SEISMIC EVALUATION OF MORTAR STRIP REINFORCED ADOBE HOUSES

Alberto Salgado[1], Ramón Sotres[2], Esteban R. Guinto[1], Roberto Arroyo[1], Hugo Acevedo[1], Angel Capistrano[3], Salomón Capistrano[3]

[1] *Professor, Dept. of Earthquake Engng, Autonomous University of Guerrero, México*
[2] *Head, Institute of Urban House and Soil, Government of Guerrero State, México*
[3] *Grad Student, Dept. of Construction Engng, Autonomous University of Guerrero, México*

Email: asalgadorodriguez@yahoo.com.mx

ABSTRACT :

South of Mexico is considered one of the most seismic areas on the world. In this region, almost 50% of the people lives in adobe houses and is recognized as high poverty zone. Both reasons mentioned before are mandatory to look and find out economical solutions to improve the seismic capacity of those dwellings, to mitigate the seismic damage and save people. In this work, the seismic behavior of mortar strip reinforced adobe houses is studied. This type of retrofitting is relatively economic and efficient because is applied in the structural critical zones of the house, like the union of walls and the high perimeter ring. Taking account the house typology, very similar in several countries of Latin-America, some laboratory test were performed to determine earthquake resistant properties. Those properties were used to build 3D finite element models of adobe houses. With the use of information about observed adobe houses seismic damage, a vulnerability function is proposed and applied to predict the scenario of damage of reinforced adobe houses on the south of Mexico, for some periods of return of the seismic activity.

KEYWORDS: Seismic evaluation, adobe houses, vulnerability function.

1. SEISMIC HAZARD EVALUATION

In this work, seismic hazard evaluation is performed using three different attenuation relationships (subduction, middle and low depth earthquakes). For subduction earthquakes, an attenuation law proposed by Ordaz (1989), based on an comprehensive number of earthquakes records obtained by the Guerrero Accelerometric Network (including Michoacan 1985 earthquake), is used. For middle depth earthquakes, a model proposed by Ordaz (1989) is also applied. In this case, earthquakes from normal faulting are exclusively included, like the case of 1989 earthquakes that have damaged an extended number of historical buildings in Puebla and Oaxaca. For low depth earthquakes, a model proposed by Sadigh (1997) is used. Results of this seismic hazard evaluation are shown in Figs. 1 to 4.

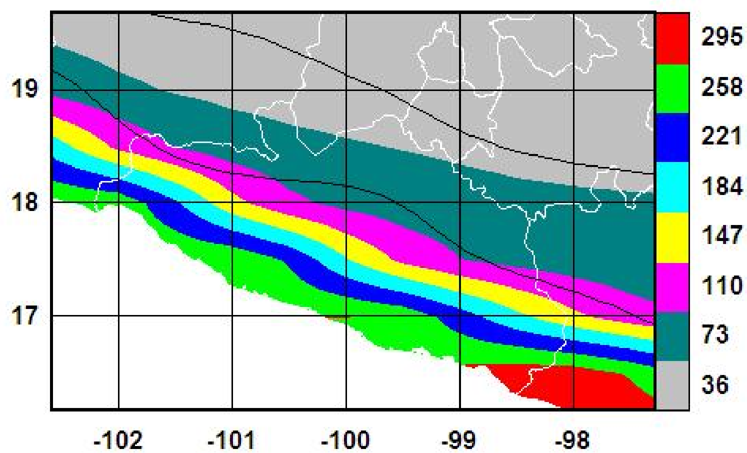

Fig. 1. Peak ground acceleration (gals) expected on hard soil for 50 years of return period for Mexican south.

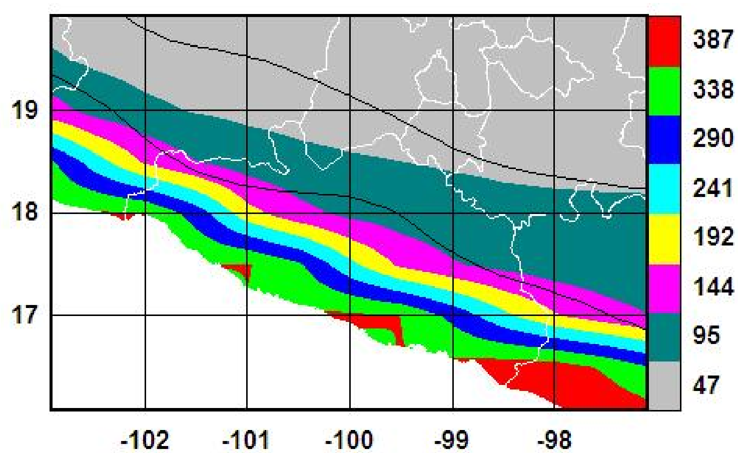

Fig. 2. Peak ground acceleration (gals) expected on hard soil for 100 years of return period for Mexican south.

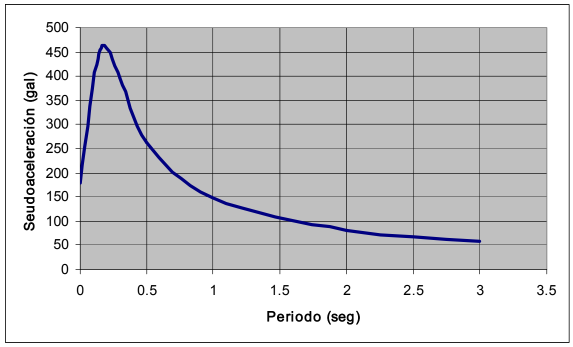

Fig. 3. Uniform hazard spectra for hard soil of Mexican south, for 50 years of return period.

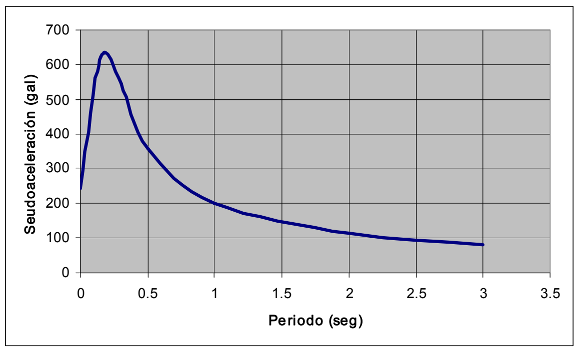

Fig. 4. Uniform hazard spectra for hard soil of Mexican south, for 100 years of return period.

2. SEISMIC BEHAVIOUR OF ADOBE HOUSES

There is much evidence that prove the extreme vulnerability of adobe houses to resist strong ground motion. Adobe walls are weighted and produce high inertial forces during the earthquake. Extreme vulnerability of the walls is related with the very low capacity to resist tension and shear stress and the impossibility to perform effective connections between perpendiculars walls. The way that floor is connected with the walls make difficult to address the seismic forces to more suitable structural elements, like the parallel walls (Flores, 2001). One of the most repetitive failures is the breakdown of the corner of the adobe houses (intersection of perpendicular walls), figs 5.

Fig. 5. Vertical breakdown in corners of adobe houses.

3. VULNERABILITY FUNCTION

Nevertheless each adobe house is different, main characteristics as those related to the structural distribution and wall thickness are quite similar in the south of Mexico (Salgado, 2002; Salgado, 2005) and several towns and cities of Latin-America. In this work, a direct relationship between peak ground acceleration (PGA) and average structural damage (ASD) was considered. ASD is calculated on the base of numerical values assigned to visual estimation of the structural damage. Vulnerability function was constructed using earthquake data from three significant Mexican earthquakes. These historical earthquakes produced considerable damage in adobe houses in the south of Mexico. In Table 3.1, PGA-ASD (Salgado, 2005) pairs for vulnerability function definition are shown.

Table 3.1 Data for defining the vulnerability function

Earthquake	PGA (gals)	ASD
Ometepec 14/sep/95	420	0.48
Oaxaca 30/sep/99	197	0.31
Colima 21/jan/03	442	0.62

In this paper, a lognormal shaped vulnerability function is considered. Parameters for this lognormal curve were estimated from Table 3.1 data, and results are $\Phi(5.875, 0.998)$. A drawing of the vulnerability function used in this work is shown in Fig. 6.

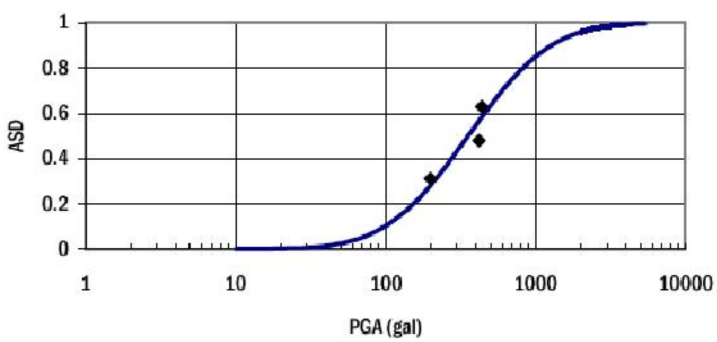

Fig. 6. Vulnerability function for Mexican south adobe houses.

4. FINITE ELEMENT ANALYSIS OF ADOBE HOUSES

In order to propose a type of retrofitting according with the observed seismic behavior of the adobe houses, a 3D finite element analysis (CSI, 2004) of a typical adobe houses was performed. In figure 7, schematic results of the stress in the structural walls under seismic loading are shown. High stress concentration zones, in the house model, are consistent with the actual observed distribution of the structural damage.

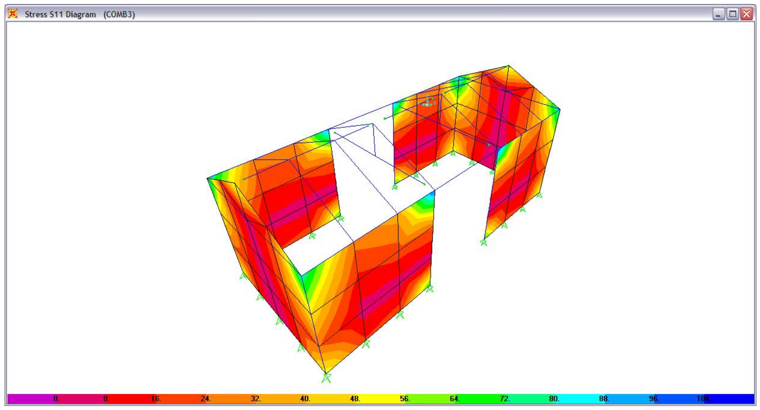

Fig. 7. Wall stress concentration under transverse seismic loading

5. MORTAR STRIP REINFORCED ADOBE HOUSES

In this paper, a system consistent in mortar strip reinforced adobe houses (figure 8) is studied. This type of retrofitting is economical and effective to improve the seismic capacity of adobe houses, (Alarcón y Alcocer, 1999).

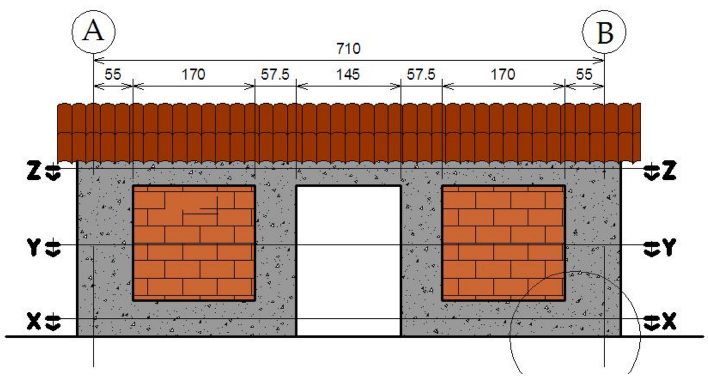

Fig. 8. Adobe house with reinforced mortar strip.

6. EVALUATION OF MORTAR STRIP REINFORCED ADOBE HOUSES

The best way to evaluate the effects of structural retrofitting of adobe houses is by observation of actual behavior and by performing controlled vibratory table test. Hernández (1979) using several types of retrofitting, for adobe houses like considered in this paper, found, by controlled vibratory table test, coefficients of increments of seismic resistance (table 6.1).

Table 6.1 Comparative strength of several structural retrofitting systems for adobe houses (Hernández *et al* 1979).

Retrofitting system	Comparative strength
None	1.00
RC top ring beam	2.67
Mortar skin with wire mesh	3.33
Steel tie rods	1.67

In this work, a simplified procedure for calculating, with safety criteria, the increment of the seismic capacity of adobe houses retrofitted with mortar strip reinforced is introduced. First of all, a coefficient of efficiency, as a function of reinforced wall area, is defined

$$IR = \frac{A_R}{A_T} \, x \, C_\alpha \qquad (6.1)$$

In this case, A_R is the reinforced structural wall area, A_T is the total area of structural walls of the house, C_α is a coefficient of effectiveness depending of the type of retrofitting employed. In this case, if mortar strip reinforced is used, C_α =3.33 (Hernandez, 1979). Obviously, with this criterion, the equation (6.1) is conservative because the spatial distribution of mortar strip in the adobe houses increases the actual seismic capacity of the dwelling.

7. PREDICTION OF SEISMIC DAMAGE IN MORTAR STRIP REINFORCED ADOBE HOUSES

In this work, a simplified procedure to predict structural damage in mortar strip reinforced adobe house is applied. The methodology is based on the shape of the vulnerability function determined for unreinforced adobe houses (figure 6). In this case, the vulnerability function of the mortar strip reinforced adobe houses is assumed with the same dispersion like the unreinforced houses and the difference is in the median of the vulnerability function of the retrofitted houses, which is increased by the coefficient IR defined in section 6 (fig. 9).

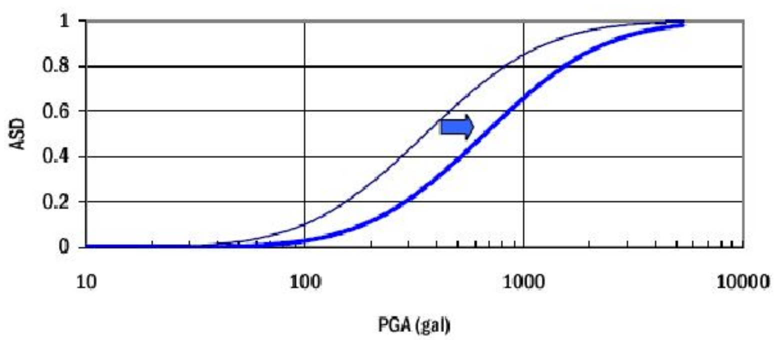

Fig. 9 Vulnerability functions of adobe houses with (right) and without (left) retrofitting system.

In this case, for the south of Mexico, using the estimated PGA for 50 and 100 years of period of return, the predicted values of ASD is 0.13 and 0.21, respectively.

8. ACKNOWLEDGMENTS

This research was partially sponsored by Institute of Urban House and Soil (INVISUR), agency of government of Guerrero State of Mexico. Authors recognize invaluable recommendations, at the initial steps of this research project, from Professors Roberto Meli, Mario Ordaz and Fernando Peña (Institute of Engineering of UNAM).

REFERENCES

Ordaz M, Jara J M, Singh S K, 1989, “Riesgo sísmico y espectros de diseño para el estado de Guerrero”, *Technical Report of Institute of Engineering, UNAM and Earthquake Research Center, AC, to Guerrero State Government.*

Sadigh K, et al, 1997, Attenuation relationship for shallow crustal earthquakes based on California strong motion data, *Seismological Research Letters*, 68, 1, pp 180-189.

Hernández O., Meli R., Padilla M, 1979, Refuerzo de vivienda rural en zonas sísmicas; *Technical Report, Institute of Engineering, UNAM*, Aug, 45 pp.

Alarcón P, Alcocer S, 1999, “Ensayes experimentales sobre rehabilitación de estructuras de adobe”, *Memories of XII National Congress of Earthquake Engineering*, November 17 to 20, Morelia, Mich., Mexico, Vol. I, pp. 209-217.

CSI, 2004, SAP2000 v9.0, User´s Guide, Berkeley, CA.

Flores L, Pacheco M, Reyes C, 2001, Algunos estudios sobre el comportamiento y rehabilitación de la vivienda rural de adobe, *Technical Report, CENAPRED*.

Salgado A, 2002, Seguridad sísmica de la vivienda económica en el Estado de Guerrero, *Technical Report*, *Universidad Autónoma de Guerrero*, Marzo. 70 pp.

Salgado A, 2005, Evaluación Sísmica de los Centros Históricos del Sureste Mexicano, *Technical Report SIBEJ-UAG-UNACH-ITO.*