Liquefaction hazard map in Korean disaster monitoring system

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ABSTRACT

The Korean government recently has been focusing to minimize natural disaster damages including earthquake damage under the slogan ‘Safe Korea’. A part of this effort is to set up Korean earthquake defense GIS system including several earthquake hazards such as liquefaction and land sliding. The purpose of this study is to make micro and macro liquefaction hazard maps in Korea based on liquefaction potential index calculated by simplified liquefaction potential assessment. The difference between micro and macro maps is consideration on the seismic amplification in soils. In case of micro liquefaction hazard map, it has been used to perform site response analysis. In other case of macro liquefaction hazard map for the whole country, soil amplification factor can replace the site response analysis because we must perform so many site response analyses to calculate LPIs. Accordingly, we verified the application of the soil amplification factor. At that time, S city was considered in its feasibility by the target. In this study, we developed a specific program to calculate LPI automatically. Finally, macro liquefaction hazard maps under various accelerations for the whole country could be drawn.

Keywords: micro and macro liquefaction hazard map, site response analysis, soil amplification factor, LPI.

1 INTRODUCTION

After the Hyogoken Nanbu earthquake (Kobe, 1995), a new academic society, which was EESK and a research center, which was KEERC were established in 1997. And after, extensive earthquake engineering researches in Korea were performed to analyze the seismic mechanisms and to establish seismic standards and guidelines. For assessing liquefaction potential for moderate earthquake (M=6.5), the modified Seed and Idriss method was proposed in 1999. (Kim et al, 2000). Based on this method, the first design guideline for liquefaction potential assessment was introduced in port and harbor seismic design guideline. Also, using this method, the several liquefaction hazard maps in port and harbor areas were drawn.

Recently, most countries have established and used a national earthquake hazard map for preparing a countermeasure. In 1999, the Technical Committee (TC4) Earthquake Geotechnical Engineering of ISSMGE has issued a revised manual on liquefaction hazard map with the Japanese Geotechnical Society. For countries like Korea who have not enough data on earthquake damage, stage 3 method is recommended. 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).

In Korea, Kwak (2001) has created a liquefaction hazard micro zonation around port facilities in coastal areas based on the LPIs. Ku (2010) used the site amplification coefficient of Eurocode8 (ECS, 1998) to evaluate the liquefaction risk. Kwak, Ku, and Choi (2015) recommended a reliable site amplification coefficient for mapping for liquefaction potential index. This study aims to create a mapping method for liquefaction hazards in macro areas effectively. As a result, various maps for the entire country will be uploaded in Korean Earthquake Defense System.

2 EARTHQUAKE PREVENTION IN KOREA

In 2004, a new Korean government agency was set up to defense and prevent fire and natural hazards. Firstly, the national facilities were classified in detail and a new Earthquake disaster prevention law was enacted in 2008. And after, Korean earthquake defense system in Fig. 1 has been developed. From 2012 to 2015, geotechnical earthquake researches to map liquefaction hazard and land sliding for the entire countries under earthquake loads was carried out. At now, other system upgrades are carrying out.
3 LIQUEFACTION ASSESSMENT

In case of Korea, it is more rational to create an index for mapping liquefaction hazards for a wide area as follows. Particularly, for domestic liquefaction evaluation, the standard penetration test results and the assessment method for simplified liquefaction potential are commonly used.

3.1 Liquefaction assessment for micro mapping

In the seismic design for new construction, it is known that assessments of liquefaction potential must be performed. In Korea, a simplified method as shown below has been used generally. The characteristics of this method is to include the performance of the site response analysis. An equation to calculate shear stress ratio of earthquake is shown below.

\[
\frac{\tau_f}{\sigma_v} = 0.65 \times \frac{a_{\text{bedrock}}}{g} \times S \times \frac{\sigma_v}{\sigma_v}
\]  

(1)

In the equation, \(a_{\text{bedrock}}\) at a depth is an amplification acceleration obtained from site response analysis using Pro-Shake program. Also, effective stress and total stress can be calculated with soil’s dry or saturated unit weight. In the site response analysis, shear wave velocities in soils and several dynamic properties of soils are necessary as input parameters.

In the determination on liquefaction resistance strength ratio of soil, a result figure proposed by Seed and Idriss was used and its equation for calculation is as follows.

\[
\frac{\tau_f}{\sigma_v} = \frac{1}{34 - (N_{\text{lqd}})} + \frac{(N_{\text{lqd}})}{135} + \frac{50}{[10(N_{\text{lqd}}) + 45]^2} - \frac{1}{200}
\]  

(2)

3.2 Liquefaction assessment for macro mapping

To draw macro liquefaction hazard map, a lot of LPIs data are necessary to point on the map. If we choose the above the conventional method including the site response analysis, the mapping time is needed too long. In this study, we introduced Euro-code method to reduce time greatly. The characteristic of this method is to replace the site response analysis with the soil amplification factor. As a result, Eq(1) for shear stress ratio is changed as follows.

\[
\frac{\tau_f}{\sigma_v} = 0.65 \times \frac{a_{\text{bedrock}}}{g} \times S \times \frac{\sigma_v}{\sigma_v}
\]  

(3)

In the equation, \(a_{\text{bedrock}}\) is a design earthquake acceleration of Korean standard and \(S\) is soil amplification factor according to the soil type as shown below.

Table 1. Amplification coefficient according to soil type.

| Soil Type | Site Classification                      | Vs (m/s) | soil amplification factor |
|-----------|------------------------------------------|----------|--------------------------|
| S_A       | Hard Rock                                | >1500    | -                        |
| S_B       | Rock                                     | >760     | 1.00                     |
| S_C       | Very Dense Soil and Soft Rock            | >360     | 1.18                     |
| S_D       | Stiff Soil                               | >180     | 1.45                     |
| S_E       | Soft Soil                                | ≤180     | 2.00                     |
| S_F       | Site Specific Analysis                   |          |                          |

4 LPI MAPPING METHOD

Based on the above micro and macro methods for liquefaction evaluation, we proposed an analytical procedure for Korean liquefaction hazard map as shown in Fig. 3. The Fig.3 shows mainly macro mapping method according to the soil classification.

In soil classification, shear wave velocity is a main criteria to determine the soil type in Table 1. For example, most sites in Korea were classified with S_C and S_D.
4.1 Site classification and shear stress ratio

There are a lot of geotechnical information data stored in Integrated DB Center for National Geotechnical Information. Thus, only necessary data were extracted. For this study, the data includes borehole code, depth, N-value, and borehole 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 2 shows part of input data that needs to be entered in the spreadsheet.

Table 2. Input site investigation data.

| Borehole Code | Depth (m) | N-value | Borehole Location |
|---------------|-----------|---------|------------------|
| 10000101      | 10        | 65      | South             |
| 10000202      | 20        | 75      | North             |
| 10000303      | 30        | 80      | East              |
| 10000404      | 40        | 85      | West              |

Based on table 1 and the data entered as Table 2, the spreadsheet calculates site classification using the stratigraphic thickness and the shear wave velocity obtained through the equation just as shown in table 3.

Table 3. Sample of the site classification and soil type.

| Borehole Code | Depth (m) | N-value | Borehole Location |
|---------------|-----------|---------|------------------|
| 10000101      | 10        | 65      | South             |
| 10000202      | 20        | 75      | North             |
| 10000303      | 30        | 80      | East              |
| 10000404      | 40        | 85      | West              |

Once the soil type has been determined, 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. Following figure 4 shows the sample of input data and the results.

Table 4. Input data sample.

| Site Name | Amax/g | Using Equipment | Standard Sampler |
|-----------|--------|-----------------|-----------------|
| Site 1    | 4      | Hammer          | Core             |
| Site 2    | 5      | Excavator       | Standard sampler |

4.2 Liquefaction resistance strength ratio and LPI

Liquefaction resistance strength ratios at every depths for liquefaction evaluation are calculated by Eq(2). The calculated values are all at magnitude 7.5. Therefore, magnitude scaling factor (MSF=1.5) must be multiplied to calculate the final factor of safety. Finally, using the following equation, we add all factors of safety at a site.

\[
SF_{\text{final}} = \left( \frac{\tau_v}{\sigma_v\text{nat}} \right)_{7.5} \times MSF
\]  

Using above equations, we can calculate a LPI at a site and we can arrange all data with the developed Macro excel sheet as shown in Table 5 and 6.

Table 5. Calculation of LPI.

| Soil Code | N-value | Borehole Code | Depth (m) | MSF | LPI  |
|-----------|---------|---------------|-----------|-----|------|
| 10000101  | 65      | 10000101      | 10        | 1.5 | 3.5  |
| 10000202  | 75      | 10000202      | 20        | 1.2 | 4.6  |
| 10000303  | 80      | 10000303      | 30        | 1.0 | 5.0  |
| 10000404  | 85      | 10000404      | 40        | 0.8 | 5.7  |

Table 6. Result of LPIs.

| Soil Code | N-value | Borehole Code | Depth (m) | MSF | LPI  |
|-----------|---------|---------------|-----------|-----|------|
| 10000101  | 65      | 10000101      | 10        | 1.5 | 3.5  |
| 10000202  | 75      | 10000202      | 20        | 1.2 | 4.6  |
| 10000303  | 80      | 10000303      | 30        | 1.0 | 5.0  |
| 10000404  | 85      | 10000404      | 40        | 0.8 | 5.7  |
5 MACRO LIQUEFACTIN HAZARD MAP

To macro liquefaction hazard map in the entire country, we collected over 100,000 borehole data as shown in Fig. 4.

Fig. 4. Geographical position of borehole data in this study.

Finally, we calculated liquefaction potential indexes about over 100,000 borehole data. Also, we drew 9 liquefaction hazard maps against desirable earthquakes with maximum accelerations ranged from 0.06g to 0.38g. An example is as follows.

Fig. 5. Liquefaction hazard map in Korea (acc=0.22g).

6 CONCLUSIONS

In this research, we made up the mapping method for liquefaction hazard. The final goal is to develop a simplified method to calculate liquefaction index at the whole positions in Korea. Also, the final results are Korean liquefaction hazard maps. As a result, we made the mapping method to calculate liquefaction hazard indexes by developing an Excel spread-sheet including soil type classification, the simplified liquefaction assessment, and calculation liquefaction potential index. From now, at any time, we can draw Korean liquefaction hazard map under the desirable accelerations in as short a time.

ACKNOWLEDGEMENTS

This research was a part of the project titled 'Development of performance-based seismic design technologies for advancement in design codes for port structures', funded by the Ministry of Oceans and Fisheries, Korea.

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