Evaluation of differential settlement following liquefaction using Piezo Drive Cone
Évaluation de règlement différentiel Liquéfaction suivante qui utilise le Piezo Promenade Cône

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ABSTRACT
Full scale field experiment by blast-induced liquefaction for the observations of liquefaction phenomena was carried out at coastal reclaimed area in Japan of fine sand and silt subsoil including. This paper discusses verifications between pre-blast evaluations of differential settlements following liquefaction using *Piezo Drive Cone* which is a new developed dynamic penetrometer with pore pressure transducer that measures pore pressure of the ground generated during dynamic penetration at the cone tip and post-blast measured ground surface settlements. This validation clearly shows that pre-blast estimating differential settlements are qualitatively in agreement of post-blast measured data. Based on this verifications obtained from full-scale field experiments, the evaluation procedure of differential settlements on the ground surface following liquefaction is proposed.

RÉSUMÉ
L'expérience du champ de l'échelle pleine par liquéfaction souffle-provoquée pour les observations de phénomènes de la liquéfaction a été portée à région réclamée côtière au Japon de sable fin et limon sous-sol inclure. Ce papier discute des vérifications entre évaluations du pré-souffle de règlements différentiels liquéfaction suivante qui utilise Piezo Promenade Cône qui est un nouveau penetrometer dynamique développé avec transducteur de la pression du pore qui mesure pression du pore de la terre produite pendant pénétration dynamique à la pointe du cône et le poteau-souffle a mesuré des règlements de la surface de la terre. Cette validation montre clairement que pré-souffle qui estime que les règlements différentiels sont qualitativement en accord de poteau-souffle mesuré les données. Basé sur ces vérifications obtenues d'expériences de champ grandeur nature, la procédure de l'évaluation de règlements différentiels sur la surface moulue la liquéfaction suivante est proposée.

Keywords : In-situ test, Liquefaction, Pore pressure, Cone penetration test, Settlement

1 INTRODUCTION

It is clear that the evaluation of differential settlements on the ground surface following liquefaction is increasingly important to forecast the damage of structures during earthquakes. It becomes difficult to reach to the exact differential settlements under local area of un-uniformed ground conditions in spite of estimating liquefaction susceptibility specifically from the limited locations. The estimation of the local liquefaction susceptibility demands on continuous use of high-definition data. Hence, more simple method which can estimate in-situ liquefaction susceptibility quickly is required to be suggested.
This paper will introduce the new method for the evaluation of settlements following liquefaction using *Piezo Drive Cone*[1)-2)] (called "*PDC*") and proposes the evaluation procedure of differential settlements following liquefaction using results acquired from a series of in-situ tests. Hereby we are able to evaluate the differential settlements following liquefaction immediately using only in-situ data.

2 EQUIPMENT OF "PIEZO DRIVE CONE"

Developed dynamic penetrometer with pore pressure transducer *PDC* is a new investigation tool that measures the pore pressure of the ground which generated at the cone tip during dynamic penetration. Figure 1 shows the schematic figure of general *PDC* system. This system consists of cone tip with pore pressure transducer, penetration displacement sensor, trigger, data logger and dynamic penetration equipment.

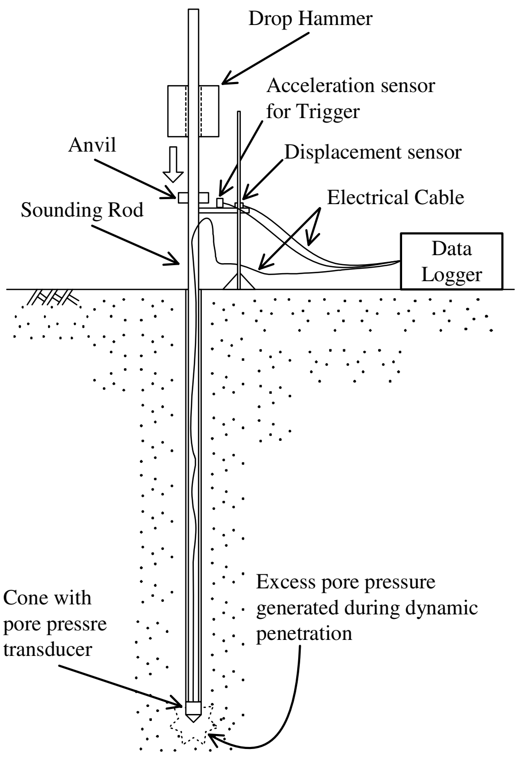

Figure 1. Schematic figure of "*Piezo Drive Cone*"

M. Hamza et al. (Eds.)

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Figure 2. Cone apex

In this examination, we used the light weight dynamic penetration device modified the Swedish Ram Sounding test equipment (*Mini Ram*) [3)].

The porous stones for measuring pore pressure are located at the cone apex as clearly shown in Figure 2. The data logger records the penetration displacement and the pore pressure response of every blow at the cone apex.

3 DATA PROCESSINGS

Flow chart for data processing to estimate liquefaction susceptibility using PDC is shown in Figure 3. Maximum excess pore pressures ($\Delta u_{\max}$), Residual cumulative pore pressure (u_R), Penetration displacement and the depth of investigation without unit weight (γ_t) are able to be obtained by *PDC*. As far as γ_t, *GWT*, F_C, *N* value are clear, we can estimate liquefaction susceptibility which is indicated in design specifications. Flow chart for data processing to estimate settlement following liquefaction using *PDC* is shown in Figure 4. Layer thickness (*H*), Penetration resistances (*N*-value) and F_C are able to be obtained by *PDC*. Finally, post-liquefaction volumetric strain (ε_v) is calculated from $\varepsilon_{v\,\max}$. And, settlement is evaluated from layer thickness (*H*).

4 OUTLINE OF FULL SCALE FIELD EXPERIMENT BY BLAST-INDUCED LIQUEFACTION

The test site is located at the New Port in the Ishikari Bay coastal area, Hokkaido Island, Japan. Main part of the test field was reclaimed in 2005. Then, the reclamation continued even through the test period. Figure 5 shows the arrangements of test field and site investigations including Boring and PDC layout. The test field is divided into three area called embankment zone, facility zone and runway track zone. PDC was mainly carried out in the facility zone named "*Area-1*". There are 16 *PDC* locations that are 4 by 4 in such arrangement as shown in the figure. And lined location is named "Line-1" at the non-improvement area in the location number from No. 1-1 to No.1-7. The site is made up of reclaimed soil. The fill and alluvial layer accumulates under ground surface with the thickness of 20m～25m, and a normal marine clay which contains the humus soil distributes beneath.

The full scale field experiment was carried out on October 27, 2007. Totally 253 plumb boreholes and 8 curved boreholes were installed in the area of 1.65 ha. Figure 5 was taken just after blasting. The several traces of sand boils are observed. Explosives used in the test were water gel type emulsion explosives, which characterizations are about 6,000m/sec of detonation velocity and high quality of water resistance. The all plumb boreholes were driven with the interval of 6.5m and curved boreholes were driven below the runway truck zone except for the parts of liquefaction remediation. The explosives of 2kg and 4kg in weight were set at GL-4.5m and GL-9.0m in each depth, and total amount weight of explosives is 1,760 kg in whole test site.

5 COMPARISON BETWEEN PREDICTS AND MEASUREMENTS

Measured ground surface settlements recorded 10 days after completion of full scale field experiment are plotted in Figure 6 corresponding to *Line-1* cross-section through the non-improvement area from embankment zone to runway track zone.

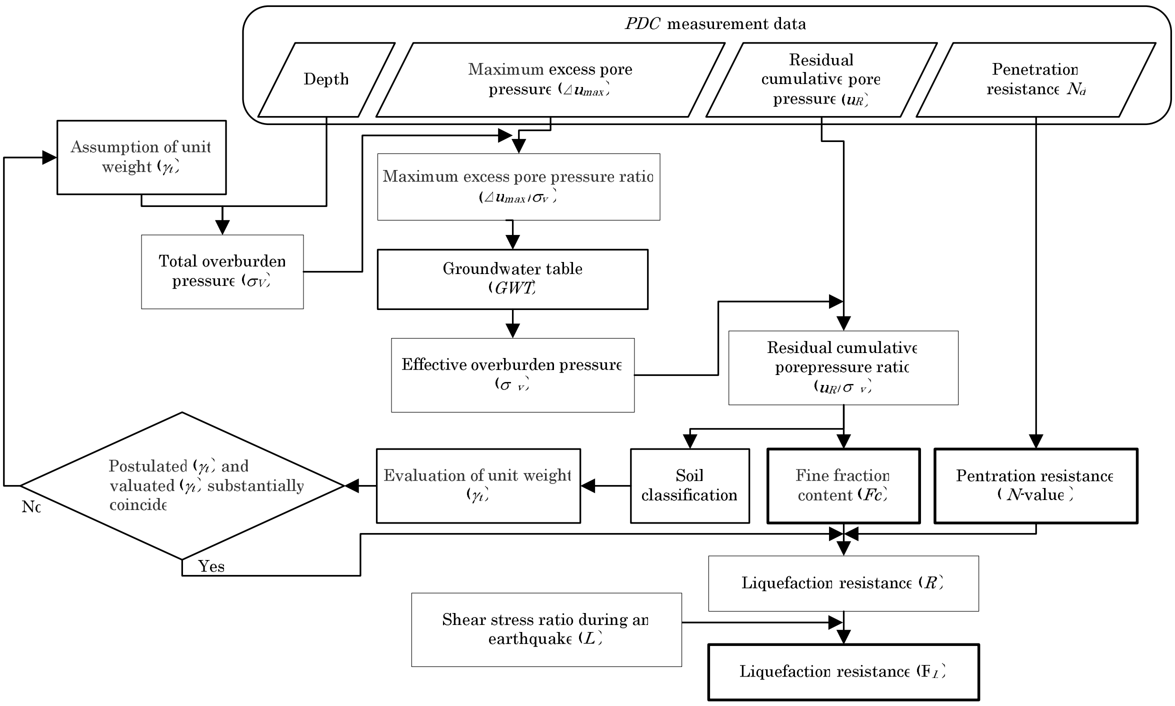


Figure 3. Flow chart to evaluating liquefaction resistance factor

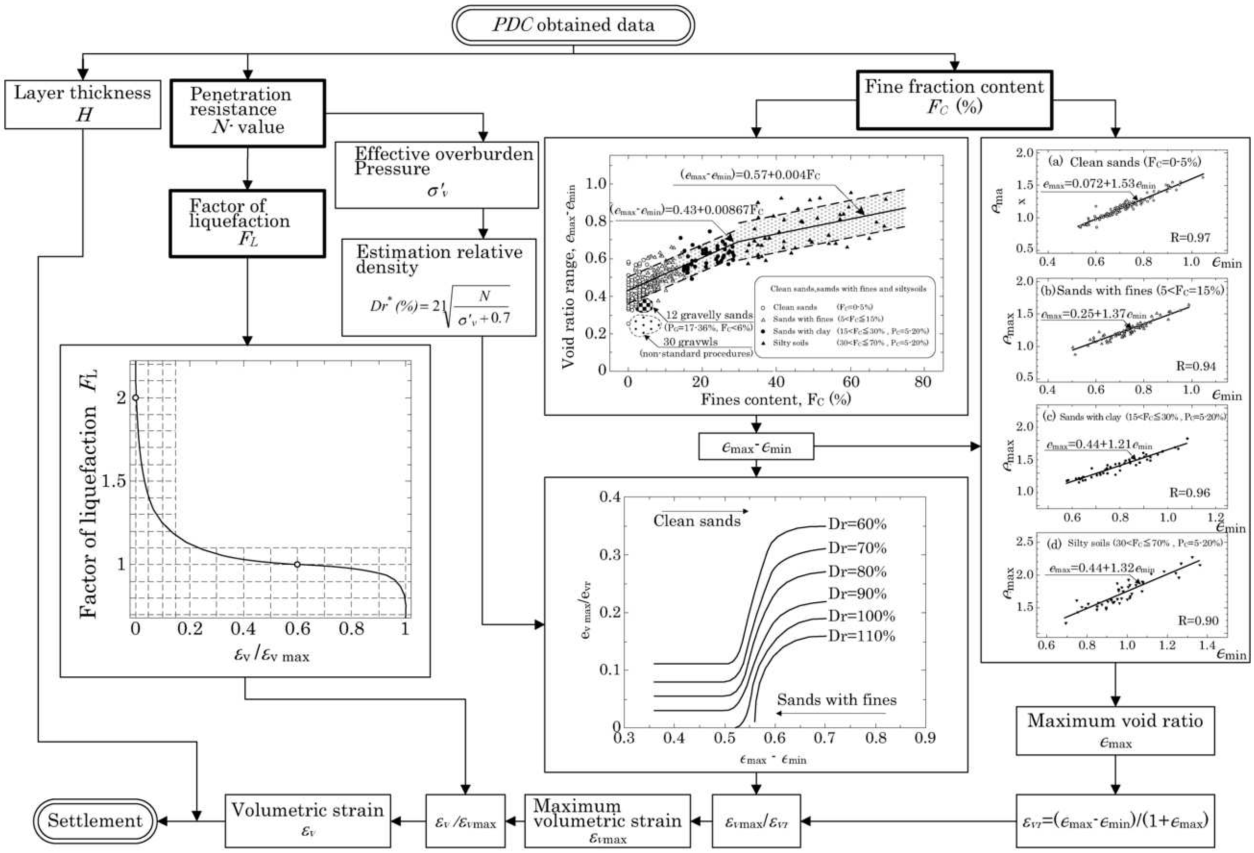


Figure 4. Flow chart to estimate settlement following liquefaction

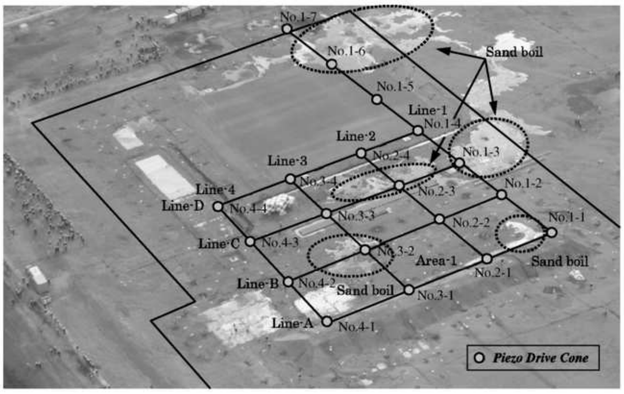


Figure 5. Bird's-eye view of the bottom phase of sand fill layer (F_S) above Area-1 using *PDC*

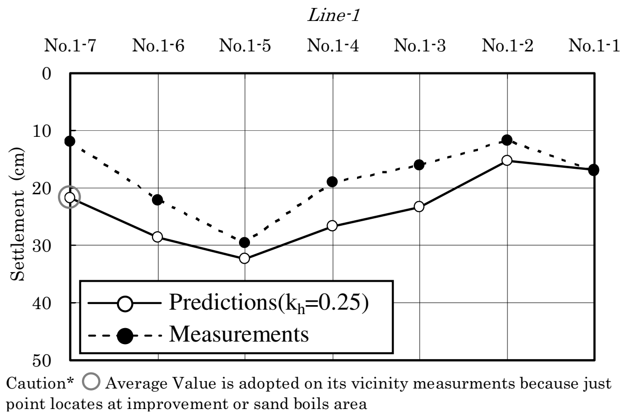
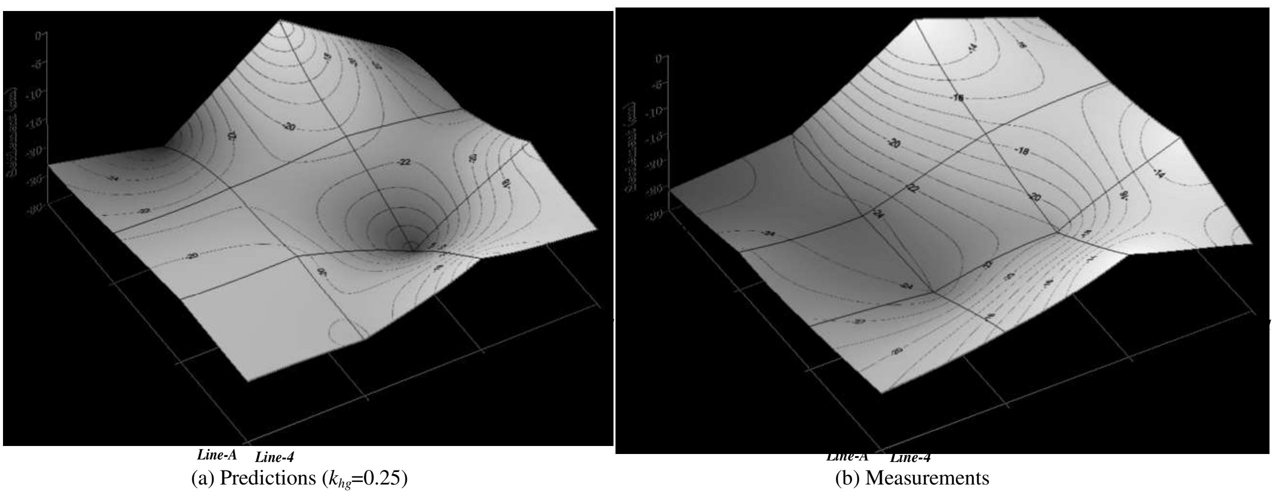


Figure 6. Comparison between prediction and measurements on *Line*-1



(a) Predictions (k_{hg}=0.25)

(b) Measurements

Figure 7. Bird's-eye view of settlements following liquefaction above *Area*-1

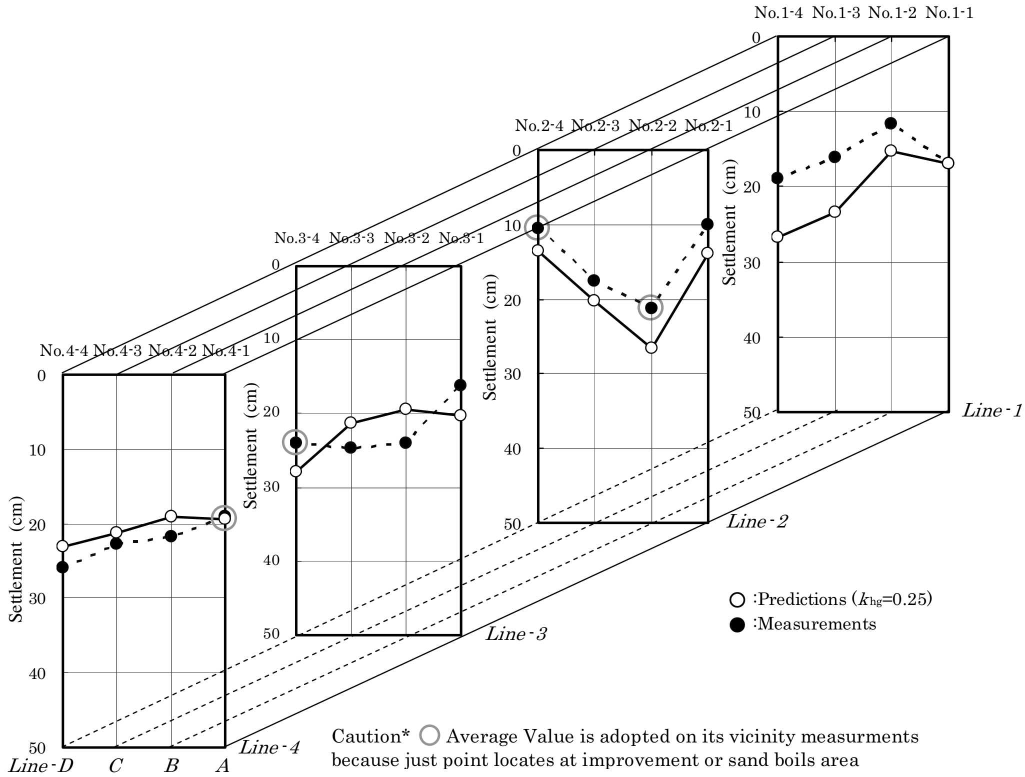


Figure 8. Comparison between prediction and measurements in *Area*-1

And these predicted ground surface settlements are plotted in the figure. The predicted settlements using PDC are estimated in the case of approximate magnitude of horizontal seismic coefficient (k_h) equals to 0.25 which is the minimum value index of Level 2 Earthquake in "Earthquake Resistant Design of Port Facilities" by Port and Airport Research Institute (2007). A similar shape profile is observed on the *Line-1* section. The predicted ground surface settlements in the case of k_h equals to 0.25 are in good agreement with field measurements. The bird's-eye views of ground surface settlements following liquefaction are shown in Figure 7. The predictions as (a) is estimated when k_h equals to 0.25 and the measurement as (b) is recorded at the time when excess pore water pressure vanished completely 10 days later. The both bird's-eye view of ground surface settlement clearly indicate that these trends of settlement coincide with each other well. Figure 8 shows the comparison of the ground surface settlement on each line which is from *Line-1* to *Line-4* in order to make difference between predicts and measurements clear. It is reasonable to suppose that the new method for the evaluation of settlement following liquefaction using *PDC* can be utilized. The reason why the proposed method using *PDC* has good agreement is that this issue is not concerned with the complicated shear stress and strain problem, on the contrary is involved with simple one dimensional problem about volume change.

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