An application of the seismic microzonation to the critical facilities in the city of Ensenada, Baja California, Mexico

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Abstract

Microzonation maps of the soil’s seismic response for the city of Ensenada, Baja California, Mexico were obtained by means of predictive empirical equations for the region. By applying damage probability matrices, the expected damage on the critical facilities of the city was estimated. The maps were elaborated considering a scenario of earthquake occurrence. A MM = 6.8 earthquake was proposed to occur in the southern portion of the San Miguel fault. The expected ground motion for the San Miguel earthquake in the downtown area would reach maximum accelerations of 135 cm/s², a maximum velocity of 9 cm/s, and an intensity of VII in the Modified Mercalli scale (MMI). Critical structures and strategic buildings of significant importance for the city were catalogued, and by applying the method of Damage Probability Matrices (DPM), the expected damage on these structures was estimated.

Keywords: seismic microzonation, Ensenada, earthquakes, seismic scenarios.

1 Introduction

Industrial countries have been successful in reducing their seismic risk, whereas undeveloped countries such as Nicaragua, Guatemala, and El Salvador, earthquakes have been responsible for losses up to 40% of the natural gross product (Geohazards International, [1]). The adequate planning and preparedness for emergencies allow the impacted area to reduce its risks and damages.
The purpose of this work is to develop microzonation maps based on the maximum acceleration and velocity values of the ground, as well as on the expected Modified Mercalli Intensities for the urban part of Ensenada, Baja California (Mexico), applying the Empirical Predictive Equations of Boore et al [2] and the correlations between the current conditions of the critical facilities and the microzonation maps using the Damage Probability Matrices (DPM), so we may have a preliminary opinion about the expected damages on those structures in the event that a strong earthquake occurs.

1.1 History

Northern Baja California cities are subject to a high seismic risk due to their closeness to the seismogenetic zones associated to the Pacific and North American plate interaction, fig. 1. This interaction manifests itself through a complex system of geologic faults, some of which dissipate the main and predominantly right lateral movement (San Andreas System), while others act as adjustment faults moving in other directions.

The region of study is located between the latitudes $31.63^0$ and $31.91^0$ N and between the longitudes $116.50^0$ and $116.75^0$ W, with an approximate area of 517 square km. The San Miguel fault was selected for this seismic scenario, for its seismic history, current activity, displacement velocity, relative closeness to the urban zone of Ensenada, and its capability of producing strong earthquakes.

![Figure 1: Tectonic frame in which the study area is set (Soares [3]).](image)

The epicentral locations obtained by the Regional Network [4] as well as by Frez et al [5] indicate a clear association of recent seismic activity of small to
moderate magnitude with the superficial trace of the San Miguel fault system, fig 2. The San Miguel fault manifests at its surface primarily due to the earthquakes of 1956 of M_L = 6.8 which lead to a maximum horizontal and vertical displacements of 78 and 91 cm respectively as shown by Shor and Roberts [6]. During these earthquakes a rupture length of approximately 20 km was identified. This system consists of en echelon fault segments of right lateral displacements.

2 Method

In regions with recent human settlements or scarce written history such as the region of study, there are no recorded data of strong earthquakes, and predictive methods have to be used in order to obtain estimates for the seismic response.

Figure 2: Seismicity registered by the RESNOM network from 1973 through 2002.

The estimate of the maximum horizontal velocity and maximum acceleration of the ground obtained by the predictive equation proposed by Boore et al (op cit) for the western coast of North America are, respectively:

\[
\log v = 2.17 + 0.49(M-6) - \log r - 0.0026 r - 0.45 \log (B/1190) \quad (1)
\]

\[
\log a = -0.242 + 0.527(M-6) - 0.778 \log r - 0.371 \log (B/1396) \quad (2)
\]
where:
\( v = \) maximum horizontal velocity of the ground.
\( M = \) Moment magnitude from 5.5 to 7.5
\( r = (d^2 + h^2)^{1/2} \)
\( d = \) shortest distance from the site where ground motion is being predicted to the vertical projection of the earthquake fault rupture on the surface of the earth.
\( B = \) Shallow propagation velocity of shear-waves.

Our study area is comprised under the same tectonic province for which the data of the predictive equations have been obtained (Southern California Shear Zone) so their use in this case is adequate.

The value of the proposed \( M_M \) was obtained accordingly to the fault length, earthquake depth and slip.

Proven relationships exist between the MMI and the damage state expected on the engineering structures, The determination of MMI was made using the following relation obtained by Esteva and Rosenblueth [7]:

\[
MMI = \frac{\log 14V}{\log 2}
\]  

where \( V \) is the ground shear wave-velocity.

In order to obtain \( V \), the different types of soils in the city were identified and then shear wave velocities (\( B \)) were obtained for each type of rock using seismic refraction profiles in those sites where there was a clear identification of the unperturbed surface rock, without any urban noise and where the terrain was clearly leveled. Of the 8 types of rocks identified, 5 direct and inverse seismic refraction profiles were made, and the values found in the literature were used for the rest.

2.1 Ensenada’s main critical facilities

The critical facilities identified within the study area were classified accordingly to the type and material used in their edification. GPS locations of hospitals, as well as fire, police, radio and TV stations, bridges, the military airport, dam and Red Cross, among others, were made.

With the help of some construction experts, we proceeded to make a Rapid Visual Screening [8], by inspecting a building from its exterior and from its interior if possible, in order to determine in a rapid way, if the edification is adequate to resist the seismic forces that it could experience. The objective was to obtain a list of potentially hazardous buildings without the cost of a detailed analysis in each one, allowing only to identify those that show vulnerability associated to strong seismic motion.

2.2 Damage estimates

2.2.1 Damage factor
We used the following quantitative measurement defined as:
The DF acquires values between 0 and 100%. Seismic engineers prefer to work with a value range of the DF or with the central value of the DF (Central Damage Factor, CDF) to which discrete grades of value are associated (Table 1).

2.2.2 Damage Probability Matrices (DPM)
In order to estimate the damage caused by the seismic movement of the ground, DPM were used, which are tables that represent the probabilistic relations between MMI and CDF for the different type of structures in a condensed matter. The matrices were constructed by an Advisory Project Engineering Panel and 58 other selected earthquake engineering experts commissioned by the Applied Technology Council in the U.S.A. [9]. These matrices were adapted to the building conditions of the city of Quito in Ecuador, by a group of civil engineers of the Escuela Politécnica Nacional of that country. Whenever possible we used those adapted for the city of Quito.

Table 1: Damage states and corresponding damage factor ranges.

<table>
<thead>
<tr>
<th>Damage State No.</th>
<th>Damage State</th>
<th>Damage Factor Range (%)</th>
<th>Central Damage Factor CDF</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>0</td>
<td>0</td>
<td>No damage.</td>
</tr>
<tr>
<td></td>
<td>Slight</td>
<td>0&lt;DF ≤ 1</td>
<td>0.5</td>
<td>Limited localized minor damage not requiring repair.</td>
</tr>
<tr>
<td>3</td>
<td>Light</td>
<td>1&lt;DF ≤ 10</td>
<td>5</td>
<td>Significant localized damage of some components generally not requiring repair.</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>10&lt;DF ≤ 30</td>
<td>20</td>
<td>Significant localized damage of many components warranting repair.</td>
</tr>
<tr>
<td>5</td>
<td>Heavy</td>
<td>30&lt;DF ≤ 60</td>
<td>45</td>
<td>Extensive damage requiring major repairs.</td>
</tr>
<tr>
<td>6</td>
<td>Major</td>
<td>60&lt;DF&lt;100</td>
<td>80</td>
<td>Major widespread damage that may result in the facility being razed, demolished or repaired.</td>
</tr>
<tr>
<td>7</td>
<td>Destroyed</td>
<td>100</td>
<td>100</td>
<td>Total destruction of the majority of the facility.</td>
</tr>
</tbody>
</table>

3 Results

The shear wave velocity values calculated from the seismic profiles and averaged for the first 30 meters are within the normal range found in the literature. The profiles show that in the southern part of the city, the alluvial deposits can reach more than 30m. in thickness, and in a personal communication, engineer César Obregón [10] states that the deposits could reach up to 100 m.

Figures 3 and 4 show the maximum expected values for acceleration (cm/s²) and velocity (cm/s) of the ground, for the city of Ensenada. The urban part of the city is encircled by a dotted line.
Figure 3: Maximum acceleration distribution, calculated for a proposed earthquake of MM = 6.8 at the southern sector of the San Miguel fault.

Figure 4: Maximum velocity distribution calculated for a proposed earthquake of MM = 6.8 for the San Miguel fault.

Several sites situated at the same distance from the source of the proposed earthquake show significant differences in amplitude due to the site effect; to the
east of Ensenada, accelerations of 130 and 60 cm/s\(^2\) are associated with alluvium and igneous rock, respectively which produce a relative amplification of 2.2.

Most of the urban zone where the majority of the critical facilities are situated (figure 6) is subject to accelerations of 100 and 135 cm/s\(^2\) except for the NE and NW which are underlain by rock and show accelerations of less than 60 cm/s\(^2\). A similar behavior is observed for the ground’s maximum velocity distribution, where the velocities are of 9 cm/s in the urban zones and less than 6 cm/s in the NE and NW areas.

![Figure 5: MMI distribution, calculated for a proposed MM = 6.8 earthquake in the southern portion of the San Miguel fault.](image)

The expected intensity values for the proposed earthquakes are shown in figure 6. The majority of the critical facilities are located in the region of maximum expected intensity. The relations between the Intensity and the associated damage probability for each type of critical facility considered is comprised in Table 2.

In some cases there is a predominant value of the damage probability, as in the case of the San Miguel Bridge (PSM) where the probability of the structure to suffer a CDF of 5, or light damage is 97%, whereas in other cases, the probability is more widely distributed, such as the Municipal Palace or County Mayor’s office (PAL), where a 55.5% of probability exists that it could suffer light damage and a 43.4% that the damage could be moderate.

Table 2 also shows that all structures would suffer some light to moderate damage, with a few exceptions such as in the case of the aluminum or plastic shed roofing open constructions where ambulances are kept (ARE and ABO) and the Emilio López Zamora (PLZ) dam which is made of massive concrete.
Table 2: Damage probability associated to the critical facilities as a result of a proposed $M_M = 6.8$ earthquake in the southern sector of the San Miguel fault.

<table>
<thead>
<tr>
<th>FCD Estructura</th>
<th>0.0</th>
<th>0.5</th>
<th>5.0</th>
<th>20.0</th>
<th>45.</th>
<th>Intensidad</th>
</tr>
</thead>
<tbody>
<tr>
<td>H08, H25, H32, HIS.</td>
<td>0.0</td>
<td>23.7</td>
<td>76.3</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>BRE, BVD, POL</td>
<td>0.0</td>
<td>23.7</td>
<td>76.3</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>HNA, TVL, C+R</td>
<td>2.5</td>
<td>95.8</td>
<td>1.7</td>
<td>0.0</td>
<td>0.0</td>
<td>VI</td>
</tr>
<tr>
<td>RVA, RAC, TEL</td>
<td>0.0</td>
<td>23.7</td>
<td>76.3</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>PAL, HMC</td>
<td>0.0</td>
<td>0.6</td>
<td>55.5</td>
<td>43.4</td>
<td>0.5</td>
<td>VII</td>
</tr>
<tr>
<td>PFP</td>
<td>0.0</td>
<td>9.1</td>
<td>90.5</td>
<td>0.4</td>
<td>0.0</td>
<td>VI</td>
</tr>
<tr>
<td>BCE, HCA</td>
<td>0.0</td>
<td>0.6</td>
<td>55.5</td>
<td>43.4</td>
<td>0.5</td>
<td>VII</td>
</tr>
<tr>
<td>HGE</td>
<td>5.2</td>
<td>52.0</td>
<td>42.8</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>HBC</td>
<td>6.3</td>
<td>43.6</td>
<td>50.1</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>HVM</td>
<td>1.1</td>
<td>34.0</td>
<td>64.9</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>RES</td>
<td>2.7</td>
<td>65.8</td>
<td>31.5</td>
<td>0.0</td>
<td>0.0</td>
<td>VI</td>
</tr>
<tr>
<td>ARE</td>
<td>0.0</td>
<td>5.9</td>
<td>59.0</td>
<td>35.1</td>
<td>0.0</td>
<td>VI</td>
</tr>
<tr>
<td>ABO</td>
<td>0.0</td>
<td>0.4</td>
<td>33.3</td>
<td>40.3</td>
<td>26.</td>
<td>VII</td>
</tr>
<tr>
<td>PSM, PTO, PTS</td>
<td>3.0</td>
<td>97.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>VI</td>
</tr>
<tr>
<td>PSC</td>
<td>0.0</td>
<td>12.3</td>
<td>85.7</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>CFE</td>
<td>0.0</td>
<td>1.8</td>
<td>64.3</td>
<td>33.5</td>
<td>0.4</td>
<td>VII</td>
</tr>
<tr>
<td>TTV</td>
<td>0.0</td>
<td>87.8</td>
<td>12.2</td>
<td>0.0</td>
<td>0.0</td>
<td>VI</td>
</tr>
<tr>
<td>AEM</td>
<td>22.</td>
<td>77.5</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>PLZ</td>
<td>57.2</td>
<td>42.8</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>QUE</td>
<td>2.5</td>
<td>92.9</td>
<td>4.6</td>
<td>0.0</td>
<td>0.0</td>
<td>VII</td>
</tr>
<tr>
<td>PTA, TPX, TGA</td>
<td>94.0</td>
<td>6.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>VI</td>
</tr>
</tbody>
</table>

4 Discussion

For the proposed $M_M = 6.8$ earthquake on the San Miguel Fault, there are two overlapping tendencies in the variation of the ground movement amplitudes:

The variation associated to distance (inelastic attenuation and geometric expansion, that can be appreciated in figure 6 by banding with decreasing amplitude from the superficial trace of the fault to the west, and the variation associated to the site effect (superficial geology), which provokes a strong amplification of the sedimentary soils, specially that associated to the riverbeds that dissect the rocky formations.

It is pertinent to mention that most of the critical facilities could suffer more damage than the one predicted, as the Rapid Visual Screening of the edifications showed internal and external fractures in their walls and floor, and in the case of the General Hospital, its steel columns present approximately a 30% grade of oxidation at its base.
5 Conclusions

Arnold and Reitherman [11] have found that a 100 cm/s\(^2\) value of acceleration can produce some type of damage on weak buildings. For this scenario, most of the critical facilities are subject to seismic solicitations that exceed this level. More effort should be made in revising the critical facilities in detail in order to determine the necessary reinforcements or modifications to be made so they would become less vulnerable to earthquakes. This factor was not taken into account for this seismic scenario, as it is the first study of this nature that has been done in Ensenada.

Emergency preparedness plans should be taken seriously in our city.

References


