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INFLUENCE OF SITE EFFECT IN DAMAGE STATE OF FRAMED STRUCTURES SUBJECTED TO EARTHQUAKE

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SUMMARY

One of the main goals of earthquake engineering is the prediction of the behaviour of soils, when they are overload by seismic events, and its influence on the response of civil engineering structures. In order to improve earthquake mitigation strategies, it seems very important to quantify local seismic site effect described by acceleration and damage amplification due to soil movement in active seismic areas. The soil properties correspond to the geological data of the city of Mérida, which is developed on an important active seismic fault in Venezuela.

The structural response is based on a damage model developed at the University of Los Andes in Venezuela. This damage model combines the plastic hinge concept with fracture mechanics and continuum damage theory. The simulations measure the influence of site effect on the state of damage in framed structures. The model was included in a commercial structural analysis program, called ABAQUS, as a new finite element. Soil was represented using the conventional finite elements included in the library of the program. The fault was represented as a discontinuity with unilateral contact conditions in the soil mesh. The earthquakes are generated numerically by the application of shear forces on the lips of the fault.

A parametric study is carried out through the variation of the mesh dimensions and materials properties. Structural configuration was also modified. All the results describe the seismic response of soils and the structure; and point out the importance of the amplification of the seismic waves and the influence of site effect on various levels of damage of framed structures subjected to earthquakes.

1. INTRODUCCION

Because of the increase of tragedies related with natural's events in Venezuela, a seismic microzonation of the main cities of the country was initiate to approach all the problems caused by the interaction between the geological medium and human activities [Schmitz, 2005]. Geological conditions of local site, such as: nature of the soils, topography, depth of the basement and the phreatic level, can produce amplification of seismic waves that will results in important material damages and sometimes tragic loss of life. This phenomenon is well known as seismic site effect.

Various tools exist for the analysis and evaluation of structures under seismic overloads. The lumped damage mechanics is one of then. This is a theory that combines fracture mechanics, damage mechanics and the concept of plastic hinge and allows the numerical simulation of the seismic behaviour in framed structures [Cipollina, 1995; Flórez-López, 1998]. With the lumped damage mechanics is possible to represent in simple and effective

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way phenomena such as the influence of concrete cracking, the yield of the reinforcement, the low cycle fatigue and the reinforcement hardening, etc. In the case of reinforced concrete frames, the main mechanism of deterioration is cracking of concrete. In lumped damage mechanics cracking as well as plasticity are concentrated in plastic hinges. As a result of the numerical simulation of structures under seismic overloads, it is possible to determine the magnitude and localization of the damage in the elements of the frame and the process of deterioration and collapse of framed structures.
The Venezuelan Andes represent one of the most populated zones of the country where an active strike-slip fault was recognized and described as the Boconó Faults Zones [Schubert, 1982]. Historically, the region has suffered destructives seismic events (1610, 1674, 1812 and 1894) where magnitudes were estimated stronger than 7 [http://sismicidad.hacer.ula.ve/]. Mérida city is exposed to this intensive seismic risk and a seismic microzonation were proposed in [M.O.P., 1976] which represents the basic information of the simulations presents in this paper.

2. PROPAGATION OF SEISMIC WAVE WITH THE FINITE ELEMENT METHOD

To simulate the propagation of a seismic wave, various numerical method are often used: the finite difference method [Virieux, 1986], the finite element method [French, 1993; Richter, 1994], the spectral method [Komatitsch and Tromp, 2002] and the ray tracing method [Cerveny and Soares, 1992].
This paper describes some numerical simulations, using the finite element method, of ground motion due to a seismic event, the propagation and characteristics of these ground motion and its influence in the damage level of the structure under the generated seismic overloads. In these simulations, a surface traction load is applied on the fault zone which generates waves that propagates up to the free surface where the accelerations were measured. These accelerations are applied in the base of a reinforced concrete framed structure and analyzed with the lumped damage mechanics obtaining the magnitude of the damage in the elements of the frame.
To evaluate the effects of soil conditions in the propagation of the ground motion, we use the soil profile of the terrace of Mérida city [M.O.P., 1976]. The simulation was carried out in the Element Finite program ABAQUS.

2.1 Description of the Finite Element Model

2.1.1 Parts and Partitions

The two-dimensional model used three parts representing the different layers in the terrace of Mérida city [M.O.P., 1976]. Figure 1 shows the geometry and the dimensions used in each layer. The deeper layer has three partitions where the partitions that represent the fault zone have a tangential behavior with a friction coefficient of 0.85.

2.1.2 Material Properties

The elastic model used has three types of materials with different properties (Table 1): i) a superficial layer of sand and clays, with gravel and few cobbles; ii) an intermediate layer with cobbles and clays; iii) a deep layer of a rock mass. The damping coefficient is 3 % for the three layers.

2.1.3 Loads

A surface traction load is applied parallel on the fault zone with an upward movement simulating the displacement of an inverse fault.

2.1.4 Boundary Conditions

In the lower part of the terrace, the vertical and horizontal displacements are restricted; on the right side, only the vertical displacements are restricted and on the left side, restrictions are imposed only in the deep layer of rock mass to represent the basement in the terrace of Mérida city.

2.1.5 Steps

The boundary conditions of the model are applied in the initial step; in the second step, the load on the fault zone is applied. The duration of this second step is 15 seconds.

2.1.6 Mesh

The meshing of the model (Figure 2) consists in 251 elements (type CPE4R): 4-node, bilinear plane strain quadrilateral, reduced integration, hourglass control.

2.1.7 Field Output and History Output

Vertical and horizontal accelerations in all the nodes of the surface are requested as output files.

Table 1: Material Properties in the terrace of Mérida city according to [M.O.P., 1976]

Layer	Density	Elasticity Module (E)	Poisson Ratio
1. Superficial	2700 Kg/m3	0.4 – 3.5 GPa	0.36 – 0.42
2. Intermediate	3300 Kg/m3	6.0 – 10.0 GPa	0.21 – 0.36
3. Deep	5500 Kg/m3	12.0 – 40.0 GPa	0.23 – 0.35

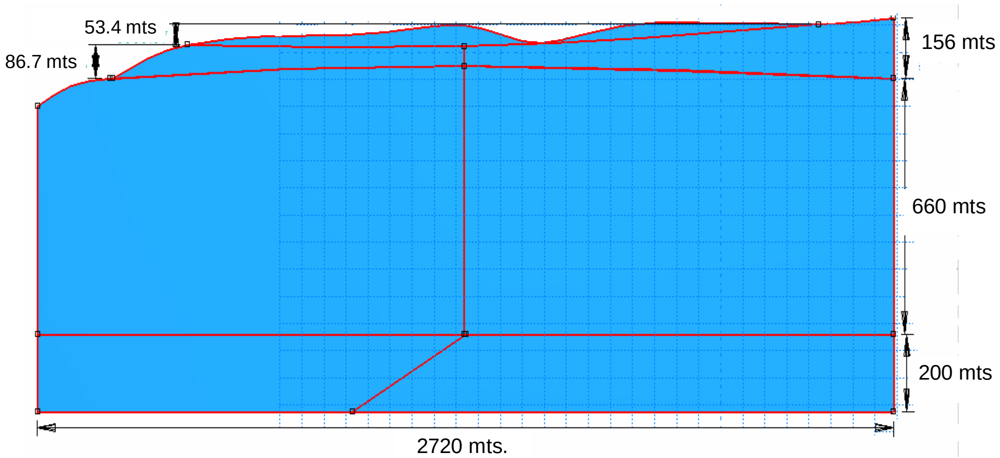

Figure 1: Geometry and Dimensions for a three-layered soil configuration

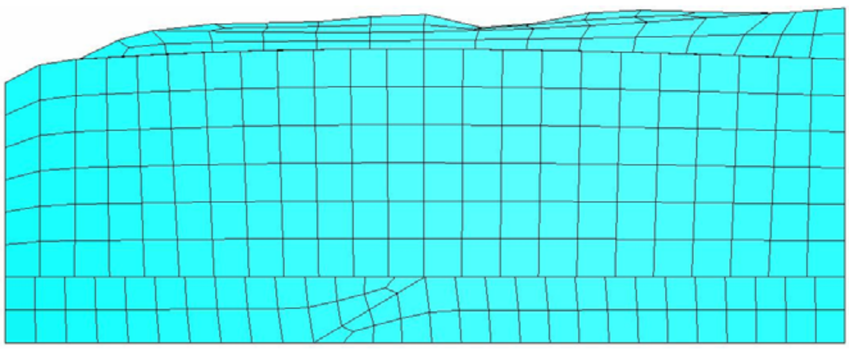

Figure 2: Mesh Generation and finite elements

3. PARAMETRIC STUDY

To evaluate the influence of local site conditions in the ground motion and in consequence in the level of damage in the structures, a parametric study was carried out simulating a multilayered soil profile with different characteristic in the properties of the materials of the layers. The magnitude of the load is changed to simulate earthquakes with different intensity. The location of the structure in the surface of the terrace takes with respect to the fault zone and the thickness of the superficial layer to assess the effects of the nearness of the fault and the topography of the surface. The main objective is to measure the effect of local site which is produced principally by factors like: topography of the place, depth of the rock basement, type of material and directivity of the fault.

The simulations of the soil profile were carried out taking minimum values in the material properties to represent soft soil, maximum values to represent hard soil and average values for intermediate cases. Four nodes in the surface are taken in account to measure the horizontal acceleration which is applied in the base of the framed structure (Figure 3).

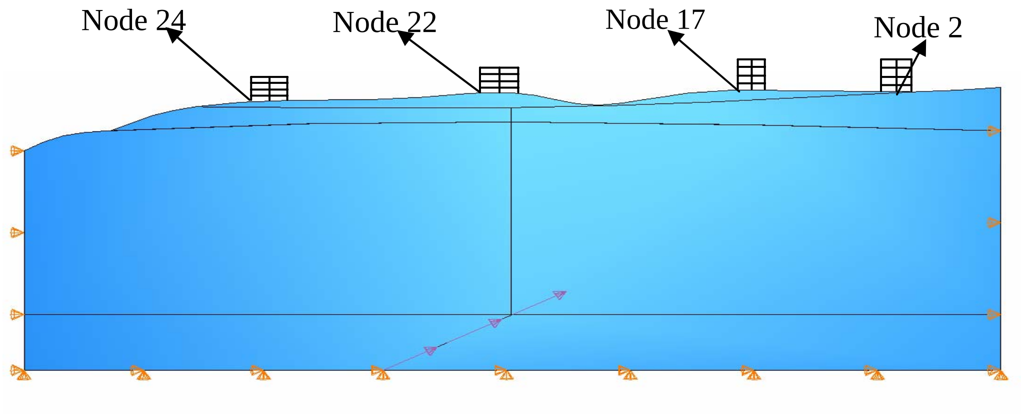

Figure 3: Localization of the frame with respect to the fault zone

The nodes 2 and 17 are located in the right side of the fault zone, the node 2 belongs to the intermediate zone and in the node 17 the thickness of the superficial layer is approximately 18 meters. In the node 22 the thickness on the superficial layer is approximately 50 meters and is located vertical to the fault zone, in the node 24 the thickness of the superficial layer is approximately 20 meters and is located in the left side of the fault zone. The framed structure analyzed was a reinforced concrete frame with seven floors and five spans designed according to the current Venezuelan code Covenin (1753-85) (Figure 4). After obtained the distribution of the damage in the elements of the frame, a global damage of the frame is calculated [Uzcátegui, 2005] taking the initial rigidity and the final rigidity when the accelerations records obtained in the simulations are applied to the base of the frame.

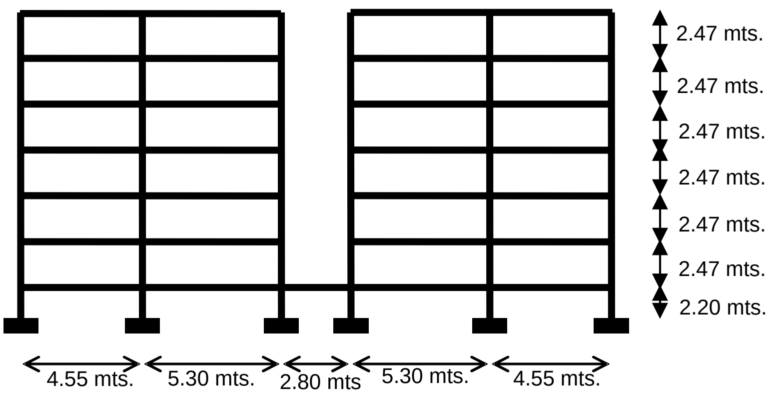

Figure 4: Geometry of the reinforced concrete frame analyzed

4. RESULTS

After dynamic simulations of a three-layered soil profile of the Mérida city with the finite element method, the accelerations in the surface nodes are obtained. Figure 5 shows some acceleration records corresponding to the nodes analyzed in this study.

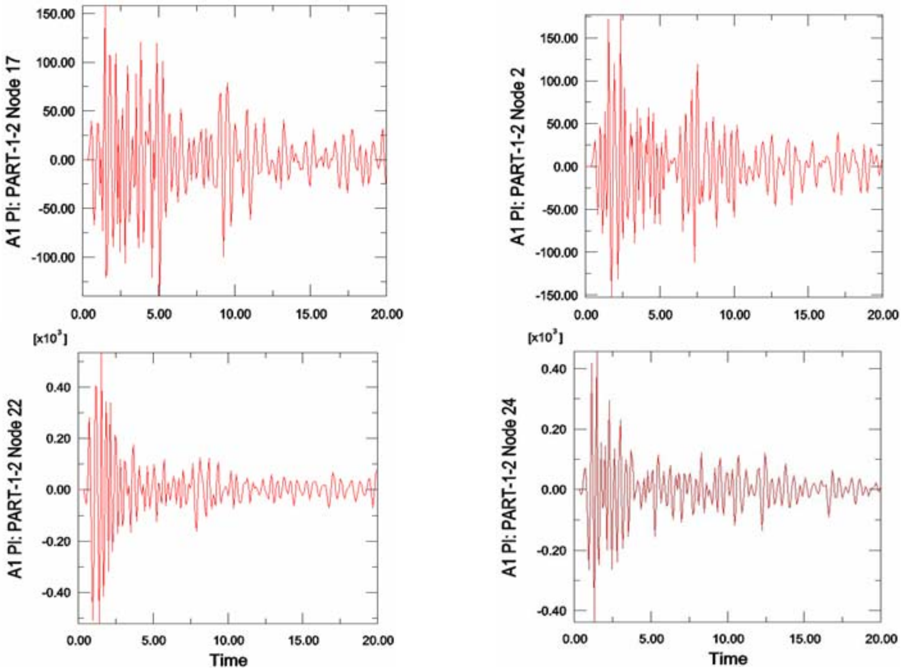

Figure 5: Accelerations records: Horizontal acceleration surface response for the simulation with the average values of the material properties.

From the accelerations records, we calculated the acceleration response spectrums to evaluate the influence of the characteristic of the soil in the frequency contents of the movement and therefore in the spectrum shape. Figure 6 shows the accelerations spectral response corresponding to: a place near the fault zone (1), a place far from the fault zone and in a harder soil (2) and a place where the thickness of the superficial layer is bigger (3). It can be observed the change in the maximum acceleration of the area and in the spectral forms.

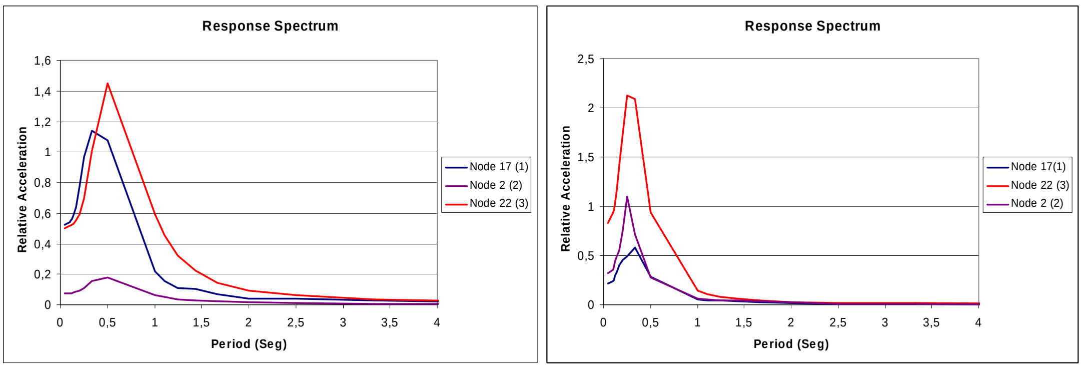

Figure 6: Acceleration response spectrums calculated: a) with the minimum values in the material properties of the soil profile, b) with the maximum values in the material properties of the soil profile

The figure 7 illustrates the damage distribution in the elements of the frame analyzed after applying the accelerations records in the base of the frame. Values of damage of 0.20 or lower are considered insignificant, values of damage lower to 0.45 corresponds to repairable damage and values of damage higher to 0.50 indicate that the frame is on the verge of structural collapse [Flórez-López, 1998]. In the simulation corresponding to the lower values in the material properties of the profile soil (Elasticity Module, Poisson Ratio, etc) the frame reach high values of damage in most of its elements, mostly in the lower columns where the higher value of damage is

0.50 in a column of the second floor. With the maximum values in the material properties, the damage in the elements of the frame gets lesser; being the elements more damaged the columns in the upper levels of the frame. In the simulation with the average values in the material properties, the frame has damage in almost all its elements (Figure 8).

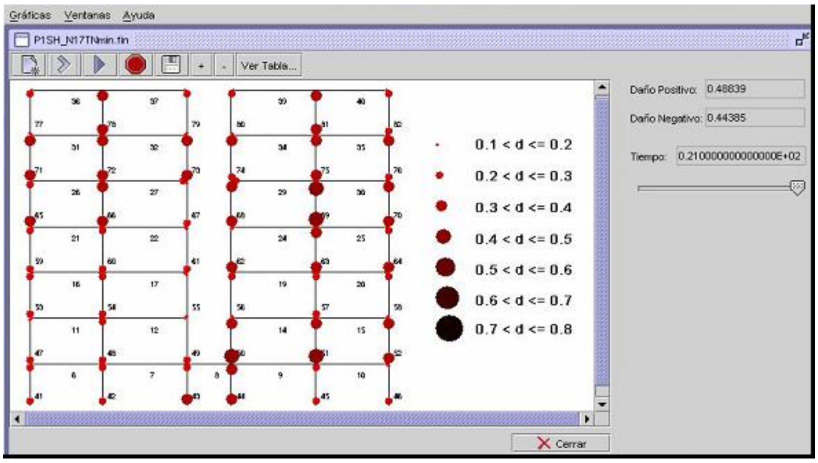

Figure 7: Distribution of damage in the frame elements. Simulation corresponding to Node 17 with the minimum values in the material properties

With respect to the thickness of the superficial layer, the most damaged frame for all the simulations was the analyzed with the accelerations record corresponding to the node 22 which is located in the zone of more thickness of the superficial layer. The frames analyzed with accelerations records corresponding to the node 24 reach considerable damage, in the simulation related to hard soils, the elements in the upper level of the frame reached more damage (Figure 9). In the simulations associated with the average values in the material properties, the frames had damage in almost all its elements (Figure 10). The frames analyzed with the acceleration response corresponding to soft soils had damage in the elements of its lower levels (Figure 11).

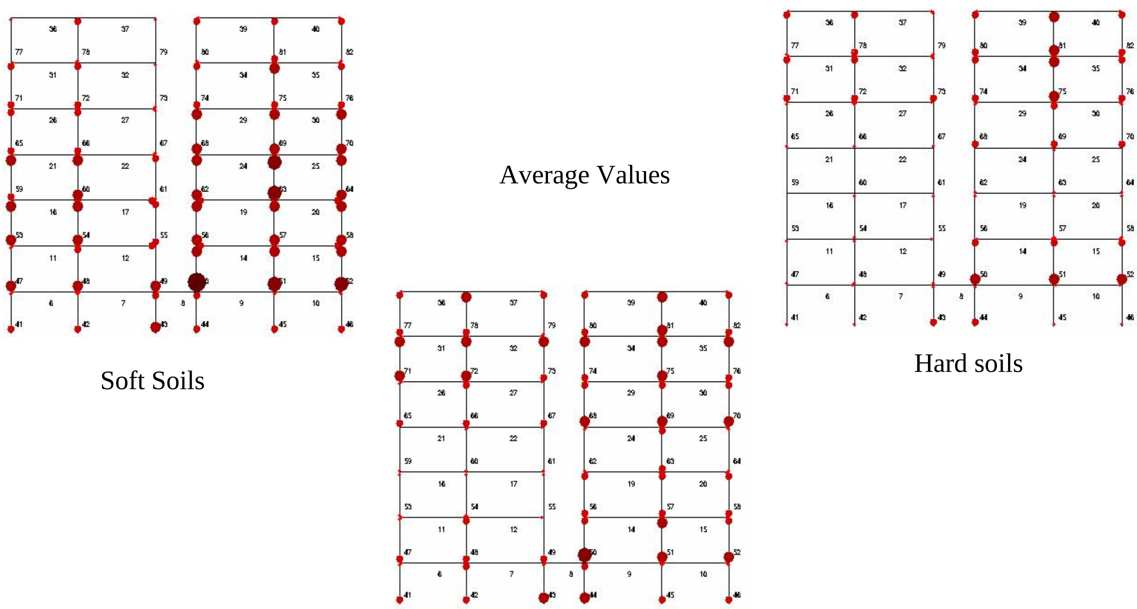

Figure 8: Damage distribution in the frame elements corresponding to the simulations with the different values in the material properties

The frame subjected to accelerations records from the node 2 and 17 reached insignificant values of damage (Figure 9 and 10), except in the simulation corresponding to the node 17 with soft soils where the frame elements presents higher values of damage (Figure 11).

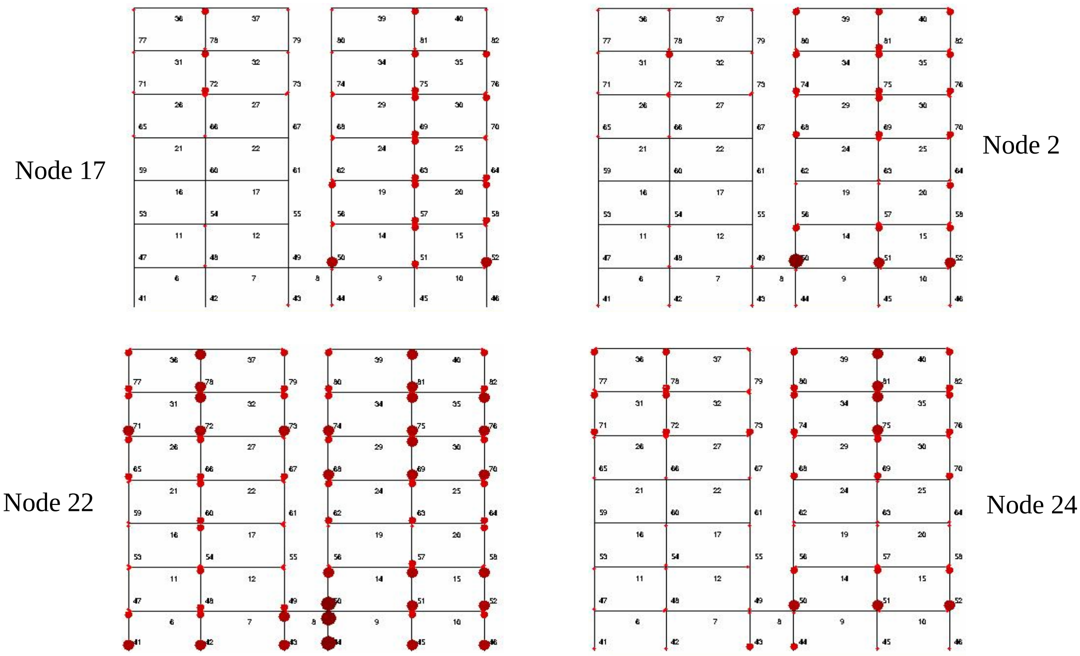

Figure 9: Comparison in the Level of damage in the frame elements with respect to the location of the nodes; simulation corresponding to the maximum values in the Properties of the Material (Harder Soils)

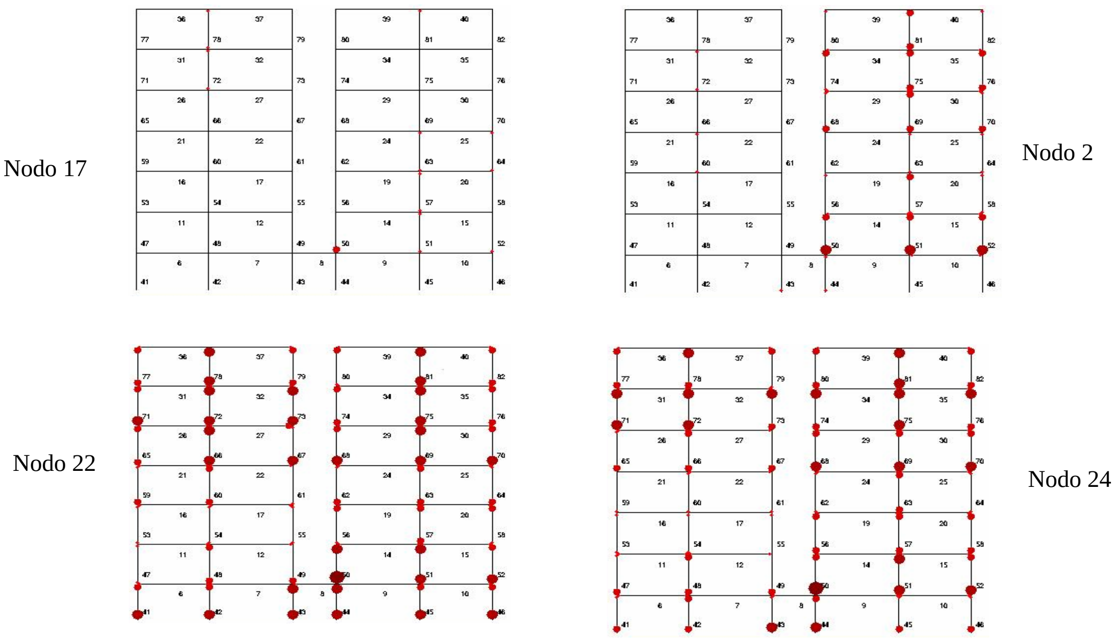

Figure 10: Level of damage in the frame elements with respect to the location of the nodes; simulation corresponding to the average values in the properties of the Material

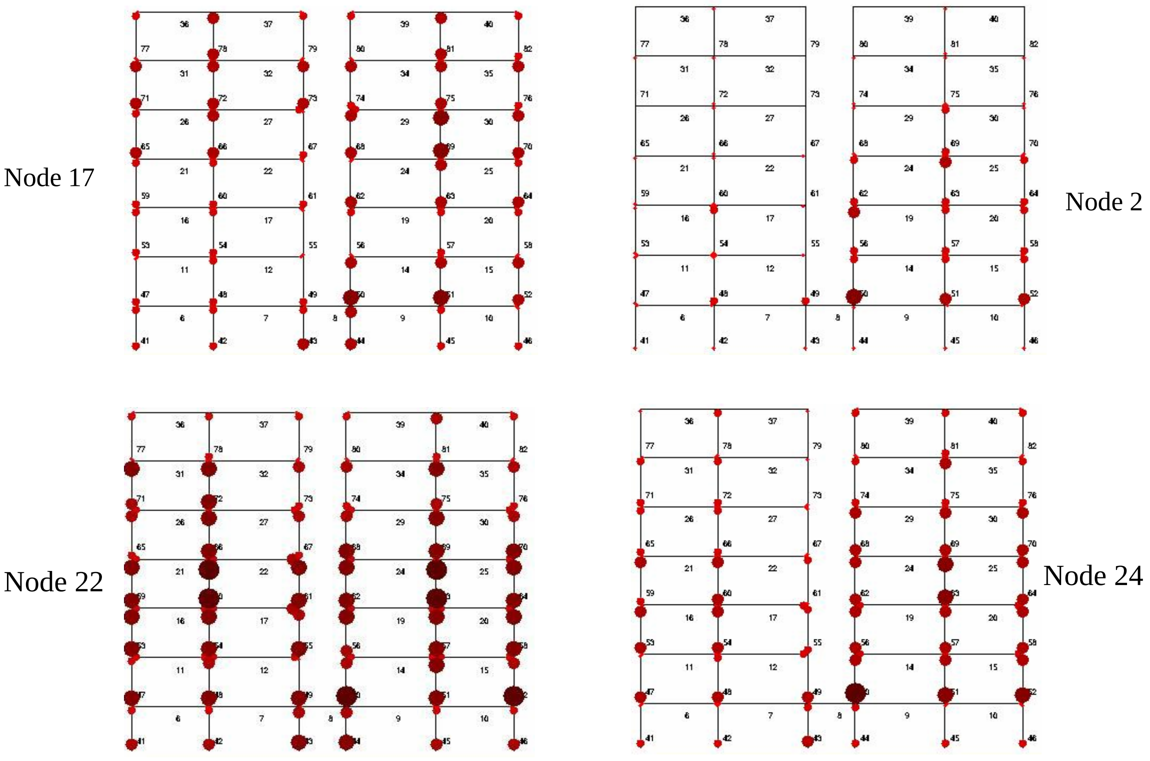

Figure 11. Levels of damage in the frame elements corresponding to the simulation with the minimum values in the material properties.

A global damage is obtained for all the frames after the dynamic analysis with the accelerations records applied in the base of the frame. This value is calculated taking the initial rigidity of the frame and the final rigidity which is obtained with the damage level reached for the frame elements. In Table 2, the global damages are shown for all the simulations. The frame with the higher level of global damage correspond to the simulation analyzed with the accelerations record of the node 22 (more thickness of the superficial layer) and the minimum values in the material properties (soft soils).

Table 2. Global Damage in the frames analyzed.

Frame	Node	Desp.	Initial Force	Final Desp.	Final Force	Global Damage
P1SH_N17max	43	0,005	1,12E-01	0,005	9,39E-02	0,16
P1SH_N17min	43	0,005	1,12E-01	0,005	7,51E-02	0,33
P1SH_N17p	43	0,005	1,12E-01	0,005	9,33E-02	0,17
P1SH_N22max	43	0,005	1,12E-01	0,005	7,90E-02	0,30
P1SH_N22min	43	0,005	1,12E-01	0,005	3,88E-02	0,65
P1SH_N22p	43	0,005	1,12E-01	0,005	7,95E-02	0,29
P1SH_N24max	43	0,005	1,12E-01	0,005	9,11E-02	0,19
P1SH_N24min	43	0,005	1,12E-01	0,005	9,32E-02	0,17
P1SH_N24p	43	0,005	1,12E-01	0,005	7,85E-02	0,30
P1SH_N2max	43	0,005	1,12E-01	0,005	9,90E-02	0,12
P1SH_N2min	43	0,005	1,12E-01	0,005	8,16E-02	0,27
P1SH_N2p	43	0,005	1,12E-01	0,005	9,97E-02	0,11

5. CONCLUSIONS

- The tools used for the dynamic analysis with the finite element method and cracking characterization with the lumped damage mechanics are perfectly adapted to the solution of the problem.
- An instrument is developed to evaluate the damage state in reinforced concrete framed structures, taking the effects of the local site when an earthquake occurs.
- It can be seen the difference in the behavior of the frame under diverse solicitations related with the localization of the frame with respect to the fault, the properties of the soil and the thickness of the soil layers, indicating that the characteristic of the soil profile play a significant role in the ground motion due to an earthquake and in the damage reached for the structures.
- According with the accelerations response obtained for the simulations of the soil profile of Mérida city an amplification is observed in the values of acceleration in the surface, especially when the thickness of the superficial layer increase.

6. RECOMMENDATIONS

- A three dimensional model should be developed to carry out simulations with more realistic geometries of the soil profile of Mérida city and the underlying fault.
- Simulations with characteristics and properties of the soil profile generated from new studies of seismic microzonation of Mérida must be made, and extend this study to other cities of Venezuela.

7. REFERENCES

Cerveny V. and Soares J.E.P. (1992), Fresnel volume ray tracing, *Geophysics*, vol. 57, pp. 902-915.

Cipollina A., López-Inojosa A., Flórez-López J. (1995), A simplified damage mechanics approach to nonlinear analysis of frames, *Computers & Structures*; 54 (6), pp. 1113-1126.

Flórez-López J. (1998), Frame analysis and continuum damage mechanics, *J. Eur. Mech*; 17 (2), pp. 269-284.

French D.A. (1993), A space-time finite element method for the wave equation. Comput. *Methods Appl. Mech. Engrg*, vol. 107, pp. 145-157.

Komatitsch D. and Tromp J. (2002), Spectral-element simulations of global seismic wave propagation, Part I: Validation, *Geophysical Journal International*, vol. 149, pp. 390-412.

Ministerio de Obras Públicas, (1976), Microzonificación Sísmica de la Meseta de Mérida. *Publicaciones tecnicas del Ministerio, Caracas, Venezuela*. Tomo I. pp. 169.

Richter G.R. (1994), an explicit finite element method for the wave equation. *Applied Numerical Mathematics*, vol. 16, pp. 65-80.

Schmitz M., Hernández J., Audemard F., Malavé G., Andrade L. (2005), Proyecto de microzonificacion sísmica en las ciudades de Caracas y Barquisimeto, *IV Coloquio sobre Microzonificación Sísmica*, Barquisimeto, Venezuela, November 2005.

Schubert, C., (1982), Neotectonics of the Bocono fault, Western Venezuela. Tectonophysics 85, pp. 98-111.

Uzcátegui F. M. (2005), Implementación de elementos finitos en un programa de análisis estructural basado en la Web. *Tesis de Maestría. Universidad de Los Andes*, Venezuela, April 2005.

Virieux J., (1986) P-sv wave propagation in heterogeneous media, velocity-stress finite difference method. *Geophysics*, vol. 51, pp. 889-901.

http://sismicidad.hacer.ula.ve/, Sismología histórica en Venezuela.