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Attenuation of Peak Ground Acceleration with Distance of the June 15, 1999, Tehuacán, México, Earthquake

Rudolfo B. Sancio
University of California, Berkeley, CA

J. M. Mayoral
University of California, Berkeley, CA

R. E. S. Moss
University of California, Berkeley, CA

J. M. Pestana
University of California, Berkeley, CA

R. B. Seed
University of California, Berkeley, CA

See next page for additional authors

Author

Rudolfo B. Sancio, J. M. Mayoral, R. E. S. Moss, J. M. Pestana, R. B. Seed, and J. D. Bray

ATTENUATION OF PEAK GROUND ACCELERATION WITH DISTANCE OF THE JUNE 15, 1999, TEHUACÁN, MÉXICO, EARTHQUAKE

Rodolfo B. Sancio
University of California
Berkeley, California 94720- USA

J. M. Mayoral
R. E. S. Moss
J. M. Pestana
R. B. Seed
J. D. Bray
University of California
Berkeley, California 94720 - USA

ABSTRACT

A seismic event of moment magnitude 7.0 struck the central region of Mexico on June 15, 1999 at 15:41 hrs (local time) between the states of Puebla and Oaxaca. The epicenter of the earthquake was located approximately 20 km to the south-southeast of the town of Tehuacán, Puebla and 55 km to the northeast of Huajuapan de León, Oaxaca. A reconnaissance team consisting of a group of researchers from the University of California at Berkeley (UCB) and the Autonomous University of Mexico (UNAM) visited the area and gathered some preliminary information on the geotechnical aspects of this earthquake. This paper briefly presents some key geotechnical observations and then focuses on the attenuation of peak ground acceleration with distance. A total of 29 strong-motion recordings over a variety of geologic site conditions were compiled and used to develop the observed attenuation of the peak ground acceleration (PGA) with distance for the main event. The results obtained were compared with estimations of PGA using North American attenuation relationships.

INTRODUCTION

A seismic event of moment magnitude 7.0 (USGS) struck the central region of Mexico on June 15, 1999, at 15:41 hours (20:421 GMT). An earthquake with magnitude 7.0 was also registered in the same area on October 24, 1980. According to the National Seismological Service of Mexico (SSN), the focus of the seismic event registered on June 15, 1999, was located at 18.20° north latitude and 97.47° west longitude at a depth of 60-80 km. The epicenter was calculated at 20 km south southeast of the city of Tehuacán in the state of Puebla, approximately 55 km northeast of the city of Huajuapan de León in the state of Oaxaca. The United States Geological Survey (USGS) located the epicenter at 18.40° north latitude and 97.45° west longitude at a depth of 71 km. A second strong event with a moment magnitude of 6.3 (USGS) occurred on June 21 at 12:43 hours (17:43 GMT) which also affected the central region of Mexico. According to SSN the focus was located at 18.09° north latitude and 101.78° west longitude at a depth of 42 km. The USGS published data locating the second event at 18.34° north latitude and 101.49° west longitude with a depth of 50 km. Figure 1 shows the location of the epicenters of these two seismic events, which together affected cities in the states of Guerrero, Hidalgo, Mexico, Michoacán, Morelos, Oaxaca, Puebla, Tlaxcala, Veracruz and Distrito Federal.

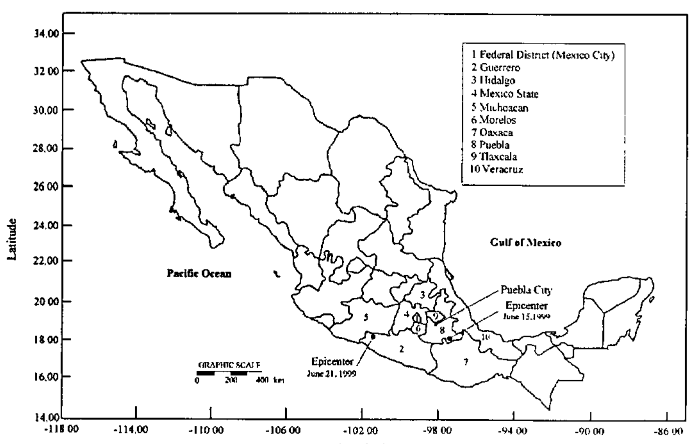


Fig. 1: Location Map of Mexico showing the Epicenters of the June 15 and June 21, 1999 events and states affected

The June 15 event occurred in a complex region of normal and reverse faults with a regional tectonic mechanism associated with the subduction of the Cocos plate under the North American plate. The fault mechanism was that of a normal fault and appears to have consisted of two sub-events, separated by several seconds as suggested by the rapid moment-tensor solution. The central region, in which Puebla city is located is characterized by upper tertiary and quaternary volcanic structures of diverse type and textures such as basaltic flows, tuffs and ashes created successively by many volcanoes during the Cenozoic period. The southern portion of the state of Puebla is composed of a combination of metamorphic, igneous and sedimentary rocks affected by intense erosion, and the structure is characterized by normal and reverse faulting with a predominant northwest strike and a predominant dip toward the northeast.

EARTHQUAKE RECONNAISSANCE

By far, the largest damage was concentrated in unreinforced masonry (URM) structures such as churches and small adobe and cane houses in the states of Puebla and Oaxaca. Over 7500 dwellings were significantly damaged in these two states. In addition, several modern buildings completely collapsed and significant structural as well as non-structural damage/distress was observed in hospitals and schools in the city of Puebla (Alcocer et al., 1999). Similar observations of damage were observed in the state of Oaxaca following the 7.4 magnitude earthquake on September 30, 1999 (Alcocer, 1999).

Puebla City, located approximately 125 km from the location of the June 15 epicenter, has a population of about 5 million and is home to more than 2,000 churches and temples. More than 100 of these structures were damaged by the two seismic events. A typical example of the effect of local site conditions was observed in downtown Puebla. In this case, 2 out of 4 (apparently) similar four story buildings completely collapsed or were severely damaged in an area underlying by alluvial soil deposits. Figure 2 shows one of the buildings which collapsed in the area. A second building with a street level garage also collapsed likely due to column shear (or buckling) since no punching, settlement or foundation failure was apparent. Local soil conditions at this site had led to the prediction of significant amplification in earlier microzonation studies performed by Chávez-García et al., 1995. Another example of "local site effects" is the damage to the church in the town of Cholula, approximately 10 km west of Puebla city (Pestana et al., 1999). The church was built on top of an ancient stone pyramid. The severe damage observed may be attributed, in part, to topographic amplification of ground motions due to the pyramid.

In the states of Morelos and Hidalgo the damage was minor and mainly affected churches and historical monuments built in the 16th and 17th centuries. In the state of Tlaxcala only one fatality was reported and the damage was minor. It consisted of small landslides along road cuts, cracking of the old churches and houses, and a fire in a textile factory that resulted in one injury. The towns in the area surrounding the rupture plane are mostly small agricultural and mining towns where the damage was concentrated predominantly in URM structures, such as churches, houses, and rock walls. The bigger towns of Tehuacán, the closest to the epicenter, and Acatlán de Osorio, located approximately 60 km to the east of the epicenter, were affected in a similar manner.

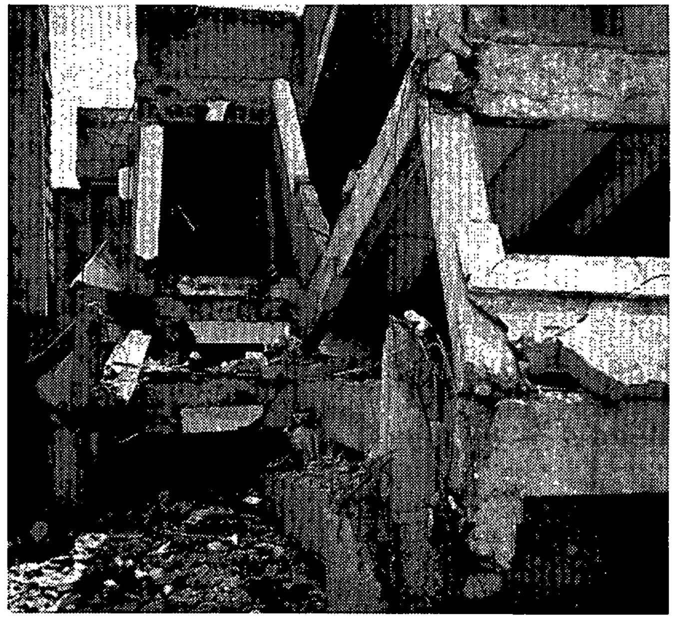


Fig. 2: Collapse of a four story structure in downtown Puebla in the zone of predicted maximum amplification

The most severely affected town visited by the reconnaissance team was Acatlán de Osorio, located approximately 50 km west of the June 15 epicenter. Site effects were prominent in this town with the most damage occurring to structures in the sediment filled valley with little or no damage to the structures located on rock in the foothills. Many unreinforced masonry houses were reduced to rubble. Figure 3 shows a relatively modern two-story structure showing partial collapse. Figure 4 shows the cracked dome of the church of Acatlán de Osorio, which is typical of the damage experienced by the churches in the epicentral region. In nearly every town, regardless of how small the population is, there is a church similar to the one shown. With unerring regularity, these churches were damaged during the strong ground shaking. Even in the towns least affected by the tremors, the churches often had some sort of damage.

Soil liquefaction was observed in the highlands ("altiplano") of the State of Tlaxcala, about 20 km northwest of the City of Puebla. This is a rural area primarily used for corn fields and therefore the effect of liquefaction is non existent. Nevertheless, to the authors' knowledge, this is the first time this phenomenon was reported in the Puebla-Tlaxcala valley.

Small slides were common along the cut slopes adjacent to roads in the vicinity of the epicenter. Figure 5 shows a large reactivated slide on the road from Tehuacán and Huajuapan de León. These failures included rockslides, rock toppling, block sliding of both earth and rock, and surficial raveling. In the states of Puebla and Oaxaca, slides deposited debris on the roadways causing traffic delays and road closures. Surface expression of fault rupture was not observed along the path followed by the reconnaissance team.

Fig. 3: Damaged modern reinforced concrete structure in Acatlán de Osorio.

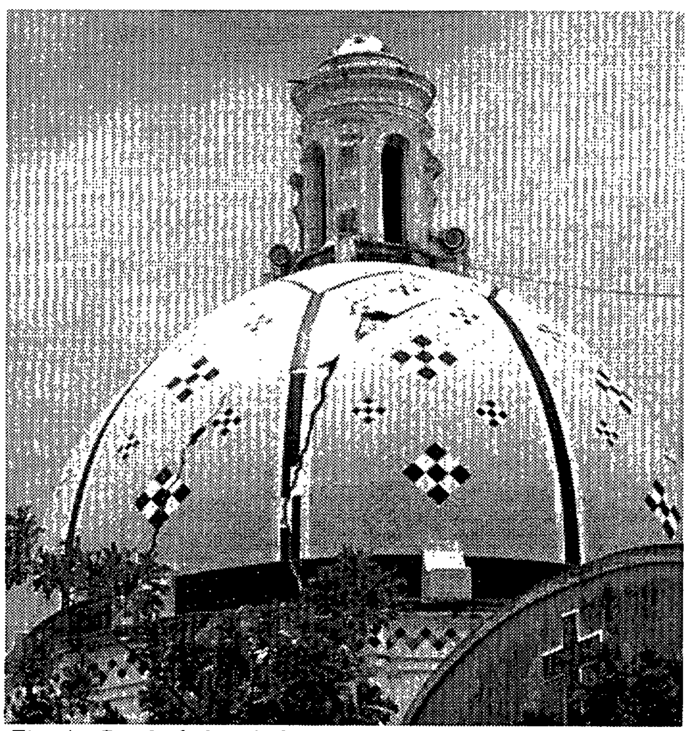


Fig. 4 : Cracked church dome in Acatlán de Osorio, typical of observed damage in the churches in the State of Puebla.

Not many earth dams are built in the state of Puebla; the water demand is mainly supplied by groundwater in underlying aquifers. "Valsequillo" is a small rockfill dam located to the south of the city of Puebla with a maximum crest height of approximately 25 m. Inspection of the 2H:1V upstream and downstream slopes of the embankment showed no evidence of cracking or displacement. The solid-waste of many of the cities and towns in the proximity of the epicenter is eliminated by incineration in the open field. The solid-waste landfill of the city of Puebla, Chiltepeque, is a modern facility with side slopes of 3H:1V and a base liner system. During the landfill inspection of this site no signs of either major instability or localized failure were observed in the slopes. The solid-waste landfill of the City of Tehuacán also showed no evidence of seismically-induced deformations.

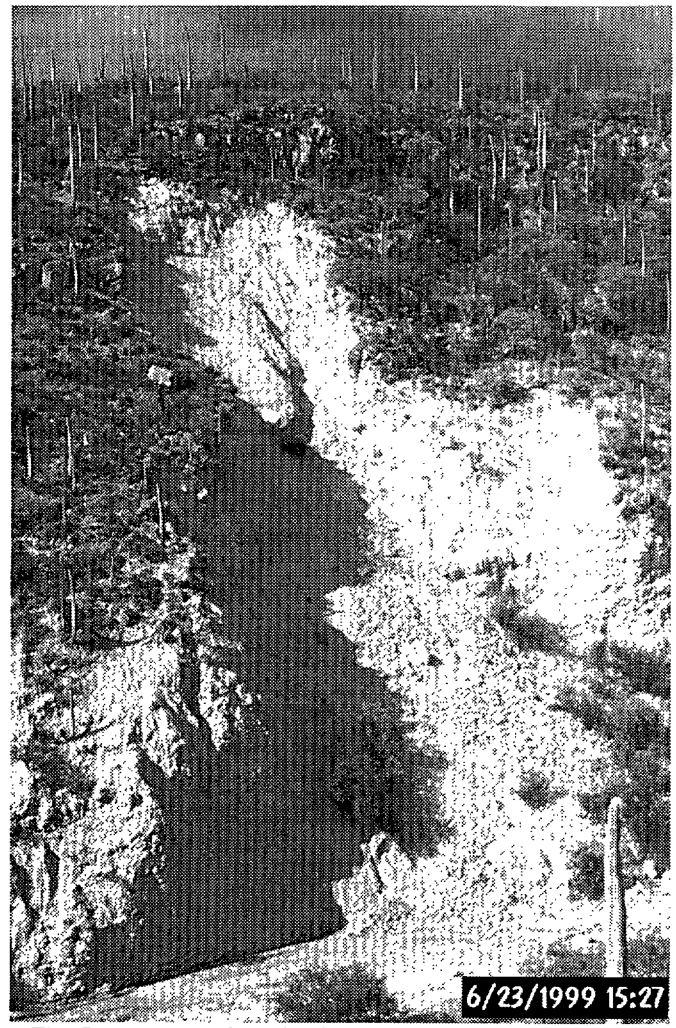


Fig. 5: Reactivated landslide on the road from Tehuacán to Huajuapan de León.

STRONG GROUND MOTION

The M_w= 7.0 event on June 15, 1999, in central Mexico, generated a number of strong-motion recordings over a variety of geologic site conditions, including free-field soil and rock as well as motions from various instrumented structures. Attenuation of the horizontal Peak Ground Acceleration (PGA) with distance was developed using 18 rock, 2 transition/soil, and 9 soil site recordings at strong-motion stations located throughout the affected region. This information was provided by UNAM, the Autonomous University of Puebla (BUAP), and the National Center for Disaster Prevention of Mexico (CENAPRED). The discrepancy between SSN and USGS location of the epicenter for the June 15 event made determination of the distance to the rupture surface for attenuation calculations difficult. The rock sites on which the strong-motion recording stations are located correspond to 1997 Unified Building Code (UBC) Site Classes B-C, with most rock sites appearing to be soft and weathered rock (UBC Site Class C). The soil sites correspond to UBC Site Classes C-D, with most soil sites being UBC Site Class D.

Figure 6 shows the location of 29 strong ground motion stations. Using the limited data available, a contour map of peak ground accelerations was developed. The contours exhibit a north-western trend that was observed during the field investigation through damage patterns and also agrees with the orientation of the east dipping thrust faults in the region. This apparent directivity phenomenon has also been reported by Singh et al. (1999) and Gutierrez, as reported by Alcocer et al (1999), although no relation between maximum intensity and damage was reported.

A series of North American attenuation relationships were analyzed with the collected ground motion data (Pestana et al., 1999). The Toro et al. (1997) Central and Eastern North America "Gulf" hard rock attenuation relationship appeared to represent the trends of the recorded data well, although the PGA values were slightly underestimated by this hard rock relationship as seen in figure 7a. This is attributed, in part, to the fact the rock stations correspond to sites with soft rocks characteristics Figure 7b and 7c shows the Youngs et al. (1997) intraslab attenuation relationship for rock (UBC, Type B) and soil (UBC, Types C and D) sites respectively, which is consistent with the conditions encountered at the ground motion stations. This attenuation relationship was developed for intraslab earthquakes associated with subduction zones using data that included, among many others, the August 28 1973, M_w=7.0 Mexican event as well as other Central Mexico earthquake events. The distance parameter used by this attenuation relationship is the closest distance to the rupture. In this work hypocentral distance was used in lieu of the distance to the rupture. This substitution is consistent with Youngs et al. (1997) when the fault plane geometry is not available, and is not considered to introduce a significant error due to the great source-to-site distance of the recordings.

Figure 8 shows the vertical peak ground acceleration as a function of distance for the June 15 event. It can be observed that the attenuation relationship for the vertical peak acceleration is nearly the same regardless of soil conditions as opposed to the peak horizontal ground acceleration. For these deep seismic events, the ratio of peak vertical to horizontal ground motion is relatively large when compared with those measured due to shallow earthquakes resulting from subduction mechanisms near the Pacific coast.

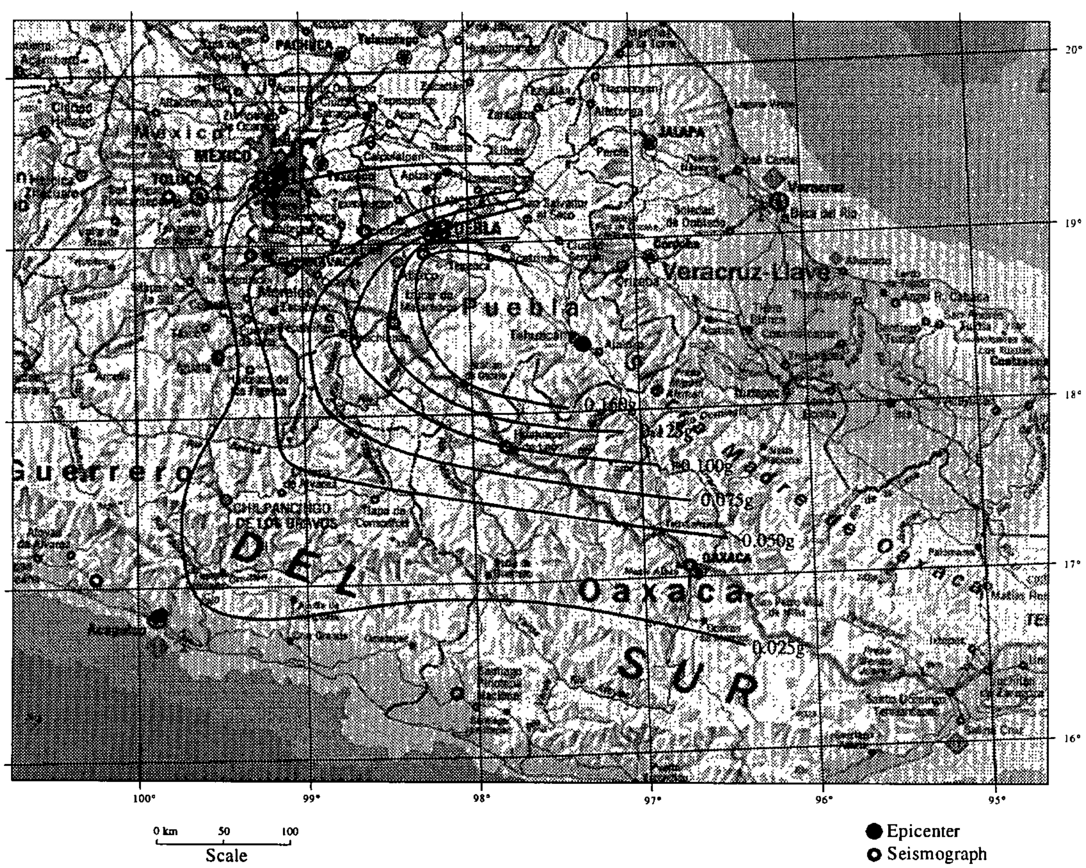
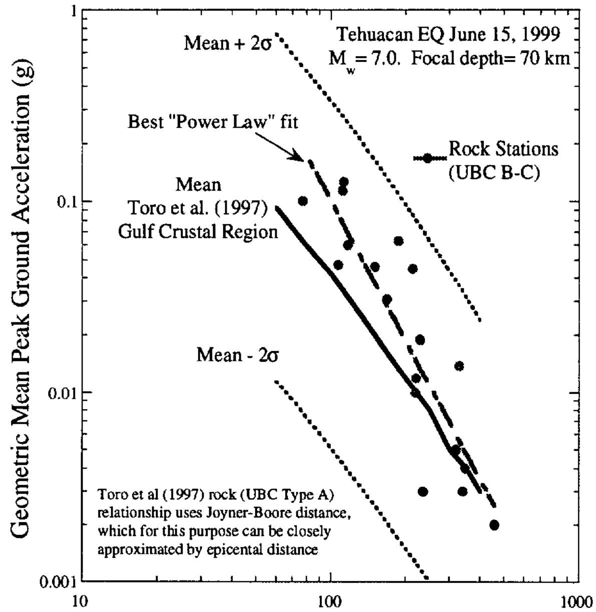


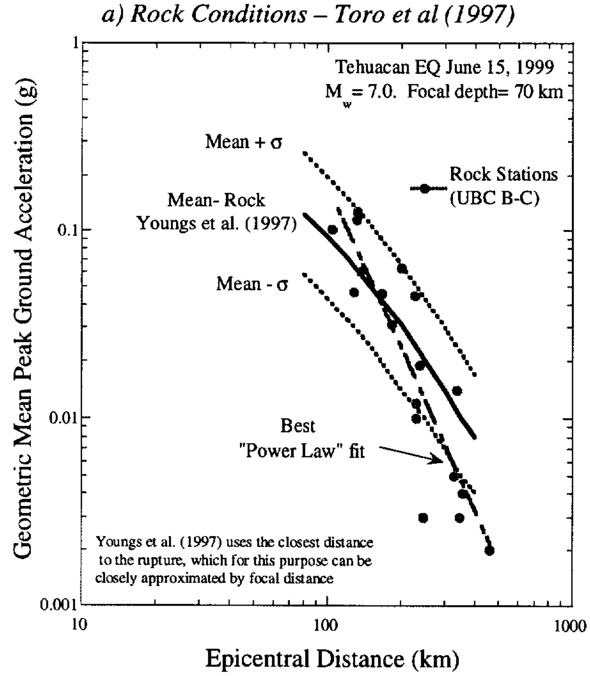
Fig. 6: Location of 29 strong motion stations with regional PGA contours for the June 15, 1999 Tehuacán Earthquake

EFFECT OF LOCAL SOIL CONDITIONS

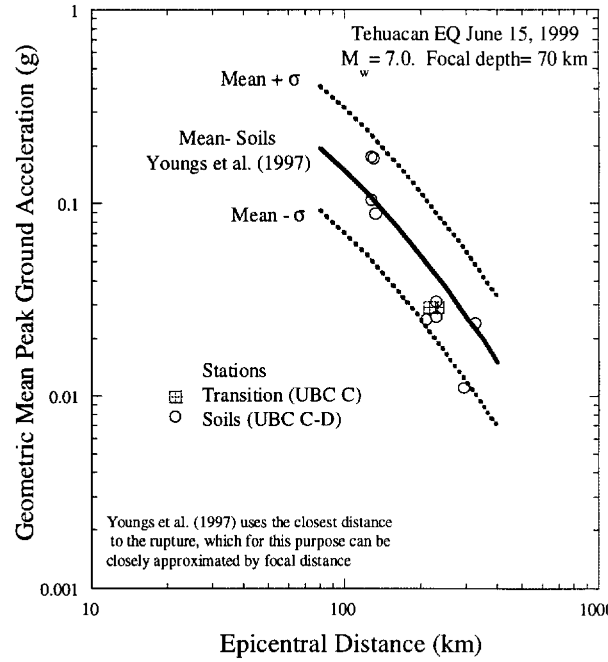
In Mexico City, located around 200 km from Puebla City and more than 300 km from the epicenter, shaking levels were low, but clear site effects were observed. Figure 9 shows the uncorrected acceleration time history recorded at the Secretaría de Comunicaciones y Transportes, SCT (located on soft clay) and UNAM (located on rock) strong ground motion instrument. Amplification of accelerations by a factor of about 3 can be observed, as can the clearly longer-period nature of the motions at the soft clay site (cf., Fig. 10). Local site effects were also observed in Acatlán de Osorio, which suffered a substantial amount of damage.



a) Rock Conditions – Toro et al (1997)



b) Rock conditions- Youngs et al (1997)



c) Soil conditions- Youngs et al (1997)

Fig. 7:Attenuation Relationships for the Mean Peak Ground Acceleration (PGA) vs. distance

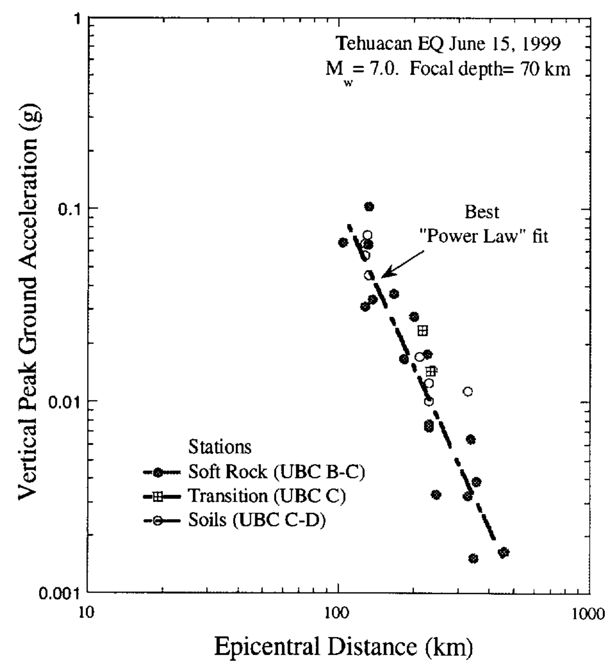


Fig. 8: Vertical Peak Ground Acceleration as a function of distance for the Tehuacán Earthquake of June 15, 1999

SUMMARY

The Tehuacán earthquake with a moment magnitude 7.0 struck the central region of Mexico on June 15, 1999 at 15:41 hrs (local time) between the states of Puebla and Oaxaca. The earthquake caused significant damage of unreinforced masonry structures, such as churches and houses. Significant structural and non-structural distress was observed in areas where significant soil amplification was predicted in microzonation studies. In contrast to the shallow earthquakes originating from the subduction zone in the Pacific Coast of Mexico, Attenuation relationships for deep and intermediate earthquakes that originate inland are not well established. Attenuation relationships of peak ground acceleration with distance for this earthquake are based on a total of 29 strong-motion recordings over a variety of geologic site conditions. The results obtained were compared with estimations of PGA using North American attenuation relationships.

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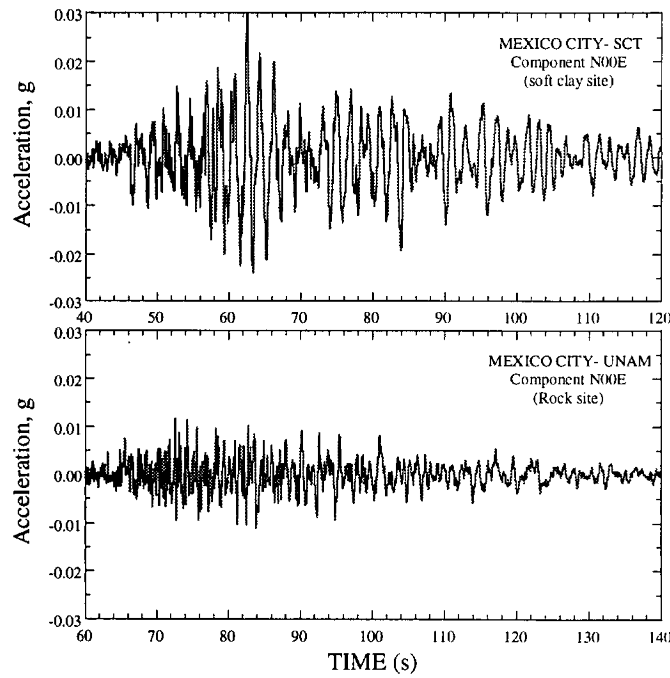

Fig. 9: Acceleration time histories at Mexico City SCT (soft clay) and UNAM (rock) stations during the June 15, 1999 EQ

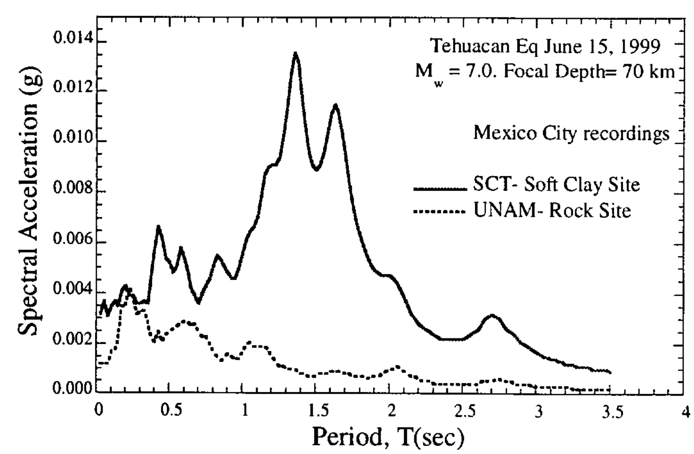

Fig. 10: Measured Soft Site Amplification in Mexico City (distance ~ 300 km)