

Technical News

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

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INTRODUCTION

Cone penetration test is one of the most important and convenient tools for subsoil investigation and many efforts have been made in the recent decades to extend its application to a variety of field of geotechnical engineering. The present paper addresses a new development of dynamic cone penetration with pore water pressure measurement in the course of impact. The validation test results indicate that this newly developed equipment is highly useful for mitigation of liquefaction-induced problems due to earthquakes.

MECHANISM OF DYNAMIC CONE PENETRATION WITH PORE PRESSURE MEASUREMENT

Figure 1 illustrates the overall structure of the new CPT device. The device penetrates into soil by means of dynamic impact which employs 35cm falling of a drop hammer that measures 300N in weight using the mini-RAM device. This device is characterized by the monitoring of pore pressure change during impact near the cone tip. The detailed design of the cone tip is shown in Fig. 2. The transient change of excess pore water pressure in the course of dynamic penetration is measured and recorded near the cone tip through porous stones. Note that the cone tip is covered and protected by a disposable coverage that remains underground upon removal of the device after penetration.

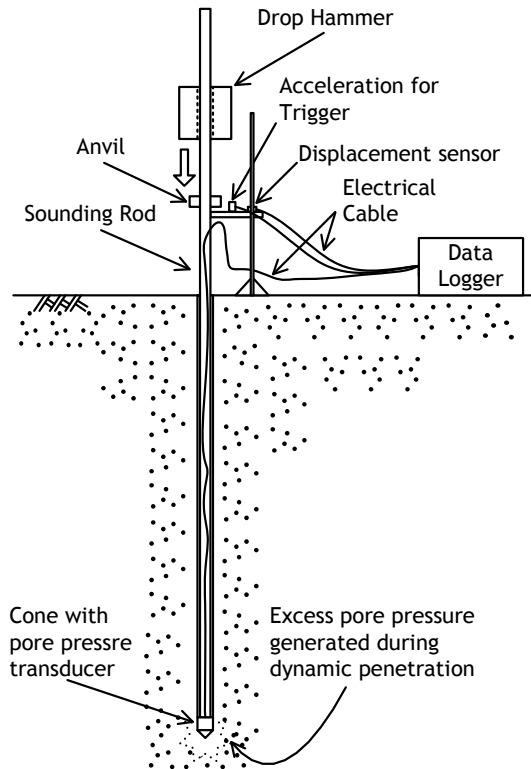


Fig. 1 Schematic illustration of the new piezo drive cone

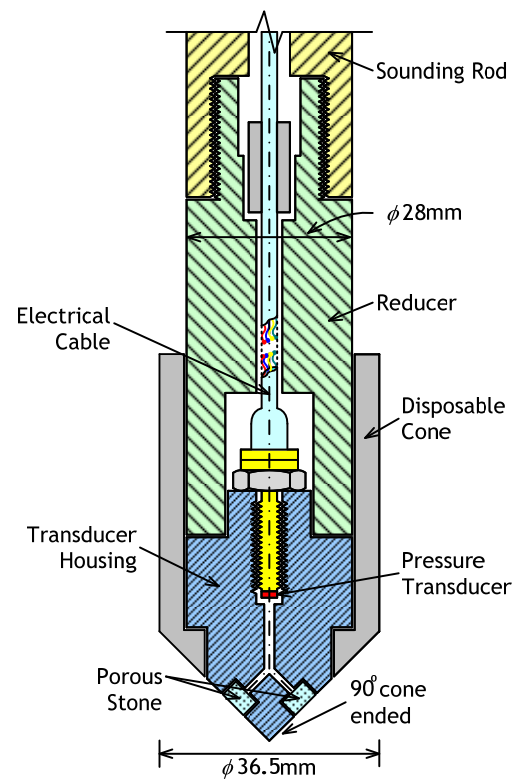


Fig. 2 Detailed structure of cone apex with pore pressure transducer

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

EXECUTION OF DYNAMIC CONE PENETRATION IN THE FIELD

Figure 3 demonstrates the ongoing cone penetration in the field. The device is equipped at its bottom with a small hydraulic motor mechanism that uplifts the drop hammer (30 kg) to make a free fall of 35 cm. The impact is made at a time interval of 2 seconds. See Fig. 4 for more details where the cone apex with pore pressure transducer is shown. Noteworthy is that the relatively small size of this device allows its use on a small and inexpensive platform on water (Fig. 5).



Fig. 3 Onshore practice of dynamic cone penetration.

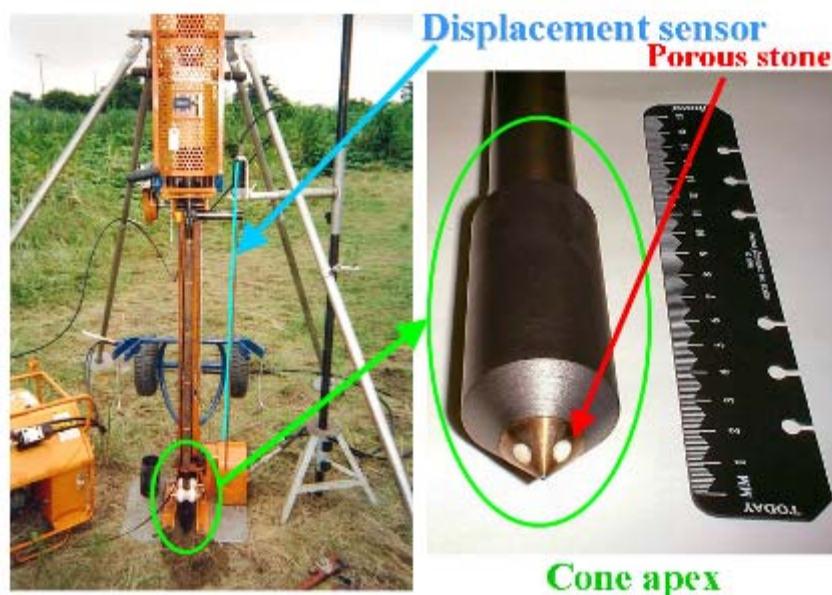


Fig. 4 Details of the new device.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction



Fig. 5 Cone penetration test upon a small platform in river.

INTERPRETATION OF MEASURED RECORD

This section is going to describe the application of the new device to liquefaction problems. The major output from dynamic cone penetration tests is the number of blows for penetration of 20 cm into soil and is named N_d . Fig. 6 compares the SPT-N profiles together with the N_d profiles at two sites. The N_d value is obtained after each impact and therefore the interval of N_d records is 1 to 5 cm.

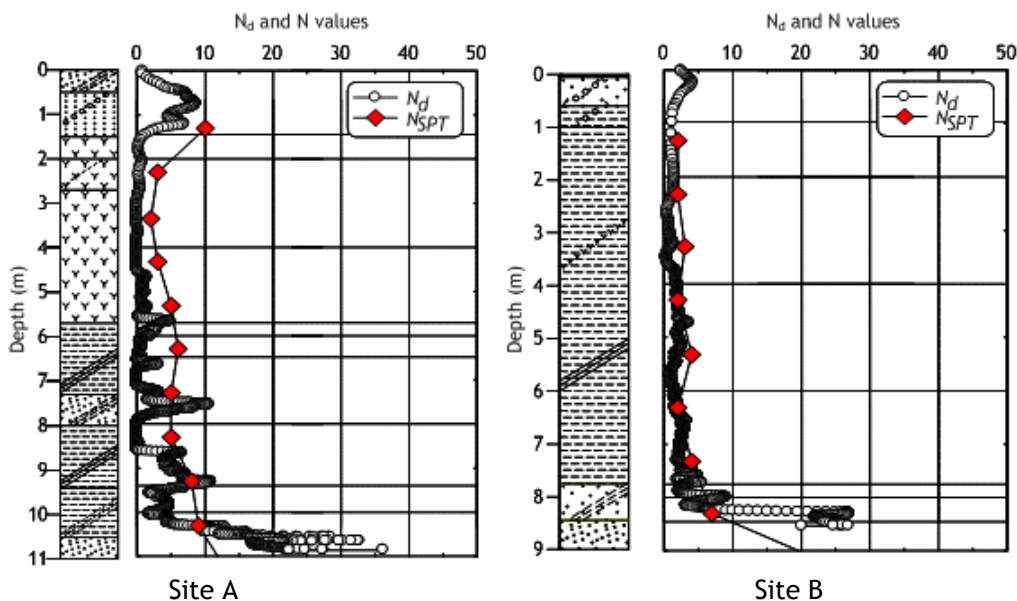


Fig. 6 Penetration resistances at two sites of study.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

Because the current practice of liquefaction studies relies rather on SPT-N values than the direct use of CPT penetration resistance, the measured N_d value has been converted to equivalent N values by $N = N_d$. Moreover, the accurate assessment of liquefaction resistance of subsoil by means of penetration resistance requires soil types (cohesive or cohesionless) to be determined. This goal is achieved by examining the time history of excess pore water pressure during penetration. Fig. 7 illustrates the schematic variations of excess pore water pressure and penetration displacement for sandy and clayey soils, respectively. It is reasonably stated that excess pore water pressure in sandy soil dissipates within a short time because of the high permeability of sand, while it remains unchanged for a while in less pervious clayey soils. Thus, the residual cumulative pore pressure, u_R , is defined as the excess pore water pressure that remains at the end of the initial penetration phase of the cone tip (the cone tip still moving down after each impact). This pore pressure is called cumulative because the effects of previous impacts have been accumulated in the magnitude of excess pore water pressure after the particular impact. By dividing this u_R by the initial effective vertical stress, the pore pressure ratio in Fig. 8 is determined and employed for evaluation of fines content in the soils. The pore pressure ratio may become more than 1.0 in less pervious soils because of practically undrained conditions and high impact pressure exerted by the cone tip. Fig. 9 indicates that the soil types thus determined are consistent with soil types found by SPT procedures.

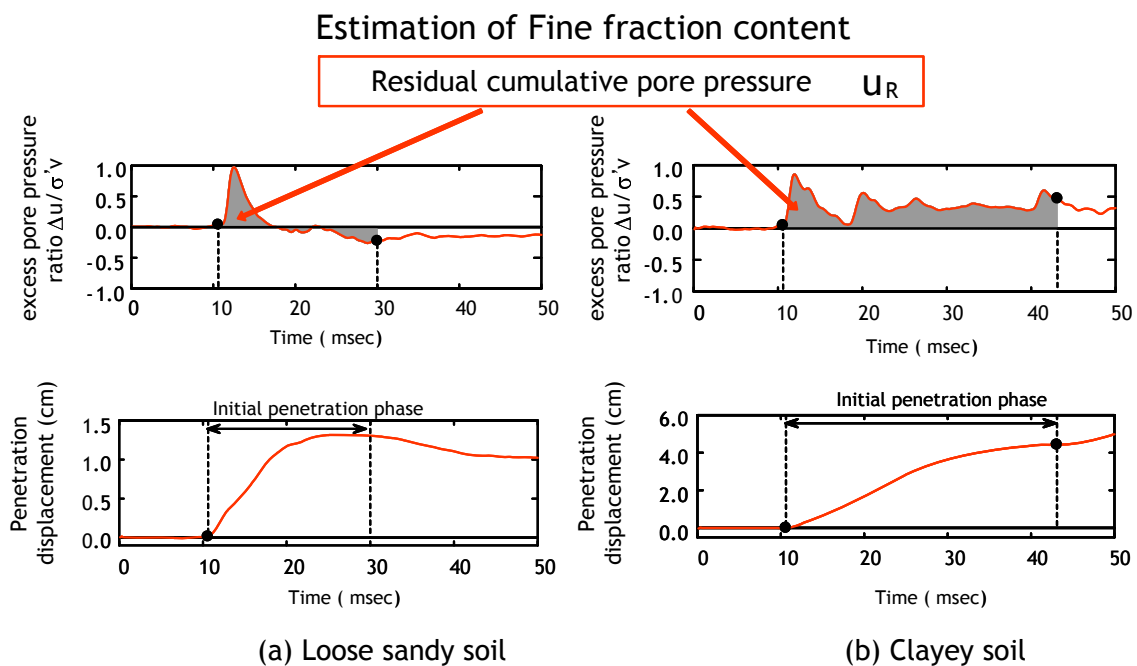


Fig. 7 Schematic illustration of pore pressure change during cone penetration

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

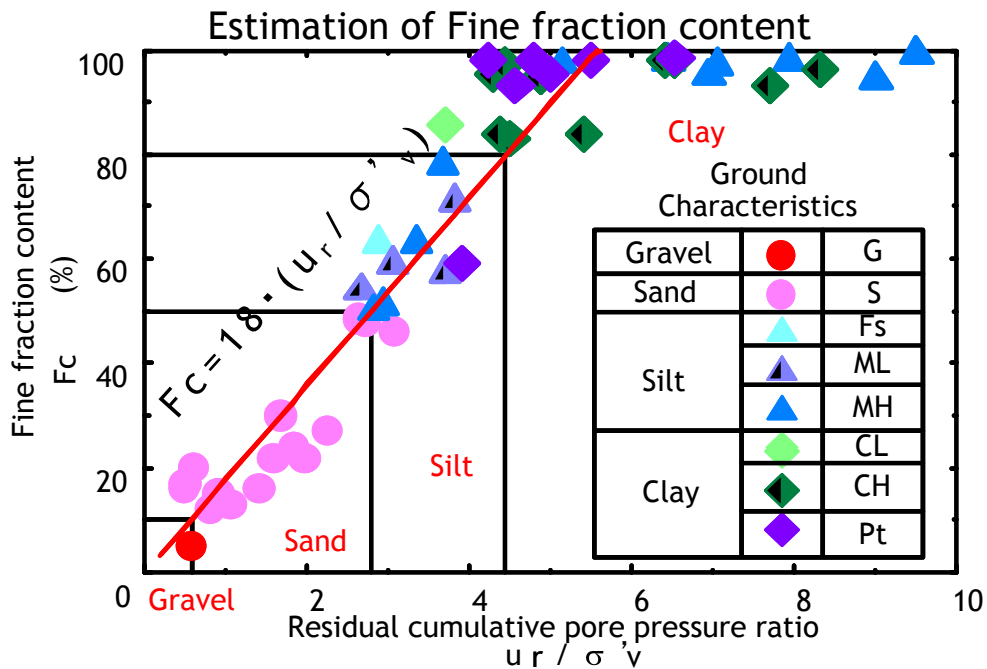


Fig. 8 Determination of fines content on the basis of pore water pressure record.

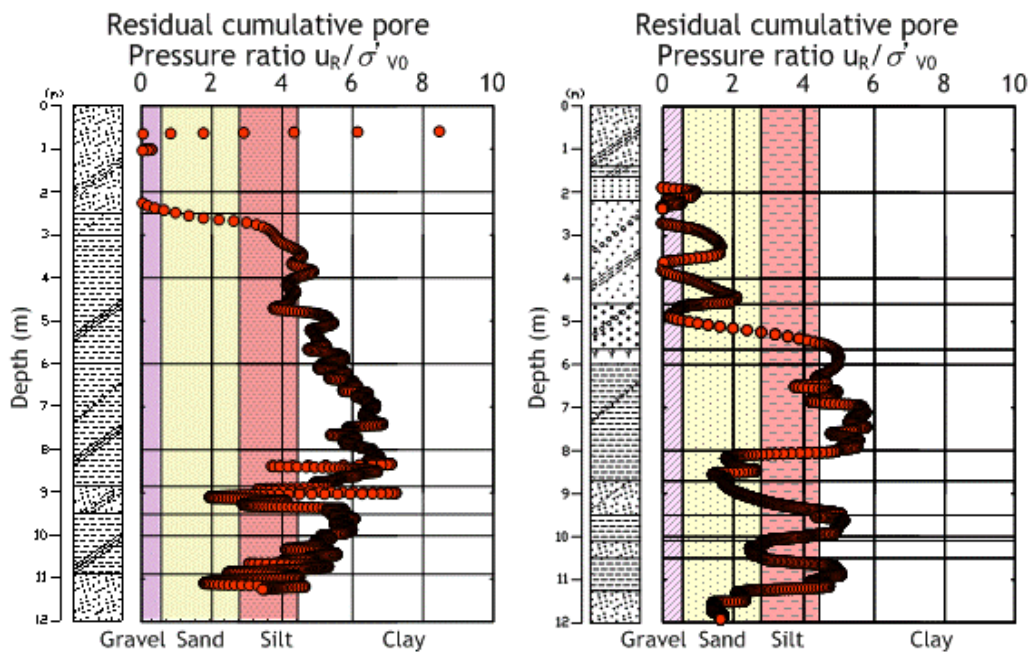


Fig. 9 Profiles of soil types determined by residual pore pressure record.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

ASSESSMENT OF LIQUEFACTION RISKS BY NEW DYNAMIC CPT

Probability of liquefaction

The liquefaction risk is assessed in two ways. First, as widely practiced, the factor of safety, F_L , is determined. As illustrated in Fig. 10, the liquefaction resistance, R or otherwise called CRR, is determined by using the equivalent SPT-N = N_d together with the assessed fines content. The pore pressure record is further used to determine the level of the ground water table. After assessing the fines content, the unit weight of soil, γ , is obtained, and if this γ is different from the initial guess, the effective vertical stress has to be modified and leads to the new cumulative pore pressure ratio and fines content. Thus, there is a provision for feed-back flow in the bottom left of Fig. 10. Two examples of assessed liquefaction risk are illustrated in Figs. 11 and 12. The new method was able to take into account locally greater penetration resistance and presented greater values of F_L than the conventional SPT-N based calculation.

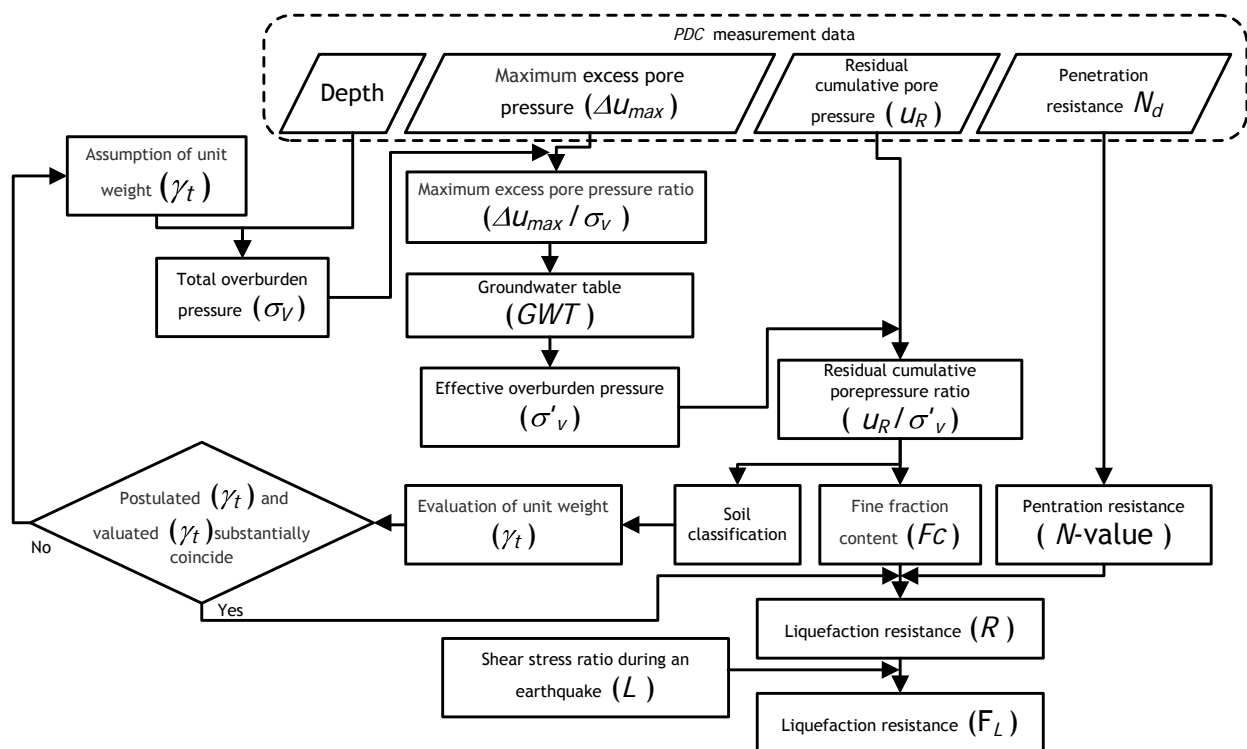


Fig. 10 Assessment of liquefaction probability from new cone penetration data.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

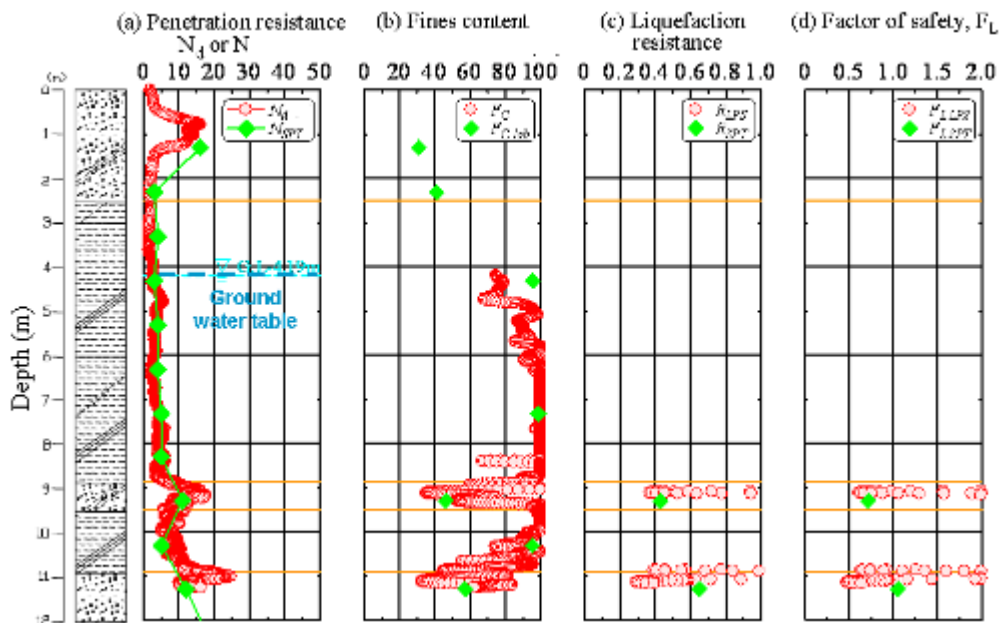


Fig.11 Example of assessed liquefaction risk (site A).

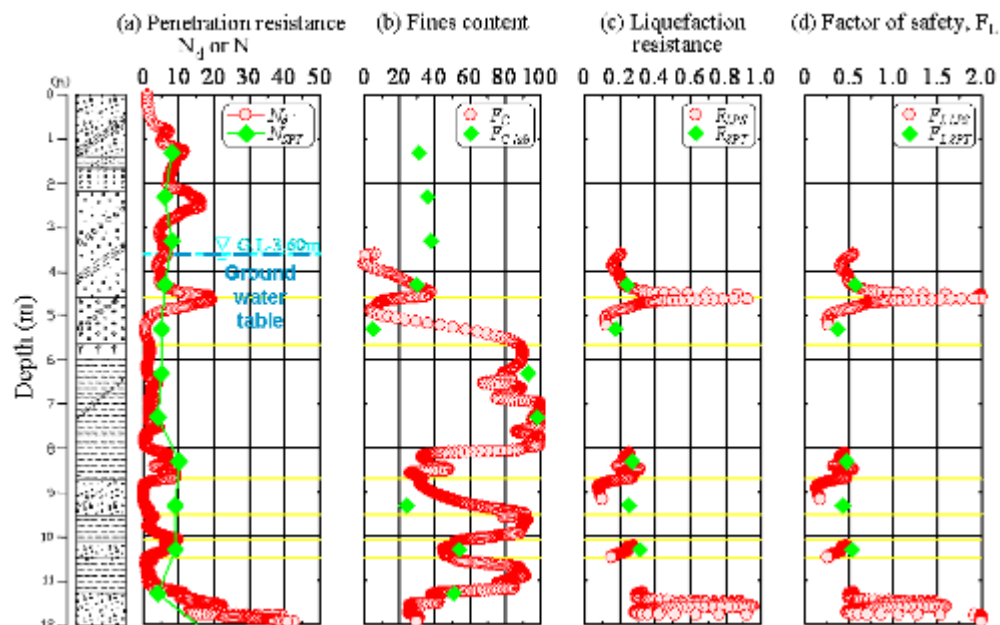


Fig.12 Example of assessed liquefaction risk (site B).

Liquefaction-induced subsidence

Another problem that is possibly caused by subsoil liquefaction is the ground subsidence which occurs after dissipation of excess pore water pressure. The procedure for evaluation of this subsidence is illustrated in Fig. 13. This methodology consists of 1) the assessment of volume contraction of clean sand after dissipation that is based on equivalent SPT-N, and 2) the modification of the clean-sand behavior by taking into account to fines content. Fig. 14 shows the assessed volumetric compression and the consequent subsidence at the ground surface at two sites in Figs. 11 and 12.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

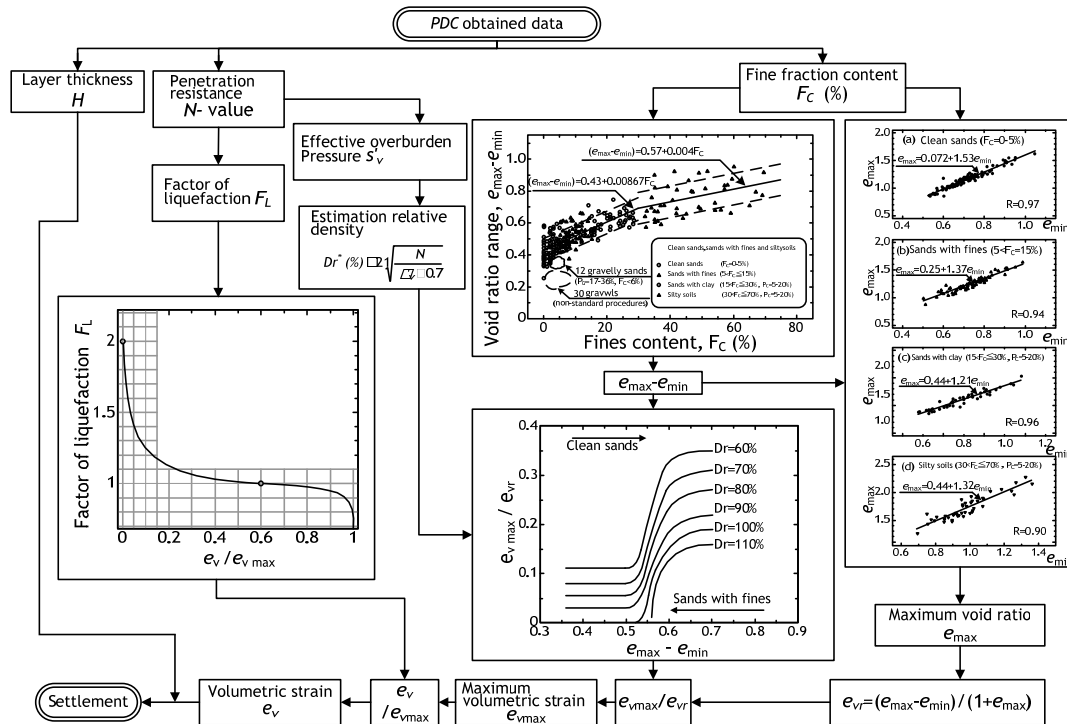


Fig. 13 Assessment of liquefaction-induced subsidence of soil by using new cone penetration data.

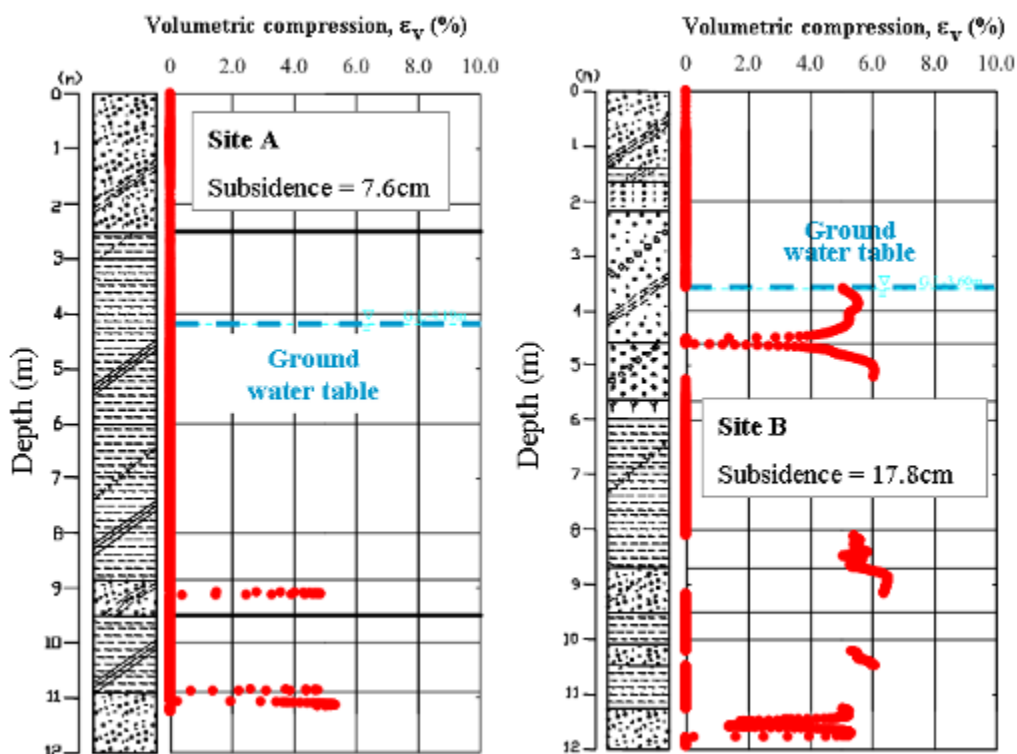


Fig. 14 Example assessments of ground subsidence at two sites.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

APPLICATION OF NEW DYNAMIC CPT AT FIELD BLASTING SITE

The Ministry of Land, Infrastructure, Transport and Tourism, carried out a field blasting test on a large scale in Hokkaido in November, 2007 in order to validate a variety of liquefaction countermeasures. Two months prior to this test, a preliminary blasting test was conducted in a smaller scale. The present CPT device was applied to this test for the purpose of predicting liquefaction-induced subsidence at the ground surface. Fig. 15 illustrates the site. The test site consists of two areas; one with soil improvement by Compaction and Permanent Grouting Method and the other without improvement (named Area 1). The results of the new Piezo Drive Cone are going to be discussed in what follows.



Fig. 15 Aerial view of site of preliminary field blasting.

The assessed subsidence along Line 1 in Fig. 15 is indicated in Fig. 16. The liquefaction potential was assessed by assuming that the maximum acceleration at the ground surface is 25% of gravity. There is a good consistency between measurement and calculation. Similarly, Fig. 17 indicates the distribution of subsidence over the entire study area (Area 1).

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

Line-1

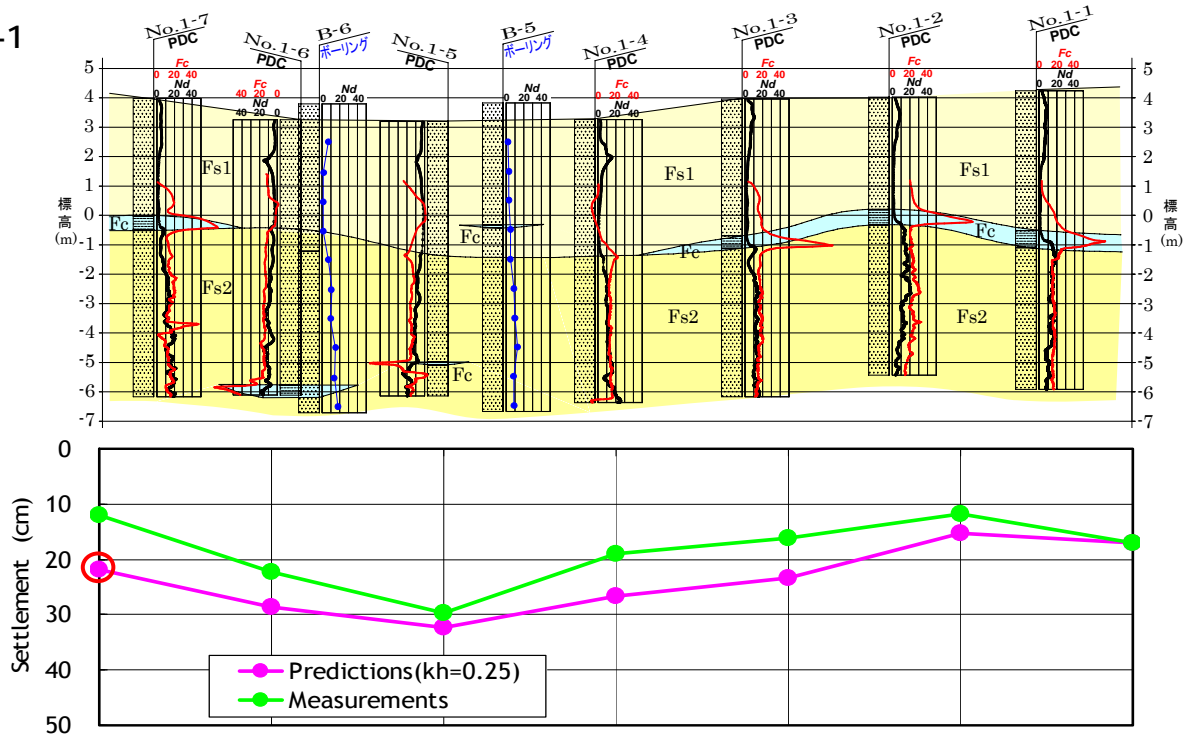


Fig. 16 Assessment of ground subsidence caused by underground blasting and liquefaction.

Area-1

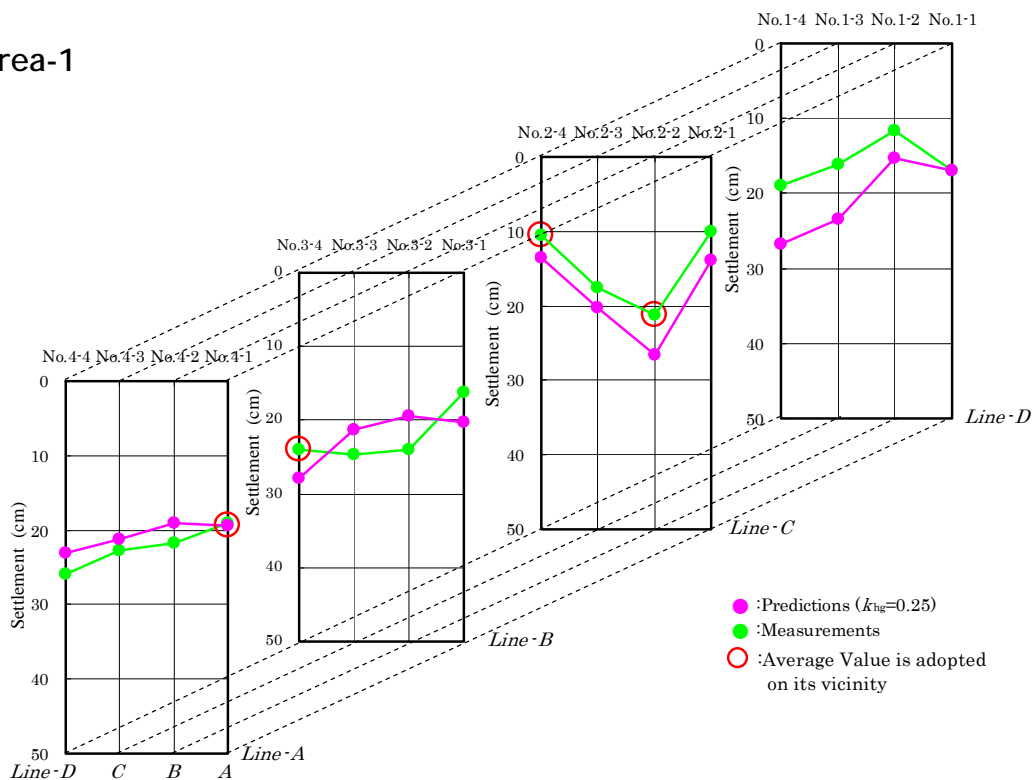


Fig. 17 Overall distribution of liquefaction-induced subsidence.

Technical News (continued)

Use of Piezo Drive Cone for evaluation of subsoil settlement induced by seismic liquefaction

CONCLUSION

This article addresses the new development of cone penetration device that is equipped with pore pressure transducers. It is shown herein that the new device, which is called the Piezo Drive Cone, is a time-efficient tool that can evaluate the liquefaction risks such as the factor of safety and ground subsidence. The time efficiency makes it possible to study a large area in a relatively short period.