Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-3149

Technical session 1c: In-situ testing

Séances techniques 1c: Tests in-situ

C. Sagaseta
University of Cantabria, Spain
J.J.M. Powell
Building Research Establishment, UK
J. Takemura
Tokyo Institute of Technology, Japan

1 INTRODUCTION

Technical session (TS) 1c: In situ Testing, chaired by Prof. César Sagaseta (University of Cantabria, Spain) was held in the morning of September 14th with a very full audience in the session room (Room 1003). As shown in the program of TS 1c (Table 1), after the opening address and introduction of the general reporter and panelists by the chairman, Dr. John J.M. Powell (BRE, UK) provided a comprehensive general report on the conference papers relating to in situ testing. Following the general report, five panelists gave the presentations of various topics on the theme of the session. After the panel presentations, questions and discussions continued by the end of the session for more than 30 minutes.

In this report, discussion points and summaries of the general reports and panel presentations are first introduced. The questions and comments from the floor given in the open discussion and replies to the questions from the general reporter and panelists are also introduced.

Table 1 Program of Technical Session 1c

Opening Address: Prof. César Sagaseta (Spain)

General Report: Dr. John J.M. Powell (UK)

Panelists Presentation:

Prof. Koji Tokimatsu (Japan) - V_s profiles and local site effects estimated from SASW methods using microtremors

Prof. Paul W. Mayne (USA) - Versatile site characterization by seismic piezocone

Prof. Martin Fahey (Australia) – Stiffness of sands of different ages from seismic CPT and self-boring pressuremeter tests

Dr. K. Rainer Massarsch (Sweden) - Deformation properties of fine-graded soils determined from seismic tests

Prof. Fred H. Kulhawy (USA) – Notes on penetration tests & gravelly soils

Open Discussions

2 GENERAL REPORT BY DR. POWELL (BRE, UK)

In the introductory part of general report, Dr. Powell first reconfirmed the reasons why we should be using in-situ testing and emphasized the following three factors:

- **Speed** – Many in situ tests are, in contrast to sampling and laboratory testing, quite quick, giving real-time information on the ground properties, which are generally more representative of reality. So they can be quicker, easier and cheaper than sampling and laboratory testing.
- **Quantity** – In situ testing can deliver more information about a profile of the ground, often near-continuous information. Therefore the spatial variability of the deposit can be more fully investigated.
- **Quality** – When undertaken correctly, in situ testing can offer much more consistent and repeatable information than routine sampling and laboratory testing. The soil can be assessed in its natural environment without the potential problems of sample disturbance.

Dr. Powell explained applicability and usefulness of some of major in situ tests in terms of soil parameters and ground types using a table (Table 1 of Powell (2005)).

After the introduction, the general reporter first classified 27 conference papers dealing with in-situ testing in terms of devices: CPT/CPTU, Seismics (Geophysics), MPM & SBP (Pressuremeters), DMT, SPT & DP, Plate load test, Case history and others. He reported that the papers offered experience in Equipment validation/ Equipment development/ Improving existing correlations/ Developing new correlations/ Increasing the range of soil types/ Combining different devices for greater coverage and detail. From the breadth of topics covered by the papers he inferred the versatility and potential usefulness of in situ testing for ground investigation.

In the general report, Dr. Powell highlighted the following discussion points on in situ tests using both material or data he had prepared or was given in the conference papers; this was instead of giving brief introductions of each paper (this would be done by the authors in a later session).

- **Base data gathering**
  - Standardisation and equipment variations
  - Operational variations
  - Test repeatability
  - Test data corrections
  - New devices or modifications to old
- **Interpretation**
  - Theory vs. empiricism
  - Quality and source of database information for correlation
  - Appropriateness of test method
  - Validity / appropriateness of correlations
  - Local correlations - are they transferable

From the results of CPTs with different sizes in UK clays (Powell and Lunne, 2005), he first showed reasonable consistency of the cone tip resistance (q_t) (corrected for pore pressure (u_2) and inner cone geometry), as well as sleeve friction (f_s) and u_2 irrespective of cone type and size. Then he pointed out that this is not always the case showing the results of 8 different types of cone done in one site, Onsoy in Norway. Multiple penetration results (q_t, f_s, u_2) from each cone were quite consistent, however, significant differences in the mean value of q_t and f_s were observed from the 8 cones. These differences may be attributed to different operators; different types of cone, or cone geometry and different calibration procedures.

As the second discussion point, he introduced depth profiles of Ménard limit pressure (p_{LM}) and Ménard pressuremeter modulus (E_M) interpreted but different people from the same set of base data of Menard Pressuremeter (MPM) tests. The profiles showed a wide range of difference for both parameters depending on the interpreter. He also showed a large variation of N_{10} values obtained from dynamic penetration (DP) tests with different configurations, which might cause a large scatter in the engineering parameter, such as strength and stiffness if different correlations are used for the different configurations. On the other hand, there is a possibility to interpret the DP test in terms of the dynamic point resistance q_d which should be consistent for all configurations as it takes into account the effects of important conditions such as input energy, rod weight etc and thereby gives a consistent correlation to the parameters for all the variety of devices.

From the above examples, it was reconfirmed that in the same kind of test, there are different devices, different interpretation procedures and different correlation source information. As a further example, there are five common types of pressuremeter, such as PBPM, MPM, SBP, FDP, CPM, giving different level disturbance and different methods of interpretation (e.g. the definition of limit pressure). With these differences, the correlations developed might not be transferable between the different devices. We should know possible test variability to know what the relative effect on the derivations is. He gave an example about correlations of CPTU for clays. The historical scatter in the correlations in clays may be due to mixing q_c and q_t , the quality of base data, and source of c_u. Hence we should have the basic information on which the correlation is based, the type of device, know what type c_u and how obtained $c_{u,}$, e.g. from block sample, piston sample or vane. Other examples of confusion and mixing of incorrect correlations were also presented.

In the later part of the report, he introduced interesting information on data and research found in the conference papers, which can contribute to the improvement of equipment and interpretation, resulting in more reliable correlations and applicability of the in situ tests. Explanation and discussion about these papers and conclusions from the all papers in the field of in situ testing are documented in the general report (Powell, 2005). Beside the conclusions written in the report, he also showed the following points at the end of presentation:

- Not intended to be negative.
- But we need to address the points discussed earlier if we are to have confidence in correlations.
- Should we expect global correlations?
- Would we have more confidence in local correlations?
- We need to understand what the tests are doing and what we want from them.
- Standards can help us try to get consistent information.
- Better access to databases and test sites? (Geotechnet)

3 PANELISTS PRESENTAIONS

3.1 *Prof. Koji. Tokimatsu (Tokyo Institute of Technology, Japan)*

Prof. Tokimatsu first gave a brief introduction of V_s profile estimation using microtremors arrayed two dimensionally on the ground surface. As an advantage of the method using the microtremors, he emphasized the shorter testing time and deeper measurable depth, down to 200m, compared to the conventional method which requires boreholes. He then explained the applicability of this technique showing the following examples.

1. V_s profiles estimated by SASW method using microtremor measurements at two different sites in Ojiya, Niigata - the affected area of the Niigata-ken Chuetsu earthquake of 2004 were compared with those obtained from PS logging. The V_s profiles from the two methods were in good agreement.
2. At the two sites in Ojiya, strong motions were observed at the 2004 Niigata-ken Chuetsu earthquake. Dynamic response analyses were conducted for the ground with the V_s profiles from the microtremor measurements by applying input motion observed at the base rock. The calculated motions at the ground surface compared well with the observed one, showing the applicability of V_s profile estimation by SASW methods using the microtremors for characterizing site conditions during earthquakes.
3. Phase velocity measurements with allay at six sites and H/V measurements with a single station at more than 200 locations were done in Kushiro, Hokkaido. From the extensive measurements, three-dimensional V_s profile was estimated in the city, which unveiling a hidden valley in the central part of Kushiro city as shown in Figure 1. This hidden valley was confirmed by check borings, which implies the potential capability of the method in characterizing a three-dimensional V_s profile from the ground surface down to the bedrock with a reasonable degree of accuracy.

Details of the observation at the two sites are presented by Tokimatsu, et al. (2006 & 2004) respectively.

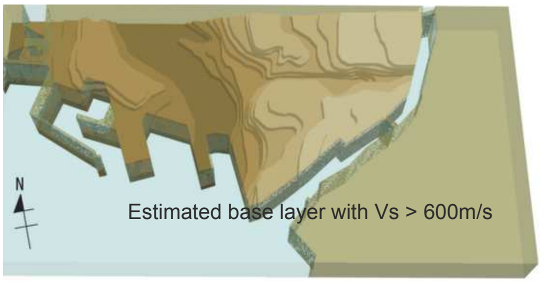

Figure 1 Estimated base layer by microtremor measurement at Kushiro city.

3.2 *Prof. Paul. W. Mayne (Georgia Institute of Technology, USA)*

Prof. Mayne began his presentation with beautiful photographs showing ripple marks in deserts, close view of carbonate sand, cobbles, etc. What he emphasized is the diversity of geomaterials with a complexity which requires us to know so many parameters to quantify the soils as engineering materials, such as, index parameters, state parameters, and mechanical and chemical parameters. Beside the traditional and most commonly used set of simple boring and standard penetration test, that is N-value , he reminded us of current modern technology in geotechnical site characterization, which can be routinely applied not only for the special projects.

Among the various soil investigation techniques, he emphasized the versatility of the seismic piezocone, which can be used as a minimum soil investigation method in Georgia Institute of Technology. Seismic piezocone provides four different measurements, tip resistance (q_t), sleeve friction (f_s), pore water pressure at the cone shoulder (u_2) and shear wave velocity (V_s) in a downhole manner. Furthermore, the dissipation test done at certain depth gives the decay in pore water pressures with time, e.g., the time to reach fifty percent consolidation (t_{50}). The seismic cone test recording the five separate parameters is called SCPTÙ in French pronunciation.

Prof. Mayne showed the profiles of these five parameters obtained from various ground conditions with very complicated stratigraphy in various projects, such as "nonetextbook" type residual silt, at Atlanta airport, a crust underlain by soft varved clay at University of Massachusetts, Amherst, and marine clay, at Port of Anchorage, Alaska.

As an example of interpretation of soil parameter, he showed the relationship between the normalized tip stresses and effective friction angles obtained from frozen samples of sands in three countries, Japan, Canada and Norway. The relationship can be reasonably estimated by the equation derived by calibration chamber tests (Kulhawy and Mayne, 1990), except of the sands with higher fine content.

$$\phi'(\deg ree) = 17.6 + 11.0 \log(q_t / \sqrt{\sigma'_{v0} \sigma_{atm}}) \qquad (1)$$

Interpretation of CPT data for determining some selected parameters, i.e., V_s, ϕ', preconsolidation stress and undrained strength of clays, equivalent soil modulus, and consolidation rate and permeability are discussed in the conference paper by Mayne and Campanella (2005).

3.3 *Prof. Martin Fahey (the University of Western Australia, Australia)*

Prof. Fahey started his presentation showing the following summary:

- Sands under center of Perth are of different ages, late Pleistocene in upper layer (10-15m) and early to middle Pleistocene below it (down to 35m)
- Seismic CPT test and Self-Boring Pressuremeter (SBP) test allow non-linear stiffness model for sand to be calibrated from in situ tests.
- Test results at the site of tunnel under Central Business District, Perth shows "older" sands have higher G_0 than "young" sands; G/G_0 for "older" sand reduces faster than G/G_0 for "younger" sand.

After introducing the project of an underground rail link and geological conditions at Perth, Prof. Fahey explained distorted hyperbolic models shown in equation (2)

$$\frac{G}{G_0} = 1 - f\left(\frac{\tau}{\tau_{\max}}\right)^g \qquad (2)$$

where τ_{max} is the shear strength, f and g parameters required to distort hyperbolic model to fit monotonic behavior. g distorts hyperbolic model. The smaller g value, the faster deterioration of G/G_0. f forces Mohr-Coulomb failure at finite strain. To obtain the curves expressed by equation (2), he used in situ tests, seismic CPT for G_0 as small strain stiffness and SBP as large strain test for f and g. With a typical cavity strain-cavity pressure curve of sand obtained from SBP test, the process how to fit the model to the curve was briefly explained, which based on no-linear model incorporated into cavity expansion program CAMFE. He explained that the process is very robust requiring high quality of SBP test and measurement of G_0 from seismic CPT. From the profiles of G_0 and g with depth estimated at the tunnel construction site in Perth, Prof. Fahey confirmed the stiffness and softening properties of the sands with different ages as explained in the beginning of the presentation.

At the end of presentation Prof. Fahey emphasized that the SBP test is the best choice for "large strain" measurement of stiffness for sand. However, as SBP is not commonly used and cannot be carried out for all soil types, he also suggested applicability of other in situ tests, such as MPT, DMT and CPT as alternatives to SBP.

3.4 *3.4 Dr. K. Rainer Massarsch (Geo Engineering AB, Sweden)*

In the presentation, Dr. Massarsch first showed a slide of conclusions and pointed out the followings:

- Determination of soil stiffness is very important for the design at serviceability limit state where no failure occurs for the loading conditions.
- Empirical relations on stiffness are confusing and it is very difficult to estimate the deformation properties from the relation, showing scatter.
- Shear strain causes stiffness degradation, not strain rate. Strain rate of seismic tests are as slow as that of static laboratory tests and the strain rate of cone penetration tests is very fast compared to seismic test for small strain stiffness.
- G_{max} at small strain can be determined accurately from seismic test and G_f at large strain from static test, since the strain rate of static test and seismic tests are the same.

Dr. Massarsch displayed a figure on the relationship between E_u/τ_f and plasticity index, PI derived from various sources, which showed very large scatter varying from 50 to 4000. He attributed this scatter to the inconsistency in the definition of E_u, strain level, reminding of the effect of strain on the soil modulus. Showing soil modulus degradation curves with linear scale, he confirmed that shear modulus decrease of clay with strain is much slower than that of sand. He also showed the relationship between modulus degradation factor (R_m=G/G_{max}) and PI for different shear strain levels, 0.1, 0.25 and 0.5 % depicted from a huge data sources on resonant column test. The figure shows clear trend with less scattering, considering variety of the sources.

As the second point of discussion, Dr. Massarsch showed the figure on typical strain rate of various tests and strain rates are well compared between resonant column tests and static laboratory tests. From the above discussion he suggested that the stiffness degradation curves of fine graded soil can be established by combining the modulus degradation curves from resonant column test and conventional static laboratory shearing test from the starting point of G_{max} determined from seismic test.

3.5 *Prof. Fred H Kulhawy (Cornell University, USA)*

Prof. Kulhawy first briefly surveyed Standard Penetration Test (SPT). The SPT is common and worldwide, having been used for about a century. However, the SPT is poorly standardized both in dimensions and type of hammers and many SPT correlations are based on early hammer types from sand soils without large gravels. Because of small sampler size and insufficient input energy, SPT is inappropriate in gravelly soils. To overcome these limitations, Large Penetration Test (LPT) and Becker Penetration Test (BPT) have been developed. Brief reviews of LPT and BPT were also introduced about development history and the comparisons of drive method and test conditions between SPT, four different LPTs and BPT.

Dr. Kulhawy reviewed existing correlations between the LPT and BPT with SPT. He concluded that generally good correlation between LPT and SPT has developed with scaling ratio for both energy and area, but BPT correlations have still less developed. He also suggested that particle size, particle shape, particle hardness and cementation remained to be considered for the interpretation for both LPT and BPT. Some details of his presentation are given by Kulhawy and Chen (2005).

4 OPEN DISCUSSIONS

After five presentations by the panelists, questions and comments relating to in situ tests were accepted from the floor. The followings are the contents of Q & A and comments which were derived from audio records of the discussion session. Please note that some discussion points and name of discussers could not be captured due to the low quality of recording.

(Q: Dr. Diego Lo Presti, University of Pisa, Italy)
I would like to have any suggestion about how to obtain small strain parameters and large strain parameters from CPTU or the seismic cone. I can understand something about the pressuremeter and dilatometer, but I would like to hear something about more small strain?
(A: Prof. Fahey)
G_0 or G_{max} is affected by age, stress and so on. We have to examine the trend in more detail, which gives us the better expression. But I think dilatometer is a better choice than the ratio of G_0 or G_{max} to dilatometer parameters might be challenging.

(A: Dr. Powell)
For both sand and clay there are a similar correlations between G_{max} and q_t, but in clays G_{hh} correlated far better with q_t than G_{vh} or G_{hv}..
(Q: Dr. Marwan Shahien, Tanta University, Egypt)
If I had a site of sand and gravel composed soil, how to compare the SPT, LPS, how to obtain the mechanical parameters, e.g., friction parameter, state parameters, and compressibility parameters from LPT and then how to obtain the mechanical and engineering properties?
(A: Prof. Kulhawy)
Back to the paper by Gorge Becker in late 60s and early 70s on this subject, what he attempted to do is to develop the design approach to deal with geo-foundation on SGC type of materials. They did cross-correlation in terms of characterization and mechanical properties of materials available at that time, largely based on rockfill testing on strength, compressibility, and particle size and shapes. When he did large sized and small sized laboratory test parameters, they were back correlated to a series of full scale field tests on geo-foundation. In his process, field tests, laboratory tests and in situ tests, SPT and BPT provided the final arrangement with SGC we use. So there is a piece of information we rely on with good cross-correlation.
(Q: Prof. Harry Poulos, University of Sydney, Australia)
Prof. Mayne uses Fahey & Cater degradation function together with minimum values obtained from SCPTÙ and has significant success representing the axial load – settlement behavior of piles. Have you attempted to extend this approach to make a new model of piles as a possibility of replacing p-y method for estimating pile response?
(A: Prof, Mayne) "no", but I'm willing to do that if I have a sponsor funding.
(C: from ??)
About normalized degradation curves of G/G_{max} and τ/τ_{max}, proposed by Prof. Fahey, I suggested the use of cone penetration test to obtain τ_{max} , which contributes reduction of lab tests.
(Q: from ??)
What is the suitable field testing to characterize decomposed residual soil?
(A: Prof. Mayne)
Minimum test on that material is seismic piezocone. In Atlanta, SCPT has been applied to totally decomposed residual granite.
(C: Prof. Poulos)
Suitable method depends on what kind of cake you want to bake. If you are more concerned to deformation, you better conduct the penetration test rater than seismic tests.
(Q: Dr. Turan Durgunogw, Turkey)
I would like have comments about the difference of G_{max} or G_0 obtained from SCPTÙ and the other geophysical tests like down hole and cross hole tests and SASW.

(A: Prof. Mayne)
In the comparison in a site with K_0 =0.5, V_s obtained from SASW, down hole and cross hole tests are similar to that obtained by SCPTÙ. However, as K_0 increase there will be a difference because of difference of confining stress.
(C: Prof. Fahey)
One important thing on seismic CPT is the cost. The marginal cost of seismic CPT over the normal CPT is small considering the usefulness of the parameter obtained.
(C: Dr. Massarsch)
From TC-10 website, useful information of SCPT tests can be down loaded.
(C: Prof. K. Stoke)
Comments about the in situ tests of gravelly soils, the seismic surface wave which propagating on the surface without nay disturbance can be a good standard. If you measure surface wave and use cone penetration, you might worry about global vs. low price measurements, in which you probably want to get the latter. That needs to pay attention to some of correlation to find or develop.
(A: Ayothiraman Ramanathan, IIT Guwahati, India)
About the CPT correlation, there is big scattering and variation in cone factors? How to deal with this?
(A: Dr. Powell)
Key point is standardization. In the EU, the standard for cone penetration test will be coming out very soon. But it is only broad. We need more reference calibrations and consistent base data to develop/validate the correlations.

(C: Dr. K. Karlsrud, NGI)
The dissipation of pore water pressure depends on permeability and compressibility. What permeability and what compressibility are supposed to be a constant parameter. Compressibility changes in the stress-strain, that really have degradation. And there are enormous scatters in the deduced permeability from the dissipation measurement. Hence it is necessary to have a better framework in the interpretation of dissipation test.
(R: Prof. Mayne)
We have developed some model in a space of cavity expansion critical state that allows us to propose monotonic decay of pore pressure to time as well as the increase which keeps and then decrease to time. We have calibrated those in a 1998 paper of Canadian Geotechnical Journal. In my paper (Mayne and Campanella, 2005) in the conference proceeding, there is empirical correlation between measured t_{50} and soil permeability.
(R: Dr. Powell)
From the graphs c_v and k should always be taken with a +/- range of about half and order of magnitude. The results indicated our best estimates, but we should take our value with minus.
(R: Prof. Fahey)
The value of c_h estimated from dissipation test in normally consolidated clay is not the c_h of the normally consolidated clay, because the compressibility is somewhere between compression index and swelling index. So we should correct the value with compression index.
(Last comments on strain rate from ??)
Strain rate of resonant column test is occasionally comparable at small strain with that of static tests. But the rate under sinusoidal loading condition increase by five orders at large strain level. And we should remind that strain rate of the tests, 99% of the test are much higher than that in the real construction.

The time had run out very quickly under very active discussions. When we had the last comments, it had been over the time for the session. The chairman, Prof. César Sagaseta, then thanked the general reporter, the panelists and the audience, and session was closed.

REFERENCES

Kulhawy, F. H. and Chen, J.R.(2005). Evaluation of penetration tests and their correlations in gravely soils, 16th ICSMGE, Vol.2, pp.707-710. Osaka.

Mayne, P. W. and Campanella, R. G. (2005). Versatile site characterization by seismic piezocone, 16th ICSMGE, Vol.2, pp.721-734. Osaka.

Powell, J.J.M. and Lunne, T. (2005). A comparison of different sized piezocone in UK clay, 16th ICSMGE, Vol.2, pp.729-734. Osaka.

Powell, J.J.M. (2005). General report of Technical Session 1c: In situ Testing, Proc. 16th ICSMGE, Vol. 5, Osaka.

Tokimatsu, K., Arai, H. and Yamazaki, M. (2004), Multi-dimensional Vs-profiling with microtremor H/V and array techniques, Proc. of 13th WCEE, paper No. 1348.

Tokimatsu, K. and Sekiguchi, T.(2006), Effects of nonlinear dynamic soil properties on strong motions at Ojiya K-NET and JMA stations during 2004 Mid Niigata Prefecture Earthquake, Proc. of 8th U.S. National Conference on Earthquake Engineering(to appear)