up.

- **During Seismic Events (Earthquake conditions): FoS ≥ 1.2**

A lower FoS is acceptable during seismic activity because momentary dynamic forces are considered. However, proper design measures like reinforcement or geogrid installation are recommended.

- **During Wet Condition: FoS ≥ 1.3**

By maintaining a sufficient FoS, designers can ensure the engineered landfill's stability, even in challenging terrains like hilly regions. Regular monitoring and geotechnical evaluations are essential to adjust design parameters as needed.

2.4.5 Steps to Increase Factor of Safety

When the Factor of Safety (FoS) is found to be less than 1.1, the slope is considered unstable, posing a high risk of failure. Corrective actions should be taken immediately to enhance slope stability and ensure environmental safety. The following steps can be implemented:

A. Redesign Slope Geometry

• Reduce Slope Angle: Flatten the slope to decrease driving forces.

• Reduce Slope Height: Lower the height of the waste mass to minimize load-induced stresses.

• Bench the Slope: Introduce benches or terraces to interrupt sliding surfaces.

B. Improve the Liner and Foundation System

• Reinforce the Liner System: Use geosynthetic reinforcement such as geogrids, geotextiles, or geomembranes to increase shear resistance.

• Stabilize the Foundation Soil: Perform soil stabilization using methods like lime or cement treatment, or install stone columns or piles.

C. Drainage and Water Management

• Install Surface Drainage: Prevent surface runoff from infiltrating the waste mass.14

• Leachate Control System: Upgrade or repair leachate collection systems to reduce pore pressure.

• Seepage Barriers: Use cut-off walls or slurry walls to prevent seepage into weak layers

D. Stabilisation:

Stabilization Using Fill Materials: Place temporary counterweight fills or sandbags at the toe of the slope.

CHAPTER 3

3 Research Method

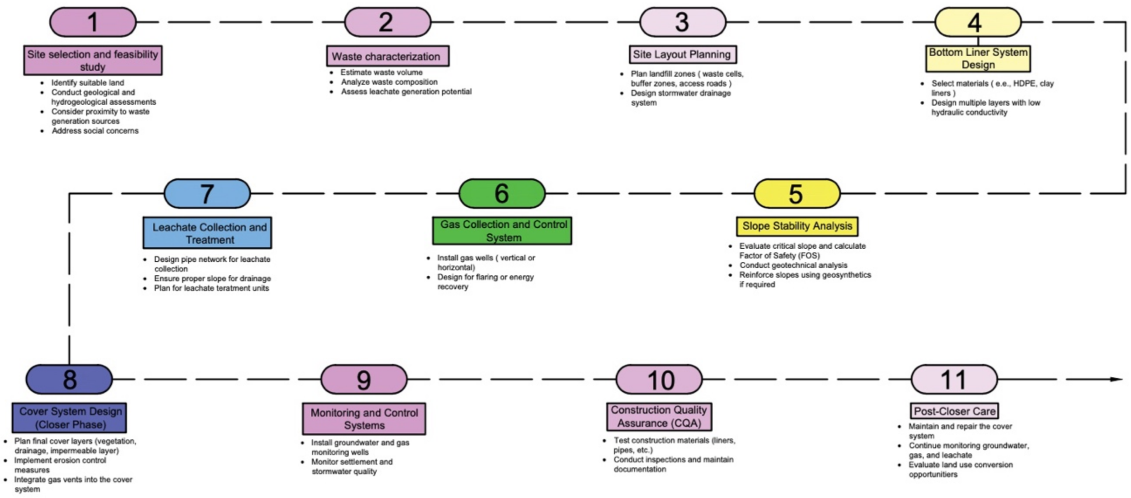


Figure 8:Methodology for designing an Engineered Landfill

1. Site Selection and Feasibility Study
The first step in designing an engineering landfill is selecting a suitable site through detailed feasibility studies. This involves evaluating factors like proximity to waste generation sources, accessibility via roads or railways, and the avoidance of environmentally sensitive areas such as wetlands, flood zones, or aquifers. Soil conditions, geology, and hydrology are also assessed to ensure the site is structurally and environmentally viable. The outcome of this phase is a comprehensive feasibility report that establishes the site's potential for landfill development.

2. Waste Characterization
Understanding the nature and composition of waste is critical for designing a landfill. This process includes analysing the physical, chemical, and biological properties of the waste, such as moisture content, biodegradability, and the presence of hazardous materials. Proper waste characterization helps determine landfill capacity, environmental risks, and the necessary engineering systems for waste containment and treatment, ensuring compliance with environmental regulations.

3. Site Layout Planning
Effective site layout planning optimizes land use and ensures operational efficiency. This step involves designing the arrangement of waste disposal cells, buffer zones, and access roads. It also includes planning for stormwater drainage systems and locating operational facilities like offices and treatment plants. A well-designed site layout minimizes environmental impact, facilitates ease of operation, and maximizes the landfill's lifespan.

4. Bottom Liner System Design
The bottom liner system is designed to prevent leachate from contaminating groundwater. It typically consists of a composite system with a compacted clay layer and a synthetic geomembrane, along with drainage layers to collect and transport leachate. This design ensures a robust barrier between the waste and the surrounding environment, meeting regulatory standards for environmental protection.

5. Slope Stability Analysis
Slope stability analysis ensures the structural integrity of the landfill by assessing the stability of its slopes under varying conditions. This process involves identifying the critical slope, which is the most vulnerable area to potential failure, and evaluating the Factor of Safety (FoS). The FoS is calculated by comparing the resisting forces (soil strength and slope design) against driving forces (waste load, water pressure, and seismic activity). This analysis minimizes risks of landslides and ensures long-term safety and functionality.

6. Gas Collection and Control System
Landfills generate gases such as methane and carbon dioxide, which need to be managed to prevent environmental harm. A gas collection and control system include the installation of gas wells and pipes within the waste layers to collect and transport landfill gas. This gas is either flared or used in energy recovery systems, reducing greenhouse gas emissions and offering a sustainable energy source.

7. Leachate Collection and Treatment
Leachate management involves designing systems to collect and treat the liquid waste generated within the landfill. This is achieved using perforated pipes and gravel layers to collect leachate, which is then treated in facilities such as aeration lagoons or reverse osmosis units. Proper leachate management protects groundwater and surface water from contamination and ensures compliance with environmental standards.

8. Cover System Design (Closure Phase)
When a landfill reaches capacity, a cover system is installed to seal the site and prevent environmental impacts. This includes a final cover layer made of clay or a geomembrane to prevent water infiltration, along with a vegetative cover to reduce erosion and improve aesthetics.
A well-designed cover system ensures the landfill remains stable and environmentally secure during the post-closure phase.

9. Monitoring and Control Systems
Continuous monitoring and control systems are implemented to track the landfill's environmental performance. These systems include groundwater and gas monitoring wells, settlement markers, and surface water testing. Regular monitoring helps detect potential issues early, allowing for timely corrective actions and ensuring long-term compliance with environmental standards.

10. Construction Quality Assurance (CQA)
CQA ensures that all construction activities meet design specifications and regulatory standards. Regular inspections, material testing, and documentation are conducted throughout the construction phase. This step verifies that components like liners, pipes, and drainage systems are installed correctly, ensuring the landfill's performance and longevity

11. Post-Closure Care
Post-closure care involves maintaining the landfill site after its closure to ensure long-term stability and environmental safety. Activities include periodic inspections, repairs to the cover system, and continuous monitoring of leachate, gas, and groundwater. Additionally, strategies for land reuse are explored, such as converting the site into green spaces, ensuring the landfill remains safe and sustainable over time.

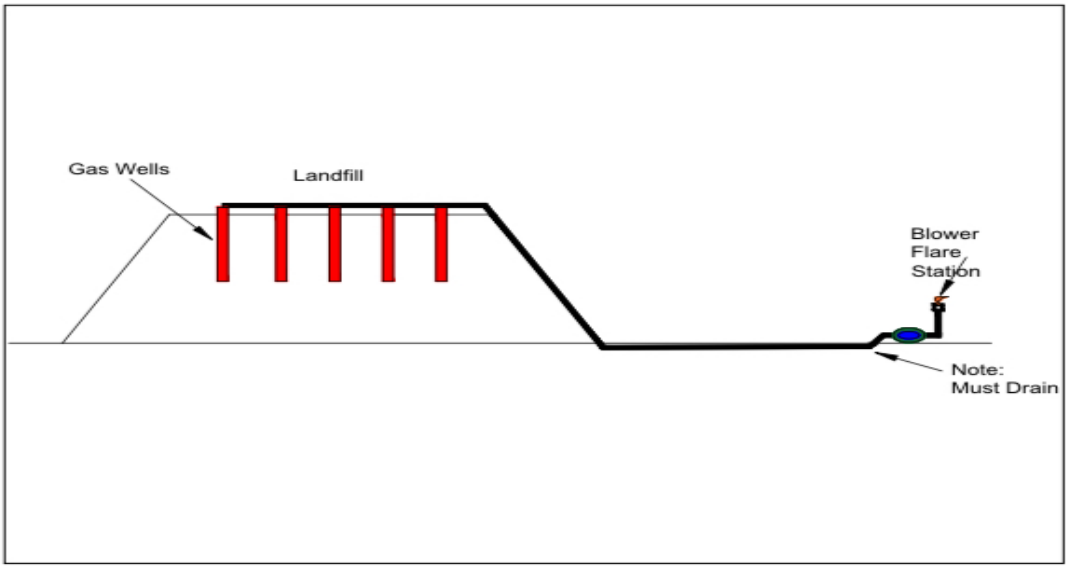


Figure 9:Process of extraction of landfill gas

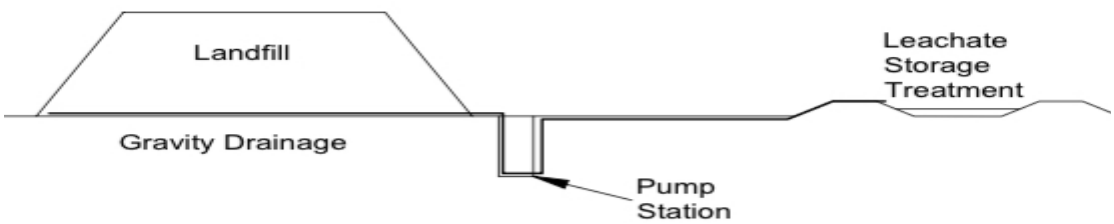


Figure 10:Leachate storage treatment facility

CHAPTER 4

4 CASE STUDY

4.1 About the site

For our design and analysis, we selected the proposed site of the Noonmati-Choonsali area. This location was chosen due to its favourable environmental conditions, as it is free from any nearby wetlands, minimizing the risk of ecological disruption. Additionally, the human population in the vicinity is relatively sparse, which reduces the potential for negative impacts on local communities and makes the site more suitable for the development of a controlled and well-managed engineered landfill. Moreover, the site is well-connected by a network of roads, providing easy access for transportation and logistics, which is critical for the efficient movement of waste and construction materials during the landfill's development and operation. These factors collectively make Noonmati-Choonsali an ideal site for our project.

4.2 Location

The proposed landfill site is strategically located approximately 11-13 kms from Dispur, making it a feasible option for waste management logistics within the region. Its proximity to the state capital ensures that transportation of waste materials will be efficient, without imposing excessive strain on travel times or increasing carbon emissions associated with long-distance hauling. Additionally, the region’s infrastructure supports this setup, as the road networks connecting the site to nearby urban areas are well-developed, ensuring smooth access for the movement of waste collection vehicles and other operational machinery.

Geographically, the proposed site sits at a mean sea level (MSL) of around 139 meters, which places it at an elevation that reduces the risk of flooding, a critical consideration in landfill design. This elevation is particularly advantageous given the site's geographical location in a region that can experience significant rainfall. Proper drainage systems and stormwater management will further ensure that the site remains safe from potential flooding issues.

The exact coordinates of the landfill site are approximately 26°12'01.89" N latitude and 91°48'28.16" E longitude. These coordinates place the site within the Noonmati-Choonsali area, which is geographically suitable due to the absence of ecologically sensitive areas such as wetlands, reducing the potential environmental impact. The latitude and longitude provide a clear reference for precise location mapping, essential for detailed planning and the integration of Geographic Information Systems (GIS) into the design and monitoring phases.

In sum, the combination of its ideal location—close to Dispur but with a sparse human population nearby—and its elevation, alongside its exact geographical positioning, makes this site a well-considered choice for the development of an engineered landfill. The site’s attributes will facilitate efficient waste management operations while minimizing environmental risks.

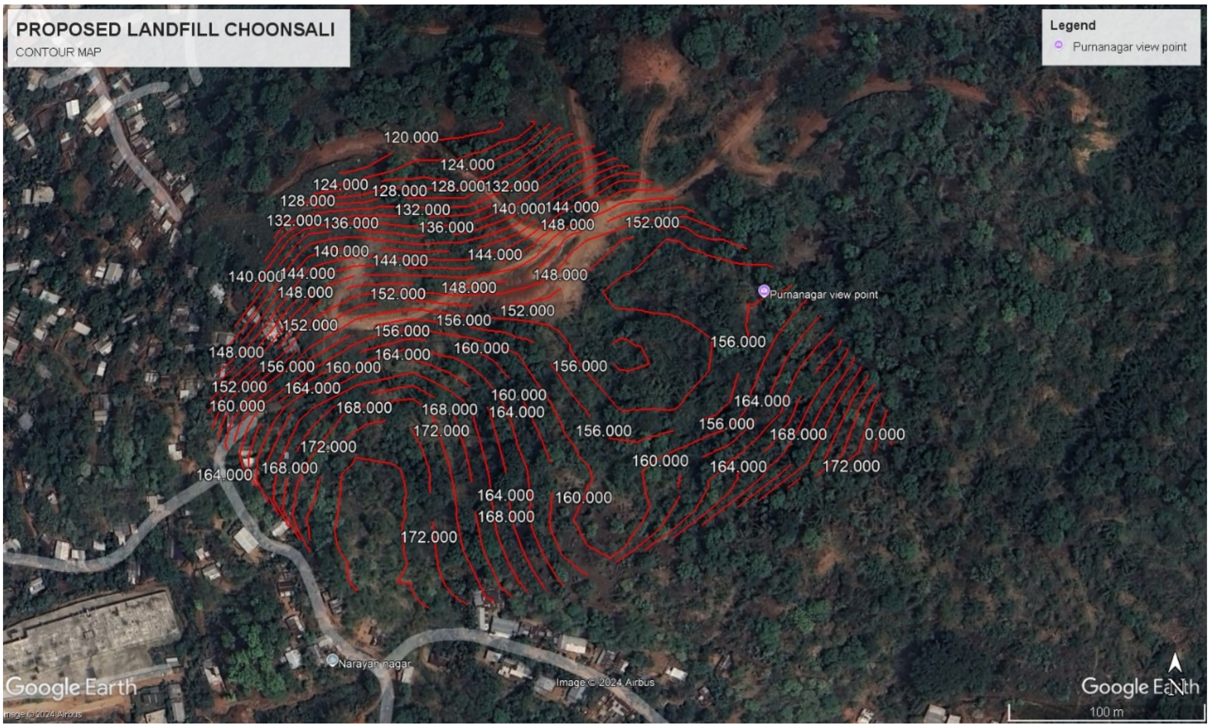


Figure 11: Proposed landfill site of Noonmati-Choonsali area

4.3 Advantages

The advantages of this proposed area are as follows:

- **Proximity to Dispur**: Located approximately 12-15 kms from Dispur, the site is close enough to the state capital for efficient waste transportation, reducing fuel costs and carbon emissions associated with long-distance waste hauling.

- **Sparse Human Population**: The surrounding area has a relatively low human population density, minimizing the risk of human exposure to landfill operations and reducing potential health and safety concerns for nearby residents.

- **No Wetlands Nearby**: The absence of wetlands in the vicinity significantly lowers the risk of contaminating ecologically sensitive areas. This reduces the environmental impact of landfill operations, particularly concerning water quality and habitat disruption.

- **No Flooding or Water Clogging**: Given the natural topography and drainage patterns of the area, the site is not prone to flooding or waterlogging. This is an essential advantage for maintaining operational efficiency and ensuring that leachate (liquid waste) is managed effectively without mixing with external water sources.

- **Potential for Future Expansion**: Due to the sparse population and availability of land, the proposed site offers potential for future expansion if needed. This provides long-term flexibility in waste management planning.

- **Lower Community Resistance**: Given its distance from densely populated areas and minimal environmental sensitivity, the site is less likely to face resistance from the local population, easing the approval and development process for the landfill.

4.4 Scope of work

The primary objective of this study is to analyse and design an engineered landfill in Noonmati-Choonsali hilly terrain, Guwahati, Assam. The study involves data collection, landfill design, and stability analysis using geotechnical principles and modern analytical tools like SlopeW. The entire process is structured into three major tasks:

A. Preliminary Data Collection

The first step in the study involves collecting essential site-specific data to create an accurate model of the proposed landfill. The data gathered includes:

- Area of the Site: The total land area available for landfill development.
- Perimeter of the Site: Measurement of the boundary surrounding the landfill area.
- Contour Data: Topographic data indicating elevation changes, necessary for designing slopes and drainage systems.
- Soil Data: the soil data of the proposed site is collected from DSMW (Digital Soil Map of the World)
- Section and slope analysis: Different sections are taken for analysis of slope stability to find the most appropriate slope.

These data points were obtained using Google Earth Pro, providing precise spatial and elevation information. The data serves as the foundation for developing the landfill design model.

B. Landfill Design

We consider the design of the engineered landfill for a design period of 25 years (2025-2050). For the design of the engineered landfill, the following steps are involved:

Waste Generation Estimation

• The waste generation rate per capita per year will be calculated based on projected population growth and per capita waste generation trends.19

• The total waste volume for the design period will be computed to determine the landfill's required capacity.

Landfill Dimensions

• Using the calculated waste volume, the landfill dimensions (area of the landfill, and height of waste) will be determined, considering operational aspects like compaction ratios, daily cover requirements, and leachate management systems.

Design Considerations
• Liner Systems: To prevent groundwater contamination.
• Drainage and Leachate Collection: To manage water infiltration.
• Gas Collection System: For methane and other gases generated during waste decomposition.

C. Slope Stability Analysis

To ensure the landfill's long-term stability, slope stability analysis will be conducted using SlopeW software. The analysis will consider section of the landfill to simulate landfill configurations in the terrain.

Analysis Method
• The Grid and Radius Method will be used to search for the most critical slip surfaces.
• Factor of Safety (FoS): The critical FoS for each section will be calculated to assess the stability of landfill slopes under static and seismic conditions.

Design Adjustments
• Based on the results, appropriate stabilization measures such as slope reinforcement, retaining walls, or drainage improvements will be suggested.

The study aims to produce a comprehensive design for a safe, environmentally sustainable, and operationally efficient engineered landfill in a hilly terrain. The findings will highlight the site's stability, identify potential failure zones, and suggest design improvements for long-term landfill performance.

CHAPTER 5

5 Preliminary Design Data

All the preliminary data collected for our project are taken from Google Earth software, including contours and sections and research papers for the material properties of the selected Noonmati-Choonsali hilly terrain area.

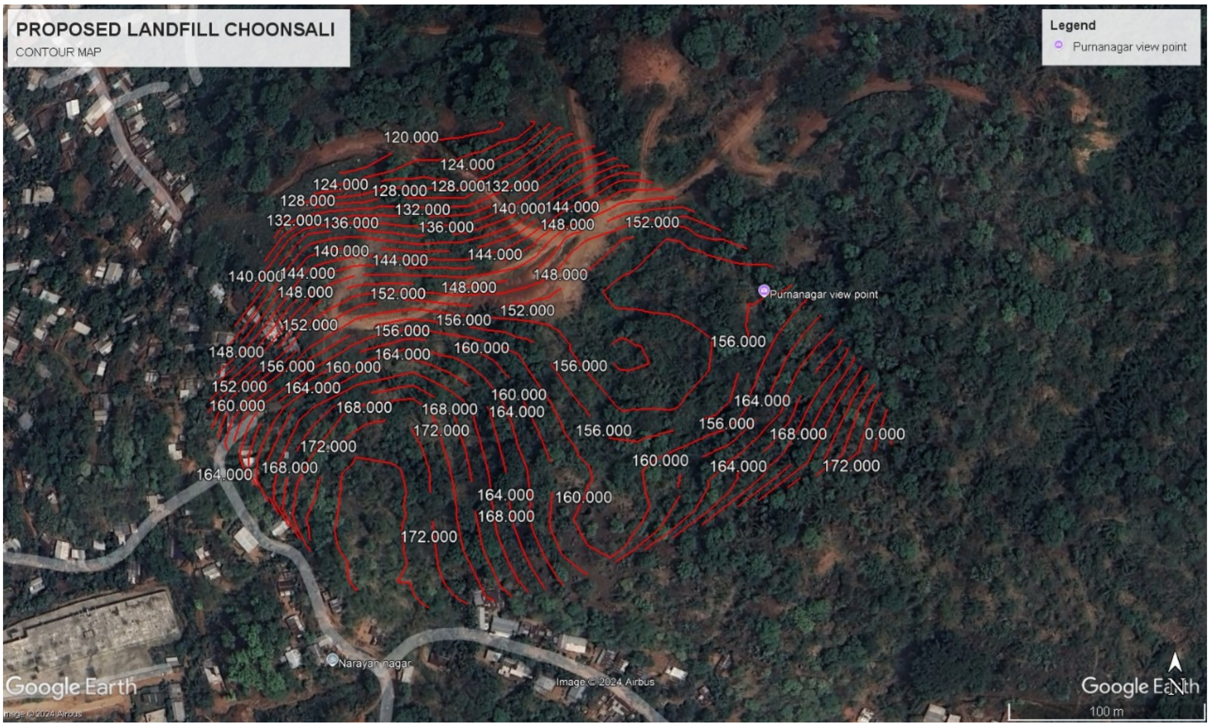


Figure 12:Contour Map

Chainage and elevation of the proposed site and we assumed that the total useable landfilling site is 1,10,879.96 m^2 considering future expansion of the area due to on going construction.

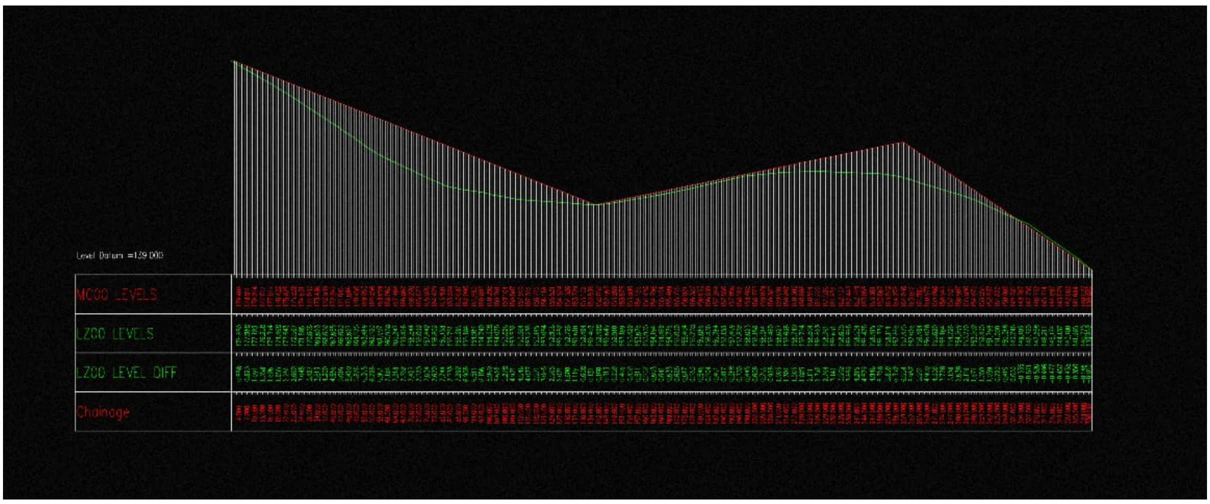


Figure 13:Section 1 chainage and elevation

Sunsali-Noonmati hill series fall within the municipal boundary of Guwahati city. The hillslope angles vary from gentle slopes to as steep as 60°. The hills are composed of the granite and gneiss as basal rocks affected by several sets of joints, intruded by quartz and quartz–feldsphetic veins, aplite and pegmatite. Quartzite, amphibolites and biotite schists, occur as thin bands or lenses parallel to the foliation (Shukla, 1989). Thick residual soil formation (up to depth of 30 m) (Das and Saikia, 2011) can be observed in zones of well-drained regions. Varying thicknesses of overburden are encountered in zones of moderate to imperfectly drained re- gions. Exposed basal rock, formation of etchforms and inselbergs due to erosion in zones of poor drainage are also observed from the geomorphology of the area.(Dey et al.,2022)

The soil type of the designated area is collected from DSMW (Digital Soil Map of the World) and the type of soil found is a mix of sandy-clay-loam. The soil falls into Group C soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

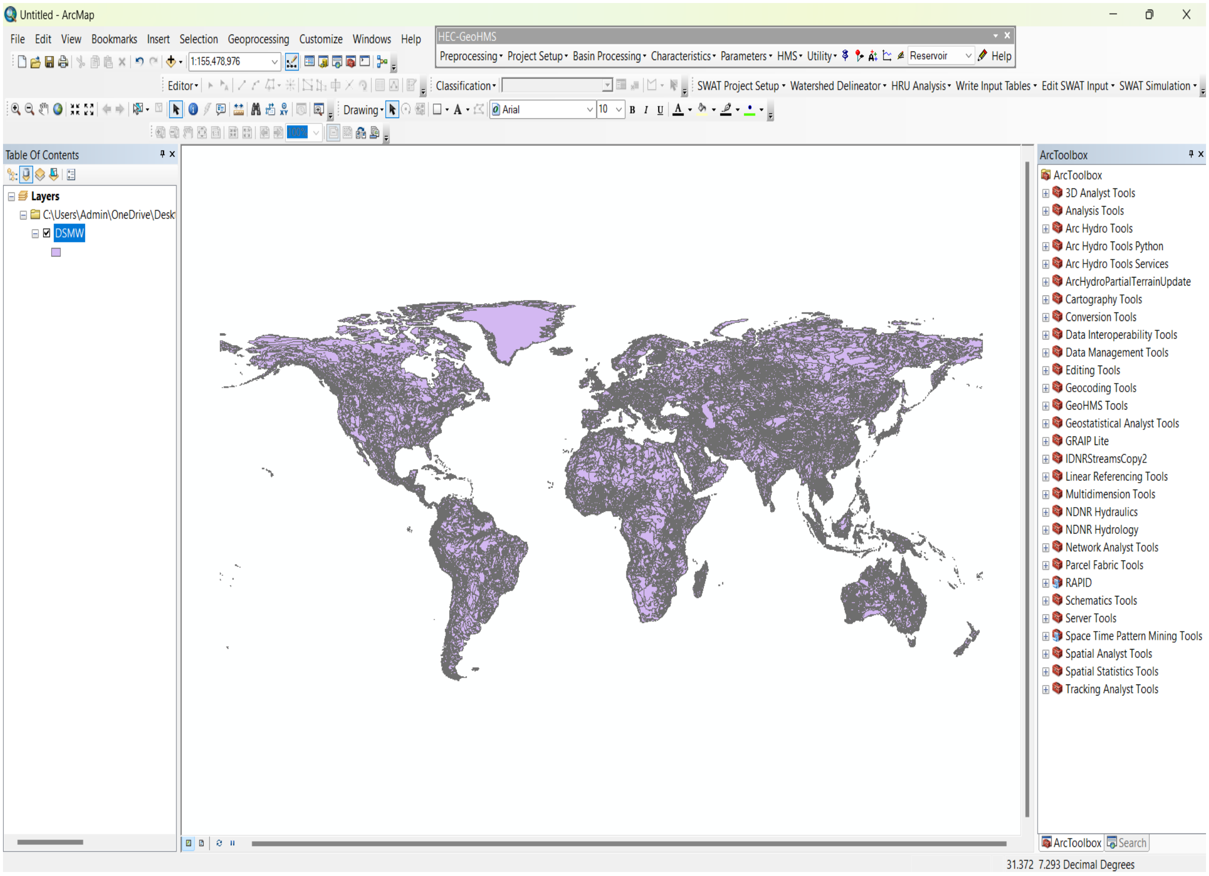
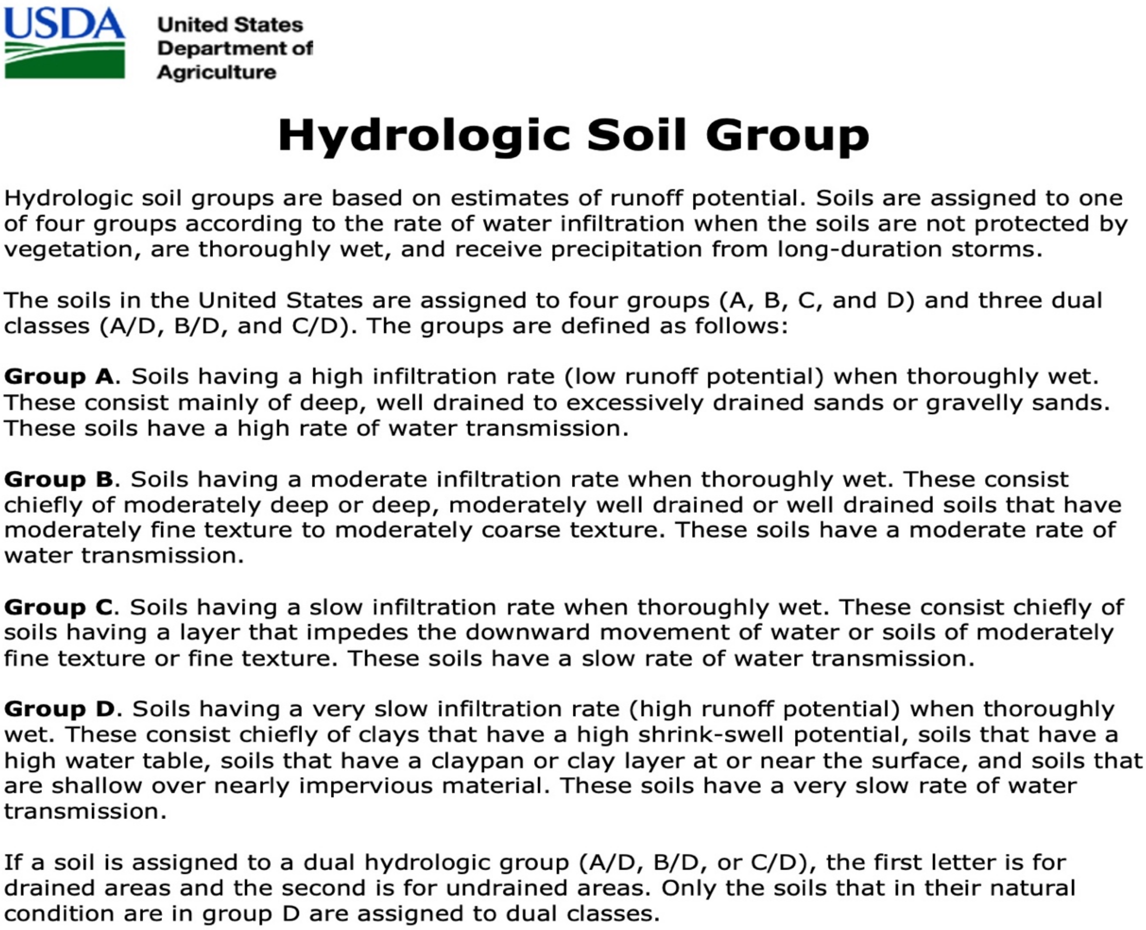


Figure 14:Digital Soil Map of the World



United States Department of Agriculture

Hydrologic Soil Group

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.

Figure 15:Hydrologic soil group

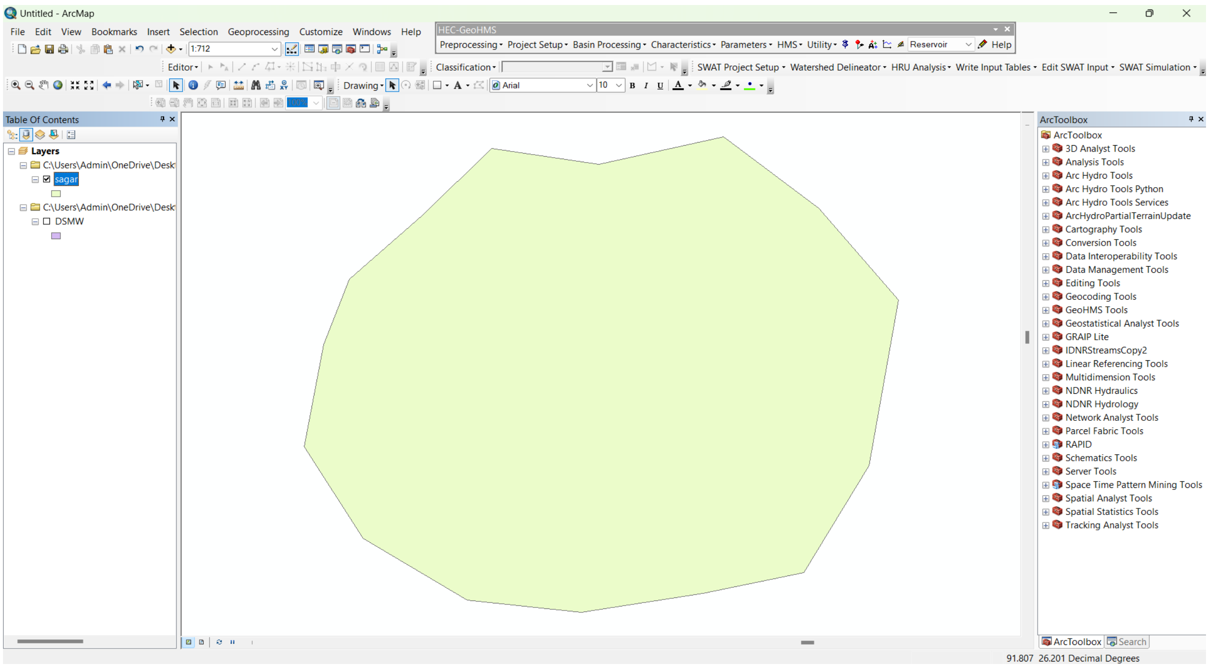


Figure 16: Soil type of the proposed area

	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
2198	3646	Ao74-2b-3646			2	C	1000	0.5	0.5	SANDY_CLAY_LOAM	300	1.4	0.175	8.45	2.5	22
2199	3647	Ao75-2b-3647			2	C	1000	0.5	0.5	SANDY_CLAY_LOAM	300	1.4	0.175	8.75	1.5	23
2200	3648	Ao77-2a-3648			2	D	1000	0.5	0.5	LOAM	300	1.4	0.175	6.57	2	24
2201	3649	Ao78-3c-3649			2	C	580	0.5	0.5	CLAY_LOAM	300	1.1	0.094	21.89	2.8	36
2202	3650	Ao79-a-3650			2	C	1000	0.5	0.5	SANDY_CLAY_LOAM	300	1.4	0.175	8.75	1.7	23
2203	3651	Ao80-2bc-			2	C	980	0.5	0.5	LOAM	300	1.2	0.175	16.01	3.1	18
2204	3652	Ao81-2b-3652			2	D	910	0.5	0.5	LOAM	300	1.4	0.103	8.02	2.5	22
2205	3653	Ao82-2-3b-3653			2	C	1000	0.5	0.5	SANDY_CLAY_LOAM	300	1.3	0.169	9.07	1.6	29
2206	3654	Ap19-2b-3654			2	C	1000	0.5	0.5	LOAM	300	1.3	0.175	9.01	6.3	24
2207	3656	Ap21-2b-3656			2	D	630	0.5	0.5	SANDY_CLAY_LOAM	300	1.4	0.104	8.36	1	23
2208	3657	Bc23-2a-3657			2	C	560	0.5	0.5	LOAM	300	1.2	0.092	18.05	1	22
2209	3658	Bc24-2b-3658			2	C	1000	0.5	0.5	SANDY_CLAY_LOAM	300	1.1	0.175	30.3	1	22
2210	3659	Bc25-2c-3659			2	C	580	0.5	0.5	SANDY_CLAY_LOAM	300	1.2	0.094	20.28	1	23
2211	3660	Bc26-2c-3660			2	C	910	0.5	0.5	SANDY_CLAY_LOAM	300	1.1	0.175	27.98	1.1	22
2212	3661	Bd29-3c-3661			2	C	580	0.5	0.5	CLAY_LOAM	300	1.1	0.085	22.31	3.1	37
2213	3662	Bd32-2bc-			2	C	960	0.5	0.5	LOAM	300	0.9	0.118	61.87	3	21
2214	3663	Bd34-2bc-			2	C	810	0.5	0.5	LOAM	300	1	0.117	35.65	4.7	24
2215	3664	Bd35-1-2b-3664			2	C	1000	0.5	0.5	LOAM	300	1.1	0.157	28.52	2.2	17
2216	3665	Bd61-2c-3665			2	C	850	0.5	0.5	LOAM	300	1.1	0.158	22.59	3	22
2217	3666	Be66-2c-3666			2	C	840	0.5	0.5	LOAM	300	1.3	0.16	8.67	1.1	22
2218	3667	Be70-2-3a-3667			2	C	1000	0.5	0.5	CLAY_LOAM	300	1.2	0.175	11.95	0.8	30
2219	3668	Be71-2-3a-3668			2	D	1000	0.5	0.5	CLAY_LOAM	300	1.4	0.17	4.2	0.7	33
2220	3669	Be72-2a-3669			2	D	1000	0.5	0.5	LOAM	300	1.4	0.175	5.45	1.1	22
2221	3670	Be72-2c-3670			2	D	910	0.5	0.5	LOAM	300	1.4	0.109	5.45	1.1	22
2222	3671	Be72-2c-3671			2	D	510	0.5	0.5	LOAM	300	1.4	0.081	5.45	1.1	22
2223	3672	Be72-3c-3672			2	C	510	0.5	0.5	CLAY	300	1.2	0.081	13.43	0.7	41
2224	3673	Be73-2c-3673			2	D	300	0.5	0.5	LOAM	300	1.3	0.048	7.97	1.3	23

usersoil

Figure 17: Decoding table of the selected site

CHAPTER 6

6. Landfill Design

6.1 Estimation of Landfill Capacity

The estimation of landfill capacity can be done by using the given steps:

Step 1: Waste generation rate = W tons per year

Step 2: Active life of landfill. = n years

Step 3: Total waste in n years (T) = W x n tons

Step 4: W is not constant but increases with time as population and per capita waste generation (WG) increases

Step 5: Future Population = Current Population $(1+ y/100)^n$
(y – 1.2% India, -0.1% Japan , 0% Germany)

Step 6:Future WG = Current WG $(1+\alpha(\text{GDP growth}) + \text{others})$

Step 7: W_i. = Future population x Future WG for i^{th} year

Step 8: T = ΣW_i

Data:
From Census of 2011 data: Initial Population (2011), $\mathbf{P_{2011}}$ = 12,60,419
Area of Guwahati city : 264 sq. km
Area under GMC : 216 sq. km

From Department of Urban Development and Housing, Assam:

- Initial Waste generation per capita ($\mathbf{WG_{2011}}$) = 0.430 kg/day/person

= (0.430*365)/1000 tons/year/person

= 0.15695 tons/year/person

Assumption:
Annual Population Growth rate, **y** = 1.2% (India)

Annual Waste Generation Growth Rate, **a** = 3%

Considering floating population as 30%

Waste Generation Calculation:
Now we will calculate the wate generation rate (**WG**) in 2025,

Time period, **n** = 2025-2011 = 14

WG_{2025} =WG_{2011}* (1 + a/100) ^{n}

= 0.430 * $(1 + 0.03)^{14}$

= 0.6504 kg/day/person

WG_{2025} = WG_{2011}* (1+a/100) ^{n}

= 0.15695 * $(1+ 0.03)^{14}$

= 0.2374 tons/year/person

Population in 2025, **P_{2025}= P_{2011}* (1+y/100) ^{n}**

= 12,60,419 * $(1+ 0.012)^{14}$

= 14,89,506

Now we'll calculate the waste generation in 2050 taking 2025 as current year,
Time period (2025-2050) = 25 years

P_{2050}= P_{2025}* (1+ y/100)^n

= 14,89,506 * $(1+ 0.012)^{25}$

= 20,07,036

Considering floating population as 30%,
Total population, **P_{2025}** = 20,07,036 + 30% of 20,07,036 = 26,09,147
Waste Generation rate, **WG_{2050}= WG_{2025}*$(1+a/100)^{25}$**

= 0.2374 * $(1+ 0.03)^{25}$

= 0.497 tonnes/year/person

Total waste generated in **2050** = 26,09,147 * 0.497

= **12,96,746.06 tonnes/year**

6.2 HEIGHT OF LANDFILL

From Google Earth, Area of proposed Landfill = 1,10,879.96 m^2
Total waste generation = 12,96,746.06 tonnes/year in Whole of Guwahati City
Density of landfill = 312 kg/m^3
Therefore, Volume = 12,96,74,606 / 312

= 4,15,624 m^3

Hence, height of landfill, h = Volume/Area

= 3.75 m

Hence 3.75 m is the height of landfill we will consider for design purpose.

6.3 LINER SYSTEM

Considering the type of waste is a mix of Hazardous and Municipal solid waste, the liner system is taken for the Hazardous Waste Landfill (India) for design safety where the Consolidated Clay Layer has depth of 150 cm and the Geomembrane layer has a depth of 10 mm. The consolidated clay layer serves as a fundamental barrier to prevent the migration of leachate and contaminants into the underlying groundwater system. The use of a geomembrane layer, with a depth generally recommended to be between 1 to 2 mm, further enhances the overall integrity and performance of the liner system. (Shankar & Muthukumar, 2017)

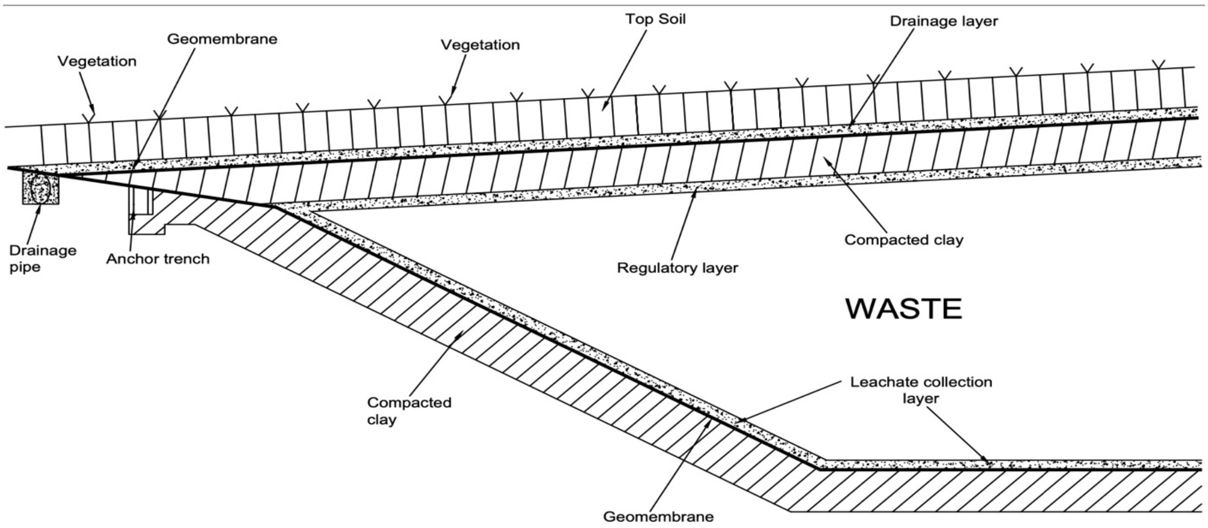


Figure 18:Section of a Liner system

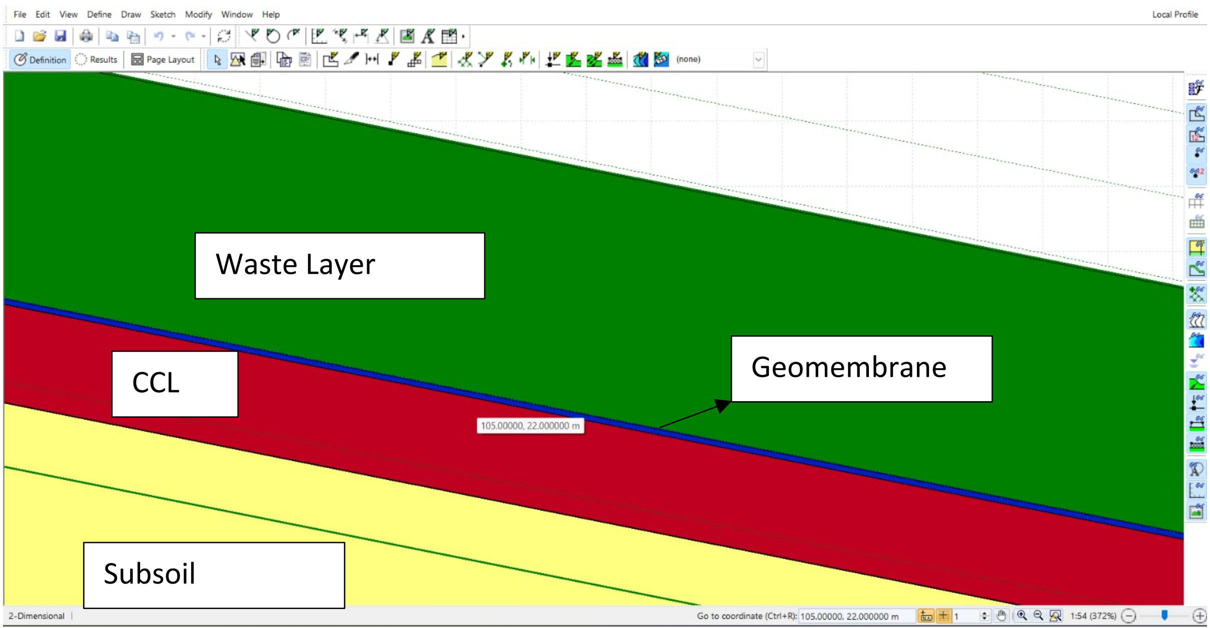


Figure 19:Layers Drawn in Slope W

For calculation and analysis, the material properties of CCL ,Geomembrane and Subsoil are taken as follows:

- Geomembranes are generally 1.5-2.5mm but the software couldn't detect it so the thickness of the geomembrane taken is 0.1m
- CCL height taken is 0.15m
- Waste layer 3.75m
- Taking grid X-10,Y-15
- Taking 10 nos. of Radius increments

Slope Angle is 21.7* and the slope selected has 138.44m in X-axis and 55.12m in Y-axis

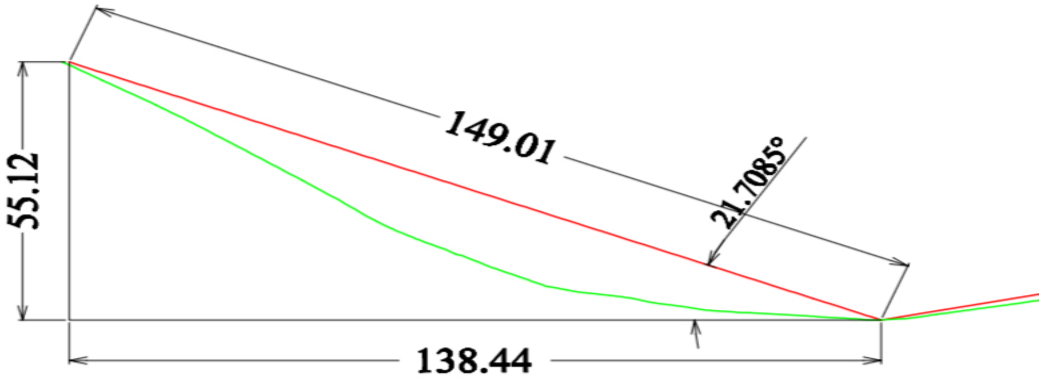


Figure 20:Section of the slope

Soil Properties	Unit Weight	Cohesion	Angle of Internal Friction(*)	References
MSW	15kN/m^3	10kPa	30	Bray et al.,2009 Kajitvichyankul et al.,2008
Geomembrane	1 kN/m^3	0	10	Bray et al.,2009 Kajitvichyankul et al.,2008
CCL	Considered as Impermeable			Bray rt al.,2009 Kajitvichyankul et al.,2008
Subsoil	18.5kN/m^3	10kPa	27	Dey et al.,2022

Table 1:Material Properties used

6.4 Calculation for design horizontal and vertical seismic coefficient

From IS 1893 (Part 1): 2016,
Design horizontal seismic coefficient, A_h = ((Z/2) *(S_a/g))/(R/I)
Seismic zone factor, Z= 0.36 (Zone V, Table 3)
Response Reduction factor, R =2 (For typical earthen structures with minimal seismic design considerations)
Importance factor, I = 1.2
S_a/g = 2.5 (Medium-stiff soil)
Hence, Horizontal Seismic Coefficient, A_h = ((0.36/2) * (2.5)) / (2/1.2) = 0.27

Vertical Seismic Coefficient, A_v = 2/3 * A_h = 0.18

CHAPTER 7

7 Slope Stability Analysis

7.1 Slope Stability Analysis of Original Section

The Factor of Safety for the different sections along the weakest layer (Geomembrane layer) were found as such:

Calculation of FOS for Dry with Seismic loading conditions:

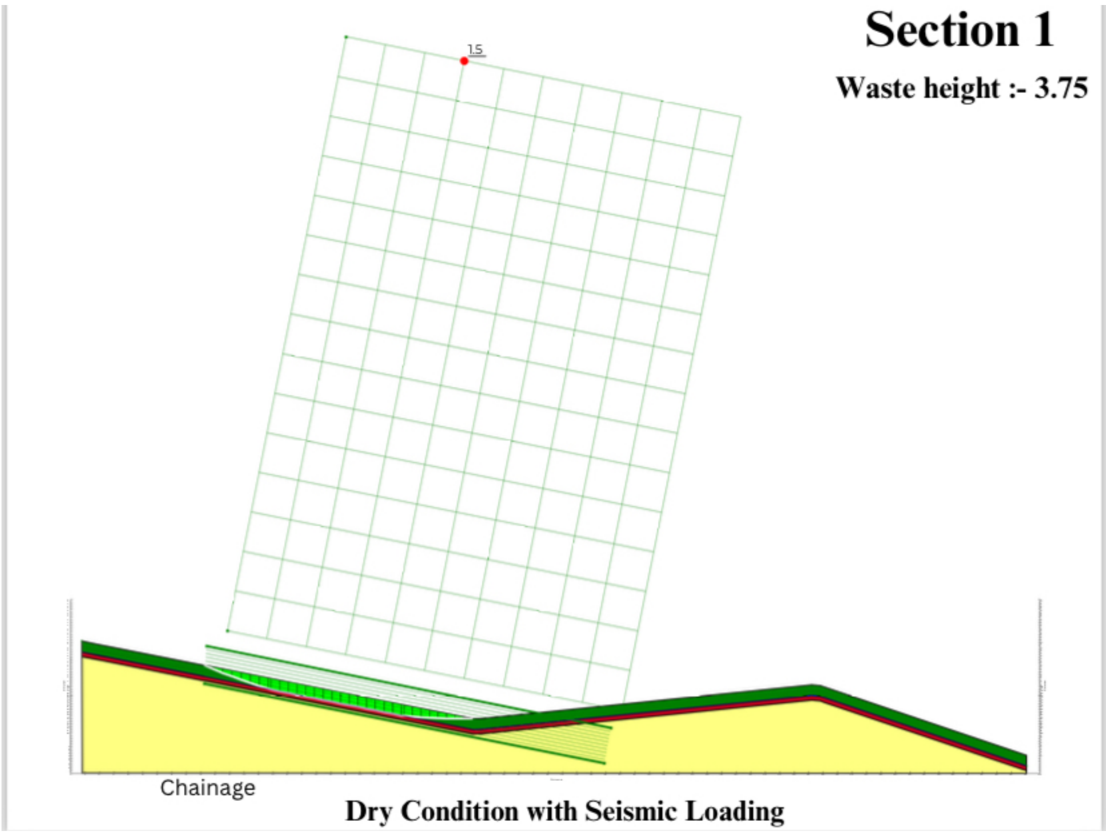


Figure 20:Section 1 FOS is 1.5

***NOTE**: These Factor of Safety values are analysed in Normal dry conditions considering Earthquake forces.
The Recommended FoS in case of seismic loading can be taken to be 1.2 or higher. As Earthquake forces are momentary forces.

Calculation for Pore Water Coefficient for Wet Condition
(Original Section)
Assuming: Unit Weight of water = 9.81 kPa
Unit Weight of Waste (MSW) = 15 kPa
Depth of Water = 1.5 m
Pore water pressure Coefficient (Ru) Calculation
Ru = Pore Water Pressure (u) / Total Overburden Pressure

Pore Water Pressure = 9.81 *1.5 = 14.715 kPa
Overburden Pressure = 15*3.75 = 56.25 kPa
Ru = 14.715 / 56.25 = 0.26

Calculation of FOS for Wet with Seismic loading conditions:

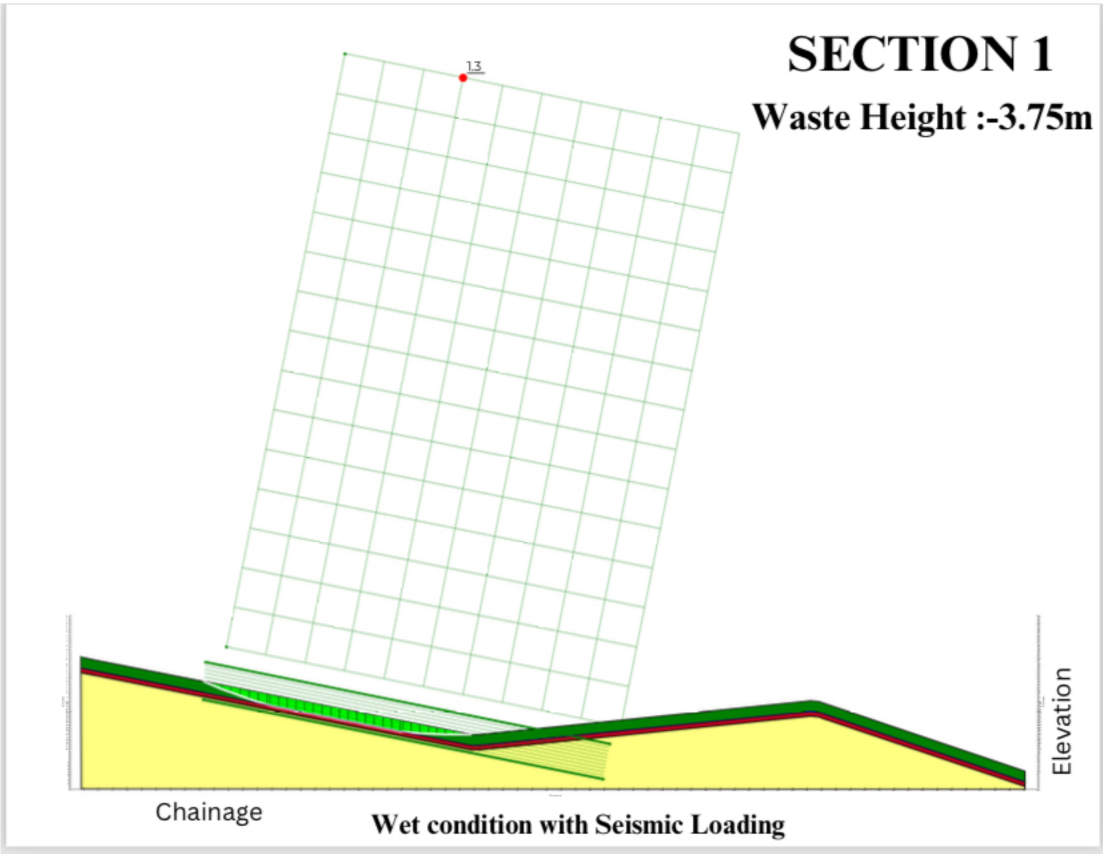


Figure 21:Section 1 FOS is 1.3

***NOTE**: These Factor of Safety values are analysed in Wet conditions considering Earthquake forces.
The Recommended FoS in case of seismic loading can be taken to be 1.2 or higher. As Earthquake forces are momentary forces.

Hence, in case of the originally calculated height, the design in the dumpsite has the necessary Factor of Safety to construct the dumpsite.

RESULT AND CONCLUSION

From the comprehensive slope stability analysis conducted, the following results have been obtained:

1. The Factor of Safety (FoS) for the waste mass, considering both dry and wet conditions with seismic loading at the original calculated slope height of 3.75 meters, is determined to be safe and suitable for the construction of the landfill. The analysis confirms that under these conditions, the slope remains stable, with no risk of failure.
2. In the case of seismic loading combined with either dry or wet conditions, the FoS further supports the adequacy of the landfill design, leading to the necessary structural improvements in the landfill section.

Thus, it can be concluded that the calculated waste height of 3.75 meters, designed for a 25-year period, results in an FoS above the minimum safety requirements. This indicates potential long-term stability and mitigates the risk of shear failure, ensuring the structural integrity of the landfill over time.

The type of soil of the site is a mix of Sandy-Clay-Loam and falls in Group C soils that can be suitable for building a landfill, primarily due to their low infiltration rate, which helps reduce the risk of groundwater contamination. However, proper drainage and leachate management systems would be necessary to ensure that water does not accumulate on the surface or within the landfill.

Considering the proposed landfill site's characteristics, we can estimate the waste collection capacity annually, assuming a constant waste layer height :

From Google Earth, Area of proposed Landfill = 1,10,879.96 m^2
Total waste generation = 12,96,746.06 tonnes/year in Whole of Guwahati City
Density of landfill = 312 kg/m^3
Therefore, Volume = 12,96,74,606 / 312
= 4,15,624 m^3
Hence, height of landfill, h = Volume/Area
= 3.75 m

Based on these calculations, the Noonmati-Choonsali site is projected to cater to the waste management demands of Guwahati City up to the year 2050. This conclusion is supported by the calculated waste height, volume, and the verified slope stability of the site, ensuring both capacity and long-term operational safety.

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