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Technical Paper

Evaluation of spatial soil variability in the Pearl River Estuary using CPTU data

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Abstract

For a project in the Pearl River Estuary a very extensive site characterisation was carried out. The aim of this paper is to use this extensive investigation campaign to understand the spatial variability of the soil in both horizontal and vertical directions based on cone penetration tests with pore pressure measurement (CPTU). The investigated area stretches over 6762 m length and 50 m width covering an area of 338 100 m^2 with CPTU soundings every 25 m. Based on boreholes and CPTU soundings the stratigraphy is known and thus the correlation characteristics can be estimated specifically for the individual soil types. Soil types found in the Pearl River Estuary are: marine clay and sand, continental clay, marine alluvial clay and sand, fluvial alluvial clay and sand. For all these soil types the vertical and horizontal scales of fluctuation are assessed. This is an important parameter for probabilistic analysis of geotechnical problems such as settlements, differential settlements, bearing capacity and slope stability.

IGC: C03; C09; D01

Keywords: Soil heterogeneity; Characterisation of spatial soil variability; Geostatistics; CPTU; Marine soils; Fluvial soils

1. Introduction

For a large scale project, a very extensive site characterisation was carried out in the Pearl River Estuary. The Pearl River Estuary is located in south-eastern China in the Guangdong province. The campaign comprised 404 cone penetration tests with pore pressure measurement (CPTU), 38 boreholes where geotechnical in situ testing and extraction of disturbed samples was carried out, and 41 boreholes to retrieve undisturbed samples of fine grained soils.

The Pearl River drainage basin was originally formed as a result of the uplift of the Tibetan Plateau during the Tertiary and Quaternary Periods. The Holocene development of the delta has been controlled and affected by the variations in the deposition of sediments, sea-levels and groundwater levels. The river delta is one of the most important and complex large scale estuarine systems in China. The deposits in the estuary consist of three cycles of upward fining sequences of delta deposits, one Holocene and two Pleistocene delta cycles. The cycles were divided by two previously exposed and subsequently eroded surfaces. The upper marine deposits of clays and sands in Fig. 2 were formed during the Holocene period. They are underlain by continental deposits of clays and sands formed during the Late Pleistocene period, originating from a once exposed surface. Underlying is a layer of marine alluvial

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Nomenclature

The following symbols are used in this paper:

$\hat{C}(\tau)$	estimated covariance function at lag τ
E	squared error
MSE	mean squared error
$\mathcal{N}(0,1)$	standard normal distribution ($\mu = 0$ and $\sigma^2 = 1$)
n	number of observations
p_a	standard atmospheric pressure (MPa)
q_c	cone penetration resistance (MPa)
q_n	normalised cone penetration resistance (MPa)
$\overline{q}_n$	de-trended normalised cone penetration resistance (MPa)
$trend$	continuous, piecewise linear trend over depth, $trend = a + bz$
$X(z)$	random 1D process
x_i	observed value of $X(z)$ at z_i
Z	sample domain length
z	depth coordinate
z_i	discrete point along z
$\gamma(Z)$	variance function
Δz	depth interval between readings (m)
θ	scale of fluctuation
$\hat{\theta}$	estimated scale of fluctuation (m)
μ_X	mean of $X(z)$
$\hat{\mu}_X$	estimated mean of $X(z)$
$\rho(\tau)$	correlation function at lag τ
$\hat{\rho}(\tau_j)$	estimated correlation function at discrete lag τ_j
σ'_{v0}	vertical effective stress (MPa)
σ_X	standard variation of $X(z)$
σ_X^2	variance of $X(z)$
$\hat{\sigma}_X^2$	estimated variance of $X(z)$
τ	separation distance or lag
τ_j	discrete separation distance, $\tau_j = (j-1)\Delta z$

deposits of clays and sands formed during the Mid to Late Pleistocene period. Below are fluvial alluvial deposits of sand and clay formed during the Early to Mid Pleistocene period. The lowest layer above the bed rock is some residual soils formed during the Early Pleistocene period. The bed rock consists of moderately to completely weathered migmatic granites overlain by highly to completely weathered migmatic schists formed during the Sinian period. The residual soils and the bed rock are not shown in Fig. 2.

The CPTU soundings were carried out along three lines parallel to each other, with a distance of -25 m, 0 m and $+25$ m from the centre line. The CPTU positions were staggered in order to have a CPTU sounding every 25 m along the project line. The CPTU reading interval is 0.02 m for 30 locations and 0.01 m for the remaining 303 locations. Fig. 1 shows the layout of 333 CPTU soundings. The remaining 71 CPTU soundings are located outside the investigated area and not further considered in this study. The coordinate system origin in Fig. 1 corresponds to approximately 22.28° North and 113.83° East. The drilling depth

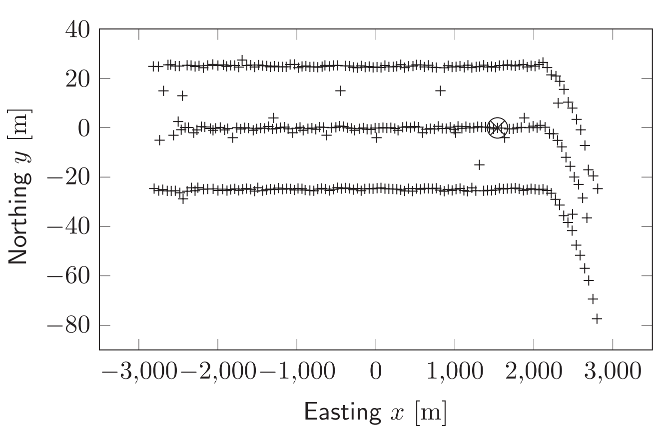

Fig. 1. Map showing the location of CPTU soundings. The large mark indicates the location of the CPTU sounding shown in Fig. 3.

of the boreholes varied from 29 to 107 m below existing seabed level. Generally two types of boreholes (disturbed and undisturbed) were drilled in pairs with a distance of approximately 5 m. The distance between the pairs of boreholes is approximately 200 m. The CPTU soundings penetrated to a depth of 27–62 m below the seabed level. They were carried out basically to refusal in the fluvial alluvial sands and clays underlying soft deposits of marine clay, see Fig. 2. The x-coordinate origin in Fig. 2 corresponds to approximately 113.83° East.

A site specific approach was followed by pairing the CPTU and borehole data in order to establish a detailed geological and geotechnical model of the subsurface conditions. Instead of using the Robertson classification chart, see Lunne et al. (1997), to categorise the geological units, the individual geological units were identified by probabilistic means. The CPTU data was analysed and correlated to the geological interpretation from adjacent boreholes. A statistical analysis was carried out to define the typical range of CPTU parameters (cone resistance, friction ratio, and excess pore pressure) for each soil type. This led to a set of filter criteria that allowed for a site specific interpretation of the soil profile based on CPTU data. It should be noted that all CPTU geological interpretations were assessed and adjusted manually by an experienced geotechnical engineer based on available data from nearby boreholes and CPTUs.

Based on the stratigraphy, the readings can be linked to a specific soil type. Table 1 shows the total number of readings for each soil type. Only soil types with 5000 or more logged CPTU readings are considered in this study leading to dismissal of the soil type continental sand. Fig. 3 shows the logged, linear trend and de-trended CPTU soundings for one location including the different soil types with soil layer depth. In this study the cone penetration resistance q_c is used. Other values obtained from the CPTU soundings are disregarded. In order to make the cone penetration resistance q_c useful for further analysis it has been normalised. The normalised cone penetration resistance q_n can be obtained according to