Detailed Investigation Method and Its Investigation Apparatus for Natural Subsidence due to In-Ground Caverns

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1. Introduction

An objective of Swedish weight sounding (SWS) test is a comprehension of soil stratums' composition by firstly measuring static penetration resistance of a stratum with weight load penetration and rotation and secondly judging its hardness/softness or stiffness.

Although in the Western nations it is widely used as one of simplified sounding methods, and despite its convenience in Japan it is not widely used because it is incapable of sampling and the intricacy of Alluviums 1)

I would like to report about NSWS which is developed as an in-situ investigation apparatus, its features, and its field experiment result. NSWS conforms to the SWS test, which is capable of collecting penetration resistance by rotating, and loading, and is capable of detecting ultra soft areas, in-ground caverns included, by applying 0 to 1000 N loading which was conventionally thought impossible to embody and controlling sinking speed with segmentalized measurement frequency.

2. Functions of NSWS

2.1 Weight Loading

Although a recent trend of developments of loading devices of the SWS test is to streamline procedures and it is widely spread, it has problems such as that it cannot measure from 0N because total weight of a motor and a gondola for loading becomes close to 500N which makes impossible to measure less than 500N for initial loading.

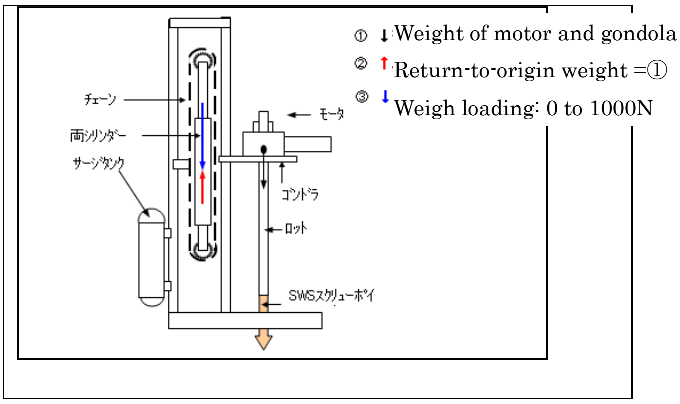


Fig. 1 - The Mechanism of NSWS and a Weight Being Loaded.

As depicted in Fig. 1, NSWS enabled itself to measure from 0 to 1000N continuously by creating zero loading state by applying an equal amount of a load created by both cylinders, air-oil pressured, opposed to total weight of the motor and gondola as indicated by ② return-to-origin loading.

2.2 Diagonal Measurement

Diagonal measurement is embodied because a loading control of NSWS is an air-oil pressure control system, and loading does not depend on measurement directions.

Photo Picture 1 - NSWS Measurement Scene

2.3 Measurement Resolution

A gear which is fixed to a cylinder functions as a movable pulley, and a gondola is attached to a chain like a chain hoist. The chain moves twice a moving distance of the cylinder, and a chain pitch which is equal to a gear pitch is 1.75 cm so the measurement resolution is 1.75 x 2 = 2.5 cm. Compared to a conventional SWS machine, which has a measurement resolution of 25 cm, NSWS can gain more detailed data.

Also, by segmentalizing a measurement frequency, calculation of sinking speed become possible. This enabled NSWS to detect a self-scuttling, which the system recognize as such when it sinks 5 cm within one second, and ultra soft areas such as caverns.

3. Field Experiment

3.1 An Investigation Result of Soft Alluvium

Photo Picture 1 is a field experiment scene using NSWS at double-track railway line construction work venue which was at JR Sagano line in Yagi district, Nantan-city, Kyoto prefecture.

Also, fig. 2 depicts boring data, which are a boring log and soil classification, measured 20 m away from the venue, and NSWS data which include number of rotation, loading weight, soil classification according to NSWS, Inada-style converted N-values.

A measurement location is a soft ground area developed over time by accumulating deposits at a bottom of a valley. Its layers are from the top a gravels mixed clay layer("GT" layer thickness 0.05 m), a Upper clay stratum("C" layer thickness 1.95 m), a humus soil layer("C" layer thickness 5.25 m), an alluvium sand and gravel layer, a diluvium cohesive soil layer, a diluvium sand, and a gravel layer. An embankment had been extended for a double-track construction work, and a soil improvement had been conducted as a safety measure.

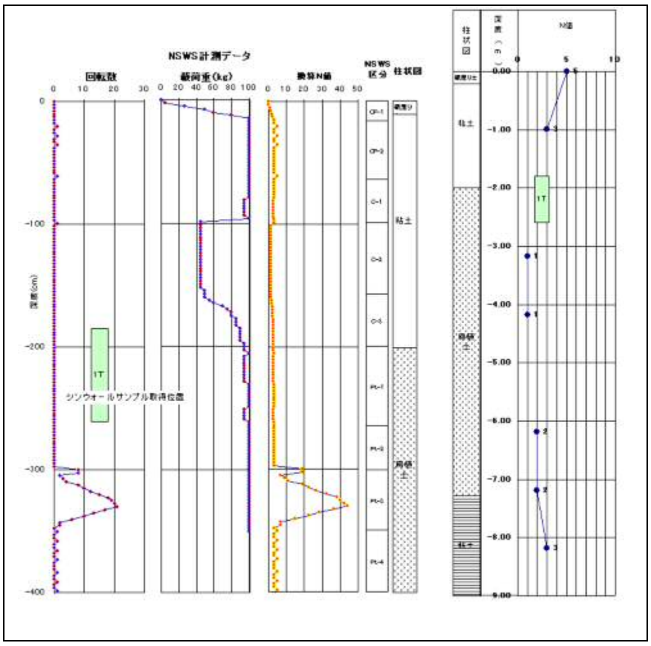


Fig. 2 - An Investigation Result Using NSWS and a Boring Investigation Nearby

※Translation of Fig. 2 is posted at the end of this paper.

資料番号		1T
深度(NSWSに換算)		1.865～2.615
観察土質名		腐植土
工学的分類	記号	Pt
	分類名	高有機質土
湿潤密度 ρt g/cm3		1.057
土粒子密度		1.798
自然含水比 Wn %		413.7
液性限界 WL %		331.8
塑性限界 WP %		163.9
塑性指数 IP		167.2
コンシステンシー指数 IC		-0.46
1軸圧縮強さ qu kN/m2		44.4～46.2
圧縮指数 Cc		5.50
圧密降伏応力 Pc kN/m2		29.0

Fig. 3 - Soil Test Result

※Translation of Fig. 3 is posted at the end of this paper.

Followings are verified by comparing a number of rotation, weight loading, which are the result of NSWS measurement, and existing soil documents

① One cay tell based on number of rotation with a measurement resolution of 2.5 cm that the upper gravels mixed clay layer extends down to about GL-60 cm. This sorting is indicated at Fig. 2 by GT-1 and GT-2 at NSWS soil partition column.

②One can tell by weight loading data

where converted N-values are equal or less than two that there is a new soft humus layer on top of the upper clay layer. This sorting is depicted at NSWS soil partition column of Fig. 2 as CT-1, CT-2, and CT-3 which are the partitions of the clay layer.

③ Thin-walled sampling was carried out at the humus layer where a weight loading was equal to or more than 95 kg and equal to or less than 100 kg without rotation. A softer layer on top of that layer was confirmed.

④ In the vicinity of GL-3.3 m where an increase in a number of rotation was indicated one could notice the drill was dragging some objects as investigating; the boring document indicates the presence of volcanic ash(silt), wood, and grass. NSWS soil partition column segmentalizes the humus layer into Pt-1, Pt-2, Pt-3, and Pt-4.

3.2 Diagonal Measurement

Fig. 4 shows the relationship of two NSWS investigation results at the same location, one was measured vertically while other was measured at 30 degrees. One can explain the downward shift of weight loading as well as rotation of the diagonal measurement is due to depth calibration, vertical depth = diagonal depth x cos(30).
One can tell the increase in loading amount of the diagonal measurement in comparison to the vertical measurement; the diagonal measurement increased overburden pressure more than the vertical measurement. I believe that a decrease in number of rotation is due to anisotropy of soil shear resistance in measurement direction.

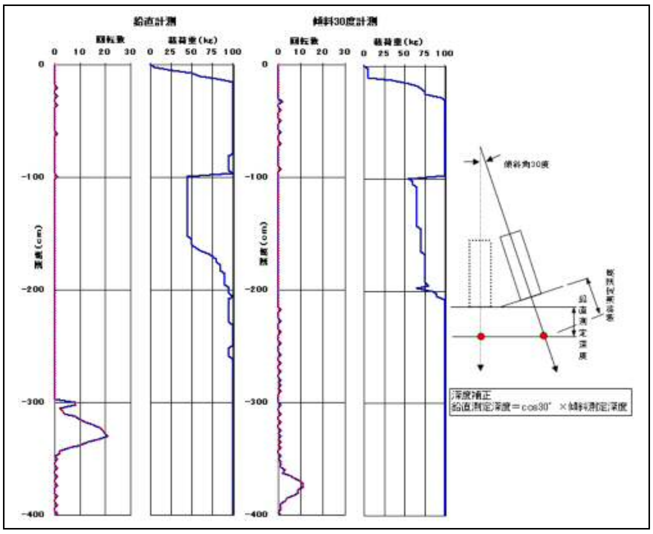


Fig. 4 - Vertical Measurement and Diagonal Measurement

※Translation of Fig. 4 is posted at the end of this paper.

3. Conclusion

Further research of development of handling method for data which are collect by segmentalzing measurement frequency and the difference in shear resistance due to anisotropy or nearby friction resistance are necessary.

On the other hand, NSWS is capable of providing data which is impossible to collect with conventional machines. And it is an effective machine for establishing reconstruction technology and disaster prevention technology for river levees, reservoirs, valley-filled embankments, extensions of existing embankments, back cavitation investigation which recently have been talked often.

Lastly, I'd like to appreciate Takenaka Civil Engineering & Construction Co.,Ltd for providing us the venue for the field experiment and existing soil documents, and Yamaichi Kensetsu Co.,Ltd for supporting the investigation.

Reference

1). The Japanese Geotechnical Society: "A Method and Its Explanation of Soil Exploration" pp280～294, 2004.

2). An Investigation Report of Sagano Line Transportation Improvement Construction Work (Accepted a copy in January 18th, 2008)

＊A Main Point of This Paper

This paper awarded the ground technology prize by the Japanese Geotechnical Society Kansai in 2009.

A main point of this paper is that Boring SPT N-value does not accurately reflect the soil property. Therefore, the construction work mentioned above sampled soil at a layer which was not the weakest.

Verification of soft layers is a must for construction works, safety measures, and safety precaution, and NSWS is best suited for solving these matters.

A Definition of SPT N-Value

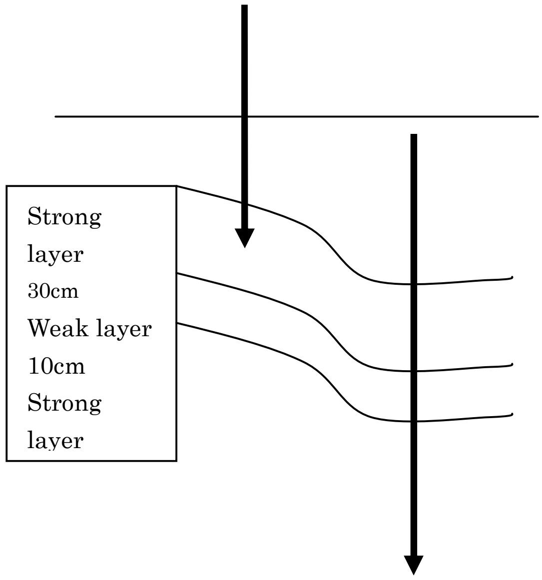
A following is a quotation of Standard Penetration Test from Wikipedia:

"Procedure

The test uses a thick-walled sample tube, with an outside diameter of 50 mm and an inside diameter of 35 mm, and a length of around 650 mm. This is driven into the ground at the bottom of a borehole by blows from a slide hammer with a mass of 63.5 kg (140 lb) falling through a distance of 760 mm (30 in). The sample tube is driven 150 mm into the ground and then the number of blows needed for the tube to penetrate each 150 mm (6 in) up to a depth of 450 mm (18 in) is recorded. The sum of the number of blows required for the second and third 6 in. of penetration is termed the "standard penetration resistance" or the "N-value". In cases where 50 blows are insufficient to advance it through a 150 mm (6 in) interval the penetration after 50 blows is recorded. The blow count provides an indication of the density of the ground, and it is used in many empirical geotechnical engineering formulae."

An Explanation of SPT N-Value and Behavior of a Boring

At the presence of a strong stratum within 30 cm N-value will be measured. If there were a 100 cm weak stratum underneath the strong stratum, it will be recorded as 100cm+, and the distinction between those strong and weak layers will not be made. This is causing a major influence over safety design. On top of that it is impossible to penetrate gravels with SWS, CPR, simplified penetration method, which means an investigation stops once gravel is encountered.



NSWS was developed to overcome these problems.

NSWS has been improved since the publication of this paper which deals with 2nd version of NSWS. Current version of NSWS is 7. Followings are the features of NSWS:

1. Data recording capability with a measurement resolution of 1.08 cm.
2. Cutting and penetration capability of gravels
3. In-situ shear data collection ability
4. Density, soil sampling, water level measurement

Conclusion

SPT N-value has been used worldwide, yet understanding of this problem and an improvement of existing technology need to done.

Fig. 2 - An Investigation Result Using NSWS and a Boring Investigation Nearby

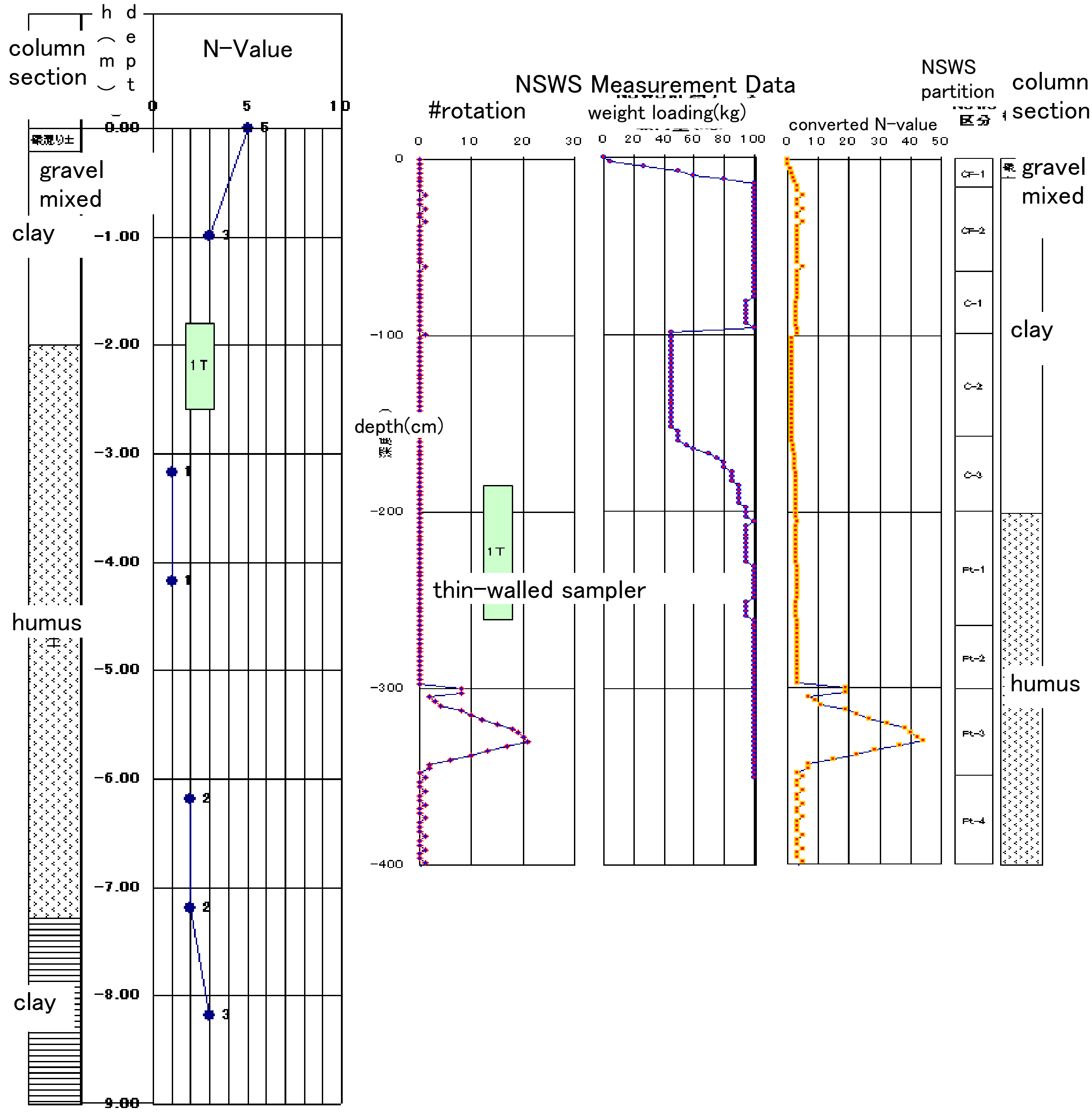


Fig. 3 – Soil Test Result

document number		1T
depth(Converted to NSWS)		1.865～2.615
soil type		humus
engineering classification	sign	Pt
	category	Highly organic soil
wet density ρt g/cm3		1.057
soil particle density		1.798
natural moist water percentage Wn %		413.7
liquid limit WL %		331.8
plastic limit WP %		163.9
plasticity index IP		167.2
consistency index IC		−0.46
unified compression strength qu kN/m2		44.4～46.2
compression index Cc		5.5
consolidation yield stress Pc kN/m2		29

Fig. 4 - Vertical Measurement and Diagonal Measurement