



## Effects of Sediment Thickness upon Seismic Amplification in the Urban Area of Chiapa de Corzo, Chiapas, Mexico

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### ABSTRACT

Local variations in soil type and (to a lesser extent) topography determine seismic amplification, thereby establishing spatial patterns in the damages caused by large earthquakes, such as the two that occurred in Chiapas, Mexico on 6 October 1975 and 7 September 2017. The latter, of Mw 8.2, was the region's strongest during the last 100 years. Based upon damage patterns, an analysis was made to identify the effects of sediment thickness and type upon seismic amplification in the urban zone of Chiapa de Corzo, Chiapas. Salgado *et al.*, (2004) had shown that the fundamental periods of soil vibration in the city vary from 0.14 s to 0.39 s. From those periods, and using the model presented in Newmark and Rosenbleuth (1976), with an average shear-wave velocity of 150 m/s, the variation of the sediment thicknesses that cause site effects in the area was determined. The thicknesses ranged between 7.12 and 14.6 m. Finally, through the use of a map prepared with GIS software, a spatial correlation was made with the historical earthquake damage recorded within the city.

*Keywords: Seismic Amplification; Sediment Thickness; Soil; GIS.*

## Efectos del espesor de sedimentos en la amplificación sísmica de la zona urbana de Chiapa de Corzo, Chiapas, México

### RESUMEN

Las variaciones locales del tipo de suelo y la topografía en menor medida, determinan la amplificación sísmica y han establecido un patrón en los daños observados durante grandes terremotos, como el que se produjo el 06 de octubre de 1975 y el 07 de septiembre de 2017 Mw 8.2, siendo el más importante en la historia sísmica del último siglo en la región. Con estas bases se realiza un análisis para identificar la participación del espesor de sedimentos en la amplificación sísmica en la zona urbana de Chiapa de Corzo, Chiapas. Para obtener el espesor en el área de estudio se utilizaron los periodos fundamentales de vibración del suelo obtenidos por Salgado *et al.* (2004), que varían entre 0.14 s y 0.39 s. Además, a través del modelo utilizado por Newmark y Rosenbleuth (1976), se determinó la variación de los espesores de sedimentos que conducen el efecto de sitio en la zona, para lo cual se considera una velocidad media de onda de corte de 150 m/s. Finalmente, mediante el uso de software tipo GIS, se elaboró un mapa que representa los espesores de sedimentos en la ciudad de Chiapa de Corzo, que oscilan entre 7.12 m y 14.62 m y se hizo una correlación espacial con los daños históricos por sismo en la ciudad.

*Palabras clave: Amplificación sísmica; espesor de sedimentos; suelo; SIG.*

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## Introduction

Of all natural phenomena that can present serious threats to property and human life, earthquakes probably claim the most victims and cause the greatest material losses per unit of time (Perepérez, 2014). Therefore, researchers attempt to find meaningful temporal patterns in the occurrence of earthquakes along specific faults (Dowrick, 2003; Işık and Kutanis, 2015), as well as spatial patterns in the associated damages to structures.

It is notably accepted among the earthquake engineering that local geology especially sediment thickness has a crucial effect on seismic motion (Livaoglu et al., 2015). Soft sediments make an important component of the subsurface lithology and carry a special nuisance in seismic hazards, as they serve as a source of seismic amplification (Khan & Khan, 2016).

Among the factors that determine those spatial patterns are topography, magnitudes of regional earthquakes, and distances of population centers from epicenters. In addition, it has been noted repeatedly that adjacent areas underlain by different soil types suffer different degrees of damage during earthquakes (Meslem et al., 2012, Vucetic, 1992). Such is the case in the state of Chiapas, Mexico, where local soil conditions play a fundamental role in seismic responses of structures.

Dynamic responses of soils to earthquakes vary significantly, and include such phenomena as soil failure and liquefaction. For that reason, municipal planners must consider the seismic response of each locality's subsoil, in order to define the specific parameters of structural design seismic resistance appropriate to the seismic history of the region (IPCMIIRD, 2010). A detailed spatial analysis of the history of damages caused by earthquakes in a specific locality is essential for identifying that locality's amplification zones. Studies such as the present, which consist basically of defining micro-zoning of seismic hazards, must look for evidence of varied soil responses within the area of

interest, then communicate that information to builders and urban planners by means of maps in a cartographic database (Tupak, 2009).

Using geo-referenced information from such databases as inputs, software for modeling seismic responses of structures can estimate the level of damage that will result to buildings at specific sites, during earthquakes of magnitudes expected within the region (Işık and Kutanis, 2015).

The area of study in the present article is Chiapa de Corzo, in the center of the state of Chiapas (Fig 1). The city has suffered frequent earthquakes during the last century because of the subduction of the Cocos tectonic plate under that of North America (García and Suárez, 1996). For example, the traumatic earthquake of 1975 changed the city radically by destroying traditional adobe houses that dated to the city's foundation (Nandayapa, 2011). Infrastructure systems failed, and most of the city was affected. Table 1 lists dates, magnitudes, and epicenter locations for 18 of the most significant earthquakes that have affected Chiapa de Corzo during the last 120 years.

In the present article, which seeks a correlation between sediment thickness underlying Chiapa de Corzo and the city's historic patterns of seismic damage, we use historical records from two events:

- The earthquake of magnitude 4.8 on Monday, 6 October 1975, at 12:55 a.m. local time. It caused major damage to Chiapa de Corzo. The epicenter was located in Ribera de Cupia, Amatal and América Libre rural localities approximately 4 km southeast of Chiapa de Corzo. This earthquake was produced by cortical failure, induced by filling the reservoir of the "La Angostura" dam (Nandayapa, 2011).
- The magnitude-8.2 earthquake of 7 September 2017, whose epicenter was in the Gulf of Tehuantepec, 133 km southwest of Pijijiapan, Chiapas. This earthquake caused heavy damage in metropolitan areas of Chiapas (SSN, 2017).

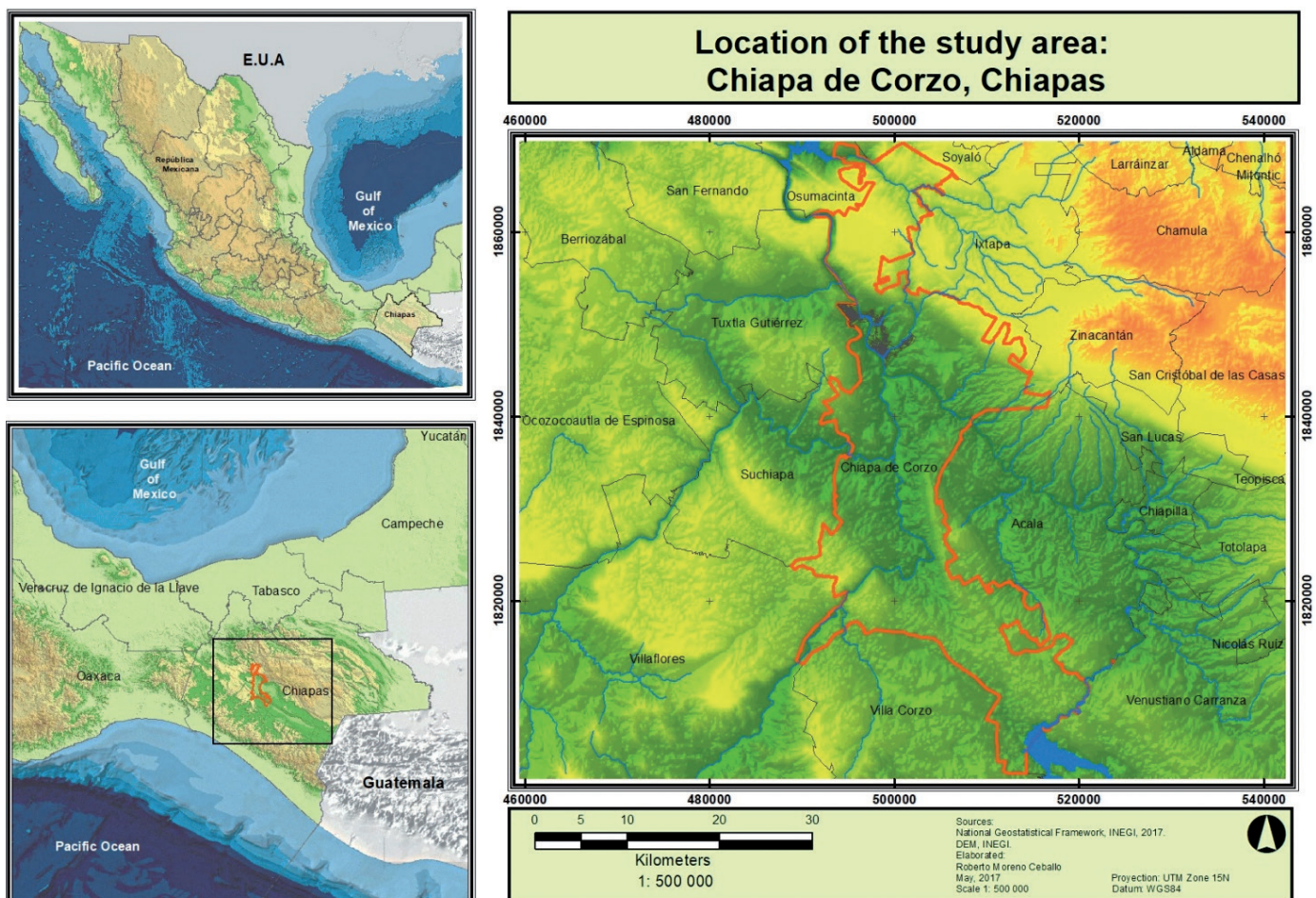


Figure 1. Location of the study area.

**Table 1.** Historical and recent local seismicity of Chiapa de Corzo (Salgado *et al.*, 2004; SSN, 2017)

Date	Latitude	Longitude	Magnitude
05/06/1897	16.30	-95.40	7.4
19/04/1902	14.90	-91.50	7.5
23/09/1902	16.60	-92.60	7.7
14/01/1903	15.00	-93.00	7.6
09/12/1912	15.50	-93.00	7.0
30/03/1914	17.00	-92.00	7.2
10/12/1925	15.50	-92.50	7.0
28/06/1944	15.00	-92.50	7.1
26/09/1955	15.50	-92.50	6.9
09/11/1956	17.45	-94.08	6.3
29/04/1970	14.52	-92.60	7.3
05/10/1975	16.74	-92.92	4.8
10/09/1993	14.20	-92.80	7.2
14/03/1994	15.98	-92.43	6.8
21/10/1995	16.81	-93.47	7.1
18/11/2001	15.45	-93.60	6.3
16/01/2002	15.58	-93.60	6.3
07/09/2017	15.76	-93.70	8.2

Zoning studies are needed urgently in Chiapa de Corzo because of the city's many historically significant buildings, high level of marginalization, and high degree of deterioration of the housing stock.

### Geological characteristics of the study area

Chiapa de Corzo lies along the banks of the Grijalva River, and is contained within the River's flood plain. The entire urban area is built upon alluvium (Schmudde, 1968). In general, seven types of rock are exposed within metropolitan regions of Chiapas. Soils in most locations are quaternary deposits. Three types of bedrock predominate: limestone (34.46% of the surface), siltstone-sandstone (29.01%), and shale-sandstone (16.55%). Cretaceous deposits are also present: siltstones (8.99%) and alluvial (7.22%). The remaining 5.40% of Chiapas's surface area is covered by soils of varied compositions (INEGI, 2004; INEGI, 2008; PDM, 2017).

The study area's shales are fine-grained rocks that fracture in laminated slabs more or less parallel to the stratification. Particles within these rocks are so small that their mineral compositions are difficult to determine precisely. It is important to note that the shales contain clay minerals, as well as silt, quartz, feldspar, calcite, and dolomite particles (Don Leet and Judson, 1980; Blanquer, 2011).

In contrast, sandstone is formed by the consolidation of individual grains of the size of the sand (1/16 mm to 2 mm diameter). Sandstone occupies, then, an intermediate position between conglomerate, which is coarse-grained, and the lodolite, which is fine-grained. Grain size varies from one sandstone to another. Sandstones and shales constitute about 99% of all sedimentary rocks, the shales being the most abundant (Don Leet and Judson, 1980).

### Methods

This research seeks to propose the relationship between flood zones associated with areas of greater sediment thickness and site-effect zones as a preliminary analysis to identify these areas in regions where studies have not been conducted.

The methodology followed in this work consists of three fundamental stages (Fig 2). In the first stage, a mathematical model was defined to calculate thicknesses of sediment layers in Chiapa de Corzo. Next, the fundamental vibrational periods of soils in each zone of the city were obtained from Salgado *et al.* (2004). Finally, historical records of earthquake damage to the city were reviewed in order to correlate soil thicknesses with local seismic amplification.

### Model

Newmark and Rosenbleuth(1976) derived the following equation for the fundamental vibrational period ( $T$ ) of a terrain that is underlain by  $n$  sediment strata:

$$T = 4 \sum_{i=1}^n \frac{h_i}{\beta_i} \quad (1)$$

where  $h_i$  and  $\beta_i$  are, respectively, the thickness of the  $i^{\text{th}}$  stratum and the propagation rate of shear-waves within it. To estimate the total thickness of sediment at each of the 20 locations for which Salgado *et al.* (2004) determined the terrain's fundamental period, we assumed, based upon (Narcia *et al.*, 2006), that  $\beta = 150$  m/s within all sediment layers throughout Chiapa de Corzo's urban area. Therefore, our estimate of the thickness  $h$  present at a location with period  $T$  seconds was

$$h_i = \frac{(T\beta_i)^2}{4} \quad (2)$$

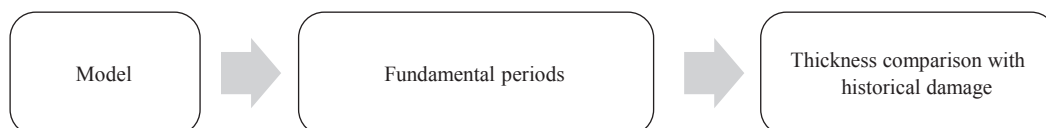
### Fundamental periods of soil vibration

As noted in the previous section ("Model"), fundamental periods for 20 locations within Chiapa de Corzo's urban area were obtained from Salgado *et al.* (2004). Periods ranged from 0.14 to 0.39 s; with most near 0.3 s.

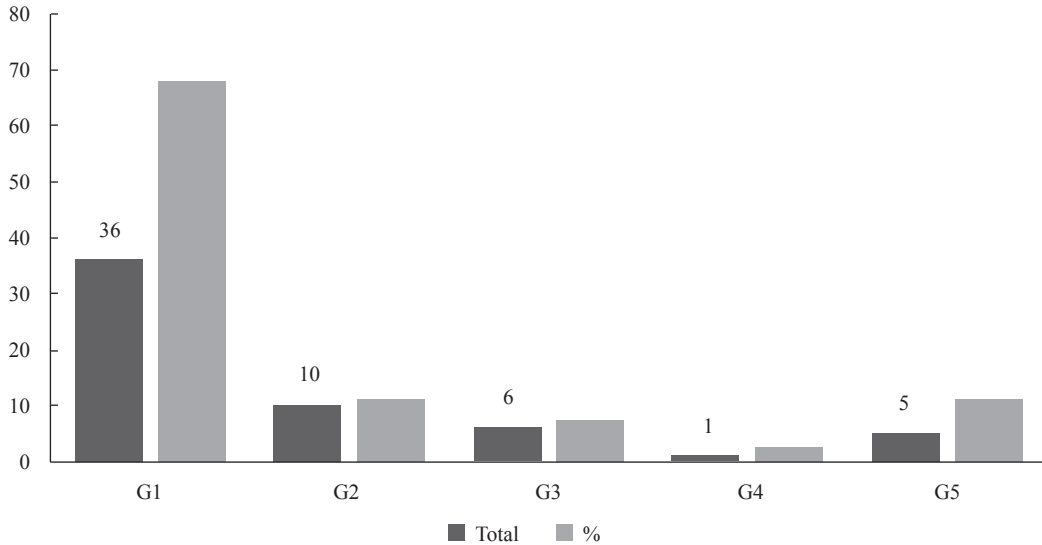
### Historical Damage

The last step in the methodology was to develop a database, in Excel (Fig 3), of levels of damage caused to structures in Chiapa de Corzo by the earthquakes of 6 October 1975 and 7 September 2018.

Through our own on-site examinations and from previous research, we also investigated whether the inherent seismic vulnerability of structures (for example, that due to design, materials, and construction methods) varied significantly among the twenty sites at which Salgado *et al.* (2004) measured fundamental periods.

**Figure 2.** Sequence of steps for determining effects of sediment thickness upon seismic amplification in the urban area of Chiapa de Corzo.





**Figure 3.** Degrees (grades) of damage caused to buildings in the urban area of Chiapa de Corzo by the earthquakes of 6 October 1975 and 7 September 2017. Grades ranged from G1 (negligible) to G5 (total collapse of the building).

**Results**

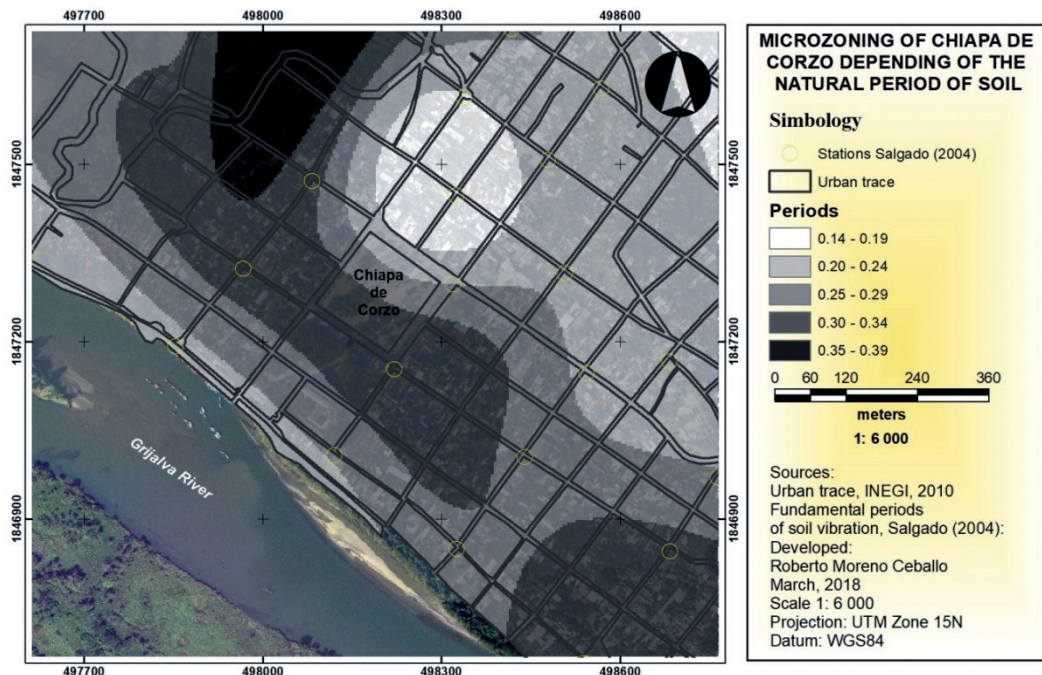
Fig. 4, prepared by ArcMap via linear interpolation of fundamental-period data from Salgado *et al.*, (2004), shows the spatial variation of fundamental vibration period within Chiapa de Corzo’s urban area. Sediment thicknesses, as estimated via Eq. (2) using data from Salgado *et al.*, (2004), ranged from 7.12 m to 14.6 m. Fig.5 contrasts surface topography with estimated thickness of underlying sediment in the central zone of Chiapa de Corzo. Comparing the interpolated spatial distribution of estimated thicknesses (Fig. 6) to historical patterns of damage (Fig. 7), we find that damage has been greater where sediments are estimated to be thicker.

Importantly, the inherent seismic vulnerability of structures did not vary significantly among the twenty sites. (For example, see Cardona, 2008).

In addition to the graph shown in Fig.8, a correlation between the period of vibration and the thickness of sediments is observed.

**Conclusions**

For the purposes of the work reported here, sediments underlying each site in Chiapa de Corzo could be modeled as homogeneous deposits with  $\beta = 150$  m/s. The resulting estimates of thicknesses correlate with degrees of structural damage that occurred during the earthquakes of 6 October 1975 and 7 September 2017: where the estimated thickness is greater, so was the degree of damage. Thus, in the case of Chiapa de Corzo, estimates of sediment thickness calculated from measurements of the terrain’s fundamental vibrational period can be a fundamental input for defining micro-zones based upon dynamic response of soils.



**Figure 4.** Micro-zoning of the city of Chiapa de Corzo according to the fundamental period of the underlying sediment. Circles show locations of Salgado *et al.* (2004)’s measuring stations.

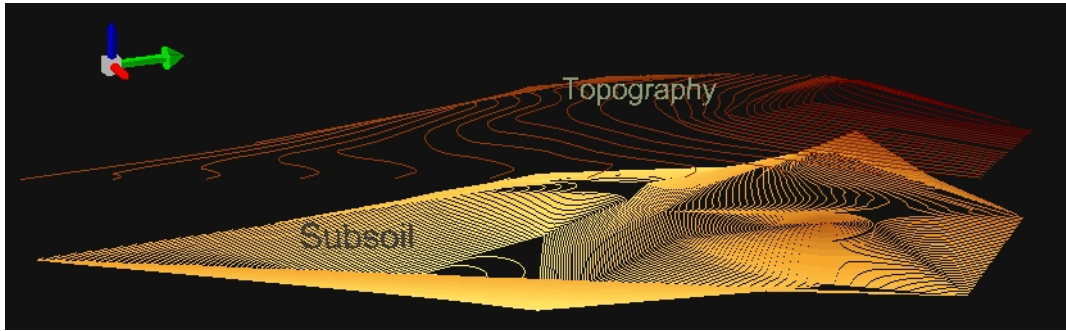


Figure 5. Comparison between surface topography and estimated thickness of underlying sediment in the urban area of Chiapa de Corzo. The green arrow points toward north.

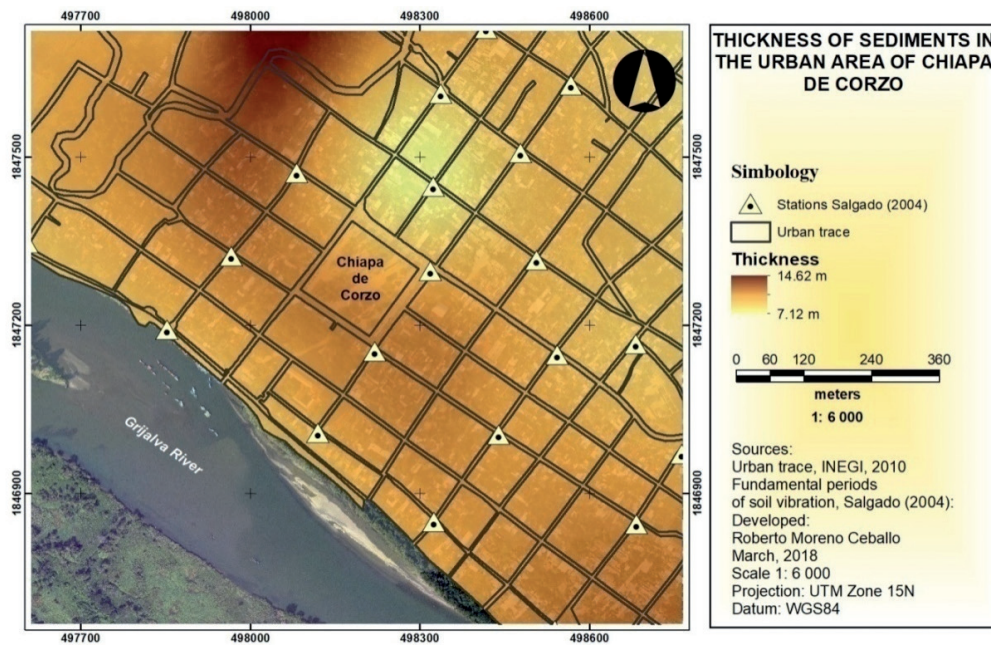


Figure 6. Spatial variation of estimated sediment thickness in the urban area of Chiapa de Corzo.

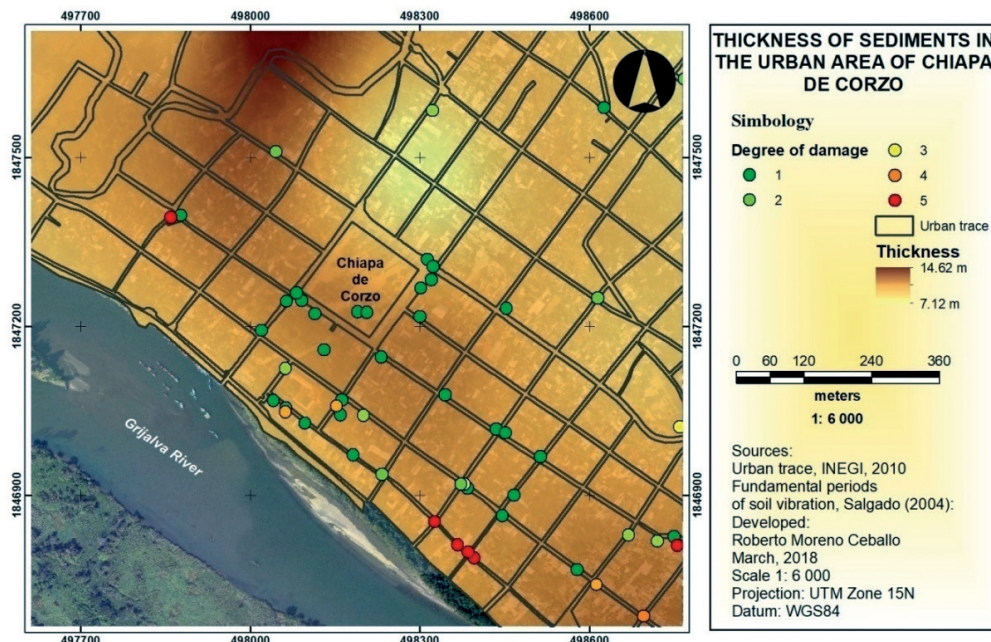


Figure 7. Comparison of sediment thicknesses and earthquake damage suffered by buildings in the urban area of Chiapa de Corzo. Degrees of damage range from 1 (negligible) to complete collapse (5).



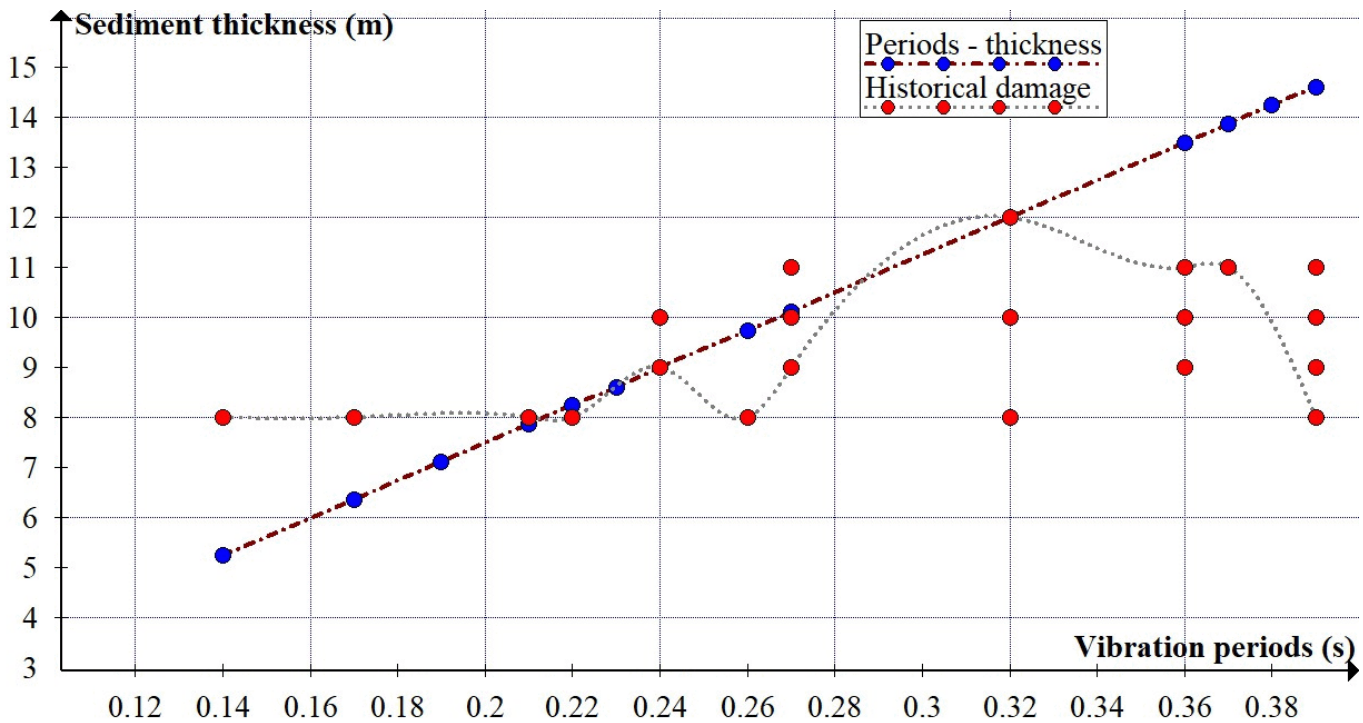


Figure 8. Correlation between period of vibration (from Salgado *et al.* (2004)), thickness of sediments (as estimated in the present article), and historical patterns of earthquake damage to buildings in Chiapa de Corzo.

This conclusion would not be tenable if the inherent seismic vulnerability of structures varied significantly among 20 sites at which Salgado *et al.* (2004) measured fundamental periods (Padrón *et al.*, 2011). That caution is an important one which future research in Chiapa de Corzo or elsewhere should consider when choosing sites at which to estimate sediment thicknesses.

In summary, dynamic response of subsoil is an important phenomenon that is sometimes given insufficient attention during the structural design of buildings and other engineering works. (See, for example, González-Herrera *et al.* (2013) regarding subsoil conditions in Tuxtla Gutiérrez, Chiapas.) Useful correlations for micro-zoning based upon this phenomenon can be developed by carefully analyzing and cross-referencing spatial patterns of earthquake damage and shear-wave velocities. The results obtained in this work should be supplemented by more-detailed studies that include current measurements located throughout Chiapas de Corzo's urban area, because population growth has been considerable during recent years.

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#### References

- Arbeláez, A. C., Posada, L., & Vélez, M. V. (2002). *Usos de suelo en la zona inundable del río San Carlos, Colombia*. XV Seminario Nacional de Hidráulica e Hidrología.
- Blanquer, J. M., Ibáñez, S., & Moreno, H. (2011). *Vertisoles*. Universidad Politécnica de Valencia.
- Cardona, O. (2008). (Transcript of personal interview). En Padrón, C. (Comp). Lineamientos para la consideración de riesgo sísmico en la planificación urbana del municipio Chacao, estado Miranda. Informe de pasantía (véase Padrón, 2009), Universidad Simón Bolívar, Caracas, 254-271.
- Don Leet, L., & Judson, S. (1980). *Fundamentos de Geología Física*. México, D.F. Limusa.
- Dowrick, D. (2003). *Earthquake Risk Reduction*. Wiley, England.
- González-Herrera, R., Mora-Chaparro, J. C., Aguirre-González, J., & Novelo-Casanova, D. A. (2013). La estructura de velocidades y su relación con el peligro sísmico en Tuxtla Gutiérrez, Chiapas. *Revista Mexicana de Ciencias Geológicas*, 121-134.
- INEGI. (2004). Guía para la interpretación de cartografía: Edafología.
- INEGI. (2008). Prontuario de información geográfica municipal de los Estados Unidos Mexicanos.
- IPCMIIRD. (2010). Sistema Estatal de Protección Civil del Estado de Chiapas. Plan Operativo de Protección Civil por Riesgo Sísmico, Tuxtla Gutiérrez, Chiapas, 2010.
- Isik, E. & Kutanis, M. (2015). Determination of Local Site-Specific Spectra Using Probabilistic Seismic Hazard Analysis for Bitlis Province, Turkey. *Earth Sciences Research Journal*, 19(2), 129-134.
- Khan, S., & Khan, M. A. (2016). Mapping sediment thickness of Islamabad city using empirical relationships: Implications for seismic hazard assessment. *Journal of Earth System Science*, 3, 623-644.
- Livaoğlu, H., Irmak, T., Güven, T., & Ozer, F. (2015). An Empirical Relationship between Sediment Thickness of Different Data and Resonance Frequency which Calculated by Using the H/V Ratio Method of Seismic Noise for Gölcük-Değirmendere Area (Turkey). *European Geosciences Union General Assembly 2015*, 17. Vienna.
- Meslem, A., Yamazaki, F., Maruyama, Y., Benouar, D., Kibboua, A., & Mehani, Y. (2012). The Effects of Building Characteristics and Site Conditions on the Damage Distribution in Boumerde's after the 2003 Algeria Earthquake. *Earthquake Spectra*, 28 (1), 185-216.
- Nandayapa, A. (2011). *Temblores de 1975 en la ciudad de Chiapa de Corzo*. Tuxtla Gutiérrez.
- Narcía López, C., Cruz Díaz, R., Aguilar Carboney, J., Ramírez Centeno, M., & González Herrera, R. (2006). El período natural de vibración del suelo en la ciudad de Tuxtla Gutiérrez, Chiapas. *Quehacer Científico en Chiapas*, 1(1), 22-36.
- Newmark, N. & Rosenbleuth, E. (1976). *Fundamentos de Ingeniería Sísmica*. 1ª ed., Diana, México, D.F.
- Padrón, C., Mendes, K. C., Schmitz, M., & Hernández, J. J. (2011). La microzonificación sísmica en el proceso de planificación urbana. Caso de estudio: municipio Chacao. *Revista de la Facultad de Ingeniería U.C.V.* 26(2), 89-101.
- Perepérez, B. (2014). La peligrosidad sísmica y el factor de riesgo. *Informes de la Construcción*, 66(534): e018. DOI: <http://dx.doi.org/10.3989/ic.13.018>.

- Salgado, A., Escamirosa, F., & Calvo, A. (2004). Zonificación sísmica de tres centros históricos del sureste mexicano. *Sociedad Mexicana de Ingeniería Estructural*, 11-15.
- Schmudde, T. H. (1968). Floodplain. In: R.W. Fairbridge. *The Encyclopedia of Geomorphology*. New York: Reinhold, 359-362.
- Secretaría de Hacienda. (2017). Secretaría de Hacienda. Retrieved 15 May 2017, from <http://www.haciendachiapas.gob.mx/planeacion/Informacion/Desarrollo-Regional/prog-regionales/Metropolitana.pdf>
- SSN. (2017). Reporte especial: Sismo de Tehuantepec (2017-09-07 23:49 M8.2).
- Suárez, G. & Singh, K. (1986). Tectonic interpretation of the transmexican volcanic belt discussion. *Tectonophysics*, 127, 155-160.
- Tiryakioglu, I., Yavasoglu, H., Ugur, M. A., Özkaymak, C., Yilmaz, M., Kocaoglu, H., & Turgut, B. (2017). Analysis of October 23 (Mw 7.2) and November 9 (Mw 5.6), 2011 Van Earthquakes Using Long-Term GNSS Time Series. *Earth Sciences Research Journal*, 21(3), 147-156. DOI: <https://dx.doi.org/10.15446/esrj.v21n3.62812>
- Tupak, O. (2009). *Microzonificación sísmica*. Universidad Internacional de Andalucía, UNÍA Huelva, España.
- Vucetic, M. (1992). *Soil properties and seismic response*. In Proceedings 10th World Conference on Earthquake Engineering, pp. 1199–1204.