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**Session Report**

# SUMMARY REPORT: SPECIAL THEME SESSION (SI) ON EXPERIMENTAL METHODS FOR STRUCTURES (Part 1: LOADING PROCEDURES IN GEOTECHNICAL TESTING)

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## SUMMARY

This is a summary report of Part 1 of the Special Theme Session : SI. It describes the outline of the State-of-the-Art report and technical papers presented and summarizes prepared discussions and discussions from the floor in this session.

## INTRODUCTION

Part 1 of Special Theme Session SI entitled "Loading Procedures in Geotechnical Testing" was started off with the introduction of session procedures by the chairperson in charge, Professor T. Kimura at Tokyo Institute of Technology. He explained that the session would be divided into three subsessions after the State-of-the-Art-reporting, with each dealing with dynamic centrifuge tests, 1g shaking table tests and on-line loading tests respectively. He then made a request to the participants to join actively the floor discussion to be held after presentation of main papers and prepared discussions.

## STATE-OF-THE-ART REPORT

The State-of-the-Art reporter for this session was Professor A. N. Schofield of Cambridge University. His lecture, "Recent Development in Dynamic Model Testing in Geotechnical Engineering", consisted of four parts : (1) Principle of centrifuge modelling (2) Modelling of liquefaction of level ground, (3) Recent tests and (4) Past errors and future investment.

In the first part, Professor Schofield described various scaling laws with respect to centrifuge modelling, particularly in dynamic problems. The principle of centrifuge modelling is to create similar stresses in a model to those in a prototype by imposing centrifugal acceleration of Ng on the model with scale ratio of 1/N. In order to satisfy stress similarity in centrifuge dynamic testing, it is essential to apply vibrations with frequency N times and amplitude 1/N times as much as the counterparts in prototype problems to centrifuge models.

When the phenomenon of dissipation exists in dynamic events a serious problem arises. The time scaling relation for the former is $1/N^2$, while for the latter it is $1/N$. Professor Schofield advocated the effectiveness of using silicone oil as a pore fluid in centrifuge models to overcome the problem. He showed some typical results of dynamic centrifuge tests at Cambridge University to confirm this.

Professor Schofield emphasized particular advantages of centrifuge modelling in the problems of slope failure and landslide. Near the surface of a slope where confinement stress is extremely low tension cracks tend to appear. In the areas below this where confinement stress is of intermediate magnitude Coulomb type failure takes place forming discontinuous failure planes. In deeper areas with high confinement stress soil behaves as a ductile plastic material. It is extremely difficult to reproduce this whole set of soil behaviour with conventional small-scale model tests. Centrifuge modelling, however, enables us to simulate this complicated soil behaviour because stresses in centrifuge models can be made similar to those in prototypes. Professor Schofield explained about the Cambridge geotechnical centrifuge and the bumpy road system especially designed for carrying out centrifuge dynamic tests.

In the second part, Professor Schofield introduced the results of liquefaction tests conducted with the bumpy road system attached to the Cambridge centrifuge. He showed that pore pressure built up during the first several cycles of vibrations causing fluidization in upper parts of a sand layer. The uppermost layer cracked and fluidized sand boiled through these cracks. This type of phenomenon has been very often observed with the occurence of actual earthquakes.

The third part was the introduction of results of dynamic centrifuge tests on the problem in which liquefaction and the inertial effect coexist – A model test on an embankment under a load of structure. He demonstrated that under a small earthquake the response was elastic, showing the amplification at the resonance frequency. The response, however, was completely different under a strong earthquake. In the early periods of earthquake, the accelerations of the structure and embankment were well coupled. With the progress of earthquake uncoupling of these accelerations took place. Softening or decrease in stiffness of embankment was considered responsible for this. In fact high pore pressure generation was observed in the embankment as time passed.

Professor Schofield talked about the past errors and future investment in the fourth part. Most of the geotechnical centrifuges built so far spin a model by placing it horizontally in the plane of rotation. According to Professor Schofield this is a big mistake because centrifugal accelerations are different even at the same horizontal planes in the model. He stressed the importance of placing the model at right angle to the plane of rotation in order to have an identical acceleration at each horizontal plane. This is especially important when carrying out dynamic testing because we can prevent Colioli's effect from coming into the test results by using this arrangement. Finally Professor Schofield expressed his regret about errors made by the U.S. centrifuge community and hoped that Japanese research workers would not make the same mistake. He concluded his lecture by urging Japanese research workers who are going to build or purchase a new centrifuge to refer carefully to books or proceedings published by the centrifuge research committee of the International Society for Soil Mechanics and Foundation Engineering.

## DYNAMIC CENTRIFUGE TEST

The first contribution was to come from Professor R. F. Scott of California Institute of Technology. Unfortunately he was not able to attend the conference, so Professor Kimura read the paper by Professor Scott (SI-01) entitled "Dynamic Centrifuge Tests" on behalf of him.

The paper dealt with scaling relations for dynamic tests both in 1g and centrifugal fields. He demonstrated that, if we believe in a so-called normalized stress-strain behaviour, similar response can be obtained even in a 1g model by using a looser material in the model than in the prototype. Based on this idea he derived scaling relations for dynamic tests in 1g field and compared them with those in centrifuge models. He also discussed the scaling relation for dissipation problems. A looser material has to be used in order to obtain similar responses in 1g models. As result it becomes impossible to evaluate the permeability coefficient of the material. This in turn makes it very difficult to establish the scaling relation for the consolidation coefficient of the 1g model. His paper stressed that more study of this point would be required.

Professor Scott then considered the centrifuge test. He reviewed most of the important papers which dealt with dynamic centrifuge tests and introduced different excitation systems. Final part of his paper was devoted to the introduction of the excitation system developed by Caltech group, which is of an electro-hydraulic type. A similar system built by Tokyo Institute of Technology was also explained by Professor Kimura.

The second speaker was Professor W. D. L. Finn of the University of British Columbia. The title of the paper (SI-02) was " Verification of Dynamic Effective Stress Analysis by Centrifuged Model in Saturated Sand ". Professor Finn compared the results of a numerical analysis using a computer programme developed by his group with centrifuge model tests conducted at Cambridge University on a soil-structure interaction problem. He showed that the programme was capable of performing complex effective stress analysis with acceptable accuracy for engineering purposes. Seismically induced residual pore-water pressures were satisfactorily predicted with the analysis and computed accelerations agreed in magnitude, frequency content and distribution of peaks with those measured. He stressed that one particular advantage of his programme was its ability to model the high frequency rocking vibration of the model structure.

The third contribution was made by Mr. T. Inatomi of Port and Harbour Research Institute (PHRI) at the Ministry of Transport. The title of the paper (SI-03) was " Development of Earthquake Simulator in PHRI Centrifuge and its Application ". Mr. Inatomi described a new earthquake simulator developed by PHRI, which is also of an electro-hydraulic type. He introduced the results of two different dynamic tests ; deformations of gravity type caisson and confined pressure effect on shear wave velocity. He concluded his presentations by pointing out that, although dynamic centrifuge modelling is a useful technique, there are still many problems to be overcome such as the effect of side friction and rigid end walls, the effect of strain rate and so on.

On completion of three main presentations, Mr. Y. Kogo of Public Works Research Institute (PWRI) at the Ministry of Construction presented a prepared discussion. He introduced a shaking system developed by PWRI and summarized the advantages and disadvantages of dynamic centrifuge modelling technique. Mr. Koga's comments were very similar to those made by Mr. Inatomi.

The session was then opened to floor discussions. The first floor discussion came from Mr. A. Clark of MTS, U.S.A. He made a comment on the type of servo-valve to be used for centrifuge dynamic testing. He recommended that the spool should be placed at right angle to the direction of centrifugal force when a standard type valve is used. Professor Finn then made a brief comment on Mr. Koga's prepared discussion. He supported Mr. Koga's view on the advantages and disadvantages of centrifuge dynamic testing. He maintained that one of the effective ways for evaluating dynamic properties of soil in centrifugal fields is to measure shear wave velocities during the test.

Dr. J. H. Troncoso of Catholic University, Chile argued that natural frequency of a model of an embankment would be different from that of a corresponding prototype. He wanted to know if the bumpy road system could cope with this difference of natural frequency. Prof. Schofield answered, since the height of the embankment was 15m or so in the prototype scale , he sees no serious problems in modelling it with the bumpy road system. He added, centrifuge research workers in Russia might be able to answer the question because they have been working on tall dam projects for many years.

Mr. S. Iai of PHRI then asked if scaling relations would hold at the ultimate stage of liquefaction or fluidization because he thinks sand particles tend to behave in an individual way as the result of cracking. Prof. Schofield preferred to take this problem as that of a Reynold's number similarity. He suggested that a series of studies changing Reynold's number in centrifuge models could give some idea to Mr. Iai's question.

Prof. Kimura summarized the first round of floor discussion session by refering to an attempt for the centrifuge community to carry out centrifuge model tests combined with prototype tests which correspond exactly to the model tests.

## 1G SHAKING TABLE TEST

The paper SI-04 entitled "Studies on Experimental Technique of Shaking Table Test for Geotechnical Problems " was presented by Mr. T. Matsuda of Ohbayashi Corporation. He described several new experimental techniques to be applied to 1g shaking table tests. With respect to preparation of model sand ground, he said, the use of upward water flow combined with vibration gave rise to very consistents results. This technique has a great advantage because it saves trouble to carry sand out of a soil box for each test. Mr. Matsuda also talked about the effectiveness of vacuum loading for applying confining pressure to model sand ground. He confirmed that the shear modulus and resonance frequency of model ground increased when vacuum loading was applied. He then showed the results of a back analysis using accelerations measured at points arranged in vertical arrays. He stressed that this back analysis technique enables us to determine the strain dependency of shear modulus and damping factor.

The next paper SI-05 entitled "Skaking Table Tests of Elasto-Plastic Soil-Pile-Building Interaction System" was delivered by Dr. S. Tamori of Shinshu University. He introduced the results of 1g shaking table tests using plasticine. He studied the dynamic properties of plasticine by triaxial and hollow cylinder torsional tests and found that the strain dependency of the shear modulus and damping factor is similar to that of cohesive soil. The model building and model piles were made of steel.

He obtained energy response defined as the total area of hysteresis loops from his experimental results and calculated the ratio of the energy response by dividing it into three different modes of motion : swaying, rocking and building deformation. The conclusion he obtained was that the ratio varied with the magnitude of plastic deformation beneath the foundation. For mat foundations ratio of energy response was higher for rocking motion, while for piled foundations the ratio for building deformation was greater.

Two prepared discussions on 1g shaking table tests were presented ; the first one from Dr. T. Kokusho of Central Research Institute of Electric Power Industry and second one from Professor C. Jin of Dalian Institute of Technology.

Dr. Kokusho pointed out that it is possible to establish similarity laws even between 1g models and prototypes if dynamic properties under extremely low confining stresses are established. He attempted to carry out this type of tests by a torsional shear testing apparatus and successfully measured the shear modulus and damping factor.

Professor Jin made a comment on the usefulness of a large-scale 1g shaking table. He maintained that similarity laws hold for natural frequencies and amplification characteristics even in 1g test although the confining stress is low. It is true to say that failure mechanisms cannot be obtained in 1g model tests but it is possible to improve a numerical model by carrying out back analyses using measured results.

The session was opened to floor discussion once again. Dr. Y. Iwasaki of Geo-Reseach Inst., Osaka Soil Test Lab. raised two questions. One was about the difficulty of evaluating dynamic properties of unsaturated part of a sand layer and the other was how Professor Finn measured the shear wave velocities in flight. Professor Finn answered the first question saying that as far as he knows, the only method available is to measure P wave velocity. Concerning the second question Professor Finn explained his method of measuring shear wave velocity. He used a transducer with anisotropic electric properties in the shape of T. He placed one transducer as inverse T, filled sand to some depth and then placed another transducer by turning it the other way round. This one couple of transducers can pick up signals, from which he calculated shear wave velocity.

## ON-LINE LOADING TEST

The final paper SI-06 entitled "Absorbing Process of Strain Energy of Soil during Earthquake " was presented by Dr. T. Katada of Musashi Institute of Technology. He introduced the result of liquefaction tests using an on-lined system.

Dr. Katada found that the accumulation process of strain energy corresponded well to the building up process of pore pressure. The strain energy required to liquefy densely packed sand is 2 to 3 times that necessary to liquefy loose sand.

A prepared discussion was given by Dr. M. Yoshikawa of Okumura Corporation. He described a hybrid experimental technique developed for measuring soil-structure interaction. The non-linear restoring force characteristics of a soil-structure system were measured experimentally and both radial damping and virtual mass effects were calculated analytically. The problems of surface footing, embedded footings and caissons were studied successfully with this technique.

The session was opened to the final round of floor discussions. Mr. A. Clark of MTS said that it would be very interesting to compare the results of on-lined tests by Dr. Katada with those of some large-scale structural pseudo-dynamic tests. The main source of errors in on-lined and pseudo-dynamic tests is considered to come from the difference in the damping factor and stiffness between a computer model or a model on a test rigs and a corresponding prototype. Dr. K. Konagai of the University of Tokyo argued that the on-lined system reported by Dr. Katada would not work for multi-layered ground because the system needs many specimens.

## CLOSING

On completion of this floor discussion, the chairperson, Professor Kimura, thanked all the attendants for their active participation to the discussion and closed the session.

## CONCLUDING REMARKS BY THE COORDINATOR GROUP

The coordinators of this session were Prof. K. Takanashi of the University of Tokyo, Mr. Y. Goto of Ohbayashi Corporation and Dr. M. Nakashima of Kobe University. They have the following concluding remarks.

Time allocated to this session at first was two hours but later the Coordinating Committee for Special Theme Sessions allowed the session to have some flexibility. Then, the coordinator group decided to invite several people to present prepared discussions on the topics relevant to each subsession. Altogether the session had four prepared discussions. The contents of these discussions were generally reasonable and one of them gave a good lead to subsequent floor discussions.

The coordinator group, however, felt doubtful about the advantage of inserting the prepared discussion between the presentation of main papers and floor discussions because floor discussions were mostly directed towards the S.O.A. report or main papers. The prepared discussions apparently cut the smooth flow into floor discussions.

One further reflection the coordinator group had was the lack of discussions by research workers dealing with different topics. The coordinator group had expected to have fierce discussions between 1g shaking table tests supporters and the centrifuge research group. Another opportunity seems to have to be sought for.