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INCLUSION OF THE FIBRES REINFORCEMENT EFFECT IN THE ANALYSIS OF SLOPE STABILITY IN MSW LANDFILL – APPLICATION TO BANDEIRANTES LANDFILL CASE

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ABSTRACT

In Germany, in the 1990 decade, new models of stability analysis in sanitary landfills had been developed. These models were based in the study of reinforcement effect of the fibres present in the composition of the MSW. This reinforcement comes from materials as plastics, papers, cardboards, rubber, wood and textiles. The reinforcement in the MSW shear strength can be denominated as fibrous cohesion or pseudo-cohesion. For the inclusion of this reinforcement it is necessary to classify the waste according to its morphology. Percentage of materials with dimension 1 + dimension 2 will indicate the values to be used. For this classification the German technical recommendation GDA E1-7 should be followed [1] .

According to this recommendation, in stability analyses of sanitary landfills, the model considering the reinforcement effect of the fibres should be used. It intends to bring a better understand of the factors that had lead into failures in the past in landfills (back-analysis). In addition to that, this model can be used in designing of new landfills and studies to make higher landfills areas in operation.

In this work, the failure occurred in the Bandeirantes landfill located in São Paulo city, Brazil, was used as an application model. Besides that, Bandeirantes case was carried out as an extension of the study developed by [2] using the German model of stability analysis. For the accomplishment of the back-analysis contained in this work, it was used a software developed in Germany (GGU-Stability) which considers in its calculations the fibres reinforcement effect through the inclusion of a new strength parameter – angle of internal tensile forces (ζ). The results had shown that, in the time when the waste started to slide down, only the friction component was responsible for the shear strength. Therefore, the cohesive activated component was contributed by the fibres reinforcement, as a consequence of the landfill waste age.

KEYWORDS

Municipal Solid Waste (MSW); Stability Analysis; Sanitary Landfill.

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1 INTRODUCTION

In the waste mechanics up to now, a consensus does not exist between the theories and models developed that try to express the MSW behavior. Stability analyses in sanitary landfills have been carried out using theories and methods of the soils mechanics, through the adoption of shear strength parameters, cohesion (c) and angle of friction (□) for MSW. These parameters are usually obtained through international bibliographies, field tests, back-analyses of landfill failures and laboratory tests. However, definition of MSW shear strength presents many difficulties due to its heterogeneity composition, anisotropic behavior, changing of its characteristic by the time (degradation process), etc. In a MSW landfill body is possible to find very steep slopes with inclinations around 90º (see *Figure 1*), being evidenced that is necessary to research the characteristics and properties of this material.

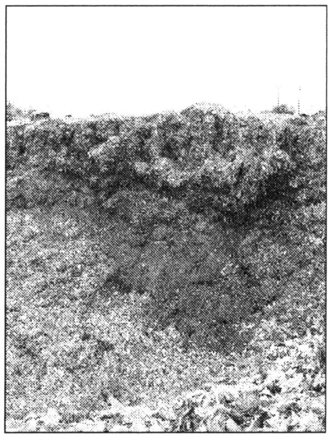

Figure 1. Bandung Landfill (Indonesian).

Unlike soil materials, the shear strength of MSW is not only originated by the friction among the grains but also for the fibrous cohesion or in other words the reinforcement effect of the fibres presents in the composition of the waste. Plastics, papers, cardboards, rubber, wood and textile compose the principal reinforcement material. Afterwards waste can be considered a material constituted of two components: basic matrix (granular particle) that presents friction behavior and fibrous cohesion i.e. the tensile forces from the fibrous components as fibres and foils.

Between 1990 and 1997, laboratory tests and models of stability analysis were developed in Germany, highlighting the Universities of Aachen, Braunschweig and Bochum. Important conclusions concerning waste mechanical behaviour were obtained from these projects, mainly regarding slope stability analyses and determination of MSW shear strength (Jessbergere, 1993; Jessberger, 1995; Kockel, 1995) [3, 4].

2 INCLUSION OF THE FIBRES REINFORCEMENT EFFECT IN SLOPE STABILITY ANALYSES OF MSW LANDFILLS

Due to the characteristics of the wastes concerning its heterogeneity and presence of elements with different sizes it is difficult to obtain representative samples for laboratories tests. In the same way a definition of an appropriate rupture model for the waste mechanical behaviour is necessary for determination of shear strength parameters.

Nowadays, the methods and models used for reinforced soils have been applied in stability analysis of the wastes. However, mistaken results can be found as a consequence of the difference between soil and MSW. Usually the void ratios of the waste materials are higher than soil leading to a larger volumetric compressibility. In addition to that, the characteristics and behavior of the waste change by the time due to decomposition process.

According to [3], the fibrous materials present in the composition of MSW (textile, plastics, etc) induce tensile forces that are function of the normal stress. The shear strength parameters of the MSW would be composed of two different parts being the first regarding to the friction forces in the shear plan and the second one regarding to the tensile forces due to the fibrous material or also denominated pseudo-cohesion.

Above all a methodology to calculate separately these two different components of the shear strength of the waste, consisting in equipment destined exclusively for the measurement of the tensile forces (see *Figures 2, 3 and 4*) was developed [4]. This tensile test was used under normal load with a sample of MSW being put in a box of large dimensions and exposed to the application of a normal load. Under this test conditions the tensile forces as well as the horizontal displacement were measured, expressing the results in a curve of tensile stress vs. deformation for several values of normal loads. The linear relationship among the tensile and normal stress can be described by the angle of internal tensile force (ζ). The shear strength component due to the friction force was determined in a direct shear device.

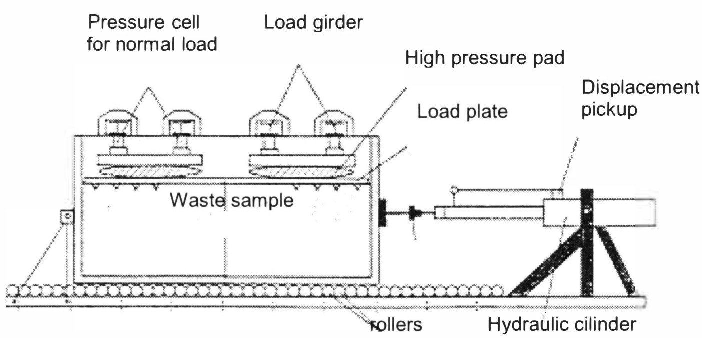

Figure 2. Test procedure [4].

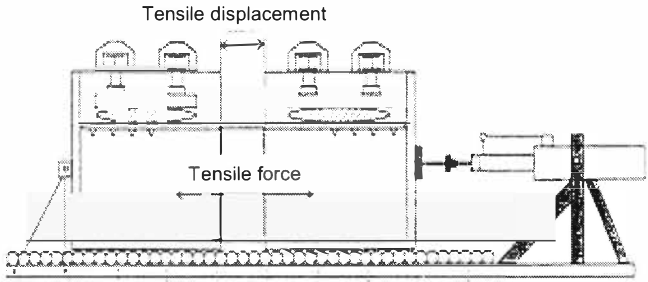

Figure 3. Test procedure [4].

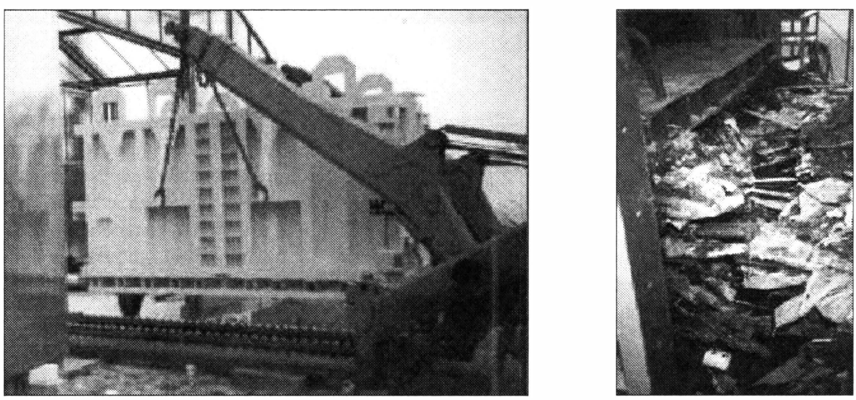

Figure 4. Illustration of the test procedure [4].

3 METHODOLOGY

According to the aim of this paper, the failure occurred in Bandeirantes landfill located in Brazil was used as a case study. Therefore, with utilization of the software (GGU-Stability) that incorporates in its formulation the reinforcement effect of the fibres (*see Figure 05*) a back-analysis of the cross section D of the Bandeirantes landfill was made. After that, a comparison between the results was made being presented in the IPT report.

In an effort to compare the results, the same established parameters were used as well as the rupture model (Mohr-coulomb). In this way, as established in IPT report, the values of shear strength parameters cohesion (c) and angle of friction (Ø) used were 13.5 kN/m^2 and of 22° respectively. The unit weight of MSW used for drained conditions and no drained were 10.0 kN/m^2 and 13.5 kN/m^2 respectively.

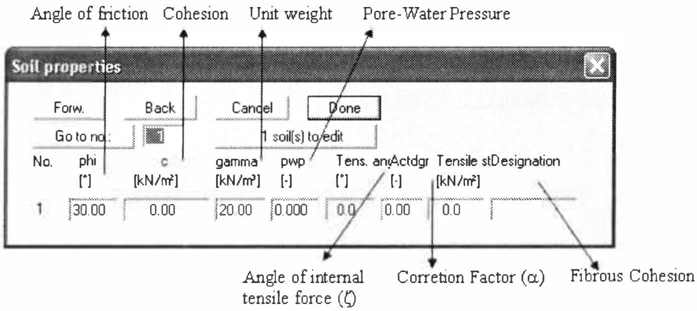

Figure 5. Entrance screen of materials properties (GGU-Stability).

The landfill drainage system conditions were represented through the variation of the parameter r_u. In analyses that consider limit equilibrium method, $r_u$works as an application of a pore-pressure value on the bottom of each portion corresponding to r_u times the total vertical stress.

Furthermore, for the inclusion of the reinforcement effect of the fibres, the angle of internal tensile force (ς) was added being considered as 35º (fresh waste) According to the morphologic classification of a Brazilian MSW sample. [5] reports values of dimension 1 + dimension 2 above 30% and then applied to the German technical recommendation GDA E 2-35 [6]. The age of the waste in the rupture section (*see Figure 6*) was considered fresh (1 year-old).

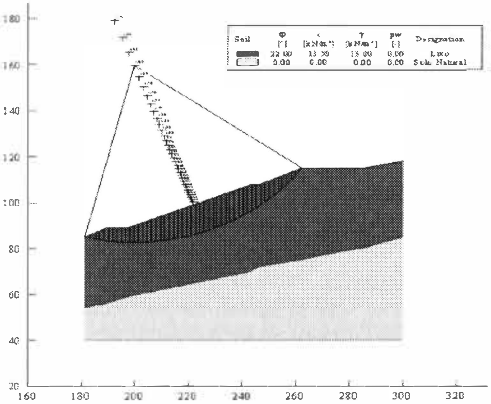

Figure 6. Cross section D of the Bandeirantes landfill used in the back-analysis of stability (GGU-Stability).

4 RESULTS

The back-analysis of the failure occurred in the Bandeirantes sanitary landfill considering the reinforcement effect of the fibres was compared to the analysis presented in [7] which was analyzed through the classic methods of the soil mechanics. Comparison among the results is presented below (see *Table 1*).

Table 1. Comparison among the results IPT and back-analysis considering the reinforcement effect of the fibres.

Parameters	**IPT Report** (classic methods of soil mechanics)			**Back-analysis** (with inclusion of fibre reinforcement effect)		
	$r_u = 0.0$	$r_u = 0.3$	$r_u = 0.6$	$r_u = 0.0$	$r_u = 0.3$	$r_u = 0.6$
Angle of friction ϕ'(°)	22.00	22.00	22.00	22.00	22.00	22.00
Cohesion c'(kN/m^2)	13.50	13.50	13.50	13.50	13.50	13.50
Unit Weight (kN/m^3)	13.00	13.00	13.00	13.00	13.00	13.00
Angle of internal tensile force ζ (°)	-	-	-	35.00	35.00	35.00
Correction factor α	-	-	-	0.50	0.50	0.50
Fibrous Cohesion (kN/m^2)	-	-	-	140.00	140.00	140.00
Safety Factor (SF)	2.06	1.55	1.00	2.25	1.83	1.38

Where:

- Angle of internal tensile force (ζ): value of $\zeta = 35°$ regarding fresh waste;
- Correction factor (α): Factor used to correct the inclination between the fibres and the rupture surface. For conservative analysis the value 0.5 was used in order to reduce 50% of the reinforcement effect;
- Fibrous cohesion (kN/m^2): Shear Strength reinforcement from the fibres.

The safety factor found in the back-analysis (SF= 1.38) for the pore-water ($r_u = 0.6$) indicates that the slope was stable in the worst condition. By using a unitary safety factor (SF = 1) for the same analysis, observed cohesion values are presented (*See Table 02*).

Table 2. Comparison among the results IPT and back-analysis considering the reinforcement effect of the fibres in the rupture condition.

Parameters	**IPT Report** (classic methods of soil mechanics)	**Back-analysis** (with inclusion of fibre reinforcement effect)
	$r_u = 0.6$	$r_u = 0.6$
Angle of friction □'(°)	22.00	22.00
Cohesion c'(kN/m^2)	**13.50**	**2.00**
Unit Weight (kN/m^3)	13.00	13.00
Angle of internal tensile force ζ (°)	-	35.00
Correction factor α	-	0.50
Fibrous Cohesion (kN/m^2)	-	140.00
Safety Factor (SF)	1.00	1.01

As a result from the back-analysis it can be affirmed that the cohesion parameter should be smaller than 2 kN/m^2 for an angle of friction of 22° differently from that presented by the IPT report.

5 CONCLUSIONS

After all, in conclusion of this paper:

• According to the application of the reinforcement effect of the fibres in a back-analysis of the Bandeirantes sanitary landfill failure, maintaining the same angle of friction, unit weight, geometry, pore-pressure condition ($r_u = 0.6$) presented in [7], however, adding the parameters of reinforcement of the fibres for fresh MSW (angle of internal tensile force $\zeta = 35°$) and the fibrous cohesion for a unitary safety factor, the result of the cohesion found was (c = 2 kN/m^2) that is significantly smaller of the value presented as a conclusion in the IPT Report (c = 13.5 kN/m^2).

That leads to conclude that the material by the exact failure time presented only granular characteristic. The responsible for the cohesion strength came from the reinforcement of the fibres more evidenced due to the age of the waste (fresh).

• In a general way, presence of weak soils in the foundation combine with high level of water infiltration in the body of the landfill that leads to high pore-pressure values is frequently the causes of slope instability failures in sanitary landfills.

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