ESTIMATION OF SEISMIC HAZARD TO REHABILATATE THE TEMPLE OF LA COMPAÑÍA IN PUEBLA, MEXICO

E. OVANDO-SHELLEY[1], M. ORDAZ[1], S. K. SINGH[2], J. LERMO[1]
[1]Instituto de Ingeniería, UNAM, Mexico City, [2]Instituto de Geofísica, UNAM, Mexico City

SUMMARY

The XVIII Century jesuitic temple of La Compañía in Puebla, Mexico, was severely damaged during a large earthquake on 15 June, 1999. This paper describes the main results of seismological engineering studies performed in order to specify the seismic design loads for an ongoing structural rehabilitation programme.

1. INTRODUCTION

Intermediate-depth normal-faulting earthquakes in the subducted Cocos plate result in significant and recurrent damage to the Mexican states of Oaxaca and Puebla. On 15 June 1999, a large earthquake (M_s=6.5) struck this region again. The largest and the most important damage in structures was recorded in over 500 historical monuments. In the city of Puebla and its environs, some 140 km from the epicentre, many churches and conventual cloisters underwent different degrees of cracking, fissuring, loss of plumb and, in a few extreme cases, the collapse of belfries, towers, domes and vaults.

One of the most important monuments in Puebla, the jesuitic temple of La Compañía underwent extreme damages during this earthquake. La Compañía is a XVIIIth century basillical church built with low quality brickwork. The temple is 29 m wide and 59 m long and shares its south wall with the former Jesuit Convent, now known as the Edificio Carolino. As seen in Figure 1, the temple's narthex is an open portal which supports the choir and two brick towers, 38.5 m tall. Nearly vertical fractures opened in both towers, large longitudinal fractures also endangered the vaults as a result of transversal displacements and rotations; evidence suggests that pillars, especially along the north wall tilted as much as 6 mm which implies disadjustments in the arch along the processional nave of about 7 cm. Damages were so large and the condition of the church so critical that authorities were forced to close it.

An obvious key issue in the structural rehabilitation programme was the specification of seismic design loads. It was therefore necessary to produce a site specific design acceleration spectrum based on an updated appraisal of the local seismicity and of the soil conditions at La Compañía.

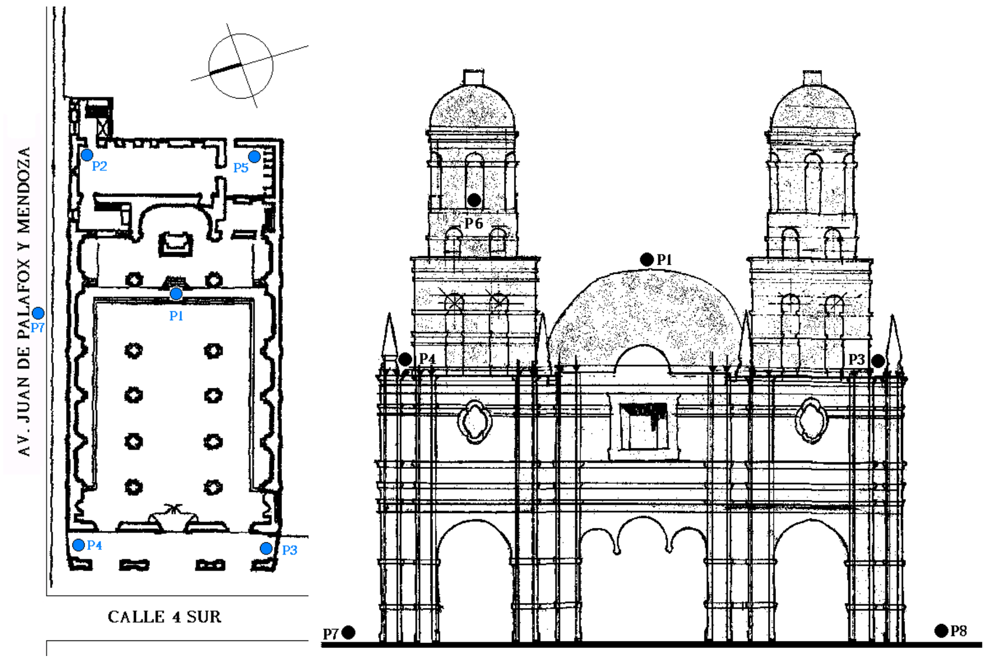

Figure 1 : Plan and elevation views of La Compañía

2. GEOTECHNICAL AND AMBIENT VIBRATION STUDIES

Soil conditions at the site were determined by means of 11 geotechnical soundings, including standard and cone penetration tests as well as sampling boreholes. Shear wave velocities, V_s, in and around the site were measured *in situ* in seismic cone penetration tests. Surficial soils at the site are high compacity silts and sands, down to 1.5 to 2.6 m (V_s= 200 to 280 m/s). Calcareous rocks, travertine stone, follow down to about 14 m on average. Quality index factors in the travertine were close to 100 % in the largest part of the stratum (average V_s= 650 m/s) but reduced significantly near the its upper and lower boundaries (V_s=220 m/s). Alluvial deposits, high compacity silts and silty sands, underlie the travertine rocks down to about 30 m (V_s= 180 to 250 m/s). Harder materials (V_s = 650 to 700 m/s), volcanic sands and alluvial gravely sands interspersed with thinner layers of travertine are found down to 50 m.

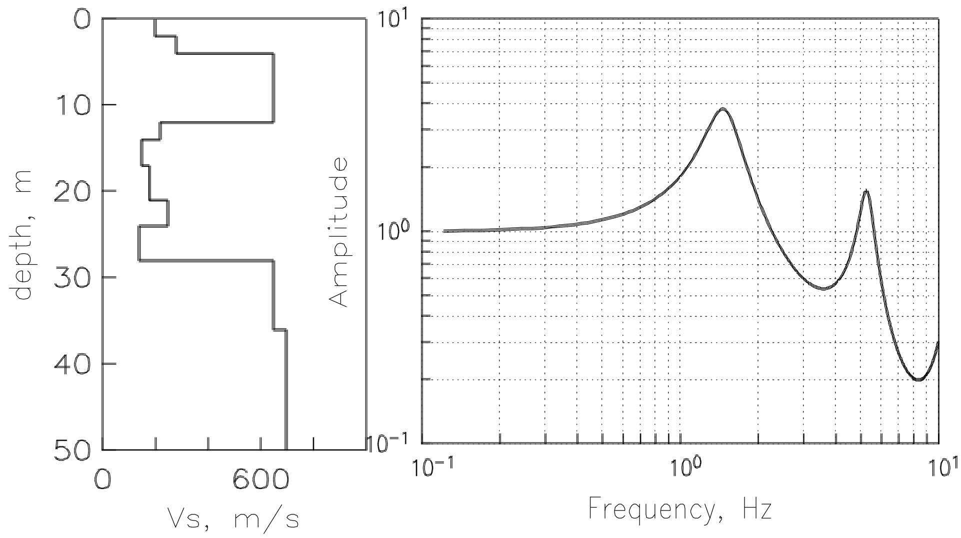

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Figure 2 : Simplified dynamic model (left hand side) and its transfer function (right hand side)

The stratigraphy at the site, mostly horizontal strata with no significant lateral heterogeneities, allows the use of one dimensional shear wave propagation models to analyse its seismic response. The graph in Figure 2 shows the simplified geodynamical model used in the analyses. Dynamic shear moduli were obtained from the results of the seismic cone tests and equivalent damping parameters were adjusted to equalise the amplification factors obtained from acceleration records obtained nearby during previous small magnitude earthquakes [1]. The model, can also be characterised by means of its transfer function, which is also shown in Figure 2. Its dominant frequency, 1.4 Hz, closely matches the one obtained from these records.

Ambient vibration measurements were used to identify the temple's vibration modes and their associated frequencies for which broad band seismometers were placed in various parts of the temple and in the free field. The plots in Figure 3 give an example of the records thus obtained. Fourier amplitude spectra show high amplitude peaks at 2.3 Hz, which is the structure's fundamental frequency associated to a translatory mode along the east-west direction. Empirical transfer functions, i. e. Fourier amplitude spectra obtained from the vibration records measured in the structure, divided by the Fourier amplitude spectrum of the free field vibrations, were used to corroborate this finding. In the same manner, the translatory mode along the north-south direction was identified at 3.6 Hz and a torsional mode at 4.0 Hz. When the ambient vibration measurements were made, the vaults had already been retrofitted with reinforced conrete, as part of an emergency rehabilitation project.

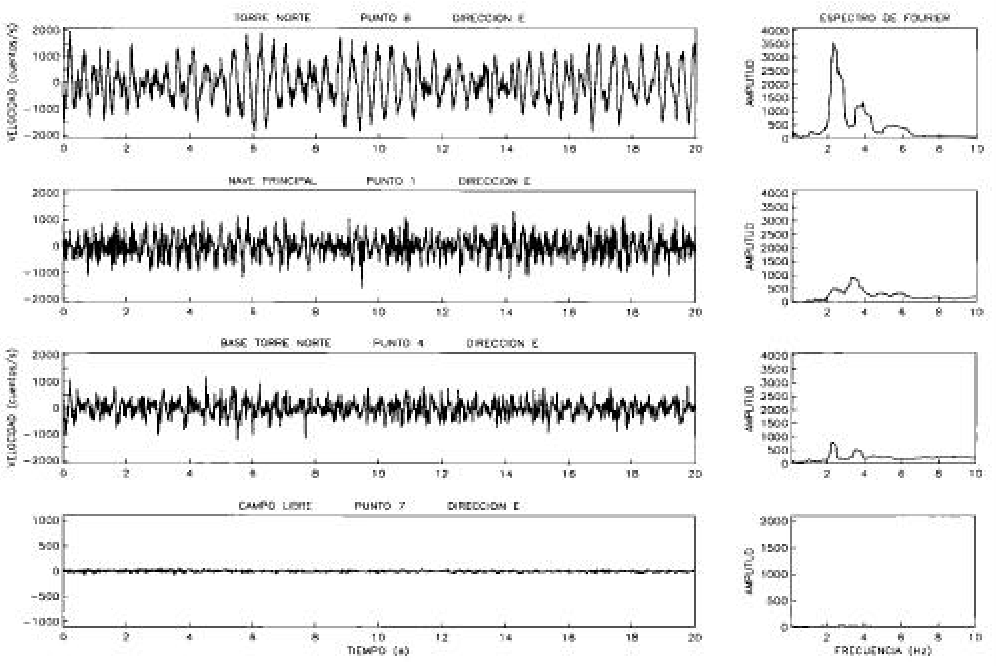

Figure 3 : Ambient vibration records and Fourier spectra for translatory movements along the E-W direction. The upper trace corresponds to records taken at the top of the north tower; the other records were taken at the main dome, the base of the north tower and the free field.

3. SEISMOLOGICAL STUDIES

The seismicity of the region is determined by a least some 30 seismo-genic sources around the state of Puebla that can be modelled with a Poissonian distribution that relates the magnitudes of expected expected earthquakes with their rates of exceedance. The model depends on unique parameters for each source that were obtained through Bayessian statistics [2]. Large subduction earthquakes having magnitudes larger than 7.0, the so called characteristic earthquakes [3], were modelled with a log-normal distribution.

Three attenuation laws were used to define the intensity of the expected seismic movements at La Compañía, depending on the different seismic sources that affect the city of Puebla. The relevant seismogenic sources were: a) the Mexican Southern Pacific coast along which large subduction earthquakes take place; b) the Neo-volcanic Axis that runs roughly from the north-west portion of Central Mexico to the south east and produces large surficial earthquakes with rather long return periods; c) the south Puebla-north Oaxaca region where intermediate depth, normal faulting earthquakes take place, like the 15 June, 1999, event. Attenuation laws for the first two sources were already available [4] and a new one was developed *ex professo* for this and other related studies, based upon the analysis of 157 acceleration records generated by intermediate depth normal faulting earthquakes [5]. These attenuation laws are frequency dependent and provide measures of the local intensity in terms of acceleration spectral ordinates for 5 % damping.

Attenuation laws do not include the influence of local soil conditions which will filter out high frequencies, in general. In the present case the site's fundamental frequency is considerably lower than the frequencies found for the structure's three most important modes, as discussed previously. Furthermore, any foreseeable strengthening of the structure will also increase its stiffness and its dominant frequencies. Hence, site effects were disregarded by assuming that the subsoil is rigid at La Compañía, which leads to conservative estimates of future seismic forces acting on it, an approach that can be justified given the monument's importance.

Seismic hazard, expressed in terms of exceedance rates of pseudo-acceleration spectral ordinates, was calculated locally adding the effects of all the seismic sources considered. Exceedance rates depend on the magnitude of the earthquake under consideration and of the distance between the source and the site. Again, a conservative approach led to using an exceedance rate of 0.002/year (500 year return period) for calculating a uniform hazard spectrum, that is, a spectrum having all its ordinates associated to the same exceedance rate. The final design spectrum, shown in Figure 4, envelopes the uniform hazard spectrum.

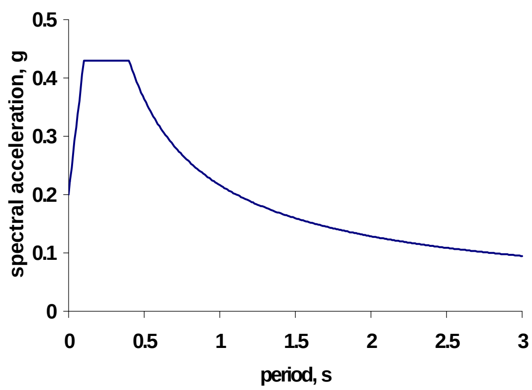

Figure 4 : Final spectrum for seismic design at La Compañía, Puebla (5 % damping)

4. CONCLUSIONS

Results from field tests were used to build a geodynamical model for the subsoil underlying the temple of La Compañía. The stratigraphic peculiarities and the dynamical properties of the subsoil at the site lead to the conclusion that local site effects may conservatively be disregarded for designing of the elements required in the ongoing structural rehabilitation programme of La Compañía. The seismic design spectrum produced in this study takes into account an up dated appraisal of the seismicity of the region, including all significant seismic sources. Conservatism in specifying the seismic design loads were justified in this case, given the importance of temple of La Compañía.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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