GROUND EVALUATION BY SWEDISH WEIGHT SOUNDING FOR DETACHED HOUSE CONSTRUCTION

MAMORU. FUJII[i], HIROSHI IJUIN[ii], MASASHI KAWAMURA[iii], TAKAKI EDAHIRO[iv], YOSUKE MIZUTANI[v], YOSHIO. WAKAME[vi] and MASAHITO. TAMURA[vii]

ABSTRACT

The basement design of detached housing in Japan depends largely on the soil data obtained by Swedish sounding. This method is simple and speedy, and now a number of automated machines are available. Because the revised Building Standard Law of Japan set forth a Swedish-sounding-based allowable unit stress formula for the use of this method is expected to become even more popular. On the other hand, the types of screw shape and rod diameter specified in the Japanese standards are different from European Norm, and test results may vary according to the site and usage of the building. In evaluating test results, rotational penetration and self-weight penetration should be considered separately. However, the mechanism of rotational penetration is still unclear. This paper reviews the soil survey techniques and automated Swedish sounding machines currently available in Japan.

Key Words : Swedish sounding, soil information, foundation design, standard test.

1 INTRODUCTION

The Swedish sounding method was introduced in Japan in around 1930. Since then, it has popularly been applied as a soil survey technique in the civil engineering field for the construction of the sub grade and base of pavements and port facilities. The method also has a long application history in the building construction field, mainly for the purpose of checking ground safety against the contact pressure of heavy machinery such as a crane. It was around 1970 when Swedish sounding was first used as a soil survey technique for the construction of small buildings. In Japan, that year also marked the beginning of detached house construction boom with the increasing focus on the development of reclaimed lands, which generated much media coverage. As a registration system was established for the designers of wooden buildings in 1988, Architectural Institute of Japan published “Guideline for Designing Foundations of Small Buildings” [1]. The Guideline recommended the use of Swedish sounding in soil surveys for small building construction. From this point on, the method has become a common soil survey technique for this type of construction work. However, it was not until 2000 when the Housing Quality Assurance Act was enacted that the method’s feasibility became the subject of serious discussion. The introduction of the Act in the foundation engineering field meant that housing suppliers were now required to restrict the detached houses’ differential settlement for 10 years; this has created the renewed awareness of the importance of soil survey. While these guideline and legal framework were gradually in place for the foundation of small buildings, the Swedish sounding method itself has still been left with a number of problems. One of the major issues pointed out by past researches is that there is an extremely low correlation between the N_{sw} value (the number of half rotations per 1-m penetration in Swedish sounding) and N-value in a weak ground whose N_{sw} is found to be 40 or less at 5m deep or shallower[2]. The difference between electric and manual sounding machines should also be fully explored. In addition, the difficulty of controlling self-weight penetration with a plumb bob remains as a major problem. The shape of screw

i) Professor, department of Architecture, Tokai University, Hiratsuka-shi, Kanagawa, Japan.
ii) Asahi Kasei Co.Ltd. Shinjuku-ku, Tokyo, Japan
iii) Professor, College of Industrial Technology, Nihon University, Narashino-shi, Chiba, Japan.
iv) UDC.Chiyoda-ku, Tokyo, Japan
v) Kanematu NISSAN Co.Ltd. Shinjuku-ku, Tokyo, Japan
vi) Sekkeisitu Soil Co.Ltd. Chuo-ku, Tokyo, Japan
vii) International Institute of Seismology and Earthquake, Building Research Institute, Tsukuba-shi, Ibaraki, Japan.

point has not been well standardized that the reproducibility of the test results has bee held in doubt. Given these, it seems that just because of its simplicity and convenience, Swedish sounding has become a popular soil survey technique for small building construction; there is a lack of adequate study to evaluate test results produced by this method. The authors have so far conducted a number of experiments for the purpose of establishing an evaluation technique for Swedish sounding[3)~7)]. This paper clarifies the above-mentioned questions and reports on the current application practice of this method in Japan and the findings obtained so far on ground evaluation techniques.

2 SWEDISH SOUNDING

Figure 1 shows the typical Swedish sounding equipment. In this method, a screw is attached to the equipment and undergoes rotational penetration. The softness of the ground is determined by the axle load applied to the rod and the number of rotations needed for penetration. It should be noted that while having been standardized as “Swedish Weight Sounding” by Japanese Industrial Standards (JIS), this method uses different maximum rotational diameter and rod diameter from those specified by overseas standards (European Norm Standards).

Figure 2 shows changes in screw shape used in Swedish sounding. There was once a method called “Danish sounding”, which used a pyramid screw, and there were times when screws that would rotate 1.5 times per 20cm with the maximum rotational diameter of 35mm were used in Japan.

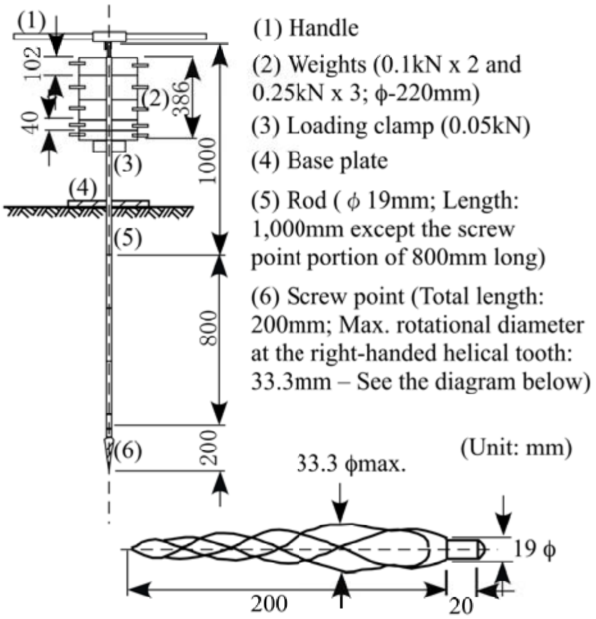

Fig. 1. Swedish sounding

3 APPLICATION PRACTICE OF SWEDISH SOUNDING

Table 1 shows the results of a questionnaire survey conducted by the authors on 12 firms who had been adopting the Swedish sounding method for small building construction. As seen from the results, the factors that give direct impacts on the results of Swedish sounding include: (i) the location of the screw point that creates the maximum rotational diameter; (ii) management of screw point abrasion; and (iii) the rotation speed of electric machines’

Table 1. Results of a Questionnaire Survey on Swedish Sounding Test

Issues surveyed	Response
Screw point related issues - Material - Manufacturing method - Max. rotational diameter point - Replacement timing	 - JIS G 4051 S45C (2 firms), JIS G 4051 S50C (10 firms) - Cutting (7 firms), Casting (2 firms), Hot twisting (3 firms) - 12cm from the screw point (1 firm), 14cm (1 firm), 15cm (6 firms), 17cm (2 firms), 18cm (1 firm), 19cm (1 firm) - When the max. rotational diameter of 33mm abraded by 3mm or more (6 firms), When any abrasion is observed (4 firms), Continue to use without any precautions (2 firms)
Rod/Weight related issues - Weight per meter - Weight tolerances	 - 20N (8 firms), 21.9N (1 firm), 22N (2 firms), 23N (1 firm), 22N (2 firms), 23N (1 firm) - ±0N (2 firms), ±1.0N (8 firms), ±0.5N (1 firm), ±10N (1 firm)
Test machine used - Power source - Motor rotation speed (of electric machines)	 - Manual (2 firms), Electricity (10 firms) - 18 rpm. (1 firm), 25 rpm. (2 firms), 30 rpm. (2 firms), 32 rpm. (3 firms), 35 rpm. (1 firm), 50 rpm. (1 firm)

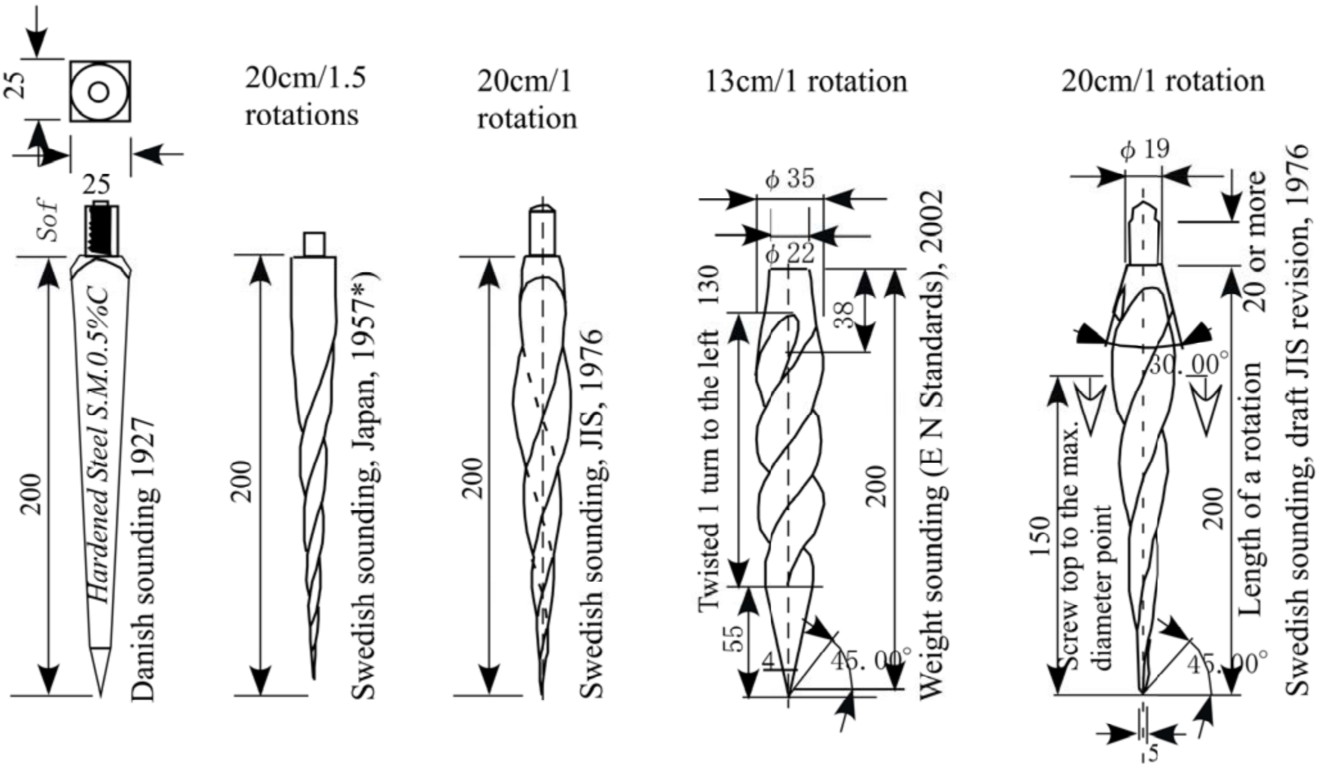

Fig. 2. Changes in screw shape in Swedish sounding

motors. As of 2001, JIS A 1221 specifies the shape of screw point but not the location that would create the maximum rotational diameter. It was found that the respondents had been using screw points with various locations of maximum rotational diameter, ranging between 12cm and 19cm from the tip. It is expected that screws with different point shapes will naturally have different cutting mechanisms; therefore, the shape of the screw point is likely to give considerable impacts on the values of W_{sw} (self-weight penetration load in Swedish sounding) and N_{sw}. The same applies to the issue of the screw point abrasion; even if screw points have been designed with the same specified shape when new, they may actually end up in different shapes according to the level of abrasion. This would consequently affect the penetration characteristics of the screw and the reliability of test results to a considerable extent.

According to the result of a questionnaire survey on 337 soil surveyors by Japan Geotechnical Consultant Association, while more than 80% respondents pointed out that the screw point's abrasion was one of the factors that would affect sounding results, they were not taking any rigid measures to control the abrasion in practice[8]. With regard to the test machine, many soil surveyors used electric machines, which had nonetheless had various

Photograph 1 Examples of automatic and electric Swedish sounding machines used Japan

performance levels. In particular, the source of the torque to the rod, namely the motor's rotation speed showed notable variations, ranging between 18 rpm and 50 rpm; this is supposed to have been causing variable cutting performance and penetration characteristics of the screws. As an example, some of the automatic and electric sounding machines used in Japan are presented in **Photograph 1**.

Future researches should shed light on how different shapes of the screw point affect the penetration characteristics, how different levels of screw point abrasion affect the test result, and how different performance levels of electric machines affect the test result.

4 COMPARISON OF N_{sw} BETWEEN ELECTRIC AND MANUAL SWEDISH SOUNDING MACHINES

Automatic or electric machines are supposed to become a more popular choice than manual ones, but as mentioned in the previous section, it is expected that different test procedures will lead to different test results. To explore this aspect, sounding tests were performed on a loamy site to compare the N_{sw} values of electric and manual machines. As the test site, the Shonan Campus of Tokai University (Hiratsuka-shi, Kanagawa-ken, Japan) was selected. **Figure 3** shows the boring log of the test site. As shown here, the ground consisted of fill and *Kuroboku* soil up to 1m deep from the ground surface, and a homogeneous loam layer below 1m up to 6m deep. The electric machine shown in **Photograph 2** was used for the tests. The speed of rotational penetration was set at between 20 and 25

Photograph 2 The electric machine used for the tests

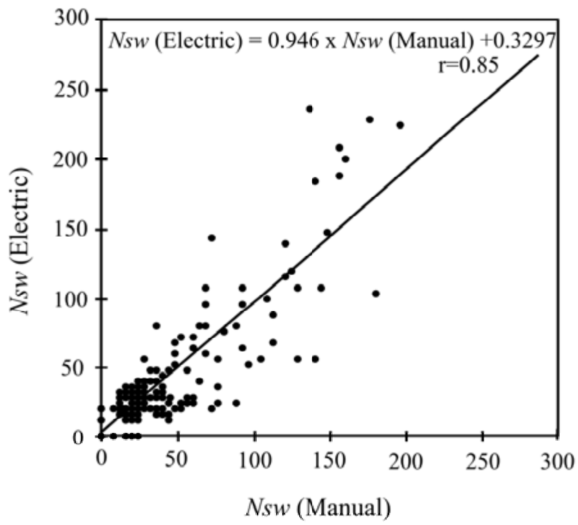

Fig. 4. Relationship between the N_{sw} values of electric and manual machines

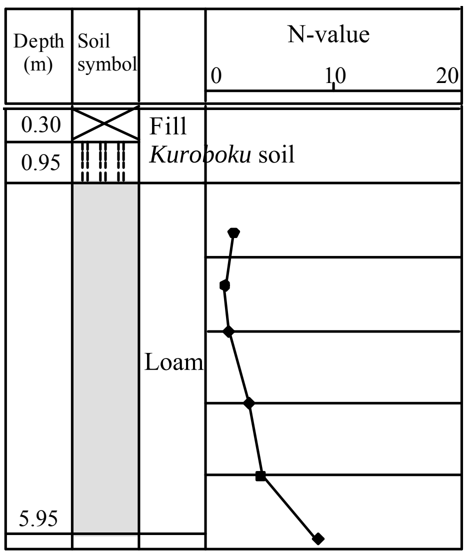

Fig. 3. Borehole log

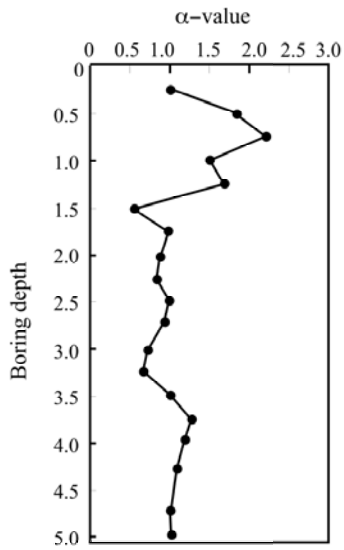

Fig. 5. Vertical changes in α

rotations/minute for the manual machine and at a constant level of 30 rotations/minute for the electric one. The tests were performed on 10 locations each, up to 6m deep within a 2m radius from the borehole. **Figure 4** shows the relationship of the N_{sw} values between the manual and electric machines. Up to an N_{sw} value of 150 or smaller, both machines showed a good correlation; however, after surpassing 150, the electric machine tended to show slightly greater N_{sw} values than the manual one. This is supposed to have been caused by the fact that with the manual machine, the harder the ground becomes, the more likely that the user unintentionally applied a downward force (thrusting force) during the rotational penetration process. To illustrate their differences in relation to depth, the ratio of N_{sw} of the manual machine to the electric one (Manual machine's N_{sw} / Electric machine's N_{sw}) was calculated for each measurement. The results were averaged for 10 measurements at a single depth and then plotted as α in **Figure 5**. In the surface region of 1.5m deep or shallower, the ratio α indicated that the manual machine tended to produce N_{sw} values of 1.5 to 2.0 times larger than the electric one. It is inferred that the manual machine's N_{sw} values were largely affected by the unsteady movement of the rod because it was impossible to perfectly fix the screw point near the surface.

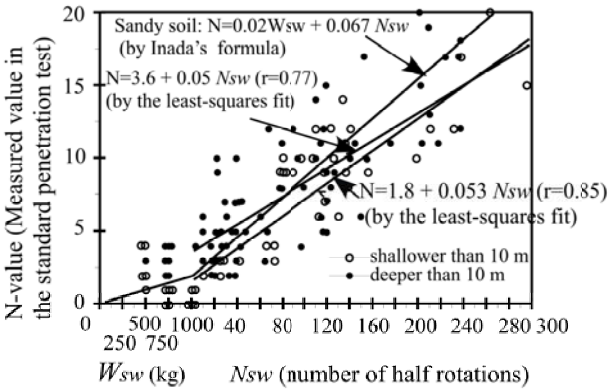

Fig. 6. Relationship between N-values and *Nsw* in sandy soil

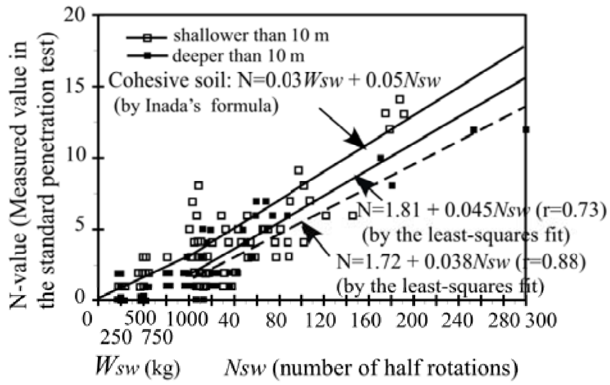

Fig. 7. Relationship between N-value and *Nsw* in cohesive soil

5 IMPACTS OF THE SOIL TYPE AND DEPTH ON N- AND N_{sw} VALUES

Figures 6 and **7** outlines the results of Swedish sounding tests performed on locations with more or less the same N-values, showing the relationship between N-values and N_{sw} and W_{sw} values. 106 Locations were tested; 70 locations were at 10m or shallower and 36 were deeper than 10m, as shown in **Figure 8**. The following insights can be obtained from Figures 6 and 7:

(i) At 10m or shallower, no considerable differences in the least squares equations are found between the sandy soil and cohesive soil. The N-values of sandy and cohesive soil is given by equations (1) and (2), respectively. To be conservative, N-values may be obtained by equation (2), regardless of the soil type.

(ii) Either Figure shows no correlation between N and W_{sw} values when W_{sw} is 100N or smaller. The reason for this would be that it is extremely difficult to control the self-weight penetration load in this region.

(iii) At 10m or deeper, the sandy soil showed particularly poor correlation.

(iv) In the cohesive soil, N-value and W_{sw} and N_{sw} values do not show good correlation

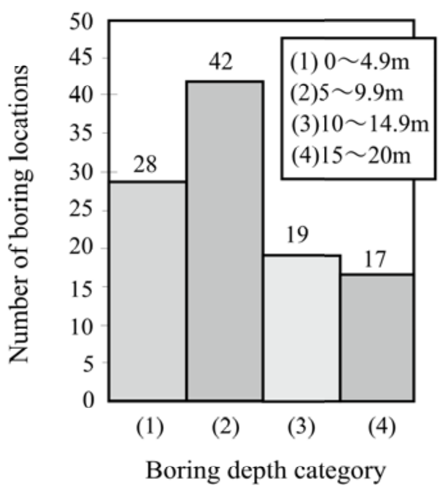

Fig. 8. Number of boring locations by dept

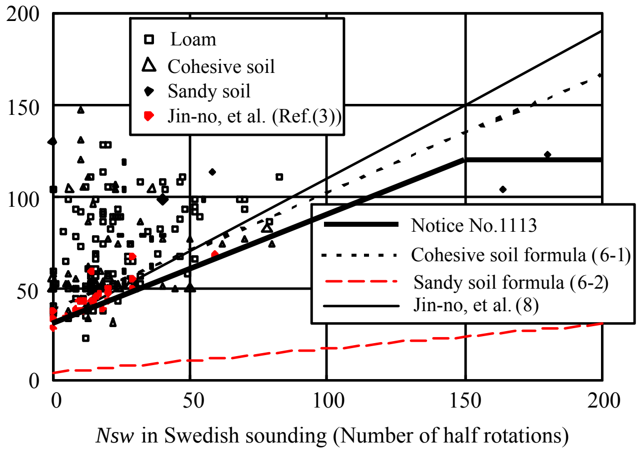

Fig. 9. Relationship between the allowable stress in plate loading test and *Nsw* values

when N_{sw} =1 to 40, as pointed out by a past research [2)]. It is likely that the shape of the screw point gives considerable impacts on penetration force or penetration resistance in soft grounds.

- Sandy soil

-

$$N = 1.80+0.053\, Nsw \quad (1)$$

- Cohesive soil (*Kanto* loam)

-

$$N = 1.81+0.046\, Nsw \quad (2)$$

6 SWEDISH SOUNDING AND ALLOWABLE STRESS OF GROUND

Figure 9 shows the relationship between the allowable stress q_a (kN/m^2) in the plate loading test and *Nsw*. The thick solid line in the figure represents equation (3) set forth in the Notification No.1113 issued by the Ministry of Land, Infrastructure and Transportation, which is close to the lower limit of the measured q_a.

$$q_a = 30 + 0.6\, Nsw \quad (3)$$

Nsw: The Average for the regions up to 2m from the bottom surface (Each *Nsw* value≦150)

The chain line in the figure was a relationship between long-term allowable stress of the ground (q_l) and sws (N_{sw}) obtained by substituting the relationships between q_a and N_{sw},, N_{sw} and N and ϕ and N (equations (4) and (5))[10),11)] into the equation (1) of the Notification No.1113 (equation (6) in this paper, with no load inclination) (Unit of W_{sw}: kN). Equation (6-1) can be used for cohesive soil and equation (6-2), can be used for sandy soil. They show a slightly larger value than equation (3) when applied to cohesive soil. In the sandy soil on the other hand, the accuracy of the W_{sw}-based estimation of ϕ is low, and the N_γ value demonstrated low reliability when ϕ is small. Although Jinno et al. proposed the equation (8), it covers a wider range than those of equations (3), (6), (6-1) and (6-2)..

$$q_u = 45\, Wsw\ (\text{kN}) + 0.75\, Nsw \quad (4)$$

$$N = 2+0.067\ Nsw\ , \qquad \phi = 15 + \sqrt{20N} \quad (5)^{(1}$$

)

$$q_a = 1/3\ (i_c\, \alpha\, C N_c + i_\gamma\, \beta\, \gamma_1 N_\gamma B + i_q\, \gamma_2 D_f N_q) \quad (6)$$

$$q_{ac} = 38\, Wsw\ (\text{kN}) + 0.64 N_{sw}, \quad (6\text{-}1)$$

$$q_{as} = 1.41 N_\gamma \quad (6\text{-}2)$$

$$i_c = i_q = (1 - \theta/90)^2 \quad i_\gamma = (1 - \theta/\phi)^2 \quad (7)$$

$$q_a = 30 + 0.8\, Nsw \quad (8)$$

i_c, i_r, i_q: Numerical values derived from the angle of inclination to the vertical direction of the load

θ : Inclination angle of the load (Assumed to be 0 here)

ϕ : Internal friction angle of the ground (degree)

α, β: Coefficient of the shape of the foundation

B: Length of the short side or minor axis of the foundation

L: Length of the long side

c: Cohesion (kN/m^2)

Nc, Nr, Nq: Bearing capacity factor

γ_1: Unitary weight of soil (kN/m^3)

γ_2: Unitary weight of the upper ground (kN/m^3)

D_f: Depth of embedment (m)

7 SELF-WEIGHT PENETRATION BEHAVIOR

"Self-weight penetration" refers to the behavior of a screw penetrating into ground by subsidence without any torque given. When penetration occurs with a sudden movement, it sometimes prevails against rotation. However, penetration would be smoother if rotation occurs in obedience to the helical tooth of the screw. When restricting rotation and letting the screw penetrate, there is a possibility that a reverse torque will be applied. A smooth self-weight penetration behavior is defined by the completion of a rotation for a penetration distance of 200mm, which establishes equation (10) that expresses the relationship between the rotation speed of the rod *Rp* (rpm) and the penetration speed of the screw *Vps* (mm/sec).

$$V_{ps} = L_s \cdot R_p / 600 = R_p / 3 \qquad (10)$$

V_{ps}: Recommended speed (mm/sec)
Rp: Rotational speed of the rod (rpm)
Ls: Total length of the screw (=200mm)

To study the self-weight penetration behavior, the angle of rotation and the distance of penetration that occurred during a self-weight penetration process were measured in the manner presented in **Figure 10**.

The measurement results are shown in **Figure 11**. The 18-degrees/cm line in the figure (i.e. rotation of 18 degrees during 1-cm penetration) represents a penetration behavior that occurs in obedience to the helical tooth of the screw. The test results showed

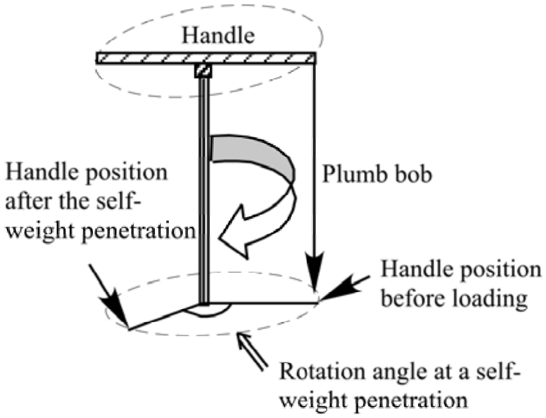

Fig. 10. How to measure the rotation angle of self-weight penetration

that penetration slightly prevailed against rotation. When the screw undergoes rotation, there is not only the screw itself but also the skin friction of the rod at work. Therefore, it is difficult to increase the rotation speed to the level above the smooth rotation without applying any torque.

With a manual machine, self-weight penetration is controlled by visual observation. With an electric machine on the other hand, the alternate process of rotation and self-weight penetration needs to be switched automatically by stopping the screw rotation and removing or increasing the load. Therefore, determination criteria should be established for each machine based on the specific self-weight penetration behavior, such as the one cited in **Figure 11**. The concept of self-weight

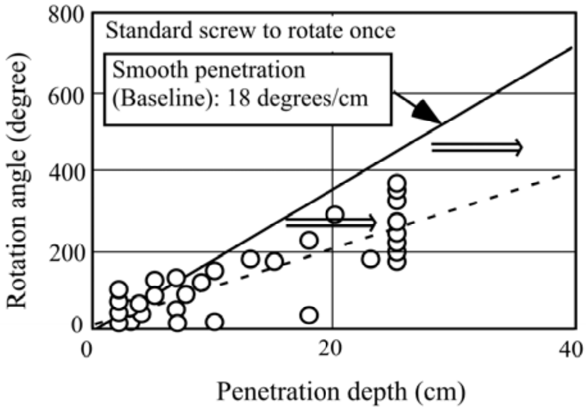

Fig. 11. Relationship between the penetration depth and rotation angle during the self-weight penetration process

penetration load W_{sw} should be given a particular attention, which refers to the load that triggers the first settling movement when the load level is changed by the controller in incremental steps, that is from 0.15 to 0.25 to 0.5 to 0.75 and to 1kN. A determination criteria mechanism should be established based on this concept, as well as the result of comparison against the behavior of manual machines.

8 CONCLUSIONS

Swedish sounding is expected to become an even more popular soil investigation technique for detached house construction due to the revision of the Building Standard Law in Japan. However, further studies should be carried out, as this method still has a number of problems including the following: (i) no definite standard for screw shape is in place; (ii) the screw's penetration mechanism and self-weight penetration criteria have not been clearly defined, and (iii) although various electric machines have recently been developed and put into practice, no clear methods of performance evaluation and indication are in place. Considering the fact that electric machines are extremely effective in eliminating user fluctuations as compared with manual ones, it would be crucial to establish a set of standards for performance evaluation and indication with clear justifications (e.g., rotation suspension criteria – such as suspension of rotation when the penetration speed becomes xxcm/sec or lower, load increase/reduction criteria and indication of loading condition).

REFERENCES

1) Guideline for Designing Foundations of Small

Building, *Japan Architectural Institute*, 1988
2) Fujii, M., Futaki, M., Ijuin, H., Kazama, S., Tamura, M.and Abe, A. (1996): Relation between *Nsw* of Swedish Weight Sounding and N value of Standard Penetration Test, *AIJ J. Technical .Des*. AIJ.No3, 64-68（in Japanese）
3) Fujii, M., Tamura, M., Goto, T. and Ijuin, H. (2000): Effect of resist raining settlement of foundation based on cases from study of differential settlement of low-rise housing around Lake Suwa, *J. Struct. Constr., AIJ*. No538, 93-100 (in Japanese).
4) Nakazato, A., Fujii, M. and Tamura, M. (2001): Exploitation of performance evaluation and performance expression technique on geotechnical engineering for small building。 part1 :Purpose and direction for design and construction technique, *Prep. Annual Meeting of AIJ, Structures* 1,.537-538 (in Japanese).
5) Kihara, T., Fujii, M., Tamura, M. and Ueda, S. (2001): Exploitation of performance evaluation and performance expression technique on geotechnical engineering for small building. Part 2: Philosophy on structure performance and performance evaluation of foundation, *Prep. Annual Meeting of AIJ, Structures* 1, 539-540 (in Japanese).
6) Shinagawa, k., Fujii, M. and Tamura, M. (2001): Exploitation of performances evaluation and performance expressing technique on geotechnical engineering for small building. Part 2: Basic philosophy and heed points based on trouble case, Prep. Annual Meeting of AIJ, Structures1, 541-542 (in Japanese).
7) Kaku, K., Ijuin, H. and Fujii, M. (1997): Effect of skin friction of rod and weight load on the result of Swedish Weight Sounding, Prep. Annual Meeting of AIJ, Structures 1, pp.621-622 (in Japanese).
8) Ijuin, H., Fujii, M., Tamura, M., Kawamura, M. and Wakame, Y. (2001): Investigation on the shape of screw point used for Swedish Weight sounding, Prep. Annual meeting of AIJ, Structures1, pp.483-484 (in Japanese).
9) Shinagawa, K., Fujii, M., Tamura, M. and Ijuin, H. (2000): Effect of weight load on the result of Swedish Weight Sounding Test, Japan National Conf. Geotch.Eng.,Vol.1, pp.477-478 (in Japanese).
10) Inada, M. (1960): Application of results of Swedish weight sounding tests, Tsuchi-to-Kiso, JSSMFE, Vol. 8, No. 2, pp. 13-18 (in Japanese)
11) Japan Architectural Institute (1988): Recommendations for design of building foundations.