DEVELOPMENT OF A NEW CONE PENETROMETER AND ITS APPLICATION TO GREAT DEPTHS OF PLEISTOCENE CLAYS

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ABSTRACT

A new piezocone was developed and applied to Osaka Pleistocene clay layers as deep as 250 m. Its geometry is the same as that of the reference procedure defined by the ISSMFE and standard of JGS: i.e., the projected cross sectional area is 10 cm²; the angle of the cone is 60°; the pore water pressure is measured at the shoulder. This piezocone does not measure the skin friction. Due to great depth at the investigated site, the capacity of the point resistance (q_t) and the pore water pressure is as large as 30 MPa and 20 MPa, respectively. The test was carried out, using a borehole drilled prior to the penetration, because of stiff sand or gravel layers and large skin friction between the rod and the ground. The q_t measured by the cone penetration test (CPT) was correlated to the yield consolidation pressure (p_y) measured by the Constant Rate of Strain (CRS) oedometer test for the soil sample recovered near the point of the CPT investigation. The cone factor for the p_y value (N_{pc}) was defined by $(q_t - p_{vo})/p_y$, where p_{vo} is the in situ total overburden pressure. The range of observed N_{pc} value is relatively narrow and between 2.5 and 2.8, which is in the middle of the range of N_{pc} factors measured in Holocene clays in the various areas in the world as well as Japan. The overconsolidation ratio (OCR) was also derived by CPT. Variation of the OCR estimated by the CPT is nearly equivalent to that measured by the CRS oedometer. It may be concluded from this investigation that the consolidation properties, especially the p_y value, derived from samples recovered from great depths, are quite reliable as design parameters.

Key words: cone penetration test, great depth, Pleistocene clay, sample quality, variation, yield consolidation pressure (IGC: D5)

INTRODUCTION

With the increase in utilization of coastal areas with great depths, settlement of reclaimed lands has become an important geotechnical issue. It has been reported that large settlements have taken place in the Osaka Bay area in the Pleistocene clay layers, which are deposited very thickly below a Holocene clay layer (see for example, Akai, 2000; Fukuda et al., 1995; Nakashima et al., 1995). It is well understood by geotechnical engineers that a high quality soil sample is essential for obtaining accurate consolidation parameters from laboratory tests. Nevertheless, if such Pleistocene clays are found at great depths, there is the possibility that the retrieved soil samples suffer from disturbance due to stress release as well as mechanical disturbance in sampling process. Indeed, a large scatter has been observed in the yield consolidation pressure (p_y) measured by the oedometer test (see for example, Kanda et al., 1991; Tanaka et al., 2002). Controversy exists on whether such a scatter is a result of a difference in sample quality or an inherent variation of soil parameters (see for example, Tanaka et al., 2002).

The cone penetration test (CPT) has been increasingly

used in practical geotechnical investigation works. Among many advantages for using CPT, the most attractive point is that test results from the CPT are nearly free from human errors, since its testing procedure is very simple compared with other in situ tests such as Standard Penetration Test (SPT) or Pressuremeter test. However, so far, the application of the CPT in Japan has been restricted to rather shallow depths, such as Holocene clay layers of at most 30 m depth.

In order to obtain highly accurate soil parameters for the construction project of the Kansai International Airport, a new type of piezocone was developed and used in an investigation of the Pleistocene layers as deep as 250 m. This paper describes the newly developed piezocone and presents soil parameters obtained by the CPT, and compares them with the data accumulated at various sites in Japan as well as overseas for Holocene clay layers.

TESTING PROCEDURE

Development of Piezocone for Great Depth

The geometry and main features of the piezocone newly developed in this investigation are shown in Fig. 1

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Fig. 1. Geometry of the cone probe developed for great depths

Table 1. Main features of the developed cone probe

Measurement	Capacity (MPa)	Non-linearity (%FS)
Point resistance	30	0.18
Pore pressure	20	0.05

and Table 1. The geometry of the cone is the same as that of the conventional CPT defined by the Japanese Geotechnical Society (JGS) (JGS 1435-1995) and the reference test procedures specified by the International Society of Soil Mechanics and Foundation Engineering (ISSMFE) (ISSMFE, 1988). The projected cross sectional area is 10 cm² and the angle of the conical tip is 60°. The pore water pressure is measured at the shoulder of the cone. The sleeve friction was not measured because of a limited capacity of memory. For the investigation at great depths, the capacity for the point resistance and the pore water pressure was as large as 30 MPa and 20 MPa, respectively.

Testing Procedure

The CPT usually does not need a borehole to reach testing depth, and the piezocone is directly penetrated to testing depths from the ground surface. This point is a great advantage over other in situ tests. However, due to the great depth at the investigation sites of the Kansai International Airport, large skin friction is generated between the rods and the ground. Also, stiff sandy or gravel layers are found at the investigated sites. Therefore, in this investigation, a borehole was drilled prior to the procedure of the CPT. After the borehole was drilled to the testing depth, the piezocone was inserted in the drilled borehole. To avoid difficulties in handling of cables for transferring electric signals from the piezocone to the data logger on the ground surface, the data recorded in the penetration process were stored in the memory housed behind the piezocone (Fig. 1). Before the installation of the cone in the borehole, all memories were initialized. The piezocone was connected to the ground by special extension rods, of which the total weight was as much as 60 kN, to reach the testing depth at the bottom of the borehole.

Fig. 2. Soil profiles at investigated sites

A boring machine was used to penetrate the cone. The self-weight of the rods connecting the piezocone was so heavy that the tensile stress always yielded in the rods during testing. Therefore, there was no anxiety about buckling of the rods due to compression force caused by penetration. The penetration of the piezocone was interrupted every 60 cm because of the stroke of the boring machine. The depth of the piezocone was recorded by the potentiometer connected to the boring machine. The force required for the cone penetration was monitored by the hydraulic pressure of the boring machine. When a large penetration force was measured, penetration was stopped to protect the piezocone. Then, the piezocone was withdrawn to the ground surface, and data stored in the memory of the cone were transferred to a personal computer. The borehole was further drilled until the depth to which the cone had previously penetrated.

Laboratory Tests

Sampling was also carried out near the point of the CPT, using the rotary core sampler (its distance from the CPT point is 5.0 m). The grading component and index properties were measured following the JGS standard (JSF T 131-1990, JSF T 141-1990). The consolidation yield pressure (p_y) was obtained by the Constant Rate of Strain (CRS) oedometer test, where the strain rate is 0.02%/min (3.3×10^{-6} /s). The size of the specimen is 60 mm and 20 mm in diameter and initial height, respectively. The upper surface is drained, and pore water pressure is measured at the bottom. A back pressure of 200 kPa was applied to keep the sample saturated.

Fig. 3. Index properties of investigated layers: (a) Doc5, (b) Ma7, (c) Ma4 and (d) Ma2

TESTED SOIL LAYERS

Including the testing site, the whole Osaka Bay area has continuously been sinking since the late Tertiary period due to tectonic movement. According to the study by Itoh et al. (2000), the average rate of subsidence in the Osaka area is about 0.5 mm/year, although this rate somewhat varies with places and the subsidence ceases at some places for a while. Such a continuous subsidence provides suitable conditions to form very thick Quaternary sediments, which have reached as much as 1500 m in

thickness. The marine sedimentation process has been altered by lowering sea levels responding to the various glaciations during the Quaternary, which is represented here by fluvial sediments, as shown in Fig. 2. Layers of the marine deposits can be counted as 14 in total, which are numbered according to the age order. These marine sediments were deposited in a warm climate in the interglacial stages. Ma13 is the youngest marine deposit, i.e., the Holocene deposit, and is found directly below the present sea bottom in the Osaka Bay. Between these marine deposits, the fluvial sediments are found, which

Fig. 4. Measured point resistance and pore water pressure: (a) Doc5, (b) Ma7, (c) Ma4 and (d) Ma2

mainly consist of coarser particles such as silt, sand, or sometimes gravel, deposited in the cold climate during the glacier stage.

The CPT penetration test was performed at two sites, as shown in Fig. 2. At site 1, the layer for the investigation by the CPT is Doc5, while investigation by the CPT is conducted in the layers of Ma7, Ma4, and Ma2 at site 2. The index properties of these layers are given in Fig. 3. It can be seen that with an increase in depth, the natural water content (w_n) of the deposit approaches close to the plastic limit (w_p).

TEST RESULTS

q_t and Pore Water Pressure Profiles

The point resistance (q_t) of the tested layers was calculated considering the effective cross sectional area and pore water pressure acting behind the cone. Figure 4 shows q_t and pore water pressure (u) profiles for the investigated layers. The testing procedure of the cone will be explained again, taking the Ma2 layer (Fig. 4(d)) as an example. The borehole was drilled until an elevation of -245.4 m was reached (the OP in the figure means the reference elevation to the Osaka Pale). Then, the piezocone was inserted in the pre-drilled borehole. Both q_t and u values were started at about 2.7 MPa, which cor-

responds to the static pore water pressure, (note that the borehole was filled with mud, of which unit weight is slightly greater than that of the sea water). These pressures gradually increase, indicating that the cone penetrates the bottom of the borehole, where the soil was disturbed by the drilling procedure. Below an elevation of -245.6 m, the q_t as well as u reach steady state, revealing that these values reflect the real soil parameters, unaffected by the drilling process. A reduction of q_t and u was observed at an elevation of -246.2 m, where the installation was interrupted because the stroke capacity of the drilling machine was attained. After these procedures were repeated three times, the cone penetration test was temporally ceased at an elevation of -247.7 m. The cone was then withdrawn, and the stored data were transferred to a personal computer on the platform. The borehole was extended by drilling to an elevation of -247.7 m, and the cone penetration was started again in the same manner until an elevation of -252 m was reached, where a hard stratum was encountered.

Unlike a soil profile based on the observation of the recovered core, the CPT can provide a continuous soil profile, except for interruptions due to either the end of the stroke capacity of the boring machine or the drilling of the borehole deeper. Several very thin sandy soil sub-layers are observed by the CPT investigation. For example, in the Doc5 layer (Fig. 4(a)), two sand sub-layers were clearly detected at the elevations of -185.5 and -190.5 m. At these elevations, not only does the value of q_t suddenly increase, but also the value of u decreases at the same elevation due to the positive dilatancy of the sand layer.

Correlation with p_y

The main purpose of this investigation is to obtain the p_y value from the cone penetration test. The p_y value may be correlated with q_t , as indicated by the following equation.

$$p_y = (q_t - p_{vo}) / N_{pc} \quad (1)$$

where p_{vo} is the in situ total overburden pressure and N_{pc} is the cone factor for p_y . Like N_{kt} , which is usually used as the cone factor for the undrained shear strength, the N_{pc} factor is not constant, but varies with different soils. Using the authors' database, where p_y is measured by the CRS oedometer test at a strain rate of $0.02\%/min$, the N_{pc} factors for soils recovered from various sites in the world are given in Fig. 5. The N_{pc} factors are plotted against plasticity index (I_p), which cannot recognize any systematic tendencies in these relations. Although considerable scatters are in general observed in the N_{pc} factors, the range of the N_{pc} for a given soil is relatively narrow, suggesting that a unique relation can be established between p_y and q_t values.

Figure 6 shows an OCR profile at the site of the Kansai Airport for the Ma13 layer, a Holocene clay deposit, which is deposited just below the sea bottom. The CPT investigation for this layer was carried out using a

Fig. 5. The cone factor N_{pc} for p_y values for various clays in the world

Fig. 6. OCR profiles measured by CPT and CRS test for Ma13 layer

conventional piezocone. With the aid of N_{pc} , its OCR is obtained from q_t using the following equation.

$$OCR = p_y / p'_{vo} = (q_t - p_{vo}) / (N_{pc} p'_{vo}) \quad (2)$$

where p'_{vo} is the in situ effective overburden pressure. As shown in the figure, if the N_{pc} factor is taken as 3.2, then the OCR obtained by the oedometer test agrees well with OCR from the CPT. The investigation was carried out after the sand layer was spread for the sand drain work. The p'_{vo} is calculated under the assumption that the consolidation due to the weight of the sand layer does not take place. Since the consolidation is proceeding from drainage surfaces, a high OCR for both CRS and CPT is

Fig. 7. OCR profiles measured by CPT and CRS test for the investigated layers: (a) Doc5, (b) Ma7, (c) Ma4 and (d) Ma2

apparently observed in the soil layer at about an elevation of -20 m, which is just below the sand layer. In addition, the discrepancy between p_y measured by CRS and CPT in the upper layer can be explained by a difference in the date of conducting the sampling and the CPT. The increase in OCR measured by CPT at an elevation of -33 m is due to the presence of volcanic ash called Akahoya tephra. The sudden increase in OCR at an elevation of -40 m is caused by reaching the gravel layer

between the Ma13 and the Ma12 layers. As indicated by the above description, the CPT has a great capability to show the soil profile in detail compared with conventional soil investigations.

Following the same procedure as described above, the OCR profiles measured by the CPT conducted in the present investigation are shown in Fig. 7, and are compared with the OCR obtained by the CRS oedometer test. In this figure, the data points are omitted where the

Table 2. N_{pc} factor for investigated layers

Layer	N_{pc}
Ma13	3.2
Doc5	2.5
Ma7	2.8
Ma4	2.6
Ma2	2.6

penetration was interrupted, or at the bottom of the drilled borehole where there was a disturbance. The N_{pc} factor for the CPT was selected to fit the OCR values measured by the CRS test. The selected values of N_{pc} for each layer are given in Table 2. As can be seen in the table, the N_{pc} is somewhat different in each investigated layer, and is considerably smaller than that of the Ma13 layer (see Fig. 6). This means that if the N_{pc} factor is taken to be the same as the factor of the Ma13, the OCR calculated by Eq. (2) for the Pleistocene clays is smaller than that measured by the CRS test. If the sample quality is not good enough to evaluate the p_y value from the CRS test and underestimates the real p_y value, then the N_{pc} factor will be larger than that in the case of a good sample quality. However, the test results show completely the opposite trend.

The OCR calculated by the CPT considerably varies with depth with some patterns, which are slightly different in each layer, as indicated by Fig. 7. For example, the OCR for the Doc5 layer varies with short frequency, but its variation is relatively small, i.e., from 1.4 to 1.9. The OCR points enclosed by a rectangle are in the sandy layers, which could be judged from the drop in their excess pore water pressure, as shown in Fig. 4. Or such a high OCR may be obtained by cement material such as volcanic ash, as indicated in Ma13 in Fig. 6. The pattern of OCR variation for the Ma7 layer is somewhat different from that of the Doc5 layer. Its OCR monotonously increases from an elevation of -182 m, and shows a peak of 1.5 at an elevation of -192 m. Then the OCR keeps decreasing with depth until an elevation of -198 m, despite some small scatters. Below an elevation of -198 m, the OCR varies significantly with depth. For the Ma4 layer, a periodic change in OCR is observed. Especially between -221 m and -226 m elevations, its variation is more than 0.3. On the other hand, the Ma2 layer shows a relatively uniform distribution of the OCR. It is considered that these patterns and variations of the OCR are not reflecting the stress history to which it has been subjected to in the past, but may be the reflection of different depositional and post depositional environment. The OCR measured by the CRS corresponds surprisingly well to that estimated by CPT, despite noticeable discrepancies at some elevations, such as, -215 m and -227 m of the Ma4 layer.

Variation in the p_y Value

Previous reports investigating the Pleistocene layers in

Fig. 8. Relation between the effective overburden pressure and the yield consolidation pressure measured by the CRS test

the Osaka Bay areas indicate considerable variation in the p_y value measured at laboratory with depth (see for example, Kanda et al., 1991). One of reasons for such large scatters in the p_y value is considered to be due to the method of its determination, in which the p_y value was derived from the $e-\log p$ relation measured by the conventional increment loading (IL) oedometer test, by increasing the subsequent consolidation pressure by two times the previous pressure. Since the $e-\log p$ relation for the Pleistocene clays at the Osaka bay area is significantly non-linear even after the consolidation pressure exceeds the p_y value, it is difficult to determine the accurate p_y value from the $e-\log p$ relation measured by the conventional IL oedometer test. This fact seems to have caused such large scatters in the p_y values. As a result, in recent investigations, the CRS test has been employed, which can provide nearly a continuous $e-\log p$ relation.

Figure 8 shows relation between the in situ effective burden pressure (p'_{vo}) and p_y values measured by the CRS test at the construction site of the Kansai International Airport. No systematic trend in these values can be observed, for example, neither the OCR decreases nor increases with depth, but the OCR is apparently constant with depth. As can be seen from the figure, however, considerably large scatters still exist in the measured OCR values. It may be that the reasons for such a large scatter in the p_y value could be due to sample disturbance.

Until now, many researchers have proposed indicators to evaluate sample quality. Among them, the well-known indicators are the volumetric strain yielded at the in situ effective stresses ($\Delta \varepsilon_v$) (Andresen and Kolstad, 1979), and change in the void ratio ($\Delta e/e_0$, where e_0 is the in situ void ratio), proposed by Lunne et al. (1997).

Fig. 9. Relation between sample quality and OCR, after Tanaka et al. (2002): (a) Sample quality assessment by following Andresen and Kolstad (1979) and (b) Sample quality assessment by following Lunne et al. (1997)

Figure 9 gives the relation between the above mentioned indicators of the sample quality and OCR revealed in Fig. 8, at various depth ranges. It may be noted that quality of the samples retrieved at this site is mostly classified into “fair” according to Andresen and Kolstad’s assessment and “good to fair” according to Lunne et al.’s assessment. It may be anticipated that, as depth increases, the sample quality becomes worse because the effect of stress release on the sample quality becomes more prominent. However, as shown in Fig. 9, neither $\Delta\varepsilon_v$ nor $\Delta e/e_o$ increases with depth. It is recognized that the OCR slightly decreases with an increase in $\Delta\varepsilon_v$ or $\Delta e/e_o$. This fact suggests that the variation of OCR may be partly attributed to the sample quality. However, it should be kept in mind that the scatter of OCR at the same $\Delta\varepsilon_v$ or $\Delta e/e_o$ is much larger than the tendency described above. Therefore, it is considered that the deviation of OCR mostly reflects the inherent variation in the p_y value of the soil layer. This consideration is also supported by the OCR profiles measured by CPT, as mentioned earlier.

Table 3 shows a comparison of the standard deviation (SD) for the OCR derived from the CPT and the CRS tests. For calculating the SD from the CPT, points enclosed by the rectangles were omitted because these data are in the sandy layer or heavily cemented layers probably caused by volcanic ash and so on. Also, the table shows the SD obtained from Holocene clays previously carried out by the authors, as a reference. The OCR profiles at these sites are indicated in Fig. 10. For their detailed soil properties the reader may refer to Tanaka et al. (2001a) for Singapore, Tanaka et al. (2001c) for Yamashita, Tanaka et al. (2001b) for Drammen and Tanaka et al. (2001d) for Pusan, respectively. The OCR profile at the Yamashita site is nearly constant with depth. Otherwise, the OCR profile for Singapore,

Table 3. Comparison of the average and standard deviation of OCR measured by CPT and CRS test

Layer	CPT			Laboratory (CRS)		
	Average	SD	RL	Number	Average	SD
Doc5	1.66	0.124	C	7	1.56	0.132
Ma7	1.39	0.090	C	11	1.39	0.092
Ma4	1.30	0.080	C	8	1.40	0.073
Ma2	1.58	0.069	C	3	1.51	0.108
Ma13	—	0.208	P	—	—	—
Borehole 6	—	—	—	72	1.38	0.260
Borehole 7	—	—	—	60	1.49	0.214
Singapore (Lower)	1.21	0.037	C	8	1.22	0.082
Yamashita	1.96	0.082	C	7	1.92	0.138
Drammen	—	0.160	P	—	—	—
Pusan	—	0.159	P	—	—	—

SD: Standard Deviation

RL: Regression Line, C: Constant, P: Parabola

Drammen, Pusan and the Ma13 of the Osaka bay varies with depth. These OCR profiles can be fitted by a parabolic or a linear line with depth, as indicated in Table 3 and Fig. 10. For Singapore clay, the line was fitted below the depth of 18 m. For the Ma13 layer (in Fig. 6), the elevation for the calculation is between 23 m and 39 m. The SD for these clays is calculated as the deviation from the regression line, instead of the mean value as usually done. For the calculation of the SD value, irregular values enclosed by rectangles are omitted in the same manner as that of Fig. 7.

The SD value of OCR for the Doc5 layer is the largest among the Pleistocene clay layers in this investigation.

Fig. 10. OCR profile at Holocene clay layers: (a) Singapore, (b) Yamashita, (c) Drammen and (d) Pusan (Yansang)

According to microstructure observation by the Scanning Electron Microscope, it is found that the Doc5 layer contains a lot of microfossils, especially diatoms (Tanaka and Locat, 1999). It is anticipated that these microfossils influence the variation in the q_t value. Compared with Holocene clays, the SD values for the presently investigated Pleistocene clay are not particularly large. For

example, the SD value for Singapore clay is, indeed, as small as 0.037, but the SD value for the Ma13 layer is considerably larger than that for the Pleistocene clays.

Let us compare the SD of OCR measured by the CPT with that by CRS test. The OCRs for Drammen, Pusan and Ma13 layer are not considered because they clearly vary with depth. As shown in the table, the variation of

the OCR measured by the CPT for the Pleistocene layers is quite comparable to that by the laboratory test, similar to that obtained at the Yamashita and the Singapore sites where the sample was recovered from ordinary depths. From these comparisons, it may be concluded that the degree of the influence of sample quality on the p_y value measured by the CRS test for the Pleistocene clays is the same as that for the usual Holocene clays, whose depth is, say, at most 30 m. However, as shown in Table 3, the relatively large SD values are observed at Boreholes 6 and 7, and are 0.260 and 0.214, respectively. These SD values are about two or three times larger than the ones observed by CPT and CRS tests at the presently studied layers.

Why are such large variations observed at these boreholes? The SD values observed by the present study in Table 3 are for restricted layers at a certain depth, such as the Doc5 or the Ma7 layer. Indeed, the OCR for each layer is considerably different from both CPT and CRS (see the average values in Table 3). As already discussed, there is still controversy on whether such OCRs have been created by mechanical overconsolidation, i.e., the change in the effective overburden pressure (p'_o), or other reasons such as ageing or chemical effects. At the present stage, the latter reason for the high OCR is supported by many geotechnical researchers, and it is quite reasonable that the OCR would vary with each layer, because the deposited age and environment are considerably different for each layer. In addition, it is natural to consider that even for the same layer, if the location is different, the observed OCR will also be different. For example, the difference in the average OCR between Boreholes 6 and 7 is more than 0.1. Since Borehole 6 is located 1.8 km away from Borehole 7, it is understandable to observe such a difference in the OCR value. It should be pointed out that the variation in OCR measured by the laboratory test is also caused by heterogeneity in soil properties even in the same layer, as already mentioned in Fig. 7.

Considering these test results and arguments, it is dangerous to disregard irregular data by simply considering their deviation from the average value. It is also not advisable for geotechnical engineers to blindly apply the criteria of sample quality, for example $\Delta\varepsilon_v$ or $\Delta e/e_o$, or apply methods for correcting the consolidation properties using these indicators. Instead, it is wiser to consider the geological history as well as the environment during and after sedimentation, while analyzing the data. In such cases, using CPT for soil investigation is quite helpful for interpreting the test results from laboratory tests, because CPT can provide continuous soil information required for the correct interpretation.

CONCLUSIONS

Accurate soil parameters are required for reliable prediction of settlement in the Pleistocene clay layers at Osaka Bay. Using samples retrieved from great depth, the oedometer test was carried out. However, measured overconsolidation ratio (OCR) considerably varied with depth. It was thought that these scatters in OCR were

either due to sample disturbance, or a reflection of the inherent variation of the soil layers.

Using a newly developed piezocone for deep investigation of the Osaka Pleistocene clay, consolidation properties, especially the yield consolidation pressure (p_y), were studied and compared with those of the Holocene clays, which are found in relatively shallow depths. The following interesting findings were obtained by this investigation:

- (1) The point resistance (q_t) measured by the cone penetration test (CPT) was correlated to the p_y values obtained by the Constant Rate of Strain (CRS) oedometer test, whose sample was recovered near the CPT site. The cone factor of $N_{pc} (= (q_t - p_{vo})/p_y$, where p_{vo} is the total in situ overburden pressure) is 2.5, 2.8, 2.6 and 2.6 for the Doc5, Ma7, Ma4 and Ma2 layers, respectively. These N_{pc} factors are in the usual range for the Holocene clay layers from tests previously carried out by the authors.
- (2) The OCR profiles for the Pleistocene clay layers considerably vary with depth, and patterns of the variation are different for each layer. The average of the OCR is also different for each layer.
- (3) It is likely that such variations and magnitudes of OCR are affected by ageing or cementation, instead of by a difference in the stress history.
- (4) The OCR profiles measured by the CRS test are very similar to those estimated by the CPT.
- (5) The standard deviation (SD) was calculated for OCR profiles measured by both CPT and CRS tests. It was found that these values were nearly of the same order.
- (6) From the above conclusions of (4) and (5), it may be concluded that the p_y value measured by the CRS is reliable, even though the sample for the oedometer was retrieved from great depths.

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