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PREDICTION OF SPATIAL DISTRIBUTION ON SOIL SURVEYING VALUES USING GEOSTASTICS METHODS

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ABSTRACT: Recently, land subsidence and liquefaction are becoming evident. But neither the countermeasure nor research technique have not been established. In order to determine the cause, more detailed comprehension of soil properties is essential; therefore, in this research new-typed Swedish sounding testing machine (the NSWS testing machine), capable of measuring more detailed physical properties of in-ground was utilized and conducted a subsurface investigation at a narrow detailed house at which land subsurface have occurred. Based on the result of the investigation presented physical properties of the in-ground in the plane manner using Kriging method, one of geostatistics methods. Also, the comparison of converted N-value measured by the NSWS and converted N-value estimated by Kriging method is presented to examine the composite capability and benefit of Kriging method and NSWS for simplified on-site verification and re-measurement for reaffirmation (diagonal measurement) in the confined detached house ground.

Keywords: disaster prevention, geostatistics, Kriging method, new-typed Swedish sounding test

1. INTRODUCTION

The vast area of Urayasu city, Chiba prefecture was liquefied when 2011 Tohoku earthquake struck and followed by the permanent displacement causing heavy damage to the buildings. Although JIS standard for a research method or countermeasure construction method for liquefaction have been around for long time, they are still being developed. A technology that correspond to fast-paced changes in the natural disaster has not been established. Especially, the detached house grounds are having difficulties because they are private properties and very small in Japan [1-3]. Also, due to the reasons of time, finance, vibration, a mechanical reason for installation area [4]. And the conventional JIS method enable a limited number of data collection when conducting in-situ soil analysis. For that, in a general estimation is carried out using some methods based on a limited number of soil analysis for un-investigated area [5].

In this research, the NSWS was utilized at an embankment of a sunk detached house measuring converted N-value in details at each survey point. Furthermore, based on depth distribution of measured converted N-value, Kriging method [6] is used to predict space distribution of the unknown domain with unclear N-values within the survey ground. Also, the comparison of converted N-value measured by the NSWS and converted N-value estimated by Kriging method is presented to examine the composite capability and benefit of Kriging method and NSWS for simplified on-site verification and re-measurement for reaffirmation (diagonal measurement) in the confined detached house ground.

2. SUMMARY OF INVESTIGATION, TESTING EQUIPMENT AND ON-SITE CONDITIONS

The research conducted a ground survey at land subsidence occurred site. On this survey, the NSWS was utilized as the survey testing machine [1-3]. Figure 1 shows NSWS. Figure 2 shows outline of NSWS. The machine has refined the conventional Swedish sounding testing machine; it evaluates soil strength by loading weight on a penetrating rod and collecting data by rotation.

The followings are the characteristics of the NSWS:

(1) Maximum loading amount is 2500N possessing high penetration capability
(2) It can penetrate soil layers with gravels mixed, and soft rock layers.
(3) A measurement resolution is 0.01m, very fine, enabling to collect detailed data.
(4) Not only a vertical measurement but diagonal measurement is possible enabling to collect many data at the confined research area.

The next is about the venue. The venue is a detached house embankment in Nishinomiya city, Hyogo prefecture. It is a slope area with a stair-casing residential area; two two-story general detached houses are line up on the site. A part of the site caused land subsidence causing distortion on the

Fig. 1 New-typed Swedish sounding testing machine (NSWS)

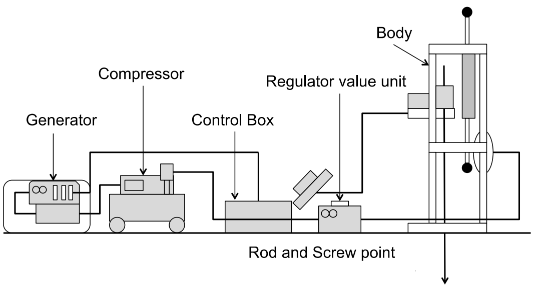

Fig. 2 Outline of the NSWS

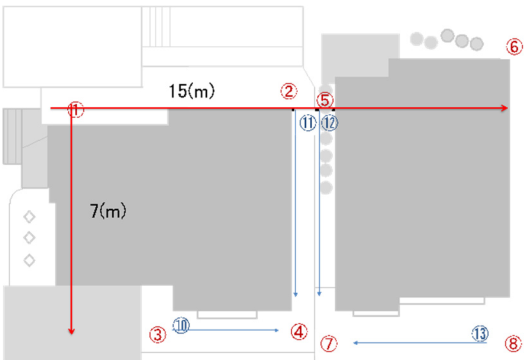

Fig. 3 Summary of on-site conditions

part of the building and concrete-block wall that surround the house. These phenomena mainly happened at the South part of the site. As depicted in Fig. 3 survey locations are the vertical measurement points at the North of the site (1, 2, 5, and 6) and the vertical measurement points at the South of the site (3, 4, 7, and 8), the side of the retaining wall. Also, diagonal measurement of survey locations (10, 11, 12, and 13) are meant to comprehend the bounds of weak area and insufficiency of compaction in the vicinity of the retaining wall.

3. PREDICTION OF SPATIAL DISTRIBUTION BY ORDINARY KRIGING

In this study interpolated a cross section among survey locations using Ordinary Kriging method and estimated the distribution of converted N-value along the cross section. Ordinary Kriging method is one of Kriging method under the assumption of fulfillment of stationary in random variables and calculates weighted mean value of the variables [7]. In this study, random variables are converted N-values. Also, stationary means that expected values of random variables are fixed throughout the whole targeted area [8]. And a covariance depends solely on distance among data and is independent of the locations of data [9].

A general equation of Ordinary Kriging method is as following Eq. (1) [10]:

$$\hat{w}(x) = \sum_{i=1}^{n} b_i \, w(x_i) \tag{1}$$

$\hat{w}(x)$: Estimated value, $w(x_i)$: Measured value, b_i: Weight at each survey location.

Also, Eq. (2) [10] is necessary to fulfill the aforementioned stationary requirement:

$$\sum_{i=1}^{n} b_i = 1 \tag{2}$$

Eq. (2) requires the sum of weights to be equal to one; under this condition, Kriging method can be applied [12].

In this study, Ordinary Kriging method was carried out based on converted N-value measured by the NSWS. The NSWS can collect data with 0.01m pitch. So, with this measurement resolution, or by changing the number of data analyze the change of results of interpolation and also analyze the accuracy of the estimations by changing the number of data assuming the measured values as true values. Kriging method was carried out with 0.01m pitch and 0.25m pitch. And, besides comparing these two, the applicability of Kriging method to the detached house grounds was examined as well.

Also, in order to make estimations on same cross sections. Then, number of point is changed on horizon. It is thought how precision turns out by increasing point.

Finally, in order to make estimations on different cross sections, Kriging method was utilized likewise at survey locations 3 and 7 with 0.01m pitch. This is to judge the applicability of Kriging method at different cross sections. On the cross sections created between survey locations 3 and 7 exist survey location 4 that was measured vertically, and survey location 10 that was diagonally measured from survey point 3. Therefore, by estimating this cross section and comparing with vertically and diagonally measured data, the applicability of Kriging method can be judged as well as judging whether it is possible for Kriging method to interpolate point data in a plane manner.

4. APPLICABLE EXAMINATION BY ORDINARY KRIGING

Figure 4 shows the results of Kriging method with 0.01m pitch at survey points 1 and 5. Figure 5 is the results of Kriging method with 0.25m pitch at survey points 1 and 5. By comparing these two one can confirm that from about 1.0m to 1.5m. Figure 4 has a finer and more various distributions. Therefore, finer measurement resolution enables more detailed estimations. Figures 4 and 5 show the soft ground to depth 1.0m by Kriging method. Therefore, it sees very likely to be the soft ground to depth 1.0m by Kriging method. Figure 6 shows measured values on point 1, 5 and 6. Higher N value is seen on depth 1.4m of point 1. Figure 7 is a comparison of two predictions with measured converted N-value at survey point 2. One can tell that at the deep ground

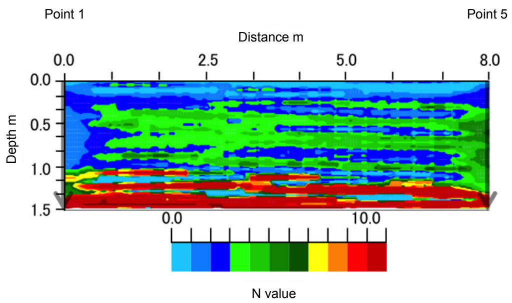

Fig. 4 Prediction by Kriging with 0.01m pitch

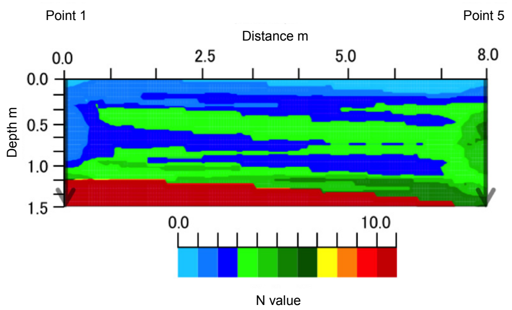

Fig. 5 Prediction by Kriging with 0.25m pitch

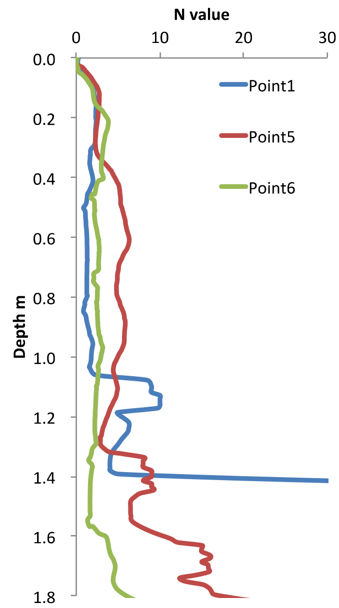

Fig. 6 Measured values on Points 1, 5 and 6

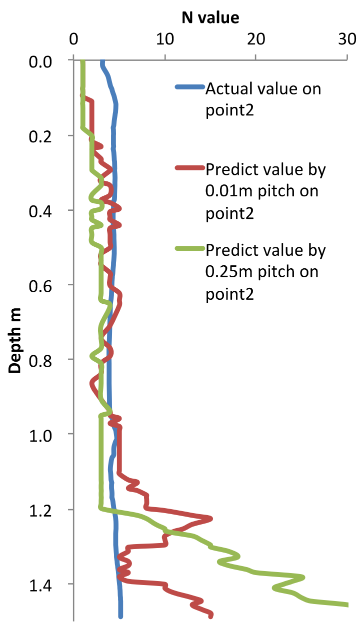

Fig. 7 Comparison between measured and predicted values on point 2 with 0.01m pitch

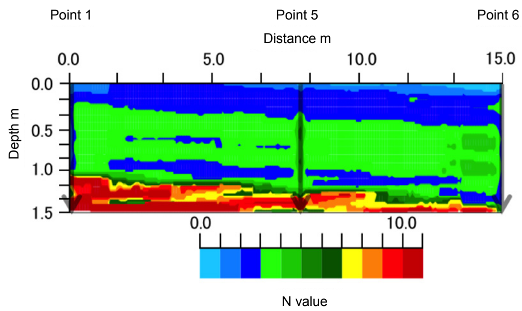

Fig. 8 Distribution by Kriging on Point 1, 5 and 6 with 0.01m pitch

the estimated value with 1.0cm pitch deviates less from the measured value. From this confirmation, one can see the need to collect many data by measuring with narrow interval. Also, since both predictions have small deviations up till 1.2m depth, it is safe to say the estimations have high-precision when treating measured values as true values. It thinks Kriging method has applicability on vertical.

Figure 8 shows the results of Kriging method with 0.01m pitch at survey points 1, 5, and 6. Figure 9 is the results of Kriging method with 0.25m pitch at survey points 1, 5, and 6. By comparing these two one can confirm that from about depth 1.0 m to 1.5m. Figure 8 has a finer and more various

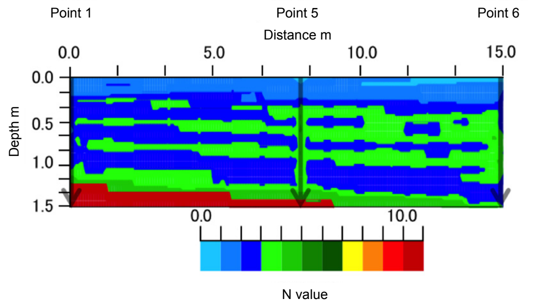

Fig. 9 Distribution by Kriging on Point 1, 5 and 6 with 0.25m pitch

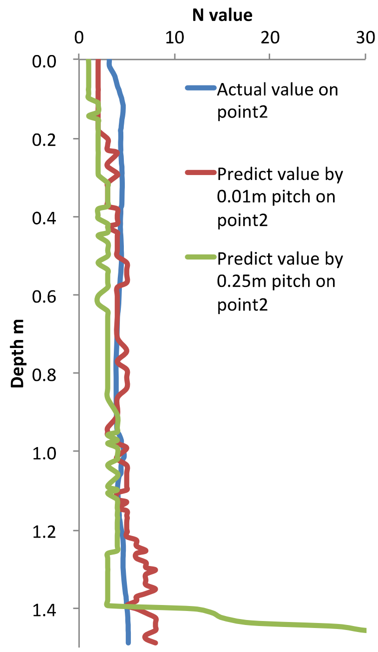

Fig. 10 Comparison between measured and predicted values with 0.01 and 0.25m pitch

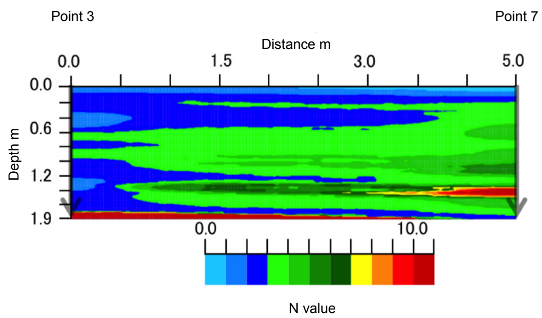

Fig. 11 Distribution by Kriging on other cross section

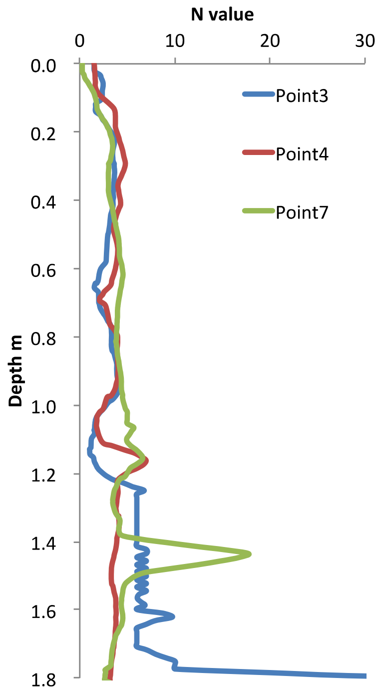

Fig. 12 Measured values on Point 3, 4 and 7

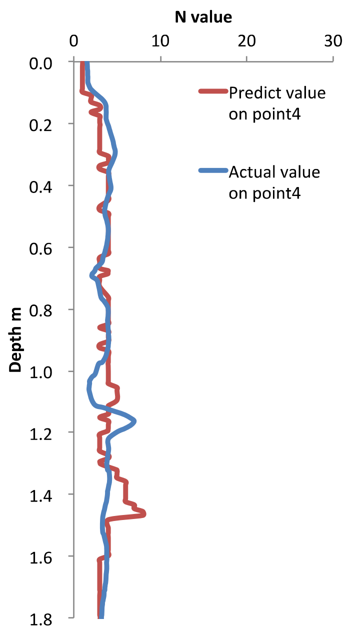

Fig. 13 Comparison between measured and predicted values on point 4

distributions. Therefore, finer measurement resolution enables more detailed estimations. Figures 8 and 9 show the soft ground on depth 100cm. Therefore, it sees very likely to be the soft ground to depth 100cm by Kriging method. Figure 10 is a comparison of two estimations with measured converted N-value at survey point 2. One can tell that at the deep ground the estimated value with 1.0cm pitch deviates less from the measured value. From this confirmation, one can see the need to collect many data by measuring with narrow interval. Also, since both estimations have small deviations up till 1.4m depth, it is safe to say the estimations have high-precision when treating measured values as true values. It thinks Kriging method has applicability on vertical. And, Figs. 7 and 10 are compared. From a comparison, Fig. 10 has smaller detail than Fig. 7. One can think that measuring many data on horizon is necessary on ground survey.

Figure 11 shows the result of Kriging method from survey point 3 to 7 with 0.01m pitch. With Fig. 11 one can confirm the existence of soft grounds down until 1.2m deep. From there, at the vicinity of survey point 12 hard grounds appear at the vicinity of 1.2m depth, and at the vicinity of 1.8m depth a wide-ranged hard grounds appear. Figure 12 shows

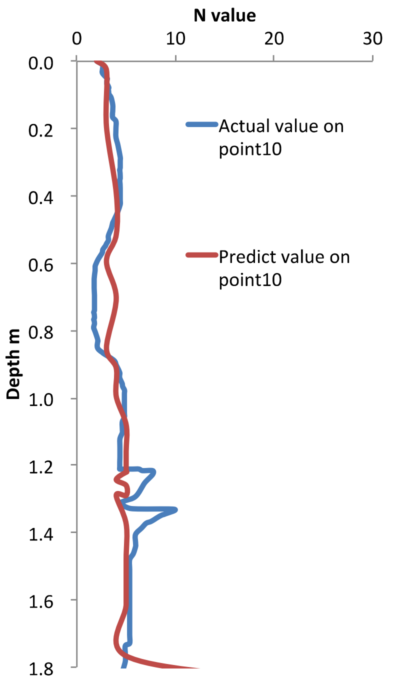

Fig. 14 Comparison between measured and predicted values on point 10

Table 1 Relative error with the measured value

Items	Relative error
Point 4	0.284210892
Point 10	0.595928736

measured values on point 3, 4 and 7. Higher N value is seen on depth 1.8m of point 3. Figure13 is the comparison of the measured value to estimated value at survey point 10. Figure 14 has small deviations at all. Table 1 shows relative errors of at point 4 and point 10. According to Table 1 both points have the relative errors less than one. This means both have relatively small errors. Because of these results, it is fair to say that the estimations for vertical and diagonal measurements are highly precise. Therefore, Kriging method is capable of interpolating in a plane.

5. CONCLUSIONS

In this study, the followings were examined:
(1) Applicability of Kriging method to the detached house grounds with a small area.
(2) It is possible for Kriging method to interpolate point data in a plane.
(3) The change in the estimation accuracy by changing the number of data.

Kriging method was carried out by changing measurement data pitch. One could confirm that the increase in number of data leads to higher accuracy. Also, Kriging method was applied at two cross sections, and relative errors with estimated values were small; one could support the applicability of Kriging method to the vertical measurement. Lastly, the applicability of Kriging method was tested against the diagonal measurement; Kriging method was applied at the cross section of survey point 3 and 7. The result supports Kriging method for the diagonal measurement. Therefore, it is fair to say Kriging method is capable of interpolating in a plane. Therefore, it sees Kriging method has applicability on detached house ground with a small area. Also each section has soft grounds to depth 100cm, it on this detached house grounds by Kriging method.

Kriging method is used on interpolation in grounds with a small area. Thereby, on this study it thinks interpolation in grounds with a small area become precision.

This means if estimated value by Kriging method has small deviation to measured value of additional search for verification, the soil survey can be finished; this helps financially as well.

Likewise, in this study, Evaluation of the ground base on interpolation of the aspect by Kriging method. Also, the applicability of the Kriging method is evaluated by compare to measured value and estimation value.

In the future work, ground is evaluated by estrangement condition of measured value and the estimation value. Ground is evaluated by Risk engineering.

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