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Case Studies of Penetration Characteristics of DCM Wall Using Spiral Mixing Blades in Soil Layers

특수교반날개를 사용한 DCM 공법의 지반 관입 특성에 대한 사례연구

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요 지

DCM 공법(심층혼합처리 공법)은 흙막이 벽체 등 구조물 조성에 적용하였다. 이러한 DCM 벽체는 경질층에서 관입능력이 있어야 한다. DCM 장비에 부착된 교반날개에 의해 경질지반의 관입능력이 증가되는 알아보기 위해 특수교반날개가 고안되었다. 경질점토층에 관입되는 특수교반날개의 관입특성은 김해와 인천현장에서 조사하였다. 고안한 특수교반날개는 관입속도가 다소 느려도 N=30 이상 되는 지반까지 관입되었고 관입시 효율이 경질지반에서 낮아질 수 있으므로 경제적인 교반날개의 관입깊이를 분석하였다.

Abstract

DCM (Deep Cement Mixing Method) has been applied to build structures such as self-supported earth retaining walls. DCM columns should be penetrability into the stiff layer to assure the self-supporting ability. On the penetration increase of blade attached to the DCM mixing tools, a spiral mixing blade has been revised. Penetration characteristics of spiral blades in the stiff soil layer were evaluated through Gimhae and Incheon areas. The spiral mixing blades could penetrate into the stiff soil layers which have the N-value of greater than 30 although the penetration rate is somewhat slow. Penetration characteristics and economical efficiency should be discussed to determine the critical depth of the spiral mixing blade because the penetration efficiency can decrease in the stiff layer in this paper.

Keywords : Construction efficiency, Spiral mixing blades, Penetration characteristics

1. Introduction

For the development of DCM, design strength and elastic modulus can be studied. Self-supported earth retaining systems have been employed to minimize the use of bracing components while securing the stability and to maximize the construction efficiency. These technologies include the use of PS beam or IPS method in which a pre-stress is introduced to widen the spacing of struts, a self-supported diaphragm wall incorporated with a counter-fort wall, or a self-supported DCM wall without a bracing component. Among these, a self-supported DCM wall is highly applicable to wide excavation works, underground structures with a complicated configuration,

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or shallow excavation works not exceeding 10 m in depth. In Korea, DCM method has been employed for land applications to support structures, to prevent settlement, or to support excavation works since it was applied to build Su-Young waste water treatment plant in Busan in 1985. In recent days, the accumulated length of DCM wall construction in Korea is increasing.

Deep cement mixing (DCM) technologies have been applied to build self-supported earth retaining walls supporting underground excavation works. For the self-supported DCM wall to assure the self-supporting ability, DCM columns should be penetrated into the stiff layer to derive a sufficient passive resistance against the lateral forces acing on the wall. However, a conventional mixing blade attached to the DCM mixing tool was originally developed for soft soils and therefore the penetration efficiency of conventional blades is significantly lowered in the stiff layer. The construction efficiency of DCM method in the stiff soil layer largely depends on the penetration characteristics of blade attached to the DCM mixing tool. A spiral mixing blade has been revised to increase the construction efficiency of DCM method in the stiff layer while building a self-supported DCM wall in Incheon area. Trial constructions have been carried out to evaluate the penetration characteristics of new blades both in Gimhae and Incheon areas. Penetration characteristics of spiral blades employed to build a self-supported DCM wall in the stiff soil layer are presented herein in terms of soil types and their stiffness.

2. DCM Method

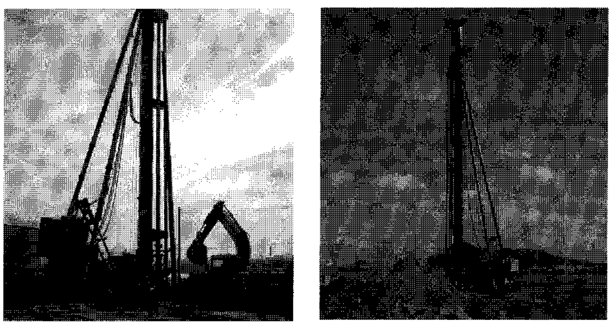
2.1 Overseas Trends

In the late 1960's, Scandinavian countries and Japan independently developed a deep lime mixing (DLM) method using quicklime or slaked lime as binding materials. Today, in Sweden and Finland, a combination of lime and cement are extensively used in the deep mixing method. Lime or lime-cement is introduced in the form of dry powder. In 1975, Japanese CDIT (Coastal Development Institute of Technology) developed a DCM method in which binding materials are introduced in the form of slurry. The deep mixing method utilizes such agents as quicklime, slaked lime, cement, slag, fly ash or a combination of these agents. The accumulated volume of treated soil using the deep mixing method reached over 1,000,000 m^3 in Sweden and Finland since 1966. From 1977 to 1998, the accumulated volume of treated soil using the DCM method reached 38,000,000 m^3 in Japan. The deep mixing methods were first introduced as a preventive measure against liquefaction in the United States in 1987. The deep mixing method has been applied to several highway projects such as Central Artery highway construction and is becoming a viable construction technology in the United States. In recent days, the deep mixing method is also applied to a variety of construction projects in Asian countries.

2.2 Domestic Trends for Land Application

In Korea, the DCM method was first introduced as a SEC (Special Earth Concrete) method for the construction of Su-Young waste water treatment plant in 1985 and it was applied to build a self-supported earth retaining wall and a foundation.

The treatable depth with the DCM method largely depends on the capacity of equipment. The earlier version of equipment, 110P, could improve soils up to the depth of 20~25 m. However, a modern version of equipment, 170P, can improve soils up to the depth of 35~37 m. In the introductory stage of DCM method in Korea, a two-shaft mixing tool (ϕ 1,000×2rod) was used for foundation applications whereas a three-shaft mixing tool



(a) 135P (b) 170P

Fig. 1. DCM mixing rigs on land application

(ϕ 550×3rod) was employed for the construction of earth retaining walls. Afterwards, a four-shaft mixing tool (ϕ 1,000×4rod) has been developed to meet a demand for a variety of improving configuration. The four-shaft mixing tool has several advantages over the two-shaft mixing tool. They include the higher construction efficiency due to a wider improving area, a better mixing efficiency and a higher stability of earth retaining wall due to a better overlapping.

3. Case Studies

3.1 Plan of Self-supported DCM Wall

The subsurface soil at the site of Hak-ik waste water treatment facility in Incheon consists of reclaimed soil, alluvial clay, weathered soil and weathered rock. A self-supported DCM wall was planned to be constructed as an excavation support system as shown in Figures 2 and 3. A number of DCM columns were determined based on the excavation depth to assure the stability of the excavation work.

3.2 Characteristics of Subsurface Soils

Based on the standard penetration test performed during the subsurface investigation, the N-value of upper reclaimed layer was less than 20/30 and showed a wide scatter. The N-value of alluvial clay layer ranged 1/30~50/30, and the N-value of weathered soil and rock exceeded 50. The ground water table is located 0~7.9 m below the ground surface.

3.3 Alteration of Original Design

Incomplete DCM columns were found in the stiff clay

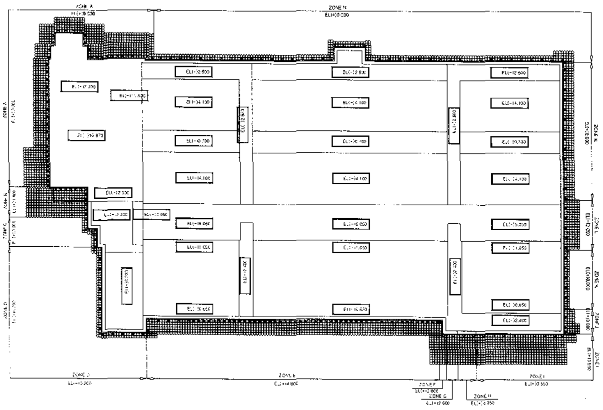


Fig. 2. Plan view of self-supported DCM wall

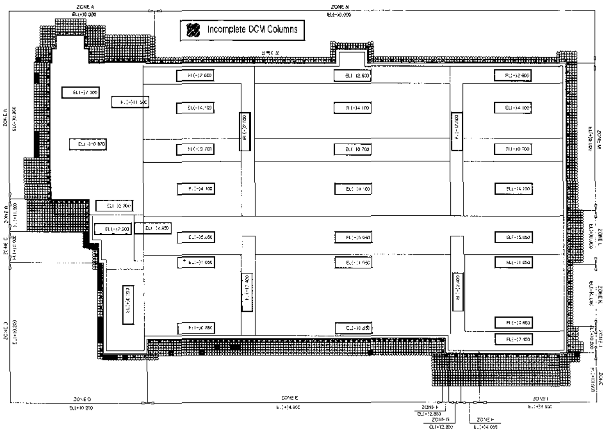


Fig. 4. Plan view of incomplete DCM columns

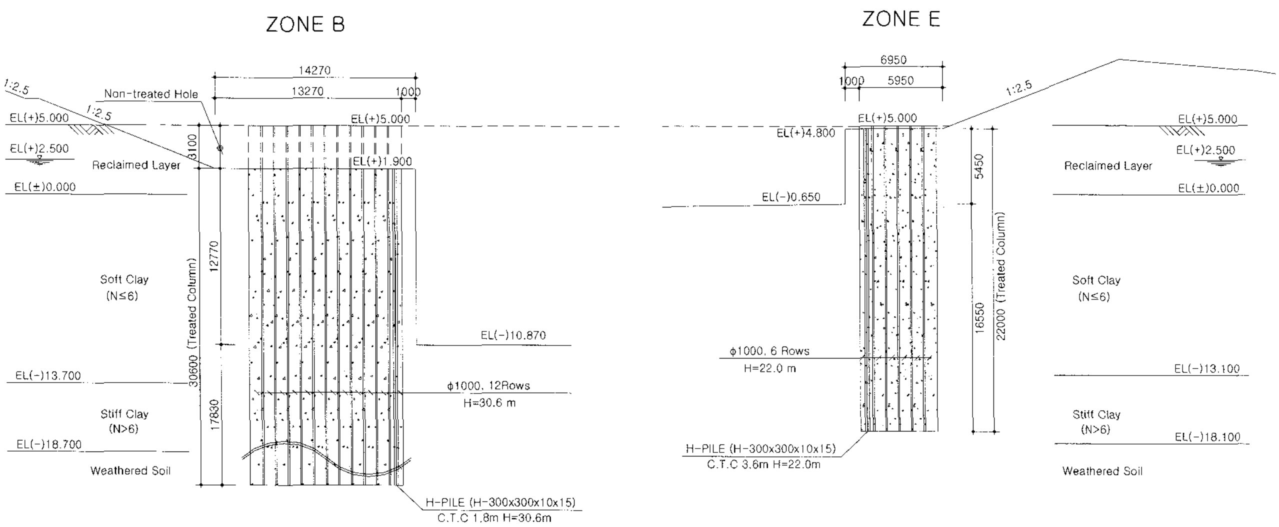


Fig. 3. Cross sectional view of self-supported DCM wall

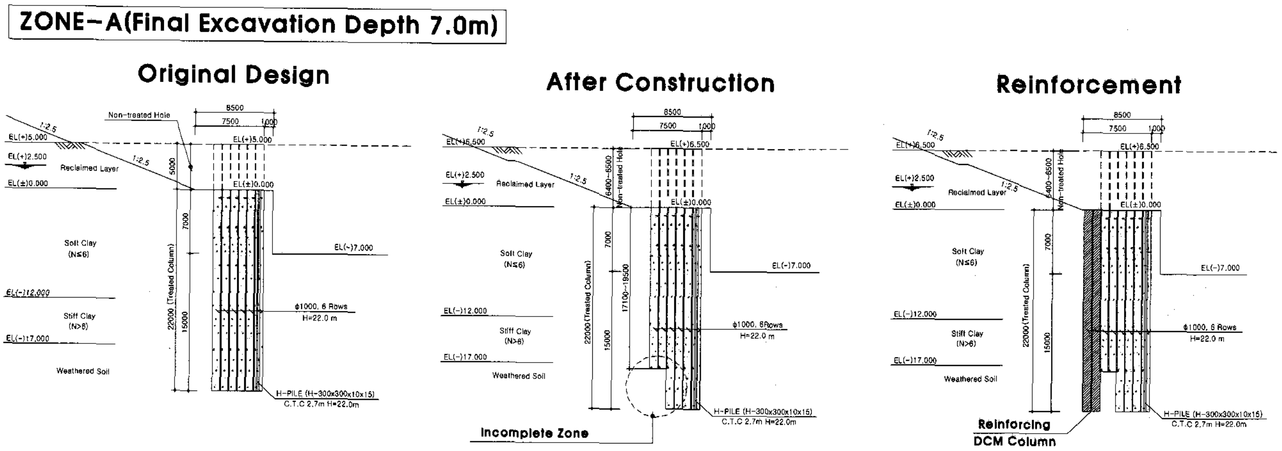


Fig. 5. Cross sectional view of reinforcement in the stiff soil layer

and weathered soil layers during the construction of DCM wall. The uncompleted thickness ranged 0.1~5.0 m as presented in Figure 4. A reinforcement was planned to assure the stability of DCM wall as presented in Figure 5. In addition, two types of mixing blades were revised to facilitate a penetration into the stiff soil layer.

4. Development of Mixing Blades to Penetrate into Stiff Soils

4.1 Characteristics of Conventional Blade Used in Soft Soils

Mixing blades used in domestic DCM methods were developed for an application to the soft clay layer and employed a two-stroke type in which water is introduced in the process of penetration. In recent days, a one-stroke type where slurry is introduced and mixed both in the process of penetration and retrieval is mainly employed. The one-stroke method is proved to be effective for a quality control. Figure 6 shows a conventional mixing blade employed in soft clayey soils.

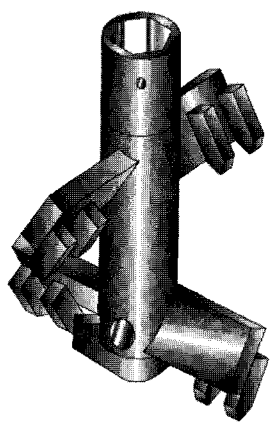


Fig. 6. A configuration of conventional mixing blade for soft soils

Figures 7 and 8 show penetration characteristics of one-stroke DCM mixing tool equipped with a conventional mixing blade employed to form DCM columns with a diameter of 1,000 mm in Gimhae area located in the

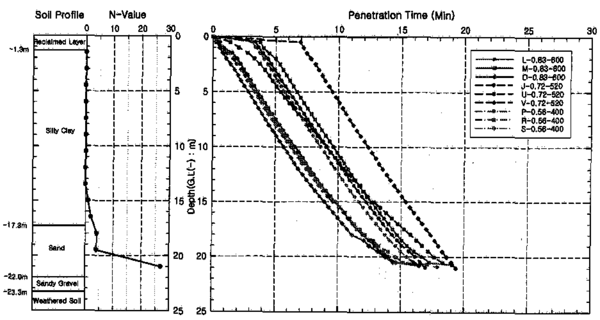


Fig. 7. Penetration time (Gimhae)

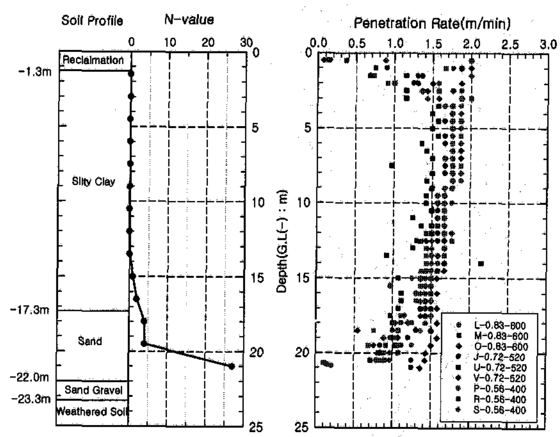


Fig. 8. Penetration rate (Gimhae)

southern coastal area over which a thick soft clay deposit is distributed. A four-shaft mixing tool, 135P was employed in the project. As presented in Figure 10, time required for the penetration into the reclaimed layer and the sand layer with greater N-values appeared to be irregular and long whereas the penetration time in the silty clay layer was consistent. It took 16~19 minutes to penetrate the whole design depth of 21 m.

Figure 8 shows a variation of penetration rate with depth. The penetration rate appeared to be slower in reclaimed soil and dense sand layers than in silty clay layer. The penetrating rate appeared to be almost constant in the silty clay layer. The slower penetration rate recorded in the reclaimed-soil layer may be attributed to larger particles mixed in the reclaimed soil. However, the penetration rate decreased because it requires a longer mixing time to assure a complete formation of DCM column end in the dense sand layer. The penetration rate appeared to be 1.3~1.9 m/min in the soft silty clay layer.

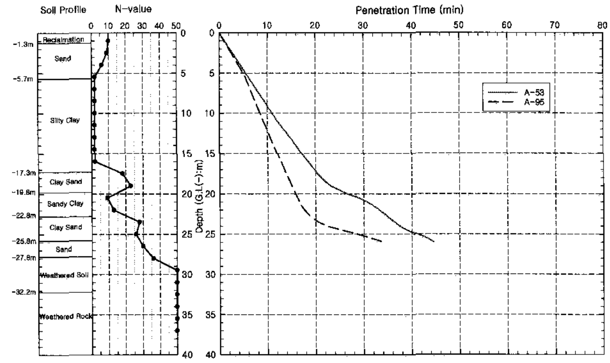


Fig. 9. Penetration time of conventional mixing blade (Incheon)

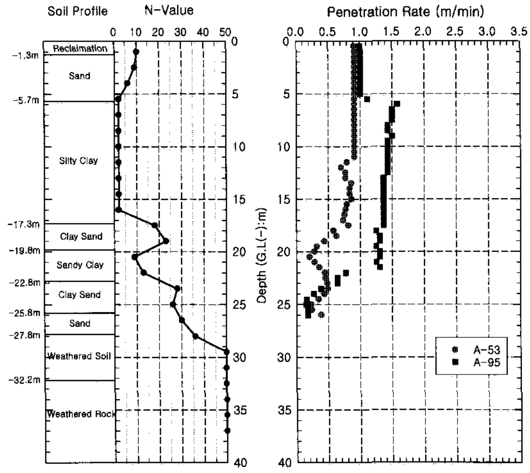


Fig. 10. Penetration rate of conventional mixing blade (Incheon)

4.2 Penetration Characteristics of Conventional Mixing Blade in Stiff soils of Incheon

Clay soils in Incheon area tend to have higher N-values or contain more silt or sand components compared to those in southern coastal area. The penetration efficiency of DCM equipment can decrease in this area. Thus, a re-evaluation of penetration capability of DCM equipment equipped with a conventional mixing blade was required to treat stiff clays (N>4) as well as dense sandy soils (N>10).

A trial construction was performed by using a two-stroke type instead of using a one-stroke type in order to increase the penetration depth. In the two-stroke type, water is introduced in the process of penetration and slurry is then introduced and mixed in the repeated process of penetration and retrieval. Penetration time and rate obtained from the trial construction are presented in Figures 9 and 10. Penetration time appeared to be similar in both the one-stroke and the two-stroke types. The critical penetration depth appeared to be 26 m where a sand layer (N=30) exists.

As indicated in Figure 10, the penetration rate based on the two-stroke type ranged 1.0~1.5 m/min and decreased to 0.5 m/min in the depth of below 20 m where a stiff layer exists. In the stiff layer, the penetration rate decreased both in the one-stroke and two-stroke types if a conventional mixing blade is employed. In addition, the penetration was impossible in the sand layer with a N-value of greater than 30.

4.3 Penetration Characteristics of Spiral Mixing Blade in Stiff Soils

4.3.1 Demands for the Development of Spiral Mixing Blade

The penetration capability of conventional mixing blade significantly decreased in the stiff layer distributed over Incheon area and also the penetration was impossible in the stiff layer with a N-value of greater than 30.

Therefore, a special mixing blade is required to be developed to improve the penetration capability of DCM equipment in the stiff layer.

4.3.2 Types of Special Mixing Blades

Two types of mixing blades were revised to increase the penetration capability of DCM mixing tool in the stiff layer as shown in Figure 11. The special mixing blades are equipped with a spiral auger and it facilitates a removal of the cuttings while penetrating into the ground. Special bits are attached to the bottom of Type 1 blade whereas special bits are attached to blade of the helical auger as well as to the bottom of Type 2 one.

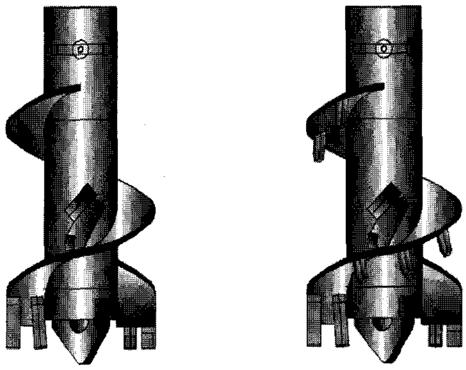


Fig. 11. Configuration of spiral mixing blades (Type1, Type2)

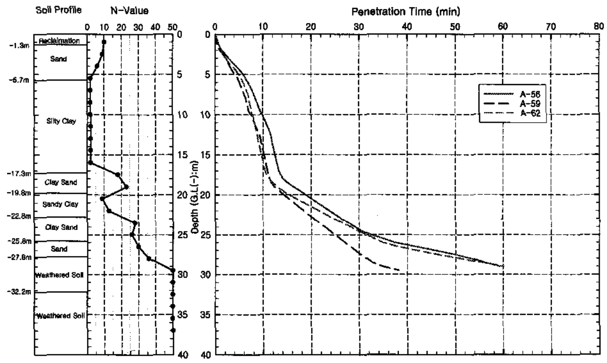


Fig. 12. Penetration time (Type1 blade)

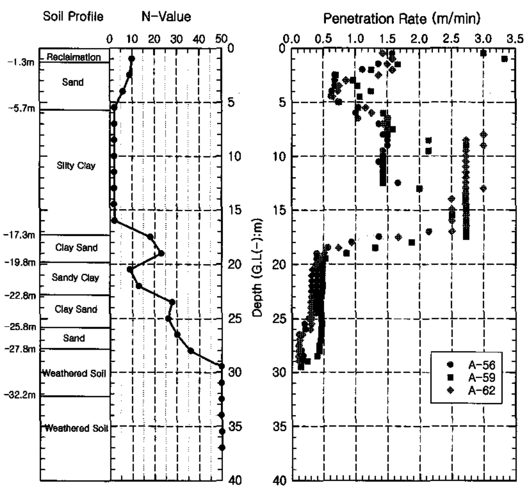


Fig. 13. Penetration rate (Type1 blade)

4.3.3 Penetration Characteristics of Type 1 Blade

Based on trial constructions, penetration characteristics of Type 1 blade are presented in terms of penetration time and penetration rate in Figures 12 and 13.

Although the penetration characteristics of Type 1 blade were similar to those of a two-stroke conventional blade in the soft soils (N =0~4 for clay, N=0~10 for sand), the penetration time was reduced by about 10 minutes and also the penetration rate increased in the stiff layer (N=4~15 for clay, N=10~30 for sand). However, Type 1 blade was able to penetrate into the stiff layer such as dense sand (N>30) and weathered soil layers where the conventional blade could not. As shown in Figure 12, the penetration rate was measured to be 0.3~0.5 m/min in the sand and the weathered soil layers (N>30) and 0.1~0.3 m/min in the weathered soil layer with a N-value of greater than N>50.

However, in the sand and the weathered soil layers with N-values of greater than 30, the penetration rate decreased below 0.5 m/min and the constructability was lowered.

4.3.4 Penetration Characteristics of Type 2 Blade

The penetration characteristics of Type 2 blade obtained from trial constructions are presented in Figures 14 and

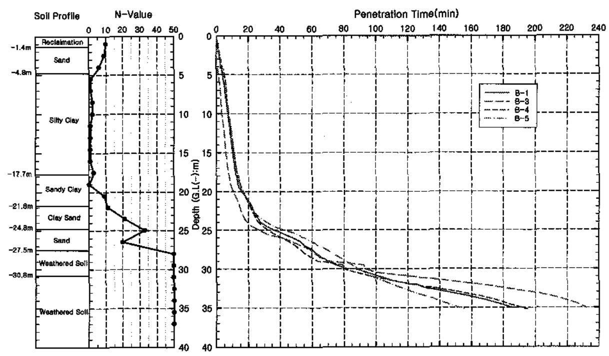


Fig. 14. Penetration time (Type 2 blade)

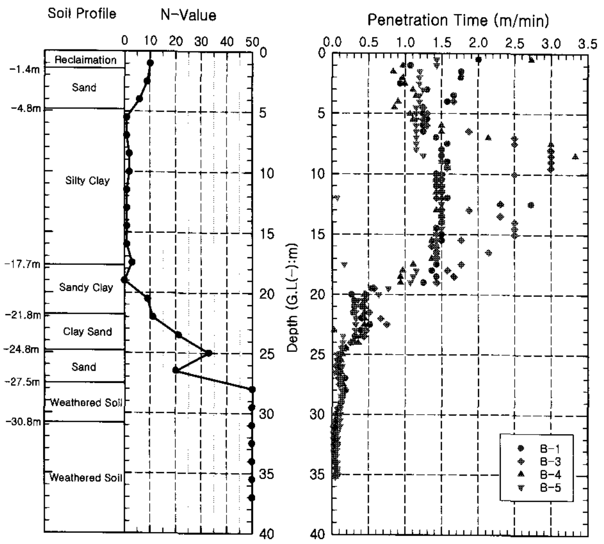


Fig. 15. Penetration rate (Type2 blade)

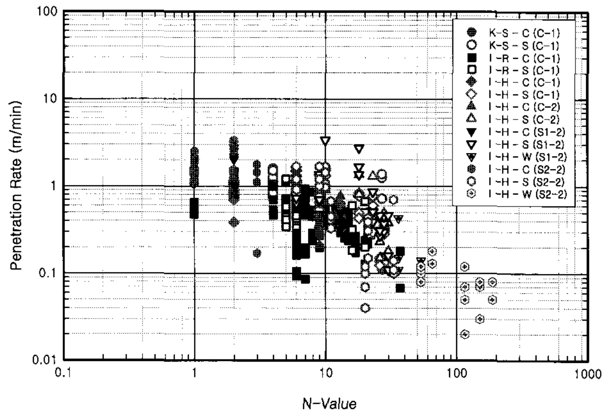


Fig. 16. N-value vs. Penetration rate

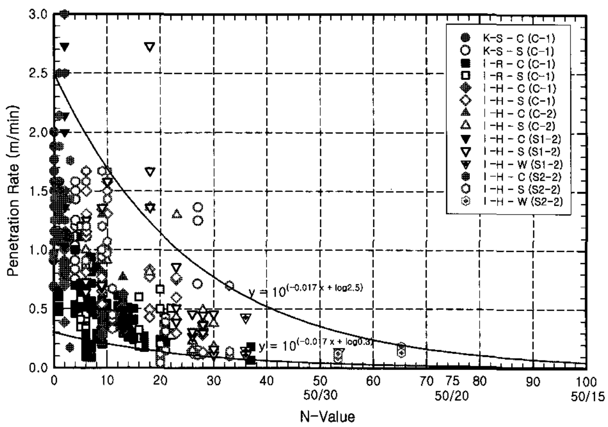


Fig. 17. Correlation of N-Value and Penetration rate (summary)

15. The penetration time of Type 2 blade was similar to that of Type 1 blade up to the depth of 28~29 m where N-value increases to about 50. Nevertheless, Type 2 blade could penetrate into the weathered rock layer (N>50) where Type 1 blade could not. However, the penetration efficiency of Type 2 blade was lowered to 0.1~0.2 m/min in the weathered layer with a N-value of greater than N>50.

4.4 Correlation of Penetration Characteristics

The penetration rates of various blades, measured from trial constructions, were analyzed based on N-value to evaluate the penetration characteristics of DCM equipment depending on soil type and their stiffness. Their correlations are presented in Figures 16 through 18. N-values of greater than 50/30 were converted to the number of blows for the 30 cm of penetration.

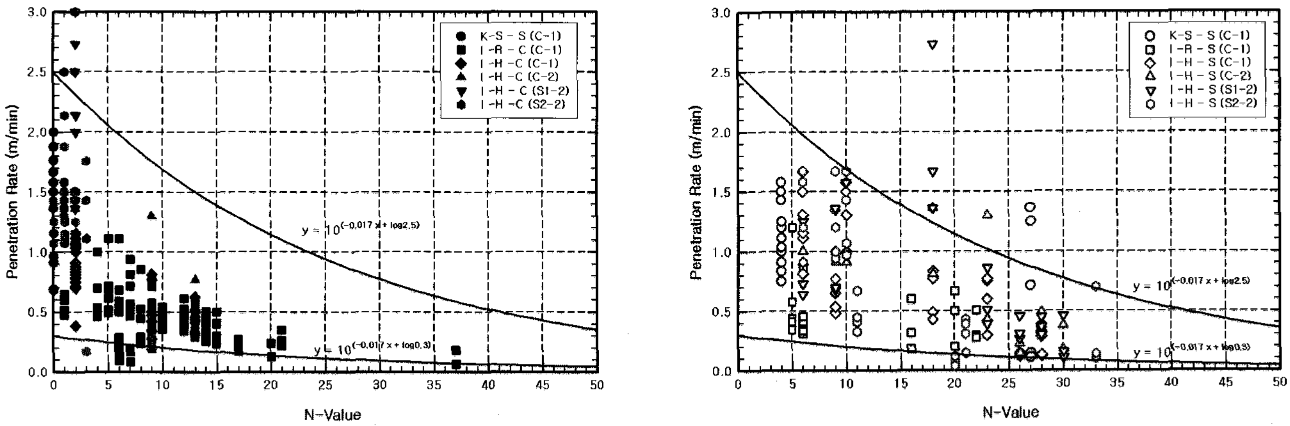
A correlation of penetration rate and N-value obtained from both Gimhae and Incheon areas is presented in Figure 16. As indicated in Figure 16, the penetration rate tends to decrease as the N-value increases.

After eliminating the converted N-value of greater than 100, a correlation of penetration rate and the converted N-value of soil layers to which the DCM method can be applied is presented in Figure 17. The penetration rate tends to decrease as the N-value increases. The scatter of correlation tends to decrease as the converted N-value increases.

Figure 18 (a) shows a correlation of penetration rate and N-value in the clay layer. The penetration rate tends to decrease as the N-value increases. The average penetration rate was about 1.0 m/min for the N-value of 0~4 but it decreased to 0.50 m/min for the N-value of 4~15. The average penetration rate appeared to be slower than 0.3 m/min for the N-value of greater than 15.

A correlation of penetration rate and N-value in sand layer is shown in Figure 18 (b). The average penetration rate was 1.0 m/min for the N-value of 0~10 and it decreased to 0.5 m/min for the N-value of 10~30. For the N-value of greater than 30, the average penetration rate decreased below 0.3 m/min.

In Japan, a standard penetration rate of 1.0 m/min is established as a criterion to select a soil type where an application of DCM is possible. Based on Japanese criterion, DCM can be applied to clay soils with an N-value of less than 4 and to sandy soils with an N-value



(a) Clay (b) Sand

Fig. 18. Correlation of N-Value and Penetration rate

of less than 8. Penetration rates obtained from trial constructions fall within Japanese criterion.

Penetration rates in the clay layer appeared to be slower than those in the sand layer which has a similar N-value.

5. Conclusions

Based on the case studies of penetration characteristics of mixing blades employed for the trial constructions of a self-supported DCM wall in Gimhae and Incheon areas, conclusions are as follows.

(1) The penetration efficiency of a conventional mixing blade decreased in the stiff soil layer distributed over Incheon area and the conventional mixing blade could not penetrate into the stiff layer if the depth exceeds certain limit.

(2) A spiral mixing blade revised to improve the penetration capability of DCM mixing tool can penetrate into the thick and stiff layer where the conventional blade can not. Penetration characteristics and economical efficiency should be considered to determine the critical depth of the spiral mixing blade because the penetration efficiency can decrease in the stiff layer.

(3) Results of construction areas showed correlations of penetration rate and N-value falls within a limited range. The penetration rates of mixing blades used in Korea may be similar to those in Japan.

(4) The DCM method was developed to improve soft foundation soils or to build an earth retaining wall to support excavation works. The development of DCM, design strength and elastic modulus can be studied.

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