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Macro earthquake hazard map for liquefaction potential using big data of site investigation

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ABSTRACT: The Korean government recently has been focusing on minimizing natural disaster damages including earthquake damage under the slogan 'Safe Korea'. Part of this effort is establishment of GIS system to prevent earthquake hazards such as liquefaction. In takes a study on application of various soil investigation data to find out the risk of liquefaction caused by an earthquake. This study made the liquefaction hazard map by developing an Excel spreadsheet based on simplified method for liquefaction potential using the site amplification coefficient of metropolitan area with high population density. For this, 14,040 borehole in-situ data from metropolitan area were collected. The Excel spreadsheet that utilizes this simplified liquefaction evaluation takes significantly less time than the site response analysis was based on seismic design criteria of Korea. It will also be a big help in creating a liquefaction hazard map for a wide area, where the risk has to be evaluated using a lot of site investigation data.

1 INTRODUCTION

Korea does not experience earthquakes often and has no record of big earthquake damages. Thus, compared to countries such as Japan, New Zealand, and the United States where earthquakes occur frequently, Korea is not considered a region of high seismic hazard – it is rather categorized as a moderate seismicity region like Europe. In 1999, the Technical Committee (TC4)Earthquake Geotechnical Engineering under the auspices of The International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) has issued a revised manual on liquefaction hazard map with the Japanese Geotechnical Society. This manual categorizes mapping method for liquefaction hazard into 3 stages. For countries like Korea who have not enough data on earthquake damage, stage 3 method is recommended – using estimation, rather than stage 1 or 2 that uses experiences (JGS, 1999). In general, when using the stage 3 method, it is common to use an index from the simplified method for liquefaction potential. Iwasaki et al. (1978) suggested the standard index, liquefaction potential index (LPI), and Todorovska and Trifunac (1999) suggested a liquefaction hazard map based on experiment and the concept of energy. Also, in 1998, Monge et al. (1998) categorized standards into qualitative standards such as size distribution and quantitative standards such as shear stress ratio, proposing a method of evaluating in a 3-dimensional space. In Korea, Kwak (2001) has created a liquefaction hazard micro zonation around port facilities in coastal areas based on the LPI suggested by Iwasaki (1978). Ku (2010) used the site amplification coefficient of Eurocode8 (ECS, 1998) to evaluate the liquefaction risk. Domestic studies on site amplification coefficient used in liquefaction hazard map include the study of Sun (2005, 2010) and Park et al. (2012) who have suggested a reasonable site amplification coefficient for Korea and a site classification system that considers regional characteristics of Korea. In addition, Kwak (2013) has recommended a reliable site amplification coefficient, comparing the liquefaction hazard map where site amplification coefficient by reliability has been applied. The liquefaction hazard map created based on the result of site response analysis. This study utilized site inspection data of 14,040 sites in metropolitan area used the site amplification coefficient by soil type specified in the Korean seismic design criteria based on the site amplification coefficient of Euro-code, not the site response analysis suggested by the Korean seismic design criteria. The study aims to develop a spreadsheet for making liquefaction hazard maps to shorten the time taken to create a liquefaction hazard map for a wide area or the entire country.

2 LIQUEFACTION HAZARD MAP DRAWING WITH SIMPLIFIED METHOD FOR LIQUEFACTION POTENTIAL

Fig. 1 uses the stage 3 prediction method to perform liquefaction preliminary evaluation and simplified evaluation based on site investigation data. Using safety factor for liquefaction potential each boring depths, the liquefaction potential indexes, LPIs are calculated to be used on the map. And this method is appropriate for drawing a liquefaction hazard map for wide area used. The used site investigation data are data on 14,040 boreholes in metropolitan area obtained from Integrated DB Center of National Geotechnical Information of Korea Institute of Construction Technology. In the DB data, coordinates and standard penetration test results were used (http://www.geoinfo.or.kr).

2.1 *Macro liquefaction hazard map based on LPI*

In a moderate seismicity region like Korea, it is considered rational to create a liquefaction hazard map for a wide area as follows. In particular, for domestic

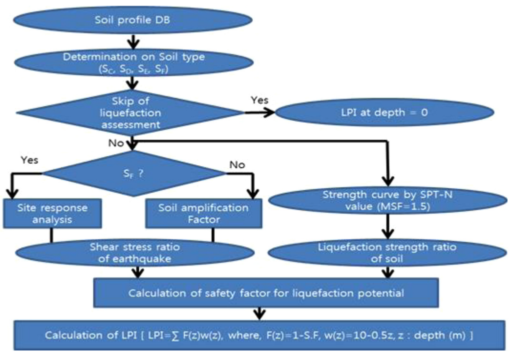

Figure 1. Analytical procedure for Korean liquefaction hazard map.

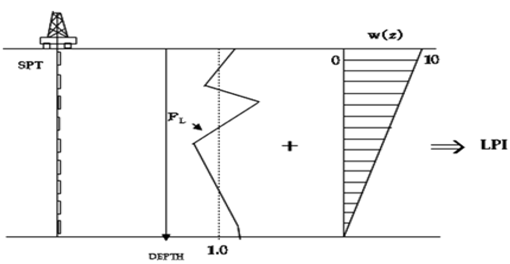

Figure 2. Calculation procedure of LPI at a site.

liquefaction evaluation, the standard penetration test results and the assessment method for simplified liquefaction potential are commonly used. Considering this, it would be most appropriate to use the liquefaction potential index (LPI) calculated based on the figure below as the index. Also, it is general to use SPT-N value (Standard Penetration Test Value) for liquefaction evaluation.

3 APPLICATION OF LIQUEFACTION POTENTIAL EVALUATION USING SPREADSHEET

There are a lot of geotechnical information data is stored for 14,040 boreholes in metropolitan area in Integrated DB Center for National Geotechnical Information. Thus, for this study, only necessary data were extracted. The data used for this study included holecode,depth, N-value, and hole location. However, while analyzing the data, the underground water level, and unit weight were found missing, thus they were excluded. As a result, the unit weight was set as 1.8γt for all sites, and the underground water level as 100%. Table 1 shows part of input data that needs to be entered in the spreadsheet

3.1 *Site classification*

To calculate the LPI as the method mentioned in Fig. 1, the soil has to be classified first. Table 2 shows the Korean seismic design criteria and the site amplification coefficient by site type specified in Eurocode. In Table 1, the site classification is done using the information on boreholes. The site classification is decided by calculating the average value of shear wave velocity up to ground level of 30m. This study classified the sites by amplification coefficient by site type specified in the Korean seismic design criteria.

For shear wave velocity, the equation of Seon et al. (2005), which is modified to suit the situation in Korea, was used.

$$V_s = 65.64 N_{60}^{0.407} \quad (1)$$

Here, N_{60} is the SPT-N value when the energy efficiency is 60%.

Based on Table 2 and the data entered as Table 1 the spreadsheet automatically calculates site classification

Table 1. Input Site Investigation Data

N.O	HOLE_CODE	지반종류	γ_t Unit weight	Total stress	Underground Water Level	DEPTH_SPT	SPT_N	Driving Counts	hole_original_tm_x X-Coordinate	hole_original_tm_Y Y-Coordinate
1	B0001BH001		1.8	2.7	0	1.50	15	30	200708.34	422829.16
2	B0001BH001		1.8	5.4	0	3.00	29	30	200708.34	422829.16
3	B0001BH001		1.8	8.1	0	4.50	50	14	200708.34	422829.16
4	B0001BH001		1.8	10.8	0	6.00	50	10	200708.34	422829.16
5	B0001BH001		1.8	13.5	0	7.50	50	8	200708.34	422829.16
6	B0001BH001		1.8	16.2	0	9.00	50	6	200708.34	422829.16
7	B0001BH001		1.8	18.9	0	10.50	50	3	200708.34	422829.16
8	B0001BH001		1.8	Omission	0	30.00	51	4	200708.34	422829.16
9	B0001BH002		1.8	2.7	0	1.50	4	30	200721.09	422867.29
10	B0001BH002		1.8	5.4	0	3.00	50	24	200721.09	422867.29
11	B0001BH002		1.8	8.1	0	4.50	50	18	200721.09	422867.29
12	B0001BH002		1.8	10.8	0	6.00	50	14	200721.09	422867.29
13	B0001BH002		1.8	13.5	0	7.50	50	6	200721.09	422867.29
14	B0001BH002		1.8	16.2	0	9.00	50	7	200721.09	422867.29
15	B0001BH002		1.8	18.9	0	10.50	50	5	200721.09	422867.29
16	B0001BH002		1.8	21.6	0	12.00	50	5	200721.09	422867.29

using the stratigraphic thickness and the shear wave velocity obtained through the equation just as shown in Table 3.

3.2 *Input data of simplified method for liquefaction potential*

Once the soil classification has been completed, the results go to the result sheet, and the existing geotechnical data changes as the macro automatically changes the location of site.

Here, the entries include 'site name', 'Amax/g', 'using equipment', and 'standard sampler'. Factors such as 'thickness', Vs, site classification, total stress, and overburden pressure are automatically calculated. Table 4 shows the sample of input data and the results.

Table 2. Amplification coefficient according to soil type (Korea & Euro-Code).

Soil Type	Soil Classification	Shear Wave Velocity Vs (m/s)	site amplification factor Korea	Euro cod
SA	Hard Rock	>1500	–	–
SB	Rock	>760	1.00	1.00
SC	Very Dense Soil and Soft Rock	>360	1.18	1.14
SD	Stiff Soil	>180	1.45	1.45
SE	Soft Soil	≤180	2.00	2.00
SF		Site Specific Analysis		

3.3 *Shear stress ratio of earthquake*

There is no specific regulation about modulus of foundation, but as in Fig. 3, the maximum value of short period on the standard spectrum represents modulus of foundation.

Equation (2) calculates shear stress ratio using modulus of foundation.

$$\frac{(\tau_d)_{max}}{\sigma_v} = 0.65 \times \frac{a_{bedrock} \times S}{g} \times \frac{\sigma_v}{\sigma'_v} \quad (2)$$

S = Site amplification Coefficient.

Table 5 shows the sample of auto-calculated shear stress ratio.

3.4 *Liquefaction strength ratio of soil & calculation of LPI*

Resistance stress ratio calculation is done through Here, the magnitude scaling factor is 1.5 and the

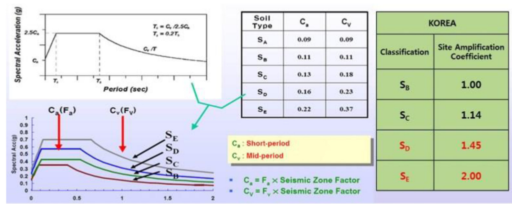

Figure 3. Response spectrums of Korean Standard Coefficient.

Table 3. Sample of the Site Classification.

Thickness	Vs Acceleration	Vs*Thick	Process	Vs(avg)	Site Classification	Hole Counts	hole_original_tm_X X-Coordinate	hole_original_tm_Y Y-Coordinate
1.5	197.623	296.435	1					
1.5	258.443	387.664	2					
1.5	360.000	540.000	3					
1.5	360.000	540.000	4					
1.5	360.000	540.000	5					
1.5	360.000	540.000	6					
1.5	360.000	540.000	7					
19.5	760.000	14820.000	8	606.803	SC	1	200708.34	422829.16
1.5	115.400	173.100	1					
1.5	360.000	540.000	2					
1.5	360.000	540.000	3					
1.5	360.000	540.000	4					
1.5	360.000	540.000	5					
1.5	360.000	540.000	6					

Table 4. Input Data Sample.

Safety Factor For Liquefaction										
Hole number	1		Underground WL	0.0		Boring N.O			Altitude	
Location			x-coordinate	200708.340		y-coordinate	422829.160			
Closing day				amax/g	0.260	Inspector			Operator	
Hammer	Safety Hamm	Diameter	150	Length of rod	4.0	Sampler	Split spoon sampler			
Hole code	Depth	N-Value	Driving Counts	Thickness	Vs	Vs*Thick	Vs(avg)	Site Classification	Total Stress	Effective Stress
B0001BH001	1.5	15	30	1.5	197.623	296.435			2.70	1.20
B0001BH001	3.0	29	30	1.5	258.443	387.664			5.40	2.40
B0001BH001	4.5	50	14	1.5	360.000	540.000			8.10	3.60
B0001BH001	6.0	50	10	1.5	360.000	540.000			10.80	4.80
B0001BH001	7.5	50	8	1.5	360.000	540.000			13.50	6.00
B0001BH001	9.0	50	6	1.5	360.000	540.000			16.20	7.20
B0001BH001	10.5	50	3	1.5	360.000	540.000			18.90	8.40
B0001BH001	30.0	51	4	19.5	760.000	14820.000	606.803	SC	Omission	Omission

Table 5. Shear Stress ratio of the earthquake.

Hole code	Depth	Site Classification	S	amax/g	A/g	Total Stress	Effective Stress	Shear Stress Ratio
B0001BH001	1.5	SC	1.18	0.260	0.3068	2.70	1.20	0.449
B0001BH001	3	SC	1.18	0.260	0.3068	5.40	2.40	0.449
B0001BH001	4.5	SC	1.18	0.260	0.3068	8.10	3.60	0.449
B0001BH001	6	SC	1.18	0.260	0.3068	10.80	4.80	0.449
B0001BH001	7.5	SC	1.18	0.260	0.3068	13.50	6.00	0.449
B0001BH001	9	SC	1.18	0.260	0.3068	16.20	7.20	0.449
B0001BH001	10.5	SC	1.18	0.260	0.3068	18.90	8.40	0.449
B0001BH001	30	SC	1.18	0.260	0.3068	Omission	Omission	Omission

Table 6. Liquefaction Strength ratio of Soil.

Hole code	Nm	PA	Effective Stress	Z	CN	CE	CB	CR	CS	N160	Shear Resistance Ratio
B0001BH001	15	10	1.20	1.5	0.750	0.95	1.05	0.85	1	9.539	0.109
B0001BH001	29	10	2.40	3.0	0.750	0.95	1.05	0.85	1	18.441	Omission
B0001BH001	50	10	3.60	4.5	1.667	0.95	1.05	0.85	1	70.656	Omission
B0001BH001	50	10	4.80	6.0	1.443	0.95	1.05	0.85	1	61.190	Omission
B0001BH001	50	10	6.00	7.5	1.291	0.95	1.05	0.85	1	54.730	Omission
B0001BH001	50	10	7.20	9.0	1.179	0.95	1.05	0.85	1	49.962	Omission
B0001BH001	50	10	8.40	10.5	1.091	0.95	1.05	0.85	1	46.255	Omission
B0001BH001	51	10	Omission	30.0	0.000	0.95	1.05	0.85	1	0.000	0.049

Table 7. Calculation of LPI.

SSR	SRR	MSF	Safety Factor(F)	Fz	Wz	Fz*Wz	Procces	LPI
0.449	0.109	0.164	0.365	0.635	9.250	5.877	5.877	5.877
0.449	Omission	Omission	Omission	Omission	8.500	Omission	Omission	
0.449	Omission	Omission	Omission	Omission	7.750	Omission	Omission	
0.449	Omission	Omission	Omission	Omission	7.000	Omission	Omission	
0.449	Omission	Omission	Omission	Omission	6.250	Omission	Omission	
0.449	Omission	Omission	Omission	Omission	5.500	Omission	Omission	
0.449	Omission	Omission	Omission	Omission	4.750	Omission	Omission	
Omission	0.049	0.074	Omission	Omission	-5.000	Omission	Omission	

Equation (3) is used to calculate the resistance stress ratio.

$$\left(\frac{\tau_t}{\sigma'_0}\right)_{\tau_0} = \frac{1}{34-(N_1)_{60}} + \frac{(N_1)_{60}}{135} + \frac{50}{[10(N_1)_{60}+45]^2} - \frac{1}{200} \quad (3)$$

The safety ratio is obtained by comparing the shear stress ratio and the resistance stress ratio. Multiply the value by 1.5, the MSF for the design earthquake magnitude of 6.5. This gives the final LPI. (4) is the equation that represents this process.

$$SF_{Final(M=6.5)} = \left(\left(\frac{\tau_t}{\sigma'_v}\right)_{7.5} / \frac{(\tau_d)_{max}}{\sigma'_v}\right) MSF \quad (4)$$

$\left(\frac{\tau_t}{\sigma'_v}\right)_{7.5}$ = Shear stress ratio for a magnitude-7.5

$\frac{(\tau_d)_{max}}{\sigma'_v}$=Shear stress ratio of earthquake

MSF = modification factor by earthquake size LPI is calculated as the equation (5).

$$\mathrm{LPI} = \sum \mathrm{F}(z)\omega(z) \quad (5)$$

$$\mathrm{F}(z) = 1 - SF$$

$$\omega(z) = 10 - 0.5z$$

Table 6 and Table 7 is the sample of resistance stress ratio and LPI calculated using the spreadsheet.

3.5 *Macro earthquake hazard map of the Korea metropolitan area*

Fig. 4, show the earthquake hazard map of the Korea metropolitan area sample using simplified method of liquefaction evaluation.

It based on the Arch GIS program using LPI.

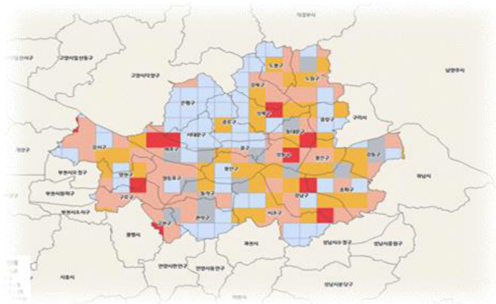

Figure 4. Earthquake hazard map of the Korea metropolitan area sample using Arch GIS (a = 1.0 g).

4 CONCLUSION & LIMITATIONS

(1) Currently, the Integrated DB Center of National Geographical Information has information for nearly 150,000 boreholes. To create a national liquefaction hazard map based on this information using site response analysis, it takes 50,000 hours just to analyze. In this study, the new analytical procedure for macro hazard map for liquefaction potential is proposed. Also, the spreadsheet was developed based on a simple algorithm for liquefaction potential evaluation that fits the situation in Korea. And it is found reliable to use the suggested site amplification coefficient for drawing a liquefaction hazard map. Thus, when creating a liquefaction hazard map for a wide area in a moderate seismicity region like Korea, this method would be effective in saving a lot of time.

(2) More sophisticated analysis is needed in the future based on comparison of soil classification following soil analysis by depth or an LPI analysis based on SPT-N value.

(3) When paired with a study that enhances the reliability of the data at National Geotechnical information DB Center (underground water level, unit weight, sampler), or if the soil information DB is updated, this study will serve as a good basic data for liquefaction hazard map for Korea.

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