Study of Municipal Solid Waste in Road Embankment

Parul Rawat and Supriya Mohanty

Abstract In developing country like India, waste generation and management have become a serious problem. The volume of waste projected to increase from 64 to 72 million tons at present to nearly twice by 2031. Improper disposal of these wastes causes adverse effect on the environment. To reduce their impact on natural ground these have been under the utilization process in the field of civil engineering such as; road material, cement, and other applications. In the present study, an attempt has been made to investigate the use of municipal solid waste (MSW) as a fill material for road embankment. A comparative study of embankment filled with MSW and natural soil over soft subsoil has been done. The numerical modeling of the embankment and foundation soil system has been carried out using 2-dimensional finite element software PLAXIS 2D. The numerical analysis of embankment has been performed under both static and seismic loading condition. The Chamoli earthquake (Mw 6.4) has been considered as input motion for the seismic analysis of embankment foundation system. In this study, the effective use of municipal solid waste for road embankment construction is presented.

Keywords Municipal solid waste · Finite element method · PLAXIS 2D · Embankment

1 Introduction

Slope instability in road embankment is a very common phenomenon, which causes ultimate failure of the embankment. In general the embankment fill comprise of different soil mixes like clayey sand, loamy sand, silty clay etc. Due to different factors like climate change, water table variation, swelling and shrinkage, varying

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load and other parameters of soils underneath the structure like pavement or embankment cause the settlement. This causes cracking and undulations on the surface ultimately causing difficult driving condition on highways.

Countries all over the world are dealing with the problem of disposal of Municipal Solid Waste (MSW) and easiest solution is to dispose off the waste in landfill sites. Indian MSW generally consists of house hold wastes, industrial wastes, agricultural wastes, medical wastes etc., which makes MSW highly non homogeneous and variable in its content. Working with MSW is very difficult because of dependency of test results on the source site, particle size, age, and content of the waste. The particle size of MSW is very large as compared to the laboratory equipments, so segregation of MSW is required before using it as a fill material. In addition, the volume of solid waste is increasing day by day and is projected to increase from 64 to 72 million tons at present to nearly twice by 2031 [1]. Dixon and Jones [5] studied the effect of different parameters like compressibility, shear strength, lateral stiffness, in-situ horizontal stress, and hydraulic conductivity on landfill lining system design and performance. Havangi et al. [6] concluded MSW to be a coarse grained material with 70% particles to be retained on 75 micron IS sieve and recommended about 65–75% segregated waste can be used for embankment construction. Naveen et al. [10] showed damping ratio of dumped waste varies from 14 to 32% and for dry waste it varies from 14 to 18%. Ramaiah and Ramana [13] conducted cone penetration testing with pore pressure measurement (CPTU) on Ghazipur land fill site, Delhi and compared the results with the reported data from other landfill sites. They noticed that, the average tip resistance of the site varied from 1.5 to 2 MPa (upto 5 m) and 3–4 MPa from 5 to 13 m.

Numerical modeling of highway embankment by using Plaxis 2D on different embankment fills has been done by many researchers. There are study which shows slope stability of embankment filled with different soils on Plaxis 2D and gives factor of safety for different fill material [9]. Wang and Miao [14] proposed a light weight fill material for embankment using cement-treated Yang-zi river sand and expanded polystyrene (EPS) beads. Numerical analysis by PlaxisV8 concluded that, settlement of new light weight embankment was less than the general lime stabilized soil embankment. Analysis for settlement and factor of safety on fly ash fill embankment with geogrids under static and seismic loading conditions was conducted and parameters like maximum acceleration, vertical and horizontal displacement were found to be least at crest, toe, and bottom of embankment [7, 8]. There are few on Plaxis 2D to simulate dynamic traffic loading on embankment filled with different soil models [4]. Numerical simulation on geosynthetic reinforced embankment over locally weak zones was also conducted [3]. They analyzed the road embankment with foundation soil of high compressibility, low bearing capacity, and locally weak zones of limited extent. Settlement analysis of the embankment was carried out. The results show improvement in settlement due to the combination of the membrane strength effect of the geosynthetic and the arching effect within the embankment fill. Aseeja [2] analyzed the consolidation behavior of embankment on soft soil and compared the results with field data. In addition, they performed a parametric study to check the effectiveness of ground improvement techniques (preloading, stone columns and prefabricated vertical drain). They found that, PVD shows better results by fast consolidation rate and minimum pore water pressure generation.

There are various studies have been done for MSW landfill stabilization but, very limited work has been done on utilization of MSW as a fill material. In the present study, a comparison has been made between a normal soil fill and MSW as a fill material for embankment under both static and seismic loading conditions.

2 Numerical Simulation of Road Embankment

For numerical modeling of road embankment, Plaxis 2D 2018 [11, 12] version has been used which is a finite element program for geotechnical applications. 15 noded triangular elements are used for the discretization of the embankment as well as foundation soil. Because of the symmetry of the problem only half part of the embankment is considered for numerical modeling. The width of the crest of the embankment is about 8.5 m and height is of 5 m with side slope of 2H: 1 V. The optimum finite element mesh of the embankment section obtained after convergence analysis (see Fig. 1). Staged construction has been adopted for the construction of embankment with two equal parts. Consolidation period of 60 days are allowed for the dissipation of excess pore water pressure. Water table is considered to be at 5 m below the ground surface. Analysis has been carried out for both static and seismic conditions under Chamoli earthquake motion.

2.1 Properties of Subsoil

The subsoil layer considered upto 15 m depth consisting of 3 layered soils. Thickness of each layer as follows:

Subsoil layer 1(sand) = 5 m
Subsoil layer 2(clay) = 5 m
Subsoil layer 3(sand) = 5 m.

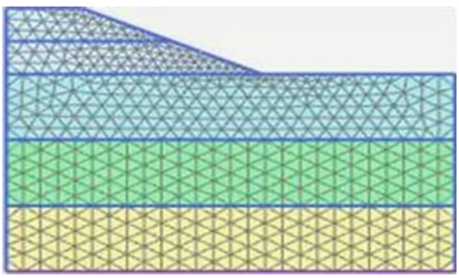


Fig. 1 Finite element mesh of the road embankment

Table 1 Parameters of foundation soil

Parameter	Foundation soil	
Soil type	Clay	Sand
Material model	Soft soil	Hardening soil
Material behavior	Undrained (A)	Drained
γDry (kN/m^3)	15	17
γSat (kN/m^3)	18	20
c (kN/m^2)	1	0
ϕ (°)	25	33
e_o	1	0.5
k (m/day)	0.04752	7.128
Damping ratio	12.74	10

Properties of foundation soil are listed in Table 1.

2.2 Properties of Fill Material

Two different fill materials have been considered for the embankment construction. One is normal soil fill and other one is MSW fill. The properties of fill materials are listed in Table 2. The general properties of MSW in this study are taken from the Ghazipur landfill site, East Delhi [6]. The stiffness is computed with the correlations of average resistance of the same site with SPT values [13].

Table 2 Parameters of the embankment fill material

Parameter	Embankment fill material	
	Soil	MSW
Material model	Hardening soil	Mohr-columb
material behavior	Drained	Drained
γDry (kN/m^3)	16	16
γSat (kN/m^3)	19	18.25
E (kN/m^2)	2.5E4	19,122.96
c (kN/m^2)	1	25
ϕ (°)	30	28
e_o	0.5	0.8
k (m/day)	3.499	1.0454E-3
Damping ratio	10	15

2.3 Input Motion

For seismic analysis of the road embankment, Chamoli earthquake (Mw: 6.4) is considered as input motion. The Peak Ground Acceleration (PGA) of the input motion is about 2 m/s^2 at 5 s and the total time duration of the motion is 25.4 s (Fig. 2).

3 Results and Discussions

The results of the numerical analysis summarized comparison between the two different fill materials based on settlement, acceleration, excess pore water pressure and stresses under static, and seismic loading conditions. Table 3 shows the comparative results between the soil and MSW fill embankment.

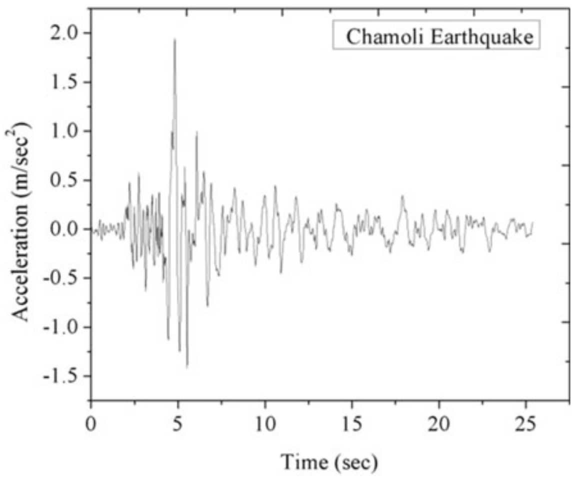


Fig. 2 Chamoli earthquake input motion

Table 3 Comparisons of results between soil and MSW fill embankment

	Deformation (m)		$\sigma'(yy)$ (kN/m^2)		P (excess) (kN/m^2)		a_x (m/s^2)
	Static	Seismic	Static	Seismic	Static	Seismic	Seismic
Soil	0.1516	0.3263	– 218.2	– 239.6	0.8684	38.51	0.6733
MSW	0.1444	0.2362	– 216.9	– 234.9	0.9798	39.52	0.4198

3.1 Deformation Variation

At the end of static analysis maximum horizontal displacement (*Ux*) for soil and MSW fill embankment are comes out to be 0.02361 m and 0.02005 m, respectively, which shows more deformation for soil embankment. At the end of seismic analysis, the variation of horizontal displacement (*Ux*) with depth at different horizontal distances ($X = 0$, 9 and 14.25 m) for both soil and MSW embankment are presented in Figs. 3 and 4. The figures show that, horizontal displacement is minimum at center ($X = 0$ m) at a depth of 5 m where as it increases toward the toe for both the cases.

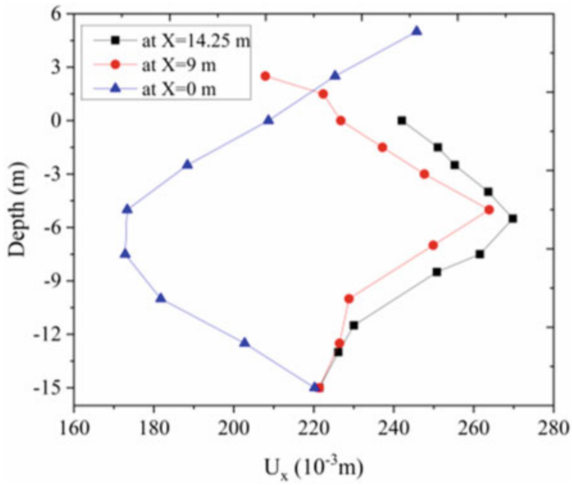


Fig. 3 *Ux* variation with depth for soil

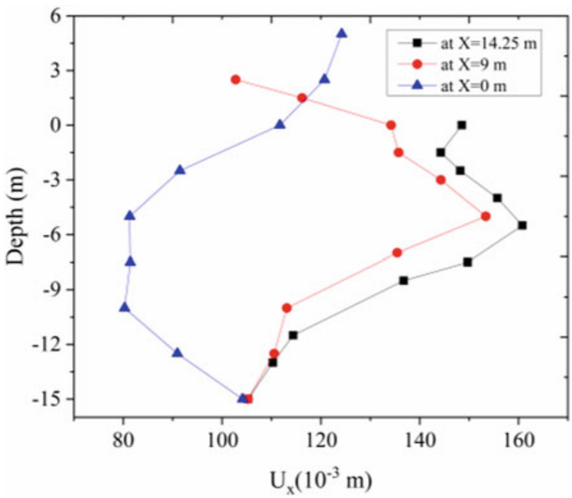


Fig. 4 *Ux* variation with depth for MSW

Vertical displacement (*Uy*) at the end of static analysis shows maximum values of 0.1516 m and 0.1444 m for soil and MSW filled embankment, respectively. Figures 5 and 6 show the variation of vertical displacement with depth at the end of seismic analysis for soil and MSW filled embankment. Vertical displacement for both fill material goes on decreasing toward the toe of the embankment due to decrease in the overburden pressure.

The maximum resultant displacement |*U*| after the static analysis gives values 0.1516 m and 0.1444 m for soil and MSW filled embankment, respectively. Similarly, at the end of seismic analysis, it increases to 0.3263 m and 0.2362 m, respectively, for soil and MSW fill embankment. Figures 7 and 8 show the variation of resultant

Fig. 5 *Uy* variation with depth for soil

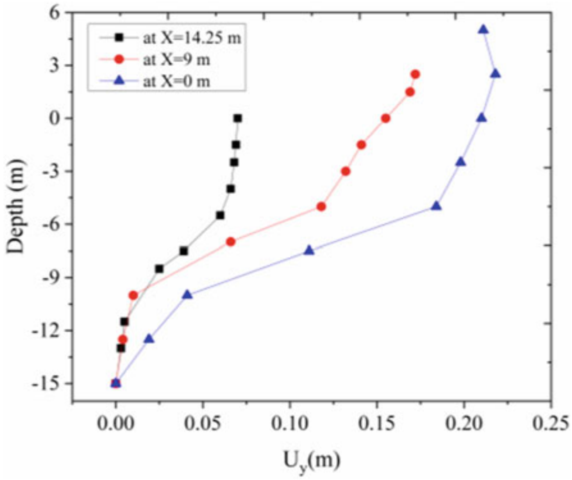
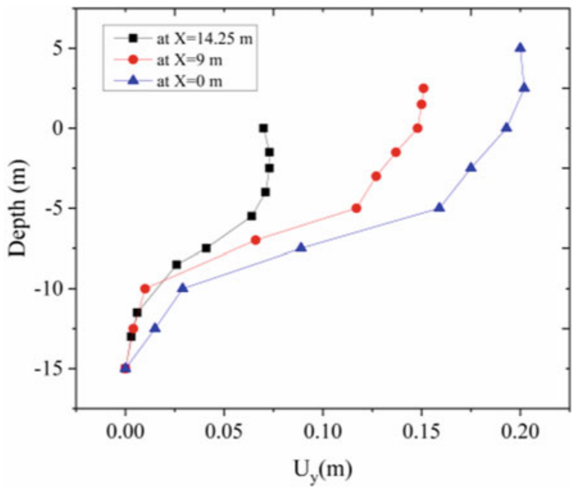


Fig. 6 *Uy* variation with depth for MSW



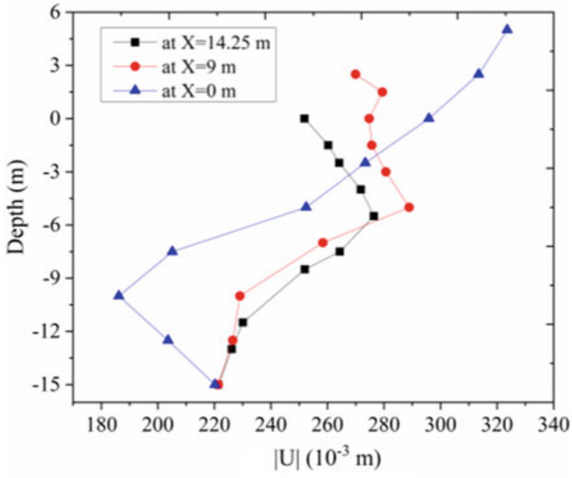


Fig. 7 Variation of $|U|$ with depth for soil

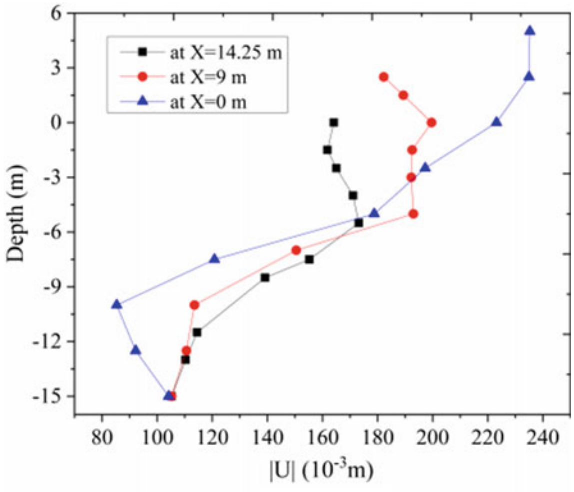


Fig. 8 Variation of $|U|$ with depth for MSW

displacement $|U|$ with the depth with varying horizontal distances ($X = 0$, 9 and 14.25 m) for both soil and MSW fill embankments.

3.2 Acceleration Variation

At the end of seismic analysis, the absolute maximum horizontal acceleration is observed at different locations of the embankment. The variation of horizontal acceleration with depth is shown in Figs. 9 and 10 at different horizontal distances ($X =$

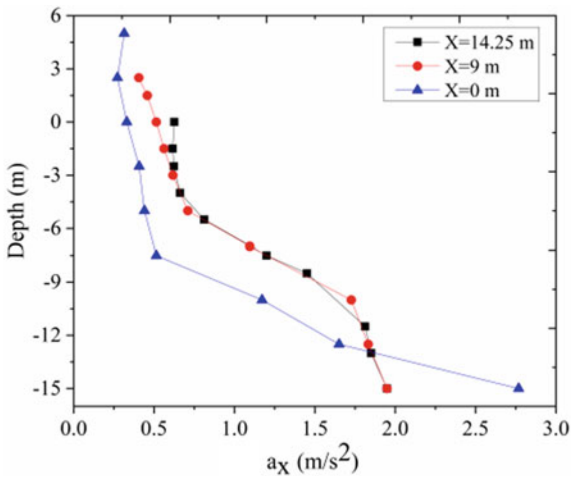


Fig. 9 Variation of ax with depth for soil

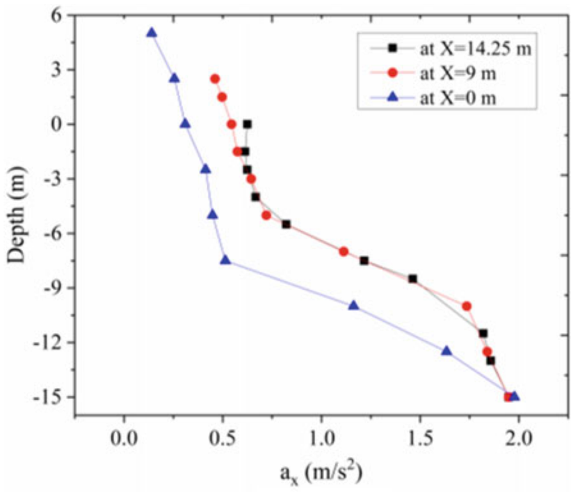


Fig. 10 Variation of ax with depth for MSW

0, 9 and 14.25 m) for both soil and MSW fill embankments. Horizontal acceleration increases as the depth and horizontal distance from the center of embankment increases.

3.3 Excess Pore Water Pressure Variation

At the end of static analysis, the excess pore water pressure is negligible and maximum values reaches upto 0.8684 kN/m^2 and 0.9798 kN/m^2 for soil and MSW fill embankment, respectively. At the end of seismic analysis, the excess pore water pressure increases to the value of 38.51 kN/m^2 and 39.52 kN/m^2 for soil and MSW fill embankment, respectively. Figures 11 and 12 show typical variation of excess pore water pressure with depth with varying horizontal distances ($X = 0$, 9 and 14.25 m). The maximum excess pore water is developed in between the foundation soil in clay layer.

Fig.11 Variation of *P* excess with depth for soil

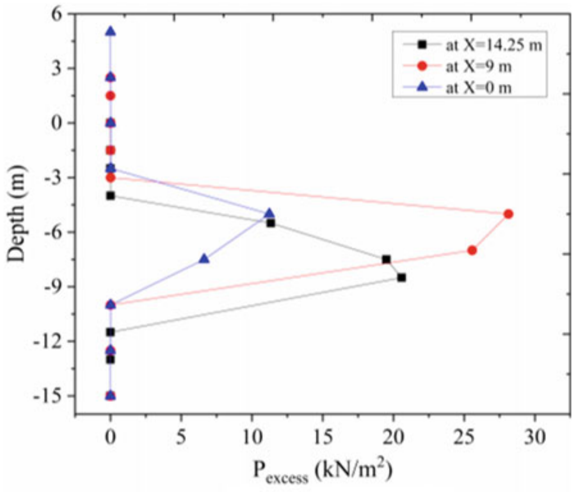
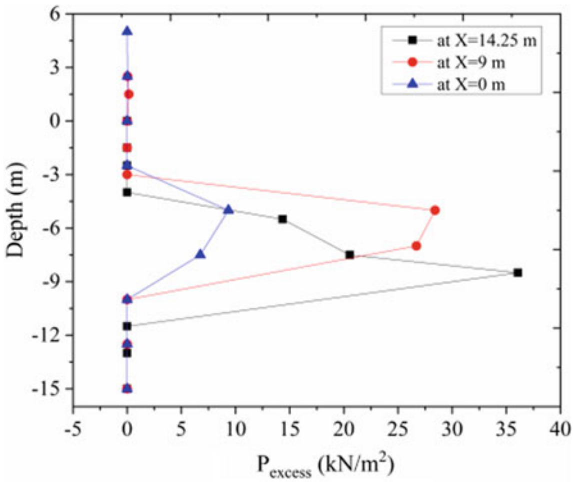


Fig. 12 Variation of *P* excess with depth for MSW



3.4 *Effective Vertical Stress Variation*

In static case, the maximum effective vertical stress is observed to be − 218.2 kN/m^2 and − 216.9 kN/m^2 for soil and MSW fill embankment, respectively, which increases to − 239.6 kN/m^2 and − 234.9 kN/m^2, respectively for the seismic loading condition. Figures 13, 14, 15 and 16 show the contour fill of effective vertical stress in embankment and foundation soil after static and seismic analysis.

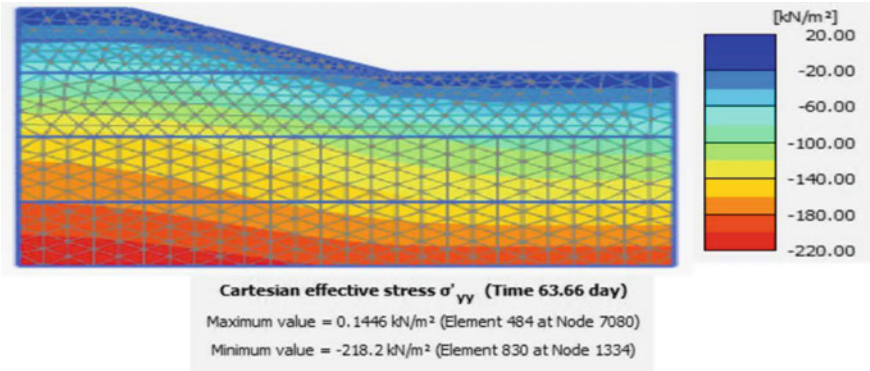


Fig. 13 Contour plot of effective vertical stress for embankment filled with soil (static analysis)

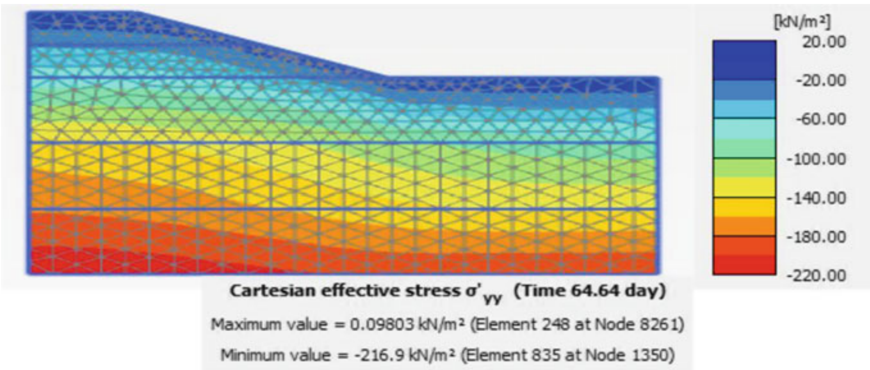


Fig. 14 Contour plot of effective vertical stress for embankment filled with MSW (static analysis)

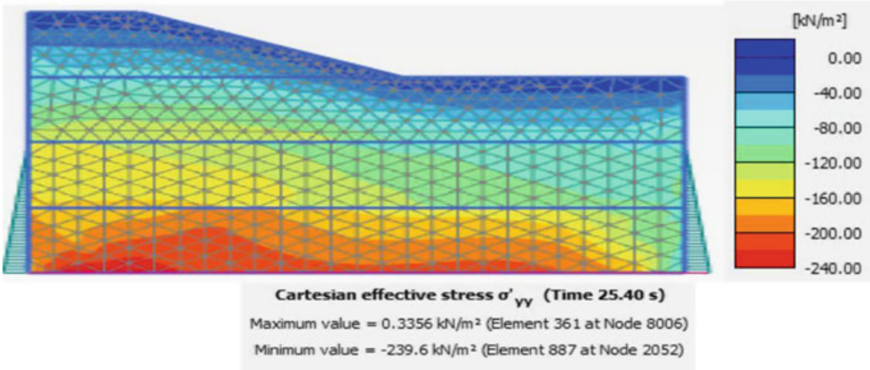


Fig. 15 Contour plot of effective vertical stress for embankment filled with soil (seismic analysis)

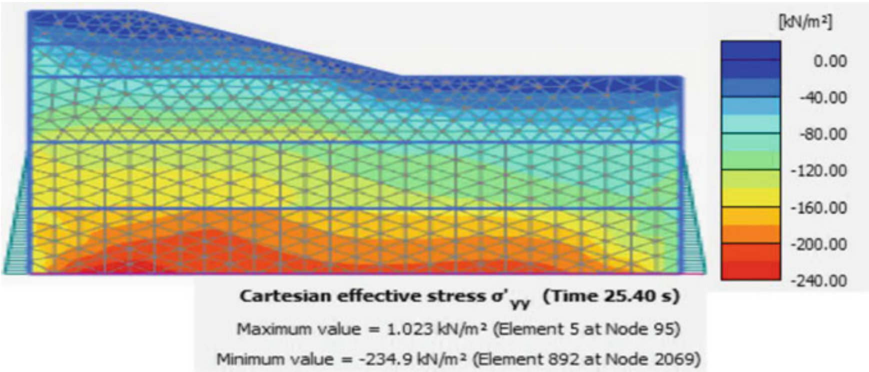


Fig. 16 Contour plot of effective vertical stress for embankment filled with MSW (seismic analysis)

4 Conclusions

Following conclusions can be drawn from the results of the numerical analysis:

- MSW fill embankment shows less deformation both for static as well as seismic analysis as compared to that of soil fill embankment.
- Horizontal displacements are found to be more toward the sloping side where as vertical displacements are more at the center of the embankment.
- Horizontal acceleration increases with the increase in depth and found to be more at the base of foundation soil. Also, it is more toward the sloping side and shows less value for MSW fill as compared to the soil fill embankment.
- The maximum excess pore water pressure is observed in the clay layer during the seismic loading condition.
- The effective vertical stress increases with depth and found maximum at the base for both the cases.

The results of the numerical analysis show that MSW can be considered as a fill material for road embankment as it shows better results compared to the normal soil fill embankment. However, MSW is widely heterogeneous material and there are no proper codes and methods for characterization of MSW. Hence, further research is required in this field.

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