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Slope Safety Risk Analysis of The Embankments Made of Different Landfill-Mined Waste

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Abstract. Municipal solid waste management is a growing worldwide challenge. Landfill mining is a promising technique to reduce MSW landfills. In the present study, arbitrary embankments made of different MSW fractions are analyzed to find the safety factor of their slopes. Properties of Municipal solid waste fines (MSWF), Shredded MSW, MSW Incineration Ash, and MSW having particles less than 35 mm are used in the analysis. For doing the same, finite element-based application 'Plaxis-2D' is used. The safety of slopes is assessed while the water table is inserted, and a uniform load is applied to the embankment to establish how well they will perform in critical situations. It was found that the slope made of shredded MSW is most safe due to its low density and high friction angle, while the least safe slope is made of MSW having less than 35 mm fractions.

Keywords: FEM; Slope Stability; Plaxis; MSW

1 Introduction

The growing height of landfills is becoming a growing problem worldwide [1]. Some ways to reduce the amount of trash in a landfill are landfill mining and reclamation [2]. "Landfill reclamation" is a process that uses waste that has been dug up from a landfill to recover recyclable materials like metal, glass, and plastic, as well as soil, fine materials, and the volume of the landfill itself. Landfills have been cleaned up in a few places in the United States, but people worldwide are becoming more interested [3]. Older dumps that aren't lined can pollute nearby groundwater sources with liquid waste, so landfill reclamation is necessary to fix this problem. Other reasons to think about landfill reclamation are the need to increase the size of the landfill and the lower costs of closing the landfill due to its smaller footprint [4]. Another problem in this row is finding ways to use the materials that have been reused. The reclaimed MSW can be burned, used as filler material, and so on [5]. However, from a civil engineering point of view, the reclaimed MSW can be used effectively in embankments, subgrades, slopes, and fillers for low-lying areas. This study focuses on how different types of reclaimed landfill material can be utilized in embankment slopes. The current study examines the safety of embankment slopes constructed from various types of recycled landfill material at the water table and when they are loaded. An application called "Plaxis-2D" based on the finite element method (FEM) is used for the same goal. The finite element method is a well-known way to use numbers in engineering [6–8]. This technique does not use a continuous model with an infinite number of unknowns. Instead, it uses a mathematical model with finite numbers of unknowns at discrete points called "nodes" [9]

2 Method and principle

For the present study, an arbitrary slope shown in Fig. 1(a) is analyzed for its safety. The slope is assumed to be constructed with two layers. The FEM analysis is done on three slope conditions, which are given in Table 1. The water table is assumed to be below the embankment in the first condition. In the latter case, the capillary action of the water table causes it to pass via the coordinates of (18, 7) and (0, 10) in the embankment, which is considered 3 meters above the slope's base. While in the third case, an external uniform loading of 50 kN/m/m is imposed on the top of the embankment. The typical condition is given in Fig. 1. The slope safety analysis for all the material and case combinations is carried out through 'Plaxis 2D', a FEM-based application. Through this, the safety factors of slopes for different cases are analyzed. The ratio of the collapse load to the working load is a standard definition for the safety factor. This term, however, may not always apply to soil structures. It is unlikely that an increase in soil weight would cause an embankment to collapse because soil weight accounts for the majority of the loading. In the present case, the safety factor is defined as

$$Safety\ Factor = \frac{S_{maximum\ available}}{S_{needed\ for\ equilibrium}}$$

S stands for shear strength. The safety factor in soil mechanics is the ratio of the actual strength to the calculated minimum strength required for balance. The safety factor can be calculated as follows by using the standard Coulomb condition:

$$Safety\ Factor = \frac{c - \sigma_n tan\varphi}{c_r - \sigma_n tan\varphi_r}$$

Here c and φ are the actual shear strength parameters, and σ is actual normal stress. At the same time, cr and φ are reduced parameters that can only maintain slope equilibrium. The above discussed is the method of calculating global safety factors in Plaxis. Therefore, the angle of friction and the cohesion are defined as:

$$\frac{C}{C_r} = \frac{\tan\varphi}{\tan\varphi_r} = \sum Msf$$

Here multiplier ∑Msf (safety factor) controls the reduction of strength parameters during the safety calculation while gradually increasing the slope load. On failure, the safety factor ∑Msf becomes almost constant [10]. Before analyzing the slope, the embankment model meshing is done to get an accurate analysis; the meshed embankment model is shown in Fig 1(b).

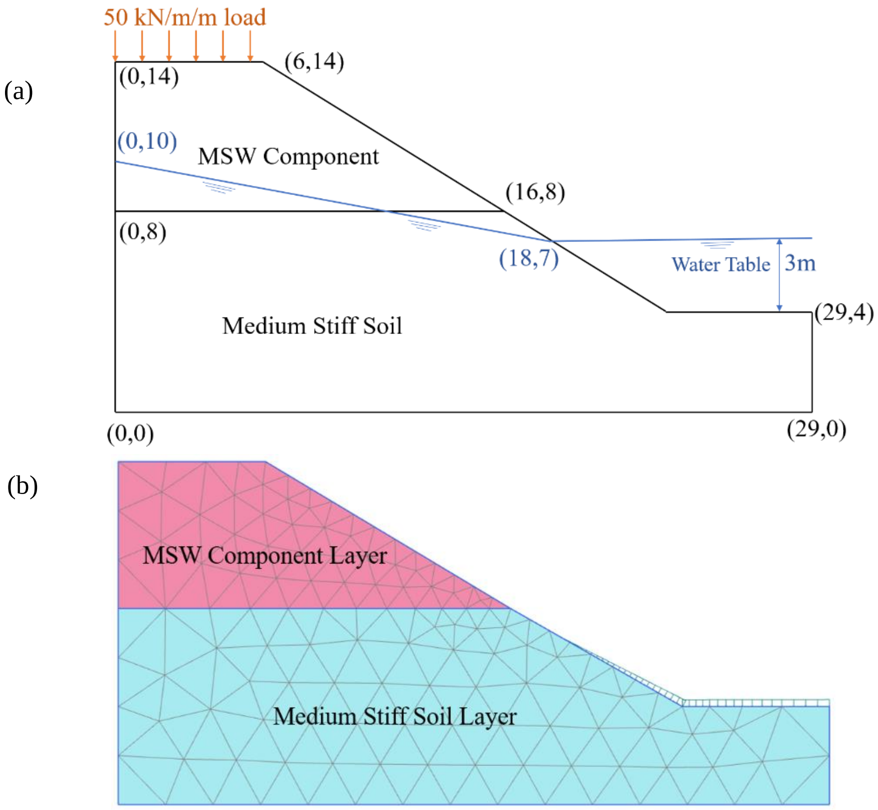

Fig. 1. (a) The coordinates of embankment slopes with loading and water table analysed in the study. (b) FEM Meshing of embankment

Table 1: Details of embankment slope, loading, and water table condition

Case 1	Typical slope with no water table or below the embankment (Normal Slope)
Case 2	Slope with the water table at 3 meters above the slope base (Slope +WT)
Case 3	Slope with the water table and 50 kN/m/m load above the embankment (Slope +WT +load)

3 Material used

Over an arbitrary embankment, four different types of landfill material (MSW components) are laid. The first material is Municipal Solid Waste Fines (MSWF), which the author himself collected at a landfill in Sarriya Varanasi. The term "MSWF" refers to the amount of MSW that passes through a 4.75 mm sieve. The basic properties are determined in the lab and given in Table 2. The other three material properties are taken from the published literature. The properties of the second material, MSW incineration ash obtained from Michigan Monofill used in the study [10]. The incineration ash is the ash that remained after the closed-burning of MSW. It usually contains ash, unburnt stone, metal, and ceramic components. Shredded MSW is the third material trait chosen for research. The MSW was shredded into particles ranging in size from 0.75 to 40 mm. The study was carried out by (Reddy K. R. et al. 2008) [11], and a sample was collected from Orchard Hills Landfill, USA. The fourth MSW sample property is taken from the Gazipur landfill in Delhi, the report prepared by CSIR-Central Road Research Institute, Delhi, India [12]. The report is made for 5, 10, and 15 years old MSW; for the present study, only the properties of the 10-year sample are adopted. In the particular MSW component, the properties of sieved remains after 35 mm sieving is taken. The typical images of the above-discussed material are shown in Fig. 2. The secant elastic modulus, which is required for the study, is calculated by the stress-strain curve of the particular material. Fig. 3 displays the stress-strain curve for each material. The material's secant modules are calculated as the ratio of stress at 2% strain to the value of 2% strain. The values of a different form of MSW are given in Table 2. These MSW components are laid over an 8-meter-thick medium stiff soil layer, and the particular layer properties are given in the same table.

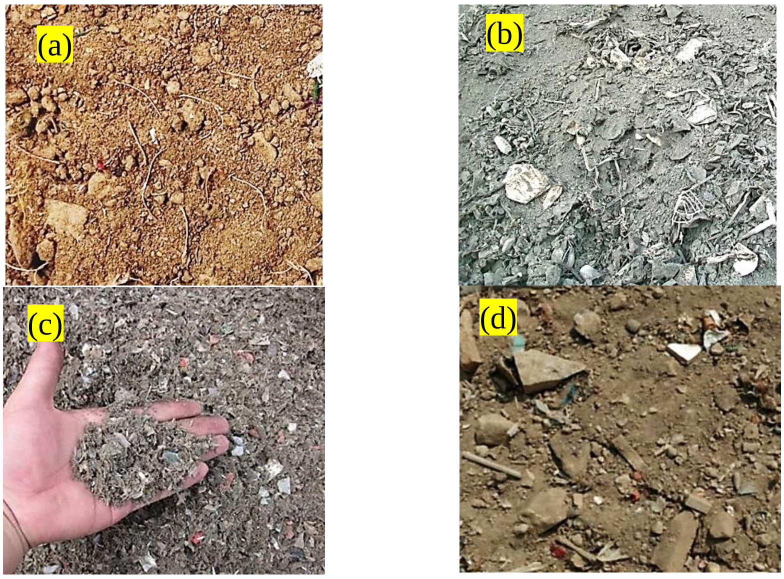

Fig. 2. Different MSW components adopted in the study (a) MSWF (b) MSW Inciniration Ash (c) Shredded MSW (d) MSW<35mm (Image source b-c: Internet, c: CRRI Report)

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Table 2. Properties of the landfill mined material were taken for the study.

Properties	Specific Gravity	OMC (%)	MDD (kN/m^3)	Cohesion (c) (kPa)	Angle of friction (φ)	Shear Stress at 2% Strain	E' (Secant Modulas) (kn/m^2)
MSWF (Varanasi Landfill)	2.23	17.10	16.8	64.7	35.7-18.8	86.82	4341
MSW Incineration Ash (Michigan Monofill)	2.10-2.61	18.9 - 28.4	11.65 - 16.4	20.1 - 52.4	42 - 44.5	326.81	16340.5
Shredded MSW (Orchard Landfill)	0.85	70	4.4	38	16	44.12	2206
MSW<35mm (Delhi Landfill @10m depth)	1.9	16	15	25	28	58.45	2922.5
Lower layer Medium stiff soil	--	--	18	8	25	--	15000

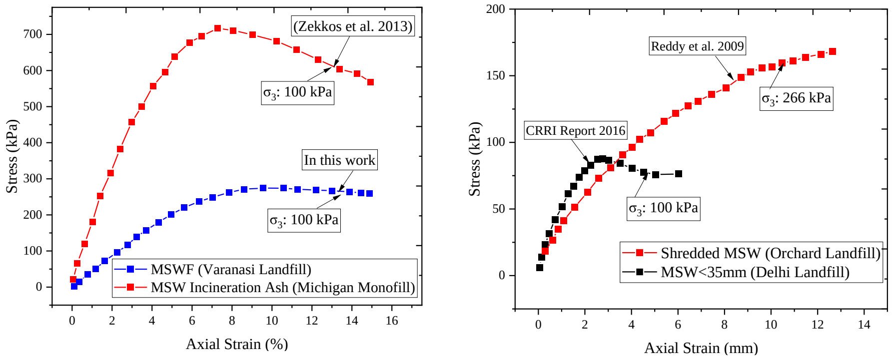

Fig. 3. Stress-strain curves of the materials taken for the study.

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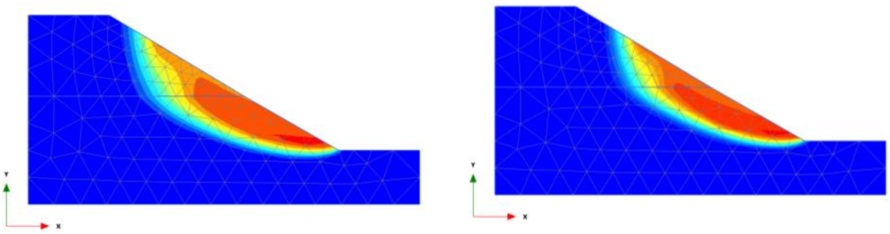
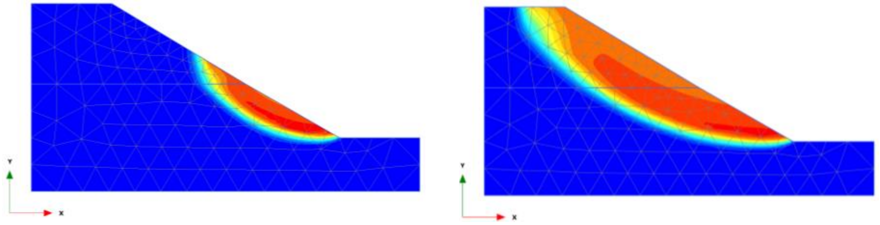
4 Result and discussion

4.1 Case 1 (Typical slope)

In case the only typical slope is analyzed with having no water table or imposed loading. All failures are 'Toe failure.' On analyzing the failure pattern, the embankment slope consisted of Shredded MSW having the smallest slip circle. It is because of the low density of the shredded MSW by which slope experienced the least self-weight. Moreover, failure shows the smallest slip circle. The MSW<35mm from the Delhi landfill shows the biggest slip circle. It is because of the low elastic modulus and cohesion while the density is comparatively higher. While analyzing the safety factor plot, the maximum stability can be obtained by the shredded MSW, while the minimum stability is obtained by the slope made of MSW<35mm. The failure patterns are shown in Fig. 4, and the safety factor plot is given in Fig.7.



(a) MSWF (Varanasi Landfill) (b) MSW Incineration Ash (Michigan Monofill)



(c) Shredded MSW (Orchard Landfill) (d) MSW<35mm (Delhi Landfill)

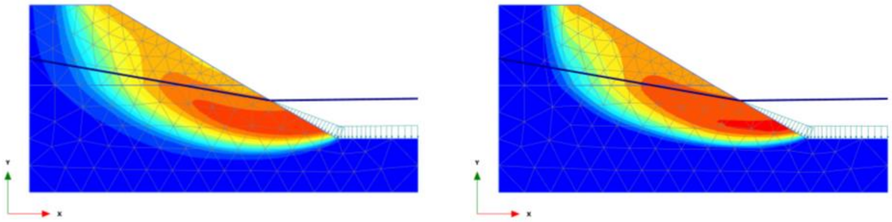
Fig. 4. Failure slope for Case 1.

Table 3. Safety factors for all materials and cases.

	Normal Slope	Slope + WT	Slope + WT+Load
MSWF (Varanasi Landfill)	1.76	1.48	1.38
MSW Incineration Ash (Michigan Monofill)	1.82	1.57	1.41
Shredded MSW (Orchard Landfill)	1.99	2.02	1.64
MSW<35mm (Delhi Landfill)	1.71	1.47	1.27

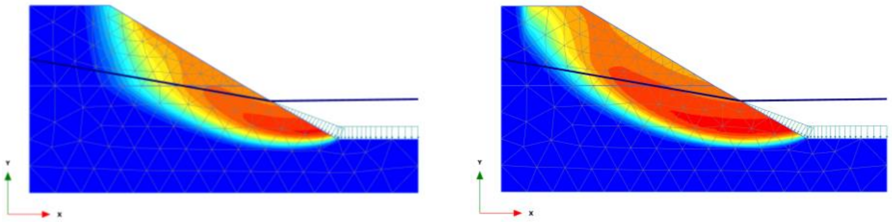
4.2 Case 2 (Slope + WT)

In the case of the water table at the 3 m Hight of slope-base, the slip circle is shown in Fig. 5. In this case, the tow failure occurs. The slip circle is more significant than that obtained in the typical slope case; because of the water table insertion, the pore pressure induced in the slope, and the slopes become more susceptible to failure. The maximum stability in case-2 is of the embankment consisted shredded MSW. Moreover, it is all because of the indexed property of the shredded MSW. The shredded inorganic part of the MSW combined with the fines may have made the bonding within the material matrix resist shear failure. Also, the presence of the low-density material help in reducing self-weight. The safety factor for MSWF slopes is 1.48; for MSW Incineration Ash, it is 1.57; for the Shredded MSW case, it is 2.02, while for MSW<35mm, the maximum safety factor is calculated as 1.47. The graph of safety factor w.r.t FEM itrations is given in Fig.7.



(a) MSWF (Varanasi Landfill)

(b) MSW Incineration Ash (Michigan Monofill)



(c) Shredded MSW (Orchard Landfill)

(d) MSW<35mm (Delhi Landfill)

Fig. 5. Failure slope for Case 2.

4.3 Case 3 (Slope+WT+Load)

It is the most critical case taken in the present study. Self-weight, pore pressure due to a water table, and forced loads are the three factors responsible for slope failure in this case. While analyzing the values of maximum safety factors, the minimum values among all the cases are obtained in this case. A 50 kN/m/m uniform load is applied over the top of the embankment. Due to the low density of shredded MSW waste and soil-like material, shredded MSW makes a low weight and firm slope profile with high cohesion and internal friction angle. However, having low secant modulus shredded MSW resistance against shear failure due to self-weight and imposed load is higher

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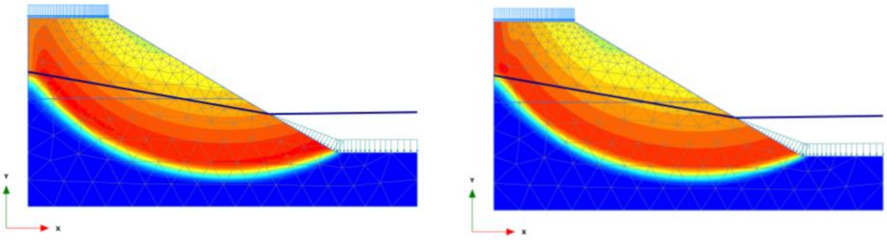
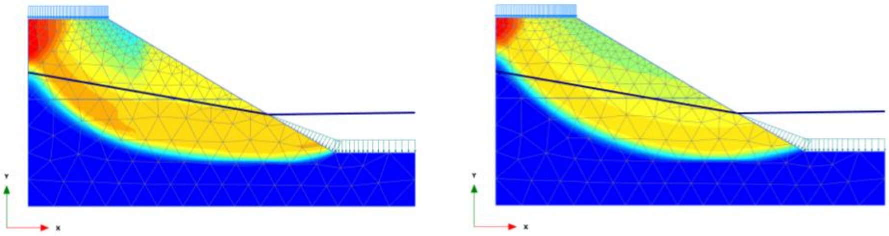
than other MSW materials. In this case, the safety factor of shredded MSW is 1.64, while safety factors are 1.38, 1.41, and 1.27, respectively, for MSWF, MSW incineration ash, and MSW<35mm. Compared to MSWF and MSW<35mm, the incineration ash has a higher friction angle and secant modulus. Among MSWF, MSW incineration ash, and MSW<35mm, the friction angle and the secant modulus are the least, as the least safety factor obtained in this case. The slip failure circle is shown in Fig.6. The graph between the Safety factor and FEM iterations is given in Fig.7.



(a) MSWF (Varanasi Landfill)

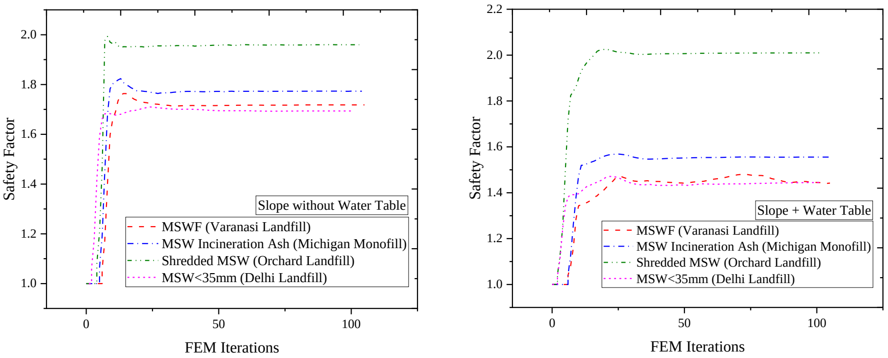
(b) MSW Incineration Ash (Michigan Monofill)



(c) Shredded MSW (Orchard Landfill)

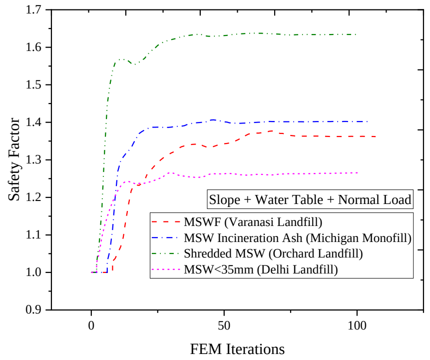
(d) MSW<35mm (Delhi Landfill)

Fig. 6. Failure slope for Case 3.



(a) Safety factor vs. FEM iterations curves for Case1

(b) Safety factor vs. FEM iterations curves for Case 2



(c) Safety factor vs. FEM iterations curves for Case 3

Fig. 7. Safety factor vs. FEM iterations curves for all cases.

5 Conclusion

In the present study, the slopes having a layer of different mined MSW components such as MSWF, MSW Incineration ash, Shredded MSW, and MSW<35mm are analyzed for safety. The study is done in low to high critical conditions by insertion of the water table and load, and the following conclusion is drawn:

1- Shredded MSW has a low density and high internal friction and cohesion angle, due to which the slope is safest in all conditions compared to others.

2- Slope safety is reduced by inserting a water table and imposing a load over the embankment.

3- While the secant modulus is higher in the case of MSW incineration ash due to its higher self-weight, the slope is more susceptible to failure than shredded MSW.

4- MSWF is safer than MSW<35mm because of the more secant modulus, although their self-weights are almost identical.

5- Due to its lower secant modulus and cohesiveness, MSW slopes with a layer of MSW<35mm are shown to be the least safe of all material slopes.

6- The present study has a few assumptions and limitations; analysis can be improved by deploying more accurate data by performing more experiments.

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