Application of RI-cone penetrometers in sandy foundations

L'application de RI-Pénétromètre en fondations de sable

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ABSTRACT: Two types of radio-isotope cone penetrometers (RI-CONES) have been described. Effectiveness of these in clayey soils are well established. In this paper, their effectiveness in the sandy deposits are demonstrated. Results from two sites are presented: (1) Higashi-Ogishima, Japan; and (2) Holmen sand, Norway. The former is a reclaimed land and the later is a natural sand deposit. Both , these sites are characterized by low penetration resistance (q_c < IOMPa). The relative density was calculated using the data obtained from RI-CONES and was compared with the empirical relation proposed by Jamiolkowski et al. (1988) and Lancellotta (1983). Higashi-Ogishima frozen samples show a wide scattering, the RI-CONES data do not show such a wide scattering. For Holmen sand , a good match was found below 12 m using Jamilokowski's relation. For all depth Lancellotta's relation gave a higher value. These discrepancies are not very surprising as these relationship s are derived using clean sand.

RESUME: Deux types de pénétromètres (RI-CONES) sont décrits. Leur efficacité dans sols argileux a déjà été établie. Dans cet article, leur efficacité dans les sables est montrée. Des essais ont été realisés sur 2 sites (1) Higashi-Ogishima au Japon (dépôt artificiel) et (2) sable de Holmen en Norvège (dépôt naturel). La résistance en pointe qc est, dans les 2 cas, faible (inférieure à 10 MPa). La densité relative calculée à partir des donnees des RI-CONES est comparée aux voleurs obtenues par les relations empiriques de Jamiolkowski et al (1988) et Lancellotta (1983). La dispersion des résultats à Higashi-Ogishima entre les valeurs de Dr% mesurées sur des échantillons gelés et celles des RI-CONES est grande. A Holmen, la relation de Jamiolkowski a donné , à des profondeurs supérieures à 12 m, des résultats similaires à ceux des RI-CONES. La relation de Lancellotta a, dans tous les cas, donné des valeurs supérieures. Les diffrérences étaient prévisibles puisque les relations empiriques ont été developpées sur des sables propres.

1 INTRODUCTION

Geotechnical engineers have traditionally relied upon simple soil parameters such as relative density (Dr%) or index of density (I_D) to base their preliminary assessment of the sandy soils. It is possible to get good quality of samples in clayey soils with sampler such as Laval sampler or Sherbrook sampler etc., however, it is impossible to get a good quality of sandy soils for routine physical characteristic determination. Of course, it is argued that frozen samples preserve the internal structure of the soil but the expenses involved can not be justified for routine projects. Even this method may be susceptible to errors as the freezing and thawing process has to be carefully monitored. Sampling in sandy soil is difficult due its very nature, there is a chance that during the pulling out the sampler, below the ground water the sample may fall out of the sampling tube. To avoid the falling-out of the sample, a core catcher is provided but it introduces its own disturbance. Below the ground water table it is very difficult to obtain a sample, especially right below the bottom of the borhole, because it is disturbed by the ground water flow.

In recent years, the design based on the constitutive equations have made a tremendous progress. Inspite of these progresses made, some of the basic parameters for input in the constitutive equations are still obtained from the samples.

From the on-going discussion it is clear that what is required or preferred is to measure these basic soil parameters in-situ. Authors have been involved in such an effort for last few years, and have developed so-called radio-isotope cone penetrometers (RI-CONES). In this paper, a brief description is given on the working principle of these cone penetrometers. Following that, two sandy sites are introduced which have been extensively studied. One of the sites is Higashi-Ogishima site, Japan and the other site is Holmen, Norway. At the Higashi-Ogishima site frozen sampling was carried out beside other tests to compare the test results. Holmen site is well known site that has been used by Norwegian Geotechnical Institute (NGI) for many years as a research site. Other researchers from all over the world have also used this site to calibrate their system. Finally, relative density (Dr%) or index of density (I_D) was calculated based on the data obtained in the laboratory from the frozen samples and compared with those obtained from RI-Cones in the case of Higashi-Ogishima site. In the case of Holmen sand, Lancellotta's (1983) and Jamiolkowski et al.'s (1988) empirical relationships were used to obtain Dr% and these results were also compared with those obtained by the RI-Cones.

2 DESCRIPTION OF RI-CONE PENETROMETERS

Following is the brief description on the working principle of the RI-Cones.

2.1 Neutron Moisture Cone Penetrometers (NM-Cone)

Neutrons are slowed down in the presence of hydrogen and this very fact has been used in designing the NM-Cone, if it is assumed that all the hydrogen present in the soil is in the form of water then the slowed down neutrons are related to the water or moisture content of the soil. Of-course, care must be taken when using this method in organic rich soil or if halides are present in the soil. The fast neutron source used in the NM-Cone is the isotope of Californium ^{252}Cf with the half-life of 2.56 years. ^{3}He-filled proportional tube is used as the detector. Fast neutrons are emitted from the source in the soil and after several collisions they loose their energy and these thermal or slow neutrons are captured by the detector which is a measure of hydrogen in the soil which in turn is related with the water or moisture content of the soil. Figure 1 shows the schematic diagramme of the NM-Cone.

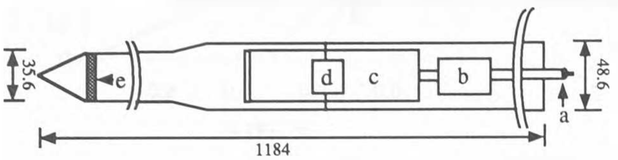
2.2 Nuclear Density Cone Penetrometer (ND-Cone)

In the construction of the ND-Cone gamma source is used to determine the bulk density of the soil. The principle of using gamma ray to measure the density of the material is well established. The gamma ray interacts with the matter principally in three ways depending on the level of the energy. The Compton scattering which is predominant in the energy range between 600 keV and 1.2 MeV and is the function of the density of the material, therefore, if the detector is so designed that it measures only the incoming photons with in the range described, then the incoming photons are only the function of density of the material and is given be the following:

$$I = I_0 \exp(-\mu_m \rho_t x) \qquad (1)$$

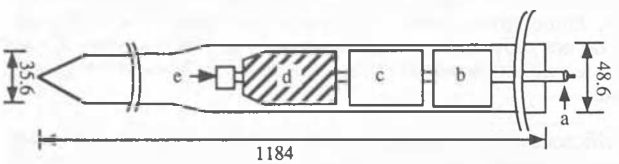
where; I_0: incident radiation intensity; I: transmitted radiation intensity; μ_m: total mass absorption coefficient; ρ_t: density of the absorbing material; and x: thickness of the absorber.

The gamma source used in the construction of the ND-Cone is ^{137}Cs with a half-life of 37.6 years and the detector is NaI(Tl) scintillator mounted on the photomultiplier tube. Figure 2 shows the schematic diagramme of the ND-Cone.



a: cable leading to data collection system
b: pre-amplifier; c: ^{3}He-filled proportional tube
d: ^{252}Cf fast neutron source ; e: porous ceramic filter
(all dimensions in mm)

Figure 1. Schematic diagramme of NM-Cone.



a: cable leading to data collection system
b: pre-amplifier; c: photomultiplier tube
d: lead (Pb) shield; e: ^{137}Cs gamma-ray source
(all dimensions in mm)

Figure 2. Schematic diagramme of ND-Cone.

3 DESCRIPTION OF TEST SITES

3.1 Higashi-Ogishima Site, Kawasaki, Japan

Higashi-Ogishima site is located about 30 km south of Tokyo. Geographical location is shown in Figure 3. It is a port city. During the last two decades this site was reclaimed from the sea by pouring sand from the adjacent localities. As Japan experiences a lot of earthquakes, soil failure due to liquefaction triggered by the cyclic loading due to earthquake is always a concern to geotechnical engineers. Also, it is important for the effective operation of the ports that the port facilities do not fail during severe earthquake. This was made abundantly clear during the Great Hanshin-Awaji Earthquake (also known as Kobe earthquake) of 1995.

Extensive investigation was carried out at this site. Various in-situ instruments such as seismic cone, pressuremeter testing etc., were carried out to delineate the in-situ soil conditions. RI-Cones were also employed at this site to obtain soil strength properties along with the in-situ natural water content (w_n%) and the wet density (ρ_t, t/m^3) of the soil in-situ. Frozen sampling was also carried out at this site to compare the results.

To determine the wet density of the soil from the frozen sample, care must be taken. Water content of the frozen sample was determined for the melted state by using following simple expression:

$$w_m = \frac{w_f}{0.917} \tag{2}$$

where; w_m is the water content of the melted state and w_f is the water content of the frozen state. Thereafter, the wet density of the soil was determined using the expression given below:

$$\rho_t = \frac{(1 + \frac{w_m}{100})}{\rho_w / [(Gs + w_m) / Sr]} \tag{3}$$

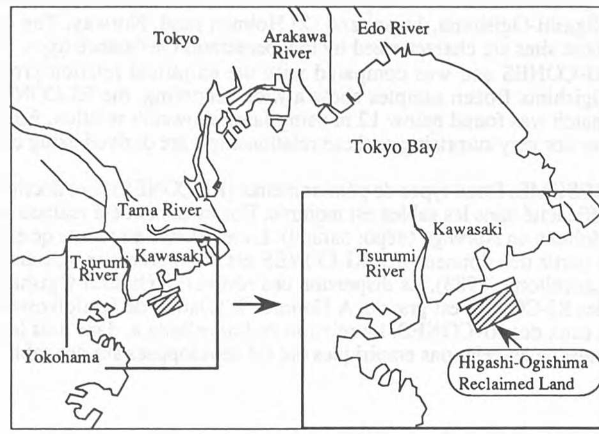


Figure 3. Geographical location Higashi-Ogishima site, Japan.

in the above equation (3) ρ_t is the wet density; ρ_w is the density of the water; Gs is the specific gravity of the soil and Sr is the saturation of the soil in percent.

RI-Cone results are shown in Figure 4. Also plotted are the results obtained from on the frozen samples. The natural water content (w_n%) as well as the wet density (ρ_t, t/m^3) profile shows some scattering when compared with those obtained by the RI-Cone but on the whole the data are well matched.

The water content measured in the laboratory on the frozen sample may not be the actual in-situ water content as the effect of the freezing and thawing cycle is not well defined and the authors believe that the speed by which freezing is done may also affect the final results. However, in the case of NM-Cone what we measure is the actual in-situ water content with the minimum of the interference of other processes.

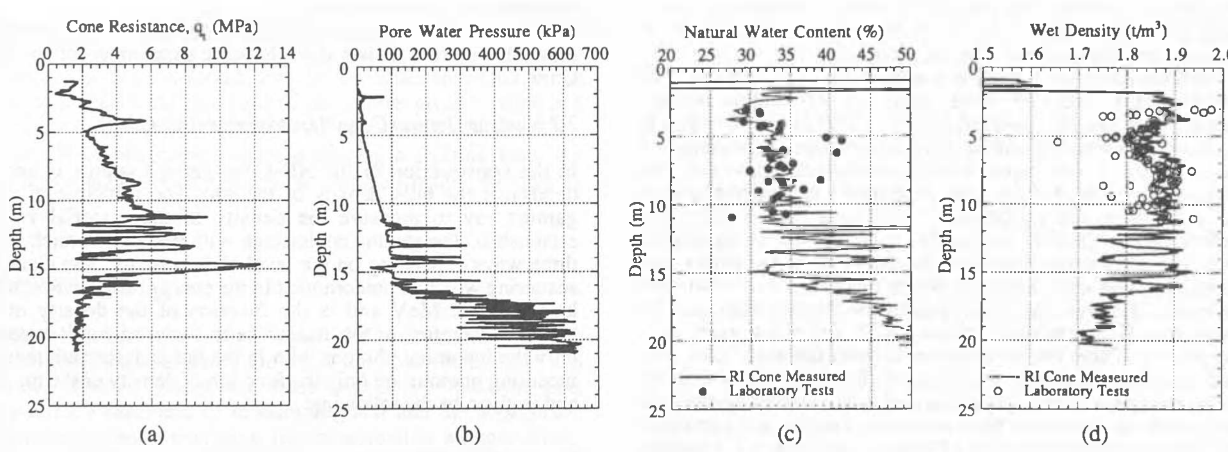


Figure 4. RI-Cones data from Higashi-Ogishima site.

3.2 Holmen site, Norway

Joint research was carried out in Norway in cooperation with the NGI at their well documented sites in Sept. 1995. Testing were carried out at the Holmen sand site. The geographical location of the test site is shown in Figure 5. Holmen is an island in the Drammen river just outside the city of Drammen. Below a fill of stones, gravel and sand one to two meters thick, a uniform layer with medium and medium to coarse, subrounded and mainly quartz, loose to medium dense sand extends upto a depth of about 28 m. At about 22 m, the sand changes from medium (to coarse) to fine (to medium). The site is subjected to tidal and seasonal water table variations. Occasional layers of silt and some organic matter can be found below 8 m. The site has been used by NGI for research purposes for many years (Lunne et al, 1986). RI-Cones testings were carried out upto a depth of 22 m.

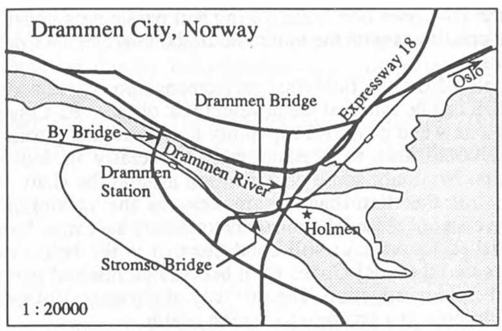


Figure 5. Geographical location of Holmen site, Norway.

Measured results with RI-Cones are shown in Figure 6. Also plotted are natural water content (w_n%) and the wet density (ρ_t, t/m^3) obtained on samples in the laboratory. The sampling at this site was carried out by the NGI staff using triple sampling tube. The site is characterized by very low q_c (q_c < 10 MPa). The excess pore pressure (u) during the penetration traces the path of the hydrostatic pressure. A comparison of the natural water content (w_n%) obtained from RI-Cones and the sample is made in Figure 6c. A reduction of almost 30% is seen, which is not very surprising. It is believed that this difference is due to the compaction of the loose sand during sampling. Also, during the extraction of the sample from the sampling tube free water at the end of the tube was observed which lends credence to the believe that the loose sand densified during sampling and transportation process (Lunne, 1995). Similar difference in wet density (ρ_t, t/m^3) can be seen in Figure 6d. RI-Cones based results are more consistent and show very little variation (ρ_t varies from 1.9 t/m^3 to 2.0 t/m^3) as compared to wet density obtained in the laboratory (ρ_t varies from 1.9 t/m^3 to 2.1 t/m^3).

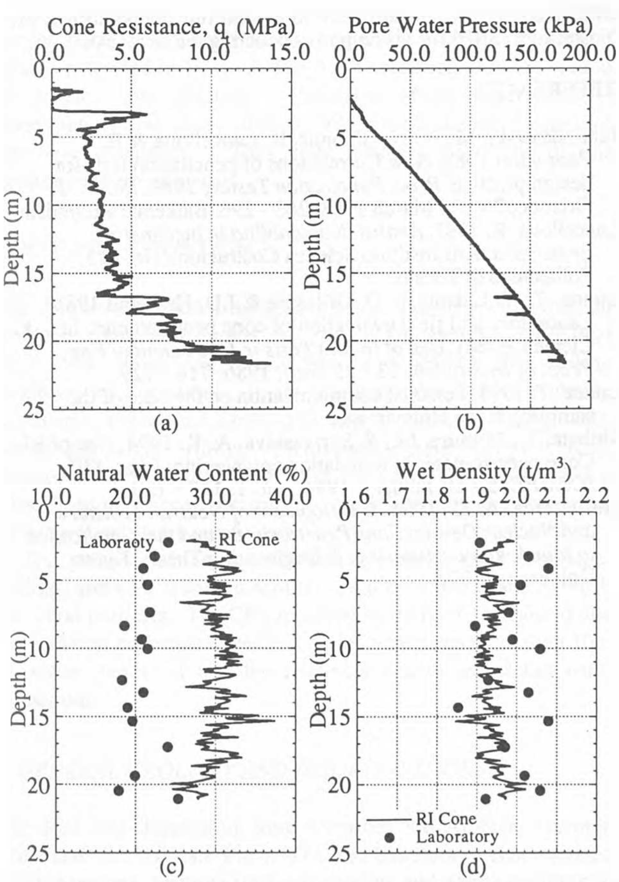


Figure 6. RI-Cones data from Holmen site, Norway.

4 INTERPRETATION : RELATIVE DENSITY (Dr%)

Geotechnical engineers intuitively relate the strength of sand with the relative density (Dr%). They recognize that an increase in this parameter of the soil increases its strength which in turn relates to less compressibility and less permeability. Relative density (Dr%) is also used in the calculation of the liquefaction susceptibility of soil, though, research has shown that the normalized N_{SPT}, is a better index of liquefaction than the relative density (Dr%). Whatever the case may be, in the field, the operators, the technicians and the engineers still base their preliminary judgment of the quality of the sandy groundmass on such parameters as relative density.

In the following paragraphs, the relative density obtained by two different means (laboratory testing on samples and empirical relations) have been compared with those obtained with the RI-Cones data.

4.1 Higashi-Ogishima Site

At the Higashi-Ogishima site frozen sampling was done upto a depth of 11 m to determine various physical parameters in the laboratory. Figure 7 shows the stratigraphy and the N_{SPT}. It is seen that the reclaimed sand deposit at Higashi-Ogishima site is found to be weak enough to have to pay attention to liquefaction. Figure 8 shows the profile of the density of soil particle for the Higashi-Ogishima site. Inspite of some variation for all the plotted depths, the values of the density of particle are fairly constant (ρ_s = 2.70). The void ratio (e_{min}, e_{max}, and current e) distribution is shown in Figure 9. Carefully seen, e_{min} and e_{max} show two distinct patterns above and below 7 m. Above 7 m, the values of e_{min} and e_{max} are 0.697 and 1.125 respectively. Below 7 m the void ratio decreases slightly and their values are e_{min} = 0.661 and e_{max} = 1.058. The current void ratio, e was determined to be 0.9. Knowing these parameters it is easy to calculate the relative density (Dr%) of the soil under consideration.

Figure 10 shows the relative density (Dr%) as obtained in the laboratory from the data obtained on the frozen sample. Also plotted in the figure is the relative density calculated from the data obtained from RI-Cones. A lot of scattering can be seen in the relative density obtained from the frozen sample. On the other hand, the RI-Cones based relative density (Dr%) is more consistent and follows the void ratio profile.

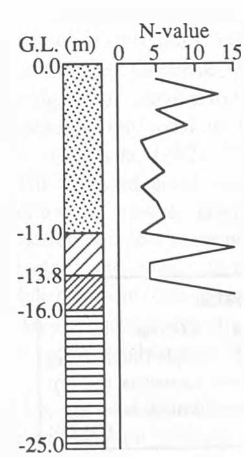


Figure 7. N_{SPT} at Higashi-Ogishima site.

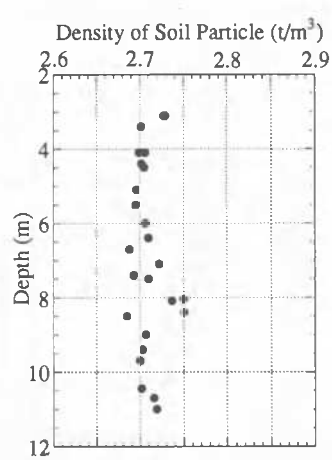


Figure 8. Density of soil particle at Higashi-Ogishima site.

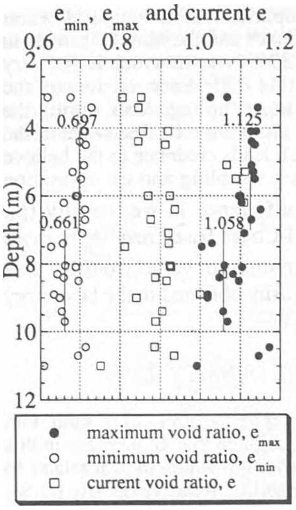


Figure 9. e_{min}, e_{max} and e profile at Higashi Ogishima site.

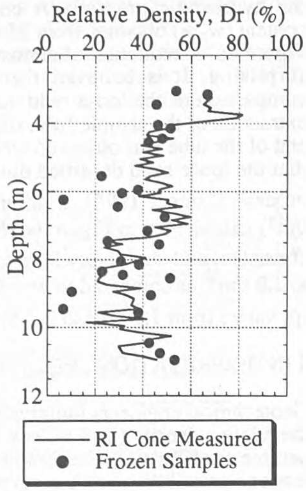


Figure 10. Comparison of relative density at Higashi Ogishima site.

4.2 Holmen Site

For the Holmen site a different type of comparison is presented. Use has been made of the empirical relationships proposed by Lancellotta (1983) and Jamiolkowski et al (1988). They have proposed these relationship based on the extensive calibration chamber testing and related cone penetration resistance, q_c, to relative density, Dr%, by following equations:

Lancellotta's relationship:

$$Dr = -98 + 66 \cdot \log_{10} \frac{q_c}{(\sigma'_{v0})^{0.5}} \tag{4}$$

Jamiolkowski et al.'s relationship:

$$Dr = \frac{1}{2.73} \cdot \ln \left[\frac{q_c}{18.5 \cdot (\sigma'_{v0})^{0.51}} \right] \tag{5}$$

In Figure 11 the results are plotted using the empirical relationships shown above. Also plotted are the results obtained from the triple tube sampler at NGI. These results are compared with those obtained using RI-Cones data (solid squares). For all the depth under consideration, the relative density (Dr%) obtained from triple tube sampler and Lancellotta's relationship gave higher values. Comparison with the Jamiolkowski et al's reveals a good match below 12 m. However, above 12 m their relationship also overestimate the relative density. The reason for this discrepancy can be, that these relationships have been obtained both by Lancellotta and Jamiolkowski and his co-workers are based on the calibration chamber testing on clean sand, which can not faithfully produce the in-situ conditions. Similarly, various factors affect the sampling process therefore these results are suspect at best.

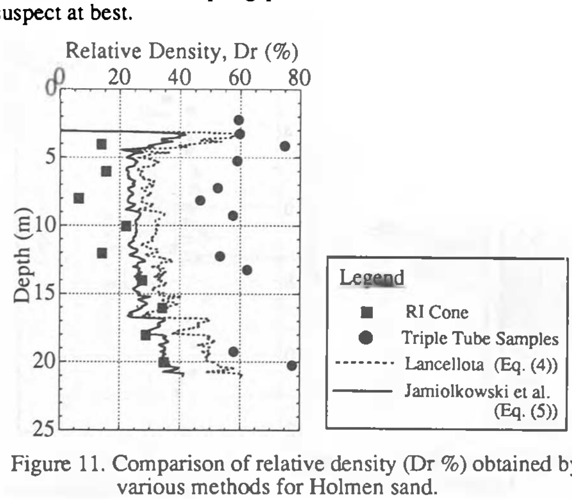


Figure 11. Comparison of relative density (Dr %) obtained by various methods for Holmen sand.

5 CONCLUSION

In this paper results are presented where RI-Cones results were compared with those obtained on the frozen samples (Higashi-Ogishima site, Japan), triple tube samples (Holmen site, Norway). Further, the relative density (Dr%) obtained using by various empirical relationships were also compared with RI-Cones data.

The inherent difficulties associated with the freezing and thawing process, where, theoretically 9% by volume water should be added during thawing process can lead to erroneous results. Also, the authors believe that the rate of freezing and thawing may play a role in the final outcome of the results.

The comparison of relative density obtained by various available methods (empirical and sample) with those obtained with RI-Cones leads to believe that RI-Cones give more consistent results when compared with other means. Because with the RI-Cones one is measuring soil parameters under actual in-situ conditions with the minimum of the interference from other sources.

Finally, from the field data performance presented above and before, it can be said that the development of these RI-Cones have added a new and powerful capability in investigating soils under in-situ conditions very accurately, especially in loose sand deposits. No doubt some densification around the shaft do take place, but the disturbances are kept to the minimum. The effectiveness of these RI-Cone Penetrometers have now been well established for various soil conditions. It is the believe of the authors that these RI-Cones shall become an integral part of the overall soil investigation. The intensity of the radio-isotopes is so low as to pose any problem to human health.

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