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Development of Static Rock Penetrometer for Locating Rock Stratum During Construction of Drilled Shafts

암반에 근입된 현장타설말뚝 시공시 선단부 강도확인을 위한 정적암반관입기 개발연구

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요 지

암반에 근입된 현장타설말뚝 시공 시, 말뚝 선단부의 위치 및 강도는 반드시 확인되어야 한다. 그러나, 실제 현장타설말뚝의 시공 시 굴착액 등으로 인하여 선단부의 위치 및 강도 확인이 힘든 실정이다. 따라서, 본 연구에서는 현장타설말뚝 굴착장비에 간단히 부착하여 선단부 암반의 위치 및 강도를 측정할 수 있는 정적관입기를 개발하였다. 일련의 실내교정을 통하여 만들어진 정적암반관입기는 여러 현장에서 수행된 검증시험을 성공적으로 수행하였고, 이에 따라서 현장타설말뚝 선단부의 위치 및 강도 확인을 가능하게 하였다.

Abstract

During construction of deep foundation in soft rock under varying soil properties, it is essential to locate the rock stratum, especially when drilling with slurry. When slurry is used for drilling, the bottom of the borehole cannot be seen, thereafter soil cuttings cannot be differentiated from soft rock cuttings. A new static rock penetrometer, known as Rock Penetrometer was developed during this study. It could be a simple mechanical device that is attached to the bottom of a Kelly bar which is used to attach drilling tools such as augers and core barrels while drilling. After its calibration in the laboratory, the performance of the static rock penetrometer was verified in the several field test sites.

Keywords : Drilled shafts, Slurry, Field verification tests, Rock, Static rock penetrometer

1. Introduction

Standard Penetration Test (SPT) has been used since early 1900 to determine the in-situ soil properties from the blow counts. Due to its mode of operation, it is different to incorporate SPT test during drilling to construct deep foundations. Cone Penetration Test (CPT) is used in determining the type of soil and various other soil properties. However, it cannot be used in hard soil or soft rock because of penetrability problem.

Likins et al. (2000) indicated that it was possible to monitor routinely torque versus auger depth on ACIP pile drill rigs, which helped operators to identify the soils or rocks that were being penetrated. This was done by measuring the pressure in the hydraulic line that powered the rotary motor, which is always hydraulic. This pressure, which was measured using electronic pressure transducer placed in the line, is transmitted wirelessly to the rig operator and, if desirable, to a recording device near the rig to provide a record of pressure (implied torque)

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versus depth of the auger tip. Auger tip depth is acquired electronically by measuring the drop of the stem of the auger relative to a fixed point. This process made it possible to identify the depth of rock in most situations.

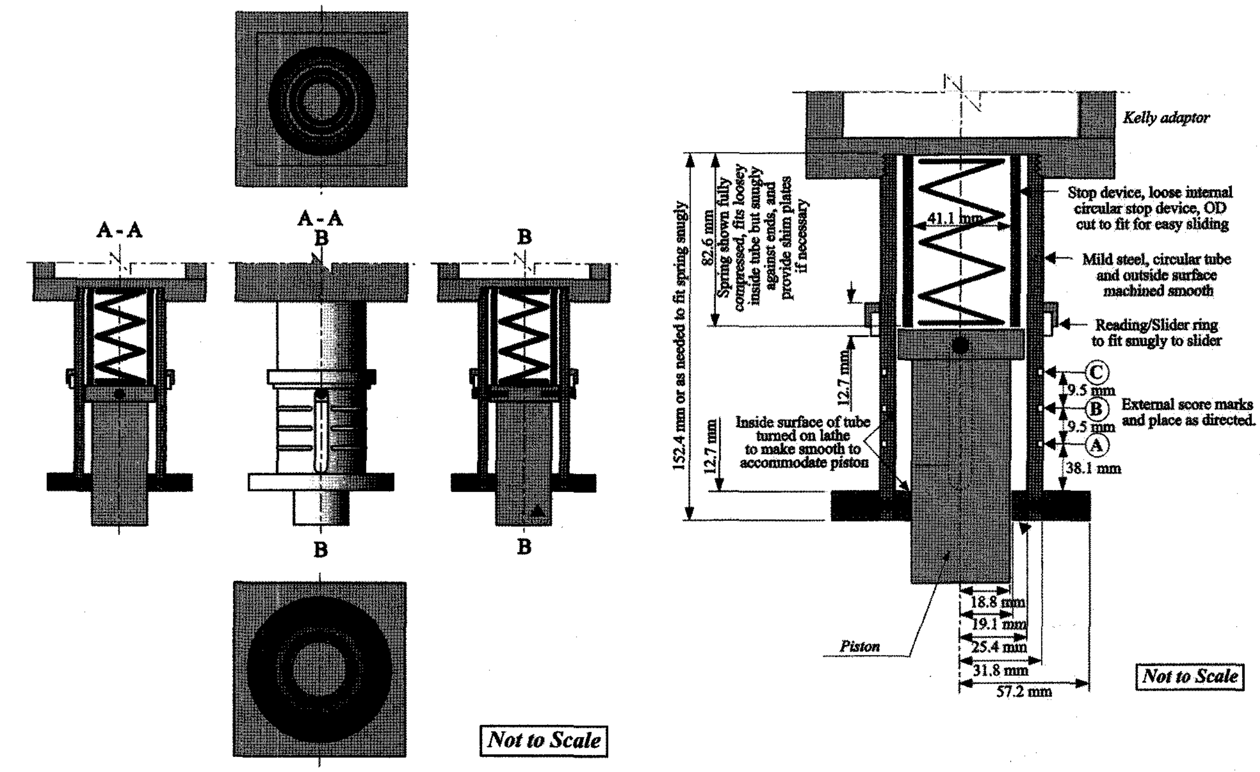
No such instrument has been developed for drilled shaft rigs. This may be because of the wide variety of devices that exist for supplying torque to the Kelly bar, including older mechanical devices and newer hydraulic devices, which make it difficult to develop a "universal" torque-measurement instrument. Therefore, it was necessary that the presence of rock be identified with a static rock penetrometer (SRP) which is a simple mechanical device as shown in Figure 1 that could be attached to the bottom of the Kelly bar on the drilling contractor's drill rig using the same pin (Kelly pin or tool pin) that is usually used to attach drilling tools (augers or core barrels).

The SRP was designed to identify a rock stratum during construction, especially when drilling with slurry, in which the bottom of the borehole could not be seen and the cuttings might be so disturbed that overburden (soil) cuttings cannot be easily distinguished from cuttings of soft rock. The design of SRP is based on the concept of the "pocket penetrometer," which has been used by field geotechnical boring loggers in clayey soil for years.

2. Laboratory Calibration

The SRP was calibrated in a conventional testing machine with capacity of 22.2 kN. Three score marks were placed on the shaft of the penetrometer based on this calibration. These marks are intended to represent soils or rocks with unconfined compression strengths (q_u) of 0.7 MPa (Mark A), 1.4 MPa (Mark B), and 2.1 MPa (Mark C), representing hard soil (Mark A), very soft or weathered clay shale (Mark B), and sound clay shale or soft limestone (Mark C) as described in Table 1. It is noted that these marks can be adjusted with different rock strength by changing spring stiffness (Figure 1).

In Table 1, it was assumed that the ultimate bearing capacity factor for the toe of the piston would be 4 (Nam, 2004). Using the known area of the toe of the piston, these marks A, B and C represented ultimate bearing



(a) Schematic of SRP (b) Body of SRP

Fig. 1. Schematic of SRP

Table 1. Unconfined Compressive Strength Corresponding to Score Marks on Static Rock Penetrometer

Score Mark	Represented Geomaterial	Unconfined Compressive Strength, q_u (MPa)	Bearing Capacity* (MPa)
A	Hard soil (overburden)	0.7	2.8
B	Soft or highly weathered clay-shale	1.4	5.6
C	Sound clay-shale or soft limestone	2.1	8.4

*Assuming the bearing capacity factor for the toe of the piston would be 4 with respect to q_u

capacity of 2.8 MPa, 5.6 MPa and 8.4 MPa, respectively. Corresponding to the three marks the score marks were computed and placed as shown in Table 1. It was also assumed that the bearing failure induced by the piston of the penetrometer is undrained, since rock penetration test takes only a few seconds after it is lowered down into the borehole.

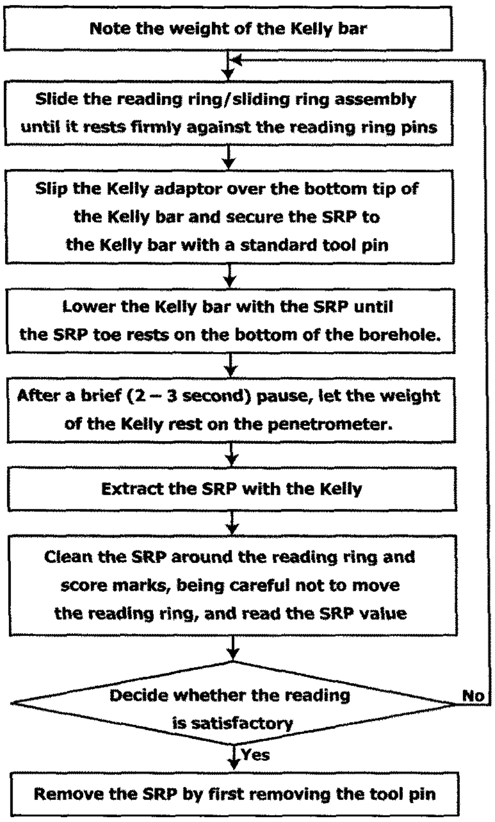


Fig. 2. SRP Operation

3. Operations

The details of operation of the SRP are important. These details are summarized in Figure 2. Figures 3 to 4 are photos of the penetrometer that show most of the elements referred in Figure 2. The SRP was designed to be handled by one person.

When Hollow Kelly bars applied to the SRP, it may weigh 9 to 11 kN for an "LDH" (a drilling rig manufactured by Atlantic equipment company, Inc.) or similar drilling rig. This weight may not be sufficient to push the penetrometer toe at least 50 mm into sound geomaterial at the bottom of the borehole, which is necessary in order to obtain the correct reading. Solid Kelly bars for LDH or similar rigs generally weigh 18 to 20 kN, which should be sufficient for a 50-mm penetration, or at least a C reading.

Letting the weight of the Kelly rest on the penetrometer will force the piston into the geomaterial until the geomaterial fails and at the same time push the reading ring into a position on the outside of the penetrometer body

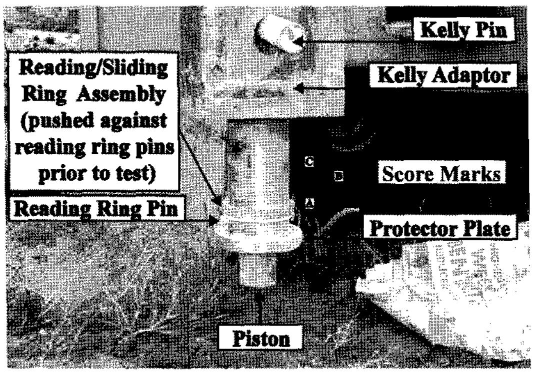


Fig. 3. SRP Mounting on Kelly

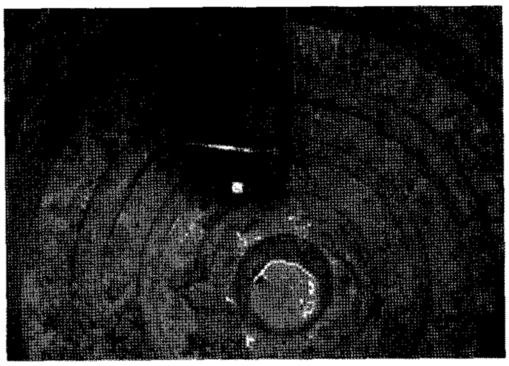


Fig. 4. SRP at Bottom of Drilled Shaft Borehole

Table 2. Static Rock Penetrometer Readings at Test Sites

Field Site	Depth (m)	Geomaterial	Reading
Rowlett Creek	0.2	Medium stiff wet clay	Less than A (min.)
	0.9	Stiff, gravelly clay	B-C
	1.1	Soft, blocky, highly weathered rock	A-B (failures along blocks)
	1.8	***Sound gray limestone***	***Higher than C (max.)***
Hampton	0.2	Soft, moist clay	Less than A (min)
	0.8	Tan, moist sand	Less than A (min)
	6.4	Gray, soft, slightly blocky clay-shale	B-C
	6.7	Gray, soft, slightly blocky clay-shale	B-C
	12.2	Gray, stiff laminated clay-shale	B-C (w/o Crowding Kelly) C (w/ Crowding)
Denton Tap	4.9	Stiff clay / clay-shale mixture	A-B
	6.1	Soft, slightly blocky clay shale	B
	11.1	Dark gray clay shale, slightly sandy	B-C

The entry in italicized boldface indicates sound, relatively hard rock with q_u of about 6.9 MPa.

that reflects the force required to cause geomaterial failure (through the relation between spring movement and force). The reading ring will stop moving even though the penetrometer is pushed farther into the geomaterial than is necessary to produce failure.

4. Field Verification

The SRP was then calibrated in the field in boreholes that were drilled at three test sites (Rowlett Creek, Denton Tap, Hampton) in Texas, USA. The SRP readings at these sites are summarized in Table 2. The readings were all made in open boreholes under slurry.

The SRP readings in Table 1 were compared with values of q_u measured in cores taken from the same elevation (Nam, 2004) as that of the penetrometer test in nearby boreholes, as shown in Figure 5. The result of field verification showed that readings of B, A-B and A were indicative of overburden materials, the reading between marks B and C was indicative of soft, sound clay shale, and a reading of C or higher was indicative of sound, hard clay shale or limestone.

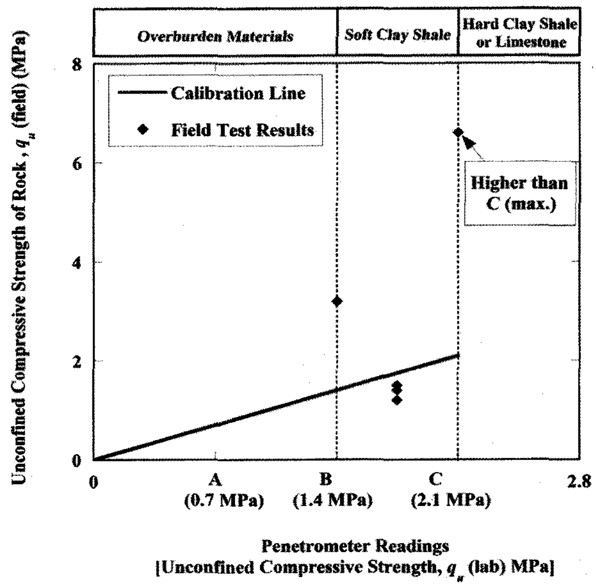


Fig. 5. Results of Field Verification

5. Conclusions

A new static rock penetrometer was designed and built to be used as a tool to locate the rock stratum during construction. It was calibrated in the laboratory and successfully verified at three field sites. Based on the results of field verification tests, the static rock penetrometer reading less than marks B was indicative of overburden materials, readings between marks B and C ("B-C") were indicative of soft, sound clay shale, and a reading higher than C is indicative of sound limestone or sound, hard clay shale.

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