Strategy for Improving Precision of Soil Liquefaction Potential

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Abstract. Ilan area is located between the east and the northeastern earthquake regions of Taiwan, which the earthquake occurs quite frequent. Langyang Plain is alluvial plain coupling with fine particles of loose granular soil and high groundwater level, the possibility of soil liquefaction in Ilan area is very high once the earthquake occurs. Therefore, soil liquefaction potential needs to be carefully investigated. In Ilan area the primary soil liquefaction areas was formed with precision is 1/25000 scale. February 6, 2016 Meinung earthquake in the southern Taiwan area brought a lot of liquefaction damages. Therefore, soil liquefaction once again gains people attention. The precision of soil liquefaction potential map is requested to improve to 1/2500 scale. In order to improve the precision of geospatial information effectively, the geological drilling density of 4 holes/km^2 are demanded. The drilling method employs the SPT method in general. The soil physical test is taken every 1.5 m or the soil layer change. This study adds about 213 boreholes of geological drilling data in the densely populated areas, low floor houses, old buildings and complex geological conditions of Ilan area. It is believed that we can use the drilling data to know the soil liquefaction potential more accurately. Finally, this study will use SPT-N HBF analysis method to calculate soil liquefaction potential value. The method is a simple evaluation technique to determine the occurrence of soil liquefaction in Taiwan with good accuracy and reliability. The proposed analysis in this study can be used to accomplish more precise soil liquefaction potential with different size earthquake occurs in the region.

Keywords: Soil liquefaction · Drilling · Borehole · Standard penetration test HBF analysis method

1 Introduction

Taiwan situates in Circum-Pacific Seismic Belt, where earthquakes occur frequently. How to protect against and reduce disasters is an important strategy of government officials. On 6 February 2016, a strong earthquake of Richter local magnitude 6.6 occurred in the Tainan area of Taiwan, resulting in many serious disasters. Soil liquefaction is then becomes one of the government's concern. Consequently, soil liquefaction issue is taken seriously in order to achieve safety, prevention, early warning, etc. The soil liquefaction potential map must be improved for the accuracy at this critical moment. Especially, in densely populated areas, low floor houses, old buildings, and complex geological condition areas, the destruction comes after soil

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liquefaction severely. Geologically, Ilan area is deposited mostly with fine particles contenting high content of weak soil, coupling with groundwater level very close to the surface. Once the earthquake occurs, the possibility of soil liquefaction is quite high.

Therefore, we need to add drilling holes in order to draw a more representative soil liquefaction potential map of intermediate level. As a result, the Ilan County Government can be more prepared for disaster prevention and early warning operations. Accordingly, people in Ilan area can get a safe and comfortable living condition. It is reason that we are obligatory to explore the soil liquefaction related problems in Ilan area.

2 Story of Soil Liquefaction

Soil liquefaction is the process of changing the soil from solid to liquid just as the name. For the period of liquefaction, the soil behavior is similar to the liquid. Due to the liquid cannot resist shear force and maintain its own shape, there is mobility and buoyancy, thus the structure will be subsidence, tilt or damage. The reason of resulting in this phenomenon is mainly caused by vibration, which may come from construction or earthquake, while most of the soil liquefaction is caused by the earthquake.

The study of liquefaction of granular soils using the concept of critical void ratio was first introduced by Casagrande in 1938. When a natural deposit of saturated sand that has a void greater than the critical void ratio is subjected to a sudden shearing stress (due to an earthquake, for example), the sand will undergo a decrease in volume and lead to the condition of soil liquefaction.

After that, many researchers kept on working in this topic. For example, Japanese scientists Mogami and Kubo (1953) suggested that the soil will be deformed as "liquefied" when cohesionless soil is disturbed. Following the 2 earthquakes of Alaska in US and Niigata in Japan in 1964, an intensive research has been carried out.

Seed (1979) mentioned that high pore water pressure would reduce the effective confining pressure of soil. At this point in time, the soil residual shear strength becomes lower and the soil mass is likely to produce deformation. As soon as the earthquakes occur, it is possible that the soil cannot afford the original stress all of a sudden. Consequently, the soil pore water increases and shear stress intensity becomes smaller. This condition provides the opportunity to produce soil liquefaction, when the excess pore water pressure continues to rise to the original effective stress (when $\sigma = \mu$). That is to say, when the earthquake induces the local average shear stress is greater than the local soil shear strength for resisting liquefaction, the soil is liquefied.

3 Liquefaction Influence Factors

The terrain of Langyang Plain is deposited by the soil particles carried down from the Langyang River, so that the soil is quite loose and soft, coupling with the conditions of groundwater close to the surface and located in the earthquake zone. Since earthquakes occur frequently, the seismic disaster caused by earthquake should not be ignored at all. Above mentioned conditions make the soil liquefaction problem needs to be assessed objectively and carefully in Ilan area. The factors of soil liquefaction are divided into three portions here: soil strength, groundwater level, and earthquake scale. These factors can be used to determine the occurrence of soil liquefaction in the region.

3.1 Resistance of Soil

Granular soils can commonly be judged by their relative density or standard penetration test. The soil particles of relatively tight condition are less prone to relative displacement, and their resistance to soil liquefaction is better. The process of soil liquefaction is that the soil particles changing the arrangement between the particles by repeated earthquake movements. Of course, after the moment of liquefaction, it will produce a more stable soil structure than the initial soil particle. Similarly, when the soil particles are stacked more closely with each other, the chance of soil liquefaction resulting in damage will be reduced greatly. Therefore, due to the getting closer relationship between the particles, easily liquefied soil particles can also have a good liquefaction resistance after the liquefaction process.

3.2 Groundwater Level

The effect of water in the soil has always been a matter of concern to civil engineers. Whether it is slope stability, excavation construction, and soil liquefaction, once the soil pores filled with water would make the soil to be in a relatively unstable state. In other words, when the groundwater level is closer to the surface, which means the more soil is saturated. When the earthquakes occur, its safety factor will become lower. On the other way, we know that the weak soil is more close to the surface, the impact to the liquefaction potential becomes more serious. When the soil elevation deep enough, one can make sure that the soil has good liquefaction resistance, thus the impact of liquefaction potential is smaller.

3.3 Earthquake Magnitude

Seismic factors are the most important influencing factors in three portions of soil liquefaction. When the earthquake occurs, it will release the energy from the epicenter to the periphery. These energies will transmit to the surrounding rock or soil through seismic waves. In the process of energies passing the soil, the shear stress inside the underground soil is generated. If the site of the soil liquefaction resistance is poor, it may generate soil liquefaction phenomenon. When the problem of soil liquefaction is discussed, the magnitude can be considered as the energy obtained for the soil. At the same time, the magnitude of the earthquake becomes greater, the shaking on the surface becomes more intense and the duration last longer. It is possible to continuous increase in pore water pressure, which increases the chance of soil liquefaction.

4 Geological Drilling Plan

Based on the geological drilling report, the soil liquefaction situation of the site can then be calculated and the potential map of regional soil liquefaction can be drawn. If the density of drilling holes can be increased, the soil liquefaction potential map will be better for accuracy, and the precise soil liquefaction situation in this area can be reflected.

In view of the February 6, 2016 Meinung earthquake happened in the Tainan area caused serious disaster, the soil liquefaction potential map needs to be refined. Especially in the Ilan region, considering the geological weakness and the groundwater level close to the surface, as well as the most critical part of locating in multiple seismic zones, soil liquefaction situation could be much more sensitive.

4.1 Existing Drilling Data Collection and Comparison

Prior to geological drilling, the first step must be done is to collect high-quality existing drilling hole data, such as from public constructions, large buildings, and other high credibility of the drilling report. The second step to compare them after evaluation in order to screen out the available drilling. Ilan County, for example, the first phase of soil liquefaction map to be reconstructed is Ilan city, Luodong Town, and Wujie Township. This study has collected about 350 borehole data as shown in Fig. 1 for their distribution.

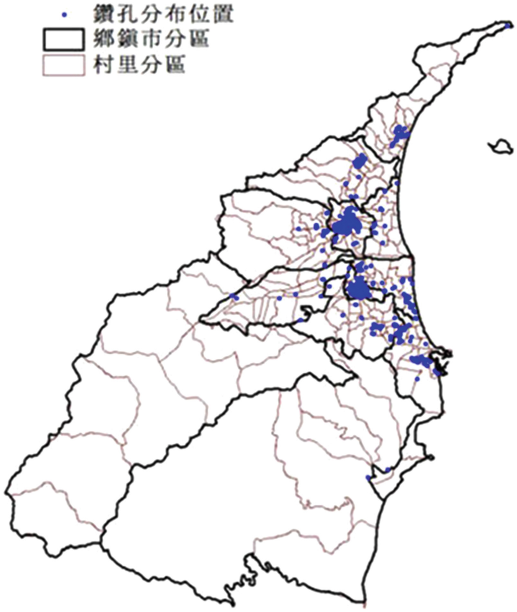

Fig. 1. Existing collected borehole data distribution map.

It can be clearly found that in the central parts of Ilan City and Luodong Town demonstrate more dense distribution of boreholes. The reason for these two places show higher degree density are the regional center of educational district for Ilan City and business district for Luodong Town. Besides, some other boreholes are located along the National Highway No. 5. because the design standards for highway construction are much strict than the country road, resulting in geological conditions of the highway must be considered more seriously.

In general, boreholes are mainly selected on the Langyang Plain while rare in the remote mountain area. As a matter of fact, the borehole distribution is quite uneven for the whole Ilan area. As a result, the existing collected borehole data cannot accurately accomplish the needs to establish a higher level soil liquefaction potential map for Ilan area. As a consequence, it is required to obtain more accurate information by means of supplementary drilling operation in Ilan area.

4.2 Drilling Holes Layout and Density

In order to make sure the new constructed potential maps of soil liquefaction to achieve intermediate precision, the key consideration is the drilling holes layout and density. The drilling density must be more than 4 holes/km^2 under the government specification. It is carefully arranged to increase the number of boreholes for areas of medium and high liquefaction potential, densely populated areas, low floors houses, old buildings, or those areas where the density is insufficient. In addition to the low potential areas or population living sparse and simple geological conditions, we have to reduce the drilling density so that the geological data obtained from the drilling holes can achieve maximum efficiency.

As the main factors affecting soil liquefaction are weak granular soil, high groundwater, etc. The drilling program of borehole distribution can be accomplish by considering following aspects: (1) The existing boreholes distribution map not only can be analyzed at the current drilling layout of the precision and accuracy, but also determine the accuracy of the liquefaction potential and decision to add the drilling holes; (2) The terrain and groundwater data over the years can be used to determine the distribution of weak soil layer and find out the areas where liquefaction is prone. It can also be used to correct drilling holes location and soil liquefaction potential value; (3) Data related to geology can comprehend the geological distribution, determine the correction of the drilling report and adjust the placement of the drilling holes position. Through the above mentioned steps, screening and adjustment boreholes location and other pre-operation can help to improve the accuracy of soil liquefaction potential map.

4.3 Drilling Technique and Supervision

Fully understanding the type of underground soil, distribution, and density is an important basis for judging soil liquefaction potential. This study takes the most widely used and most economical means of drilling technique to carry out drilling operations. The method for the standard penetration test, referred to as "SPT", is shown in Fig. 2, which is the site photo illustrating the field work condition. This test was carried out by a 63.5 kg (140 lb) hammer, which was free to fall into the drill pipe at a height of

76.2 cm (30 in.) so that punches the sampler into the soil, and records the number of blow at the same time. The blow count number is recorded by three sections of 15 cm (6 in.) for each penetration depth. The first section of the 15 cm (6 in.) penetration depth is used to determine the position of the sampler, and the sum of the second and the third segments of the 15 cm (6 in.) penetration depth is the N value. The test must reach the 45 cm (18 in.) or the N value reaches 100 blows.

Fig. 2. The field drilling photo in this study.

SPT drilling method is executed every 1.5 m while in the soil layer change should be carried out at once. All the field works are supposed to be judged by the site construction personnel according to experience to increase the basic information for soil liquefaction potential and verify the correctness of SPT drilling results. The samplers and test procedures used shall comply with ASTM D1586. It is worthwhile to mention here that the supervisors go to the sites all day long to watch the field work with very high expectation.

5 The Improvement of Soil Liquefaction Potential Map

Langyang plain is liquefied sensitive area without a doubt. The issue of life and property safety of inhabitants is surely a big matter of concern when a more violent or closer earthquake happens around the Ilan area. The improvement of liquefaction potential map accuracy is helpful for the assessments as well as the prevention of soil liquefaction disaster. However, how to decide the soil liquefaction occurs in the Ilan area, we can use the drilling data to understand the details for distribution of underground soil and groundwater level. With drilling data, we can calculate and draw the soil liquefaction potential map with the earthquake scale. Therefore, the accuracy of the soil liquefaction potential map is the important issue we must consider and try our best to improve the precision of the map.

5.1 Primary Map Precision

Ilan region soil liquefaction primary drawing precision is of 1/25000 scale, as shown in Fig. 3, by the Central Geological Survey. From the primary announced map, it can be seen that Ilan area is prone to soil liquefaction. The soil liquefaction primary in the figure is illustrated with three colors to distinguish them: represents the low potential area (Liquefaction potential index PL < 5); represents the medium potential area (Liquefaction potential index $5 \leq$ PL ≤ 15); represents the high potential area (Liquefaction potential index PL > 15).

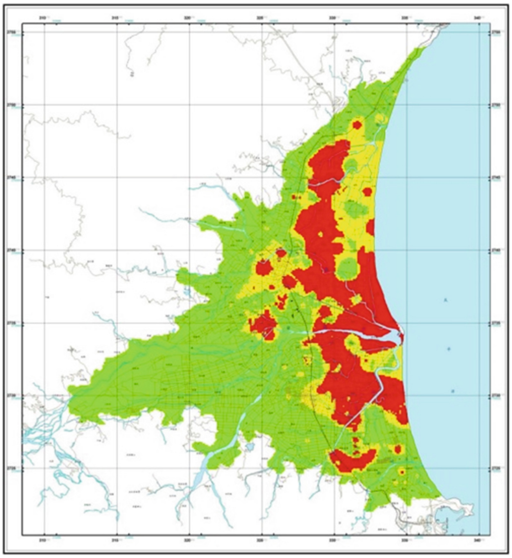

Fig. 3. Ilan area primary liquefaction potential map (courtesy of Central Geological Survey).

From the primary soil liquefaction map, Ilan city, Luodong Town, and Wujie Township contains the medium and high potential region. Additionally, the primary results of this assessment can be found to have a greater relevance between liquefaction and geological conditions. Alluvial plains area and the mountain area have totally different liquefaction potential situation. Liquefaction may occur in the area with the deposition of loose granular soil. The direction of the coastal of the Pacific oceans is likely to have a tendency to high liquefaction development trend.

5.2 Intermediate Precision

Ilan soil liquefaction intermediate precision is set to be 1/2500 scale, so that the density of geological drilling needs 4 holes/km^2. In the future study, the proposed supplementary drilling holes will be executed at the three townships in Langyang plain, which is shown in Fig. 4. The gray point in the figure is the existing collected drilling holes in the three townships. The red point in the figure is the supplementary drilling point will be added. Supplementary drilling holes have tried the best to evenly distribute within the three townships.

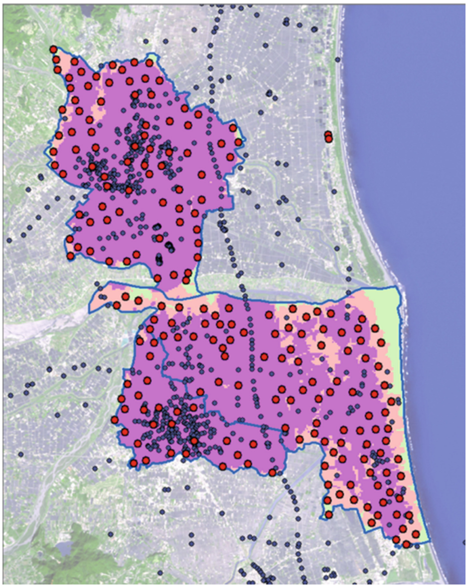

Fig. 4. Supplementary drilling holes distribution map (courtesy of CECI).

Moreover, the boreholes density in the figure can be used to view the supplementary drilling plan. The low density of drilling holes will result in the interpolation less supreme and can lead the predicted result inadequate to reflect the soil liquefaction situation. Therefore, there is expected accuracy when drawing liquefaction potential maps. This study adds about 213 boreholes of geological drilling data in the densely populated areas, low floor houses, old buildings and complex geological conditions of Ilan area. The drilling density in the figure is illustrated with three colors to distinguish them: ■ represents the boreholes density of 4 holes/km^2 or more; ■ represents the boreholes density is above 2 holes/km^2 but less than 4 holes/km^2; ■ represents the boreholes density is less than 2 holes/km^2.

The three townships (Ilan City, Luodong Town, and Wujie County) within the drilling density of 4 holes/km^2 and above covers the total area of about 95%, which can be anticipated to improve the accuracy of soil liquefaction potential map. As a final point, this study will employ the SPT-N HBF analysis method to calculate soil liquefaction potential, which is a quite simple evaluation method to determine the occurrence of soil liquefaction in Taiwan, which has been validated with good accuracy and reliability. This method can be fine-tuned for different earthquake scale to evaluate the soil liquefaction potential.

6 Conclusion

Ilan area is located in such an unique environment when the earthquake occurs would suffer quite high possibility of soil liquefaction. Although the earthquake in recent years in Ilan region did not carry serious liquefaction disasters, one cannot be ignored that Ilan area is undoubtedly highly liquefied sensitive. In view of this, it is necessary to improve the precision of soil liquefaction potential map, so that the assessment and improvement of soil liquefaction disaster can be carried out promptly.

In the current point, the improvement of soil liquefaction potential map project is mainly executed for Ilan city, Luodong Town, and Wujie Township. The initial arrangement for distribution of drilling holes has been roughly completed with the required density of 4 holes/km^2. The drilling method employs SPT standard penetration test method for the sampling every 1.5 m or soil layer change and perform the soil physical properties general test. Follow-up progresses such as data documentation, analysis operation, and related internet system construction for their benefit need to wait for the completion of the supplementary drilling operation.

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