Field application of continuous intrusion miniature CPT system in South Korea

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ABSTRACT: The cone penetration test (CPT) has been increasingly used for in situ site characterization. However, the use of CPT is often limited due to specific site conditions depending on the cone size, geometry, and capacity of the CPT system used. In South Korea, it has generally been considered that the CPT could be satisfactorily performed only in soft soils. Louisiana State University (LSU) / Louisiana Transportation Research Center (LTRC) has implemented a field-rugged continuous intrusion miniature cone penetration test (CIMCPT) system since the 1990s. The miniature cone penetrometer of the CIMCPT system has a cross-sectional cone area of 2 cm^2 allowing finer soil profiles compared to the standard 10 cm^2. The reduced cross-sectional area also enables a system capacity reduction leading to cost saving and ease in maintenance. In addition, the continuous intrusion mechanism allows fast and economic site investigations. Samsung Engineering & Construction has recently implemented a similar CIMCPT system. The performance of the Samsung CIMCPT system has been investigated by calibration with the standard CPT system at a well-characterized test site in South Korea. In addition, soil classification by the computerized probabilistic method using the CIMCPT profile is compared with soil classification from laboratory tests.

1 INTRODUCTION

Cone penetration test (CPT) is performed by pushing a cone at a constant rate (2 ± 0.5cm/sec) and normally measures tip resistance (q_c), sleeve friction (f_s), pore water pressure (u). CPT has been increasingly used for in situ site characterization due to its expediency, economics and reliability in field operations, and strong background in subsurface data analyses since its development in the 1930s. CPT data are used to determine soil classification with depth and to estimate various engineering soil properties for design and analysis of soil structures. The standard CPT system is equipped with a projected cone area of 10 cm^2 and a friction sleeve area of 150 cm^2. In addition to the standard CPT system, the CPT system with the 15 cm^2 cone penetrometer and the 200 cm^2 friction sleeve has been also extensively used for deep and stiff soil investigation.

The Louisiana State University, LSU/Louisiana Transportation Research Center, LTRC has implemented a field-rugged continuous intrusion miniature cone penetration test (CIMCPT) (Tumay and Kurup, 1997; Tumay and Kurup, 1999) system since the 1990s (http://www.coe.lsu.edu/facilities/revegits-cimcpt.htm). The miniature cone penetrometer of the CIMCPT system has a cross-sectional cone area of 2 cm^{2,} and a frictional sleeve surface area of 40 cm^2, allowing finer soil profiles due to minimized pressure bulb generated in the path of the cone compared to the standard cone penetrometer with 10 cm^2 cross-sectional cone area and the 150 cm^2 frictional sleeve surface area. The reduced cross-sectional area of the CIMCPT also enables a system capacity reduction leading to cost saving and ease in maintenance. In addition, the continuous intrusion mechanism allows fast and economic site investigations.

In South Korea, CPT systems that are applicable for stiff soils are very rare due to their expensive procurement and maintenance cost. Therefore, the application of CPT has been often limited to only soft soils. Samsung Engineering & Construction has recently implemented a similar CIMCPT system based on the system at LSU/LTRC. The performance of the Samsung CIMCPT system has been investigated by calibration with the standard CPT system at a well-characterized test site near Seoul in South Korea. In addition, soil classification by the computerized probabilistic method (Zhang and Tumay, 1999) using the CIMCPT profile is compared with soil classification from laboratory tests.

2 SAMSUNG CIMCPT SYSTEM

2.1 *Miniature Cone and Continuous Intrusion Mechanism*

The CPT system normally consists of the following major components: cone penetrometers, cone intrusion system, data acquisition system, and a vehicle. The prototype CPT system utilizing the standard 10 cm^2 or 15 cm^2 cone penetrometers typically needs a large CPT vehicle to possess a sufficient reaction force for stiff soil investigation and a cone intrusion system with segmental rods consuming time and effort to push the cone into deep soils. The CIMCPT system had been developed and implemented to overcome the drawbacks of the standard full-size CPT system. The miniature cone penetrometer and continuous intrusion mechanism are two unique features in the CIMCPT system. Fig. 1 shows the comparison between the 2 cm^2 and the 10 cm^2 cone penetrometers. Fig. 2 shows the continuous intrusion system consisting of a coiled rod and continuous push device.

Fig. 1 Comparison between the 2 cm^2 and the 10 cm^2 cone penetrometers

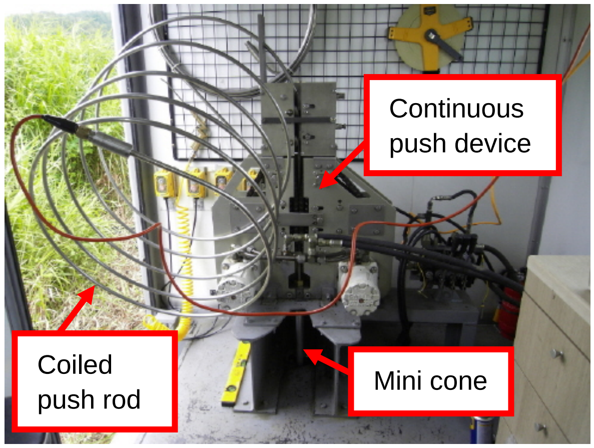


Fig. 2 Continuous intrusion system in the Samsung CIMCPT system

The Samsung miniature cone penetrometer has a cross-sectional area of 2 cm^2 and friction sleeve area of 30 cm^2 (Fig. 3). The "fiction sleeve surface area/cone cross sectional area" ratio of the Samsung miniature cone (i.e. 30/2 = 15) is the same as the ratio in the standard 10 cm^2 cone (i.e. 150/10 = 15). As shown in Fig. 3, strain gages are placed in two rows inside the cone penetrometer. Strain gages in the first row measure tip resistance, while strain gages in the second row measure tip resistance plus sleeve friction. To determine the sleeve friction, the tip resistance from the strain gages in the first row should be subtracted from the tip resistance plus sleeve friction from the strain gages in the second row. This cone is often referred to as *subtraction cone* (Lunne et al., 1997). As shown in Fig. 4, the miniature cone penetrometer is attached to a coiled penetration rod. The continuous push device that is powered by a reversible hydraulic motor allows continuously inserting and retracting the coiled rod through the coiling mechanism. The coiling mechanism straightens the coiled rod before the cone is inserted into the soil and re-coils the straightened rod after testing. It was reported that the plastic deformation of the rod accompanied with the coiling mechanism could eventually result in failure after about 300 cycles of coiling and uncoiling (Tumay and Kurup, 2001). The maximum penetration depth of the Samsung CIMCPT system is 15 m. The miniature cone and the special coiled rods were procured from the developer, Sage Engineering, Inc., USA. The CIMCPT system which also uses these special components was developed at LSU/LTRC.

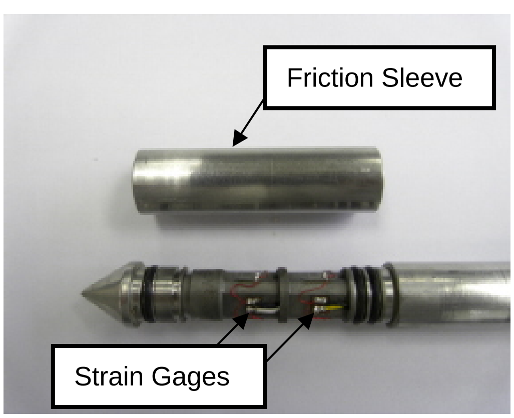


Fig. 3 Inside of the miniature cone   Fig. 4 Miniature cone attached to a coiled rod

2.2 *CIMCPT Vehicle*

Miniature cones systems have been developed and used for laboratory testing because they allow more precise investigation in soil samples (DeJong et al., 2003; Yafrate and DeJong, 2005; Shin et al., 2007). Unlike laboratory application of miniature cones, field application requires a vehicle. The vehicle transports the CIMCPT system to test sites and applies reaction force using its own weight in cone testing. As shown in Fig. 5, Samsung Engineering & Construction has developed the Samsung CIMCPT truck based on one the developed by LSU/LTRC. The Samsung CIMCPT truck is a 2.5-ton, four-wheel drive, all terrain vehicle equipped with four-foot outriggers and four-ton electrical winch considering various field conditions. The CIMCPT truck is much lighter and costs less compared to a typical full-size CPT truck because the reduced cone size requires smaller reaction force as shown in Fig. 6.

Fig. 5 Samsung CIMCPT truck

Fig. 6 CIMCPT truck and CPT truck

2.3 *Data Acquisition System*

Fig. 7 shows a data acquisition system used in the Samsung CIMCPT system. The data acquisition system consists of a data logger enclosing DGH modules for q_c and f_s, a data transformer sending data from the data logger into a computer, and a notebook computer with a software allowing system control, data display, and data store. For more information on the data acquisition system, refer to Tumay and Kurup (2001).

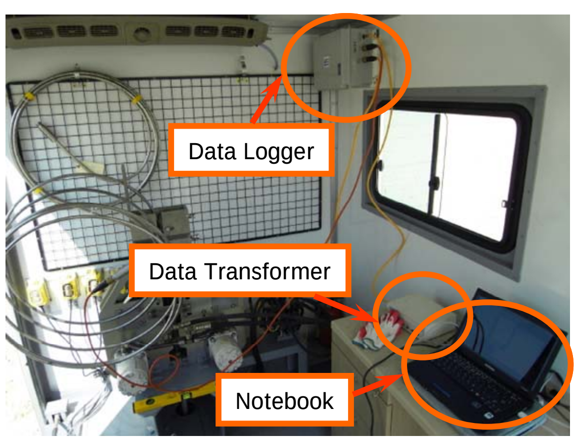


Fig. 7 Data acquisition system used in the Samsung CIMCPT system

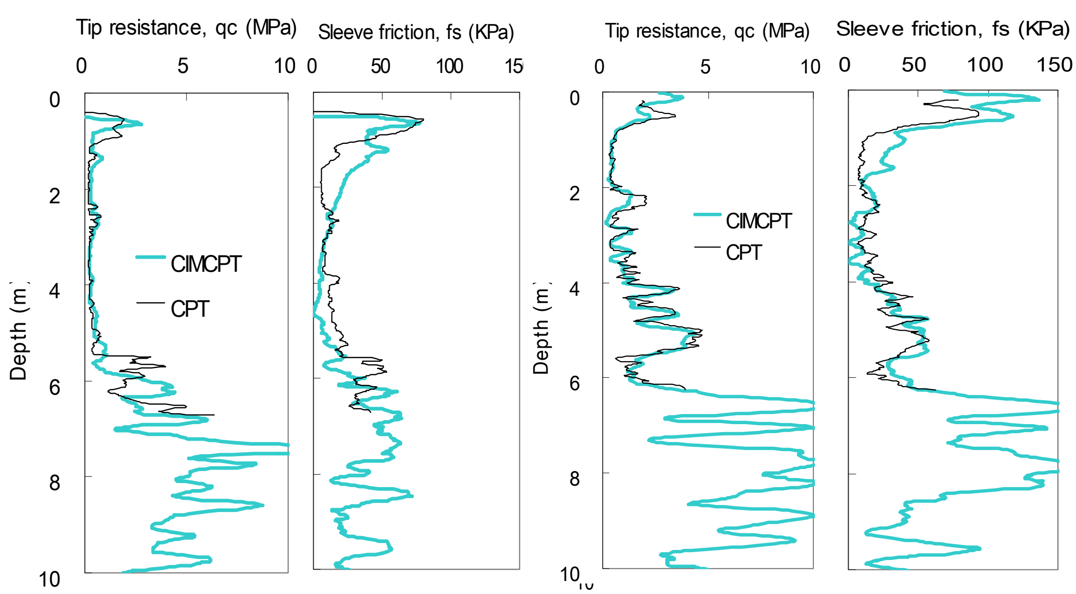
3 FIELD TEST

3.1 *Overview*

The Samsung CIMCPT and the full-size CPT have been field-tested at a construction site near Seoul in South Korea. The site is appropriate for field calibration in that it is characterized well and has homogeneous soil deposits to minimize the effect of soil variability on the measured data. The performance of the Samsung CIMCPT has been investigated by calibration with the standard 10 cm^2 CPT at the two different locations of the site spacing about 250 m. Location #1 consists of silty clay (CL) to a depth of 5.7 m, followed by sandy silt (ML) to 7.5 m, fine loose sand (SP) to 8.7 m, and fine medium sand (SW) to 10.5 m. Location #2 consists of silty clay (CL) to a depth of 2.5 m, clayey silt (ML) between 2.5 ~ 3.5 m, silt (ML) between 3.5 ~ 7.5 m, sandy silt (ML) between 7.5 ~ 8.5 m, and medium sand (SP) to the depth of 11.7 m. The ground water tables for the two locations are located at a depth of 0.7 m, 1.5 m, respectively. At each location, a CIMCPT and a standard CPT were performed 1-m apart from each other in order to minimize the interaction and influence of soil disturbance on the test results. Soil classification by the computerized probabilistic method (Zhang and Tumay, 1999) using the CIMCPT profiles has been also compared with soil boring profiles and soil classification from laboratory tests.

3.2 *Field Test Results*

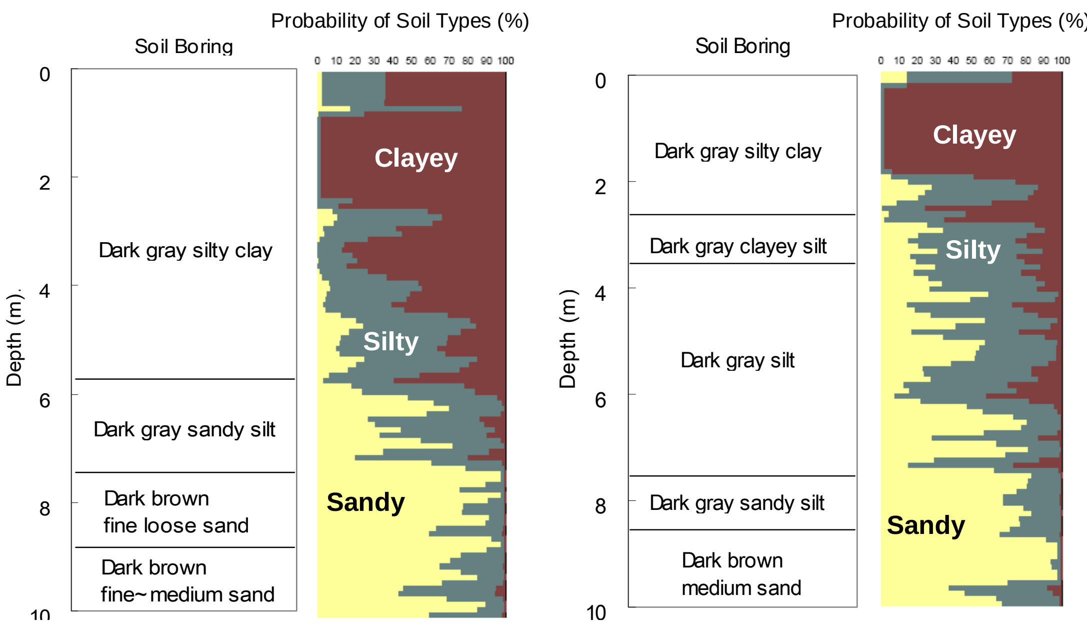
Fig. 8 shows the comparison of the CIMCPT and the prototype CPT profiles at the two different test locations, respectively. CIMCPT was performed up to the depth of 10 m, while CPT was performed up to about 6.5 m due to the insufficient reaction force. As shown in Fig. 8, generally good agreement in the q_c and f_s measurements is observed between the both cone penetrometers, although there is some small difference in measured sleeve friction at depths between 1 to 2m at both sites.



(a) Test location #1 (b) Test location #2

Fig. 8 Comparison of the CIMCPT and the prototype CPT profiles

The subsurface soils were classified using the computerized probabilistic method (Zhang and Tumay, 1999) with the CIMCPT profiles. The method is based on a CPT soil engineering classification index, U (non-dimensional) that results from preliminary data reduction on the CPT sounding data (Zhang and Tumay, 1999). Fig. 9 shows the comparison between the soil boring results and the soil classification using the CIMCPT profiles shown in Fig. 8. Laboratory tests have been performed for soil samples at the depths of 1.5 m and 3.0 m for the location #1 and at depths of 2.2 m and 4.0 m for the location #2. Table 1 describes the laboratory test results and the soil types by the Unified Soil Classification System (USCS). The soil classifications using the computerized probabilistic method (Zhang and Tumay, 1999) compare well with the boring results and the USCS soil types.



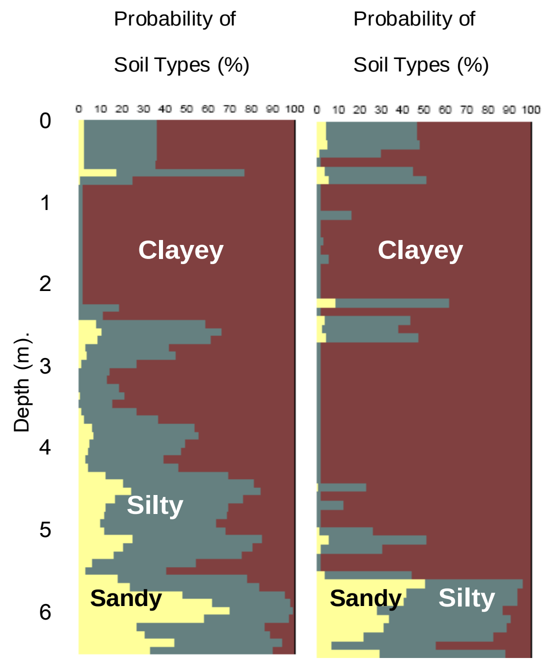
(a) Test location #1 (b) Test location #2

Fig. 9 Comparison between soil boring results and CIMCPT soil classifications by the probabilistic method

Table 1 Laboratory test results and USCS soil type

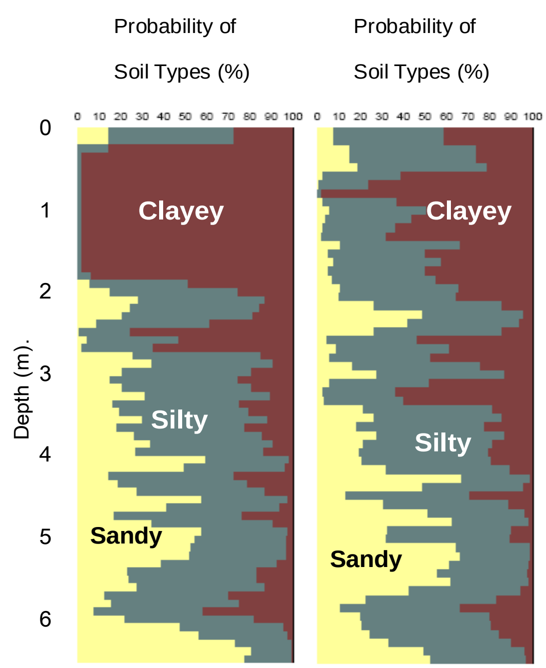
Depth / Location	Gs	W_n (%)	LL (%)	PI	#200 passing	USCS
1.5 m / #1	2.68	35.6	32.8	7.0	97.0	CL
3.0 m / #1	2.69	42.9	37.7	15.2	96.5	CL
2.2 m / #2	2.69	44.8	35.8	9.2	99.6	CL
4.0 m / #2	2.68	29.9	31.0	6.4	91.1	ML

The subsurface soils were also classified using the computerized probabilistic method (Zhang and Tumay, 1999) with the CPT profiles. Fig. 10 and Fig. 11 show the comparison between the soil classifications with the CIMCPT and CPT profiles up to the depth of 6.5 m. As shown in Fig. 10 and Fig. 11, the soil classifications with the both profiles look very similar except for more of clayey type with the full-size CPT at the test location #1.



(a) CIMCPT (b) CPT

Fig. 10 Comparison between the CIMCPT and CPT soil classifications by the probabilistic method at test location #1



(a) CIMCPT (b) CPT

Fig. 11 Comparison between the CIMCPT and CPT soil classifications by the probabilistic method at test location #2

4 CONCLUSION

Based on its original model by LSU/LTRC, the Samsung CIMCPT truck was developed and implemented for subsurface site investigation at depths up to 10 m. The "fiction surface area/cross sectional area" ratio of the miniature cone is the same as the ratio in the standard 10 cm^2 cone. The performance of the Samsung CIMCPT was evaluated by testing at a well-characterized construction site near Seoul in South Korea. From the comparison of CIMCPT and standard full-size CPT profiles at two locations, a generally good comparison is seen in the q_c and f_s measurements. Soil classifications by the computerized probabilistic method (Zhang and Tumay, 1999) with the CIMCPT profiles agree well with the boring results and USCS soil types from the laboratory tests.

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(« Soil-CPT V.4 » Computer Code available at: http://www.ltrc.lsu.edu/downloads.html)