Utilization of Municipal Solid Waste as Backfill Material

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Abstract. One of the major problems in developing India is waste generation and its management. The total municipal solid waste generated by urban India is about 68.8 million ton per year and which is likely to be increased up to 160.5 million ton per year by 2041. Agricultural wastes like rice husk ash, organic fibers, etc. and industrial wastes like fly ash, slag, and silica fumes, etc. which are also a part of solid waste are already being used in various civil engineering purposes. The paper is focused on the analysis of geotechnical use of municipal solid waste as backfill material in a cantilever retaining wall. Retaining walls are stabilizing structures that hold the soil at different levels without sliding of backfilled soil. In this study, conventional backfill soil of a cantilever retaining wall is replaced by MSW material, and stability analysis has been performed using Geo5 fine software. Then, stress and settlement analysis of the retaining wall under static and seismic condition has been done by using two-dimensional finite element software Plaxis2D.

Keywords: Municipal solid waste, Retaining wall, Geo5, Plaxis2D.

1 Introduction

Waste generation and management has become one of the upcoming challenges not only for India but also for the whole world. As the world is moving towards urbanization, one of its most important by product is over looked by urban society which is growing even in faster rate than urbanization. Improper management of waste not only affects the environment on local and global basis but also the health and economy of the society. World Bank in 1999 published, What a waste: solid waste management in Asia [12] which predicted the MSW generation rate in Asia would be 1.8 million tonnes per day which is approximately equal to the present scenario as Pacific, East and West Asia combined produced about 1 million tonnes per day of MSW. India itself produced about 62 million tonnes of waste per annum according to last censes [Censes 2011] , the number is going to increased by 165 million tonnes per annum by 2031 as predicted by planning commission [6]. Another source revels similar generation by urban India of about 68.8 million ton per year and which is likely to be increased up to 160.5 million tonnes per year by 2041[13]. This problem of waste can be sorted, if it is handled properly in initial levels. The waste generated is dumped directly in open sites or landfills without treatment. Although this waste gives opportunity and source to energy programs, but for that also a proper segregation system is required. The focus of this study is towards the waste which has already being produced and dumped in the landfill sites. Considering limited low lying areas which in near future are going to exhaust, so there is a need of alternative ideas to either use that filled land or to use the waste which has been filled. This paper deals with the reuse of soil like material of the waste for geotechnical purpose. This technique of reusing finer fraction from waste is also known as waste mining. Research are going on to predict the geotechnical, physical and chemical behavior of the MSW, so that either it can be reused or stabilized where it has been dumped. Research shows 60-70% of waste from landfill appeared to be soil like [2, 10]. A hyperbolic relation was proposed by Zekkos et al. to see the variation of MSW unit weight with compaction effort, confining stress and soil content in the waste [18]. A phased approach was proposed as a best practice for the physical characterization of MSW for geotechnical purposes as most of the mechanical properties of waste depend on the physical composition of the same waste [16]. Experimental investigations were done to find out the impact of fibrous reinforcement angle on shear strength of the specimen. It was found that largest increase in shear strength was observed at reinforcement angle of 60̊ [15]. The dynamic properties of MSW like shear wave velocity and small strain shear modulus profile, material damping curve and dynamic Poisson's ratio was compiled by Zekkos et al. [17].

In the present study a particular case of Cantilever RCC retaining wall has been considered for the analysis and comparisons are made between a granular fill material and MSW fill, to check the suitability of MSW as a backfill material. The analysis for stability and retaining structure design for both fill materials were first conducted in Geo5 Fine software and, then stress and settlement analysis were conducted on Plaxis2D.

1.1 Objective of the Study

The objective of study is to reuse the soil like fraction from MSW as a backfill material. This particular study deal with a comparative study of granular fill and MSW fill material in cantilever type retaining wall. A typical section of wall is designed by using Geo5 software (limit state analysis) and checked for stability, the passed design is then checked for settlement and stress analysis by finite element based software Plaxis2D. Analysis was conducted for both static and dynamic case (Uttarkashi Earthquake M_w: 6.5). The data used in this study is based on the past research and presented in Table 1 & 2.

2 Design Methodology

2.1 Stability Analysis Using Geo5

Geo5 program runs on the basis of limit state analysis. The program evaluates normal and shear force in the footing bottom and then verifies the wall against overturning and sliding. A typical geometry of reinforced cantilever wall was considered with height of wall of 6 m with horizontal backfill. The foundation of the wall was considered 0.7 m thick and of 4.29 m wide (Fig. 1). The retaining wall was provided with shear key of 0.3 m at the end of the heel. The water table was considered at 4 m from top of the wall. The front face of wall is supported by a sand fill of 1.5 m. The design has been done as per IS 456 standards, and materials used were Fe 456 (reinforcement) and M25 (concrete). The parameters used for backfill and foundation soil are discussed below. The angle of friction for structure-soil was considered as 20°, which is common value for non-cohesive soils.

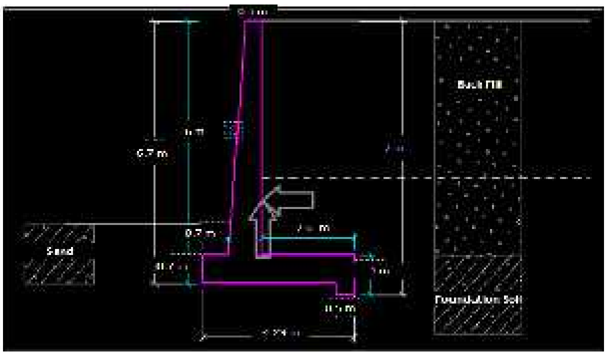

Fig.1. Dimension of cantilever retaining wall.

2.2 Numerical Analysis Using Plaxis2D

Finite element software Plaxis2D has been used for stress and deformation analysis of the retaining wall. 15 noded triangular elements were used for the meshing of the domain. The maximum, minimum boundary of the model was considered as Y boundaries from -15 to 15 m and X boundaries from -15 to 36.2 m. The structure which passed through Geo5 was used in Plaxis2D with concrete model. The general parameters were considered from Plaxis manual [7]. The parameters of the model used for cantilever wall are mentioned in Table 1 below.

Table 1. Concrete Model Parameters

Material Model	Concrete (Non Porous)
γ_{unsat} (kN/m^3)	25
E_{28} (kN/m^2)	27.79E6
ν	0.2
F_{c28} (kN/m^2)	6950
F_{con}, f_{cfn}, f_{cmm}	0.1
G_{c28} (kN/m)	35
Φ (°)	55.9
Ψ (°)	0
F_{t28} (kN/m^2)	2760
G_{t28} (kN/m)	0.09
$t_{hydration}$	28
E_1/E_{28}	0.7
Damping Parameters	
α	0.4189
β	-0.01061

Once the geometry and input parameters were defined, mesh was generated. The results converge for very fine meshing with 2275 elements and 18728 nodes (Fig. 2). The backfill was then filled with 2 layers and both static and seismic analysis was carried out. Two sections section 1(A-A), i.e., just behind the wall and section 2(B-B), i.e., near the heel of wall were considered for further analysis.

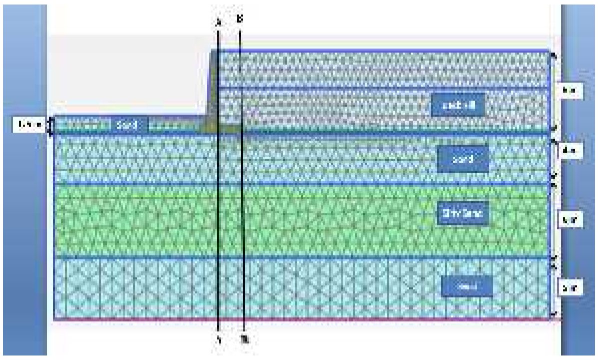

Fig.2. Generated finite element mesh of cantilever retaining wall with backfill material.

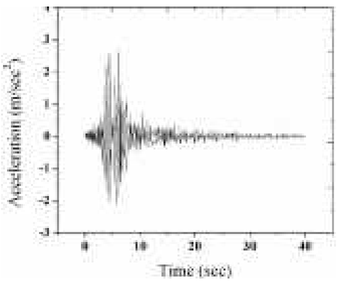

Fig.3. Uttarkashi Earthquake Input motion.

2.3 Input Motion Parameters

The input motion selected was Uttarkashi Earthquake of magnitude 6.5 and total duration of 39.9 sec with peak ground acceleration (PGA) of 3.04 m/sec^2 (Fig. 3). The pseudo-static coefficient of horizontal (K_H) and vertical (K_V) acceleration considered were 0.154645 and 0.103296 respectively. The K_H and K_V coefficients of earthquakes for this study were computed from the equation given by Hynse and Franklin [3];

$$K_{H,V} = (PGA)/2g \quad (1)$$

2.4 Material Parameters

Foundation Soil: A layered foundation soil of 15 meter depth was considered in study. Sand and silty sand type soils were assumed in model in alternative layers of 4, 6 and 5 meters. The parameters considered for foundation soils were taken from Plaxis manual and previous study [4, 9 and 14]. The Hardening Soil (HS) model available in Plaxis was used in study for both foundation soil and backfill material to represent stress strain behavior. HS model is considered superior to any linear elastic model as it produce more realistic results and capable of modeling modulus reduction with increase in strain. The HS model input parameters for foundation soils and backfill materials are shown in the Table 2 below.

Backfill Material: Granular fill and MSW backfill were considered in the model as fill materials. The parameters for conventional cohesionless granular soil were considered from the previous study [9].The parameters of MSW fill were considered from the static and dynamic research done on Indian MSW [2, 5 and 8]. The equivalent Young's modulus was considered from the correlation between SPT 'N' (number of blows) and 'E' (modulus of elasticity of soil) for non-cohesion soil [1]. MSW is considered as silty sand or gravel.

Table2. Properties of foundation soils and back fill materials.

Parameter	Foundation Soil		Back fill material	
	Sand	Silty sand	Granular Soil	MSW
Material Model	Hardening soil	Hardening soil	Hardening soil	Hardening soil

Material Behavior	Drained	Drained	Drained	Drained
γ_{Dry} (kN/m^3)	17	15	18.85	16
γ_{Sat} (kN/m^3)	20	18	19.25	18.25
E_{50}^{ref} (kN/m^2)	3.0E4	7.0E4	4.9E4	3.09E4
E_{oed}^{ref} (kN/m^2)	4.038E4	8.025E4	6.5E4	3.09E4
E_{ur}^{ref} (kN/m^2)	10.5E4	21E4	14.7E4	9.27E4
m (power)	1	1	0.5	0.5
c ' (kN/m^2)	1	20	0	25
ϕ' (^{o})	34	28	38	28
Ψ (^{o})	4	0	0	0
ν'_{ur}	0.3	0.35	0.3	0.3
e_o	0.5	0.5	0.5	0.8
k (m/day)	1E-4	1.002E-3	34.56	1.0454E-3
Damping parameters				
α	0.4189	1.074	1.698	1.047
β	0.02122	1.29E-3	0.82E-3	0.02122

3 Results and Discussions

The study was conducted for a cantilever retaining wall with two backfill materials, each consist of two cases (static and seismic). Stability analysis of the cantilever retaining wall was conducted by using Geo5 and deformation and stress analysis was performed by using Plaxis2D software.

3.1 Results of Stability Analysis using Geo5

Stability analysis of the cantilever retaining wall was conducted by limit state analysis in Geo5 for overturning, sliding and bearing capacity. There are two classic theories proposed for retaining walls, i.e., Rankine's and Coulomb's earth pressure theory. The active earth pressure has been computed according to Coulomb's theory for both the fills (Table 3). The computed values of earth pressure shows that MSW is light weight material than conventional granular fill although there is slight variation of active earth pressure on wall.

Table 3. Earth pressure analysis according to Coulomb's theory.

Material fill	K_a (Coefficient of active earth pressure)	P_a (Active earth pressure) kN/m^2	Wt. of fill kN/m
Granular Backfill	0.279	45.94	296.14
MSW Backfill	0.320	45.53	261.30

Table 4 shows the FOS obtained from Geo5 analysis for all four cases. The FOS for static cases 1 and 3 shows MSW fill has more safety factor than granular fill but for seismic conditions 2 and 4 granular fill has more values.

Table 4. Factor of safety from stability analysis using Geo5

	*Case 1	*Case 2	*Case3	*Case 4	Min. condition(static)
FOS for Overturning	4.47	2.86	6.13	2.72	>2
FOS for Sliding	2.96	2.04	3.04	1.65	>1.5
FOS for Bearing capacity (Vertical)	4.70	2.65	6.35	2.43	>2
FOS for Bearing capacity (Horizontal)	2.97	2.05	3.05	1.66	>2

***Case1=** Granular backfill (Static Condition)
***Case2=** Granular backfill (Seismic Condition)
***Case3=** MSW backfill (Static Condition)
***Case4=** MSW backfill (Seismic Condition)

The slope stability analysis was carried out according to Bishop, Fellenius and Spencer theories. A trial failure surface passing through the toe of the wall was assumed which was optimized and confirms that MSW fill has higher slope stability factor than granular fill.

3.2 Results of Numerical Analysis using Plaxis2D

3.2.1. Stress Analysis:

Stress analysis of the cantilever retaining wall was done using Plaxis2D under static as well as seismic condition at two different sections considered behind the wall (Fig. 2). A typical contour plot of shear stress for seismic case for both the fill material is shown below (Fig. 4), which shows that most of the shear stress confined behind the wall near heel area which is also a probable failure zone. Also, as compared to granular fill stress value is less in MSW fill.

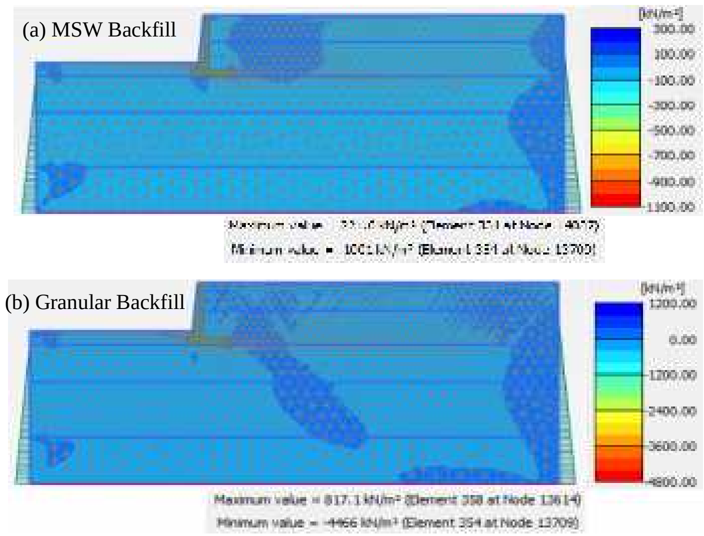

Fig.4. Contour plot for shear stresses for (a) MSW backfill (b) Granular backfill model.

Stresses at Section 1(A-A): Effective stresses were considered in backfill material, i.e. upto 6 m depth. The effective horizontal stresses behind the wall section shows less stresses for MSW as compared to granular fill under static condition. But, in seismic case the top portion experience more stress (away from wall) in case of MSW fills (Fig. 5).

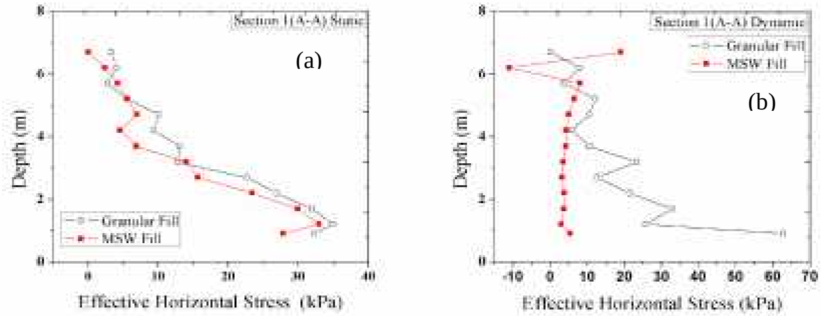

Fig.5. Variation of effective horizontal stress with depth (a) Static and (b) Seismic case at section A-A.

The variation of effective shear stress with depth for static and dynamic condition has also been studied. The average stress values were less for MSW fill as compared to granular fill. Maximum shear stress was noticed at depth of 2.5 to 3 m in static case and in seismic case it is just above the base of the retaining structure.

In static case within top 1.5 m, the vertical stresses in MSW fill can be seen more but below that it reduces (Fig.6 (a)). In seismic case, vertical stresses can be seen more in MSW fill for full backfill depth (Fig.6 (b)).

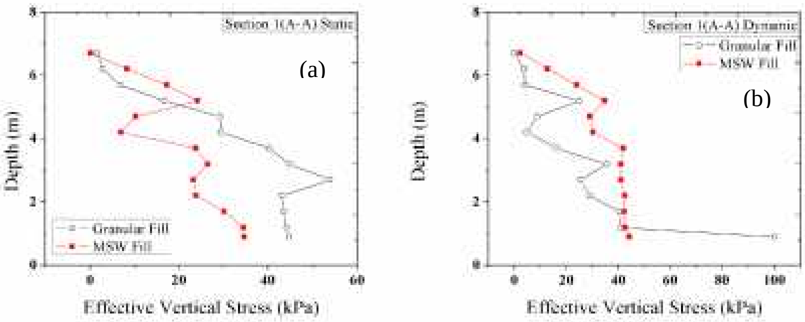

Fig.6. Variation of effective vertical stress with depth (a) Static and (b) Seismic case at section A-A.

Stresses at Section 2 (B-B). Second section is considered near the heel of the wall which is considered as a critical section as most of the stresses concentrated near the heel area. As compared to granular fill material, MSW shows more effective horizontal stress within top 2 m depth of backfill but with increase in depth stresses shows reverse trends for both static and dynamic conditions (Fig. 7).

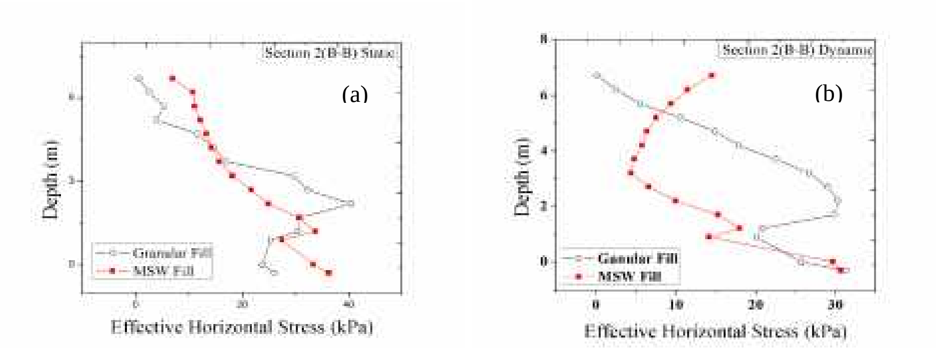

Fig.7. Variation of effective horizontal stress with depth (a) Static and (b) Seismic case at section B-B.

Shear stress result also concluded that stresses induced in MSW case are less as compared to granular fill in seismic case but in static case shear stress are induced in opposite directions for two fill materials.

Vertical stresses can be seen more in granular fill upto the depth of top 4 m for both the cases (Fig. 8) but for last 2 m backfill vertical stresses for MSW can be seen more than granular fill. The reduction in the stresses from 0 to 2m behind the wall could be because of the fill present in front side of the wall upto 1.5m.

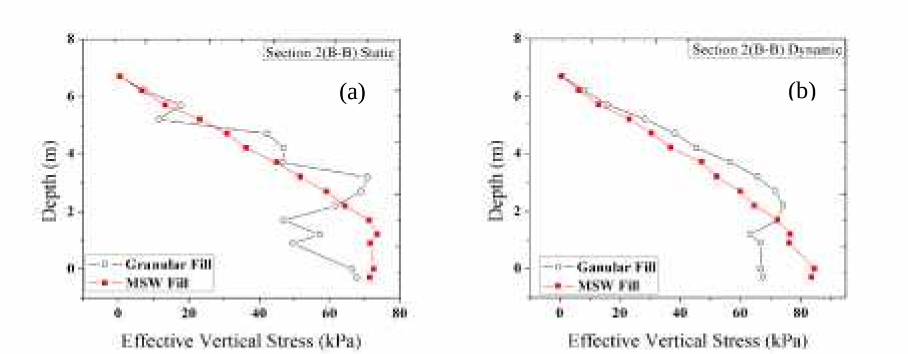

Fig.8. Variation of effective vertical stress with depth (a) Static and (b) Seismic case at section B-B.

3.2.2. Deformation Analysis:

The deformation analysis was conducted on Plaxis2D model of the retaining wall. Typical contour plots for granular backfill is shown below (Fig.9) for static as well as seismic case. Maximum deformations can be seen within 6 m depth of backfill in static case where as in seismic case deformations were more in free field location. Similar contours were seen for MSW fill also.

Deformations at Section 1(A-A). Resultant, horizontal and vertical displacements were recorded at section 1(A-A) i.e. behind the wall. In static case, MSW backfill shows less deformation than granular backfill and it goes on decreasing with depth but for seismic case deformations are more for granular backfill within top 2 m depth (Fig. 10).

It was noticed that horizontal displacements behind the wall for static case had more deformation within top 6 m depth and then it decreases with the depth but, for seismic case horizontal displacement continuously increasing with depth for both the fill materials. The horizontal displacements are found to be less as compared to vertical displacements.

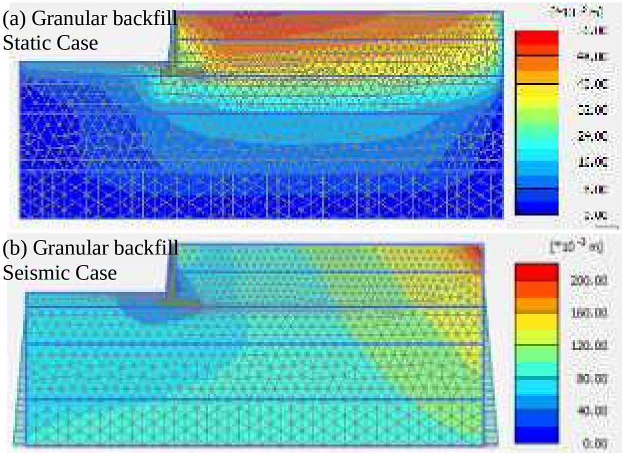

Fig.9. Contour plots for resultant displacement of granular backfill for (a) Static (b) Seismic case.

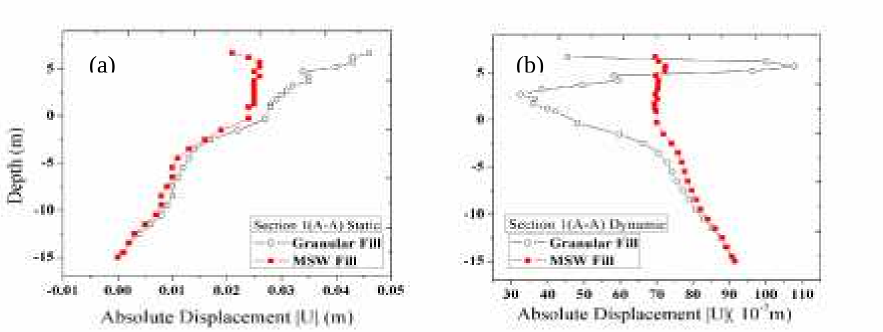

Fig.10. Variation of resultant displacement with depth (a) Static and (b) Seismic case at section A-A.

The vertical displacement for both static and seismic case noticed more variations in backfills upto 6 m and then decrease with depth, but the deformations were low in MSW backfill. This may be due to less unit weight of MSW fills. From literature it can be seen that soil like materials of MSW has low specific gravity then soil of same gradation [4].

Deformations at Section 2 (B-B). Heel of the wall is a critical place for failure, so deformation analysis has been carried out at the points selected in line near heel of the wall. The analysis shows that deformation patterns are similar to the deformation behind the wall, i.e., section 1(A-A).

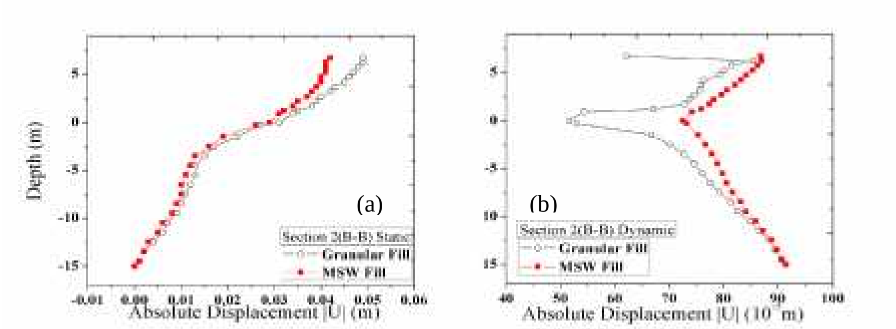

Fig.11. Variation of resultant displacement with depth (a) Static and (b) Seismic case at section B-B.

The deformation trend reduces near the heel of wall (at depth 0) and then increases again in seismic case and reduces in static case (Fig. 11). The resultant deformations can be seen more in case of MSW (seismic condition), this could be because waste has property of more damping than natural soil [11] and even the initial parameters taken from previous study shows MSW initial voids more than any soil, and this could lead to more deformations during shaking.

Horizontal displacements variation noticed same trends like in resultant displacement trends but these deformations are almost negligible. Due to light weight or low unit weight of MSW fills, the vertical displacements were noticed less in case of MSW fills than that of granular fills.

Table 5 shows the values of deformations at the end of static and dynamic phases. The maximum displacements in static case occurred behind the wall in backfill areas but for seismic case displacements are more in free field locations. At the end of phase MSW fill shows less displacements and acceleration, one of the reason could be the low unit weight of MSW and low acceleration observed may be due to material properties i.e., damping ratio of MSW shows higher damping characteristics than soils.

Table 5. Deformation results at the end of static and seismic phases for two backfills.

		U(Resultant Deformation) m	Ux(Horizontal Deformation) m	Uy(Vertical Deformation) m	a_x(Horizontal Acceleration) m/sec^2
Granular	Static	0.053	0.0165	0.0526	
Backfill	Seismic	0.217	0.1952	0.1236	1.182
MSW	Static	0.048	0.0154	0.0476	
Backfill	Seismic	0.127	0.1263	0.0318	0.358

3.2.3. Acceleration Responses:

Backfill materials are filled upto 6 m depth, the trends for the acceleration shows that for sections 1 and 2 (Fig.12) MSW fill have low acceleration values, which means most of the waves passing through it during earthquake get de-amplified.

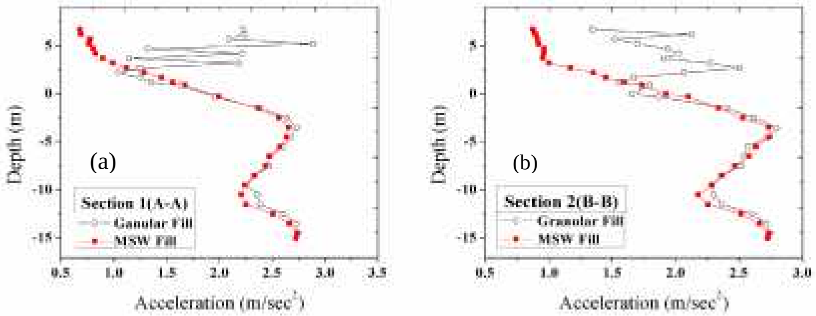

Fig.12. Variation of acceleration with depth at two positions (a) Section 1(A-A) and (b) Section 2(B-B).

4 Conclusions

The present study represents a comparative numerical model study to identify the suitability of MSW as a replacement of the conventional fill material. From the results of stability, deformation and stress analysis, it can be concluded that MSW can replace granular backfill in field as MSW fill retaining structure surpass the minimum stability criteria. Also, due to its low unit weight MSW fill possess low stresses as compared to granular fill. Most of the acceleration got de-amplified when it travels through the MSW backfill. The horizontal displacements observed at critical sections were below the permissible limits generally considered, i.e., 0.5%H to 0.7%H, where H is height of fill for static case. Although model verifies that MSW can be use as alternative fill material in field but, this requires detailed study before practical implementation, like chemical study of MSW (leachates, heavy metal and organic content study, etc), long term settlement analysis, proper segregation methodology etc.

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