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

doi:10.3233/978-1-61499-656-9-3259

TC 3 workshop – Geotechnical aspects related to foundation layers of pavements and rail track

TC3 atelier – Aspect géotechniques concernant les couches de fondations de chaussées et de plateformes ferroviaires

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1 INTRODUCTION

This workshop was hosted by the Japanese members of TC3, Dr. Y. Momoya (core member) and Dr. N. Yoshida with the supervision of Professor F. Tatsuoka, which cooperates in several occasions with other members on the TC3 related activities. To cover the scientific and technical aspects related with the theme of this workshop "Geotechnics aspects related with foundation layers of pavements and rail tracks" TC3 members were invited to participate, as well as other international experts, as the chairmen of TC6 and TC8, Prof. E. Alonso and Dr. S. Saarelainen, respectively.

This workshop covered one of the terms of references of the TC3 "Geotechnics of Pavement" defined for the period 2001-2005. It was a very successful workshop with an attendance of around 60 participants, showing a great interest of soil mechanics and geotechnical engineering community in this area.

2 PROGRAM OF THE WORKSHOP

September 13, Tue., 13:30-15:00 Room 1009 (10F)

13:30 Opening Remarks
F. Tatsuoka; A. Gomes Correia
13:35 Pavement and rail track foundations

"Soil mechanics aspects in pavement and rail track foundations", by *A. Gomes Correia, Department of Civil enginnering, University of Minho, Guimarães, Portugal.*

"The effect of relative humidity on the deformation and strength of granular aggregates", by *E. E. Alonso, Department of Geotechnical Engineering and Geosciences, UPC, Barcelona, Spain.*

Frost heave design of pavements, by *S. Saarelainen, VTT Building and Transport, Finland.*

"Frost design method for roads and railways. State of the art in France", by *C. Mauduit, Laboratoire Régional des Ponts et Chaussées, Nancy, France.*

"SUPERTRACK: SUstained PErformance of Railway TRACKs", by *A. Modaressi, Ecole Centrale Paris, France (in behalf of A. Kaynia, Norwegian Geotechnical Institute, Norway, and D. Clouteau, Ecole Centrale Paris, France).*

"Shakedown theory and its application to pavement analysis and design", by *H. S. Yu; H. Li & S. Juspi, Nottingham Center for Geomechanics, University of Nottingham, UK.*

"Influence of impact load on base course and subgrade by circulation", by *Y. Shioi (Hachinohe Institute of Technoloy, Japan), T. Sakai (Applied Research Co, Ltd.)*

14:20 Continuous compaction control

"Roller-integrated continuous compaction control (CCC)", by *D. Adam, Institute for Soil Mechanics and Geotechnical Engineering, Technical University of Vienna, Austria*

14:30 Reinforcement of pavement

"Reinforcement of pavements with steel meshes and geosynthetics - the COST 348 REIPAS action", by H. Rathmayer (VTT - Technical Research Centre of Finland; VTT - Building and Transport, Geoengineering, Finland)

14:40 Influence of considering principal stress rotation in modeling and how it affects pavement and rail track performance.

"Effects of continuous principal stress axis rotation on the deformation characteristics of sand under traffic loads", by *Y. Momoya, K.Watanabe, E.Sekine, M.Tateyama (Railway Technical Research Institute, Tokyo, Japan), M. Shinoda (Integrated Geotechnology Institute Limited, Tokyo, Japan), F. Tatsuoka(Tokyo University of Science, Chiba, Japan)*

"Development and performance evaluation of multi-ring shear apparatus", by *T. Ishikawa and S. Miura (Hokkaido University, Sapporo, Japan) & E. Sekine (Railway Technical Research Institute, Tokyo, Japan)*

"Development of rut depth prediction model considering deformation of asphalt layer and subgrade", by *T. Kanai(Graduate School of Science and Engineering, Department of Civil Engineering, Chuo University, Tokyo, Japan), S. Higashi (Technical Research Institute, Kajima Road Co. Ltd., Tokyo, Japan), K. Matsui (Department of Civil and Environmental Engineering,Tokyo Denki University, Saitama pre., Japan), K. Himeno (Department of Civil Engineering, Chuo University, Tokyo, Japan).*

Other contributions were also submitted to this workshop but not presented orally, such as:

"The effects of shear stress reversal on the accumulation of plastic strain in granular materials under cyclic loading", *by S.F. Brown, Nottingham Centre for Pavement Engineering, University f Nottingham.*

"Current state of the use of recycled materials in geotechnical works in Portugal", *by E. Fortunato & F.P Santayana, Laboratory of Civil Engineering-LNEC, Lisboa, Portugal*

All of these previous contributions, and other relevant to TC3 2001-2005 activities will be published in Gomes Correia et al, 2006.

3 SUMMARY OF THE PRESENTATIONS

The openings remarks were addressed by Prof. Tatsuoka expressing several interesting technical issues of the topic and also of the TC3 activities in the framework of ISSMGE. He pointed out important roles of geotechnical engineering in the design of foundation layers of pavements and rail track. Two short remarks from laboratory experiments: (1) with a Chiba gravel (D_{max}= 38 mm, D_{50}= 3.5 mm and U_c= 12.75), essentially zero effects of loading frequency in the range of 0.002 to 10Hz on the Young Modulus obtained have been observed in cyclic triaxial tests with a axial strain amplitude less than 0.001%; (2) in the laboratory, uniform sand (Ticino sand) exhibited nearly the same elastic shear modulus at shear strains less than about 0.001 % in static (i.e, slow monotonic loading & cyclic loading-CL) triaxial tests and dynamic (resonant column) torsional tests (i.e., fast CL tests). On the other hand, the degradation curve of shear modulus with an increase in the shear strain differs among these different test methods, which was not due to static and dynamic loading modes of loading but it was due to different shear modes and different numbers of loading cycles. Prof. Gomes Correia, thanks Prof. Tatsuoka, Dr. Momoya and Prof. Yoshida to host this international workshop and all the speakers, as well the numerous participants at the workshop. Then, he presents the TC3 activities during the period of 2001-2005, which are reported in Gomes Correia, 2006. Afterwards, Dr. Momoya runs the workshop calling each speaker to do its presentation.

3.1 *Pavement and rail track foundations*

3.1.1 *Soil mechanics aspects in pavement and rail track foundations, by A. Gomes Correia*

This presentation emphasis the importance to move from empirical approaches to mechanistic approaches applying soil mechanics framework at different levels: (1) material characterization of soils and aggregates, mainly in the small strain range and applying non saturated behaviour concepts developed in TC6. He also stressed the importance of non linear stress-strain behaviour which may conflict with simplified assumptions in the past – in this respect the use of resilient modulus was discouraged; (2) construction, mainly in respect to compaction technologies and quality control by using continuous compaction control and mechanical parameters in behalf of only index parameters; (3) modelling and design, mainly taking into account stress-strain-number of cycles relationships integrating the use of incremental damage in pavement design and shakedown concept related with the serviceability design to permanent deformations. Some future research needs were identified related with (1) the peculiar behaviour of very dense unbound granular materials (UGM), (2) the laboratory experimental differences of dynamic and cyclic stiffness of UGM at very small strains, (3) the prediction of permanent deformations for a very large number of cycles (> 10^6 cycles) and shakedown concept. Finally an attention was also oriented to the environmental aspects, mainly to soil improvement/stabilisation, reinforcement and the use of processed materials (non traditional and waste materials in road construction).

3.1.2 *The effect of Relative Humidity on the deformation and strength of granular aggregates, by E.E. Alonso*

This contribution, from the chairman of TC6, is an important input to TC3 activities. The presentation highlight very interesting experimental and modelling work to describe phenomenological behaviour of rockfill materials which are known to deform volumetrically when they become flooded under stress. The main outputs of this presentation were summarised as follow: (1) stress and total suction are the controlling variables of rockfill mechanical behaviour. Both control the rate of crack propagation in particles; (2) rockfill testing with Relative Humidity (RH) control has shown that a number of mechanical properties directly depend on total suction: Compressibility, collapse strains upon wetting, time-dependent behaviour, dilation upon shearing and peak deviatoric strength in triaxial tests; (3) a conceptual model was proposed, which explains the fundamentals of the dependence of rockfill behaviour on total suction. It is consistent with the tenets of subcritical crack propagation in loaded particles; (4) constitutive models have been developed within the framework of strain hardening and work hardening plasticity; (5) some additional aspects of rockfill behaviour were explored, such as the scale-dependent behaviour; (6) additional work is being performed on additional topics: time dependent behaviour, cyclic loading, other rockfill materials, fracture behaviour at particle level.

The trends of behaviour outlined above were established for an indurated quartzitic slate. Current research includes the development of models for time-dependent phenomena, the effect of cyclic loading under RH control and the testing of aggregates of different mineralogical and petrophysical characteristics.

3.1.3 *Frost heave design of pavements, by S. Saarelainen*

This contribution, from the chairman of TC8, is also an important input to TC3 activities, as well as the next one developed in France. The presentation, based in the Finland experience, shows that: (1) the frost heaving of pavements at a given location can be designed on the basis of local freezing index, frost heave coefficient and thermal characteristics of the pavement layers; (2) the local frost heave coefficient at a location may be determined by back-calculation from frost heave observations at site or estimated indirectly from clay content of the subgrade soil or directly with laboratory frost-heave testing of specimen from the site; (3) the allowable frost heave is determined according to the damage risk of the pavement and (4) no frost heaving is allowed from railway tracks.

3.1.4 *Frost design method for roads and railways. State of the art in France, by C. Mauduit*

The presentation summarises the national practice in design of roads and railways against frost. The verification of frost/thaw behaviour is done by assuring that frost index allowed (IA) is equal or greater than the frost index for a reference winter (IR). IR is dependent of the road manager policy and IA dependent of structure and calculated in five steps: (1) frost susceptibility of the subgrade; (2) mechanical analysis; (3) Quantity of frost allowed at the formation level; (4) thermal protection from the pavement, above the capping layer; (5) determination of the allowed atmospheric index. Current research involves validation and optimization covering 4 main topics: (1) frost behaviour of soils and materials; (2) thermal modelling; (3) mechanical approach and (4) reference frost indexes.

In which concerns railways a modernization of frost design method is under development by the LCPC network.

3.1.5 *SUPERTRACK: SUstained PErformance of Railway TRACKs, by A. Modaressi*

This presentation reported information about a European research project "SUPERTRACK" performed under the 5th Framework Program - GROWTH, taking place from July 2002 -July 2005 (*www.supertrack.no*). The main problem involved with high-speed lines is the fact that they experience more deterioration/settlement than traditional lines. The result is considerable maintenance and consequently costs. The outputs of this project will contribute to: (1) better understanding the behaviour of ballast and subgrade soil material through numerical and experimental studies and in situ measurements and (2) effectiveness of various grouting techniques for retrofitting existing weak areas.

3.1.6 *Shakedown theory and its application to pavement analysis and design, by H. S. Yu; H. Li & S. Juspi*

The presentation covers: (1) shakedown concept of plasticity theory; (2) analytical solution (lower bound); (3) linear programming method (lower bound); (4) nonlinear programming method (upper bound) and (5) experimental validation. This concept seems to be very promising to be used in the verification of the serviceability limit state of pavements and rail tracks concerning permanent deformations.

3.1.7 *Influence of impact load on base course and subgrade by circulation, by Y. Shioi & T. Sakai*

The presentation reports the records of impact wave, breakage of aggregate of base course and mechanism of bearing capacity of subgrade. The quick increase damage of pavement was pointed out after occurrence at the pavement surface of some cracks or corrugations. The main cause being unexpectedly great impact waves with very short periods which break down not only the surface layers, but also break down aggregates of base course and bring excess of pore water pressure of subgrade. In this context the abrasion test of aggregates may be requested. For railways, the impact waves from trains can induce the phenomena of mud pumping of ballast beneath rail and sleeper. The results obtained with a seismograph for high cyclic waves show: (1) that using the same truck, empty or loaded, the measured accelerations by a step of 25mm were nearly the same and (2) the values of acceleration and predominant period were smaller than the expected. At the end it was stressed that for the long life of pavement, the aggregate in the subgrade shall be composed of hard stones and be very well compacted in order to have good performance under heavy loads expected in future.

3.2 *Continuous compaction control - Roller-integrated continuous compaction control (CCC)", by D. Adam*

This topic was one of the main outputs of TC3 (2001-2005) producing a pre-standard in order to promote the use of CCC (Adam, 2006). During this presentation it was stressed that the conventional methods of compaction control for earthworks, roads and railways are not sufficient any more for high quality projects. The continuous compaction control (CCC) represents an improvement which is based on the measurement of the dynamic interaction between a dynamic roller and materials (soil, aggregates and stabilized materials, as well as non traditional materials, including waste materials). Accordingly, control data are already available during the compaction process. These data have to be calibrated by means of representative conventional tests. The sophistication achieved recently focuses on the way of roller operating during compaction. Comprehensive field tests have disclosed that the correlation between dynamic compaction values (CMV, OMEGA, Evib, etc.) depends strongly on the contact between roller drum and surface of the layer being compacted. Consequently, no generally valid correlation to conventional properties (modulus of load plate tests, Proctor compaction degree e.g.) can be obtained. But a clear correlation does exist, if the specific material and roller operation are taken into account. As a final conclusion it was pointed out that the method does not only improve the quality assurance but facilitates also an optimisation of the compaction equipment and process; furthermore it serves for detailed documentation, as it was already proved in several countries: Central and Northern Europe (Austria, Germany, Sweden etc.) and Western Europe (France, Spain and very recently in Portugal, etc.).

3.3 *Reinforcement of pavements with steel meshes and geosynthetics - the COST 348 REIPAS action, by H. Rathmayer*

The presentation summarises the development work for reinforcement of pavements and structures in the COST 348 REIPAS action. The COST 348 action is taking a step towards practicable guidelines for the structural design and execution of reinforced pavements and road sub-bases and to reach a consensus on the methods to determine relevant material parameters essential for analysing or predicting the behaviour of the reinforced structures. Design approaches developed either for the utilization of geosynthetic reinforcement materials or for the utilisation of steel grids are referred. Besides the long experience with pavement reinforcement in Europe (for geosynthetics > 40 years, for steel reinforcement > 2 decades) some drawbacks were pointed out: (1) pavement reinforcement is still not recognised as a solution at the same level with conventional methods. This is to a large extent due to the lack of technically sound models for the function mechanisms of the reinforcement and proper non product related design models. (2) Currently general road design is to a large extent based on semi empirical methods and this complicates the inclusion of new materials and methods. COST 348 REIPAS action will contribute to overcome some of these problems.

3.4 *Influence of considering principal stress rotation in modeling and how it affects pavement and rail track performance.*

3.4.1 *Effects of continuous principal stress axis rotation on the deformation characteristics of sand under traffic loads, by Y. Momoya, K.Watanabe, E.Sekine, M.Tateyama, M. Shinoda, F. Tatsuoka*

This presentation pointed out the importance of principal stress axis rotation on the deformation characteristics of sand under traffic loads. To investigate the effect of principal stress rotation, a new elemental test apparatus to control the principal stress axis under plane strain condition was developed. By using the new test apparatus, the residual strain of sand under following four stress conditions were compared: (1) the cyclic loading without principal stress axis rotation; (2) principal stress axis rotation under railway track; (3) principal stress axis rotation under compaction roller; (4) principal stress axis rotation along Mohr's circle. It was reported that the degree of principal stress axis rotation has significant effect on the residual deformation characteristics under cyclic loading. In particular, in the case with "principal stress axis rotation along Mohr's circle", the residual strain became largest although the magnitude of principal stress was kept constant. It was concluded that the rotation of principal stress is the dominant factor to predict the residual deformation under traffic loads.

3.4.2 *Development and performance evaluation of multi-ring shear apparatus, by T. Ishikawa, S. Miura, E. Sekine*

This presentation shows a new interesting testing method to examine the effects of the rotation of principal stress axes on cyclic plastic deformation of railroad ballast, not allowed by cyclic triaxial tests. The performance of this new tests "Multi-ring shear apparatus" by comparison with hollow cylinder torsional shear test shows its capability as a torsional simple shear testing apparatus of granular materials. The new tests reveal to be appropriate for simulating the actual stress state of railroad ballast under train loads, since it can evaluate the effect of principal stress axis rotation on cyclic deformation characteristics of granular materials. Furthermore, tests results show that axial strains in tests with principal stress axis rotation are larger than those in tests without principal stress axis rotation. Accordingly, the principal stress axis rotation has a significant effect on cyclic deformation characteristics of railroad ballast. These results lead to the conclusion that the newly developed multi-ring shear test is appropriate for simulating the actual stress states inside substructures under train loads. However, further research is needed to clarify: (1) How much is the rotation angle of principal stress axis inside actual railroad ballast during train passages? (2) How does the principal stress axis rotation influence cyclic deformation characteristics of granular materials?

3.4.3 *Development of rut depth prediction model considering deformation of asphalt layer and subgrade, by T. Kanai, S. Higashi, K. Matsui, K. Himeno.*

This presentation addressed a predict model of rutting depth considering deformation in asphalt layer and subgrade as dominate components in the whole rutting depth. This prediction model was applied to several test data in literature to compare calculated rutting depth with measured ones. Then, it was possible to conclude that the developed model was found so reliable that the predict values could agree with measured ones.

All these presentations were followed by very stimulating discussion interplayed by the participants, showing the interest of the topic and encouraging the continuation of TC3 activities.

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