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THE INFLUENCE OF LATERAL FAULTS IN THE NONLINEAR ANALYSIS IN AN ALLUVIONAR VALLEY

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ABSTRACT

The nonlinear dynamic behavior of an alluvionar valley situated in São Sebastião region in Terceira island (Azores archipel) is performed. The Mohr-Coulomb model is used in this paper. A bidimensional cross-section with 1240 m long and 250 m depth is considered. The cross-section of the model is composed by layers having different type of ground, each one having their own geotechnical characteristics. The Distinct Element method is employed in this case. UDE Code is used. The size of Finite Elements has been tailored to the wavelength of the propagating waves through the layers. The objectives of this paper are: 1) The analysis of seismic response in terms of maximum values of shear strain at different spots along the depth; 2) The study of the influence of the lateral faults in the seismic response in terms of maximum values of shear strain and shear strain-stress relationship; 3) The analysis of the seismic response of the soils at different locations in terms of shear strain-stress relationship for "no fault" case. This is the first attempt to study the nonlinear behavior of this valley using a 2-D refined model. The UDEC code is used for studying, not only the nonlinear behavior of the soils, but also the influence of the faults to the seismic response of the soils.

INTRODUCTION

The studies which has been carried out in recently in soil dynamics are focused toward a better understanding of the seismic behavior of soil and the development of more advanced material models, within the framework of the principles of continuum mechanics. The theoretical and experimental works have been performed. One will concentrate about theoretical approaches. Within the theoretical researches, some methods, codes and models has been used to study the elastic and non-elastic behavior of the soft soils (sedimentary alluvial soils): The approach made by Psaropoulos *et al.* [1999] with F.E. analysis with ABAQUS was based on the "Effective Seismic Excitation Method. Hataniyama *et al.* [2000] have used the elasto-plastic theory to model nonlinear stress-strain relation of the sandy alluvium and the joint element to model failure surface. The shear strength was obtained by Mohr-Coulomb criterion. Solid elements were modeled based on the Cap Model. Associated flow rule was used. In order to avoid numerical difficulties due to singularities in Mohr-Coulomb hexagonal pyramid in principal stress space, Drucker-Prager criterion was used as a failure criterion. Parameters of the cap model were determined by trial and error so that the calculated stress-strain curve fitted the curve obtained by plane strain tests. A 2-D linear finite element method (Archimedes code) has been used by Adams *et al.* [2000] to model the propagation of antiplane SH waves within the soft sediments and surrounding bedrock, forming a long alluvial valley. Kawase *et al.* [2000] have simulated theoretical seismic motions by a 3-D Finite Difference Method. As for surrounding boundaries they attach an ordinary transmitting boundary with the energy absorbing layers to prevent energy reflections. Archuleta *et al.* [2000] have modelled laboratory tests on sands by applying extended Masing rules for hysteresis that follow general hyperbolic stress-strain relationships and have incorporated this function into a visco-elastic Finite Difference Code to propagate vertically incident SH-waves in a layered medium. Tokusho [1999] have observed the effect of soft soil properties on site amplification, using equivalent linear analyses. Semblat *et al.* [1999] have used a 2-D Model using Boundary Element Method in a frequency domain. CESAR code has been used.

The linear theory of elastic waves propagated trough the solids consider that the strains associated with propagation of earthquake waves are proportional to V/β where V = particle velocity; and β = shear-wave velocity in the medium. Measurements of strong earthquake motion indicate that the particle velocity rarely exceeds 100cm/s (Trifunac *et al.* 1996). Thus, at sites having the value of the shear-wave velocity near the surface $\beta = 100$m/s, the largest linear strain could be of the order of 10^{-2}, which would lead to nonlinear response. The nonlinear behavior could appear for values of shear strain less than 10^{-2}. It is known that large particle velocities occur in case of soft soils. In this case, one of the practical objective could be the study of the regions along the depth inside the soil where the material is nonlinear. This can be approached by finding the regions where the strains exceeds say $\sim 10^{-3}$% (Trifunac *et al.*

1996). One will follows herein this criterion for studying the nonlinear zones. In this paper, the nonlinear dynamic behavior of an alluvionar valley situated in São Sebastião region in Terceira island (Azores) is performed using a 2-D model. Discrete (or distinct) element method is used. Discrete element methods represent a structure as an assembly of component blocks in mechanical interaction across joint surfaces. In the code UDEC (Itasca [2000]), used in the present study, blocks may be either rigid or deformable, the latter being discretized into a finite element mesh. The representation of contact between blocks is not based on joint elements, but relies on sets of point contacts, of either vertex-to-vertex or vertex-to-edge type (in 2D). The assignment of contact areas allows the interface constitutive relations to be formulated in terms of stresses and relative displacements across the joint. An advantage of this approach is the natural transition it allows into the large displacement regime, as the contact locations and orientations are continuously updated in the course of analysis. UDEC includes efficient routines for contact detection and update. The solution procedure is based on the explicit time integration of the equations of motion of the rigid blocks, or the nodal points of deformable blocks. This technique is also used for quasi-static problems, using artificial viscous damping controlled by an adaptive algorithm.

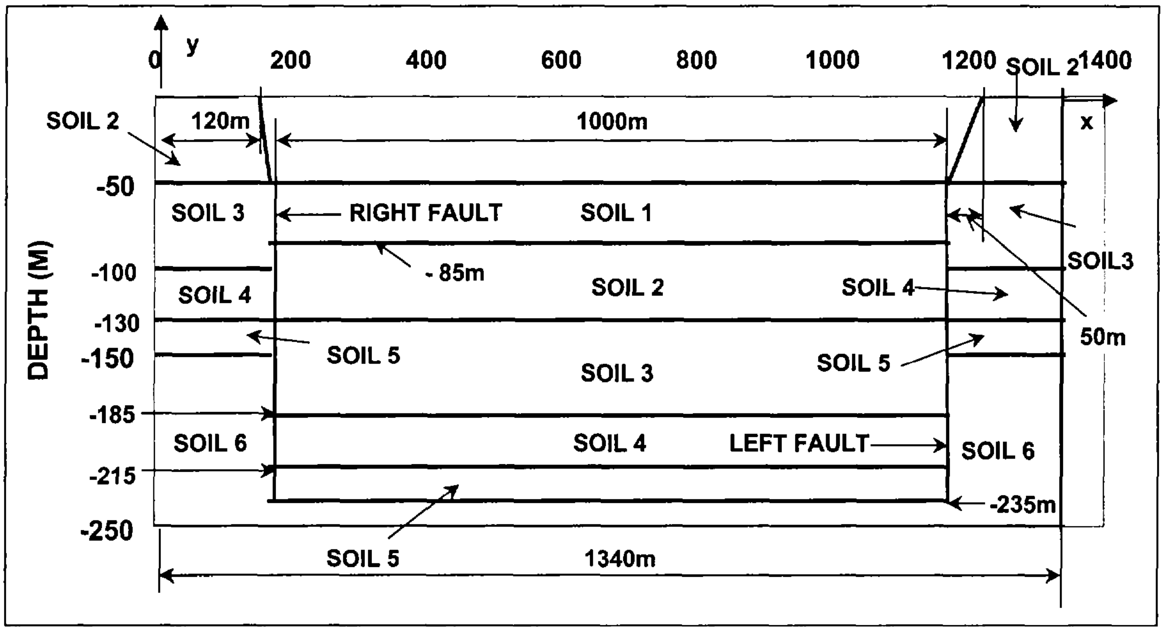

Fig. 1. The cross-section of the model.

The valley is assumed as having a vertical separation from the outer region corresponding to a collapse in the interior. From here onwards we call this separation as a "fault". The cases considering the existence of the fault ("with fault" case) and considering the nonexistence of the fault ("no fault" case) are performed.

The objectives of this paper are: 1) The analysis of seismic response in terms of maximum values of shear strain at different spots along the depth for "with fault" and "no fault" fault cases; 2) The study of the influence of the faults in the seismic response in terms of maximum values of shear strain; 3) The analysis of the seismic response of the soils at different locations in terms of shear strain-stress relationship for "no fault" case. This is the first attempt to study the nonlinear behavior of this valley using a 2-D refined model. The UDEC code is used for studying, not only the nonlinear behavior of the soils, but also the influence of the faults to the seismic response of the soils.

THE 2-D MODEL AND THE PROPERTIES OF THE SOILS

A bidimensional model is considered. The dimensions of the cross section of the model used are: 1240 m length and 250 m depth. The Fig. 1 shows the cross-section used. The cross-section presents two "old" vertical faults situated at x=170m and x=1170m and is composed by 6 types of soils, each one having their own geotechnical characteristics. The "old" vertical faults reach –235m depth. The properties gathered from "*in* situ" tests, and used herein, are represented in Table 1. These soils, which had formed as layers, can be divided in two groups. The "soft" soils as soil 1, 3 and 5 in Table 1 (Alluvial deposits) with shear velocity less than 300 m/s and rock as "soil" 2, 4 and 6 in table 1 (Basalt) with shear velocity grater than 1500 m/s. In Fig. 2, a detail of the mesh used for this model is shown. Note that each soil type appears inside and outside the valley, displaced vertically approximately 80m. Each soil type is considered as a separate deformable block. The mesh, inside each of these deformable blocks, has the same size of triangular elements. The formulation of these triangular elements is similar to the constant strain finite element formulation. The size of these triangular elements, inside the deformable blocks, has been tailored to the wavelength of the propagating waves through the layers. As a result of this, the "soft" soil zones have a more refined mesh. A less refined mesh is considered for the rock zones. The elastic joints are used, between all the deformable blocks, in case of nonexistence of the faults. The inelastic joints are used only for the faults, and elastic ones between the others, in case of considering the existence of the faults. The mesh used has 36504 nodes. Wave reflections at the model lateral boundaries are minimized by using both quiet (or absorbing) and free-field boundary conditions. The viscous (quiet) lateral boundary developed by Lysmer *et al.* [1969] is used in UDEC. It is based on independent dashpots in the normal and shear directions at the model boundaries. The free-field lateral boundaries supplies conditions that are identical to those in an infinite model. In this way, plane waves propagating upward suffer no distorsion at the boundary because of the existence of free-field grid. This approach was used in the continuum finite difference code NESSI by Cundall et al [1980]. A technique of this type is developed in UDEC. The Rayleigh mass proportional damping, is used herein. The critical damping ratio, in this case, is 5% for a frequency=0.5 Hz.

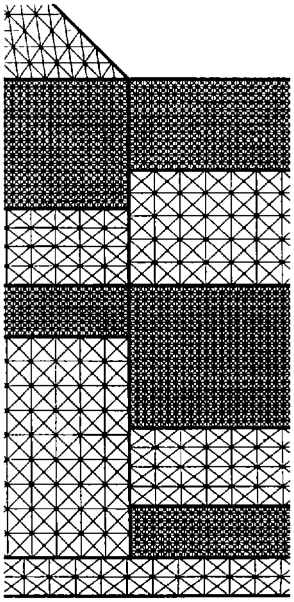

Fig. 2. The mesh used (a detail).

The "soils" 2, 4 and 6 are associated to "Nevada Test Site Basalt" regarding the cohesion, Poisson ratio and the angle of friction (Itasca, [2000]). The soils 1, 3 and 5 are associated with "soft soils" regarding the cohesion, Poisson ratio and the angle of friction (Paunescu *at al.* [1982]). The velocity and density of "soft soils" and rocks respectively were gathered from testing in soils with similarities to the ones of São Sebastião (Nunes, [2000]). This study is focused in some spots along the depth for only a few collums situated at x coordinate equal with: 150m, 168m, 172m, 190m, 480m and 670m respectively, see Fig.1.

Table 1 The properties of soils

Soil	Poisson Ratio	Density (T/m^3)	Vs (M/s)	Cohesion (KPa)	Angl. Friction (Degrees)
1	0.25	1.7	200	19	30
2	0.22	2.8	2000	66200	31
3	0.25	1.5	150	19	30
4	0.22	2.8	2000	66200	31
5	0.25	1.7	200	19	30
6	0.22	2.8	3000	66200	31

THE ACCELEROGRAM USED

The main shock of the July 9, 1998 earthquake recorded in Azores archipel and divided by 4 is used. The horizontal (N-S) and the vertical component of accelerogram used in this work are represented in Fig. 3. They are applied, as velocities, at the bottom of the model cross-section.

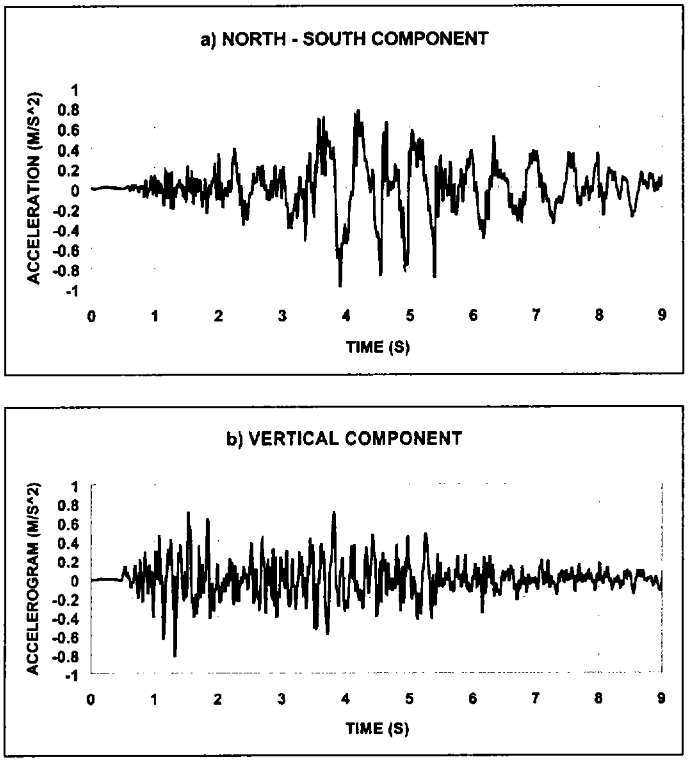

Fig. 3. The accelerogram used: a) North-South component and b) Vertical component.

THE SEISMIC RESPONSE IN TERMS OF MAXIMUM VALUES OF SHEAR STRAIN ALONG THE DEPTH

The seismic response of the soil in term of maximum values of shear strain along the depth at different positions are presented in this part. At 20m in the left hand side of the fault the seismic response is as it can be seen in Fig. 4. There is an increase of shear strain for the soil situated near the surface until almost 0.006% (soft soil) for both cases "with fault" and "no fault". Near the fault, at 2m left and right hand side respectively, there is a small increase of the seismic response in terms of maximum values of shear strain around –170m depth and a grater increase near the surface for both cases "with fault" and "no fault" (Fig.

5 and 6).

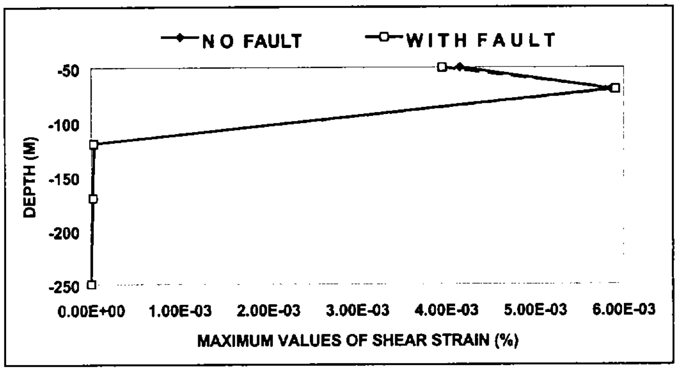

Fig. 4. The seismic response in terms of maximum values of shear strain along the depth at a spot situated at 20m left from the fault (x=150m).

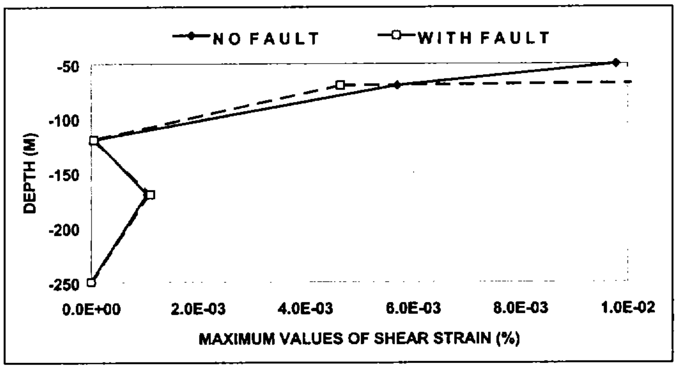

Fig. 5. The seismic response in terms of maximum values of shear strain along the depth at a spot situated at 2m left from the fault (x=168m).

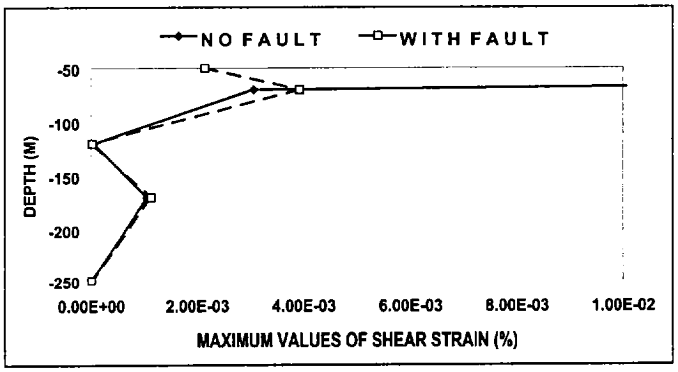

Fig. 6. The seismic response in terms of maximum values of shear strain along the depth at a spot situated at 2m right from the fault (x=172m).

The values of seismic response of the soil, in terms of maximum values of shear strain, for both cases "with fault" and "no fault", are decreasing as one is going toward the center of the valley, both at –70m and –170m depth (Fig. 7, 8 and 9). One can observe that, there is an influence of the fault at 20m right hand side for the fault. The maximum values of the shear strain, at this spot situated at 20m, right hand side for the fault, at –70m for "no fault" case are grater than for "with fault" case as it is shown in Fig. 7.

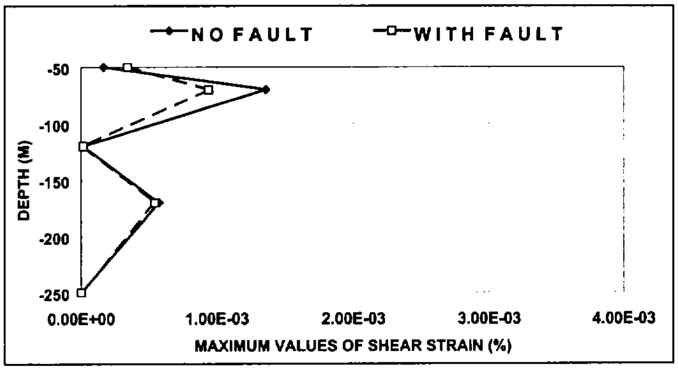

Fig. 7. The seismic response in terms of maximum values of shear strain along the depth at a spot situated at 20m right from the fault (x=190m).

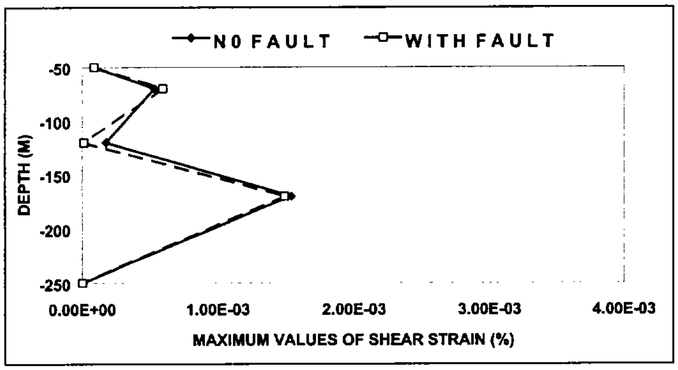

Fig. 8. The seismic response in terms of maximum values of shear strain along the depth at a spot situated on the right side of the fault (x=480m).

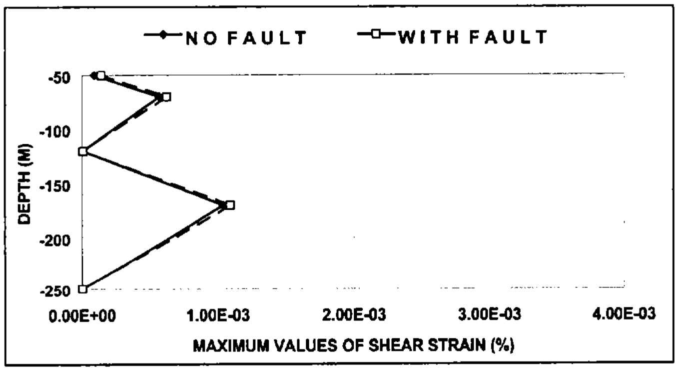

Fig. 9. The seismic response in terms of maximum values of shear strain along the depth at a spot situated at the center of the valley (x=670m).

THE SEISMIC RESPONSE IN TERMS OF SHEAR STRAIN-SHEAR STRESS RELATIONSHIP

The shear-strain-stress relationship is studied herein. The spots situated at the specific coordinates studied in the previous section, where one assume the existence of nonlinearity in the seismic response of the soil, are analyzed in term of shear-strain-stress relationship. These spots could be where the maximum values of shear strain are around 1E-03 %. Following the criterion one has referred to in introduction, for the points situated at the specific coordinates studied in the previous section, the plastified zones are observed. The "no fault" case is chosen to be presented below. As it can be seen in Fig. 10, for values of shear strain around 1E-03% it appears signs of the plastification of the "soft" soil. For the point having coordinates x=190m and y=-70m the seismic response, in terms of shear strain-stress relationship, is nonlinear.

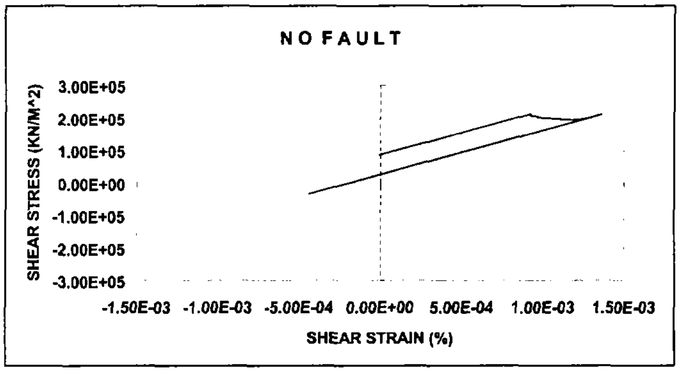

Fig. 10. The seismic response in terms of shear strain-stress relationship at-70m at a spot situated at 20m right from the fault (x=190m).

From Fig. 4 one can observe that the maximum value of shear strain at 20m left hand side from the fault at –50 and –70m respectively, is around 1E-03%. As it can be seen in Fig. 11 the behavior of the soil is nonlinear for the spot situated at –50m at 20m left hand side from the fault. A very small nonlinearity can be observed at –70m, at 20m left hand side from the fault (Fig. 12).

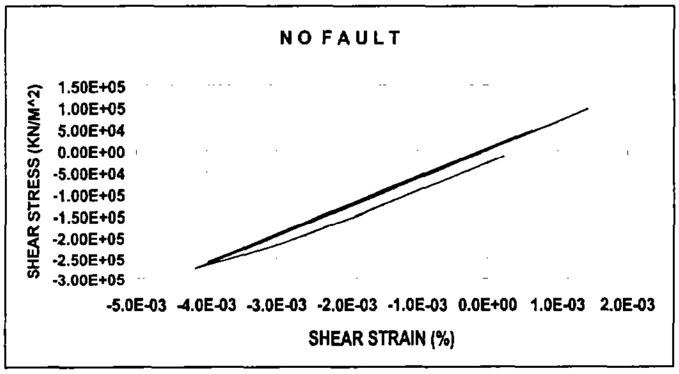

Fig. 11. The seismic response in terms of shear strain-stress relationship at-50m at a spot situated at 20m left from the fault (x=150m).

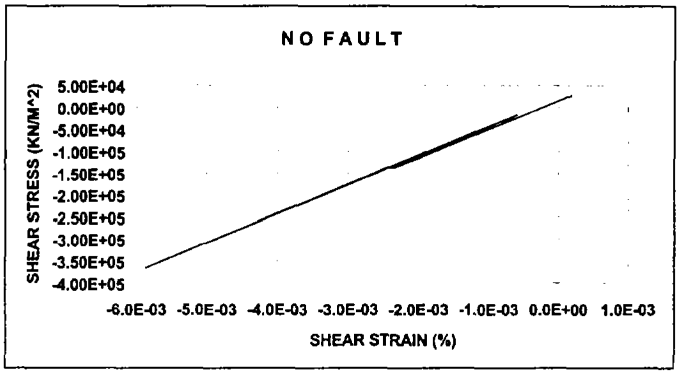

Fig. 12. The seismic response in terms of shear strain-stress relationship at –70m at a spot situated at 20m left from the fault (x=150m).

The maximum value of shear strain at 2m left hand side from the fault at –50 and –70m respectively, is around 1E-03% (Fig. 5). The behavior of the soil is nonlinear at –50m at 2m left hand side from the fault (Fig. 13). A very small nonlinearity can be noticed at –70m, at 20m left hand side from the fault (Fig. 14).

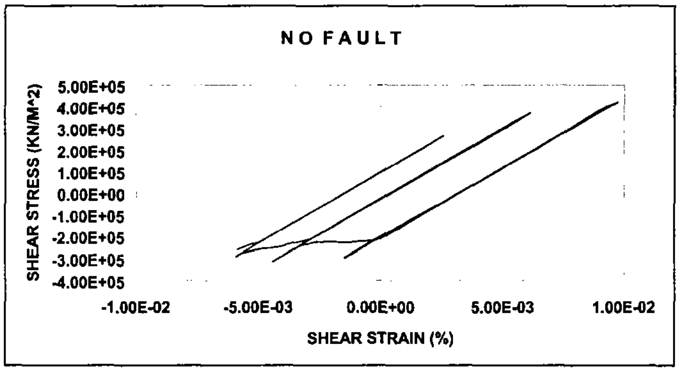

Fig. 13. The seismic response in terms of shear strain-stress relationship at the surface (–50m) at a spot situated at 2m left from the fault (x=168m).

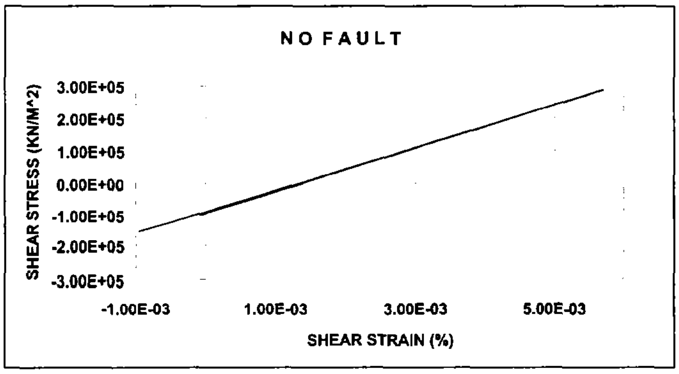

Fig. 14. The seismic response in terms of shear strain-stress relationship at –70m at a spot situated at 2m left from the fault (x=168m).

In Fig. 6, the maximum value of shear strain at 2m right hand side from the fault at the surface (–50m) and –70m respectively, is around 1E-02% and 1E-03% respectively. The behavior of the soil is highly nonlinear at the surface (–50m) at 2m right hand side from the fault (Fig. 15). Further research is needed to clarify the behavior in this region. A nonlinear behavior of the soil can be observed at –70m, at 2m right hand side from the fault (Fig. 16).

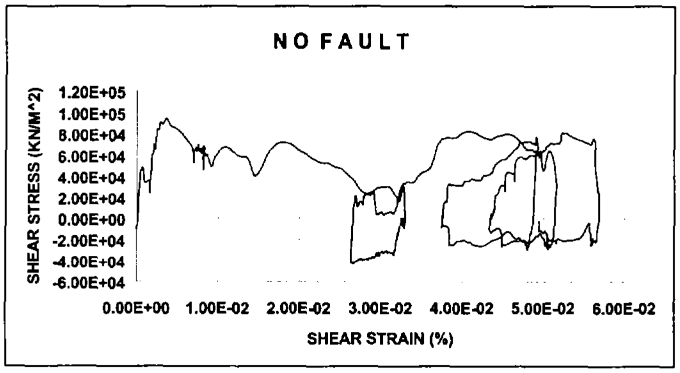

Fig. 15. The seismic response in terms of shear strain-stress relationship at the surface (-50m) at a spot situated at 2m right from the fault (x=172m).

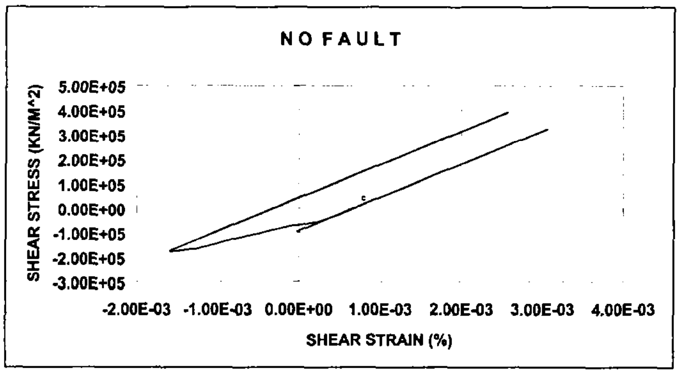

Fig. 16. The seismic response in terms of shear strain-stress relationship at –70m at a spot situated at 2m right from the fault (x=172m).

CONCLUSIONS

The follows conclusions can be taken from this preliminary study: a) Around the fault and near the surface, the seismic response of the soil in term of maximum values of shear strain has higher values (between 1E-03% and 1E-02%) than in the other parts of the cross-section; b) The existence of the fault has some influence to the seismic behavior of the soils at least in the spots were the study has been done; c) Further studies have to be done, especially near the fault for a much better understanding of the behavior of the soil in this region of the valley.

ACKNOWLEDGEMENTS

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REFERENCES

Adams, M. B., B. J. Berrill, O.R. Davis and J.J. Taber, J. [2000] “Modeling site effects in the Lower Hut valley, New Zealand” Proc. Twelfth WCEE – Aukland, New Zealand, No. 2694

Archuleta, R. J., L. F. Bonilla, and D. Lavallée [2000] “Nonlinearity in observed and computed accelerograms” Proc. Twelfth WCEE – Aukland, New Zealand, No. 1934.

Cundall, P.A., J. Marti, P. Beresford, N. Last and M.Asgian. [1980] “NESSI-Soil Structure Interaction Program for Dynamic and Static Problems” Norwegian Geo. Inst., Report 51508-9, December.

Hataniyama, A and H. Watanabe. [2000] “Deformation of sandy deposits by fault movement” Proc. Twelfth WCEE – Aukland, New Zealand, No.2209.

Itasca Counsulting Group, Inc. [2000] “Universal Distinct Element Code-User's Manual, Version 3.1” Mineapolis, Minnesota, USA.

Kawase, H., S. Matsushima, W.R. Graves and P.G. Somerville. [2000] “Strong motion simulation of Hyogo-Ken Nambu (Kobe) earthquake considering both the heterogenous rupture process and the3-D basin structure” Proc. Twelfth WCEE – Aukland, New Zealand, No. 990.

Lysmer, J and R. Kuhlemeyer. [1969] “Finite Dynamic Model for Infinite Media” Journal Of Engrg. Mech. Div. ASCE, No. 98, pp 85-105.

Nunes, J. C. [2000] “Personal Comunication” Univ. of Açores

Paunescu, M., V. Pop. and T. Silion [1982] *“Geotehnica si Fundatii”* Ed. Didactica si Pedagogica, Bucuresti

Psarropoulos, P.N., G. Gazetas and T. Tazoh. [1999] “Seismic response analysis of alluvial valley at bridge site” Proc. Second Intern. Conf. On Earthq. Geo. Engrg., Lisbon, Portugal.

Semblat, J. F., P. Dangla and A.M. Duval. [1999] “Seismic waves amplification: Experimental versus numerical analysis” Proc. Second Intern. Conf. On Earthq. Geo. Engrg., Lisbon.

Tokusho, T. [1999] “Effect of nonlinear soil properties on seismic amplification in surface layers” Proc.Second Intern. Conf. On Earthq. Geo. Engrg. Lisbon, Portugal.

Trifunac, M.D. and M.L. Todorovska. [1996] “Nonlinear soil response-1994 Northridge, California, earthquake” Journal of Geo. Engrg. Vol. 122, No. 9: pp. 725-735.