# A national project of subsoil investigation and soil liquefaction hazard map development in Taiwan

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## ABSTRACT

Soil liquefaction has become an issue of public concern since it was mistook to have been a factor in the collapse of a building and the death of 117 people in a magnitude 6.4 earthquake that struck southern Taiwan on Feb. 6. Central Geological Survey (CGS) in the Ministry of Economic Affairs released a first version of on-line soil liquefaction hazard map to pubic as a primary precision one and announce to enhance the precision level with a budget of more than a billion NTD on subsoil investigation and medium precision level soil liquefaction hazard map development around almost every township on the west side of Taiwan in the first two years. And following by a potential second generation project is of 3.8 billion NTD later on. The first and second generation projects are all aimed at enhancing the hazard map precision, hence, tremendous soil investigation and soil tests, as well as the hazard map development, raise up different type of challenge. This paper is going to share the unprecedented experience done in Taiwan.

**Keywords:** soil liquefaction hazard map; subsoil investigation; soil liquefaction

## 1 INTRODUCTION

On February 6, 2016, 03:57:26.1, an earthquake of Richter magnitude scale of ML 6.6 occurred in Meinong District of Kaohsiung City, Taiwan. The epicenter was located 22.92o North and 120.54o East and had a depth of 14.6 km. This earthquake was felt all over the island of Taiwan. According to earthquake report, the CWB real-time strong ground motion station CHN3 located in Sinhua District, Tainan City had the largest recorded peak ground acceleration of 401 cm/s2 in the east–west direction. The ground shaking level at CHN3, having an epicentral distance of 25 km, just slightly crossed the threshold of Intensity Level 7 (i.e., PGA greater than 400 cm/s$^2$).

Soil liquefaction has become an issue of public concern since it was mistook to have been a factor in the collapse of a building and the death of 117 people in a magnitude 6.4 earthquake that struck southern Taiwan on Feb. 6. An online database was launched one month later to allow the public to search for areas in parts of Taiwan that are prone to soil liquefaction and are therefore likely to suffer serious damage in a major earthquake by the central government for satisfying the right to know to the public.

The first stage of released database cover Taipei City, New Taipei City, Yilan County, Hsinchu, Tainan City, Kaohsiung City and Pintung County. And the second stage that release one year after cover Taichung, Yunlin, Changhua, and Chiayi. The database goes online, it was provided information on the risk of land subsidence due to soil liquefaction, and issued color-coded alerts to the computers or smartphones of people who sign up to receive them and they can find the corresponding level of soil liquefaction compiled with google map. Different colors are used to represent different levels of vulnerability, with green representing low vulnerability, yellow representing medium vulnerability and red representing high vulnerability. And those were results conducted by Central Geological Survey (CGS) in the Ministry of Economic Affairs in the past 10 years which can be summarized in Table 1 and shown as Figure 1.

Table 1. Summary of liquefaction potential distribution on liquefaction hazard map released by CGS Taiwan on 2016/03/14

| Total area (kM2) | | Studied area /Total area | Liquefaction potential High | Liquefaction potential Medium | Liquefaction potential Low |
|---|---|---|---|---|---|
| Taipei City | 270 | 43.92% | 6.20% | 11.92% | 25.80% |
| New Taipei City | 2,057 | 6.84% | 0.73% | 1.37% | 5.09% |
| Kaohsiung | 2,982 | 8.65% | 1.35% | 3.57% | 3.74% |
| Yi-Lan | 2,190 | 15.48% | 3.48% | 2.56% | 9.44% |
| Hsinchu | 124 | 51.34% | 0.57% | 2.44% | 48.33% |
| Hsinchu County | 1,404 | 3.73% | 0.00% | 0.02% | 3.71% |
| Tainan | 2,252 | 22.98% | 2.65% | 4.84% | 15.48% |
| Pingtung | 2,790 | 27.61% | 3.05% | 5.58% | 18.98% |
| Taichung | 2,232 | 26.51% | 1.50% | 1.90% | 23.11% |
| Changhua | 1,110 | 92.82% | 34.22% | 26.35% | 32.25% |
| Yunlin | 1,356 | 89.95% | 38.84% | 24.13% | 26.98% |
| Chiayi | 60 | 74.67% | 0.25% | 0.64% | 73.79% |
| Chiayi County | 1,951 | 38.89% | 20.67% | 9.66% | 8.56% |

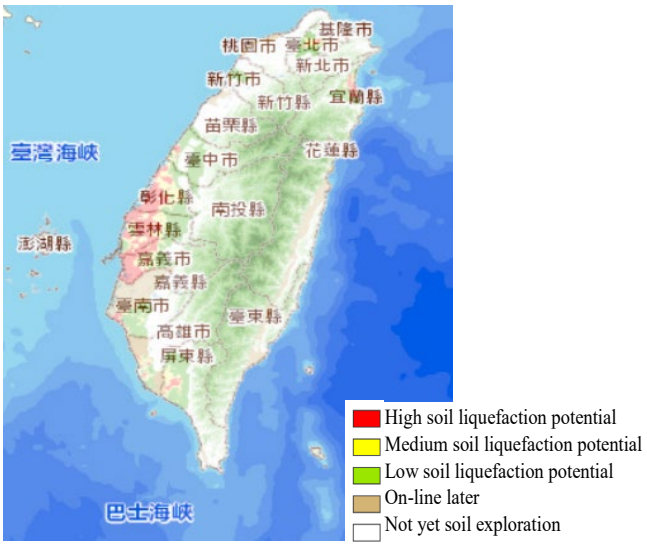


Figure 1 soil liquefaction potential map developed by CGS

However, unfortunately, the released liquefaction hazard map missed more than 80% precision on prediction for the most damaged liquefaction induced damage areas in Meinong earthquake, which caused even more public concern, instead of "the right to know" and "feel safe". The Cabinet then introduced a six-year, NT$2.4 billion (US$73.4 million) plan to improve the safety of residential buildings around Taiwan. That is the original formation of the home safety program. While half of the budget is used to promote safety inspections for old residential buildings, the other half is used to promote a project to enhance the level of precision of the soil liquefaction database. Under the project, the Ministry of the Interior subsidize efforts by local governments to compile soil liquefaction maps at a medium level of precision.

After two years executing, Cabinet has a plan to extend the national project to truly national wide and to reach precision enhanced liquefaction map recently, therefore, is aimed at carrying out 3 year project with a new budget of 3.8 billion NTD approximately. Instead of SPT and soil general property tests mostly in the previous formation, some potential academic research possibility will be involved in the following new project supposedly. I will use a term "the second generation project" for the potential project description in the following paragraph.

## 2 STRUCTURE OF THE NATIONAL PROJECT

To enhance the level of precision of the soil liquefaction data base, there are several major factors involved including, increase number of SPT holes with quality, soil general physical property test, the additional soil exploration such CPT, the soil tests such as cyclic tri-axial test, groundwater table level observation and the mapping.

The definition of the precision is announced by the CGS that the primary soil liquefaction potential map announced by CGS is of 1/25000 precision, and the precision level that the local governments aim at shall be of 1/5000~1/2500 which is defined as medium precision level. And other than the base map precision, the criterion of the liquefaction map precision is to increase the soil boring information from 1 in 4kM2 to 4 in 1kM2. Therefore, tremendous soil boring work is being carried out in almost every corner of west side in this country.

As mentioned above, to enhance the level of precision of the soil liquefaction database national widely, the Ministry of the Interior subsidize efforts by local governments to compile soil liquefaction maps at a medium level of precision. Soil liquefaction is a rare term to the officers in the local government officers, somehow, each project in the local government hence is divided into two types of work: liquefaction hazard map developer (LMD) and project control manager (PCM). Two different work teams are entrust with the corresponding work items. Each township contracts out the works by itself, the tasks on the tender documentation are more less the same in the major item and adapted to local conditions in a few item in general.

Liquefaction hazard map developer is aimed at executing the major work to fit the purpose of the medium precision liquefaction map. The PCM works for the local government and provide advice and give comment. The budget between PCM and LMD are more than 10 times different implying the work load and responsibility difference. A flowchart of the project execution is shown in Figure 2, and the following sections are introducing the details of work item in the project.

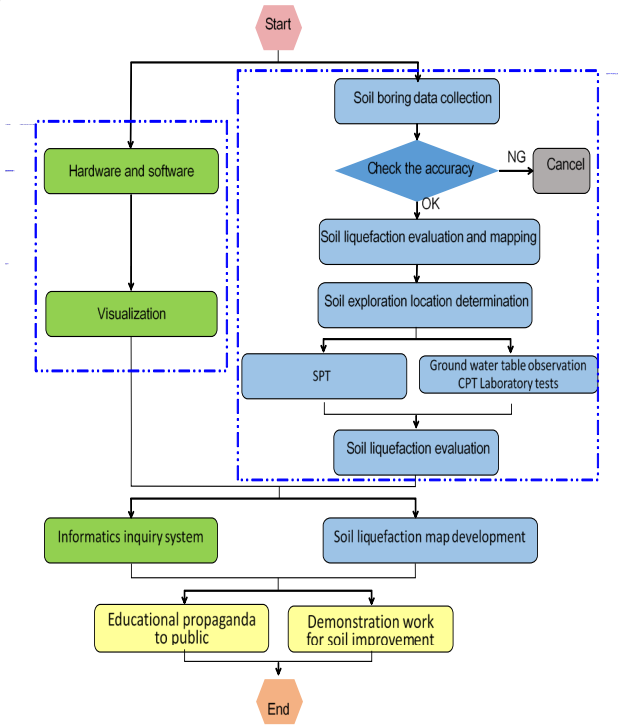


Figure 2 flowchart for the soil liquefaction map development

## 3 SUBSOIL INVESTIGATION AND SOIL LIQUEFACTION EVALUATION

### 3.1 The requirement for the SPT work

Standard Penetration Test (SPT) is used very extensively in a routine site exploration program and a preferable in- situ test method in Taiwan because the low cost laboring work as well as the tremendous existing data providing for design with the use of empirical correlations that well accepted by the engineers in practice. In Taiwan, SPT is carried out according to ASTM 1586, the brass liners are used together with the split spoon barrels. Also wash boring is taken turns with the spoon barrels in a test, usually, each 1.5m depth a SPT is assigned. The brass liners after sampled from the ground are sealed immediately and send to the soil laboratory for the general soil property test. During the in- situ work, the SP workers need to record down the SPT hammering number as well as the soil type observed during sampling and washing at each depth.

Most of the subsoil investigation being carried out in this national project is based on mostly SPT, less than a ratio of 1/20 of the number of SPT is a number of CPT work. Each project in a township has around 200-300 SPT holes with a depth no less than 30m for enhancing the precision. 4 SPT holes are suggested to be set in an area of $1kM^2$ on the liquefaction hazard map. The groundwater table needs to be investigated by installing well/piezometer. A field engineer shall be in the site watching the work process of the SPT work with a certain ratio 1 to two and an on- site camera for recording the work process is necessary for each hole. The worker needs to be trained before they work and all the devices/ equipment of the SPT need to be examined. Automatic hammer in STP is carried out in the site and each device is examined by energy loss ratio test. Moreover, PCM conducts spot check from time to time and has a right to reject the field work team. All time candid camera is installed in the field for each hole and is recorded and storage for inspection. Last but not the least, each SP machine is required energy loss test investigation. The obtained energy loss ratio (ER) is used for soil liquefaction evaluation. The frequency for this investigation is for every 10 holes and each 6 m depth in some township project.

### 3.2 The requirement for the soil lab. test

For standardizing soil test and ensuring its quality, the soil tests are assigned to TAF lab. of which TAF stands for Taiwan Accreditation Foundation that aiming to establish an impartial, independent, and transparent accreditation system observing international criteria. It seeks to provide comprehensive and effective accreditation services for a variety of clients, such as industries, consumers, and governmental agencies. In the other words, the test results accredited with TAF logo are supposed to represent less human being and machine error in the laboratory test. It directly helps to the precision of soil liquefaction map.

Therefore, general physical property of soils in this project are encouraged to be done in TAF certificated laboratory in the first two year project, and the test results need to issue with a TAF Logo. The reasons is a TAF logo experiment requires not only a standard test execution but needs to record all the work procedures and less human errors and accident could take place, especially on testing fine content sensitive soil samples. TAF accreditation body review those record from time to time. For the test items without TAF, all instrument calibration and inspection of the devices for the soil tests are necessary before being executed in the lab. For the second generation project, it is supposed that all tests need to be TAF accredited for enhancing its reliability.

### 3.3 Soil liquefaction evaluation

The designed seismic accelerations, design base earthquake and maximum design earthquake, are determined according to seismic region coefficient in Taiwan. Groundwater table is required to be an average observed water level in rainy season. The soil liquefaction evaluation method was assigned to be HBF which is developed with local data in the first year and in the former project, and then is adopted the international NCEER (2001), T&Y, AIJ and NJRA in the most of township project later on. And the liquefaction potential index, PL value, is calculated after the safety factor at each depth of the ground is evaluated and plotted on the map with three colors defining high/medium/low vulnerability to soil liquefaction. The margin of PL value to the vulnerability is less than 5, 5 and 15, and over 15. Groundwater level is measured manually as well as automatically in the project execution period (1 year), and initial ground water table is measured for calculating the cyclic soil resistance in soil liquefaction evaluation method and some controversy are about the level of ground water applied for CSR evaluation. Designed peak ground acceleration value is applied based on a national code, which considering near fault effect, soil profile type effect, and occupancy coefficient etc.

Additional work is carried out as icing on the cake in some township project that is to consider the potential damage of the shallow founded buildings/ pipe lines/ post- liquefaction settlement of ground surface, etc., which is connected the liquefaction hazard map that is more geological/ geotechnical vulnerability to building/ life line/ life vulnerability, so called consequence analysis. In the second generation project, the project owner plans to make an effort on managing a research project on studying the consequence analysis of several vulnerable subjects to soil liquefaction potential. The research project is aimed at finding a solution on soil liquefaction countermeasures to the subjects with physical test, numerical analysis and prototype model as

well as sampling technic and integrated disaster prevention system.

## 4 INFORMATICS SYSTEM

Every township is required to develop their own informatics system for liquefaction hazard map management to provide an environment for the public use as searching for the soil liquefaction vulnerability of their home address using computer and smart phone. Some township projects require backup system on-site/ off-site. And some would link the liquefaction hazard map system with other hazard map such as fault, debris flow, and flooding potential hazard map to enrich the use. All the maps are established under a frame of Geology Information System.

The other part of this national wide project is to establish an inquiry geographical information system on the web for resident, professional, and practitioner and officer with different targeted purposes, therefore, a balance integration of software and hardware and the inquiry platform that play an important role in this project success is introduced herein.

### 4.1 Hardware and software

The users of the inquiry platform are divided into three major group; firstly, it is the residents who are civilian inquiring basic information of soil liquefaction map, secondly it is professional user who are engineers inquiring more detailed information of soil liquefaction such as soil boring data, and last but not the least, it is practitioner and officer who are the staff member of the competent authority managing and maintaining the system. The service location for the system will be built in competent local government. The basic system structure of software, hardware and cloud is developed as the Figure 3. An example for the hardware requirement for CPU is 2 IntelXeon E with 16 core for each, 2.6GHz and 35MB SmartCache, for RAM is 16GB ECC DDR4×4, for HD is 2.5 inch eSSD with 1TB×4.

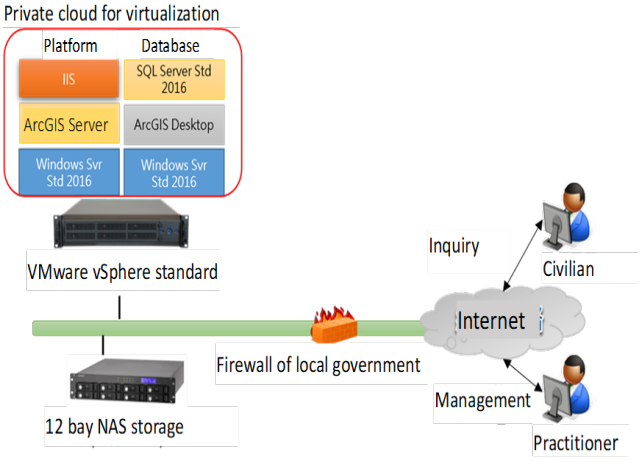


Figure 3 the structure of the web system

### 4.2 Visualization

In virtualization development, one physical host are used to provide two virtual environment for operation efficiency, in which one is for web platform that is coded by Java script and the other is for spatial data that is managed by MS SQL Server + ArcGIS. NAS storage system is used for backup the data. Figure 4 shows the structure of the soil liquefaction inquiry system.

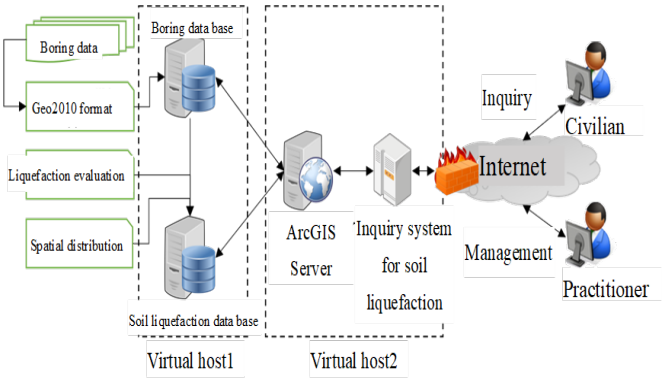


Figure 4 structure of the soil liquefaction inquiry system

### 4.3 Database development

In the spatial database, the author and his team convert Geo2010 that is a general soil data format established by Central Geological Survey, Ministry of Economic Administration, Taiwan, into Access format for a sake of convenience of soil liquefaction evaluation and other consequence analysis using SQL server. Figure 5 demonstrates the Geo2010 user interface. The soil boring data of national construction all need to be made in such a format and uploaded to the data base. Figure 6 is the converted Access data base from Geo2010 which can easily link with all types of evaluation done in EXCEL format. And the soil boring data distribution is demonstrated in the Figure 7 spatially.

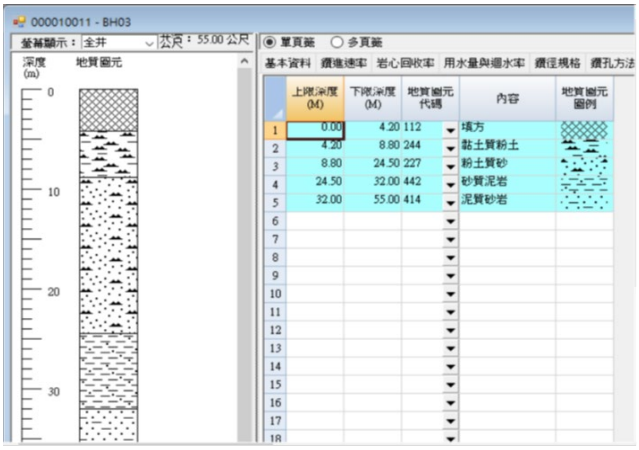


Figure5 Geo2010 input interface

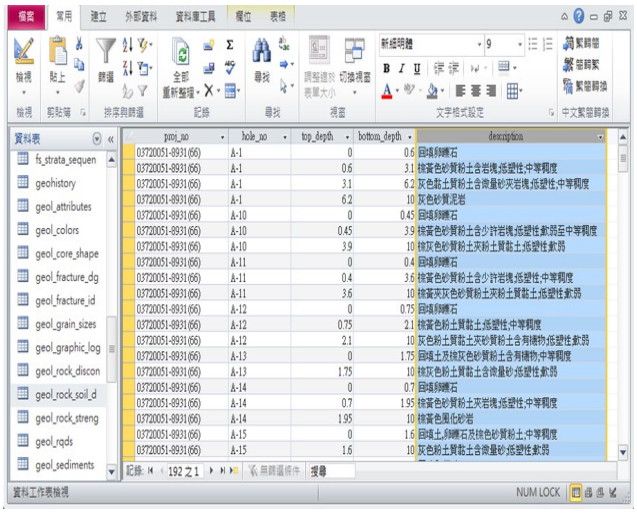

Figure 6 converted Access format database

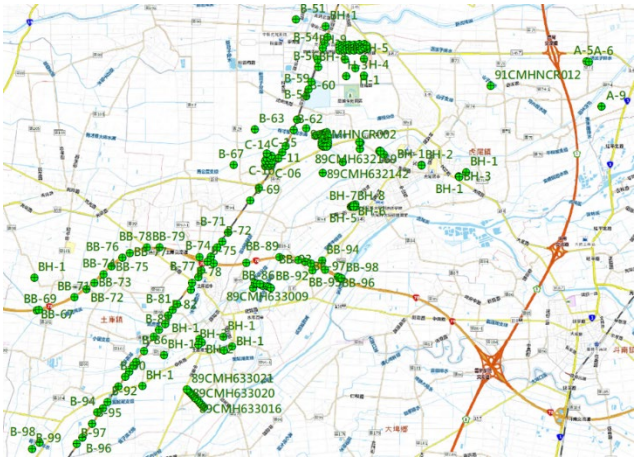

Figure 7 example of spatial distribution of the SPT holes and the information

### 4.4 Soil liquefaction hazard map

After the soil database is established, soil liquefaction evaluation moduli can be built in as semi-/ full automatic function. The selections of evaluation method can be NJRA, NCEER, T&Y and HBF or others.

The liquefaction map execution is followed an international common way, the general property and general information of the boring holes is input, the soil liquefaction evaluation will start and then PL (Potential of Liquefaction) value will be spatially located to the corresponding location after being calculated for each SPT hole. After employing other information such as historical map/ satellite photos and land use map, the entire PL value distribution on the map will be decided. The hazard map will be converted to a more portable image layer instead of data for display on the inquiry system for a sake of effectiveness. Some LMD provide the local government a convenient function that could automatically transfer a new boring data into soil liquefaction hazard map and re- distribute the PL value spatially.

### 4.5 Inquiry system

The inquiry system is the layer brings the users and the soil liquefaction map together, therefore, requires the corresponding functions to the different level of users that are targeted to be civilians, professionals, and practitioner and officers. The structures of the inquiry system is demonstrated in Figure 8. The civilian users are allowed to access the inquiry system on the basic level such as reading soil liquefaction potential map and positioning with address and GPS, and basic Q and A of soil liquefaction related problems. Professionals are allowed to access the soil liquefaction data base including soil bore- hole information as well as the test result and layer the soil liquefaction potential map with other wms and shp layers, and some interesting and practical function maybe open to them after consideration. In the case of the inside practitioners and officers, they have full priority to access the system, however, the system is still advised to be managed by the professional informatics staff, they can have the potential disaster information due to soil liquefaction at different level of PGA (earthquake) that may include the potential damage of the low rise building, pipelines and embankment if an additional evaluation method for consequence analysis is established into the evaluation moduli by a good developer.

Finally, when the middle level precision liquefaction map is made and open on line, the users from different corner at world could check in, therefore, the steady, stable and security of the system shall be cautiously taken into consideration.

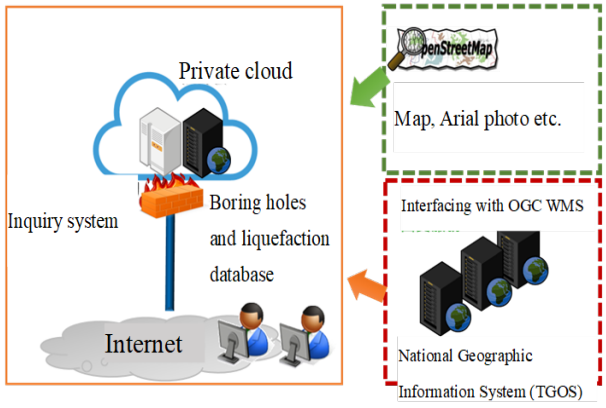


Figure 8 the structure of inquiry system

## 5 OTHER IMPORTANT WORK ITEMS

Liquefaction hazard map development is very common around the world, however, most countries develop their own liquefaction map based on the existing data that are collected during years because of different construction purpose, and the maps are made in country scale as well as city scale based on different competent authority. Not have heard that a country devote a big

budget on subsoil investigation national wide. Because it is not presciently, there are a few important work items other than mentioned above that the author considers to be very influential to the success of the precision of the soil liquefaction map instead of a 3 colored map : 1) hazard map instead of potential map. The author seriously consider the importance of subsoil investigation activity conducted in a location that matters the value of the soil exploration, 2) appropriate application of the existing boring data. Eliminate bad soil data and adopt good one after collecting. Some soil boring data with insufficient depth shall not be eliminated without a second thought, 3) interpolation and extrapolation execution based on more than only a concept of mathematics, 4) aid of other low cost method for subsoil investigation/ soil situation confirmation instead of fully SPT, 5) the mesh size adoption. The mesh size is fixed as 50m and therefore a great number of interpolation and extrapolation being carried out using Krining which would give a systematical error, 6) the consequence analysis. PL value is considered as a potential to soil liquefaction that is not prone to vulnerability of liquefaction induced hazard, such as if a shallow founded low rise building locates in a zone of PL around 5, however, the direct subsoils underlying liquefied due to a seismic activity would induce a significant settlement to the building. A soil liquefaction hazard map incorporating with a consequence analysis is considered to be more helpful to the disaster prevention therefore, 7) the development for soil sampling and incorporation with soil dynamic tests. Relatively limited undisturbed soils and dynamic tests are taken into consideration for the soil liquefaction evaluation in this project. In the second generation project, this concept is being persuaded, hopefully.

## 6 CONCLUSION

It is to be a 6 billion NTD national project unprecedentedly, which consists of tremendous SPT and general soil property tests mostly. The project result is a green- yellow- red colors clustered on a map showing soil liquefaction potential. There are several very important factors affecting the result closely to approach to the project targets: disaster prevention and renewable plan development to urban area, ones shall be cautious at other than the standard penetration test and general soil property test precision, there are the position of the SPT, the investigation of the constant groundwater table level, the interpolation and extrapolation technique, connecting the liquefaction potential value to disaster prevention and the application of other ground investigating method.

We expect the next generation project can be filled with better work items not only the obtaining soil investigation data but also raising up the soil investigation ability, as well as geotechnical research ability which is considered to be an integrated research project highlighting on the soil sampling, seismic responses monitoring and analysis, consequence analysis and soil liquefaction countermeasures.

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