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New Technique for Measuring Groundwater Level and Permeability in Small House Ground

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INTRODUCTION

Due to the 2011 Tohoku Earthquake off the Pacific coast, the social interests and attentions to ground investigation methods and liquefaction damage of detached houses have been increasing in Japan.. The Land, Infrastructure, and Transport Ministry of Japan officially uses the Swedish Weight Sounding (SWS) test as determined by Notice 1113. The authors utilized the SWS test to measure the groundwater level using an SWS test hole, and it was found that the groundwater measurement technique described in this paper may become an effective tool for simple soil classification and rough judgment of the liquefaction possibility at the ground of detached houses.

KEY WORDS: Groundwater level, Elapsed time, Permeability, Soil classification

DEVELOPMENT OF GROUNDWATER MEASUREMENT

Measurement of the groundwater level using the SWS method includes visual inspection of rod and water level in the test hole. However, visual inspection lacks reliability. Detailed reading is difficult and measurement becomes impossible when using the perforated pipes, sensors, and cables.
Analog Current (AC) Meter is more reliable compared to the DC Meter when measuring the groundwater levels. In DC mode, water level cannot be reliably measured because of electrolysis. Bubbles in the water change value of the DC meter electrodes, and that indicates data of the measurements is unreliable.

Fig. 1 Measurement of groundwater level using the SWS test hole in progress

Fig. 1 and Fig. 2 show the measurement of groundwater level using the SWS test hole and using the AC double pole resistivity sensor, respectively.

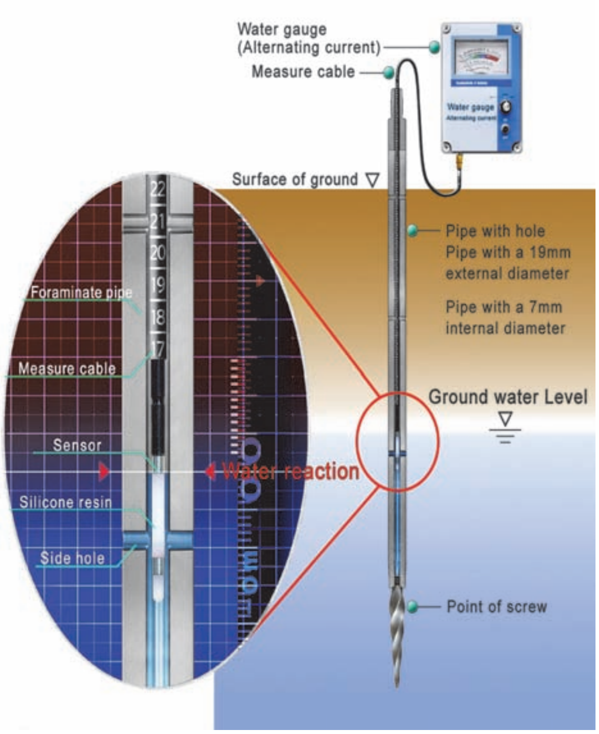


Fig. 2 Diagram of AC double pole resistivity sensor for measurement of groundwater level

Fig. 3 Apparatus consisting of a foraminate pipe (19mm outer dia., internal dia.7mm) with bore hole

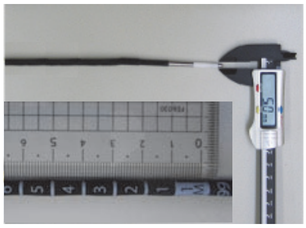


Fig. 4 Sensor and measuring cable (ϕ 5mm)

Fig. 3 shows the apparatus consisting of a foraminate pipe with borehole. In Fig. 4, a detailed measurement cable of 1cm increments (scale) is used, which is regulated by the article of JGS 1311-2003. As the maximum of 10m depth from the ground surface is required for groundwater measurement, a length of 12m of cable is used for efficiency. 25mm of silicon resin separates the 2 sensors on the water gauge to allow for accurate readings in the case where mud or debris sticks to the sensors.

REASONS FOR USING THE GROUNDWATER LEVEL MONITOR OF AC RESISTIVITY SENSOR

As the diameter of the foraminate pipe is 7mm and so small, bubbles tend to remain in the pipe and may result in inaccurate readings for measuring the groundwater level. Additionally, in case of saturated silt ground, sometimes the bubble remains below the groundwater level. In this point of view, minor changes of the groundwater level should be measured accurately when using the foraminate pipe. After several experiments, it turned out that the Alternating Current (AC) resistivity sensor is more accurate than the Direct Current (DC) resistivity sensor.

G.W.L.
Monitor ------AC signal ---Analog Meter ○ (best for accuracy and readability)
--Digital Meter △ (inappropriate for readability)
--DC signal ---Analog Meter × (inappropriate for accuracy)
--Digital Meter × (inappropriate for accuracy)

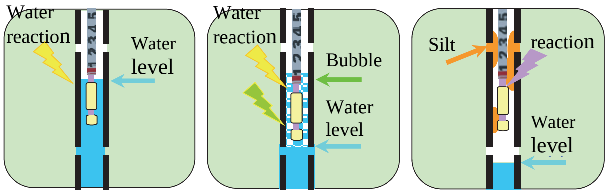
Fig. 5 AC resistivity sensor

In the DC resistivity type, the resistance increases more than 25% in a very short time due to electrolysis (gas generation) in the electrode. When the electrode is slightly moved in the water, the same phenomenon occurs and the measurement data becomes unstable.

Ground Water Level Monitor

As the sensitivity control is bad, several errors of the underground water level were observed. In order to measure the minor change of the resistance when reaching the underground water, the analogue meter system with properly adjusted time was found to be effective and appropriate in terms of readability. At present, however, the monitor using the analogue meter system is not available in the Japan market.

In the AC resistivity type, electrolysis does not occur and the sensitivity and reliability are found to be excellent. To measure the minor change of underground water level using the foraminate pipe, it has been found that the AC resistivity sensor is most effective. For this reason, the authors developed the original "Groundwater level monitor of the AC resistivity sensor", as shown in Fig. 5 and Fig. 6.



①Case of standard water level(conductivity increased rapidly)

②Case of bubble in the water(conductivity increased by 2 steps)

③Case of clay of high water content sticking to pipe

Fig. 6 Detail of measurement using the AC resistivity

RESULTS OF IN-SITU EXPERIMENT

Outline of in –situ experiment is as follows:
VP13 Vinyl Chloride pipe (outer and inner diameters are 18mm and 13mm, and diameter and distance of each horizontal hole of the pipe are 4mm and 250mm, respectively) is inserted into observation wells.
Immediately after caring out the SWS test, the foraminate pipe (19mm diameter, 7mm internal diameter, 1 meter segments with measuring cable and resistivity sensor) is inserted. At 30 second intervals, readings of the data were taken in the first 5 minutes. From the 5 minute to 10 minute mark, measurements were taken at 1 minute intervals. From the 10 minute mark and on, readings were taken at 5 minute intervals. Relationship between in-situ experiment and GWL test obtained by the measurement is shown in Fig. 7.
Of the test sites, 15 were in sandy soil and 10 sites were clay, and a total of 25 sites were tested. From the data obtained from the in-situ tests, it was found that the method of groundwater measurement is reliable.

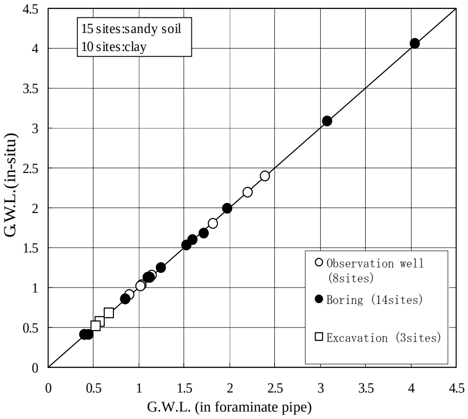


Fig. 7 Relationship between in-situ G.W.L. and experiment

Table 1 shows results of the experiment and grain size distribution in the 25 sites. No. 24 in Fukuoka Prefecture: long measurement time of 30 minutes a result of creamy silt entering the foraminate pipe.
Of the 15 sandy soil sites, 6 site measurement times were 5 minutes shorter on average. Of the 10 clay sites, 7 site measurement times took 5 minutes longer. From these results, difference of sandy soil and clay can be understood. All tests among the 25 sites were finished within 30 minutes.

Table 1 Results of the experiment and grain size

	Soil	No.	Site	G.W.	Elapsed time	Confirmation of G.L.	Grain size						2011.3.11 Liquefaction occurred
							Gravel fraction	Sand fraction	Silt fraction	Clay fraction	Coarse grained fraction	Fine grained fraction	
							(%)	(%)	(%)	(%)	(%)	(%)	
Sandy soil	Sandy soil	1	Ohmagari,Miyagi	1.53	25	Boring	0.1	77.2	7.6	15.1	77.3	22.7	-
	Silty sand	2	Takasu,Chiba	0.4	12	Boring	6.5	81	8.4	4.1	87.5	12.5	○
	Sandy soil	3	Hamamatsu,Shizuoka	1.8	15	Observation well	36.5	57.9	0	0	94.4	0	-
	Sand with clay	4	Kita,Okayama	1.03	5	Observation well	7.3	79.1	8.6	5	86.4	13.6	-
	Sandy soil	5	Ibaraki,Oosaka	0.4	5	Observation well	0.1	72.7	17.3	9.9	72.8	27.2	-
	Silty sand	6	Narashino,Chiba	1.15	4	Observation well	0	85.8	14.2	0	85.8	14.2	○
	Silty sand	7	Fujimi,Chiba	2.19	7	Observation well	0.1	77.5	15.9	6.5	77.6	22.4	○
	Granular sand	8	Fujieda,Shizuoka	0.9	3	Observation well	68	20	7	5	88	12	-
	Sandy soil	9	Fuefuki,Yamanashi	2.39	5	Observation well	0	52.2	47.8	0	52.2	47.8	-
	Silty sand	10	Kurasiki,Okayama	1.12	5	Boring	0.1	51.6	25.9	22.4	51.7	48.3	-
	Fine sand	11	Kamasu,Ibaraki	1.25	9	Boring	0	97.4	2.6		97.4	2.6	○
	Sandy gravel	12	Urayasu,Chiba	0.85	8	Boring	1.0	81.1	12.3	5.6	82.1	17.9	○
	Silty sand	13	Tosu,Saga	3.08	9	Boring	1.5	66.6	19.3	12.6	68.1	31.9	-
	Silty sand	14	Iizuka,Fukuoka	4.05	20	Boring	4.7	73.2	13.7	8.4	77.9	22.1	-
	Sandy soil	15	Higasi,Fukuoka	1.6	25	Boring	1.0	96.0	3.0		97.0	3.0	-
Clay	Clay	16	Yamagata,Yamagata	0.57	20	Excavation	0.2	30.6	30.1	39.1	30.8	69.2	-
	Clay	17	Souka,Saitama	0.67	10	Excavation	0	40.9	59.1	0	40.9	59.1	-
	Clay	18	Hokota,Ibaraki	0.52	12	Excavation	1	19	38	42	20	80	-
	Sandy silt	19	Kurume,Fukuoka	1.68	30	Boring	0	32.5	36.1	31.4	32.5	67.5	-
	Sandy silt	20	Adachi,Tokyo	0.41	15	Boring	0	16.2	43.5	40.3	16.2	83.8	-
	Sandy silt	21	Karatsu,Saga	1.98	3	Boring	1.6	33	40.5	24.9	34.6	65.4	-
	Sandy silt	22	Ichinomiya,Miyagi	1.02	8	Observation well	0.8	19.2	45.5	34.5	20	80	-
	Sandy silt	23	Edogawa,Tokyo	1.12	2	Boring	0	45.9	37.5	16.6	45.9	54.1	-
	Sandy clay	24	Funabashi,Chiba	0.85	3	Boring	1	28	37	34	29	71	-
	Clay	25	Sashima,Ibaraki	1.12	9	Boring	0	42	37	21	42	58	-

Table 2 Summary of in-situ

	Soil	No.	Site	Depth G.L-(m)	G.W.		G.W.	Elapsed time	Confirmation of G.L
					In-situ grand water Level m	Dif. cm			
Sandy soil	Sandy soil	1	Ohmagari,Miyagi	3.00	1.53	0	1.53	25	Boring
	Silty sand	2	Takasu,Chiba	20.00	0.45	5	0.40	12	Boring
	Sandy soil	3	Hamamatsu,Shizuoka	3.50	1.82	2	1.80	15	Observation well
	Sand with clay	4	Kita,Okayama	10.00	1.04	1	1.03	5	Observation well
	Sandy soil	5	Ibaraki,Oosaka	4.25	0.40	0	0.40	5	Observation well
	Silty sand	6	Narashino,Chiba	10.00	1.15	0	1.15	4	Observation well
	Silty sand	7	Fujimi,Chiba	10.00	2.20	1	2.19	7	Observation well
	Granular sand	8	Fujieda,Shizuoka	5.95	0.90	0	0.90	3	Observation well
	Sandy soil	9	Fuefuki,Yamanashi	2.80	2.40	1	2.39	5	Observation well
	Silty sand	10	Kurasiki,Okayama	10.70	1.12	0	1.12	5	Boring
	Fine sand	11	Kamasu,Ibaraki	20.00	1.25	0	1.25	9	Boring
	Sandy gravel	12	Urayasu,Chiba	20.00	0.85	0	0.85	8	Boring
	Silty sand	13	Tosu,Saga	4.00	3.08	0	3.08	9	Boring
	Silty sand	14	Iizuka,Fukuoka	6.60	4.05	0	4.05	20	Boring
	Sandy soil	15	Higasi,Fukuoka	2.10	1.60	0	1.60	25	Boring
Clay	Clay	16	Yamagata,Yamagata	10.00	0.57	0	0.57	20	Excavation
	Clay	17	Souka,Saitama	10.00	0.67	0	0.67	10	Excavation
	Clay	18	Hokota,Ibaraki	10.00	0.53	1	0.52	12	Excavation
	Sandy silt	19	Kurume,Fukuoka	12.75	1.72	4	1.68	30	Boring
	Sandy silt	20	Adachi,Tokyo	10.00	0.41	0	0.41	15	Boring
	Sandy silt	21	Karatsu,Saga	5.00	1.98	0	1.98	3	Boring
	Sandy silt	22	Ichinomiya,Miyagi	9.75	1.02	0	1.02	8	Observation well
	Sandy silt	23	Edogawa,Tokyo	8.95	1.12	0	1.12	2	Boring
	Sandy clay	24	Funabashi,Chiba	10.00	0.85	0	0.85	3	Boring
	Clay	25	Sashima,Ibaraki	8.40	1.10	2	1.12	9	Boring

Fig. 8 shows the relationship between soil type and the elapse time of the experiment. As described, the elapsed time for sandy soil is shorter than that of the clay, and the reliability of measurement of groundwater level using a foraminate pipe is confirmed.

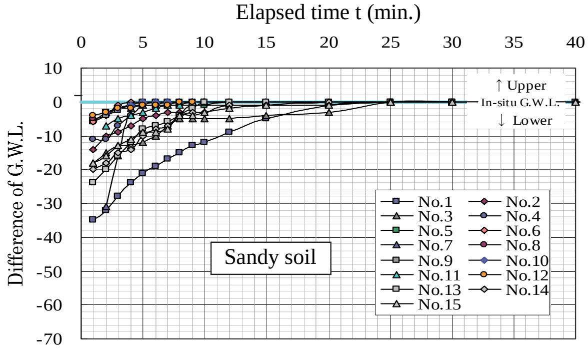


Fig. 8 (a) Measured ground water level and elapsed time (sandy soil)

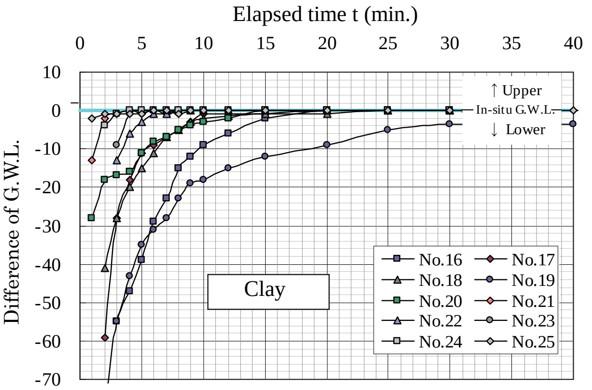


Fig.8 (b) Measured ground water level and elapsed time (clay)

The SWS test field test results show that ground water short term measurement is possible.

SIMPLIFIED TECHNIQUE OF SOIL CLASSIFICATION

Concerning small buildings and detached houses, it is difficult to ascertain the soil type using the SWS test due to the difficulty of sampling the soil specimen. However, it may be possible to discern the type of soil directly under the groundwater by considering the relationship between the groundwater level and elapsed time.

In Fig. 9, *h* and *t* are defined by the groundwater level and the elapsed time respectively, and those are very similar to the hyperbolic curves of consolidation settlement of the ground surface. From the recovery curve of groundwater level in the borehole data, information regarding the hyperbolic line parameter *a*/*b* can be easily obtained.

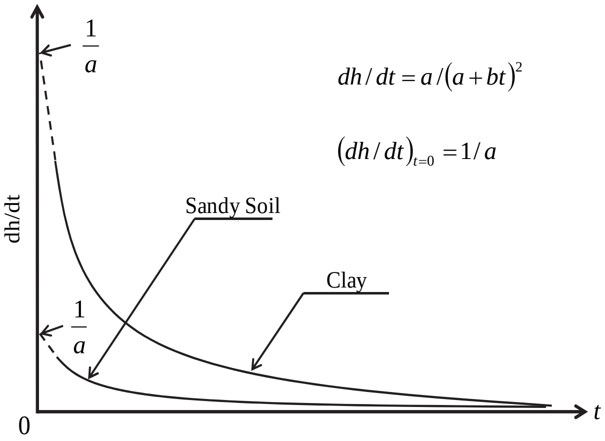


Fig. 9 Soil classification by hyperbolic model

Hyperbolic model h= t/(a+bt), $dh/dt=a/(a+bt)^2$ …… (1)

This formula was used and tried with various criteria and parameters. In addition, the authors studied the possibility of different types of soil classifications as shown in Fig. 9, based on soil texture classification of target soil layers (or permeability) and value of *dh*/*dt*, where *t*=0 (equivalence initial gradient 1/*a* of hyperbolic model).

Fig. 10 (a) and Fig. 10 (b) show the relationship between sandy soil and clay soils over elapsed time *t* and groundwater recovery rate *dh/dt*.

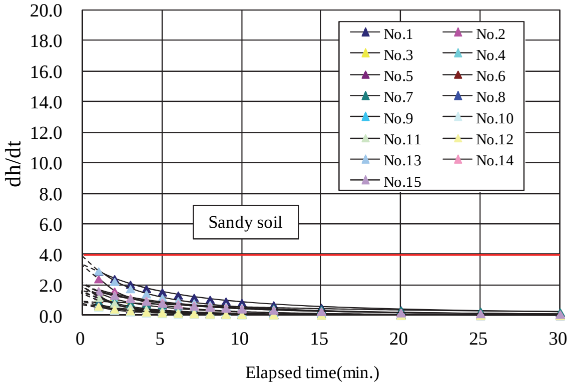


Fig. 10 (a) Relationship between elapsed time t and dh/dt (sandy soil)

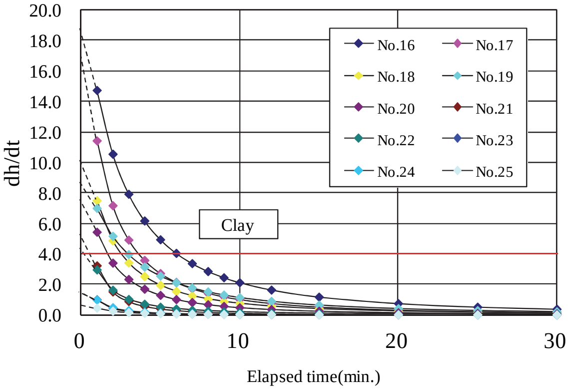
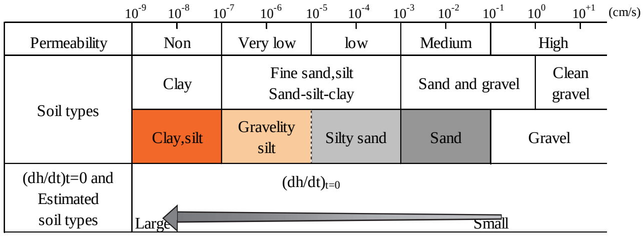


Fig. 10 (b) Relationship between elapsed time t and dh/dt (clay)

Fig. 10 (a) is for sandy soil of 15 sites and Fig. 10 (b) is for clay of 10 sites, and attention are made to the values of *dh*/*dt* where *t*=0 (equivalence initial gradient). Data from 2 sites were not included in the Fig. 10, where it did not reach *dh*/*dt*=4.0. Aside from those 2 sites, $(dh/dt)_{t=0}$ value for rough estimation of soil classification can be understood based upon the difference of the estimated coefficient of permeability. 2 sites, No. 24 and No.25 , were clay sites, but standing water from rains days before influenced the in-situ results. Therefore, aside from site 24 and 25, from this experiment $(dh/dt)_{t=0}=4.0$ has been determined as the boundary value. Fig. 11 shows the method of determining the soil schematically with (using) the small and large of $(dh/dt)_{t=0}$.



Permeability	Non	Very low	low	Medium	High
Soil types	Clay	Fine sand,silt Sand-silt-clay		Sand and gravel	Clean gravel
	Clay,silt	Gravelity silt	Silty sand	Sand	Gravel
(dh/dt)t=0 and Estimated soil types	$(dh/dt)_{t=0}$				

Fig. 11 Relationship between dh/dt and soil types

SIMPLIFIED EVALUATION OF SANDY SOIL BY NON-STEADY STATE METHOD

Relationship between permeability of sandy soil and *N*-value are investigated based on the results of in-situ experiment. The hyperbolic parameters, *a*, can be determined by the measured water level differences s= | h_0-*h*| (m) and the elapsed time t(sec) as with the prediction of consolidation settlement. Here, h_0(m) means the equilibrium (steady) water level, and the initial gradient of the hyperbolic curve was considered to be closely related to the soil classification.

In addition, assuming that the outer diameter *D* = ϕ 19 mm (0.019 m), internal diameter *D e* = ϕ7 mm (0.007 m) of the foraminate pipe and test interval length *L*, the linear gradient method with non-steady state of permeability as well as the borehole geotechnical investigation method are considered in Fig. 12 and Fig. 13.

Initial tangent slope $$a = \frac{\log(s_1/s_2)}{t_2 - t_1} \quad \cdots\cdots(2)$$

Permeability coefficient $$k\ (\mathrm{m/s}) = \frac{(2.3d_e)^2}{8L}\log(2L/D) \cdots\cdots(3)$$

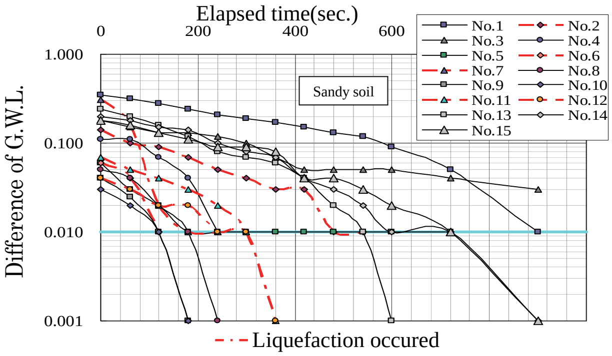
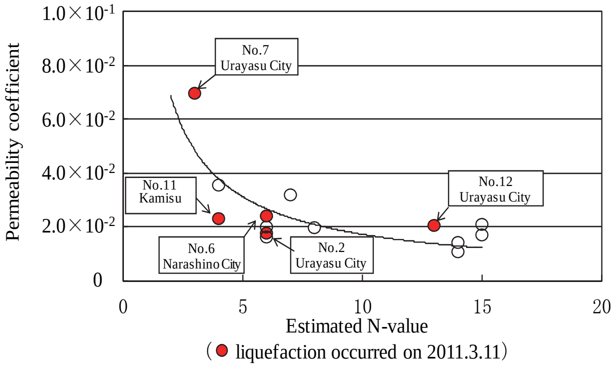


Fig. 12 log s-t curve



（● liquefaction occurred on 2011.3.11）

Fig. 13 Coefficient of permeability and estimated N-value curve

SUMMARY

In this paper, we introduce a new groundwater measurement technique using a SWS test hole, a foraminate pipe and an Alternating Current (AC) resistivity sensor. This new technique has advantages in that the steady groundwater level can be measured accurately in a very short time, and it may become an effective tool for simple soil classification and estimation of liquefaction possibility in the ground of detached houses. The authors expect that the new technique will be an effective tool for evaluating the liquefaction damage of detached houses, and be able to measure multiple ground water levels in the soil layers with accuracy.

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