PROPOSAL OF GROUND MOTION PREDICTION EQUATION (GMPE) FOR CHILEAN GROUND MOTION RECORDS AND ITS APPLICATION

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ABSTRACT

After the 2010 Chilean Earthquake, buildings design code was upgraded in topics related to spectrum design and soil classification; however, the bridge's code was not. The main target of this research is to propose a Ground Motion Prediction Equation (GMPE) in order to predict seismic intensity in Chile and to analyze the current spectrum design of the Road Manual code and use on it to evaluate the Seismic Risk Inform. I use an existing Japanese GMPE (Dr. KATAOKA Shojiro from NILIM) but modified by Chilean records using modification factors. These modification factors multiply the parameter "b" inside the original GMPE and become the geometric mean value (ratio between observed acceleration response spectrum over predicted acceleration response spectrum) to one (1). The results show excellent performance of GMPE Modified. Also, it shows that the peak of acceleration response spectrum and acceleration value at 1 second period of the current spectrum design for bridges must be examined.

Keywords: Ground Motion Prediction Equation (GMPE), Seismic Intensity, Bridge Spectrum Design, PGA.

1. INTRODUCTION

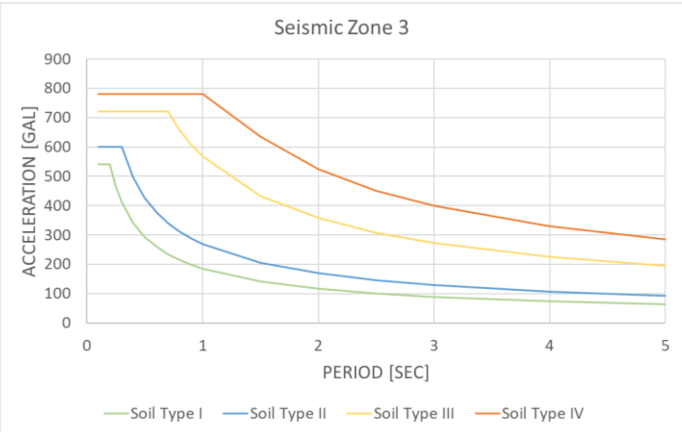

Figure 1. Road Manual Spectrum Design. Seismic Zone 3.

Chile is over the South American plate. While on its western edge, the Nazca and Antarctic plates converge and generate subduction zones, the Scotia plate slides horizontally concerning the South American plate, on a passing plate edge. These interactions produce a great deformation of the South American continent and generate earthquakes throughout Chile. Due to the high speed of convergence between Nazca and South America, the seismicity in that area is the most intense and produces the most massive earthquakes in the country. Also, Chile is one of the most prone countries to suffer from earthquakes in the world. Most of them are interplate subduction earthquakes, except for the one in 1939 that corresponds to the Chillán earthquake, which is an intraplate-oceanic earthquake, and the 1949 Punta Arenas earthquakes (M ~ 7.8), which correspond to earthquakes with a passing edge in the Magallanes fault zone. The massive earthquakes

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in recent years are the 2010 (8.8 Mw), 2014 (8.2 Mw), and 2015 (8.4 Mw). After these large earthquakes, the bridge's design code was not upgraded or modified related to the spectrum design method.

On the other hand, The Road Manual of the Road Direction is a technical document that serves as a guide for the bridge's design in Chile. It defines three seismic zones. These are divided by imaginary lines almost parallel between them. Besides, the Road Manual describe five (5) bridges design method; one of them is the Spectrum Design method including a Seismic Risk Inform (SRI). The SRI is a technical research which target is develop an acceleration response spectrum in function of the bridge's location, to use it in the bridge design. However, inside Road Direction, there is not any professional with the skills to revise this inform.

Then, the target of this research is checking the current spectrum design with the GMPE Modified and get the skills to be able to review the spectrum design included in the Seismic Risk Inform for special bridges.

2. THEORY AND METHODOLOGY

2.1. The Ground Motion Prediction Equation (GMPE)

The GMPE was developed by Dr. KATAOKA Shojiro in order to predict seismic intensities, PGA, and an acceleration response spectrum. In this case, include acceleration data of interplate earthquakes in Japan from the year 1978 to 2003, using more than 11.000 data records. From the beginning, the original GMPE shows an excellent correlation with the Chilean records. However, the geometric mean value did not show a good dispersion; in higher frequencies, the tendency value is over one (1), and for lower frequencies, the tendency value is lower than one (1). The Eq. (1) is the GMPE.

$$Y = a1 * Mw = a2 * D - b * X + c0 - log10(X + d * 10^{0,5*Mw}) \quad (1)$$

The inputs of the GMPE are (a) the soil type of the target point according to Japanese classification (I, II, III), (b) the shortest distance from the target point to the rupture area (X value), (c) the depth of the hypocenter (D value), and (d) the earthquake magnitude (Mw value).

2.2. The Ground Motion Prediction Equation Modified (GMPE Modified)

The GMPE Modified is the original GMPE multiplied by some values (modification factors) to parameter "b" for each period. These modification factors make the geometric mean value of the spectrum ratio, a trend to 1.

The spectrum ratio is the ratio between the observed data (using Chilean records) over the predicted data (using GMPE Modified).

The GMPE Modified has excellent behavior with Chilean acceleration records and has a correct performance compare it with the Chilean attenuation equation.

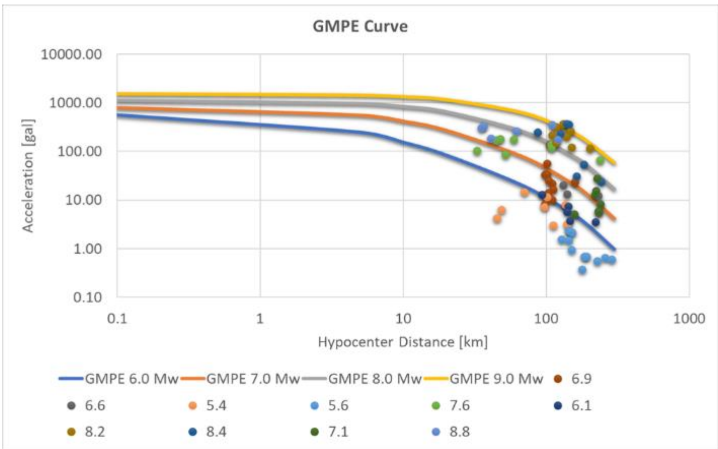


Figure 2. The original GMPE and Chilean acceleration records. Dots are acceleration records with different magnitudes. This GMPE is at 1 second period.

2.3. Analysis of the current Spectrum Design

The current Spectrum Design was developed in 2002; at that time, the Road Manual was created. The earthquake base, of the current spectrum design, is the San Antonio Earthquake (1985). It is an interplate earthquake, magnitude 8.0 Mw, and 33 km of depth. For this research, I use only the seismic zone 3 of the current Road Manual for the analysis.

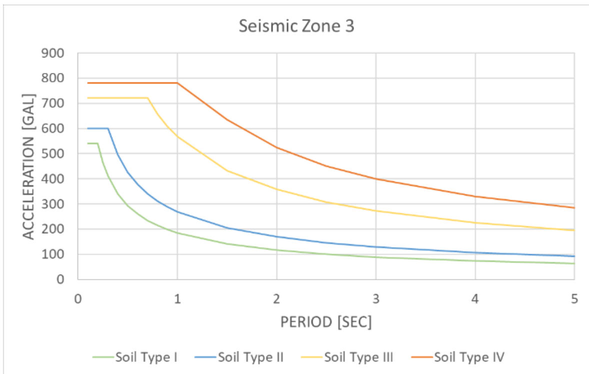


Figure 3. Road Manual Spectrum Design. Seismic Zone 3. Soil Type I, II, III , and IV in Chile.

The seismic zone 3 is the coastal area in Chile and corresponds to the zone with a higher acceleration demand (Ao = 0.4g) in the country. The seismic zone 1 is in the Los Andes Mountain location and corresponds to the lower acceleration demand (Ao = 0.2g), and the seismic zone 1 is the central valley zone (Ao = 0.3g). The target analysis area is the Metropolitan Region in the middle part of Chile. Therefore, the dip angle of the trench is around 23 degrees. With this information, I calculated the lower acceleration response spectrum possible in seismic zone 3, and the higher acceleration response spectrum possible in seismic zone 3. These two (2) spectrums I compare with the current spectrum design of bridge code.

3. DATA

3.1. Acceleration Data

All the acceleration data used in this research were obtained from the seismic Network in Chile (www.csn.cl). In total, I used 77 acceleration records of 10 earthquakes from 67 different seismic stations. However, the seismic station network is more extensive.

3.2. Soil Classification

The soil classification in Chile is quite similar to Japan; I (Ts > 0,2 sec), II (0,2 > Ts > 0,5), III (1,0 > Ts > 0,5); however, in Chile there is one more category of soil, IV (Ts > 1,0). Therefore, I assumed category III and IV in Chile, as III in Japan. The parameter to classify the soil is the Shear Velocity (Vs30) and Nakamura Method was used to transform the Vs30 to a natural period. All the Vs30 information was obtained from each seismic station that I used.

3.3. Hypocenter Distance

The hypocenter distance is the shortest distance between the target position to the rupture area. This rupture area is related to the dip angle of the trench. In Chile, the dip angle is according three zones, (1) the north location with the longitude of 15 degrees to the longitude of 27 degrees where the dip angle value is between 25 degrees to 30 degrees, (2) location with the longitude of 26 degrees to the longitude of 33 degrees where dip angle value is 10 degrees, and (3) from longitude 33 degrees to the south where dip angle is almost 30 degrees.

4. RESULTS AND DISCUSSION

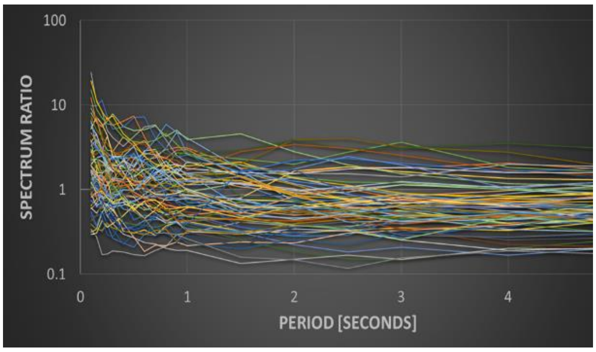
4.1. Modification Factors

Although the original GMPE surprising correct performance, the geometric mean value of the spectrum ratio (accelerations response spectrum of Chilean records over GMPE acceleration response spectrum) is not adequate, as I explained before. It is why, through the iterative process, I found some Modification Factors that fix that issue.

Table 1. Modification Factors.

T(s)	0.1	0.15	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.5	2	2.5	3	4	5
MF	0.69	0.74	0.79	0.84	0.87	0.89	0.91	0.91	0.95	0.98	1.02	1.09	1.31	1.37	1.47	1.49	1.5	1.35

Multiplying these modification factors to parameter b inside GMPE, the dispersion of the spectrum ratio value change and fix the trend of the geometric mean value. The geometric mean value tendency now is correct.



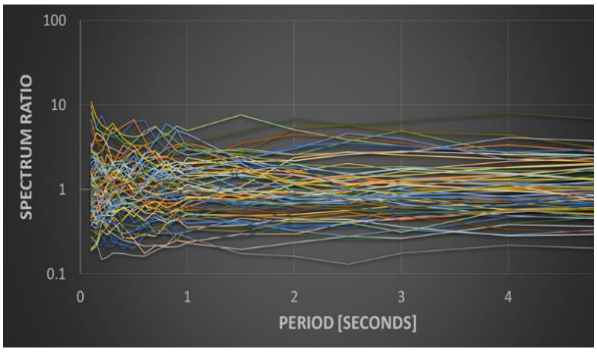
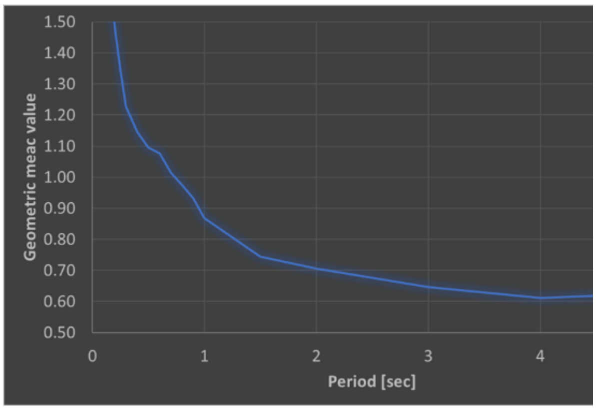


Figure 4. The spectrum ratio dispersion in 5 second period. On the left side is the GMPE and shows that for high frequency, the spectrum ratio trend towards valuing over 1, on the other hand, for lower frequency, the trending value is less than 1. On the right side, GMPE Modified, and show that the tendency to 1 is more homogeneous.



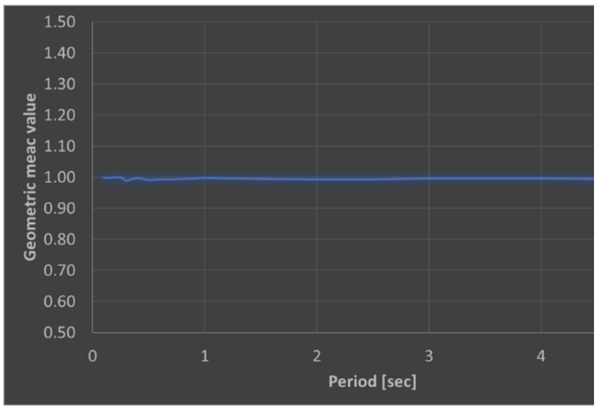


Figure 5. The geometric mean value dispersion in 5 seconds period. On the left side is the GMPE distribution, on the right side is the GMPE Modified dispersion. In this last, the dispersion is fixed due to the Modification Factors.

There are no relevant changes between the GMPE curve and the GMPE Modified curve. However, due to the modification of the parameter "b", the shape of the curve changes. One acceleration value is obtained with a hypocenter distance shorter than using the original version. The GMPE Modified keeps the adequate behavior using Chilean acceleration records and correlates correctly comparing with other attenuation equation developed in Chile like the developed by professor Boroschek from the University of Chile.

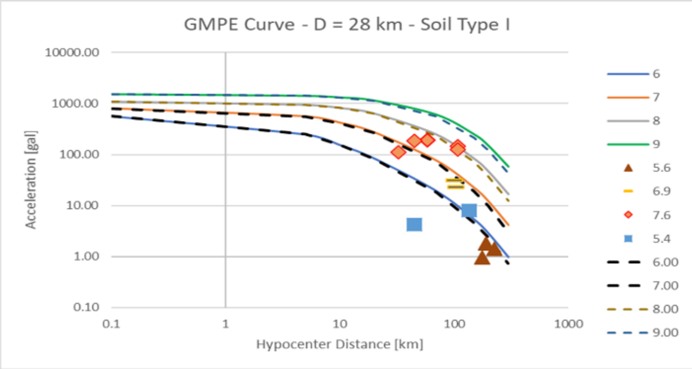


Figure 6. The GMPE is the solid line, and the GMPE Modified is the broken line.

4.2. Current Spectrum Design in Chile

The higher acceleration response spectrum possible, occur when the hypocenter distance (X value) is equal to 37 km (San Antonio city in the coastal area). The lower acceleration response spectrum possible, occur when the hypocenter distance (X value) is equal to 71 km, in the border between the seismic zone 3 and seismic zone 2 (near Santiago city). In this research, I am only analyzing the seismic zone 3 and the type of soil III.

Then, it is easy to conclude that the peak of the current acceleration design spectrum is lower than that is predicted by GMPE Modified. However, at 1 second period, the current spectrum design amount is near to lower case value.

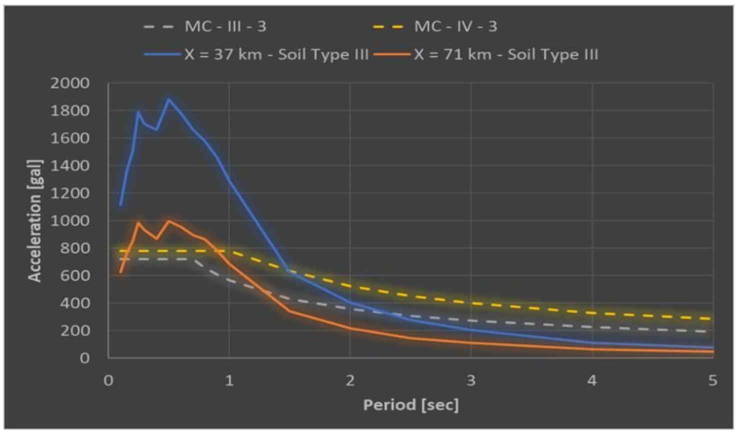


Figure 7. Spectrum Design. In segmented line spectrum for soil type III and IV (correlated as III in Japan). Orange line the lower acceleration spectrum possible inside seismic zone 3, and in blue line the highest acceleration spectrum possible inside seismic zone 3.

Quite different is comparison with the higher case; in this case, the acceleration amount is almost double. Therefore, the current spectrum design must be upgraded according to more significant earthquakes that occurred in Chile in recent years.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. GMPE Modified

a) GMPE Modified has an excellent performance with Chilean records.
b) I recommend to include more acceleration data in the database from the south part of Chile (not contained in this research) and find new modifications factors. Besides, I recommend analyzing the type of soil and modify it if necessary. However, the correct behavior of the GMPE Modified using Chilean data records should be maintained.
c) Also, I recommend the GMPE Modified as a tool to review the Spectrum Design proposed in the Seismic Risk Inform for unique bridges design. This revision should be overseen by the engineers inside the Project Department of the Road Directions in the Ministry of Public Works in Chile.

5.2. Current Spectrum Design

d) After the 2010 earthquake, 2014 earthquake, and 2015 earthquake, the current spectrum design of the Road Manual has not been analyzed or upgraded. However, the Chilean building code has been upgraded.
e) This research proves the need to analyze the current Spectrum Design and evidence that it must be modified. According to the result, it is necessary to use a hypocenter distance (X value) between 37 km and 71 km in order to define a new spectrum. However, the choice of the final amount will be determinded by the authority.
f) I propose to change the current spectrum design in two-period ranges, (a) at high frequencies (from 0 to 1,3 seconds) to increase the PGA and the peak value of the spectrum, and (b) for low frequencies (from 1,4 to 5 seconds) keep the current spectrum amount.

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