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Design and validation of a novel small calibration chamber for cone penetration tests in soils

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ABSTRACT: This paper presents the design and validation of a novel small calibration chamber and modular penetrometer for developing soil-specific cone penetration test (CPT) calibration correlations. The chamber design includes innovative aspects such as bottom up loading, horizontal stresses measurement and the capability of applying very fast and slow penetration rates. Dry Medium Hutcheson sand (MHS) specimens of different densities were prepared using the air pluviation method. Vertical stress was applied using a membrane, with chamber walls acting as a near-zero displacement lateral boundary. The stress state in the specimens was quantified using embedded zero-deformation null gauge pressure sensors. CPTs were performed to determine tip resistance and sleeve friction. With a test performed per day, the chamber offers a practical way of developing CPT interpretation correlations in a variety of soils.

1 INTRODUCTION

Calibration chamber testing offers the best tool to develop interpretation correlations for cone penetration testing (CPT) in soils, but large chambers with diameter, $D_c > 800\,mm$ are expensive and impractical. Small chambers with diameters $D_c \leq 500\,mm$ have therefore been developed in recent years as efficient, cost-effective, and more practical alternatives.

This study presents the design and validation of a novel small calibration chamber developed for CPT. The chamber which has semi-rigid lateral boundaries allowed for simultaneous measurement of cone tip resistance, sleeve friction and pore pressure using a modular miniature piezo cone penetrometer, while providing the capability of applying slow and very fast penetration rate of up to 90 cm/s.

2 EQUIPMENT AND TESTING

2.1 Equipment

The calibration chamber (Figure 1) was built from a clear scratch-resistant cast acrylic tube with a height of 500 mm, and an inner diameter of 330 mm. A 0.1-mm-thick latex membrane is sealed against the bottom platen of the chamber, enabling bottom-up uniform vertical loading. A 10 mm diameter low-friction sealed bushing at the centre of the top lid allows for the passage of the cone penetrometer.

Figure 1. Small CPT Calibration Chamber Setup

The modular miniature penetrometer mechanically decouples the tip load measurement from the rest of the assembly using a load cell located outside the chamber rather than strain gauges embedded near the tip. Additional components include a pore pressure

transducer, resulting in a penetrometer with diameter, $d_c = 10\ mm$ that measures tip resistance (q_c), sleeve friction (f_s) and pore pressure (u_2).

Horizontal stress in the specimens was measured during consolidation and cone penetration using two null gage sensors (Talesnick, 2013) placed opposite each other at the mid-depth of the specimens.

2.2 Specimen Preparation and Testing

The sand tested is referred to as the Medium Hutcheson Sand (MHS), obtained from Huntsville, Ontario, Canada. Dry sand specimens were prepared by air pluviation with a funnel. Variation of funnel drop height and opening size enabled the preparation of 13 specimens with relative densities, $D_r = 21\%$ to 84%. The specimens were then consolidated by applying vertical stresses, $\sigma'_v = 100$ to $300\ kPa$. Finally, cone penetration was conducted at the standard penetration rate (20 mm/s) while measuring q_c and f_s at a sampling rate of 20 Hz.

3 RESULTS AND DISCUSSION

The specimens had initial state parameters of $\psi = 0.00$ to -0.19 where $\psi = e - e_{crit}$; e and e_{crit} are the initial and critical state void ratios, respectively at the same mean effective stress, p' (Been and Jefferies, 1986). $e_{crit} = 0.97 - 0.089Log_{10}(p')$. Figure 2 presents CPT results from selected tests covering the full range of D_r and σ'_v. After initial mobilization, all tests showed a uniform q_c profile between 14.5 cm and 39.5 cm depth, a testament to the uniformity of the specimens and stress state in the chamber. f_s showed a stable to somewhat decreasing trend with depth. The evolution of q_c and f_s with depth exhibited better uniformity in comparison to the observations made when the same sand specimen was tested in the large chamber (1140 mm deep and 1400 mm in diameter) by Liu, Talesnick and Ghafghazi, (2025).

Figure 3 shows the $Q_p - \psi$ correlation for each test conducted, in comparison with the data from the large chamber tests by Liu, Talesnick and Ghafghazi, (2025), where $Q_p = (q_c - p)/p'$, p and p' are the total mean stress and the mean effective stress, respectively. $p = p'$ in both studies since samples were dry. $Q_p - \psi$ data in the small chamber is in good agreement with those from the large chamber. The data looser than $\psi = -0.05$ obtained in the small chamber deviated from the trendline and showed little sensitivity to changes in the state parameter. This will be further investigated in the future by testing looser moist tamped specimens.

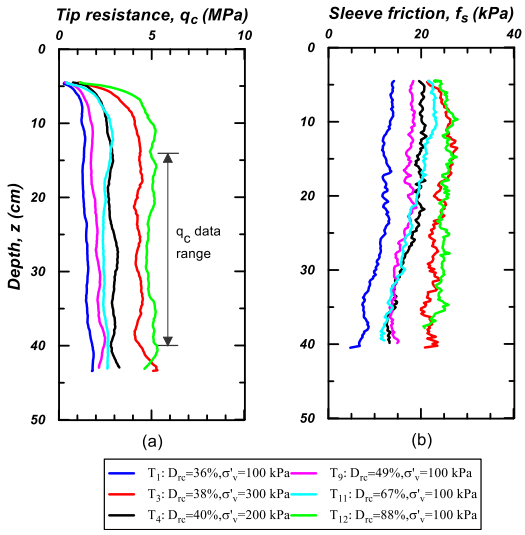

Figure 2. Cone penetration resistances for selected tests

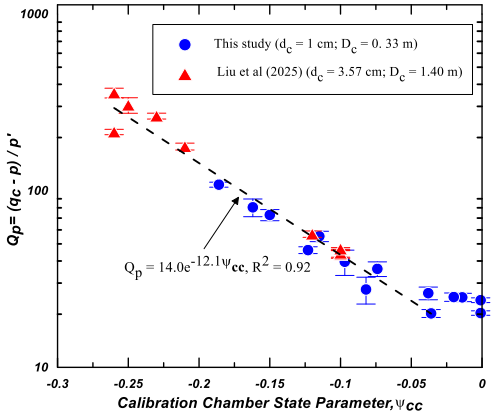

Figure 3. Calibration correlation for MHS

4 CONCLUSIONS

The small calibration chamber and miniature cone penetrometer provided stable and highly repeatable measurements of tip resistance and sleeve friction with good consistency with results obtained from large calibration chamber studies on the same sand. This confirms the capability of the small chamber to generate meaningful CPT calibration data.

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