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Primary Judgment of Liquefaction Possibility Based on Groundwater Level for Detached Houses

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ABSTRACT

In Japan, the Swedish Weight Sounding (SWS) test is a popular and essential method for evaluating the ground bearing capacity in home site. Measurement of groundwater level using a SWS test hole is applicable only when a groundwater sensor or a rod with tapeline for eye measurement can be installed into the hole. However, the method of eye measurement using the tapeline is susceptible to inaccuracies. In this point of view, in the former paper, we introduced the new groundwater measurement technique using a SWS test hole, a foraminate pipe and an Alternating Current (AC) resistivity sensor. The excellent performance of the new technique, degree of accuracy and the short settling time of less than 30 minutes were confirmed. In this paper, based on in-situ experiments, we investigated the relationship between settling time of the groundwater level in the SWS test hole and N-value with respect to the soil classification. In addition, by carrying out the two dimensional seepage flow analysis (FEM), the groundwater flow surrounding the SWS test hole was simulated numerically, and the new technique may become an effective tool for the primary judgment of liquefaction possibilities of home sites.

KEY WORDS: Measurement, Swedish Weight Sounding (SWS) test, Liquefaction, Groundwater level, Elapsed time, Detached Houses, Alternating Current (AC) Resistivity sensor

INTRODUCTION

Method for evaluating the ground bearing capacity in home sites using the Swedish Weight Sounding (SWS) test has been regulated by law in Japan, and it is required in advance to check the subsidence and displacement of buildings caused by liquefaction due to earthquakes. On the other hand, by the “Recommendations for Designing of Small Buildings Foundations”, the conventional method for liquefaction judgment with regard to the geographic features, grain size analysis and groundwater level has been prescribed for middle level earthquakes.
According to the recent study on liquefaction, it has been reported that the damage to detached houses is mainly caused by the liquefaction of saturated sand layers within 5m deep from the ground surface. In addition, it is reported that the damage is almost negligible when non liquefaction layers exist more than 3m thick above the liquefaction layer. Whether groundwater level exists within 3m deep from the ground surface is crucial in judging the possibility of liquefaction. With this in mind, the authors focused on the importance of measuring the groundwater level close to the ground surface, and developed a new technique for the primary judgment of liquefaction possibility using a SWS test hole and a foraminate pipe.

OUTLINE OF THE IN-SITU EXPERIMENT

A hollow steel foraminate rod of 1m length (19mm diameter and 12mm thickness with side surface holes of φ4mm@250mm) was used for measuring the groundwater level in the in-situ experiment. Screw point attached to the tip and the hollow steel foraminate rod inserted into the ground as in the SWS test, measurement of the groundwater level was carried out. In order to investigate the accuracy and settling time of the measurement of the groundwater level in the pipe, two observation holes of 1m distance from the rod were set before the experiment started. Details of the in-situ experiment are shown in Fig.1.

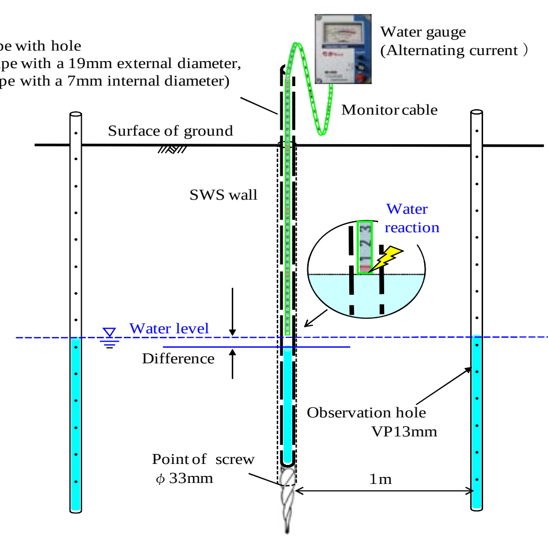

Fig.1 Method of the in-situ experiment

RESULTS OF IN-SITU EXPERIMENT

Fig.2(a) and (b) show the relationship between groundwater level and the elapsed time of the in-situ experiment for sandy soil and clay, respectively. It is recognized from Fig.2(a) and (b) that the settling time to the steady groundwater level in the pipe for the sandy soil is smaller than that of clay, meaning the settling time is closely related to the permeability of the soil. Fig.3 and 4 summarize the relationship between N-value, settling time and groundwater level in the pipe of the in-situ experiment (site A~G).

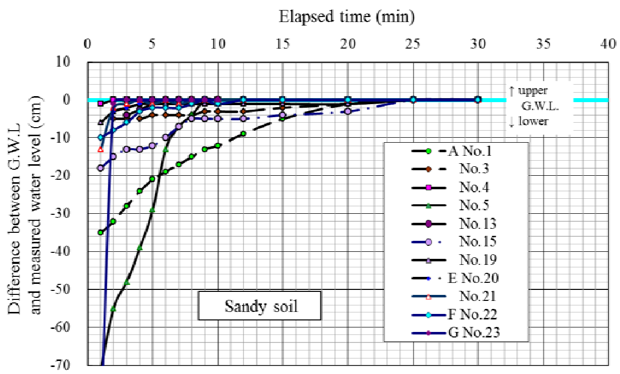

Fig.2 (a) Measured water level and elapsed time (Results of sandy soil)

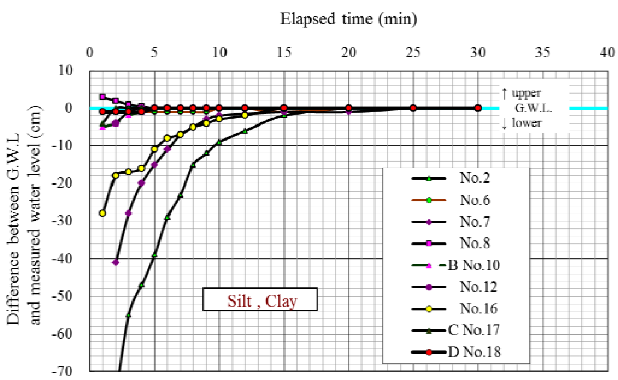

Fig.2 (b) Measured water level and elapsed time (Results of silt, clay soil)

In Fig.3, although both sites A and F are classified as sandy soil, the settling times of those sites are 5 minutes and 25 minutes, respectively. The difference of the settling time may be due to the density of sandy soil which is strongly related to the N-value. As the N-values below the groundwater level of site B~F are less than 5 and regarded as loose sand, the settling times of those sites are considered relatively small. On the other hand, although N-value of site G is about 10 and larger than that of site B~F, the settling time is only 3 minutes, due to the relatively large permeability of the soil (sand with gravel). Considering the data of settling time, it may be possible to make a rough estimation about the permeability and looseness of the soil with ease. For example, despite the geographical feature of site A being lowland and classified as "large possibility of liquefaction", relatively large N-value indicates otherwise, or that possibility of liquefaction is actually small or negligible. On the other hand, despite the geographical feature of site F being Back Swamp and classified as "middle possibility of liquefaction", relatively small N-value indicates a large possibility of "middle possibility of liquefaction".

In order to investigate the influence of permeability to the settling time numerically, two dimensional seepage flow analysis (FEM) of the in-situ experiment was carried out as follows.

	A	B	C	D	E	F	G
No.	1	10	17	18	20	22	23
Soil classification	Sandy soil	Silt	Sandy silt	Sandy silt	Silty sand	Sandy soil	Gravelly sand
Geographical Features	Lowland	Back swamp	Back swamp	Back swamp	Alluvial fan	Back swamp	Lowland
Possibility of liquefaction	Large	Medium	Medium	Medium	Small	Medium	Large
Groundwater level GL-(m)	1.53	1.65	1.12	1.23	1.12	1.83	1.11
Elapsed time (min)	25	5	2	1	5	5	3

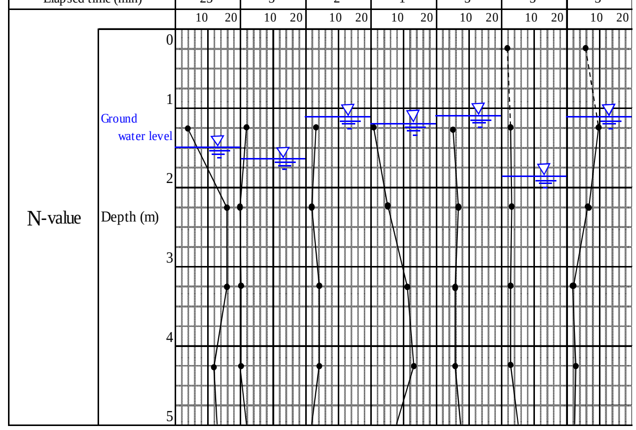

Fig.3 Groundwater level and N-value of borehole log

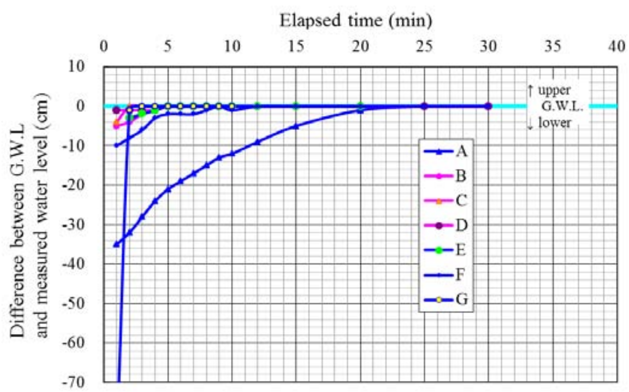

Fig.4 Measured water level and elapsed time (Results of A～G)

RESULTS OF SEEPAGE FLOW FEM ANALYSIS

Fig.5 shows the two dimensional seepage flow analysis (FEM) model of the in-situ experiment for sandy soil and clay. The analysis is based on the unsteady saturated-unsaturated seepage flow theory, and the following typical empirical van Genuchten model is applied for the soil moisture characteristic curve.

$$S_e = \frac{S_w - S_r}{1 - S_r} = \{1 + (\alpha\phi_C)^n\}^{-m} \qquad \mathrm{m} = 1 - \frac{1}{\mathrm{n}}$$

$$k_r = S_e^{\varepsilon}\left\{1 - \left(1 - S_e^{1/m}\right)^m\right\}^2$$

Here, Se: effective saturation ratio, Sr: residual saturation ratio, α, n, m: soil parameters, kr: specific permeability, ε:soil parameter (=1/2).

The foraminate pipe of 19mm diameter and 1m long is modeled in the uniform soil, and coefficients of permeability of soil (sandy soil and clay) and foraminate pipe are estimated from both Creager's equation and experimental data, as shown in Table 1. In the analysis, with the lapse of time, groundwater level surrounding the foraminate pipe changes gradually from the initial stage to the final stage. In the final stage, the groundwater level surrounding the foraminate pipe recovers to the original position, as shown in Fig.5.

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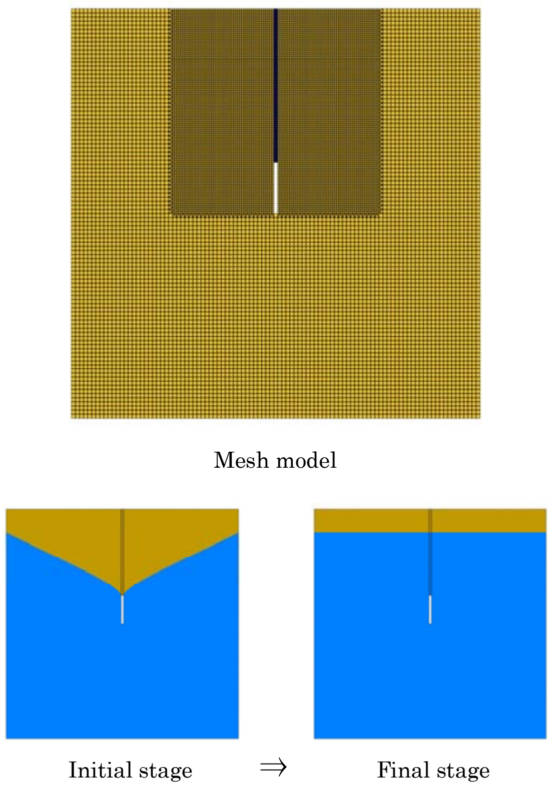


Fig.5 Model of the seepage flow analysis

Table 1 Coefficient of permeability

	Coefficient of permeability (cm/sec)	Foraminate pipe's coefficient of permeability (cm/sec)	Elapsed time (sec)
Sandy soil	1.0×10^{-2}~1.0×10^{-6}(1.0×10^{-4})	3.0×10^{-9}	60
Clay	1.0×10^{-6}~1.0×10^{-8}(1.0×10^{-7})	3.0×10^{-12}	300

Fig.6 shows the relationship between elapsed time and groundwater level at the foraminate pipe obtained by the in-situ experiment and the seepage flow analysis. Here, in order to investigate the tendency of the elapsed time qualitatively, results of No. 18(D) and 20(E) are extracted from Fig.3 as the typical cases of the in-situ experiment for clay/silt and sandy soil respectively, because these two sites are considered relatively uniform ground condition (or similar permeability) compared to the other sites. From Fig.6, although some differences are observed especially in the early stages, it is found that there is a relatively good agreement of the settling time between in-situ experiment and the simple seepage flow analysis. In this point of view, permeability of soil surrounding a foraminate pipe may be roughly but easily estimated using an SWS test hole. Considering that there is a close correlation between permeability of soil and soil classification (or grain size distribution), settling time of the groundwater level obtained from in-situ experiment may be able to give useful information on judgment of the liquefaction possibility, as shown in the following chapter.

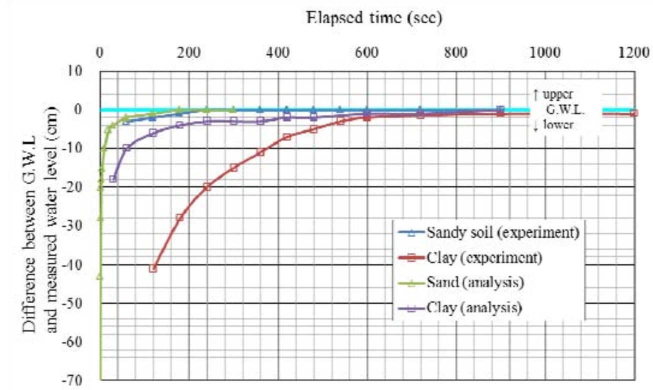


Fig.6 Comparison of the in-situ experiment and analysis

NEW TECHNIQUE FOR PRIMARY JUDGEMENT OF LIQUEFACTION POSSIBILITY

Per the "Recommendations for Designing of Small Buildings Foundations", possibility of liquefaction close to the ground surface is classified into 3 categories: Large (L), Medium (M), and Small (S). Those are simply determined by the geographical features of the site, as shown in Table.2. In Japan, on the other hand, the limit N-value method has been proposed for the conventional method of liquefaction judgment, as shown in Fig.7. In Fig.7, both groundwater level and N-value with regard to the depth are considered for the criteria of liquefaction judgment. Fig.8 also shows the relationship between influence of the damage by liquefaction and soil thickness. In Fig.8, H_1 and H_2 mean the soil thickness of liquefaction layers and non liquefaction layers within GL-5m deep of the ground surface, respectively. Here, the non liquefaction layers are defined as either sandy soil above the groundwater level or clay (fine fraction content Fc>35%), and the liquefaction layers are defined as sandy soil above the non liquefaction layers within GL-5m deep from the ground surface.

Table2 Geographical features(AIJ,2008)

Possibility of liquefaction of the ground surface	Geographical features			
Large (L)	Edge of natural levee Old river channel Sand-muddy Reclaimed land	Small natural levee Low land Gentle in dune	Shallow Old swamp Artificial shore	Low land in dune Embankment Inflow water
Medium (M)	Alluvial fan of gentle slope Swamp	Delta valley plain Cuspate delta	Natural levee Bar	Back swamp Polder
Small (S)	Sand-gravel banks Delta plain of fan type	Alluvial fan Gravel bar	Shore Dune	

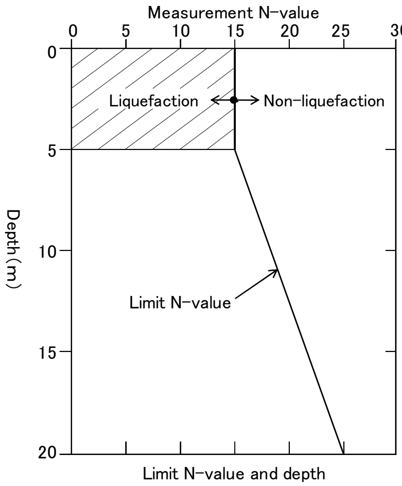
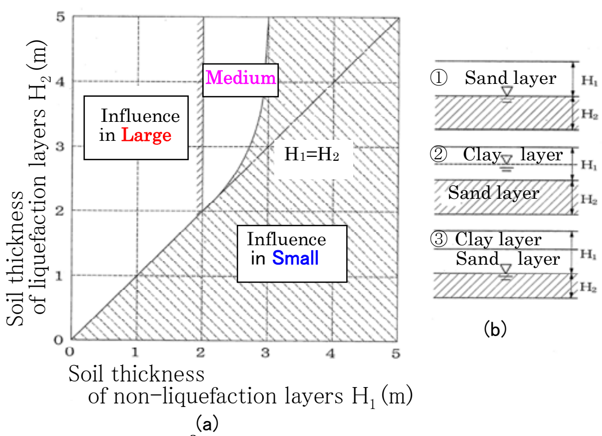


Fig.7 N-value and liquefaction/Non-liquefaction possibility
(Slightly modified)



(200cm/s^2 accelerate at the ground surface)
Fig.8 Influence of liquefaction to the ground surface (AIJ, 2008)

As the level of liquefaction possibility is influenced by the grain size distribution even in the liquefaction layers, the grain size should be taken into account for judgment, as shown in Fig.9.

For detached houses, the SWS test is commonly applied for the investigation within GL-5m deep from ground surface and N-value of less than 15. In this point of view, as shown in Fig.11, the authors proposed the new method for the primary judgment of liquefaction, and the new method is applicable to all types of ground condition in which the SWS test can be carried out.

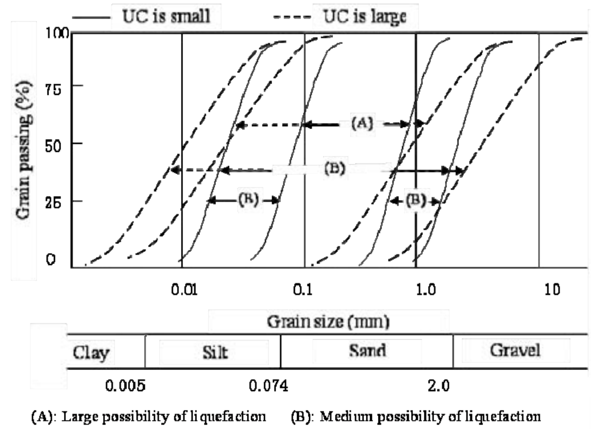


Fig.9 Grain size and possibility of liquefaction
(Basic knowledge of technical engineering)

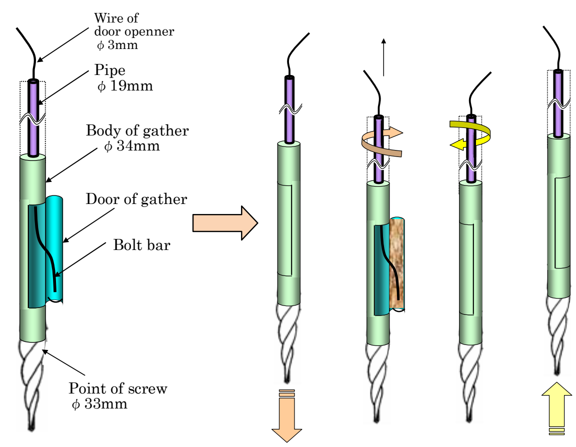
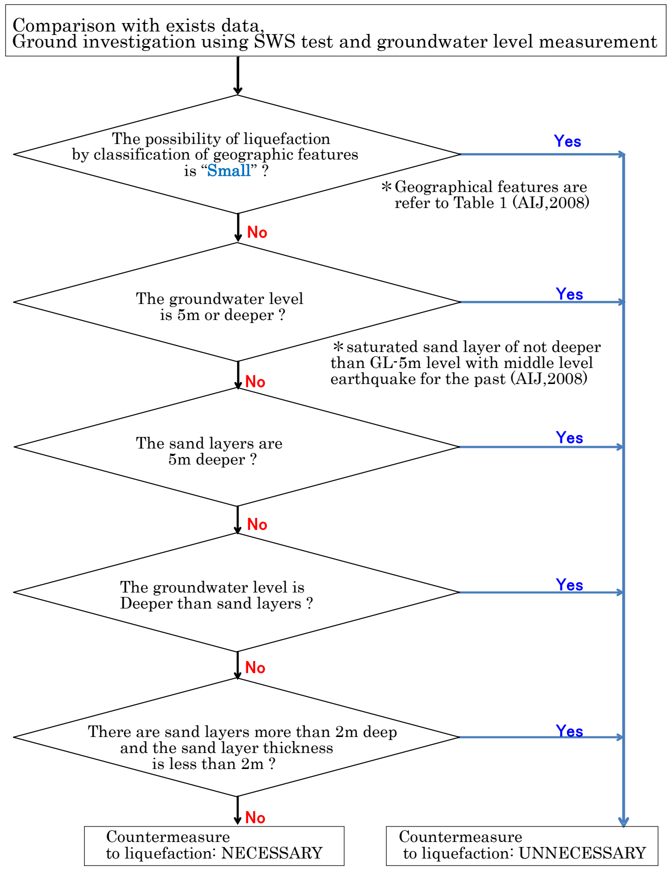


Fig.10 Method of the soil sampler

Fig.11 is the Flow-chart of the primary judgment of liquefaction based on existing data, materials and the SWS test results. In the first step, using the existing datum such as geographical features, geological and ground maps, boring data in the vicinity and local hazard maps, the first judgment is carried out for * items in Fig.11. In the next step, the second judgment is carried out considering both the groundwater level measured by the SWS test holes as shown in Fig.1, and soil classification and thickness of the sand layers measured by the newly developed soil sampler as show in Fig.10. According to circumstances, the grain size test may be carried out, and possibility of liquefaction judgment is performed based on the fine fraction content Fc. In the new method for primary judgment of liquefaction for detached houses, soil of less than 5m deep from the ground surface is usually considered in terms of the soil vertical stress. For example, when groundwater level exists GL-2m and clay exists between GL-3m and GL-5m deep from the ground surface, liquefaction judgment is unnecessary. Because the new technique using the SWS test hole is able to obtain the datum of both groundwater level and soil classification almost simultaneously, the preliminary judgment of liquefaction by Fig.11 can be easily carried out.

Primary judgment of liquefaction possibility based on groundwater level for detached houses by middle level earthquake



(Ground surface acceleration reference value: 150 to 200cm/s^2)

＊Area with non possibility of liquefaction.
・diluvial upland or diluvium which appears near the ground surface.
・Thick clay apparently exists near the ground surface.
・Ground water exists very deep.
・Regional disaster prevention map indicates the non possibility of liquefaction.

Fig.11 Flow-chart of liquefaction judgment (Slightly modified)

SUMMARY

It is reported that damage to detached houses by middle class earthquakes is almost negligible when non liquefaction layers exist within GL-3m deep from the ground surface. Therefore, measurement of the groundwater level within GL-3m deep from ground surface is very important in determining the possibility of liquefaction. The authors developed the new technique for measuring with relatively short time and accuracy the groundwater level and soil classification using the SWS test holes. In addition, as the SWS test is commonly applied to the investigation of home sites within GL-5m deep from ground surface and N-value of less than 15, the authors proposed the method of preliminary judgment of liquefaction for home sites based on the flow-chart, as shown in Fig.11.

In the next step, we will not only research the effective countermeasure to liquefaction, but also propose a more detailed new method of liquefaction judgment for home sites, especially in case of the small possibility of liquefaction estimated by the conventional method.

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