Geotechnical assessment on the failure at Meethotamualla waste fill in Sri Lanka

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ABSTRACT

A catastrophic failure occurred at the waste disposal site in Meethotamulla close to Colombo, the main city of Sri Lanka on 14th April 2014. This tragic incident claimed several lives and caused the destruction of houses and infrastructure around the waste fill. A study was carried out to determine the probable cause of failure and to access the stability of waste fill to prevent further catastrophic situations. In the stability analysis, the drone images were used to define the pre-failure geometry and the cross-sections of the waste fill. The properties of the waste fill were determined by reviewing the published literature on engineering properties of waste material. The most appropriate subsurface profiles, strength parameters and unit weight of the subsoil underneath the waste fill were determined from the borehole investigations carried out at site previously. A model was developed to represent the actual site condition at the time of failure and the applicability of model was checked by simulating the observed failure pattern using GeoStudio 2016 software. Analysis results shows that the waste fill had been in a marginally stable condition prior to the rain spell. The additional increase of weight caused by the infiltration of the rainwater could have caused the instability in underneath soft soil layers resulting in failure in the waste fill. From the results of stability analysis, it can be stated that the waste sections containing fresh garbage with higher fill height and greater slope angles underlain by very soft/soft soils were prone to higher risk of failure especially under wet condition. On the contrary, the risk of failure was comparatively low for waste fills with older waste due to its decomposition at low fill height and low slope angles, underlain with stiff sub soil.

Keywords: waste fill, soft soil, properties of waste, shear strength, stability analysis, risk of failure

1 INTRODUCTION

The garbage mound located at Pothwillkumbura, Meethotamulla, collapsed on 14th April 2017 at 14.45 hrs., destroying houses and infrastructure situated at the toe region of the south-western side of the garbage mound. According to the situation report of "Meethotamulla Municipal Solid Waste Dump Disaster" by the Disaster Management Center, 60 houses have been completely destroyed, 27 houses partially damaged while 32 bodies have been recovered from the damaged area. According to the Meteorology Department, about 100 mm rain fall had been received during the period of 11th – 13th April 2017. Due to the heavy rains experienced on two consecutive days, part of the southern slope of the waste dump site has failed and many houses situated at the toe region of the failure had been totally pushed away and damaged (Fig. 1). The on-site observations and aerial images after the incident show that the slope of the waste fill had collapsed at its crest height, and the collapsed mass had almost moved down and subsided, while the toe region of the slope had upheaved.


Fig. 1. Damage due to the failure of the garbage fill

2 DETAILS OF THE WASTE DUMP SITE

The aerial imagery shows that before 1990, this location had been a low-lying, marshy ground. The analysis of previous records at this site reveals that the site had been used for waste dumping even before 1998. With the urban growth and rapid development, the location has been receiving waste in increasing amounts in subsequent years. According to the Colombo

Municipal Council, at the time of disaster, approximately 800-900 tons of waste were being dumped at the site daily. The on-site investigations reveal that this waste fill was an unregulated open fill where waste of all forms was dumped. The waste appeared poorly compacted with no or thin cover soil while waste material was dumped on bare soft soils without any bottom liner. Also, no leachate or a gas collection system were installed. Only a shallow canal was present around the waste fill to collect the leachate which was generated in combination of rainfall infiltration and as a byproduct from decomposition of waste.

Drone survey was conducted in the area to study the physical geometry, and to obtain spatial data and cross-sections of the waste dump. The details are shown in Fig. 2.

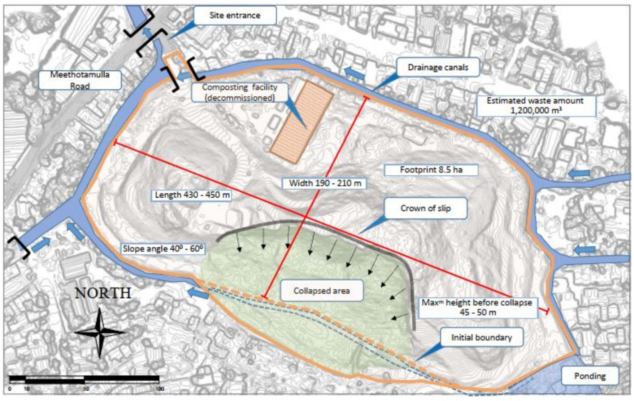

Fig. 2. Detail representation of the site after collapse

The spatial data obtained from the drone survey shows that at the time of collapse, the dump has occupied an area of 78,000 m^2, having a maximum length of approx. 413 m in the NW to SE direction and a approximate width of 189 m in NE and SW direction. The maximum crest height of the mound was in the range of 45-50 m. At this height, the garbage placement has made a ridge like shape in the NW to SE direction, and its slope inclination towards SW direction was in a range of 40^0-60^0 (Fig. 2). Compared to the failed segment of the waste fill, the rest of the segments were low in height and inclination.

2 PROPERTIES OF WASTE FILL & SUBSOIL

The properties of the waste fill and the underneath subsoil together with the scarification have been studied in order to obtain the parameters required for the stability assessment of the site.

2.1 Properties of Waste Fill

The properties of the waste fill under wet condition were considered in the stability analysis. The waste materials in landfills are greatly heterogenic in nature due to its composition, degree of compaction, decomposition etc. Therefore, respective shear strength parameters significantly differ over the waste fill. The shear strength decreases if the waste contains excess moisture, especially in upper part of waste fill (Yamawaki et al. 2017). Further, most of the degraded old waste has a relatively higher unit weight compared to fresh garbage, and as a result, unit weight increases with depth of the waste.

Considering above facts and with appropriate assumptions, the waste was categorized into four layers of varying thicknesses: Waste Fill (WF) – fresh waste in the top-most layer, Upper Waste (UW) - underlain by fresh waste, Intermediate Waste (IW) - followed by upper waste and partially decomposed and Lower Waste (LW) – immediately above the existing ground which was fully decayed (Stark and Huvaj 2008).

The unit weights of the waste fill layers were assigned to different waste layers by considering the assumed variations of compaction effect, overburden stress applied on each layer and the moisture content. Since actual shear strength parameters are not available for waste materials in Sri Lanka, the shear strength parameters for the analysis were obtained from published literature on engineering properties of waste materials at different levels of the fill reported by Dixon et al. (2005). The assumed parameters are shown in Table 1.

Table 1. Parameters considered for waste fill

Waste Type	Notation	ϒ(kN/m³)	φ'	C'(kPa)
Waste 4 (WF)		5.0	0	20
Waste 3 (UW)		6.5	38	0
Waste 2 (IW)		8.0	30	20
Waste 1 (LW)		9.5	30	20

2.2 Properties of Subsoil Layers

The strength parameters and the unit weight for underneath soil layers of the waste fill were estimated from the borehole investigation carried out at the site in 1998, 2012 and the past experiences related to the similar type of soils present in Sri Lanka as shown in Table 2. The sub-soil profile drawn based on borehole in the site shows that the top most layer is soft peat/clay with a thickness varying from 2-8 m overlain by a residual formation. The assumed full cross-section across the waste fill together with the subsoil profile and waste profile is shown in Fig. 3.

Table 2. Parameters considered for subsoil layers

Soil Type	Notation	ϒ(kN/m³)	φ'	C'(kPa)
Loose silt/sand/gravel		16	28	5
Sandy Clay		16	25	20
Peat		14	0	10
Medium dense sandy silt/ silty sand		17	30	10
Completely weathered rock		20	38	10

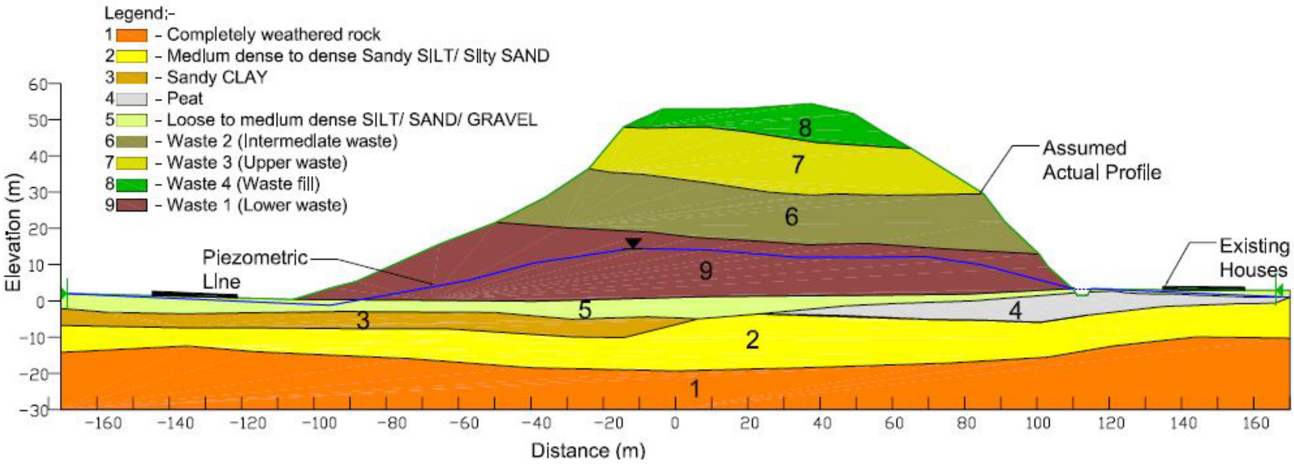

Fig. 3.Assumed full cross section across the waste fill together with the subsoil profile and waste profile

3 ANALYSIS OF THE WASTE FILL STABILITY

Numerical analysis was conducted to assess the stability of the waste fill along the failure section and as well as other sections. The stability along 4 different cross-sections was modelled covering all the critical areas of the waste fill site as shown in Fig. 4.

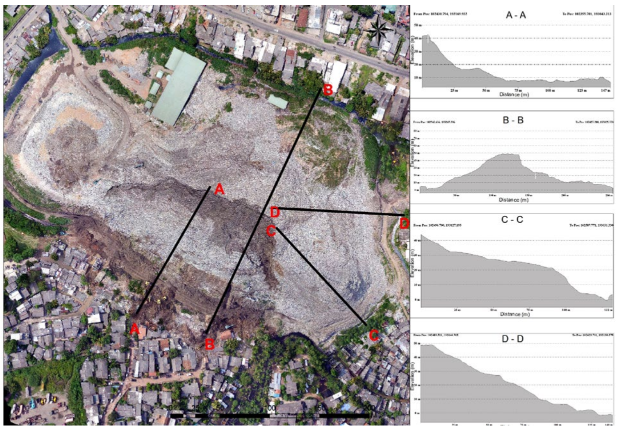

Fig. 5. Selected sections for the stability analysis

The most appropriate cross-sections of the waste fill for the stability analysis were identified based on the visual observations and the expert judgment. Several factors such as; pre-failure slope geometry, strength parameters of the waste materials and subsoil, drainage conditions of the site, erosion, weathering, etc. may have contributed to the failure. However, for the stability analysis, only pre-failure slope geometry, strength properties of the waste material and subsurface soil, and the maximum possible water table were considered as the primary factors. The assumed water table profile was based on the water level of surrounding area, the seepage observed through the failure surface and previous investigation results.

3.1 Model Validation

The applicability of the model was checked by carrying out an analysis for the full cross-section along Section B-B as shown in Fig. 5.

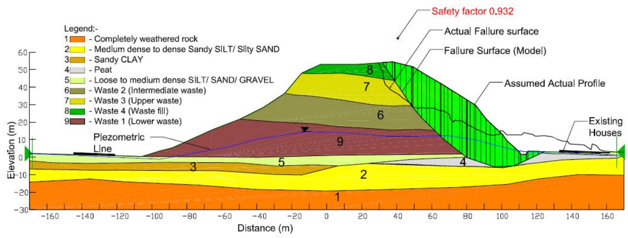

Fig. 4. Results of the stability analysis along the failure section

Stability analysis was carried out for the cross-section obtained through the drone survey and the material properties given in the section 2.1 and 2.2. The analysis was carried out using GeoStudio 2016 from Geo Slope. The Spencer method was utilized in the analysis as the actual slip surface geometry of the failure was irregular in shape. As shown in Fig. 5, the instability occurs at the Right Hand Side (RHS) of the section (where exact failure took place) and further, the failure predicted by the model conforms to the actual failure conditions. Therefore, the model seems to be capable for analyzing the section with the assigned parameters of the sub-soil and waste.

3.2 Results of the Analysis

The stability of the other sections was analysed by the model using the parameters described in the Section 2. In the analysis the profile of the waste fill developed with the aid of drone images and the subsoil profile was deduced based on the available borehole investigation data.

The Factor of Safety values calculated for the critical failure surfaces for each cross-section is presented in Table 3. The results clearly show that factors of safety of 0.807 and 0.932 were low at the failed sections A- A and B-B respectively, where waste was dumped at the time of failure. Also, the factor of safety of 0.813 calculated for the section C-C revealed that section C-C was also in an unstable condition although it did not collapse. The appeared cracks on the garbage fill on that section confirmed that it was also in an unstable condition. Therefore, section C-C would have collapsed, if the load imposed on the slope C-C were increased by further waste dumping.

Table 3. Stability of the waste fill in different Sections

Section	Factor of safety
A – A	0.807
B – B	0.932
B – B (opposite side of the failure)	1.338
C – C	0.813
D – D	1.276

According to the results, Section D-D and LHS of the Section B-B stay at stable condition relative to the other sections with a higher factor of safety greater than 1.25. The results of the stability analysis carried out along the Section D-D is shown in Fig. 6.

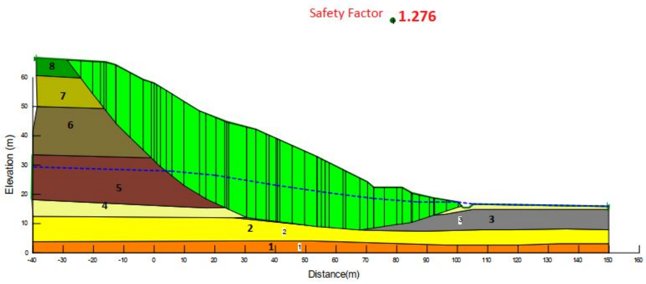

Fig. 6. Results of the stability analysis along the section D-D

From the results of stability analysis, it can be stated that the waste sections containing fresh garbage with higher fill height and greater slope angles underlain by very soft/soft soils are prone to higher risk of failure especially under wet condition. In contrary, the risk of failure is comparatively low in waste fills with older waste due to its decomposition, at low fill height and low slope angles, underlain with medium stiff/ stiff sub soil and drainage conditions.

4 IMPACT ASSESSMENT

The impact area map of failure at waste fill disposal site was prepared based on the above analysis and field observations is shown in Fig. 7.

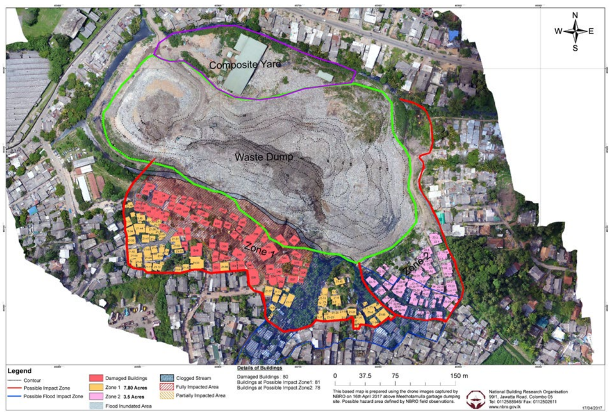

Fig. 7. Impact area map if Meethotamulla waste fill slide

The area demarcated by the red line was considered a high risk zone and the houses located within that area should be kept free from human occupation and recommended to be relocated. Also, it was advised not to carry out future development activities in that areas under the present condition. Based on the analysis results, the other areas seemed to be at relatively low risk. However, if the geometry of the waste fill is changed, the toe region is disturbed or the drainage conditions are altered without following correct stability norms, the low risk areas that are relatively stable at present may also become unstable.

5 CONCLUSION

Analysis reveals that the waste fill had been in a marginally stable condition prior to the rain spell. The additional increase of weight caused by the infiltration of the rainwater could have caused the instability in underneath soft soil resulting failure in the waste fill. Increase in water table and the decrease in shear strength in upper layer of the waste fill due to excessive moisture could have been the other contributory factors for the failure. As a consequence, a lateral movement of the peat layer in the direction towards houses and a significant ground upheaving has taken place at the toe region.

The model was set up to assess the stability of the waste fill incorporating the geotechnical properties of the waste fill and the properties of underlying subsoil. The performance of the model was checked by simulating the collapsed prolife of the waste fill. The results showed a very good agreement with the actual failure pattern and the calculated factor of safety was less than 1 for the critical slip surface, indicating that the model could successfully predict the stability of the waste fill. The risk of further collapse in other parts of the site was analyzed by the model and demarcated the areas with different risk levels.

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REFERENCES

Yamawaki, A., Omine, K., Doi, Y., Kawasaki, M, (2015). Slope Stability of Solid Waste Layers inside and outside of Japan, ISWA 15, World Congress, Antwerp, Belgium.

Stark, T.D., Huvaj, N., (2008). Back Analysis of Landfill Slope Failures, International Conference on Case Histories in Geotechnical Engineering, Arlington, VA, pp.11-16.

Dixon, N., Jones, D. R., (2005). Engineering properties of municipal solid waste. Geotextiles and Geomembranes 23, pp. 205-233.

National Building Research Organisation, Sri Lanka, (2017) Geotechnical Assessment on the Failure at Meethotamulla. Waste Fill.