On solid waste landfills seismic response analysis

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ABSTRACT: The seismic behaviour of landfill is a geotechnical problem to which more attention has been devoted after the strong earthquakes of Whittier Narrows of 1987, Loma Prieta of 1989 and Northrigde of 1994. The seismic response analysis requires the bedrock motion in terms of acceleration, frequency contents and duration; the evaluation of the dynamic properties of waste materials, the modelling of the seismic behaviour of landfill; the evaluation of performance in terms of seismically induced acceleration and displacements. In this paper a case history of a landfill is reported. The seismic input at the base of landfill has been chosen as a time history of recorded earthquake without any amplification because the site is constituted by rock. The waste material is characterised in terms of unit weight, shear waves velocity, shear modulus and damping ratio, considering the non-linear behaviour of the waste material. The seismic response analysis has been performed by one-dimensional non-linear finite element model, considering an equivalent layer for the base liner system and for the cover liner system. The results are presented in terms of time history of acceleration, velocity and displacements as well as the profile of the maximum displacements, acceleration, shear strain and shear stress.

1 INTRODUCTION

The well-documented case records of the seismic performance of Municipal Solid Waste Landfill (MSWL) during the 1994 Northridge earthquake (Augello et al., 1995a), have stimulated the researchers to better understanding the seismic behaviour of landfills. Commonly used one-dimensional equivalent-linear response have been reviewed by Augello et al. (1995b) and Bray et al. (1995). The back-analysis of the instrumented Operating Industries, Inc. (OII) landfill subjected to the 1992 Landers earthquake and to the 1994 Northridge earthquake has been performed by Augello et al., 1998. Nevertheless some uncertainties still remain about the dynamic characterization of the waste materials and some questions about the seismic behaviour of base and cove liner systems remain unanswered. In particular the seismic response of the soil-geosynthetic interface is a key point for understanding the significant damage of geomembrane tears, and cover cracking experienced by several landfills during the 1994 Northridge earthquake. Numerical analysis performed, for instance, by computer codes SHAKE ’91 (Idriss and Sun, 1992) and QUAD4M (Hudson et al., 1994) could give reliable simulations of the behaviour of landfills (Bray et al., 1998).

In this paper the computed code GEODIN (Frenna and Maugeri, 1995), developed at the University of Catania is used to perform the dynamic response of a landfill. By this code one-dimensional non-linear response analysis of landfills could be performed in terms of seismically induced acceleration velocity and displacement, at any depth that inside the landfill body and particularly at the soil-geosynthetic interface.

Because the results strongly depend on dynamic properties of the waste materials, the GEODIN code was validated by back analysis of the OII landfill, located near Los Angeles. This landfill was instrumented by accelerometers placed at the bedrock and at the top of landfill. The records of shaking during the 1992 Landers earthquake and the 1994 Northridge earthquake, reported by Hushmand Associates (1994), were compared with the numerical results obtained by the GEODIN code.

2 DYNAMIC CHARACTERIZATION OF WASTE

The dynamic properties of waste materials, needed for seismic response analysis, are: the material density, the shear wave velocity, varying along the thickness of the landfill, the shear modulus degradation laws and the damping ratio variation versus shear deformation. As concern the material density, Kavazanjian et al. (1995) have proposed an ideal operational profile depending on the depth, according to estimations of the constipated material unit volume in the landfill and to typical compressibility values of the waste materials. Such curves present a course strongly varying with the depth, from a value of around 3 kN/m^3 at the surface, up to over 13 kN/m^3 at the base of landfill. By means of dynamic penetrometric tests performed by Seco e Pinto et al. (1998), the density values are ranging from 13 up to 16 kN/m^3. The shear wave velocity is usually determined by means of the SASW technique of spectral analysis of the surface waves (Stokoe and Nazarian, 1985) or by means of empirical correlation's with the dynamic penetrometric tests.

By means of the SASW tests, Kavazanjian et al. (1995) have derived a typical Vs profile for the waste materials: the values of Vs are ranging from 100 m/s at the surface up to 500 m/s at the depth of around 100 m . Seco e Pinto et al. (1998) by means of penetrometric tests have evaluated for the superficial layers higher Vs values, of the order of 330-350 m/s. In the present study a profile according to the curve proposed by Kavazanjian et al. (1995) has been used, with the minor values at the top of landfill of 11 kN/m^3 as concern the density and of 350 m/s as concern the shear wave velocity (fig.1).

As concern the shear modulus degradation and the variation of the damping ratio with the shear strain, as measurements by dynamic laboratory tests are not available, different studies based on the analogy between the waste materials and the clayey soils have been performed. Kavazanjian and Matasovic (1995) report some curves adaptable to the waste materials (fig.2).

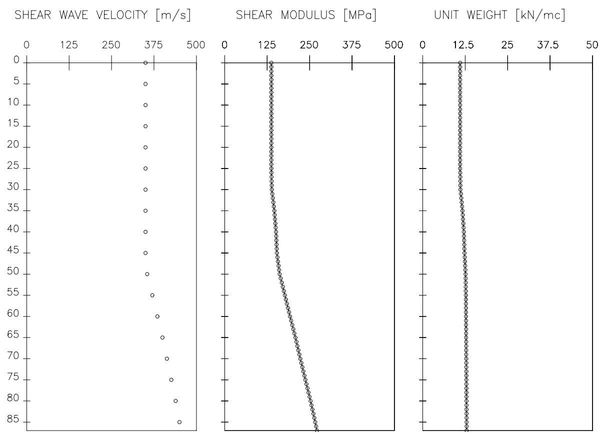

Fig.1 – Dynamic characterisation of waste materials.

The new landfill are often realised using geo-membranes as cover and base liner system. By the employment of these materials it is possible to modify substantially the dynamic response of the landfill. Yegian and Harb (1995), Kavazanjian and Matasovic (1995) and Yegian and Kadakal (1998a) have shown, by means of shaking table tests, that under the action of cyclical loads slippage can occurs along the geo-membrane surfaces, limiting the accelerations transmitted to the over-standing materials.

For the numerical analysis of the landfill dynamic response, Yegian and Kadakal (1998b) proposed a modelling of the geo-membranes with an equivalent soil layer of thickness equal to 1 meter. The stiffness characteristics of the equivalent soil layer are depending from the vertical stress, and then from the depth, and from the strain state, according to the curve reported in fig.3.

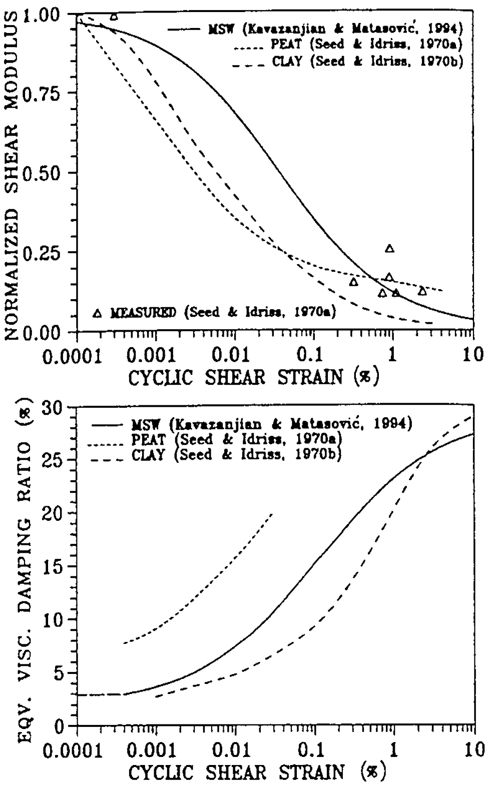

Fig.2 – Shear Modulus decreasing with shear strain and damping ratio for waste materials (after Kavazanjian and Matasovic 1995).

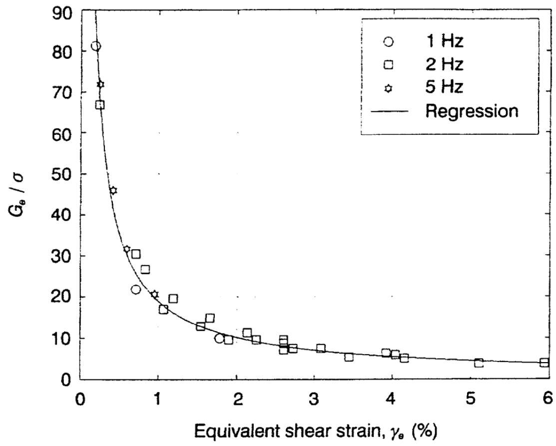

Fig.3 – Equivalent shear modulus, normalized to normal stress,versus equivalent shear strain (after Yegian e Kadakal 1998a).

For this equivalent layer Yegian and Kadakal (1998b) suggest a damping ratio equal to 0.45, due to the strong energy dissipation for friction along the interface.

3 ANALYSIS OF THE DYNAMIC RESPONSE

The dynamic response of a layered soil, subjected to seismic shear waves, can be performed in one-dimensional field considering a system with concentrated masses, connected by springs and dashpots. Similarly the «landfill» can be schematised as one-dimensional system associating to each layer the dynamic characteristics of the waste material at that given depth. At the same the possible presence of a geo-membrane can be simulated by an equivalent layer with thickness equal to 1 meter, with the dynamic characteristics reported in Fig. 3.

The one-dimensional dynamic analysis was carried out by means of the GEODIN code (Frenna and Maugeri, 1995), by which soil dynamic response in the frequency domain and in the time domain can be evaluated, taking into account the non-linear behaviour of the waste materials. To validate the applicability of the GEODIN code to waste landfills, a back-analysis of the OII Landfill (fig.4), subjected to the Landers earthquakes of 1992 and to the Northridge earthquake of the 1994 (fig.5) has been performed.

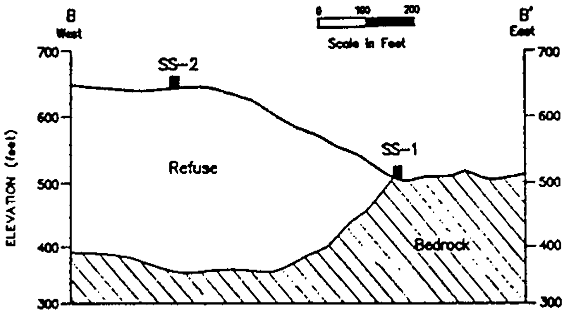

Fig.4 – The OII landfill: cross section with accelerometers location (after Anderson et Al., 1992).

At the base of OII landfill was applied the seismic loading recorded at the bedrock; the analysis was performed in the frequency domain to evaluate the predominant frequency of the landfill and in time domain, to evaluate the time history of the response at any depth in terms of acceleration, velocity and displacement.

The results in the frequency domain show a predominant period of 0.85 sec; the results of the numerical analysis in time domain are reported (figs. 6 and 7) in terms of maximum displacements and accelerations and in terms of maximum shear strain and shear stress along the layer. The response to the Landers earthquake is reported in fig.6 while the response to the Northridge earthquake is reported in fig.7.

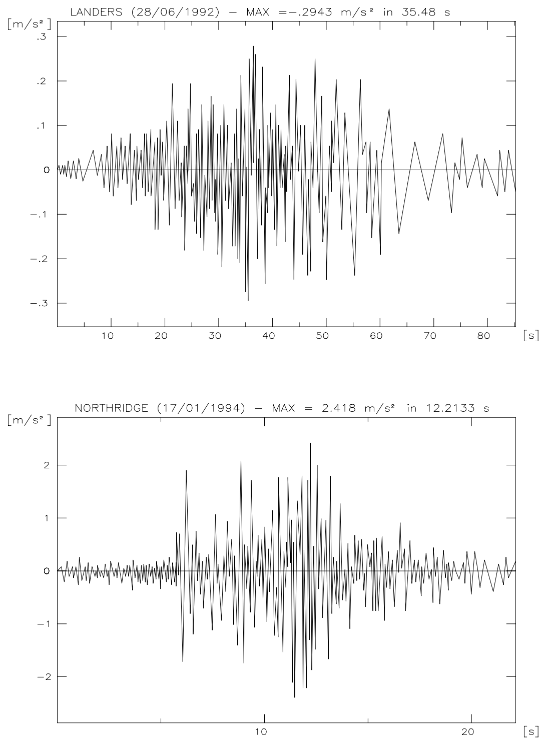

Fig. 5. Recorded acceleration at the bedrock of the OII Landfill:

a) record of Landers earthquake of 26/09/1992.

b) record of Northridge earthquake of 17/01/1994.

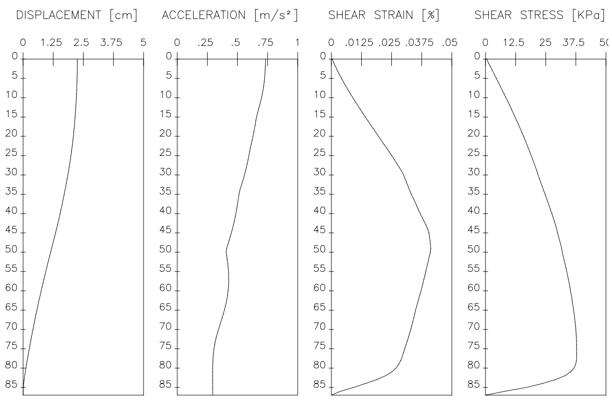

Fig.6. Seismic response of the OII landfill to the Landers earthquake of 28/06/1992.

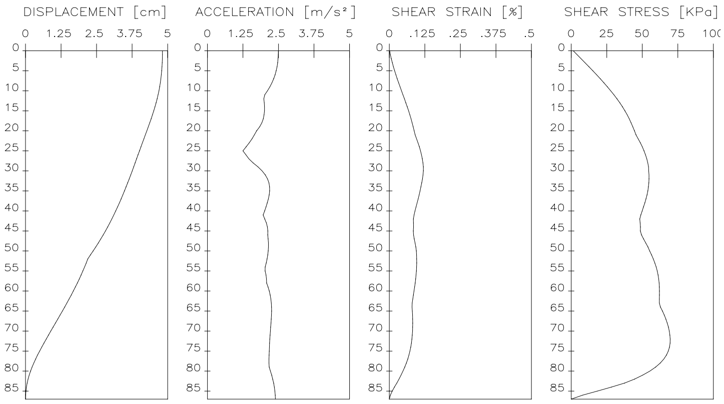

Fig.7. Seismic response of the OII Landfill to the Northridge earthquake of 17/01/1994.

In the case of the Landers earthquake, the numerical analysis shows an amplification of the acceleration at the surface of about 2.5, while the recorded acceleration at the top of the landfill, reported by Husmand and Associates (1994), shows an amplification of about 3. In the case of Northridge earthquake the numerical analysis shows an amplification factor equal to 1.03, while no amplification is shown by the recorded acceleration at the top of landfill (Husmand and Associates, 1994).

The results of the numerical modelling are then very close to the dynamic response recorded at the landfill surface. The different response to the two earthquakes depends on the different frequency content of these Landers and Northridge earthquakes considered. The frequency content of the 28/06/1992 Landers earthquake (Fig. 5a) is ranging between 0.5 and 1.0 sec, while the frequency content of the 17/01/1994 Northridge earthquake (Fig. 5b) is ranging between 0.25 and 0.5 sec. Because the predominant period of the OII landfill is very close to the predominant frequency content of the 28/06/1992 Landers earthquake, an amplification of about 3 at the top of landfill occurred, while practically no amplification was observed for the case of the 17/01/1994 earthquake.

Finally because there is a good agreement between the responses recorded and those obtained by the GEODIN code, its application can be considered reliable.

4 DYNAMIC RESPONSE OF THE LENTINI LANDFILL

The Lentini Landfill, located in the province of Catania (Italy) is founded on rock and it will be high about 15 m when it will be closed (Fig. 8).

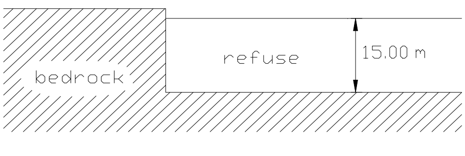

Fig. 8. Cross section of the Lentini landfill (Italy).

The Lentini landfill is made by waste materials similar to the OII landfill so can be characterised as reported in figs.1,2 and 3. The dynamic response of the Lentini landfill was performed initially applying at the base of landfill the two records of 1992 Landers and 1994 Northridge earthquakes, reported in fig.5.

Because the height of around 15 meters of Lentini landfill is considerable less of OII landfill the predominant period of 0.17 sec evaluated by GEODIN for Lentini landfill is considerable less than that of 0.85 sec evaluated for OII Landfill.

Therefore the expected response for Lentini landfill is of a greater amplification for the Northridge earthquake, with low vibration periods more close to the vibration period of the Lentini landfill, while lower amplifications for the Landers earthquake that presents high vibration periods far from the vibration period of the Lentini landfill.

The numerical analysis confirms the expected results and it furnishes for the Northridge earthquake (fig.9) an acceleration amplification factor equal to 1.92 and for the Landers earthquake (fig.10) an amplification factor egual to 1.76.

Another response analysis of the Lentini landfill, under the action of the 17/01/1994 Northridge earthquake was performed, considering the hypothesis of the presence of geo-membrane at the base and at the cover of the landfill body. At the geo-membrane cover was applied an overload of 20 kN/m^2, simulating the presence of the vegetative cover soil. The results obtained are reported in fig.11 and they clearly show as the presence of the cover geo-membranes strongly attenuate the accelerations at the surface, getting a coefficient of dynamic amplification of 1.06, while it was 1.92 without the use of geo-membrane. This occurs because of the slippage at the soil geo-membrane interface.

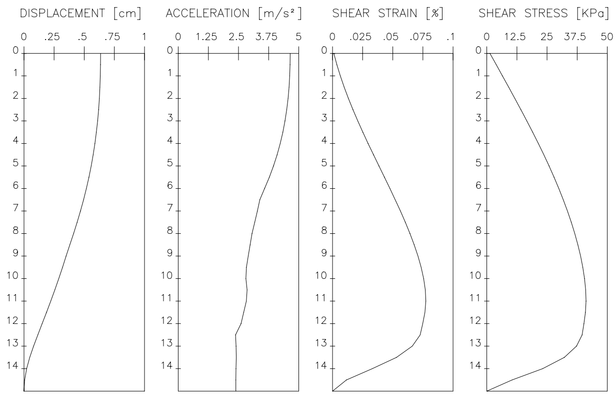

Fig.9. Seismic response of the Lentini Landfill to the Landers earthquake of 28/06/1992.

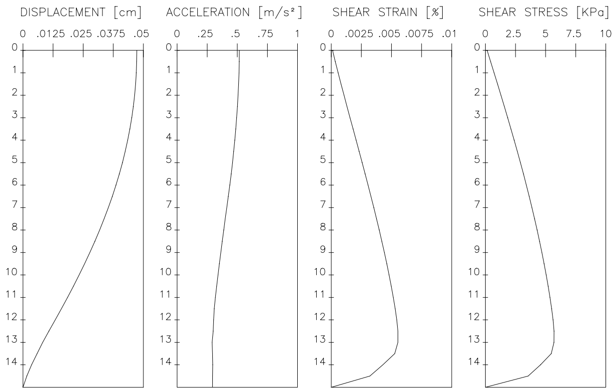

Fig.10. Seismic response of the Lentini Landfill to the Northridge earthquake of 17/01/1994.

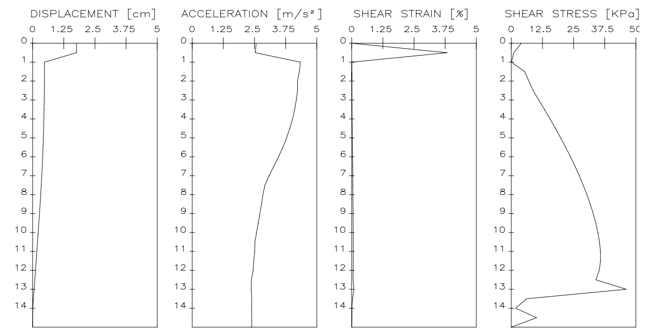

Fig.11. Seismic response of the Lentini Landfill with geo-membrane base and cover liners systems, subjected to the Northridge earthquake of 17/01/1994.

Finally the analysis of the dynamic response of the Lentini landfill under the action of the south eastern Sicily earthquake of 13 December 1990, recorded on rock at Sortino (fig.12), scaled to the same acceleration of the Northrigde earthquake, was carried out. The results of the analyses without the geo-membrane liners systems are reported in the Fig.13 while in the Fig.14 are reported the results of the analysis in presence of the geo-membrane liners systems.

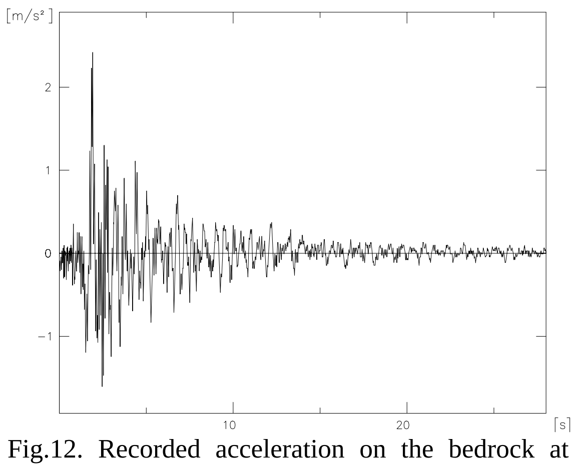

Fig.12. Recorded acceleration on the bedrock at Sortino during the 13/12/1990 South Eastern Sicily earthquake.

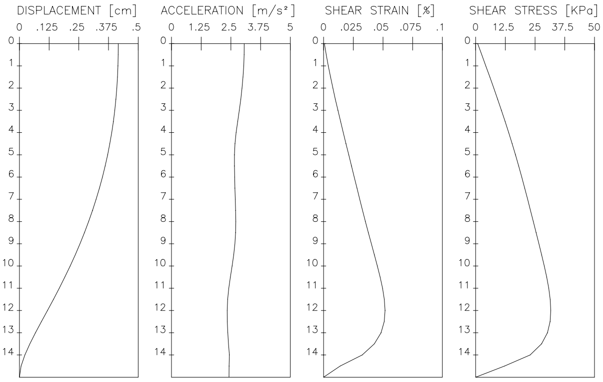

Fig.13. Seismic response of the Lentini landfill to the 13/12/1990 South Eastern Sicily earthquake.

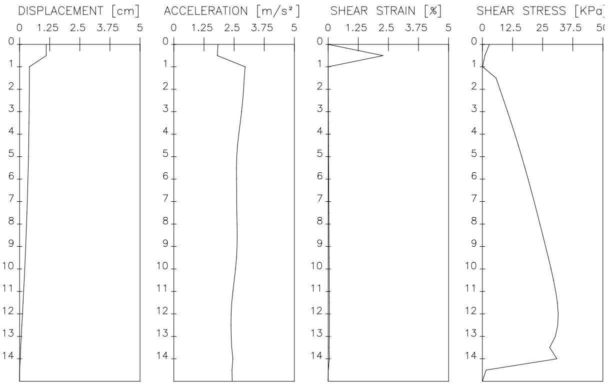

Fig.14. Seismic response of the Lentini landfill with Geosynthetics liners to the 13/12/1990 South Eastern Sicily earthquake.

This type of analysis has shown a substantial reduction of the dynamic landfill response, showing an amplification coefficient equal to 1.26 in the case of absence of geo-membrane (Fig. 13) and a reduction coefficient equal to 0.76 in presence of the geo-membrane (Fig.14) due to the slippage at the soil geo-membrane interface.

The time history of the seismic response of landfill, reported in Fig. 13 for the Lentini landfill without geosynthetic, as it is in the present state, and in Fig. 14 for the Lentini landfill as it will be realigned in the next stages of cultivation, is reported at the top of the landfill in terms of displacement, velocity and acceleration in Figs. 15 and 16. Fig. 15 reports the time history at the top of landfill without geo-membrane liners systems, while Fig. 16 reports the time history at the top of the landfill with geo-membrane liners systems.

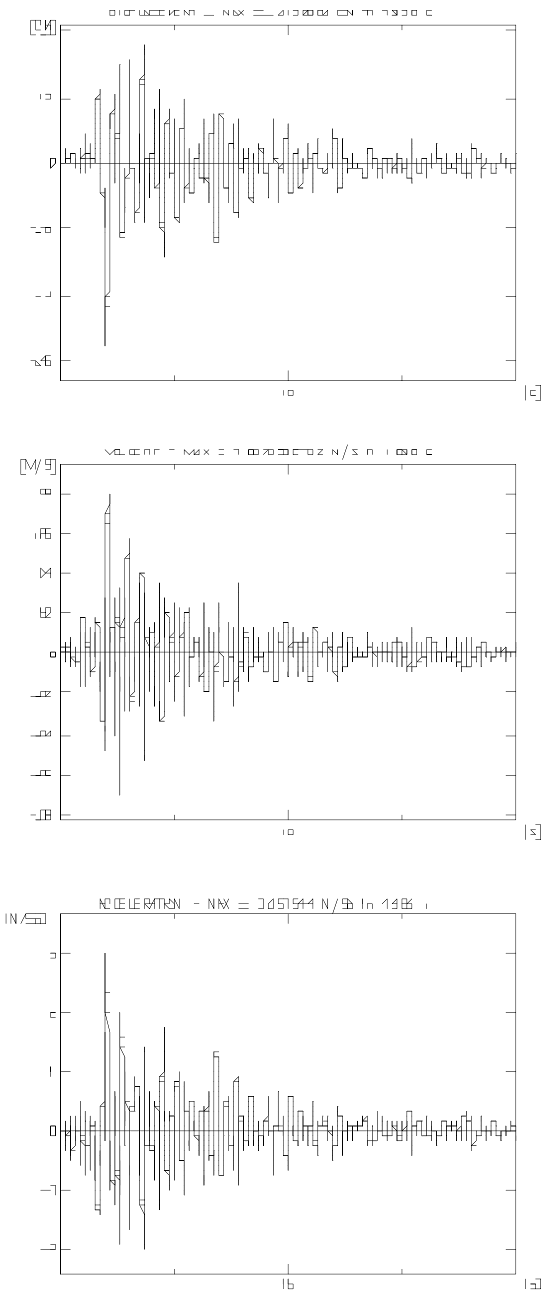

Fig.15. Time history at the top of seismic response of the Lentini landfill subjected to the 13/12/1990 South Eastern Sicily earthquake.

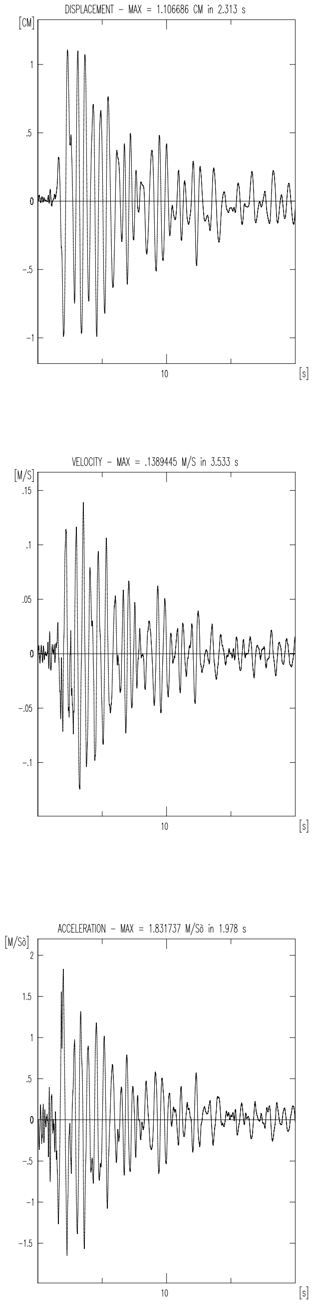

Fig.16. Time history at the top of seismic response of the Lentini landfill with geosynthetics subjected to the 13/12/1990 South Eastern Sicily earthquake.

Fig. 16 shows as the seismic acceleration at the top of the landfill with geosynthetics is less severe than in the case of absence of geosynthetics due to the slippage at the soil geosynthetics interface. As shown also by the comparison between Fig. 15 and Fig. 16, due to the slippage there is also a decreasing of the frequency in the case of the presence of geosynthetics.

5 CONCLUSIONS

The one-dimensional dynamic numerical methods, largely employed for the response of layered soils, could be also employed for the prevision of the dynamic response of landfills subjected to the seismic action of strong earthquakes.

The key points for predicting the dynamic response is a reliable waste material dynamic characterisation which is still a problem to which the researcher must give more attention.

Seismic response of landfill is controlled also by the predominant period of the landfill itself in comparison with predominant period of the earthquake applied at the base of the landfill. In the present paper as the examined landfills were founded on rock the recorded acceleration at the bedrock was applied. In the case of landfills founded on alluvial soil the amplification within the alluvial soil foundation and the changes in the predominant period of the earthquake to be applied at the base of the landfills must be taken into account.

The applying of the geo-membranes, largely employed in the modern landfill at the base and at the surface for the protection of the environment, must be taken into account with an adequate modelling to which the researchers must deserve more attention.

Using the one-dimensional non-linear models so far available the presence of the cover geo-membranes results to be of big effectiveness for the attenuation of the seismic waves at the surface, but its presence has a negative effect on increasing of the maximum horizontal displacement, with possible geo-membrane tears and cover cracking.

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