Development and field verification of borehole roughness profiler for drilled shafts

Développement et vérification du champ de profileur de l'accident du trou pour faire des forages pour les axes percés

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ABSTRACT

Based on recent studies on rock socketed drilled shafts, the side resistance of rock socketed drilled shafts was affected by unconfined compressive strength of rock as well as borehole roughness. Since existing roughness measurement systems could be conducted only in the air, a new roughness measurement system, which can measure rock socket roughness in the air and also in the water, has been needed, and developed in this study as called the BKS-LRPS(Backyoung-KyungSung Laser Roughness Profiling System), For the field verification of the BKS-LRPS, it applied to measure borehole roughness and vertical alignment on 6 drilled shafts in order to verify the stability of the BKS-LRPS against several field conditions, which were the effect of measuring unit shaking, the application of water/air calibration factors, and the resistance of high water pressure inside piles, and various turbidity. Based on the results of the field verification, vertical alignments for all drilled shafts could be measured by the BKS-LRPS. However, borehole roughness was not able to measure due to high turbidity caused by RCD drilling processing. Based on the BKS-LRPS field verification, the BKS-LRPS is the first borehole roughness and vertical alignment measurement system applying both in the water and air.

RÉSUMÉ

Base sur les études récentes sur les axes percés et pris de la roche, le côté résistant des axes percés et pris de la roche était affecté par la solidité compressive et ouverte de la roche aussi bien que la faiblesse du trou pour faire des forages. Depuis que l'existence des systèmes de la mesure de faiblesse pourrait être conduit seulement dan l'air, un nouveau système de la mesure de faiblesse, qui peut évaluer la faiblesse ouverte de la roche dans l'air et aussi dans l'eau, était obligé, et développé dans cette étude comme nommé le BKS-LRPS(Backyoung-Kyungsung Laser Roughness Prodiling System), Pour la vérification du champ du BKS-LRPS, cela est appliqué pour mesurer la faiblesse du trou pour faire des forages et l'alignment vertical sur les 6 axes percés pour verifier la stabilité du BKS-LRPS contre les plusieures conditions du champ, qui étaient l'effet de la mesure de l'unité tremblante, l'application des facteurs du calibrage de l'eau/de l'air, et la résistance de la haute pression de l'eau à l'intérieur des piles, et la diverse turbidité. Base sur les résultats de la vérification du champ, les alignements verticals pour tous les axes percés peuvent être mesurés par le BKS-LRPS. Cependant, la faiblesse du trou pour faire des forages n'était pas capable de mesurer attribuable à la haute turbidité causé par le procèssus percé du RCD. Base sur la vérification du champ du BKS-LRPS, le BKS-LRPS est la première faiblesse du trou pour faire des forages et le système de la mesure de l'alignement vertical appliqué à la fois dans l'eau et dans l'air.

Keywords : Drilled shafts, Skin, borehole roughness, BKS-LRPS.

1 INTRODUCTION

According to studies conducted by Horvath et al. (1983), O'Neill & Hassan (1994), and Seidel & Collingwood (2001), the skin friction of the rock socketed drilled shaft is affected by roughness, bedrock properties, initial vertical stress, pile diameter, bedrock joints and weathering as well as unconfined compression strength. Up to now, systems to measure borehole roughness have been developed by University of Houston (Nam, 2004) and Monash University (Collingwood, 2000). However, the system developed by University of Houston is operable only in the air, and even the one developed by Monash University can be used underwater, its operation is limited by drilling slurry turbidity. Hence, there rose the need to develop the system to measure borehole roughness in consideration of various limitations in the field.

In this study, a borehole roughness profiler called the BKS-LRPS (Backyoung-Kyungsung Laser Roughness Profiling System), which is operable in the water as well as in the air, was developed and underwent laboratory and field verifications. In laboratory verification, for specimens made of various configurations and materials, the laser sensor's behavior in the air and underwater was analyzed. Also, the influence of various field conditions (turbidity, illumination, salinity, water resistance) was carefully reviewed. After the laboratory verification, the BKS-LRPS was applied to six actual drilled shafts to measure borehole roughness and it was verified whether the BKS-LRPS could be applied in the field.

2 BKS-LRPS (BACKYOUNG-KYUNGSUNG LASER ROUGHNESS PROFILING SYSTEM)

Borehole roughness measurement is affected by various conditions such as underwater conditions affected by underground water and drilling slurry, turbidity affected by soil and rock fragments, salinity affected by seawater inflow, drilling depth, drilling diameter, illumination, water pressure, and changes in geomaterial. Therefore, a new roughness profiler should be able to reflect such conditions, and various expected field conditions were taken into consideration to develop the BKS-LRPS according to the procedure shown in Figure 1.

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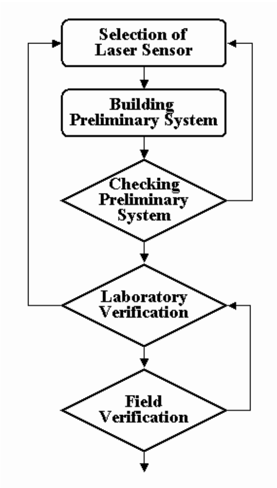

Figure 1. Flowchart of BKS-LRPS development

2.1 *Laser Sensor of BKS-LRPS*

Usually pulse laser sensors and triangulation laser sensors are used as a range finder. The pulse laser sensor measures a distance by timing laser reflection and the triangulation laser sensors by sensing angles. In general, the triangulation laser sensor is more accurate than pulse laser sensor and is suitable for surface profiling and roughness detection as it is reliable because distances are measured by laser triangulation in a non-contact way (Dwulet, 1995). The earlier mentioned roughness profilers developed by Monash University and University of Houston were based on triangulation laser sensors. Also, BKS-LRPS developed in this study uses the triangulation laser sensor.

In this study, considering the size, accuracy, effective range and handling safety of a laser sensor, a triangulation laser sensor which uses a 650nm visible laser beam with a commercially-available location detection sensor was selected (Table 1). The selected laser sensor has an effective range of 25~225mm, and a minimum gap of 0.1mm. Since the BKS-LRPS should be applicable to the field, the laser sensor was housed in the stainless steel cylinder to be protected from insects and water as shown in Figure 2.

Table 1. Specifications of laser sensor

Items	Specifications
Measurement range	20 ~ 400mm
Absolute accuracy	±0.5% 20 ~ 200mm, ±1% 200 ~ 400mm
Repeatability	±0.25% 20 ~ 200mm, ±0.5% 200 ~ 400mm
Resolution	0.1mm
Laser source	650nm - 1.2mW
Operating temperature	-20 ~ 50□

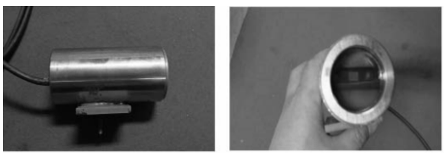

Figure 2. Protection case for laser sensor

2.2 *Configuration of BKS-LRPS*

Developed in consideration of various construction conditions (water, illumination, salinity, turbidity, shock during ascending and descending, drilling diameter, drilling depth, etc), the BKS-LRPS consists of three parts. The first part is the ascending/descending unit to ascend or descend the roughness profiler (Figure 3). Steel wire rolls are on its left and right sides to ascend or descend the roughness profiler. The left roll has a data line at its center. The right roll has a motor to prevent the steel wire and data line from becoming loose due to their self-weight and a mechanical device to ascend the profiler. Also, there is a depth encoder to measure depth when the steel wire moves up and down.

The second part is the roughness profiler. As four sensors are located at every 90 degree to measure roughness in four directions, measurement time is reduced to prevent delays at the construction site. Wires are installed at four points on the plate that supports four laser sensors to minimize shocks when the roughness profiler moves up and down.

The third part is the program to operate the BKS-LRPS. This program can decide whether the laser sensor and encoder work properly; save data safely and easily; and calculate vertical alignments on the screen. Figure 4 shows major screen shots of the BKS-LRPS program.

Figure 3. Photo of BKS-LRPS System

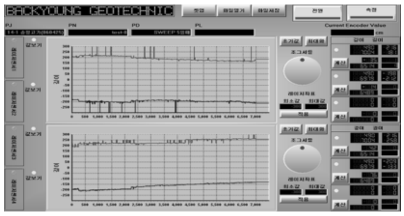

Figure 4. Screen shot of the BKS-LRPS program

3 LABORATORY VERIFICATION OF BKS-LRPS

To verify how field conditions affect the BKS-LRPS, the laboratory verification system (Figure 5) was built with the same laser sensor and operation program as those for field uses. Then, influence from the following factors was tested.

(1) Materials (plastic, aluminum, cement, gypsum)
(2) Reflexibility (glazed and non-glazed object)
(3) Configuration (plate, square, triangle, circle, trapezoid)
(4) Effective range (Air: 67.7 ~ 467.7 mm, Underwater: 78.0 ~ 438.0 mm)
(5) Illumination
(6) Salinity (0 %, 3 %)
(7) Turbidity (NTU = 10.8 ~ 63.3)

With the laboratory verification for the BKS-LRPS, influence from various factors such as object types, illumination, materials (air, underwater), effective range, salinity, turbidity, configuration and object reflexibility was tested to secure reliability. According to the laboratory verification results, material, illumination and configuration had almost no influence. Also, as for salinity, within 3% salinity, measurement was not affected.

When air measurement values and underwater ones were compared, regardless of materials or other factors, underwater values are 74% of air ones (Figure 6). From this result, the underwater measurement value multiplied by 1.35 (1/0.74) is equal to air one.

When there was no turbidity, the effective range of the laser sensor was analyzed, and the effective range was found to be 400mm. However, within an effective range of 227.7mm, the standard deviation was less than 0.2mm. If the effective range was beyond such ranges, the standard deviation reached up to 0.5mm.

Finally, turbidity influence on the effective range is presented in Figure 7. In this figure, the effective ranges are compared when they were measured in the turbid liquid with and without salt. The lower measurement limit according to turbidity is presented in following equation (1). To analyze turbidity influence, drilling slurry was collected from actual boreholes, dried, and then the residue was used to produce liquids with various turbidities. Table 2 shows the engineering characteristics of soil used for the turbid liquids.

$$EMD = B_{ks} \times T_b^{-0.63} \tag{1}$$

where, EMD : effective range of the BKS-LRPS (mm)
B_{ks} : Coefficient of the BKS-LRPS (= 1149.2)
$T_b^{-0.63}$: Turbidity (NTU)

When reflexibility influence was analyzed, for the glazed object, the BKS-LRPS showed high values with noise. It is planned to analyze quantitatively how reflexibility influence affects the laser sensor when the borehole surface is highly reflective.

Table 2. Engineering properties of soil in turbid liquids.

USPS	Finer of #200	Specific gravity	Liquid limits	Plastic limits	Plasticity index
SC	50 %	2.73	25 %	12 %	13

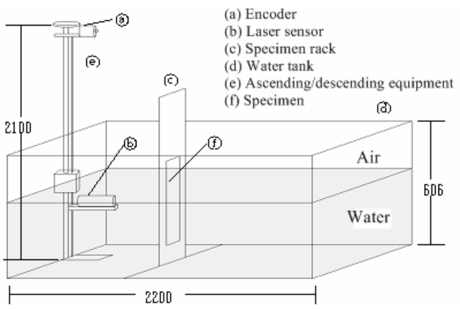

Figure 5. Laboratory verification System

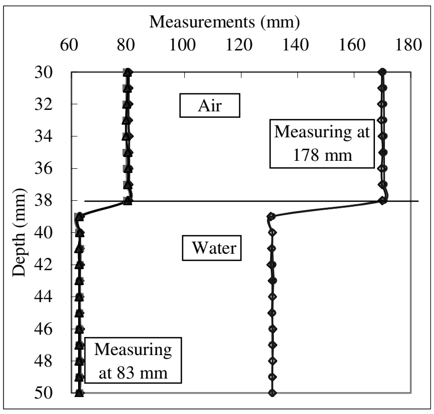

Figure 6. Comparison of measurements in the air and underwater

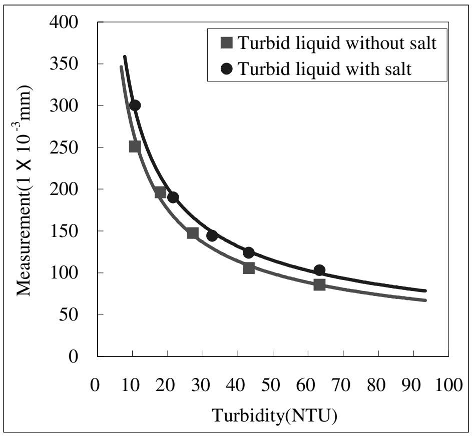

Figure 7. Effective range with various turbidities

4 FIELD VERIFICATION OF BKS-LRPS

After the laboratory verification, the BKS-LRPS was field-tested in OO site as shown in Figure 8. For drilled shafts with a diameter of 1.5 m, which were constructed in an all-casing method, borehole roughness was measured in the air condition. From the surface, the ground condition consisted of filling, deposit, sedentary deposit, and weathered rock. The weathered rocks with roughness were distributed at a depth of 10.8m from the surface. To measure roughness for the weathered rock, a casing was drawn by 1 m to exposure the weathered rock surface. Then the BKS-LRPS was descended to the final penetration depth, and borehole roughness was measure with ascending.

Figure 9 shows the measurement results of the BKS-LRPS in OO site. For a depth of 11.8 m or less where positing the steel casing, a little roughness was measured due to soil attached to the casing inside. For a depth of 11.8m or more, data shows the roughness of weathered rock. It is noted that Sensor 1 (S1) and 2 (S2) were shaken a bit, Sensor 3 (S3) and 4 (S4) produced relatively reliable results.

The BKS-LRPS was also applied to drilled shafts constructed in a RCD method. However, due to the characteristics of the RCD method and no viable way to reduce turbidity in the site, it was almost impossible to measure borehole roughness with the BKS-LRPS.

According to the laboratory verification and two field application results, the BKS-LRPS can be applied to drilled shafts constructed in the all-casing method but its applicability drops sharply for drilled shafts constructed in the RCD method. In order to use the BKS-LRPS to measure roughness under more turbid conditions, it should be complemented, and to that end, studies are underway.

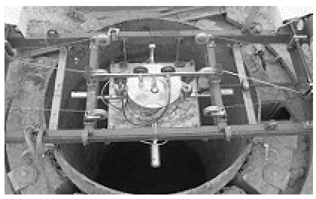

Figure 8. Photo of field verification

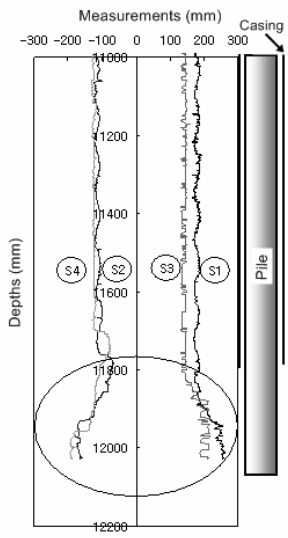

Figure 9. Results of field verification

5 CONCLUSIONS

In this study, the laboratory and field verifications were conducted to develop the roughness profiler available both in the air and in the water. The results are summarized as follows.

(1) The BKS-LPRS is developed to measure borehole roughness and is designed to be operable in the water as well as in the air.

(2) The laboratory verification results show that measurement conditions (air or water), reflexibility, and turbidity have the biggest influence on measurement. For these factors, calibration factors and effective ranges are proposed.

(3) The BKS-LRPS can be applied to all-casing drilled shafts but its applicability drops sharply for RCD drilled shafts.

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