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ARTICLE

Study of Response Spectra for Ulaanbaatar city

Munkhsaikhan Amarsanaa[1]*, Odonbaatar Chimed[1], Dembereldulam Munkhjargal[1] and Ganzorig Erdene[2]

[1] Earthquake Hazard Analysis Laboratory, Department of Seismology, Institute of Astronomy and Geophysics, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia
[2] Department of Civil Engineering, School of Civil Engineering and Architecture, Mongolian University of Science and Technology, Ulaanbaatar, Mongolia

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Abstract: According to researchers, Ulaanbaatar, the capital city of Mongolia, is in an active seismic zone, and more active faults around the city have been discovered in the last few decades. This is an alarming news for the city that has been expanding and developing rapidly. Therefore, consideration of the construction of structures that can withstand strong earthquakes has been becoming a complex problem from economic perspective and urban planning. This study aims to develop response spectra for all and any structure constructs in the city. To complete this requirement, we generated maximum response spectra correlating different soil classes, and taking into considering all potential active sources around the city. In this research work, we have proposed various response spectra that are associated with five different soil classes, and these response spectra can be used for the city.

Keywords: *response spectra; seismic hazard analysis; Vs30; Ulaanbaatar;*

INTRODUCTION

The main problem of calculating seismic force in the design of construction is a still question that has not been completely resolved at the current scientific and social development level. However, there are solutions in engineering for construction that can withstand strong earthquakes, it is impractical to build all construction in this manner because of economical consideration and urban planning. For example, living in a yurt or masonry house is safer than living in a high-rise apartment building, but this is far from an appropriate solution for metropolitan cities. For many decades, seismologists and earthquake engineers have developed methods to predict ground motion generated by an earthquake to assess seismic hazards. Seismic hazard can be determined by approaches of Deterministic and Probabilistic Seismic Hazard Analysis – DSHA and PSHA [1]. For the design of important constructions, such as infrastructure, power plants, and factories, the DSHA approach is used and for the design of common constructions, the PSHA approach is used [2].

***corresponding author: munkhsaikhan.a@iag.ac.mn** **https://orcid.org/0000-0002-3640-1653**

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This study aims to develop maximum response spectra using the seismic hazard analysis approaches for Ulaanbaatar city, Mongolia. Ulaanbaatar is the capital city of Mongolia with a population of around 1.5 million and in recent years, the city has been developing and expanding very fast with an increasing number of high-rising buildings and infrastructures coming up. On the other hand, this increases the seismic hazard for the city. According to research on seismic sources [3–5], 7 seismic sources are located at a distance of 10 to 200 km from the city, which is indicative that the city is highly likely to be affected by the surrounding potential seismic sources. From 1987 to 2016, 11 earthquakes occurred around the city within a 400 km radius that was felt by the city with minor damage. For instance, in 2013, an earthquake with a local magnitude of 3.7 occurred in the Emeelt area, and it was felt by the city residents with an intensity of II to III on the MSK-64 scale [6]. These examples indicate that seismic hazard analysis should be done for the city. In an effort to fulfill this requirement, we covered an area of the city with grid points (Figure 2) and calculated maximum response spectra by using seismic hazard analysis approaches. In the calculation, 19 active faults and 4 seismic zones within a 350 km radius circle centered at the city were chosen. We used soil classification according to the American Society and Civil Engineering standard (ASCE 7-10), an average shear-wave velocity from the surface to the depth of 30 meters or simply said Vs30. Civil engineers can directly apply these general response spectra to design earthquake-resistance constructions for the city.

MATERIALS AND METHODS

DSHA and PSHA approaches are generally used for determining seismic force at particular sites. The DSHA determines a "worst-case" ground motion generated by an earthquake among the potential sources surrounding the site. The calculation requires the expected maximum magnitude or Maximum Credible Earthquake (MCE) that can occur on individual faults. An empirical ground motion attenuation law is utilized to calculate ground shaking at particular sites. Then the closest source-to-site distance is selected. The PSHA evaluates the probability of exceeding various ground-motion levels at the site given all potential sources. The calculation requires all source characterization and the attenuation law. This method was developed by Cornell (1968) [1] and improved by McGuire (1974, 1978) [7,8]:

$$\lambda(a) = \sum_{source} \nu_{source} \times \iint_{(m,r)\in source} I[PGA \geq a/m, r]\ f_M(m) f_R(r)\ dm\ dr \quad (1)$$

- $\lambda(a)$ is an occurrence rate of the ground motion concerning level a.
- ν_{source} is the annual activity rate (the mean annual rate of occurrence of events with a magnitude greater than the detection threshold in the source considered).
- $I[PGA \geq a/m, r]$ is the indicator function for the predicted PGA of an earthquake of magnitude m and distance r from the site concerning level a.
- $f_M(m)$ and $f_R(r)$ are the probability density function of magnitude M and distance R respectively for the source considered.

The attenuation law or the empirical Ground Motion Prediction Equation (GMPE) predicts earthquake ground motion as Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV), and Peak Ground Displacement (PGD) during different periods at a certain distance from the source. The input parameters of the GMPE greatly affect the equation's output, and it consists of magnitude, distance, focal mechanism, source parameters, and site condition. The equation is a major part of seismic hazard analysis.

Input parameters

For the seismic hazard calculation, we chose the GMPEs of the NGA-West2 research project for the attenuation law [9], which are Abrahamson, Silva, Kamai (ASK), Boore, Stewart, Seyhan, and Atkinson (BSSA), Campbell and Bozorgnia (CB), Chiou and Youngs (CY), Idriss (I). Most of the GMPE

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input parameters were taken in default, yet 12 km for the seismogenic depth, 100 m for a basin depth of the city, and the Vs30 were taken at 150m/s, 300m/s, 400m/s, 550m/s, and 760m/s. For the calculation's input parameters of seismic sources and seismicity in the region, we selected 19 active faults and 4 seismic zones within a 350 km radius of the city center (Figure 1). Detailed information on the sources' input is shown in Table 1.

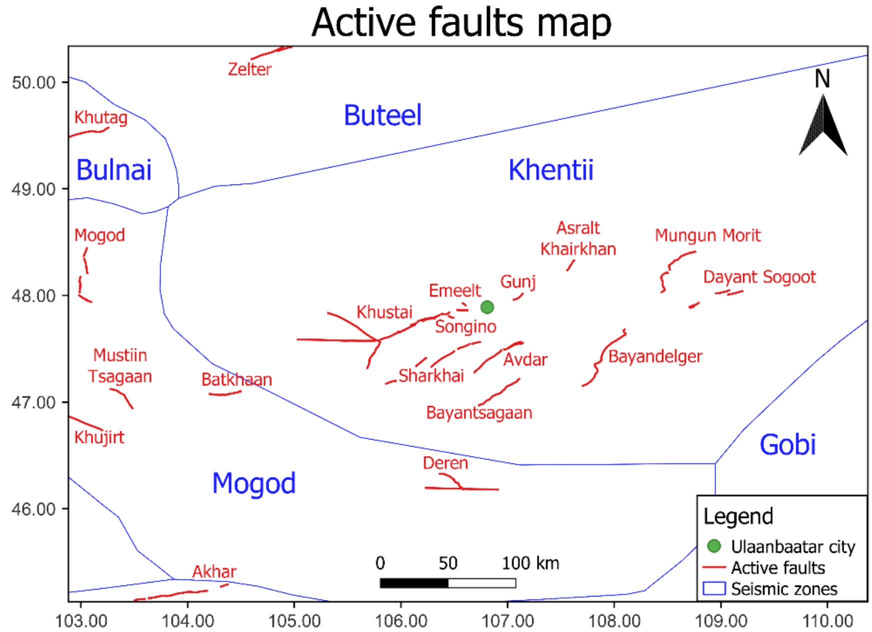

Figure 1. The map shows the seismic sources, faults and zones, which are used in the PSHA calculation

Table 1. The seismic source parameters for the PSHA calculation

Source name	Source type	Mw	Fault length (km)	a – value	b - value	Source-to-site distance (km)
Buteel	Zone	6.5	-	3.64	0.84	171
Bulnai	Zone	6.5	-	3.65	0.82	241
Mogod	Zone	6.5	-	3.55	0.76	153
Khentii	Zone	6.5	-	3.68	0.91	0
Avdar	Fault	7.1	50	1.12	0.65	36
Asralt Khairkhan	Fault	6.2	10	1.0	1.0	63
Akhar	Fault	7.5	140	1.7	0.74	336
Batkhaan	Fault	6.7	23	2.4	1.2	189
Bayandelger	Fault	7.2	70	1.0	1.0	86
Bayantsagaan	Fault	6.9	40	1.0	1.0	73
Gunj	Fault	6.7	20	3.9	1.4	15
Dayant Sogoot	Fault	6.2	10	1.1	0.6	155
Deren	Fault	6.8	27	2.86	0.88	171
Zelter	Fault	7.4	60	2.66	0.76	295
Mogod	Fault	7.4	45	3.33	0.74	269
Mungun Morit	Fault	7.3	90	1.95	0.87	41
Mustiin Tsagaan	Fault	7.0	25	1.2	0.8	264
Songino	Fault	6.5	18	2.49	0.94	9
Khutag	Fault	7.7	110	1.93	0.79	310
Khustai	Fault	7.8	194	2.49	0.94	25
Khujirt	Fault	7.0	21	1.1	1.0	293
Sharkhai	Fault	7.1	50	1.17	0.68	30
Emeelt	Fault	7.0	35	2.95	1.12	8

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Calculation process

We gridded the city with points. Distances between the points are around 3 km, and selected 53 points that are landed in the urban areas where the population is dense (Figure 2). After the selection, the response spectra calculation was performed using the seismic hazard analysis approaches at each point. The calculation was executed by an ODPSHA, 2014 program developed by Odonbaatar Chimed, which was written in Matlab programming language.

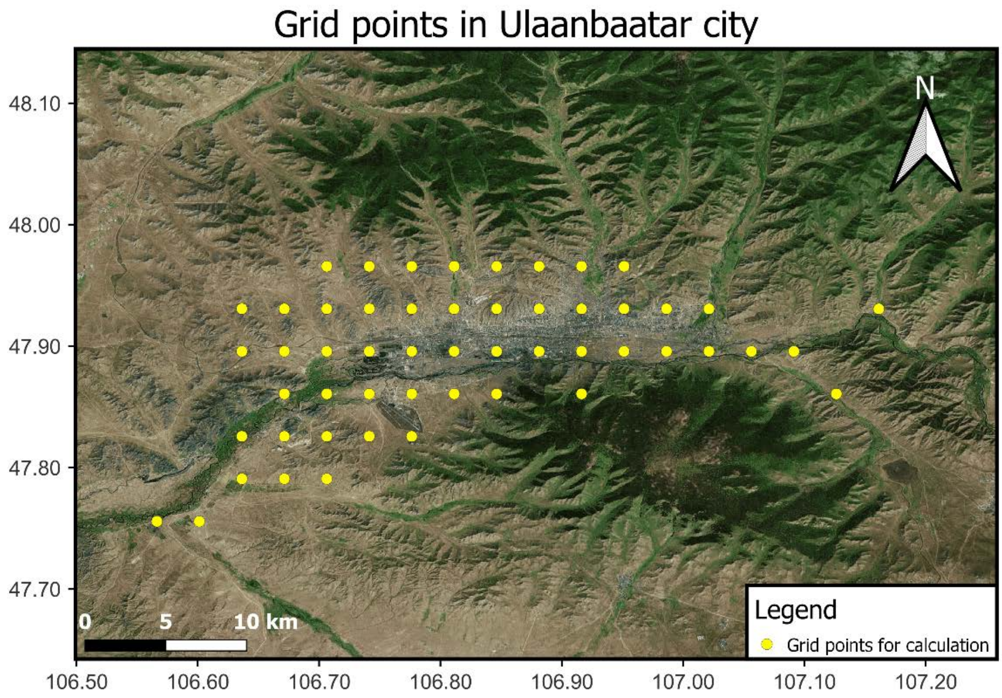

Figure 2. The research site of Ulaanbaatar city is covered by 53 grid points after the elimination

DSHA calculation process

In the DSHA calculation, 3 major faults that may pose serious damage to the city were taken into consideration, namely Khustai, Emeelt, and Gunj. Emeelt is the closest prominent fault, about 10 km from the western part of the city, and its possible maximum magnitude is about 7.0 [6] and Khustai is the second most threatening fault to the city, about 15 km west of the city, and the possible maximum magnitude is between 7.5 and 8.0 [8, 9,10]. For the Khustai fault, we decided to take 7.8, the average value of the magnitudes, for the calculation. Gunj is the third closest fault to the city, about 25 km from the northern part of the city, and the magnitude is about 6.7 [6].

We calculated the response spectra for the various Vs30 at each grid point using the NGA-West2 research projects' GMPEs.

For periods, twenty periods within the range of zero to five seconds were chosen. In Figure 3.a, the blue curves represent the response spectra that was calculated at each point. The points that are close to the active faults give high values in spectral acceleration making high curves, and the low curves belong to the points that are far from the active faults. After the calculation, the response spectra values were normalized at 0.1 g by its PGA, a spectral acceleration value at T=0, and they were combined in a single graphic to compute the upper peak envelope, which is the maximum value for each fault (Figure 3.b). It can be clearly seen from Figure 3.b that after the normalization, the distinction between curves that are calculated by the GMPEs are are polarized. In Figure 3, one of the calculation results is shown as an example.

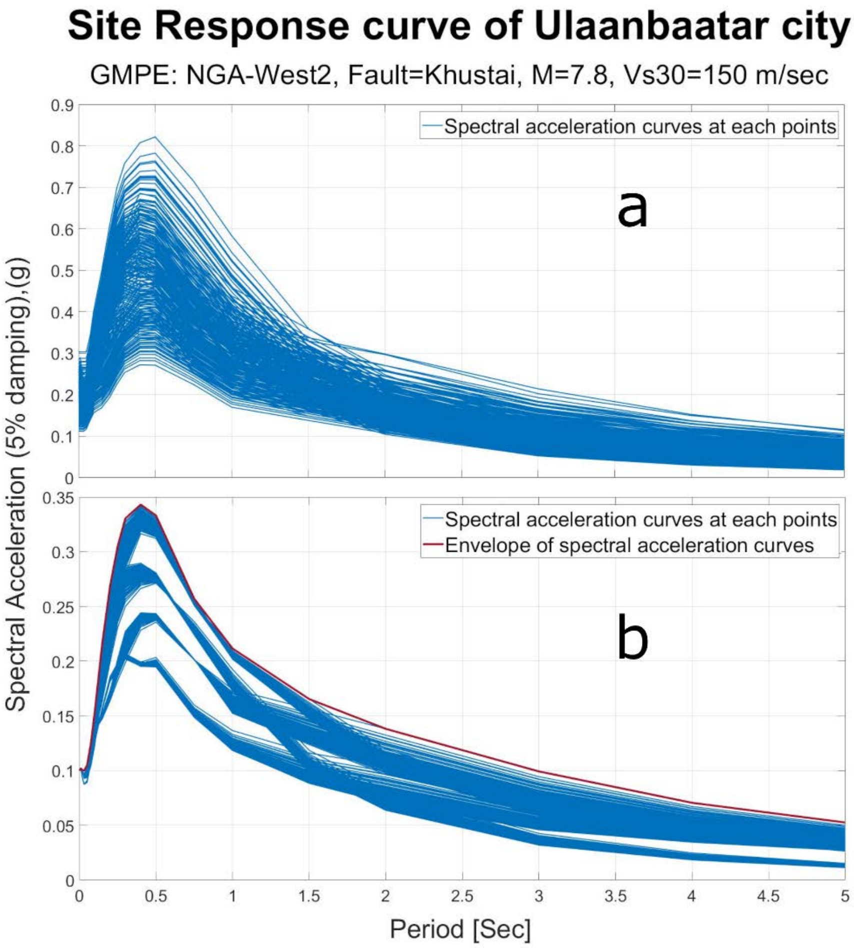

Figure 3. The response spectra of the Khustai fault when Vs30=150 m/s.
a) the calculated response spectra at each point, b) the normalized response spectra. Blue curves – calculated spectral acceleration at the grid points, Red curve – upper peak envelope curve

Furthermore, we took the upper peak envelope values from each normalized response spectra of the individual faults such as Khustai, Emeelt and Gunj, and then added and averaged them mathematically corresponding to the same Vs30. Figure 4 shows the averaged upper peak envelopes classified by Vs30.

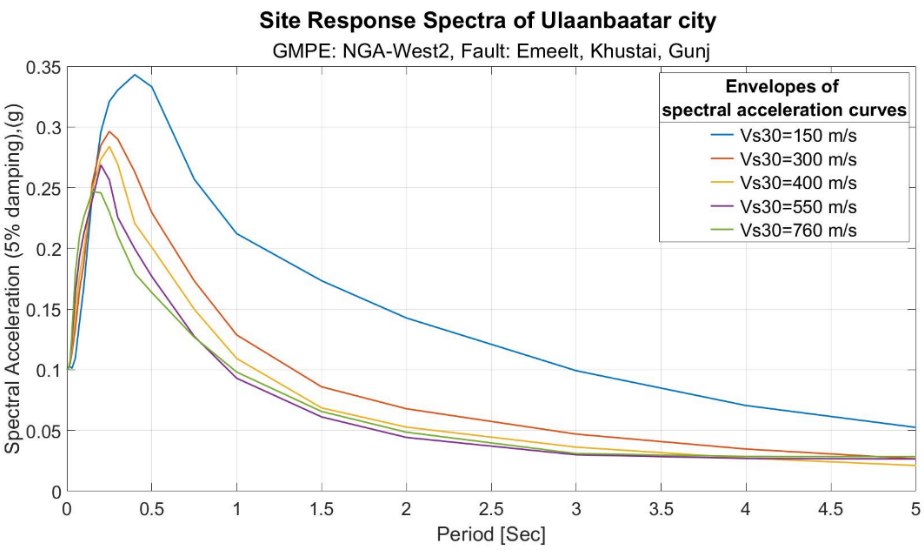

Figure 4. The normalized response spectra of all upper peak envelopes with various Vs30

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PSHA calculation process

The seismic sources were determined as 2 distinct parts, seismotectonic zones, and individual sources. The Institute of Astronomy and Geophysics (IAG) provides seismotectonic zones or models based on Mongolia's seismicity data and tectonic settings. For the active faults, the magnitude is determined by historic earthquakes, paleo-seismological research, and the magnitude-area scaling relationship of Wells & Coppersmith [12]. We assumed the earthquake in a buffer zone has the same probability to occur in any part of the buffer zone. The buffer zone width was defined as at least 5 km based on the fault length and the seismicity estimated by Gutenberg-Richter law. The calculation was performed in the 475 (10% probability of exceedance in 50 years) and 2475-year return periods (2% probability of exceedance in 50 years) including 19 faults and 4 zones. Besides, the same parameters' values, the GMPEs, the Vs30s, and the periods were used. In the calculation, the faults and the zones were estimated individually, and then the estimated values were added up to obtain a total hazard curve. This process was executed in each period to obtain a uniform hazard response spectra. After that, it was normalized at 0.1 g by its PGA to obtain the maximum values. Figures 5 and 6 show the normalized response spectra of the return periods with the various Vs30, respectively.

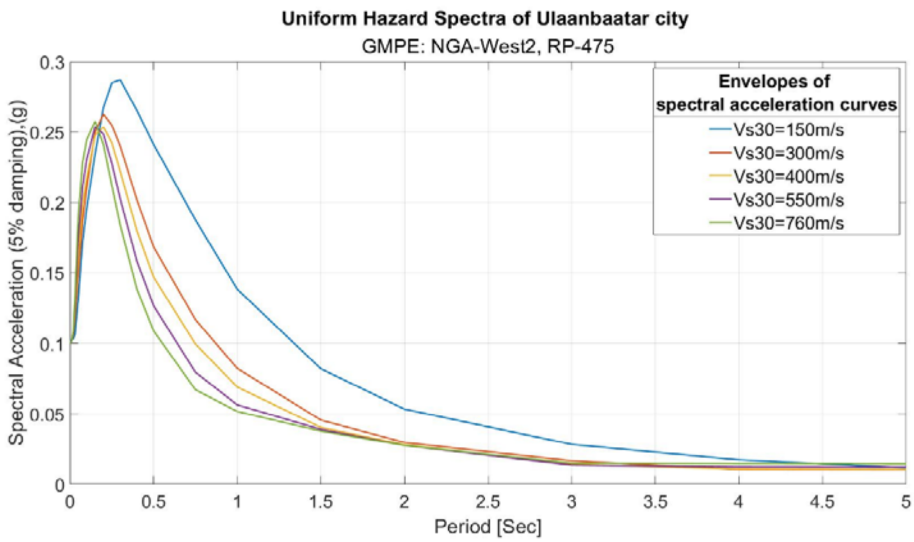

Figure 5. The compiled uniform hazard response spectra in the various Vs30 as calculated in the 475-year return period.

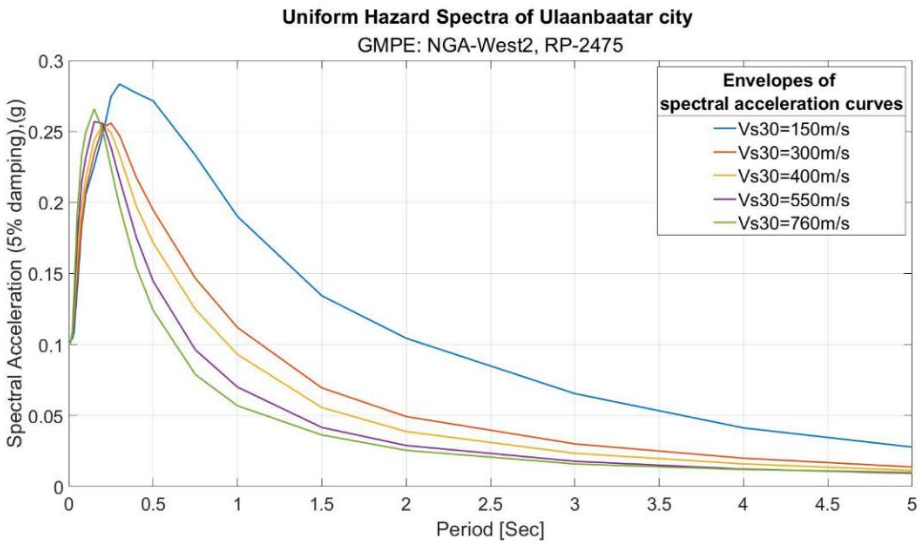

Figure 6. The compiled uniform hazard response spectra in the various Vs30 as calculated in the 2475-year return period.

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RESULTS AND DISCUSSION

We calculated the response spectra on 53 grid points covering the urban areas of Ulaanbaatar city. In the calculation, seismic hazard analysis approaches were used. The soil classes or the Vs30, varying between 150 to 760 m/s, were taken, and the NGA-West2 research project GMPEs were selected for the attenuation law [9]. The results of the response spectra calculation have been normalized by its PGA at 0.1 g, approximately with an intensity of VII on the MSK-64 scale [13], for estimation of the maximum spectral acceleration values. Normalizing at 0.1 g is the minimum intensity requirement for the capital city, because the city is in the intensity of VII, VIII and IX on the MSK-64 scale according to the Mongolian Building Code. Then, the maximum spectral acceleration values were compiled in graphics by different Vs30, respectively. To see the normalized response spectra clearly, we combined the normalized response spectra of the DSHA and PSHA in a single graphic (Figure 7). In comparison between the normalized response spectra in the figure, the highest spectral acceleration values for each Vs30 belong to the DSHA, which are represented as dashed lines. The RP475 and RP2475's spectral acceleration show almost the same values in the short period, but the RP2475 has higher values in the long period than the RP475. The curves corresponding to the 150 m/s of the Vs30 have the maximum spectral acceleration values, whereas the curves corresponding to the 760 m/s have the minimum spectral acceleration values, which indicates that loose soil intensifies the ground motion. For all Vs30, the high spectral acceleration values fall in the short period section between 0.2 and 0.5 seconds, and then the values decrease exponentially until 5 seconds.

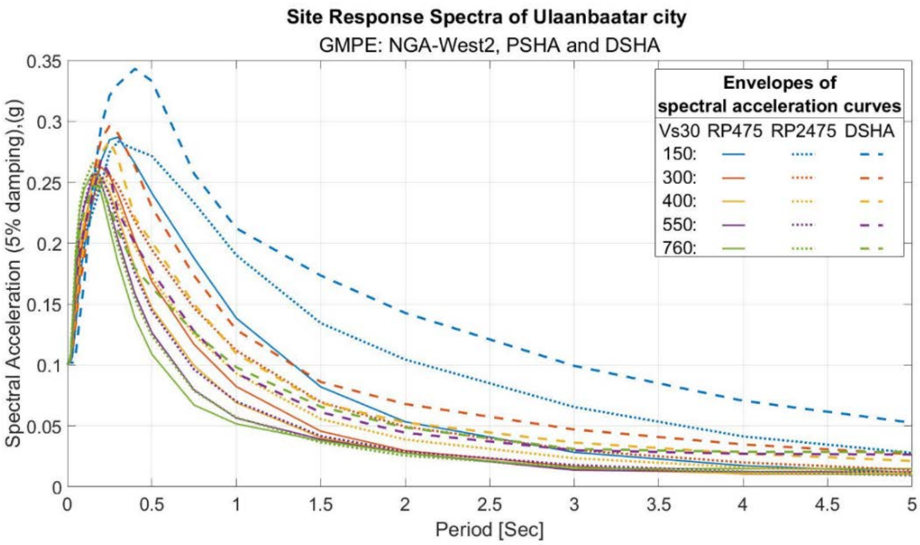

Figure 7. Combination of normalized response spectra of the DSHA and PSHA. The curves of the DSHA are represented as dashed line, the curves of the RP2475 are represented as dotted lines and the RP475 is represented as solid line

These normalized response spectra exhibit the maximum spectral acceleration values, which are the minimum requirement for any construction of structures to be built in Ulaanbaatar. If a study site's Vs30 is known, the spectral acceleration values corresponding to the Vs30 are multiplied by a certain number relating to a PGA determined at the site.

For instance, multiplying the normalized response spectra by two to obtain the response spectra of the intensity of VIII, if the site is in a zone with the intensity of VIII on the MSK-64 scale, or multiplying by four to obtain the response spectra of the intensity of IX, if the site is in the intensity of IX and so on and so forth.

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CONCLUSIONS

This research study aims to develop the response spectra for any construction constructed in the area of Ulaanbaatar, a capital city of Mongolia. In the calculation, we gridded the city with points and calculated the response spectra for different soil classes. Then, we normalized the results at 0.1 g, approximately with the intensity of VII on the MSK-64 scale, to fulfill the minimum intensity requirement of the constructions. In this study, we recommended different response spectra correlating five distinct soil classes or Vs30 of the city area for any structures to withstand strong earthquakes. Civil engineers can directly apply these general response spectra for construction. However, should they require a much more specific study at the construction site, an additional study of the seismic hazard analysis would be required.

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