

## **Seismic Risk Assessment of Hanoi Using the Japanese Assessment Method**

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**Abstract :** *The seismic risk was assessed for a part of Hanoi by applying a ground motion prediction formula and a liquefaction assessment method developed in Japan. The analysis was performed for a target area of approximately 50 square kilometers using an elevation map. Bore holes data were also collected, and the ground of the areas lacking boring information was assessed using microtremor measurements. Ground motion prediction for an inland earthquake was calculated based on the ground assessment results. It was determined that the Mercalli intensity would be 7 or greater on the ground surface if an earthquake occurs at an epicentral depth of less than 30 km and that the loose sand stratum will be liquefied by this large shaking.*

**Keywords** – seismic risk, ground motion, liquefaction, bore hole data, microtremor measuring

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### **I. Introduction**

Although Vietnam has less seismic activity than Japan, there are reports of seismic damage, and according to Vietnam Academy of Science and Technology (VAST) there are several faults in northern Vietnam. An earthquake-resistant design code was introduced in Vietnam in 2006, and new buildings are designed with seismic forces taken into consideration. However, existing buildings do not have sufficient resistance to seismic forces, and if an earthquake occurs on one of these faults, substantial damage is expected near its epicenter.

Hanoi, the capital city of Vietnam, is located on a floodplain in the middle of the Red River, with large cities on almost-flat land. Just under Hanoi, a fault runs along the Red River, and in the worst case, an inland earthquake may occur. In such a case, the buildings without earthquake-resistant designs may collapse, resulting in significant damage. The vast Red River floodplain is not uniform, having areas of ground where the earthquake motion is particularly large or the sand may liquefy. Predicting the degree of damage through a prior assessment will allow disaster-reduction measures to be taken. Therefore, understanding the seismic risk by assessing Hanoi's ground condition will give us important information.

Japan is a country where earthquakes occur frequently, and seismic risk can be established based on ground assessment data that becomes the basic information for disaster-prevention measures. Japan Seismic Hazard Information System (J-SHIS) which is developed by National Research Institute for Earth Science and Disaster Resilience (NIED) is one source of publicly-available seismic risk data. This data shows the predicted impact of future quakes based on seismic activity probabilities and the results of ground assessment across Japan. Although the ground assessment method and earthquake prediction methods used are based on data acquired in Japan, we assume that these methods can also be utilized in other countries. In Japan, the PL value represents the soil liquefaction risk index, and it is desirable to take measures to address potential liquefaction in areas where the PL value is large. The Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has published a worksheet calculation program so that the soil liquefaction risk for a housing site can easily be assessed; the soil liquefaction risk is automatically calculated when values based on subsurface investigation data are entered.

This study attempts to assess the seismic risk of Hanoi by applying these Japanese disaster-prevention techniques to the ground data of several districts in Hanoi. The seismic activity is assumed to occur approximately once every 1,000 years, and by simulating the quake hypocenter at different depths, the size of an earthquake that may affect Hanoi can be assessed. We also attempted to assess the soil liquefaction risk using the PL value. The method used in this research could be developed to

apply to all areas of Hanoi, and we believe that these risk assessment results will provide essential data for considering disaster prevention for Hanoi.

## II. Earthquakes and landforms of Hanoi

According to studies by Vietnam, there are numerous fault zones running in the northwest to the southeast direction in Northern Vietnam, and the Red River fault zone, assessed to have moderate seismic activity, passes through Hanoi City. According to the published map from VAST, the magnitude of the earthquake predicted to occur once every 1,000 years in Hanoi is 6.2. Small- to medium-sized earthquakes have been confirmed along the fault zone. Although no large earthquake has been confirmed in the history of Hanoi, because it lies on a fault band, it is necessary to understand the risks anticipated when a future earthquake occurs.

In Vietnam, micro-topographic maps and subsurface geological maps of the entire country are available to the public. The scales are rough, but an outline of the ground conditions can be understood. The whole of Hanoi is located mostly in the floodplain, and the subsurface geology is a Thai Binh stratum throughout the city. Although this is a stratum in the floodplain that contains a large portion of clay, further detailed information could not be obtained.

Therefore, an elevation map was created using the DEM data. The area targeted in this study is  $7 \text{ km} \times 7 \text{ km}$ , centered on the Ba Dinh district of Hanoi. The Old City and government agencies of Hanoi are located in this district. Figure 2 shows the created elevation map. The elevation of the target area is 5 m to 15 m, and the map shows that most of the area has an elevation of 10 m or lower. Levees built along the rivers and lakes are 10 m or taller, and the levee built between the Ho Thai Lake and the Red River has an elevation of 15 m. The elevation near the Old City, where the government agencies are located, is approximately 10 m. Many ponds are scattered in the lowland region of the area of interest, and this area may have once been a channel. Even terrain that may look flat at first glance has a height difference of about 10 m.

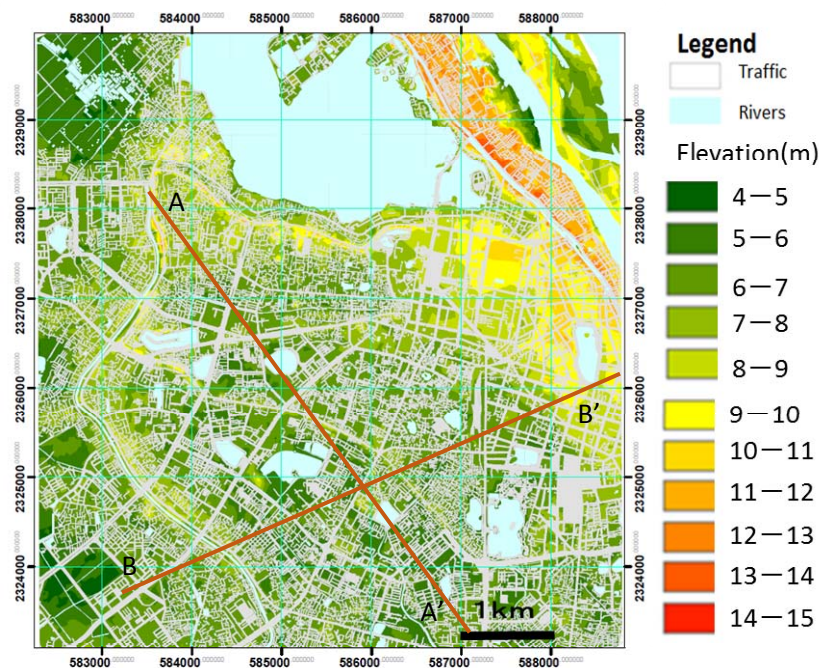


Figure 1 Elevation Map of Ba Dinh District

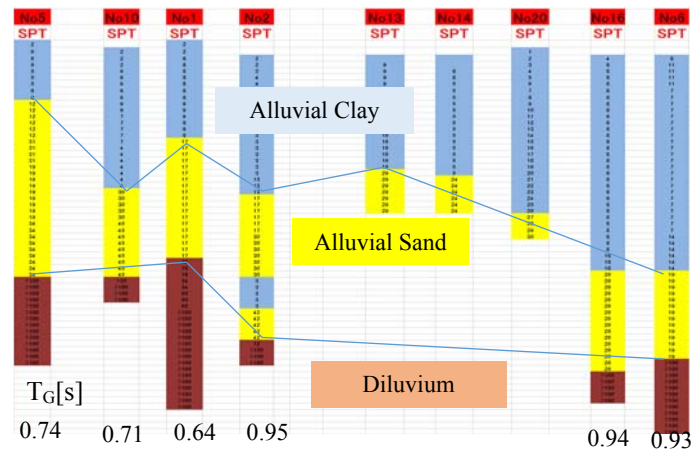
## III. Assessment of ground environment

### (1) Analyzing data from bore holes

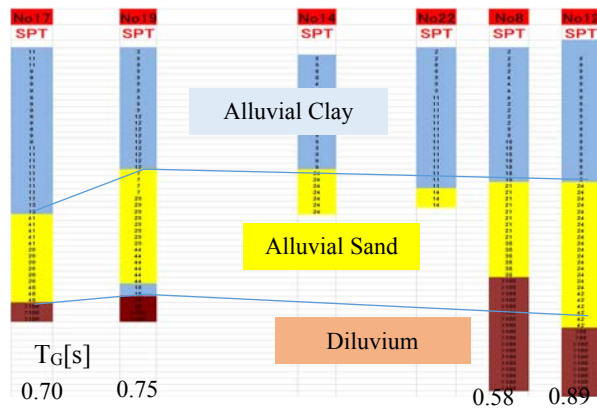
We could acquire data from 22 bore holes in the area of interest. Approximately one bore hole is collected per two square kilometers, and these data can be used to assess the ground conditions. Although the thicknesses of the strata differed, the bore holes data resulted in similar data. The area is

composed of four strata, in order from the top: the Thai Binh and the Hai Hung strata, which are both alluvial clay, the Vinh Phuc stratum, consisting of alluvial sand, and the Hanoi stratum, which consists of diluvium. There are cases where clay and sand are mixed in the alluvium.

Figure 2 (a) shows the cross-section of the strata along the Red River, which is shown as A-A' in Figure 1. The light blue represents alluvial clay, yellow is alluvial sand, and brown is diluvium. Some of the borings did not reach the diluvium, but the thickness of the alluvium is approximately 30 to 50 m. In the downstream direction, the clay stratum becomes thicker, and the surface of the diluvium becomes deeper. Figure 2 (b) shows the cross-section of the strata perpendicular to the river (B-B'). The diluvium surface is at about the same level in this view, and the thickness of the clay stratum is also generally consistent. In the area targeted by this study, the changes in the strata are gradual and continuous which confirms that interpolating the assessment results of the boring points is reasonable.



(a) Change of Strata in A-A' section



(b) Change of Strata in B-B' section

Figure 2 Change of bore holes data

Next, we calculated the natural period of the ground. The natural period of the ground is a ground assessment value required for construction design, and a longer natural period indicates softer ground. A formula from Specifications for Highway Bridges is used for this calculation. Equation (1) is the formula, and the natural period is four times the time it takes for a shear wave to pass through the subsurface.

$$T_G = 4 \sum H_i / V_{si} \quad (1)$$

Where  $H_i$  is depth of each layer and  $V_{si}$  is the shear wave velocity of the layer numbered as  $i$ .

The shear wave velocity,  $V_s$ , can be estimated empirically from the  $N$  value of SPT. Figure 2 shows the calculation results of the natural period of the ground. The natural period could not be

calculated at the points where the boring did not reach the diluvium. The resulting values are between 0.5 and 1.0 s, confirming that this ground requires caution when designing earthquake-resistant structures.

The average S-wave velocity, AVS30, as well as the natural period of the ground are important criteria for ground assessment. The AVS30 is the average value of the shear wave velocities up to 30 m below the surface, and the smaller the value is, the softer the ground. In J-SHIS, ground motion is predicted using a subsurface amplification factor that is based on the AVS30. The formula is beneath.

$$AVS30 = (\sum H_i \cdot V_{si}) / 30 \quad (2)$$

As with  $T_g$ , the shear wave velocity can be estimated from the N value. Figure 3 provides a contour figure that shows the AVS30 values calculated using the data from the 18 bore holes data that reached depths of 30 m or greater. The calculation results are between 170 m/s and 220 m/s, and the values are small due to the soft clay stratum in the central part of the target area. The clay stratum is thinner around the Old City, and, therefore, the AVS30 there is larger.

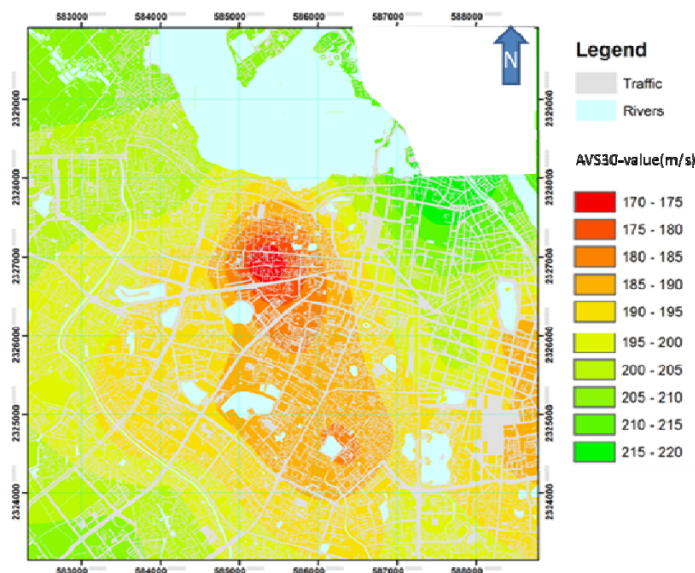


Figure 3 Map of estimated AVS30 value

## (2) Ground assessment using tremor measurement

Of the 22 bore holes data, 12 reached the diluvium. Because the amount of boring data is limited relative to the surface area, the ground was also assessed using microtremor analysis to supplement the boring data. The H/V spectrum of the microtremor indicates the characteristics of a Rayleigh wave transmitted through the subsurface, and the peak frequency of the spectrum is similar to the normal-mode frequency. In this study, a velocity meter (NewPIC, System and Data Research Co., Ltd.) was used, and measurements were taken in 45 places. The H/V spectrum is calculated by applying the Fourier transform to the measured waveforms in the vertical and horizontal directions, and, after smoothing using the moving average, the horizontal and vertical ratios were calculated, and the average of the two directions was calculated. A single measurement was approximately 40 seconds, and four to six measurements were taken per point. The average was calculated, excluding noisy data, and the H/V spectrum was determined for each observation point.

The natural period of the ground,  $T_g$ , calculated from the boring data and the peak frequency acquired by the micro-tremor is compared with the predominant period obtained by converting the period. Figure 4 shows the comparison of 11 point-pairs within 500 m of each other. The predominant period obtained from the tremor is slightly larger; however, it is confirmed that the two are roughly consistent.



The ground vibration characteristic is assessed using both the  $T_g$  from the boring data and the predominant period from the microtremor data. Figure 5 shows a map of the natural period of the ground. We can see that there is ground with a period of approximately one second in the downstream area of the Red River. Where the ponds are scattered, there is ground with a period of approximately one second that means to quake with large amplitude. From the tremor measurement results, it can be confirmed that the levee along the Red River has a period of approximately 0.7 seconds. The period around the Old City is relatively short, approximately 0.5 seconds.

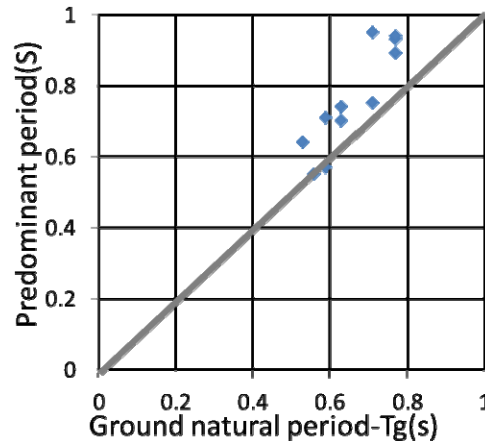


Figure 4 Comparison between ground natural period and dominant period by tremor

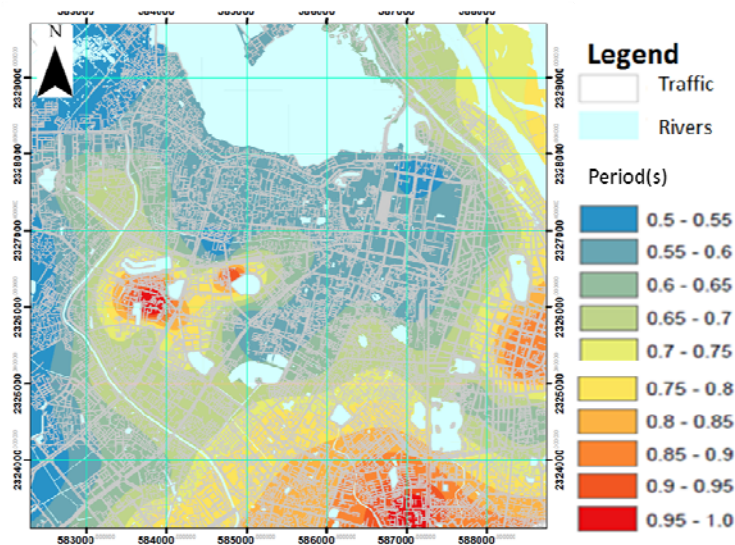


Figure 5 Map of estimated natural period  $T_g$

#### **IV. Prediction of ground motion during an inland earthquake**

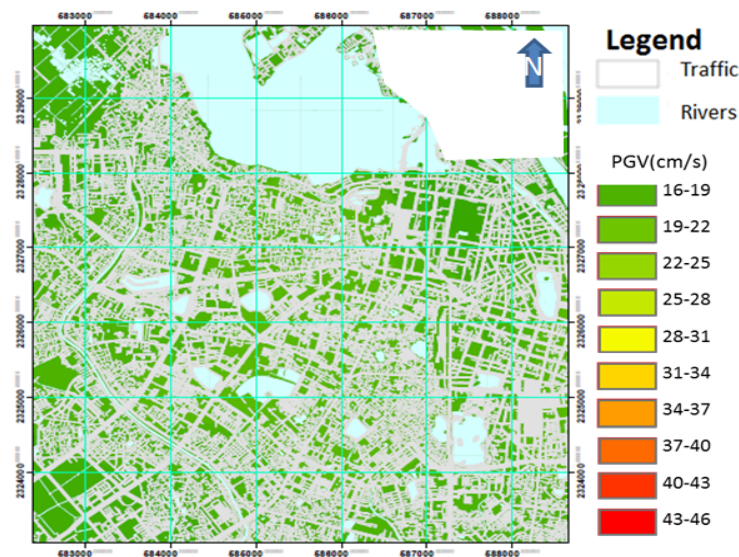
Ground motion is estimated using the prediction equation in J-SHIS and the results obtained in Chapter 3. The simple ground motion prediction formula in J-SHIS has two stages. First,  $PGV_{b600}$ , which is the maximum velocity in the bedrock of a shear wave velocity of 600 m/s, is calculated using the attenuation formula from the fault, whose functions include the magnitude, seismic depth, and shortest fault length. For this calculation, the target area is assumed to have a horizontal fault plane just beneath it, and the same values are used for the epicentral depth and fault length. A magnitude of 6.2 is used based on past research. The epicentral depth is unknown, so calculations are performed for three depths: 10 km, 20 km, and 30 km. In these calculations, the maximum velocity in the bedrock directly under the district of interest is assumed to be a constant value.

Next, the maximum velocity of the ground surface is calculated by multiplying the amplification factor,  $R$ , calculated from the AVS30, times the estimated velocity in the bedrock. The formula of  $R$  is beneath.

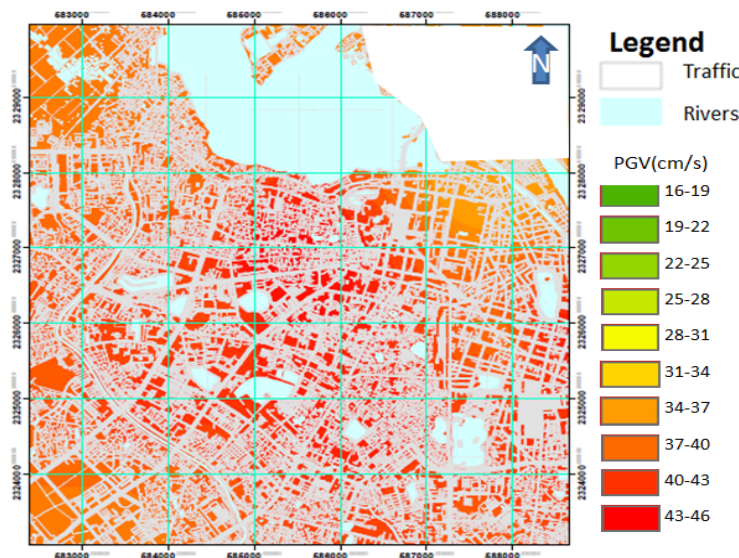
$$\log R = 2.367 - 0.852 \log \text{AVS30} \quad (3)$$

The greater the AVS30, the greater the maximum velocity. Although both the attenuation formula and the amplification factor are regression formulas based on Japanese data, we assume that they are used for Vietnam as they are the same in Vietnam.

Figure 6 shows the simulation results at the different epicentral depths: (a) and (b) are the simulation results for epicentral depths of 30 km and 10 km, respectively. The maximum velocity of the ground surface is approximately 20 cm/s and 40 cm/s for epicentral depths of 30 km and 10 km, respectively. The result of depth of 20 km is mid value of two cases shown, about 30cm/s. In all three cases, the maximum velocity is greatest near the center of the target area, where the soft clay is deposited. We found that, when this maximum velocity is converted to the Mercalli intensity scale, it is a large quake of 7 to 8.



(a) Estimated peak ground velocity in case of 30km depth



(b) Estimated peak ground velocity in case of 10km depth

Figure 6 Estimated peak ground velocity at the time of inland earthquake

From the above, we found the possibility of a large quake occurring directly above the assumed fault zone. In Japan, if the size of the quake is known, the amount of damage to buildings or others can be predicted through calculations based on past damages. However, this prediction cannot be performed for Vietnam because there is no estimated building damage formula for Vietnam. The materials and designs of buildings vary in each country; therefore, the Japanese damage estimation formula is not suitable for Vietnam. In the future, it will be necessary to examine how a large earthquake with a ground velocity as large as 40 cm/s will affect Hanoi's buildings.

## **V. Assessing soil liquefaction risk using PL value**

The target area may experience liquefaction when an earthquake occurs directly beneath it if there is a loose sand stratum. We performed a liquefaction assessment using the bore holes data obtained in this study. The criteria to determine is the PL value, and software released by the City Bureau and National Institute for Land and Infrastructure Management (NILM) of MLIT that determines the liquefaction risk of a housing site was used. This software provides assessments based on the Building Foundation Structure Design Guidelines and on Specifications for Highway Bridges, and in this study, we adopted the assessment calculation methodology of the latter.

In the liquefaction assessment calculation, the shear stress (L) acting on each stratum and the liquefaction resistance force (R) are calculated to determine the ratio such that  $FL=R/L$ . If the value of FL is 1 or smaller, the soil will liquefy, and if it is greater than 1, the soil will not liquefy. The smaller the FL value, the greater the soil liquefaction risk. The PL value is an index calculated, for those areas where  $FL < 1$ , by adjusting the calculated FL value from the ground surface to 20 m deep. The greater the PL value is, the greater the soil liquefaction risk is at that point. The formula is beneath.

$$PL = \int (1-FL(z))(10-0.5z)dz \quad (0 < z < 20m) \quad (4)$$

Where z means coordinate of vertical length from the surface, and  $FL(z)$  is FL Value at z m deep with the condition to be set to  $FL = 1$ , if the FL Value exceeds 1. The thicker the liquefying stratum is, or the smaller the FL value is, the larger the PL value becomes.

The shear stress acting on the stratum is proportional to the acceleration of the ground surface. Per Specifications for Highway Bridges, the horizontal seismic coefficient,  $k_h$ , is selected and used in the calculations. In this study, the calculations were performed for two cases:  $k_h=0.12$  and  $k_h=0.2$ . The standard horizontal seismic coefficient for a Vietnamese building with an earthquake-resistant design is  $k_h = 0.12$ , and  $k_h = 0.2$  is the standard horizontal seismic intensity for designs in Japan. According to the ground motion prediction for inland earthquakes, this degree of acceleration is assumed to be generated.

The calculation results for the PL values are shown in Figure 7. Twelve pieces of boring data were used. This map is roughly interpolated because only twelve data were used and liquefaction depends on local stratum condition. We assumed as the strata of surface gradually changed. The ground surface of the area of interest consists mainly of clay, but there are some sand strata mixed in some areas. For  $k_h = 0.12$ , the PL value is small, and the soil liquefaction risk is low. On the other hand, for  $k_h = 0.2$ , there are two areas with large PL values. The first, a point near Ho Thai Lake, although in an area of clay stratum, has a small plasticity index,  $I_p$ , which results in a high risk of liquefaction according to the Japanese judgement rule. The other, at a point along the Red River, the soft sand stratum is shallow, resulting in a large PL value.

In the case where a large earthquake occurs that significantly exceeds the horizontal seismic design coefficient for Vietnam, a possibility exists that the loose sand strata in the floodplain will liquefy, causing substantial damage. However, the assessment method used in this research is an estimation formula developed in Japan, and it is necessary to estimate it and consider the application conditions, etc.



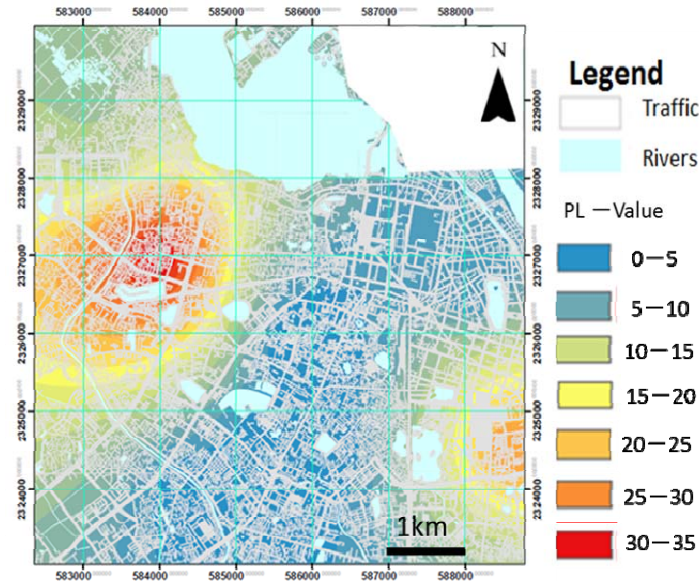


Figure 7 PL Value Map at the condition of horizontal seismic force  $kh = 0.2$

## VI. Conclusion

The seismic risk was assessed for a part of Hanoi by applying a ground motion prediction formula and a liquefaction assessment method developed in Japan. The analysis was performed for a target area of approximately 50 square kilometers using an elevation map. Bore holes data were also collected, and the ground of the areas lacking boring information was assessed using microtremor measurements. Although these assessments were conducted for a small area, the ground's characteristics differed, and we discovered that the condition of floodplain is too large of a division for a thorough assessment.

In addition, ground motion prediction for an inland earthquake was calculated based on the ground assessment results. It was determined that the Mercalli intensity would be 7 or greater on the ground surface if an earthquake occurs at an epicentral depth of 30 km and that the loose sand stratum will also likely be liquefied by this large tremor. The risk of earthquakes and soil liquefaction are significantly influenced by the assumed earthquake, but it is necessary to think of the worst case because there is a fault zone beneath the city.

Because only a part of Hanoi was analyzed in this study, it is desirable to study a larger area. In addition, although the Japanese estimation formula was applied as-is, it is necessary to verify its validity for use in Vietnam.

## Acknowledgements

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