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Seismic microzonation of Torrevieja (Southwest of Spain)

J.J.Giner
Alicante University, Spain

C.L.Casado, J.A.Peláez, M.A.Peinado, J.Delgado & J.Chacón
Granada University, Spain

ABSTRACT: Historical macroseismic data analysis from the 03/21/1829 Torrevieja earthquake, actual "in situ" geotechnical information, civil structures characteristics and empirical methods, based on the surficial layer ages and compactation degrees, are used to perform the seismic microzonation of Torrevieja (Alicante) together with a seismic vulnerability assessment of its actual buildings.

1 THE 1829 TORREVIEJA EARTHQUAKE

On March 21, 1829, at 18h 30m (local time), occurred the last catastrophic earthquake located at the southwestern part of Spain. From the isoseismal map and other macroseismal data, Muñoz and Udías (1991) estimated the following earthquake parameters: epicenter ~ 38°N 0.38°W, I_o ~ X (MSK), magnitude ~ 6.9 and depth ~ 10 km.

According to several sources (López Marinas 1976, Rodríguez de la Torre 1984), there were 389 deaths, 2965 buildings collapsed and other 2891 were damaged.

The main villages affected were Torrevieja, Almoradí and Torrelamata with intensity X, Benejúzar, Daya Nueva and Formentera del Segura with IX-X, and Algorfa, Benijófar, Puebla de Rocamora, Rojales, San Bartolomé and San Fulgencio with IX (Muñoz 1984). Another twelve reached the intensity VIII.

On the whole area around these villages, there were important ground effects. Sand boils, sand vulcanoes, cracks and water flows were the usual ones. These effects were located mainly at both sides of the Segura river. However, these liquefaction effects were not the only ones producing damages on building. Also amplification site effects played an important role.

Excluding Torrevieja town, builted twenty years before this earthquake, the other villages showed low quality construction in its buildings. In all the cases, the vulnerability of the whole area can be considered as very high. This situation corresponds to the typical social and economical development in that epoch.

The foreshock and aftershock periods related to this earthquake were peculiar. On September 15, 1827, Torrevieja was shaken by a VII intensity earthquake. Six hours and thirty minutes before the mainshock, a small and a big (VII-VIII intensity) earthquakes beat again the village and surrounding areas. During at least another six months, the seismic activity following the mainshock produced, several times, earthquakes with intensity close to VIII.

Next paragraphs will deal with the seismic evaluation of the microzonation and vulnerability of the Torrevieja town. The methodology used will be supported on the information above mentioned and on several actual geotechnical field tests.

2 SEISMIC HAZARD AT TORREVIEJA

Our research was additionally supported by performing a seismic hazard analysis for Torrevieja. A seismic zonning is not used and the probabilistic distribution of earthquakes is aproached by an extreme-values Gumbel type III function (Epstein and Lomnitz 1966, López Casado 1990).

The historical record was chosen to begin at XVI century. The first damages earthquakes (VIII intensity) on this area is dated at 1523. A circular area with a 250 km radius was considerated as sesimic influence zone surrounding Torrevieja. The period taken for the analysis, from 1500 to 1990, was divided in intervals of 10 years.

Results for Torrevieja shown that a VIII intensity or a 251 cm/s^2 mean horizontal accelerations is expected in a 200 years time with a 63% probability (see figure 1) and a IX or 501 cm/s^2 in 500 years.

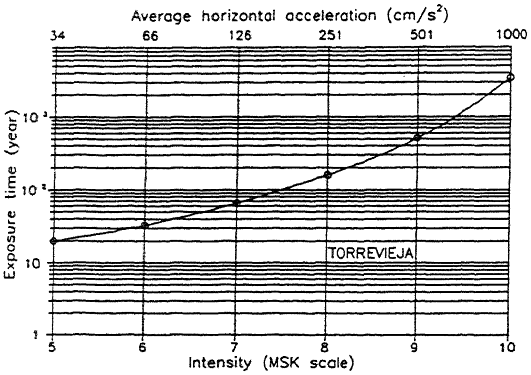


Figure 1. Intensity or mean horizontal acceleration vs. espected time.

According to the up to date historical catalog of the area (Mézcua and Martínez Solares 1983) from the date of the big earthquake, no VIII or IX intensities have been felt at Torrevieja. So, this additional information increases the interest of our research.

3 GEOLOGICAL AND GEOMORPHOLOGICAL FRAMEWORK

In this area there are sedimentary basins filled during Tortonian to Quaternary ages when many deformations took places. The fractures and main faults controlling all of these deformations may be grouped into three systems: N60 to E-W, NW-SE and NE-SW. The movements of these accidents, specially the vertical ones during the Quaternary, have produced the formation of areas trending to uplift (i.e. Cap de Santa Pola, Molar, Benejúzar and Torreagüera-San Miguel de Salinas) and others trending to a subsidence (i.e. Segura basin and lagoons of Torrevieja and Santa Pola).

The deformations produced from Tortonian to Quaternary ages show more clearly distensive than compresive effects. The compresive and distensive movements are correlated with speed variations between the African and Iberian plates.

The basement is composed mainly by schists into the Betic area and limestones into de Prebetic area. The sediments of Miocene and Pleistocene ages are mainly marls and sandstones. The Plio-Pleistocene is composed by red silts with a calcareous crust on top.

In the Torrevieja area the Quaternary is composed by black silts around the lagoons. In the beach there are some dune fields and calcarenites (see figure 2).

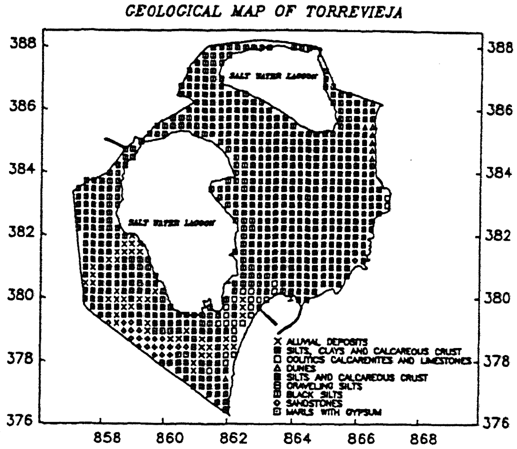


Figure 2. Geological map of Torrevieja county.

The topography of this region is mainly plain, excepting a few hills with low slope angles. However, to the North of the Segura river basin, the sharpness of the topography is roughly edged due to impressive normal faults.

The Torrevieja district is affected by uplifts at the coast and subsidences inside. The consequence is a shore with little cliffs and great lagoons.

4 GROUND RESPONSE

From historical data there is no evidence of amplification phenomena at Torrevieja. The topography of the area does not allow to suppose that it will produce, in the future, amplification effects or rockfalls (only it should occurs at the cliffs).

In order to study the ground response (amplification and liquefaction phenomena) we have collected some geotechnical information about lithologies, density, moisture and SPT´s number N of each formation and, also, about depths to the water table. In those places where we had not enough information, we performed a number of SPT.

The geothecnical data showed the uniformity of soil properties under Torrevieja town. Only close to the Torrevieja harbour there is fill urban deposits with very poor bearing capacity. Unfortunately the town is growing in this direction with multistorey buildings.

In this way, in Table 1, we show the four most typical lithological columns.

Table 1: Typical surficial lithological columns in Torrevieja county.

Depth(m)	Column 1 (SPT)
3.00	sand
4.00	silty sand (15)
6.00	silty gravel (≥40)
13.00	crushered sandstone (R)
-----	compact sandstone (R)

Depth(m)	Column 2 (SPT)
1.80	clayeys silt (10)
2.60	clay (6)
3.90	sandy silt (16)
5.60	silty sand (25)
-----	compact sand (≥40)

Depth(m)	Column 3 (SPT)
1.20	filled land
3.50	clayey sand (~30)
6.00	calcarenite (R)
7.00	sand with shells (R)
-----	calcarenite (R)

Depth(m)	Column 4 (SPT)
1.00	clay
-----	calcareous crust (R)
-----	red silt and marl (R)

It will be observed that, at the lagoons area, a layer of black silts and salt, 2 to 4 m thick, appears over any of the above four columns.

To calculate the ground response, we have considered that the bedrock (before the Miocene) is aproximately horizontal (the maximun dip of the layer is 10^{o}) and the mechanical properties are homogeneous at this area. For this reason we suppose that ground response is only due to surficial formations.

To quantify this effect we apply the Medvedev's methodology. It correlates the relative amplification of Intensity with the seismic impedance and water table depth.

From the geothecnical information we know the density of surficial formations. We assign values to longitudinal waves velocity from mean values obtained by geophysical prospecting surveys made in Spain. When a formation has randomly values, we have take an averaged value.

About the depth of water table we have plot a map of depths from well logs and geothecnical boreholes. The obtained distributions of depths is showed by the figure 3.

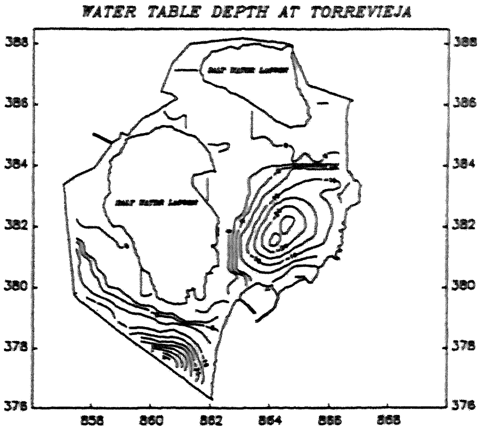


Figure 3: Water table dethps (referred to ground surface).

Both factors are the entering variables of this expression given by Medvedev (1962):

$$\Delta I=1.67\,LOG\frac{\rho_0 V_0}{\rho V}+e^{-0.04h^2} \qquad (1)$$

Finally, this equation gives the relative amplification of intensity plotted in figure 4.

5 SOIL LIQUEFACTION

Another aims of this research was to study the susceptibility and opportunity of ground liquefaction.

In order to study the susceptibility we consider the nature of the materials and the water table depth. The only susceptible materials are sandy silts (around the river), sands, lagoon silts, silty sands and sands (over calcarenite). For this reason we

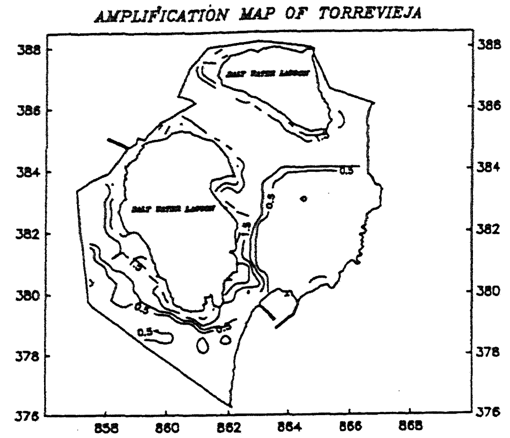


Figure 4: Relative amplification of intensity (referred to intensity in calcarenites).

do not consider the others.

The depth of water table varies between -0.1 m near the lagoons to -10.0 m in the cliffs area, -25 under the city and -5.0 m at south of Torrevieja lagoon. A susceptibility map is made with these data (see figure 5).

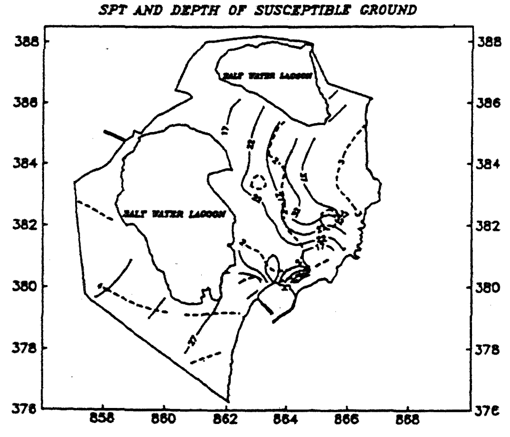


Figure 5: Susceptibility to liquefaction map of Torrevieja.

As the map shows, the susceptibility level is low, there is a greater susceptibility at the coast where the water table is near to the surface and where there is a 3 meters thick layer of sands.

Regarding to the liquefaction oportunity we follow the simplyfied method introduced by Seed and Idriss (1983) for assessing the liquefaction potential and a methodology introduced by Cornell (1968) to assess the seismic hazard of the region.

Following the Seed's method the state of a soil during an earthquake is given by its modified penetration resistence (N_1) and the cyclic stress ratio (CSR) at the point studied. The modified penetration resistence is calculated by the following expression:

$$N_1=NC_N \qquad (2)$$

where C_N is a correction factor to modify the SPT value and to do it compatible with an overburden pressure of 100 kPa. This factor is equal to:

$$C_N=0.77\,LOG\frac{1915}{\sigma(kPa)} \qquad (3)$$

The critical cyclic stress ratio is equal to (Seed and Idriss 1983):

$$\frac{\tau_{av}}{\sigma}=0.65\frac{\sigma}{\sigma}\frac{a}{g}r_d \qquad (4)$$

To correlate N_1 with critical CSR we follow Atkinson (1984):

$$\frac{\tau_{av}}{\sigma}=\frac{N_1}{12.9M-15.7} \qquad (5)$$

Knowing N_1 and introducing it into eq. 4, we obtain critical CSR and with it critical acceleration for each magnitude.

Once we have the minimum critical acceleration for each magnitude, (i.e. the minimun acceleration necesary to produce liquefaction), in a first step, we calculate the critical area surrounding this point where it must be an event of that magnitude through the attenuation law of calculated for this region (Finn 1988).

After that, we evaluate the seismic hazard of this acceleration in this point due to the active seismic sources in the region surrounding this point. In order to do it we follow the total probability theorem (i.e. the inclusion of a model of generation of the earthquake for each source into the evaluation of the time probability of occurrence of an event like it was introduced by Cornell in 1968).

In detail, the annual probability of

no occurence of liquefaction due to a source and with a certain magnitude is, assuming the well known Poisson model:

$$p_0=e^{-\lambda} \qquad (6)$$

where λ is the annual rate of occurrence of earthquakes with this magnitude in this source, calculated by:

$$\lambda=\frac{S_{crit}N(M)}{S_{source}} \qquad (7)$$

where S_{crit} is the surface of the critical area into the seismic zone, N(M) is the annual number of earthquakes with magnitude greater or equal than M calculated with our model of generation of earthquakes (Gutemberg-Ricter) and S_{source} is the area of the seismic source.

Finally, we only have to multiply the annual probabilities of no occurence (assuming independence of the events and different sources) to obtain the annual probability of liquefaction and the mean return period of liquefaction.

$$P_{liq}=1-(\prod_{sources}\prod_{M}p_0) \qquad (8)$$

$$T=\frac{1}{P_{liq}} \qquad (9)$$

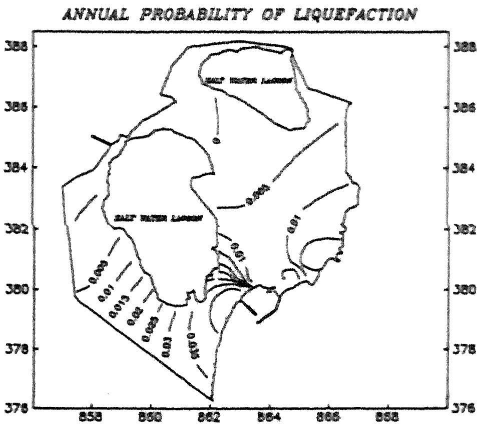
In those points where the liquefaction is possible, the mean return period obtained varies between forty years in the beach at few meters of the shore, a few hundreds of years at the town area and over thousand years in the area around the lagoons.

The last step is an attempt of correlate both of these factors (i.e. the susceptibility and the opportunity to liquefaction) in a simple way. For this reason we have plot the SPT (uncorrected) versus annual probability of occurrence of liquefaction in figure 6.

6 VULNERABILITY

To perform the vulnerability analisys of Torrevieja we sort the buildings depending on their height (H), inhabitants density (D), construction characteristics (A B C, MSK scale) (C) and nature of soil foundation (S). We evaluate vulnerability as a function of five variables.

The two first variables increase from 1 to 3 as height and density increase. The third variable decreases from A (3) to C type building (1). The last variable is a function of three factors: liquefaction, amplification potential and construction characteristics. So height buildings founded on low liquefaction potential areas will have a big degree of vulnerability. A map showing this analysis appears in figure 7.



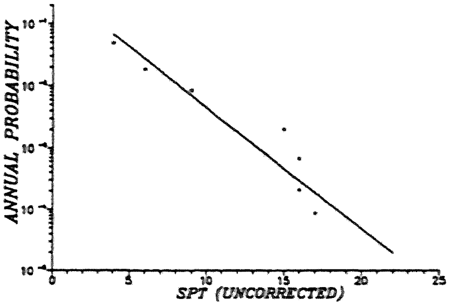


Figure 6: Plot of SPT vs annual probability of liquefaction.

7 CONCLUSIONS

The 1829's earthquake produced big damages at Torrevieja town. The main causes were the proximity to the seismic focus. So, from our analisys we

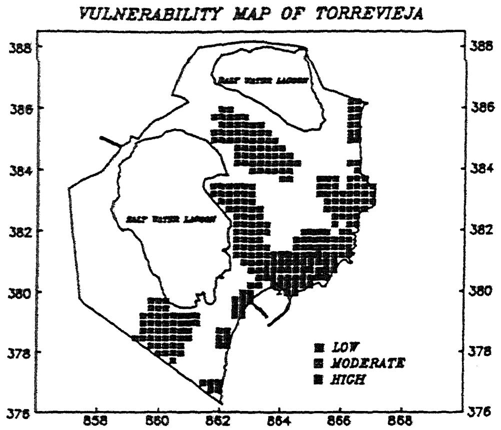


Figure 7: Vulnerability map of Torrevieja.

obtain that ground failure and topographical amplification are not able to be expected. Only low degrees of soil liquefaction opportunity and amplification in surficial soils are though to occur.

The potential amplification areas in Torrevieja district are around the two lagoons. The zones more prones to liquefaction are located at the harbour. From the opportunity analysis in this area liquefaction in a average period of 150 years is expected.

The vulnerability study shows that again the harbour area, due to its population and construction characteristic (tall buildings), has the higest degree.

Finally we suggest that in the future the new urban plan should follow the initial code regulations given for the reconstruction of the town after the 1829 earthquake. Although this regulation fixed wide streets and one floor buildings, the opposite criteria has been followed along this century.

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