

Investigation of the Shear Strength and Slope Stability of Turkish Municipal Solid Waste Composition[†]

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ABSTRACT

Along with the developing world population municipal solid waste amount increases enormously. Uncontrolled waste storage, which is not in abidance with well defined engineering regulations endangers human life and cause economic loss. In this study, natural water content, organic matter content, specific gravity and pH values of the synthetic waste (with pre-determined compositions) and natural waste samples were investigated in laboratory conditions. The shear strength parameters of synthetic and natural MSW samples were determined by using a large scale direct shear test system. The slope stability analyses were conducted for present slopes at static and dynamic conditions and the factor of safety values were obtained. The obtained engineering parameters of Turkey MSW composition can be used in the design of safe and economical landfills in Turkey.

Keywords: *Municipal solid waste, shear strength, aging, composition, slope stability.*

1. INTRODUCTION

The amount of solid waste, an inevitable by-product of human life, is rapidly increasing in parallel with the the developing world conditions. It is required to minimize the volume of municipal solid wastes, they must be stored regularly and they must be recycled with the help of technology. The basic engineering material of the sanitary landfills is the municipal solid waste itself. However, compared to other engineering materials, it is difficult to characterize the engineering properties of municipal solid wastes. Municipal solid wastes which includes different characteristic materials are heterogenous materials are heterogenous and their engineering and their engineering parameters such as unit weight, water content, shear strength, hydraulic conductivity may change depending on time, location and environmental conditions. Location selection of sanitary landfills is a problem all over the world and this further increases the importance of the areas which are reserved for sanitary landfill. In order to store large amounts of solid waste sanitary landfills must have steeper slopes and higher storage heights. When all these conditions are evaluated, sanitary landfills must be designed as precisely and comprehensively as possible and they should have long service life. Compositions of municipal solid wastes may change from country to country and even from city to city. For this reason, determination of the engineering properties of solid wastes

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whose characteristics vary with time are very important in terms of establishing safe and economical sanitary landfills. A limited number of studies have been carried out on the engineering characteristics of the MSW in our country. Turkey Institute of Statistics reported that the total amount of municipal solid waste was 25.28 million tons/year in 2010. The average daily waste per capita was calculated as 1.15 kg/day. The 82% of the total population of the country and 99% of the municipal population benefit from the waste collection service. The 54.4% of waste collected from municipalities is stored in storage facilities in accordance with waste management legislation and 0.8% is composted. The remaining 44.8% is stored in dumpsites. In order to design safer and more effective and economical sanitary landfills in Turkey, it is necessary to use suitable engineering parameters defined for Turkey's municipal solid waste composition. However, some problems are encountered when selecting the appropriate design parameters of municipal solid wastes. In this study, design parameters which can be used in sanitary landfill projects of Turkey's municipal solid waste compositions were determined.

1.1. Shear Strength Behavior of Municipal Solid Wastes

One of the most important factors affecting the stability of a slope formed naturally or man made is the shear strength of soil. It has been reported in the literature that the shear strength parameters of municipal solid wastes are in a wide range [1, 3, 4, 5]. There are many reasons why the shear strength parameters of MSW are in a wide range. The most important reason is that municipal solid wastes have different characteristics and various compositions which contain numerous materials. Municipal solid wastes contain strengthening fibrous materials with strip shaped such as plastic, paper and textile. This reinforcing effect consists of two main components: bonding resistance observed under the influence of normal stresses and tensile strength occurred due to the fibrous property of the material [6, 7]. Different from shear strength behavior of soils, tensile strength of strip shaped materials affects the shear strength. The shear mechanism of municipal solid wastes is divided into four phases [6]. In the first phase only frictional forces increase during deformation. In the second phase, tensile force was observed with increasing deformation due to strain in the fibrous material. Following this, in the third phase, the tensile strengths of the fibrous materials are exceeded and breaking and slipping are observed in their structure. In this phase, municipal solid wastes reach the maximum shear strength. Finally, the shear strength decreased in the fourth phase, shear strength only includes friction force. In the literature, the studies about the shear strength behavior of municipal solid wastes were generally divided into laboratory and field studies. The large scale direct shear tests were performed with natural samples taken from different dumpsites of Canada. As a result of large scale direct shear tests cohesion ranged between 10 and 23 kPa, internal friction angle varied from 24° to 42°[8]. Experiments conducted with aged municipal solid wastes taken from Blackfoot and Burbank dumpsite show that internal friction angles ranged between 38° and 42°, cohesion varied from 16 to 19 kPa. The decrease in the shear strength parameters is related to the one year degradation. Previous studies reported that fibrous and strip shaped wastes (paper, cardboard, textile, plastic) affects the shear strength positively [6, 7]. It is emphasized that tensile stresses produced by fibrous wastes increase

the shear strength and reinforce the structure of municipal solid waste [6, 9]. It was determined that internal friction angle was 35° for fresh MSW, 14° for degraded MSW and finally 0° for sample with no fibrous waste [9]. Experiments performed with large scale direct shear test reported that the internal friction angles are between 24° and 41° and the cohesion are between 0 and 23 kPa [10]. Shear strength parameters of MSW obtained from standard direct shear test were summarized in Figure 1 [11]. Previous literature studies reported that cohesion of MSW varies from 0 kPa to 50 kPa, internal friction angle ranged between 27° and 41° [3, 4, 8, 10, 12]. Because of aging, chemical, and biological degradation, municipal solid waste stored in dumpsites undergoes physical change. These changes lead to considerable changes in the engineering parameters such as water content, organic matter, unit weight, particle size distribution, internal friction angle and cohesion of MSW samples. Because of degradation, fibrous and strip shaped wastes deteriorated and lost their strengthening effects. It was remarked that fresh samples have lower internal friction angles than aged MSW samples [6]. Furthermore, it was reported that strength of municipal solid waste increased with time depending on unit weight [13]. It was stated that due to the increase in unit weight with time, solid waste skeleton turned into a tighter and stronger structure, whereas the structure of fibrous materials deteriorated. When the shear strength of 3, 5 and 15 year old MSW samples were examined, it was reported that the internal friction angles decreased from 40° - 38° to 35° - 32° and then to 26° respectively. The cohesion values decreased from 50 - 40 kPa to 15 - 12 kPa then to 10 kPa.

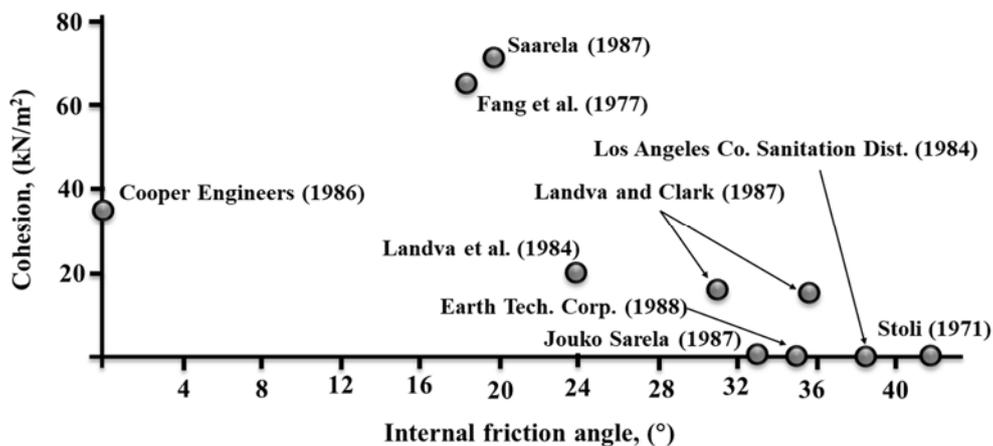


Figure 1. The reported shear strength values of MSWs [11]

1.2. Slope Stability of Municipal Solid Wastes

The shear strength of MSW has great importance in terms determining the maximum storage height and slope angle of sanitary landfill. Because of uncontrolled storage, heavy rainfall, lack of evacuation system, inadequate compression process, fire, extreme slope angle slope failures occur all over the world. These incidents can lead to great loss of life and property. The stability of the sanitary landfill is one of the most important property to

consider during the design process. Slope stability analysis can also be done by using the engineering properties of failed slope's waste sample. Researchers using the classical shear polygon method in slope stability analysis have determined that the most inconvenient slip circle passes through the slope heel region [15]. It was reported that the lowest safety factor is observed when the waste water content is increased [16].

In this study, engineering properties of synthetic and natural samples that are observed Turkey MSW composition were examined. For this purpose; unit weight, natural water content, organic matter content, specific gravity and pH of the synthetic Turkish and natural Manisa MSW compositions were determined in the laboratory condition. The changes in the engineering parameters of the synthetically aged samples stored in plastic containers under atmospheric conditions were investigated. The shear strength behavior of MSW was determined with large scale direct shear tests. Laboratory studies performed with synthetic samples were also conducted with natural samples taken from the Manisa dumpsite. Stability analyses were carried out by using parameters obtained from the laboratory test performed with MSW samples. In this way, safe slope angles and safety factors were determined for natural and manmade slope models.

2. MATERIAL CHARACTERISATION

In this study, synthetic and natural MSW samples were used. The synthetic MSW sample represents the Turkish average municipal solid waste composition (T-S) and natural MSW sample was taken from Manisa dumpsite (M-N). Average Turkish synthetic MSW composition constituted with widely encountered 11 waste materials (paper, cardboard, plastic, metal, wood, glass, park-garden waste, kitchen waste, soil, ash and textile). The Turkish synthetic (T-S) MSW composition ratios were compiled from the reports of the Ministry of Environment and Forestry [17], data from the Turkish Statistical Institute and academic studies [18, 19]. Table 1 shows the average municipal solid waste composition ratios determined for Turkish composition. The synthetic samples were prepared in laboratory conditions and divided into two parts. MSW samples were affected by biological degradation and chemical decay and have lost their natural texture. Prepared synthetic samples were stored in plastic containers under atmospheric conditions (rainy, sunny, and snowy weather) for one year. Fine drainage holes were opened in the lower parts of the plastic containers in order to prevent the flooding of the containers due to the increase of rainfall during winter. The natural municipal solid wastes to be used in the study were obtained with permission of the Manisa Metropolitan Municipality from the dumpsite located at 38° 36' 29" North, 27° 28' 44" East near the Spil Mountain in Manisa province Şahindere town. The maximum storage height of the Manisa dumpsite varies from 30 m to 40 m. The slope angles were measured between 40° and 50° in the field. Figure 2 shows the dumpsite area and transferred MSW samples. The samples taken from the dumpsite are divided into Manisa-Natural-Fresh (M-N-F) and Manisa-Natural-Aged (M-N-A) samples. Geotechnical laboratory experiments have particle size limitations, thus large scale sieves were made (50 mm x 50 mm) to eliminate the unsuitable particle size in the experiments. Samples were transferred to laboratory with sealed bags in order to preserve their natural moisture contents. The composition ratios of natural waste taken from Manisa dumpsite were obtained

from the Manisa Municipality 2010 annual report. Natural Manisa MSW composition ratio is quite similar to average Turkish synthetic MSW composition ratio [20].



Figure 2. The MSW landfill of Manisa city

Organic wastes cover approximately 50% of Manisa MSW composition. Due to the large coal mine resources the region has, there is a large percentage of ash waste in the composition.

3. EXPERIMENTAL METHODS

The synthetic MSW compositions have the maximum particle size limitations. For that reason, oversized materials were eliminated with sieves. Textile particles 1" (25.4 mm), paper and cardboard particles 1/2" (12.5 mm), chrome metal shavings 1/4" (6.3 mm), kitchen waste, garden waste and plastic particles No.4 (4.75 mm), glass fragments and wood shavings No. 10 (2 mm) and ash particles No. 40 (0.425 mm) were sieved and oversized materials were eliminated. The largest particle size belongs to textile parts which are very flexible and can be easily deformed. The specific gravities of waste materials used in the study were determined by applying vacuum according to [21] standard. It has been determined that the specific gravities of MSW in the literature and this study have been very close to each other. It was reported that specific gravities of three different municipal solid waste samples; natural fresh, natural aged and synthetic were 0.85-0.97-1.09, respectively [22]. The synthetic sample represents the waste composition of the United States of America were prepared in laboratory condition and specific gravity was reported as 1.60 [23]. Natural water content values of 11 waste samples were defined according to [24] standard test method. Samples were dried at 65 °C and 105 °C in constant temperatures and the natural water content difference was smaller than 1-2% and organic matter content difference was smaller than 1%. There was no significant change in two temperatures, for this reason the samples were dried at 105° for 24 hours for water content determination. The organic matter content values

of MSW samples were determined according to [25] standard. The samples were dried at 105°C for 24 hours and then burned at 440 °C to constant mass. The pH values of MSW samples were determined by the method proposed by [26]. MSW includes materials that are in a wide particle size distribution range, thus they are not suitable for use of standard equipments designed for soils. Because of particle size limitations defined in the standards, experiments conducted with small scale direct shear box may not give the correct and reliable results for MSW samples [27]. For this reason, a high-capacity, fully automatic large-scale direct shear test system (TC-S001-01) has been specially manufactured to determine the shear strength parameters of the MSW samples. The direct shear box had a cross-sectional area of 900 cm² (300mm×300mm) and a net height of 150 mm. Horizontal and vertical electronic displacement gauges (transducer) and load cells automatically send data to the computer. As a result of the literature studies, it was determined that similar to loose soil samples, there is no peak shear stress (maximum value point) of MSW samples. For this reason, the maximum lateral deformation was chosen as 20% (60 mm). Average shear rate determined with consolidation test (t_{90}) was 3 mm/minute [26]. The unit weight of MSW taken from dumpsite and sanitary landfill displays values in a wide range depending on some operations such as compaction, shredding and covering. In order to obtain uniform test samples, they were compacted between 9 and 13 kN/m³ unit weight range [10, 13, 20]. The optimum moisture content of MSW obtained from Modified Proctor test was 73% [20]. The synthetic fresh Turkish MSW sample was prepared at natural water content and then water required to reach the optimum water content (73%) is added. After the water addition the sample was mixed to obtain a homogeneous test sample. Samples were compacted in five layers by using Standard Proctor hammer with 25N weight (100 strokes/layer). The hammer was dropped repeatedly from a constant height to obtain a target unit weight (9 - 13 kN/m³). Thus, the same compression energy was applied to all test specimens. When the sample preparation process was completed, the total weight was divided by the total volume of direct shear box and unit weight of sample was checked. It was calculated that initial unit weight of Turkey-Synthetic-Fresh samples were determined as 10-11 kN/m³. The large scale direct shear tests were conducted at the saturated and partially saturated conditions. The direct shear tests were carried out under the effect of three normal stresses (49, 98 and 196 kPa).

In this study, fresh and aged slope stability analyses of Turkey-Synthetic and Manisa-Natural samples in different unit weights and geometrical properties were performed. The FLAC-2D computer program using finite difference method was used for stability analysis. Furthermore, the stability analyses of Manisa-Natural-Fresh and Manisa-Natural-Aged samples were carried out using the Talren (V.4) program. Literature studies show that unit weight of MSW samples ranged between 4 and 16 kN/m³ [4, 28]. It was determined that the unit weight values of natural and synthetic samples varied between 8 and 13 kN/m³. In the slope stability analyses loose and dense unit weights were used ($\gamma_{loose} = 7 \text{ kN/m}^3$ and $\gamma_{dense} = 14 \text{ kN/m}^3$). Mohr-Coulomb model was used for all analyses, at the end of the literature survey modulus of elasticity and Poisson's ratio values were 10000 kN/m³ and 0.3, respectively [1, 4].

4. EXPERIMENTAL RESULTS

4.1. The Physical and Chemical Characterisation of Municipal Solid Waste Samples

The natural water content, the natural water content, organic matter content, specific gravity and pH determination tests of the synthetic and natural MSW samples used in the study were carried out. The specific gravity values of the 11 different materials which were used in the MSW sample production are given in Table 1. The highest specific gravity value of 7.41 belongs to metal waste and the lowest specific gravity value of 0.76 belongs to plastic waste. The volume and weight percentages of the waste materials in the composition are given in the Table 1. As can be seen from Table 1, the volume percentage of sawdust is approximately twice the weight percent. It has been determined that there is no significant difference between weight and volume percentages of other waste materials used to form the compositions. The values of natural water content of the waste materials determined by keeping the material at 105 °C for 24 hours are shown in Table 1.

Table 1. The material properties forms the Turkish-Synthetic (T-S) sample

Material	Composition percentages		Water content (%)	Specific gravity	Maximum grain size (mm)
	Weight (%)	Volume (%)			
Kitchen waste	22.5	24.1	620	1.32	4.75
Broken glass	4	1.8	0.1	2.41	2.00
Garden waste	22.5	24.1	468	1.05	4.75
Plastic particles	10	15.5	0	0.76	4.75
Wood shavings	4	8.6	8	0.96	2.00
Metal-dust-chips	2	0.3	0.1	7.41	6.30
Ash	15	6.3	1	-	0.425
Paper pieces	12	11.8	3	1.77	12.50
Cardboard pieces	3	2.9	2	0.95	12.50
Textile pieces	5	4.7	0	1.18	25.4

The Turkish-Synthetic (T-S) sample contained a high organic content, whereas a low content of specific gravity values higher materials such as metal, glass, and soil caused low specific gravity. It has been determined that Turkey-Synthetic-Fresh (T-S-F) sample has a basic property with high pH value. The reason for this is ash waste in high proportion within the composition (Table 2). Organic wastes have a higher water content value than other waste materials. As a result of this situation, the water content value of the Manisa-Natural-Fresh (M-N-F) sample is higher than the Manisa-Natural-Aged (M-N-A) sample. The experiments to determine the characteristics of Turkey-Synthetic-Aged (T-S-A) samples were carried out during the autumn season when the amount of rainfall was high. For this reason, the natural water content of synthetic aged samples is higher. The amount of organic matter in Turkey-Synthetic-Aged (T-S-A) sample was 62% at the end of 3 months, but it decreased to 52%

after 12 months. The pH value of the the fresh sample was 10.47 sample was 10.47, but the pH value decreased to 9.42 after 12 months.

Table 2. The physical and chemical properties of the MSW samples

Sample	Specific gravity (Gs)	Natural water content (%)	Organic matter content (%)	pH
Turkish-Synthetic-Fresh (T-S-F)	1.24	62	65	10.5
Turkish-Synthetic-Aged (T-S-A)	-	114	52	9.4
Manisa Natural Fresh (M-N-F)	1.12	94	61	-
Manisa Natural Aged (M-N-A)	1.43	68	41	-

While the natural fresh wastes (Manisa-Natural-Fresh) obtained from Manisa Metropolitan Municipality waste storage area consist of samples which are 5-7 days maximum in storage, the storage period of the aged wastes (Manisa-Natural-Aged) taken from different regions of the storage area starts from 5 years up to 10 years. The natural water content of Manisa-Natural-Fresh sample was determined as 94% and the amount of organic matter as 61%. The specific gravity value of the Manisa-Natural-Fresh sample was found to be 1.12 near the Turkey-Synthetic-Fresh sample (Table 2). Turkey-Synthetic-Fresh sample prepared according to Turkey's average solid waste composition with Manisa-Natural-Fresh sample having similar compositional characteristics to each other has very close values in terms of percentage of organic matter ($OM_{MNF} = \%61$, $OM_{TSF} = \%65$). When the specific gravity values of Manisa-Natural-Fresh and Manisa-Natural-Aged samples are compared, it is seen that the specific gravity value of the aged sample is larger than the fresh sample. The reason for this situation is that the biodegradation of organic wastes at high levels in the fresh sample are transformed to higher specific gravity wastes.

4.2. The Shear Strength Behavior of the Synthetic Municipal Solid Wastes

Large scale direct shear tests have been carried out in order to determine the shear strength properties of synthetic specimens of Turkey MSW composition prepared in the laboratory condition. Higher permeability MSWs can reach a saturated state in areas where the perched water table is elevated or where rainfall is high. In order to be able to represent this situation in the laboratory environments, the experiments were carried out while the sample was in a saturated state by filling the outer casing of the direct shear box with water. Experiments of natural water samples were carried out with samples of optimum water content in the absence of water in the outer chamber. During the tests, lateral deformations and corresponding shear stresses were recorded by the computer. The maximum shear stress values and corresponding normal stress values for three different normal stress values are shown in Fig. 3 for the case of saturated and at optimum water content for the Turkey-Synthetic-Fresh sample. In the case

of optimum water content, the effective internal friction angle of the sample was 21° and the effective cohesion value was 50 kPa. In the saturated condition, the effective internal friction angle was 23° and the effective cohesion value was 49 kPa.

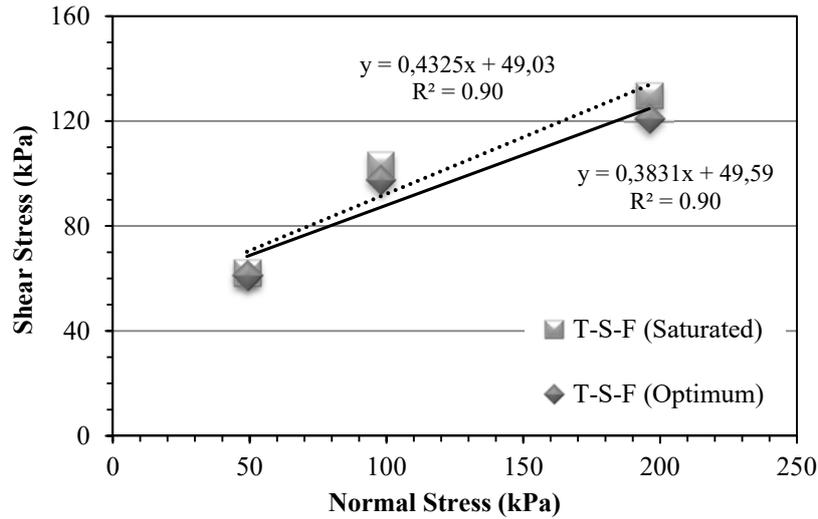


Figure 3. The shear strength envelopes of the T-S-F samples in saturated and at optimum water content conditions

It has been determined that the value of the internal friction angle of Turkey-Synthetic-Fresh saturated sample, in which the situation under the perched water table is represented, is 12% higher than the value of the Turkey-Synthetic-Fresh sample which is at optimum water content. It was determined that the cohesion values were almost equal to each other, while the internal friction values of the samples of the same composition differed under two different test conditions. The cohesion is due to the chemical and physical bonding forces between fine grained soils, whereas in municipal solid wastes, cohesion is interlocking effect of the components which is very different than the soils [7]. This parameter is also defined as artificial cohesion, which is caused by capillarity forces. For both samples, the vertical deformations were between 2.4 and 4.4 mm during shearing and settlement behavior was observed during the experiment.

Freshly produced synthetic samples were aged in large plastic tanks for 12 months exposing them to outdoor conditions and the shear strength parameters were determined by large-scale shear tests. The water content and organic matter content of the Turkish-Synthetic-Aged sample was obtained as 115% and 52%, respectively. Considering that the amount of organic matter in Turkey-Synthetic-Fresh sample is 65%, it is seen that there is a 20% reduction in the amount of organic matter during 12 months. The relationship between shear stress and lateral deformation obtained from computer controlled direct shear test is shown in Fig. 4.

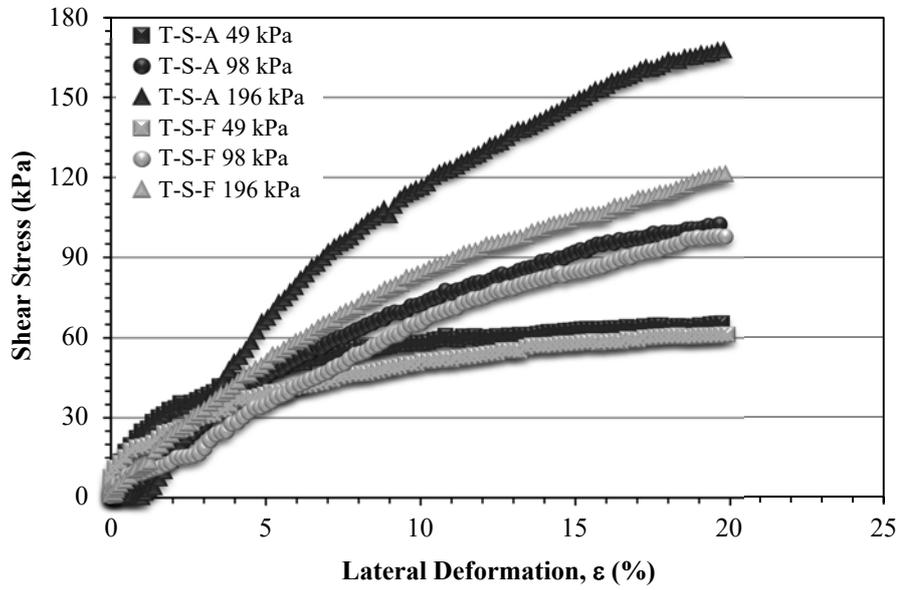


Figure 4. The τ - ϵ relationship of the Turkish Synthetic Aged and Turkish Synthetic Fresh samples

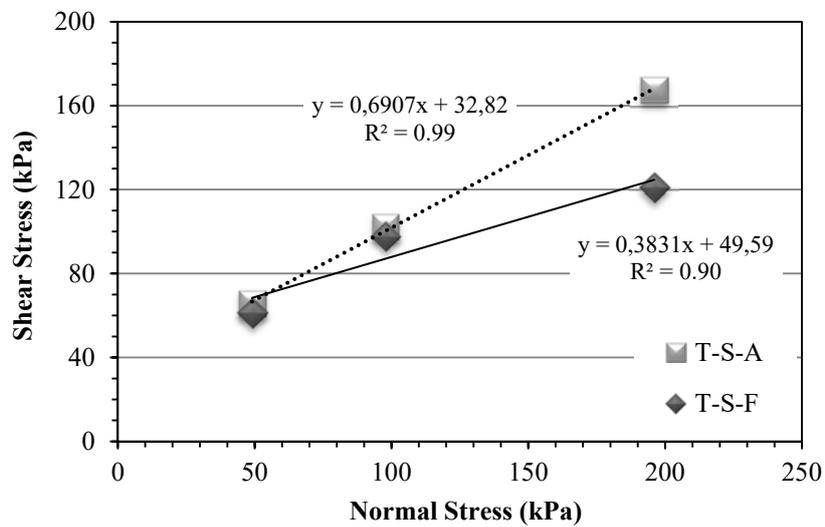


Figure 5. The shear strength envelopes of the fresh and aged Turkish MSW compositions

According to the results of large scale direct shear tests, the angle of internal friction value is 35° and effective cohesion value is 33 kPa of the Turkish-Synthetic-Aged sample. The shear envelopes of the fresh and aged samples of the synthetic MSW composition of Turkey are shown comparatively in Fig. 5. The angle of internal friction values of aged sample greater than the fresh one ($\phi'_{T-S-A} = 35^\circ > \phi'_{T-S-F} = 21^\circ$). It is observed that the cohesion value of the aged sample is 33 kPa, whereas the effective cohesion value of the fresh sample is 50 kPa.

According to the results of this study, the cohesion values decrease while the angle of internal friction increases with the effect of aging. Parallel to these results, it was also determined that the internal friction angle of fresh wastes is smaller than the aged wastes by [6]. It has been determined that the components (paper, cardboard, plastic, textiles) that act as reinforcing agents in fresh wastes play a more active role than the aged sample. The reason for the decrease in cohesion value due to aging is that the interlocking materials lose their properties over time. The results have shown that, cohesion values are also decreasing in parallel with the decrease in the amount of organic matter, which is an important effect on the value of cohesion over the end of the aging period.

4.3. The Shear Strength Behavior of Natural Municipal Solid Wastes

Natural waste samples from the Manisa Metropolitan Municipality landfill were sieved through 50mmx50mm sieve to eliminate large particles that did not meet the grain size limits specified in the standards. After compression of the fresh MSW sample, the initial unit weight of the sample was determined to be 11 kN/m³ (Figure 6). The shear envelopes of Manisa Natural Fresh (M-N-F) and Turkey Synthetic Fresh (T-S-F) MSW samples are shown comparatively in Fig. 7.



Figure 6. The Manisa natural fresh (M-N-F) sample placed in the shear box

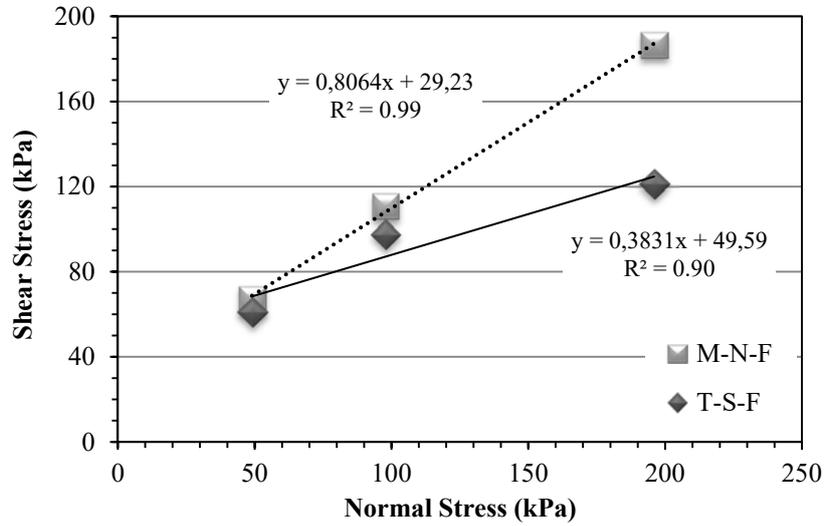


Figure 7. The shear strength envelopes of the M-N-F ve T-S-F samples

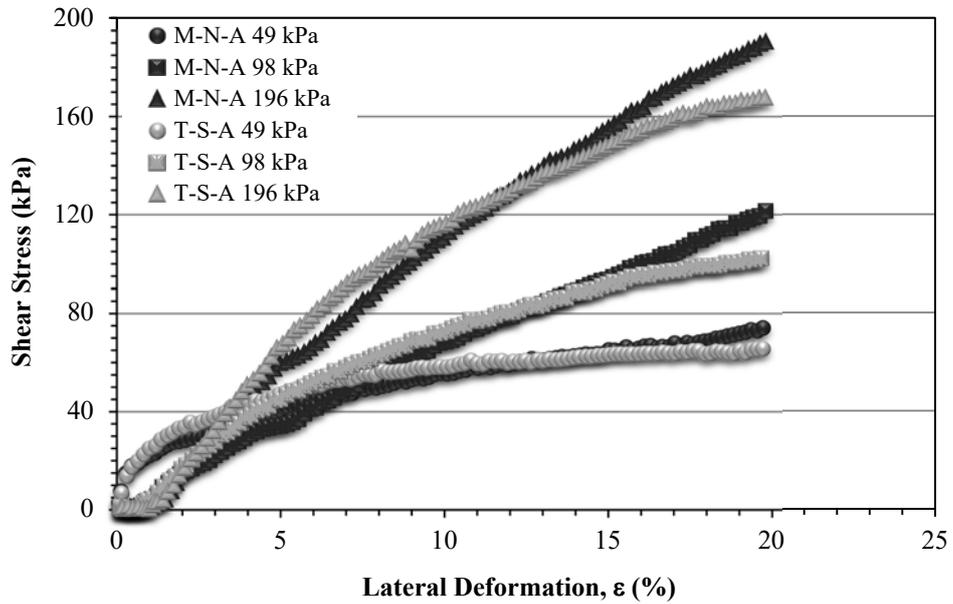


Figure 8. The $\tau - \epsilon$ relationship of the Manisa Natural Aged and Turkish Synthetic Aged samples

As a result of the large scale direct shear test performed, the effective internal friction angle of the Manisa Natural Fresh (M-N-F) sample was 39° and the effective cohesion value was 29 kPa. The angle of internal friction of the M-N-F sample was much higher than the T-S-F sample ($\phi'_{M-N-F} = 39^\circ > \phi'_{T-S-F} = 21^\circ$). The formation of this situation indicates that the Manisa Natural Fresh sample has a much larger grain size distribution than the Turkey Synthetic Fresh sample. Manisa Natural Fresh sample taken from the natural environment had been subjected to various sorting and sieving processes, but it has larger particles than the Turkey Synthetic Fresh sample. The unit weight at the beginning of the experiment was measured as 12.5 kN/m³ for the natural aged Manisa Natural Aged sample taken from the Manisa landfill.

The relationship between shear stress and lateral deformation of Manisa Natural Aged and Turkey Synthetic Aged samples is shown in Fig. 8. The angle of internal friction and effective cohesion values of the Manisa Natural Aged sample was seen to be as 38° and 40 kPa, respectively. When comparing the shear strength parameters of the Manisa Natural Aged sample with the Turkish Synthetic Aged sample of similar composition, it was observed that the aged samples had closer values compared to the fresh samples. Manisa Natural Aged sample had 20% greater values of internal friction angle and 10% greater values of cohesion compared to Turkey Synthetic Aged sample. This is due to the fact that the natural waste samples have a larger grain size distribution than the synthetic samples.

When direct shear tests results using natural MSW specimens are examined, it is seen that the effective internal friction angles are higher than the synthetic samples. The most important reason for this is the larger particles inside the MSW samples. When the cohesion values of natural and synthetic samples are compared, there is no great difference between them. In this study, the results of large scale direct shear tests using synthetic and natural, fresh and aged MSW samples are summarized in Table 3.

Table 3. The effective shear strength parameters of the MSW samples

MSW type		Sample	ϕ' (°)	c' (kPa)
Synthetic	Fresh	T-S-F (Opt.)	21	50
		T-S-F (Sat.)	23	49
	Aged	T-S-A	35	33
Natural	Fresh	M-N-F	39	29
	Aged	M-N-A	38	40

It is seen that Turkey Synthetic Aged sample has a higher effective friction angle value than Turkey Synthetic Fresh samples which have large organic matter content. The comparison of the obtained test results with the other studies from in the literature is shown in Figure 9. It is seen that the shear envelopes obtained from various studies and the shear envelopes obtained within this study are in good agreement. The bold cut lines in the graph represent the limits of the largest and smallest shear strength parameters encountered in the literature.

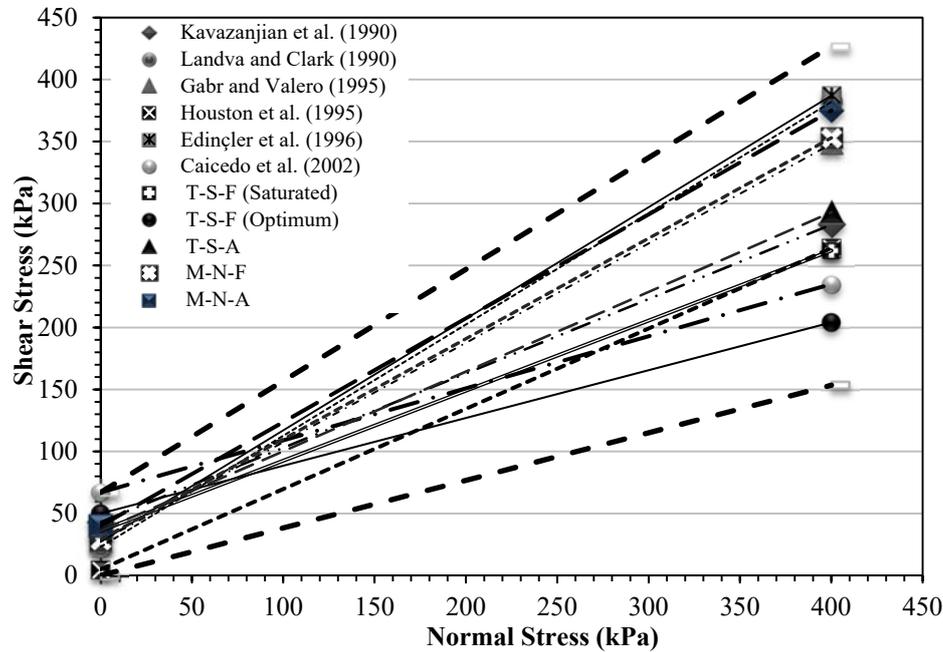


Figure 9. The comparison of the different shear envelopes from literature

4.4. Slope Stability Analyses of the Municipal Solid Wastes

In this study, for the slope stability analysis FLAC (V:7.0.419) computer program was used. As a result of literature studies, it was determined that the slope angle of the MSW landfills changes between 15° and 45° [29, 30, 31, 32]. In the world, some waste landfills have been found to be much larger than it should be, but they have not been used in analyses because they present a great danger. Two different slope angles were used in the stability analysis: 1 unit vertical 2 unit horizontal ($\alpha = 26.6^\circ$) and 1 unit vertical 3 unit horizontal ($\alpha = 18.4^\circ$). In the literature, studies conducted with natural MSW samples, the unit weight values of MSWs changed between 4 kN/m^3 and 19 kN/m^3 . Undoubtedly, the lower limit and upper limit remains much higher than the unit weight values to be met in normal conditions. The experimental studies with natural and synthetic samples in the laboratory showed that the unit weights of the MSWs varied between 7 kN/m^3 and 14 kN/m^3 and these values were used as upper and lower limit values in the slope stability analysis. Two different slope angles, two different unit weight values, aging effect (fresh and aged) were taken as stability analyses variables. In the slope models the ground water table level was defined at the base level. Table 4 shows the factor of safety values obtained from the analyses made with the models with different unit weight, slope angle, aging effect variables.

As can be seen from Table 4, the observed shear strength parameters, unit weight values, and the factor of safety values of the modeled slopes can be considerably larger (overdesign). In this way, it was investigated how the slope modeled with the same shear strength parameters and unit weight values reached the required factor of safety values ($FS = 1.5$) at which height

and slope. The results obtained from the models with different storage heights and slope angles at two different unit volume weight values (7 kN/m³ - 14 kN/m³) with the required factor of safety values of Turkey Synthetic Fresh composition are shown in Figure 10. In addition to the models defined by the water level at the slope base level (inactive), the phreatic line defined on the slope surface and analyses were also performed for these models. As a result of the analyses made, it was determined that the phreatic line defined along the slope surface adversely affected the stability and reduced the number of safety by 10-20%.

Table 4. The factor of safety values of modeled slopes with different engineering parameters

Slope angle	Unit weight (kN/m ³)	Composition	Shear strength parameters		FS
			ϕ' (°)	c' (kPa)	
1V/3H $\alpha=18.4^\circ$	7	T-S-F	21	50	4.5
		T-S-A	35	33	4.9
	14	T-S-F	21	50	3.1
		T-S-A	35	33	3.8
1V/2H $\alpha=26.6^\circ$	7	T-S-F	21	50	3.8
		T-S-A	35	33	3.8
	14	T-S-F	21	50	2.5
		T-S-A	35	33	2.8

As can be seen from Fig. 10, the approximate storage height for a unit volume weight of 14 kN/m³ and at a slope angle of 50° is 30 m, while at a unit volume weight of 7 kN/m³ this value would be about 45 m. The lower unit weight MSW sample can be stored at larger heights than the large unit weight sample at the same slope. When the effect of the slope angle on the stability was examined, it was seen that the modeled MSW with a slope of 1V / 2H ($\alpha = 26.6^\circ$) had much lower safety numbers than the slope of 1V / 3H ($\alpha = 18.4^\circ$). As the slope angle increases, the shear stress on the surface of the MSW materials also increases, so the safety of the slope is reduced.

Another important variable on the stability analysis of MSWs is the unit weight. When the unit weight values were examined, it was seen that the unit weight of 7 kN/m³ had a higher factor of safety in two different slope angles ($\alpha = 26.6^\circ$ and $\alpha = 18.4^\circ$). Since stresses in slope body originate from materials own weight, the greater weight of the slope body, the lower slope stability, the smaller factor of safety. Regular waste landfills are required to be able to maintain large volumes of waste as possible in order to be able to serve for a long time and be economical. For this reason, it is desirable that storage heights should be as high as possible. However, it has been observed that the storage height and the factor of safety of the

modeled slopes are inversely proportional, that is, as the storage height increases, the factor of safety decreases.

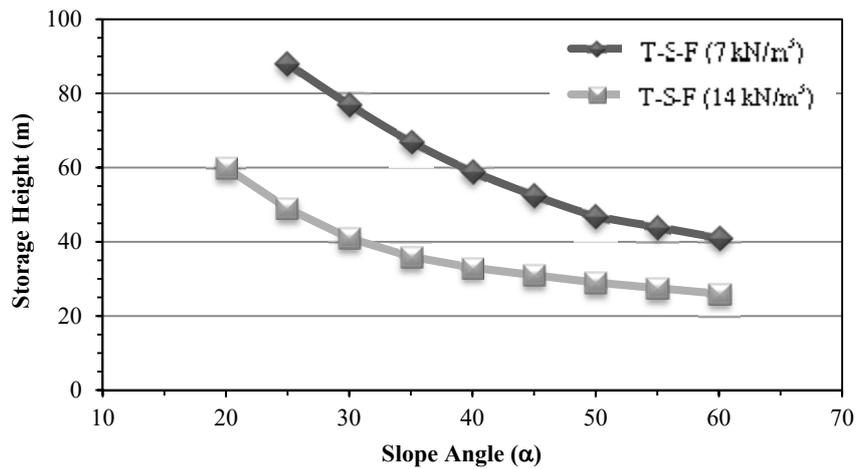


Figure 10. The storage heights corresponding to slope angles with critical safety

The geometric features of the landfill site Manisa province were determined using photographs taken. Stability analyses of fresh and aged samples from the Manisa wild solid waste storage site were carried out for three different slope gradients (40° - 45° - 50°) and a storage height of 40 m. The stability analyses of natural waste slopes were carried out with the help of the FLAC-2D program, which uses the finite difference method, in addition to this Talren (V.4) programs which uses limit balance (Bishop and Fellenius) methods were used and factor of safety values were obtained comparatively. The factor of safety values obtained for fresh and aged Manisa natural MSW samples using two different analysis programs are shown in Table 5.

Table 5. The results of the stability analysis results of the Manisa landfill samples

Slope Angle	FLAC 2-D		TALREN			
			Fellenius		Bishop	
	Fresh	Aged	Fresh	Aged	Fresh	Aged
α=40°	1.7	1.9	1.5	1.6	1.7	1.8
α=45°	1.5	1.7	1.4	1.5	1.5	1.6
α=50°	1.3	1.5	1.2	1.4	1.3	1.4

As it is seen from Table 5, it is determined that the factor of safety values of the aged samples are 10% -15% higher than the factor of safety of the fresh samples. The stability analyses of the Manisa natural MSW samples were performed with the same geometric and material properties under the influence of dynamic forces. The seismic data of the region were obtained from the site of the strong earthquake observation network managed by the Prime Ministry Disaster and Emergency Management Presidency Earthquake Department (<http://kyh.deprem.gov.tr/>).

The earthquake magnitude between 5.5 and 8.0 was investigated and 11 earthquake records were obtained since 1976. These records were analysed on the basis of the fault characterization, the magnitude of the earthquake, the distance to the landfill site, the cleanliness of the acceleration records and Bornova earthquake with 5.3 magnitude which occurred in December 16, 1977 at 38.41 North - 27.19 South epicenter, at a depth of 24 km from the surface, was selected for analyses. The duration of the earthquake was 9.31 seconds and the sampling interval of the seismograph was 0.005 seconds. The obtained earthquake acceleration records were scaled to have maximum acceleration values of 0.4g - 0.2g - 0.1g and 0.05g. Four different maximum acceleration values were applied to the modeled base rock and maximum displacements in the slope were obtained. The displacements of the first two acceleration values (0.4g and 0.2g) were 59 mm and 11 mm respectively while the displacements of the other two accelerations were very small ($\Delta D < 1$ mm).

5. CONCLUSIONS AND FUTURE RECOMMENDATIONS

In this study, geotechnical characterization of natural and synthetic municipal solid waste samples belonging to Turkey compositions was determined by laboratory experiments and the stability analyses of existing and designed slope models were performed by using the obtained engineering parameters.

When the physico-chemical properties of synthetic and natural MSW samples with different properties are examined, it has been seen that the amount of organic matter decreases over time for synthetic and natural samples, depending on the effect of aging. The specific gravity values of the samples were between 1.12 and 1.43. Although the natural water content of the samples is dependent on outdoor conditions (snow, rain), the natural water content value decreases as the proportion of organic waste decreases. As a result of the large coal mine reserves of the district, ash waste has a large percentage (15%) in the composition, which turns the pH values of the samples to basic (pH = 9.4-10.5).

When shear strength parameters of the Turkey-Synthetic-Fresh samples were examined at the optimum water content and saturated condition, it is seen that the samples in the saturated condition have a higher ϕ' value. In this case, materials with high water absorption capacity, such as paper, cardboard, textile, sawdust, which are found in the composition of MSW, would probably swell by adsorbing water and cause extra tensile strength against shear stresses. It has been determined that Turkey Synthetic Aged sample with aging effect has a higher effective internal friction and lower cohesion value than Turkey Synthetic Fresh sample. This explained the decrease in the amount of high water content organic waste in the sample, the increase in the proportion of the fibrous waste that influences the strengthening effect by aging. When shear strength parameters of Turkey Synthetic Fresh sample and Manisa Natural Fresh sample are compared, it has been determined that the effective internal

friction angle of the Manisa Natural Fresh sample is higher and the cohesion value is smaller. Similar results were obtained for synthetic and natural aged samples. The fact that the natural samples have larger particles than the synthetic samples which led to greater internal friction.

As a result of the stability analysis of the slope models with different engineering characteristics, it was determined that the factor of safety values of the slopes with 1V / 2H slope were 15% - 25% smaller than the models with the slope of 1V / 3H. Based on the slope factor of safety used in the designs (FoS = 1.5), storage height-slope relationships of two different unit weight values (7 and 14 kN/m³) Turkey Synthetic Fresh composition were seen to be effective and useful.

The factor of safety values of the slopes, modeled with the same geometry and geotechnical properties, were higher with FLAC program when compared with TALREN program. In addition to the static stability analysis of Manisa natural MSW samples, the behavior of models with the same geometric and material properties under the influence of dynamic forces is also investigated. As a result of the analyses made using four different scales (0.4g-0.2g-0.1g and 0.05g), 59 mm and 11 mm displacements occurred at the first two acceleration values (0.4g and 0.2g), respectively.

The composition of municipal solid wastes can vary from country to country even city to city. For this reason, when designing the MSW landfills, it is necessary to design according to the parameters of the MSW composition in that area. In addition, reliable and economical MSW landfills can be constructed when changes in water content and engineering parameters due to aging effects can be taken into consideration in the design criteria.

Symbols

MSW	: Municipal Solid Waste
T-S	: Turkish Synthetic
M-N	: Manisa Natural
T-S-F	: Turkish Synthetic Fresh
T-S-A	: Turkish Synthetic Aged
M-N-F	: Manisa Natural Fresh
M-N-A	: Manisa Natural Aged
FS	: Factor of Safety
OM	: Organik Matter
γ	: Unit weight by volume
ϕ'	: Effective internal friction angle
c'	: Effective cohesion
α	: Slope angle

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