EFFECT OF MATERIAL PROPERTIES ON THE STABILITY OF SOLID WASTE LANDFILLS AND POTENTIAL FAILURE MECHANISMS

Azad KOLIJI, Soil Mechanics Laboratory, EPFL, Lausanne, Switzerland[1]
Nader SHARIATMADARI, Civil Engineering Department, IUST, Tehran, Iran

ABSTRACT
An investigation was undertaken to evaluate the static behaviour of a solid waste landfill receiving both municipal and industrial wastes. Stability analysis of the landfill was performed using FE code PLAXIS (Ver. 7.2) and the potential failure mechanisms were investigated. Moreover, parametric analyses were performed in order to find out the sensitivity of static stability safety factor of the landfill to the properties of waste and soil materials. Values for waste properties were selected based on the information given in literature. Results of the analyses showed that when soils with relatively high friction angle is used for the intermediate covers of landfill, the potential failure curve continues through straight lines along these covers. Moreover, comparing the obtained results from the sensitivity analysis, it can be seen that the friction angle of waste material has the most influence on the stability safety factor of landfill.

RÉSUMÉ
Une étude a été menée pour évaluer le comportement statique d'une aire de stockage de déchets recevant des déchets ménagers et industriels. L'analyse de stabilité a été réalisée en utilisant le code éléments finis Plaxis (Ver. 7.2) et les mécanismes de rupture potentiels ont été étudiés. De plus, des analyses paramétriques ont été faites, afin de dégager la sensibilité du facteur de sécurité avec les propriétés des déchets et du sol. Les valeurs des propriétés des déchets ont été choisies à partir de résultats donnés dans la littérature. Les résultats montrent que lorsqu'on utilise pour les couvertures intermédiaires des sols à angles de frottement relativement élevé, la surface de rupture potentielle se développe à travers ces couvertures. Enfin, en comparant les résultats des analyses de sensibilité, on constate que l'angle de frottement des déchets a une grande influence sur le facteur de sécurité.

1. INTRODUCTION

During the recent years, the investigation of geotechnical aspects of solid waste landfills has become of great importance. Several researches have been performed in this field and in some cases (Law et al. 1996, Dixon and Bentley 1996, Landrum et al. 1995, Koerner and Soong 200, Yang and Drumm 2002, stark et al. 2002). The results obtained from these studies are used as design criteria for the engineers. The main goal of this study is to verify the static behaviour and stability of solid waste landfills. First, the selected case and the required parameters are introduced. The static analyses have been then performed using the finite element code PLAXIS (Ver 7.2). The results of these analyses are presented. By changing the strength parameters, the potential failure mechanisms are investigated. Finally, the stability of the landfill and its evolution due to change in different parameters is studied through a parametric study and the influence of different parameters on the stability of the landfill is evaluated.

2. LANDFILL CHARACTERISTICS

The selected landfill for this study is located at the suburbs of Mahshahr that is a city located at southwest part of Iran. The landfill will receive industrial and municipal solid wastes of a petrochemical complex located in the same region (Mahshahr petrochemical complex). This study is performed before the construction of the landfill and the required information such as the landfill geometry and the material properties are determined according to design data of the landfill (Tahkim Mabna Conslt. Co. 2003)

2.1 Geometry of the landfill

Due to high level of water table at the region, this landfill has been designed as a surface landfill. The general configuration of the landfill is depicted in Figure 1. The landfill has a rectangular plan with 480m length and 77m width. Wastes are deposited with a slope of 3h:1v at all four sides. The height of the crest is 12m and the height of the landfill is divided into five different lifts of wastes. Between each two lift, there is an intermediate cover of granular soils with thickness of 30 cm. The liner of the landfill consists of clay and bentonite with 90 cm thickness that is lying on the field soil. Moreover, the final cover is a 45 cm thick layer of modified clay on which a layer of 15 cm organic soil is lying. An embankment of 2 m height encircles the landfill. The role of this embankment is to increase landfill capacity as well as to provide stability for slopes.

[1] This research has been performed at Iran University of Science and Technology, Tehran, Iran

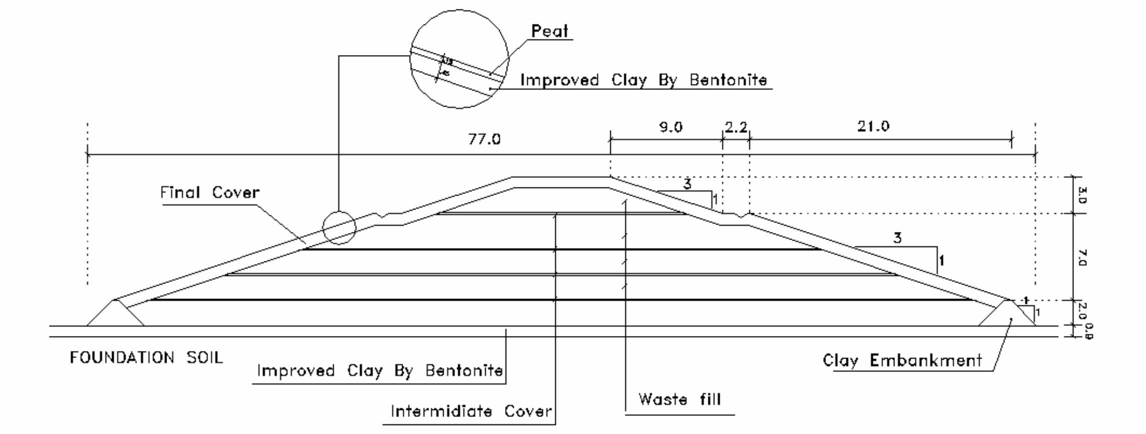


Figure 1. General configuration of the landfill

2.2 Solid waste properties

This landfill is devoted to the common generated wastes of the industrial complex that are highly similar to the municipal solid wastes. Since there is no precise information available about the engineering properties of these materials, the required values of these parameters are selected based on the literature in accordance with the existing condition of the landfill and the wastes that it receives.

The wastes that are received by the studied landfill are very similar to the wastes of the OII landfill (CA, USA) on which several studies have been performed (Augello 1998, Morochnik 1998, Mundy 1995). Due to this similarity, the results of these studies are used here to estimate the values of the engineering properties of waste materials.

a) Unit weight: Since the wastes are not well compacted at the initial placement, it is recommended to use the lower values of the suggested unit weights for municipal solid wastes (Kavazanjian et al. 1995). Therefore, the value of 8.6 kN/m3 is selected for the unit weight of wastes and the values of this parameter are distributed in the depth according to the modified profile suggested by Kavazanjian et al. (1995).

b) Shear strength parameters: a cohesion value equal to 10 kN/m^2 and a friction angle equal to 23 degree are selected for solid wastes. These values are selected based on the comparison of the results of the researches performed by Howland and Landva (1992) using the Moher-Coulomb failure criteria and the suggested curves by Sharma and Lewis (1994).

c) Poisson's ratio: based on the results obtained from earlier investigations (Cuellar et al. 1998) a Poisson's ratio equal to 0.35 is selected for the wastes and it is considered to be constant over the depth.

Table 1. Soils characteristics of different parts.

Characteristics	Intermediate cover	Final cover, liner, embankments	Field soil[1]
Dry unit weight (kN/m^3)	16	20	18.3
Cohesion (kN/m^2)	5	50	44
Friction angle (degree)	25	25	22.5
Poisson's ratio	0.35	0.4	0.4

[1] the soil on which the landfill is located

2.3 Soil properties

Geotechnical properties of the soil on which the landfill is lying are selected based on the geotechnical studies of the project (Tahkim Mabna Conslt. Co. 2002). According to the available data, the depth of the bedrock is assumed to be 30m from the surface. The geotechnical properties of the soil under the landfill as well as the soils used in the covers and embankments are given in table 2.

3. NUMERICAL MODELLING

The finite element code Plaxis (Ver. 7.2) is used for modelling the landfill. Considering the high ratio of the landfill length to its width, the landfill is analysed using a 2D plain strain model. Moreover, due to the landfill symmetry, only half of the landfill section is modelled. For convenience of modelling, some details such as berms and slopes of the landfill flooring are ignored. 15 node elements with an automatic meshing option are used and at the vicinity of the covers and embankments, the meshing is modified into finer ones. Figure 2 illustrates the geometry of the model as well as the standard boundary conditions. Due to the widely acceptance of Mohr-Coulomb constitutive model for solid waste materials (Topolnicki, 1999), this model is used for the behaviour of material.

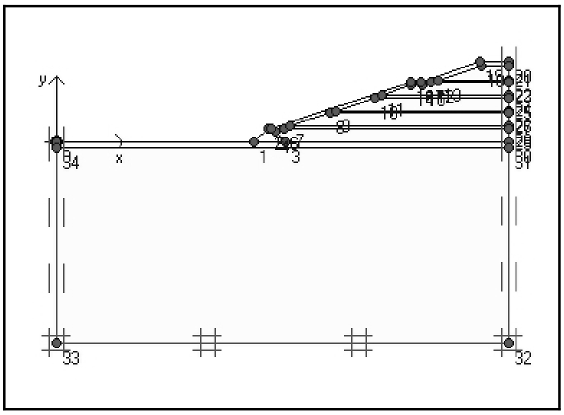


Figure 2. Geometry of the model and standard boundary conditions

4. STUDY OF THE STATIC BEHAVIOUR OF THE LANDFILL

In order to study the stability of the landfill and the potential failure mechanisms, at first, the static stability analysis of the landfill is done using the initial values of the parameters. The potential failure mechanisms and their evolution are then studied by changing the strength parameters of the waste materials.

4.1 Stability of the landfill

For each analysis, the following three phases have been done and the safety factor of the landfill against instability is determined using the option of safety factor analysis provided in Plaxis (Ver. 7.2).

i) Self-weight analysis of the soil on which landfill is lying: The main goal of this phase is to find the displacements due to the self weight of the soil that have already accrued and should not come into the results of the landfill analysis. This can be done by setting all displacements to zero at the end of this phase.

ii) Stage construction analysis of the landfill: In this phase the landfill is modelled in different stages according to the real construction condition. Then, plastic analyses are performed in order to obtain the stresses and the strains due to the construction of the landfill.

iii) Safety factor analysis: in this phase the safety factor of the landfill against instability is determined. The method used by Plaxis (Ver. 7.2) to calculate the safety factor is similar to the limit equilibrium methods. It means that the safety factor is calculated by reducing the strength parameters of the materials.
The calculated value for the safety factor for the landfill with the initial values of the parameters is equals to 2.782 that shows a good stability condition for the landfill.

4.2 Failure mechanisms

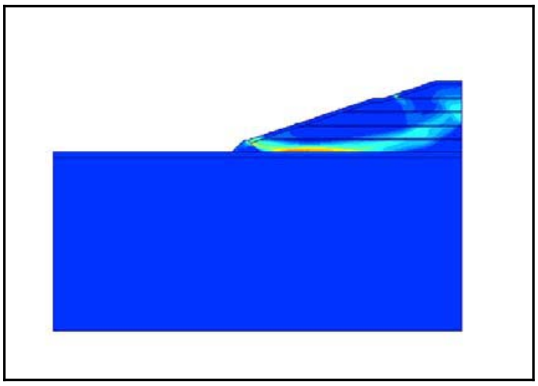
Presence of the intermediate covers influences the potential failure surfaces. Moreover, in some cases, the final cover, the liner or the lateral embankments can play role in determination of the dominant failure mechanisms.

The idea is to investigate the potential failure mechanisms as well as their evolution due to change in the strength parameters of materials. In order to perform this investigation, two series of analyses are performed. In the first series, the friction angle of the waste materials is changed from its lower limit up to its maximum value and at each stage the shear strain increments at failure are determined. In the second series of analyses, the same procedure is repeated by changing the friction angle of the intermediate soil covers instead of the waste materials.

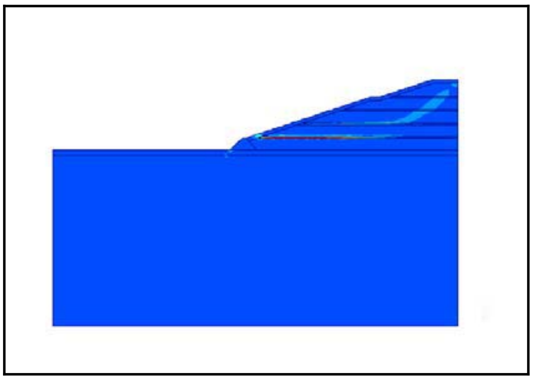
Figure 3 shows the shear strain increments at failure condition for two different values of the friction angle of waste materials. The shear strain increments at failure condition represent the failure surface. In these figures points that are in lighter colours represent higher values of the shear strain increments at failure.

As it can be seen in these figures, in the case that the friction angle of waste materials is relatively low in comparison with the intermediate covers (Figure 3a), the failure surface is created as a curve in the waste mass. In this case the failure surface crosses the intermediate covers without any change in its direction. As soon as this curve reach to the liner of the landfill that has relative high strength, the failure surface continues along the liner and ends up at the intersection of the liner and the embankment slopes. As the friction angle of waste materials increases, their strength increase in comparison with the intermediate covers and as a result composite failure surfaces are formed (Figure 3b). It means that the failure surface changes its direction when it meets the intermediate covers and the failure surface continues its path along these covers. So it can be seen that by increasing the waste material strength in comparison with the intermediate covers, the dominant failure mechanisms change and they tend to form and slide along the intermediate covers.

Figure 4 depicts the results of the other series of analyses in which the friction angle of intermediate covers is changed from a low value to a relatively high value. These figures show the shear strain increments at failure for two different values of friction angle of intermediate cover soil. By increasing the friction angle of soil used in these covers, the strength of these covers increases in comparison with the waste material. It is observed that when the friction angle of the intermediate covers is relatively low (Figure 4a), these covers play role as weak planes along which the failure surfaces can be emerged. When the strength of these covers increase, the failure surface changes from the linear one to the composite ones (Figure 4b). In the other word, the intermediate covers are not considered as weak planes any more and the failure surface experiences no change when crossing them.

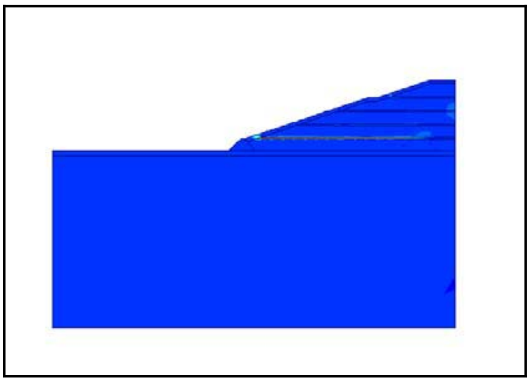


(a) Friction angle of wastes = 10°

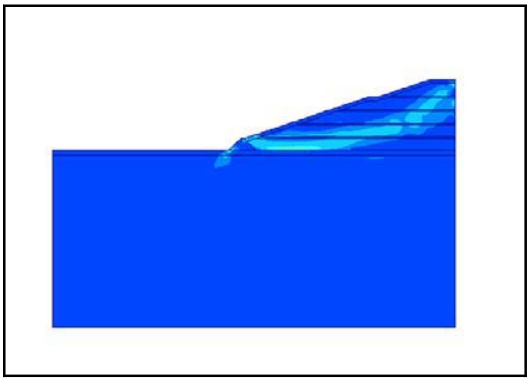


(b) Friction angle of wastes = 27.6°

Figure 3. Shear strain increments at failure condition variation of friction angle of waste material



(a) Friction angle of intermediate cover soil =10°



(b) Friction angle of intermediate cover soil =32.5°

Figure 4. Shear strain increments at failure condition variation of friction angle of intermediate cover soil

5. ANALYSIS OF LANDFILL STABILITY SENSITIVITY TO THE MATERIAL PROPERTIES

The main goal of the presented analyses is to investigate the effect of waste material properties as well as the cover soils properties on the safety factor of the landfill against instability. In order to study the effect of each parameter, the value of the parameter is changed while the values of the other parameters are kept constant as well as the analysis conditions.

5.1 Effect of waste materials

a) Unit weight: in order to study the effect of unit weight of waste materials on the landfill stability, the value of the unit weight is changed in the recommended range and at each case the corresponding values for different depths are calculated according to the modified profile presented by Kavazanjian et al. (1995). Figure 5 shows the evolution of the safety factor of the landfill versus the unit weight of the waste materials. As it can be seen in this figure, an increase in the value of this parameter results in a decrease in the safety factor of the landfill.

b) Strength parameters: Figures 6 and 7 represent the evolution of safety factor versus cohesion and friction angle of waste materials respectively. As it can be seen in these figures, these parameters have great influence on the safety factor. The safety factor increases by increasing the value of these parameters. It can be also seen that the rate of the safety factor increase is higher in the lower values of these parameters and as these parameters increase, the rate of safety factor augmentation decreases. This observed behaviour can be explained in this way: at the low values of the strength parameters, the existing resisting forces against instability are relatively low, therefore the increase of resisting force due to increase of strength parameters can play an important role in the stability of the landfill. In the other word, in high values of the resisting forces, the ratio of the increase in the available resisting forces does not change very much due to the change in the strength parameters. Moreover, it was shown in section 4.2 that by increasing the strength parameters of the wastes, the dominant failure mechanisms change and the failure surfaces tend to form along the intermediate covers. Therefore, the intermediate soil covers replace the wastes to play the most important role in determining the failure mechanisms.

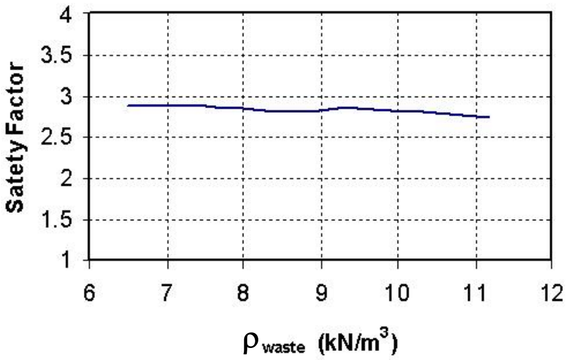


Figure 5. safety factor of the landfill versus the weight of waste material

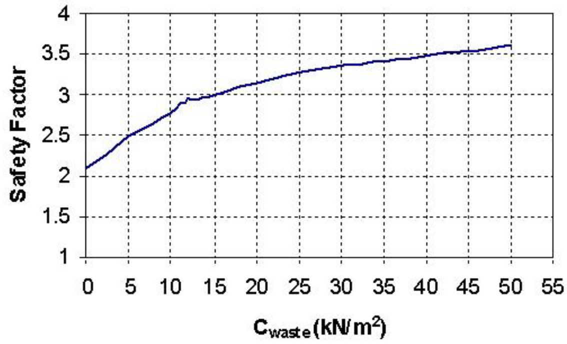


Figure 6. safety factor of the landfill versus the cohesion of waste material

Figure 7. Safety factor of the landfill versus the friction angle of waste material

d) Poisson's ratio: Figures 8 shows the evolution of the safety factor of the landfill due to changes in Poisson's ratio. As it is shown in this figure, change in the value of this parameter has no considerable effect on the safety factor. And as the Poisson's ration of waste material changes there are only some local alterations in the value of the safety factor that shows no important effect of this parameter on the safety factor of the landfill.

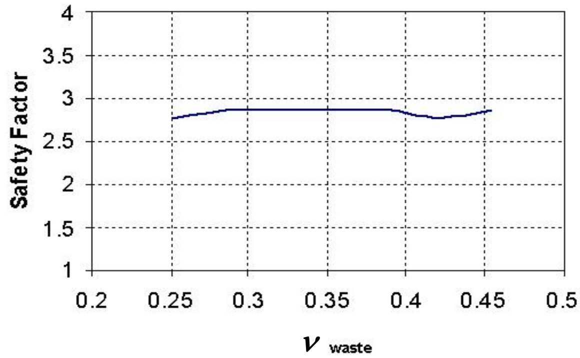


Figure 8. Safety factor of the landfill versus the poisson's ratio of waste material

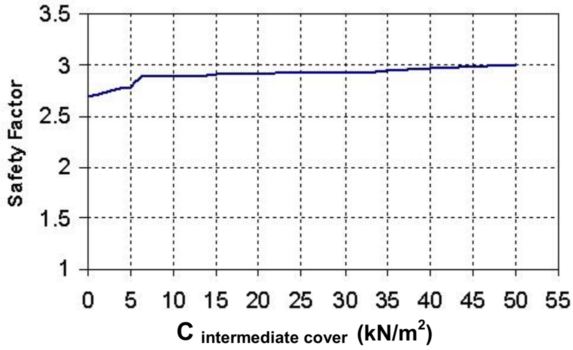


Figure 9. Safety factor of the landfill versus the cohesion of intermediate cover soil

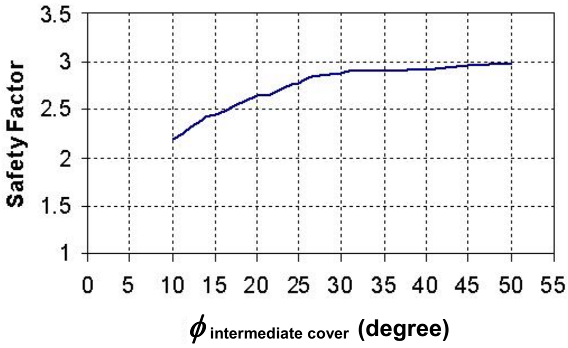


Figure 10. Safety factor of the landfill versus the friction angle of intermediate cover soil

5.2 Effect of intermediate cover materials

Intermediate soil cover strengths can highly influence the failure surfaces. The strength of these covers in comparison with the waste materials determines their influence on the formation or progress of failure mechanisms. Therefore, the effect of the strength parameters of the intermediate soil covers on the safety factor of the landfill is investigated here. Figures 9 and 10 show the effect of the cohesion and friction angle of intermediate cover soils on the safety factor of the landfill respectively. As it can be seen in these figures, the safety factor increases by increase of these parameters. It is also shown that effect of strength parameters on the safety factor decreases as the values of these parameters increase. This can be explained in the same way that was presented for the strength parameters of the waste materials.

Comparing Figures 5 to 10, it can be concluded that the strength parameters of the waste material and specially the friction angle of this material has the most important influence on the safety factor among the other studied parameters. However, It should be mentioned that the influence of different parameters on the stability of landfill strongly depends on the landfill type and its configuration.

6. CONCLUSION

The results of the static analyses of the landfill indicate that for the initial values of the parameters, the landfill is statically stable and its safety factor against instability is equal to 2.8. Investigation of the potential failure mechanisms in the landfill demonstrate that in conditions in which the strength of waste materials is low in comparison with the intermediate covers, the failure surfaces are created in the mass of the waste in a curved shape. In this condition the failure surface experiences no change when crossing the intermediate covers. On the other hand, when the waste materials are relatively strong, the composite failure surfaces are formed in such a way that when the failure surface reaches the intermediate cover, it continues its way as sliding along the cover. Moreover, the influence of the unit weight of the waste materials on the safety factor of the landfill is studied as well as the influence of the strength parameters of the wastes and intermediate covers. The results of these analyses show that in the higher values of the strength parameters, influence of these parameters on the safety factor decreases. Based on the results of these analyses, it seems that the friction angles of waste materials has the most important effect on the safety factor of the landfill.

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