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Technical session 1e: Analysis

Séances techniques 1e: Analyse

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1 INTRODUCTION

Technical Session (TS) 1e entitled 'Analysis', is comprised of a total of thirty papers addressing a wide range of applications under different topics. This general report of TS 1e can be devided into two major parts. The first part provides a review of all the papers involved in the session by classifying them into eight groups. The second part lists five topics which will be discussed at the session by the panelists. The references for the papers submitted to TS 1e are shown in italics to distinguish them from other published papers.

2 REVIEW SUMMARY OF THE PAPERS

The thirty papers listed in Table 1 were receivied for review; they are classified into the following eight groups according to their contents of study.

- Group A: Constitutive models and their applications
- Group B: Bearing capacity under 2D or 3D condition
- Group C: Localized deformation in soil specimens
- Group D: Soil-structure interaction under static loading
- Group E: Seismic responses of soil/structures
- Group F: Numerical techniques
- Group G: Observed and predicted behavior
- Group H: Hydraulic fracture, flow, and drainage

2.1 *Review of the Group A papers: Constitutive models and their applications*

In this category, constitutive models are formulated to predict the behavior of structured soil including both clay and sand in a single, consistent framework. In Paper No. JA-17 by *Nakano et al.,* the Super/subloading Yield Surface (SYS) Cam-clay model is developed under the three loading surfaces found in Figure 1 to account for structure, overconsolidation, and anisotropy. In the model, sand and clay are clearly discriminated from each other such a way that sand will show a rapid decay in structure, but its loss of overconsolidation will be extremely slow. On the contrary, clay requires a great deal of plastic deformation to produce any structural decay, but its loss of overconsolidation will be relatively rapid.

Both the compaction/densification of sand and the large-scale compression of clay under a repeated drained shearing load and the resultant decay of the skeleton structure are explained in the paper through laboratory tests and *in situ* observations based on the SYS Cam-clay model. The model is also applied in Paper No. JA-18 to an analysis of the bearing capacity of naturally deposited clay, and its results are reviewed in the subsequent section amidst a discussion on the competing numerical methods used to evaluate the bearing capacity.

Paper No. JA-15 by *Hinokio et al.* alternatively incorporates the subloading concept into the t_{ij}–clay model originally developed by Nakai *et al.* (Nakai and Matsuoka, 1986). This paper is referenced in detail in the review of Group C papers, namely, Section 2.3, in which the localization within the soil specimen is discussed under the application of the model.

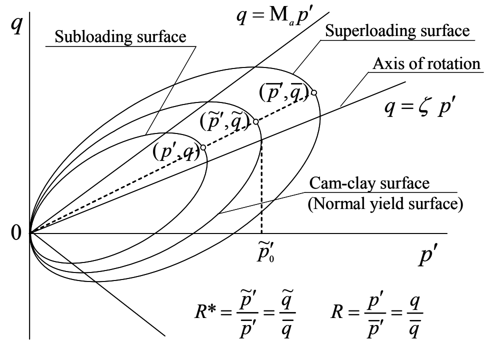


Figure 1. Three loading surfaces (*Nakano et al.*)

As contrasted with the SYS Cam-clay model, the Sydney Soil Model (SSM) is proposed in Paper No. AS-13 by *Carter and Liu* to simulate the behavior of clay and sand, including calcareous clay and sand which deform under both drained and undrained conditions, in conventional triaxial tests and true triaxial tests, where the differences between the clay and the sand, are the curvatures of the intrinsic compression line, the elastic compression line, and the additional voids ratio compression line. They can all be incorporated into a single model by allowing the soil to possess material dependent compression lines. A detailed description of the model can be found in the references (Liu and Carter, 2004).

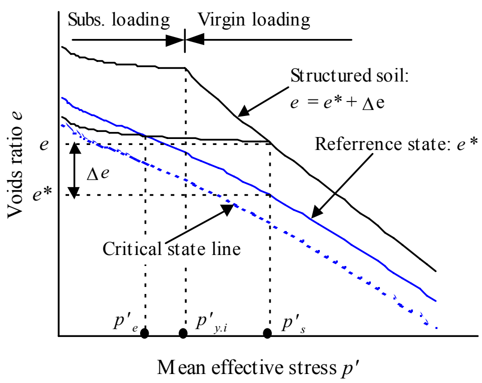


Figure 2. Compression behavior of soil (*Carter and Liu*)

Table 1. Classification of the TS 1e papers into eight categories

Group A: Constituive models and their applications

JA-17	M. Nakano, A. Asaoka, K. Nakai, M. Tashiro	Large-scale occurrences of soil compression due to decay of soil skeleton structure during repeated loading under drained conditions
AS-13	J.P. Carter, M. D. Liu	Some applications of the Sydney soil model
SR-02	U.G.A. Puswewala, M.A.K.M. Madurapperuma	Numerical implementation of a constitutive model for soil creep
UK-28	H.-S. Yu, Y. Yang, X. Yuan	Application of noncoaxial plasticity models in geotechnical analysis

Group B: Bearing capacity under 2D or 3D condition

JA-16	S. Kobayashi	Mechanics and mathematics of rigid-plastic analysis - From the point of design methods -
US-10	M.D. Evans, D. V. Griffiths	3D finite element analysis of bearing capacity failure in clay
JA-18	T. Noda, S. Yamada	Soil-water coupled elasto-plastic analysis on bearing capacity of foundation on naturally deposited clay soil
JA-20	S. Sreng, K. Uenno, A. Mochizuki, X. Ma	Image analysis and a new elasto-plastic FE analysis on deformation behavior of sand under shallow foundation
US-59	M. Zhu, R.L. Michalowski	Bearing capacity of rectangular footings on two-layer clay
RU-03	V.G. Fedorovsky, N.V. Vorobyov	Bearing capacity of strip footing on cohesionless soil base under inclined eccentric load

Group C: Localized deformation in soil specimen

JA-15	M. Hinokio, T. Nakai, M. Miyata	Numerical analysis for localized deformation in clay specimens using subloading tij model
IL-02	C. O'Sullivan, J.D. Bray	Use of DEM to analyse incremental strains along localizations in granular materials

Group D: Soil-structure interaction under static loading

AU-07	F. Scharinger, H.F. Schweiger, V. Galavi	FE-analysis of deep excavations in lacustrine clay with different constitutive models
UR-05	M.P. Doubrovsky, M.B. Poizner, D.K. Kalichava, Y.V. Kuzmenko, A.V. Kaluzhniy	Assessment of soil lateral pressure depending on retaining wall displacements
US-16	J. Huang, J.G. Collin, J. Han	3D numerical modeling of a geosynthetic-reinforced pile-supported embankment - Stress and displacement analysis
RU-11	V.N. Paramonov, K.G. Shashkin, V.A. Vasenin	Overall regularities of soil-structure interaction
UK-22	M. Rouainia, A.C.H. Chan, P.F.C. Ng	Finite element analysis of soil-pipeline interaction under lateral and uplift loading
FR-10	O. Thépot, R. Frank	Study in small deformation of the interaction between a shallow foundation and a buried pipe

Group E: Seismic response of soil/structures

MA-02	L. Dimitrievski, S. Tomov	Earthquake analysis on 12-story building in Ohrid - Macedonia with Plaxis software
IN-11	B.K. Maheshwari	Linear and nonlinear seismic analysis of layered soil stratum
IR-08	T. Akhlaghi, A. Nakhodchi	Investigation of dynamic response of cantilever retaining walls using FEM

Group F: Numerical technique

BR-03	M.M. Farias, T. Nakai, R.D. Durand	Analysis of an excavation with soil nails using embedded finite elements and advanced constitutive models
ME-01	E. Rojas, M. Arroyo, J. Arzate	The process of soil cracking and faulting
JA-19	T. Setsuyasu, S. Arimoto, A. Murakami	Applicability of meshless method to soil-water coupled problem

Group G: Observed and predicted behavior

AS-17	B. Rankine, N. Sivakugan, V. Wijeyakulasuriya	Observed and predicted behaviour of clay foundation response under the Sunshine motorway trial embankment
BA-02	A. Siddique, A.M.M. Safiullah, M.A. Ansary	An investigation into embankment failure along a section of a major highway
SL-01	P. Žvanut, J. Logar, B. Majes	Back analyses of anchored bored-pile walls

Group H: Hydraulic fracture, flow and drainage

IR-04	S.A. Sadrnejad	Numerical investigation of hydraulic fracture in saturated cohesive body
PL-04	E. Koda, E. Wienclaw	Flow and transport modeling in old landfill subsoil with vertical barrier
AS-05	K.S Rankine, N. Sivakugan	A 2-D numerical study of the effects of anisotropy, ancillary drainage and geometry on flow through hydraulic fill mine stopes

Two other papers which deal with the creep model and non-coaxial modeling fall within Group A. In Paper No. SR-2 by *Puswewala and Madurapperuma*, a differential form of the 1D creep model proposed by Bjerrum in 1967 is extended to a multi-dimensional state of stress and strain by incorporating the concepts of visco-plasticity in order to account for both the volumetric creep strain and the deviatoric creep strain. The model is applied to complicated foundation-soil interaction problems involving the creep of soil under a flexible uniform load on the soil layer. The sensitivity of various parameters on the numerical performance of the model is also investigated.

Paper No. UK-28 by *Yu et al.,* deals with the non-coaxiality between principal stress levels and principal plastic strain rates during principal stress rotation on the plastic flow of granular materials. Recent experimental studies using a hollow cylindrical apparatus show that principal stress rotation causes significant deviations between the directions of the principal stress and the principal plastic strain increments (Gutierrez and Ishihara, 2000), and several models have been proposed to consider the non-coaxial response. Models to be addressed in this paper are by Harris (1993) and Rudnicki and Rice (1975). The application of these two non-coaxial plasticity models to the prediction of simple shear tests and footing settlements is presented along with a comparison of coaxial predictions. Simple shear behavior and footing settlement problems which involve strong stress rotation are analyzed using the finite element program and an 8-noded element with a reduced integration under the Mohr-Coulomb and Drucker-Prager yield surfaces with the associated and the non-associated flow rules to validate these two models in their responses. The numerical results suggest that for a given load, the predicted deformatioin when using a non-coaxial model is larger than that when using a conventional, coaxial model. This causes signficant implications in the geotechnical design involving granular soil, in which the design is usually controlled by the deformation rather than by the limit loads. Full details of the contents can be found in Yang and Yu (2004).

Other certain constitutive models are also introduced to solve several types of problems, for example, the MMX model based on the double yield surface for Paper No. JA-20 in Group B, an isotropic double hardening model and a multilaminate model for Paper No. AU-07 in Group D, the Advanced Linear Interpolation Model (ALIM) model for Paper No.UK-22 in Group D, and the Hierarchical Single Surface (HiSS) model for Paper No. IN-11 in Group E. Their applications are described in the sections related to each group.

2.2 *Review of the Group B papers: Bearing capacity under 2D or 3D conditions*

Group B covers the numerical strategies for evaluating the bearing capacity of the different shapes of the foundations for the soil stratum under 2D/3D conditions and inclined loading, which are classified into two categories, namely, the elasto-plastic (US-10 by *Evans and Griffith*; JA-18 by *Noda and Yamada*; JA-20 by *Sreng et al.*) and the rigid-plastic methods (JA-16 by *Kobayashi*; RU-03 by *Fedorovski and Vorob'ev*; US-59 by *Zhu and Michalowski*). For the former category, the elasto-plastic finite element analysis has been utilized to evaluate the bearing capacity, particularly for the practical design of soil structures in which the initial stress levels and the boundary conditions may significantly affect the solutions. Paper No. JA-16 by *Kobayashi* provides a clear classification among the different rigid-plastic methods from a theoretical point of view, as summarized in Table 2, and insists on the benefit of the rigid-plastic finite element method, while reviewing the mathematical structure of the limit analysis.

Table 2. Classification of various rigid-plastic methods (*Kobayashi*)

	MC	LE	LA	
			UB	LB
Equilibrium	○[*1]	△[*2]	×	○
Stress boundary cond.	○	○	×	○
Yielding cond.	○[*1]	△[*3]	×	○
Compatibility	×	×	○	×
Velocity boundary cond.	×	×	○	×
Associated flow rule	×	×	○	×
Solution	L[*1]	?	U	L
Convergence	≈T[*4]	?	T	T
3 dim. problems	×	○	○	○
Complicated geometry or strength distribution	×	△	○	○

L: Lower bound value, T: True value, U: upper bound value

*1: Incompleteness due to no check in the rigid zone.
*2: Insufficiency, partly satisfied
*3: Insufficiency, no check in each blocks
*4: Incompleteness due to no check in the rigid zone

In Paper No. US-10 by *Evans and Griffith*, the results of Mohr-Coulomb, elasto-viscoplastic, bearing capacity analyses are performed using a finite element code running on massively parallel computers. Square, rectangular, and strip footings are considered in these analyses to determine the bearing capacity factors and to compare the determined values to those in the literature. The bearing capacity factors and the failure mechanisms were investigated for weightless cohesive soil. The bearing capacity factor for the square footings determined in this study, N_q, was closed to the theoretical values for smaller friction angles, but was 15% to 25% lower for larger friction angles. The failure mechanism for the rectangular footings is observed to be strongly dominated by the long sides of the footings. This point should come as no surprise, and it is clearly illustrated in this paper.

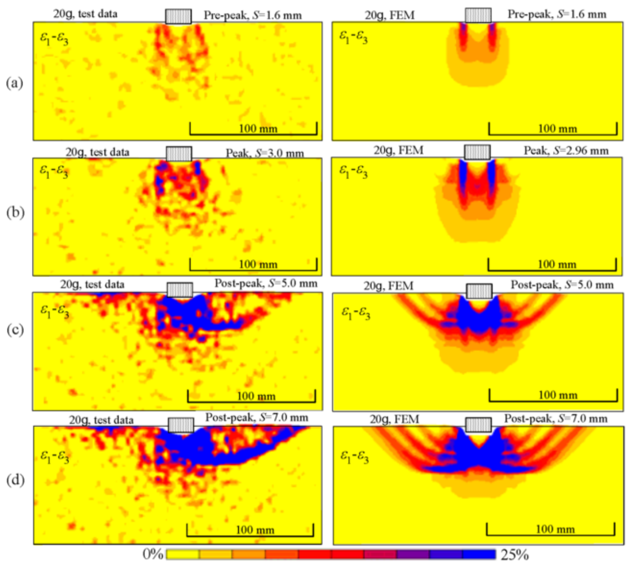


Figure 3. Measured and calculated displacement distribution for a 20g loading test on a dense Toyoura sand (*Sreng et al.*)

Paper No. JA-18 by *Noda and Yamada* describes a soil-water coupled finite deformation calculation (Asaoka *et al*., 1994) of the bearing capacity of a naturally deposited and highly structured clay soil, performed with an elasto-plastic model, that explains the soil skeletal mechanisms of the structure, overconsolidation, and anisotropy (Asaoka *et al.*, 2000, 2002). The influence of the soil structure, the anisotropy, the initial imperfection in the geometrical shape, and the loading rate on the calculated bearing capacity is numerically discussed.

Paper No. JA-20 by *Sreng et al.* presents the loading tests for a shallow foundation on a sand deposit under a centrifugal force field of 20g using a model with a footing width of B_0 and measuring 20 mm, while the measuring deformation profile of sand through a newly developed image analysis method is referred to as the CCIP (Cross Correlation and Isoparametric) method, as seen in Figure 3. The feature of the CCIP method is that there is no need to install the target in the sand model, and it is available for measuring the deformation with high accuracy (errors are within 0.2 pixels). The following points were observed from the image analysis: (1) As for the behavior at the pre-peak, a bulb-shaped equi-displacement zone formed with an active wedge beneath the foundation in the sand ground. Zones with a high shear strain of over 15% developed underneath both edges of the foundation. (2) At the peak, the deformation behavior was concentrated more in a vertical direction and formed shear bands along the fringe of the active wedge. It is noticed that at this stage the slip line in the passive zone was not yet observed. (3) At the stage after the peak, a slip line in the passive zone was clearly observed.

Apart from the elasto-plastic analyses listed above, rigid-plastic analyses allow for rather rigorous evaluations of the bearing capacity under the different-shaped foundations and inclined loading based on their theoretical backgrounds. In Paper No. JA-16 by *Kobayashi* insists on the advantage of the rigid-plastic finite element method (RPFEM) among the different methods within this category after classifying them for rigid-plastic analyses and reviewing the mathematical structure, and develops the hybrid type of RPFEM based on the interior point method while examining the bearing capacity problem of a shallow foundation under uniform inclined loading.

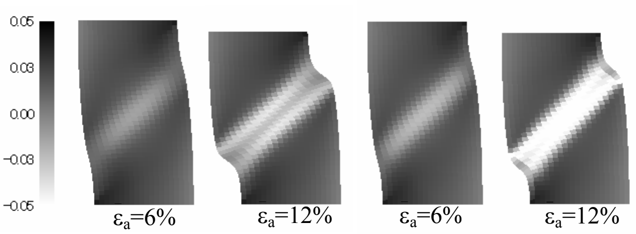
Paper No. US-59 by *Zhu and Michalowski* presents a 3-D finite element analysis of square and rectangular footings over a two-layer clay foundation soil, where a weak clay is overlaid by a strong crust. A parametric study on the bearing capacity was carried out for a range of aspect ratios (*L/B*), the soil strength ratio (c_1/c_2), and the depth ratio (*H/B*). The results are presented in terms of bearing capacity coefficient N_c* and shape factor s_c*. It is found that the limit load is affected by both the depth of the weak layer and the ratio of the strengths of the two layers. However, the shape factor appears to be only weakly dependent on the depth ratio, whereas it varies distinctly with a changes in the strength ratio of the two layers.

Paper No. RU-03 by *Fedorovski and Vorob'ev* describes a solution to the problem of stability for a plate on a cohesionless soil base. The required mathematical tools for solving this problem are the Kötter equation for stress levels along the slip-line and Boussinesq equations for the cohesionless wedge limit equilibrium. This solution generalizes the known Lundgren-Mortensen (1953) solution in the same sense as the solution (Fedorovsky, 1989, 2003) generalizes the Prandtl (1920) solution for the case of a weightless cohesive soil base.

2.3 *Review of the Group C papers: Localized deformation in soil specimens*

In the Group C papers, the onset and the characteristics of localized deformation in the form of a shear band within a soil specimen are investigated in detail by both continuum and discrete approaches.

As a continuum approach, several numerical simulations of localization are carried out in Paper No. JA-18 by *Hinokio et al.* using a drained analysis for the whole section under plane strain (2D) and triaxial (3D) conditions for both normally consolidated clay and overconsolidated clay (OCR=10) specimens using an elastoplastic constitutive model for soil, namely, the 'subloading t_{ij}-model' which can properly describe the typical characteristics of soils. These include (1) the influence of the intermediate principal stress on the deformation and strength of clay, (2) the influence of the stress path on the direction of the plastic flow, and (3) the influence of the density and/or the confining pressure. Based on the comparison of the infinitesimal and the finite deformation finite element analyses, it is revealed that the finite element analysis can simulate the formation of a shear band, which is observed in actual laboratory tests, not only with the finite deformation theory, but also with the infinitesimal deformation theory, and the generation of the shear band can be explained with simple drained analyses without using soil-water coupled effects. It can also be concluded that the localization is more likely to be produced under two dimensional conditions and the isotropic hardening elastoplastic model like the subloading t_{ij} model is proven to be a useful tool for studying localization problems with the finite element analysis.



(a) Infinitesimal deformation theory **(b)** Finite deformation theory

Figure 4 Distribution of volumetric strain for 2D (OCR=10)

Paper No. IL-2 by *O'Sullivan and Bray* contains another analytical approach, also comparing 2D and 3D analyses based on the use of the distinct element method to examine the relationship between dilation along the shear band and the macro-specimen response by quantifying the incremental volumetric and shear strain levels along the localizations in dense granular materials within the specimen of the compression tests.

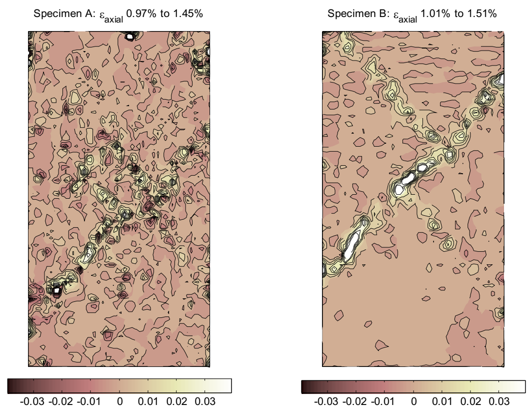


Figure 5. Contours of the incremental volumetric strain levels for dense two-dimensional specimens close to the point at which the peak stress is mobilized: Specimen A contains 5,728 disks (left) and Specimen B has 12,532 disks (right) (*O'Sullivan and Bray*)

For idealized granular materials comprised of uniform disks or spheres in regular packing arrangements, the incremental strain levels are relatively uniform along the shear band. There is also a clear correlation between the incremental volumetric strain along the localization and the macro-scale response. For irregular, non-uniform specimens, this correlation is less clear and the incremental strain levels along the localization are highly non-uniform, with both contraction and dilation being observed within the zone of localization during a single increment of axial strain.

In comparable numerical compression tests, seen in Figures 4 and 5, the first antisymmetric mode dominantly appears in the volumetric strain distribution of the specimen as a bifurcation mode with the same shape (height-to-width) ratio of 2.0. However, the relation is not clear between both apparently consistent results, even though the material properties are different from each other between the continuum and the discrete analyses and the results in Figure 4 are valid only for the overconsolidated clay specimen, not for normally consolidated soil.

2.4 *Review of the Group D papers: Soil-structure interaction under static loading*

Group D involves six papers on the analysis of the interaction between soil and a structure, e.g., soil-wall interaction, a pile-supported embankment, interaction between the subsoil and a building, and soil-pipeline interaction.

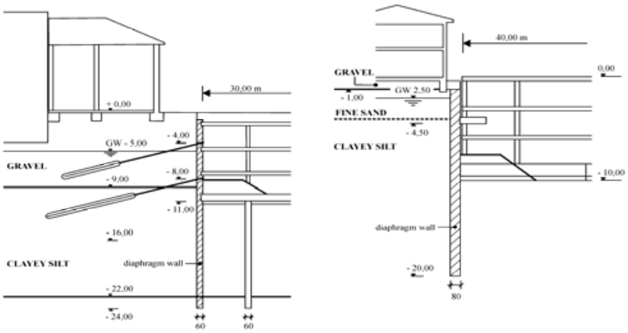


Figure 6. Layout of projects 'AMV' (left) and 'Hypobank' (right) (*Scharinger et al.*)

Paper No. AU-07 by *Scharinger et al.* presents comaparative finite element analyses of deep excavations in a soft ground in the city of Salzburg, as depicted in Figure 6. The regional subsoil situation in Salzburg can be described as fully saturated soft clay (referred to as "Seeton") overlain by a quaternary gravel fill. The poorly graded Seeton can be classified as fine silt or fine sand, and shows unfavourable soil properties with respect to the deformation behavior of the deep excavations. To describe the complex behavior adequately, advanced constitutive models have been used to analyze two different deep excavations, namely, the Hardening Soil model, an isotropic double hardening model implemented in the commercial version of finite element code, PLAXIS, and a newly developed constitutive model based on the multilaminate concept. The comparison with *in situ* measurements shows that both models are capable of representing the behavior of soft soil, at least for this type of problem.

Paper No. UR-05 by *Doubrovsky et al.* addresses structures including rigid retaining walls (dry docks, locks, quay walls and others) and buildings erected on deformed soils. To describe the behavior of the considered structures more exactly, it is proposed in this paper that the lateral pressure of soil be defined in accordance with the structure's realized deformed state. Soil pressure is considered in the interval from the pressure at rest to the pressure corresponding to the current value of the generalized displacement (in the limit - to active or passive pressure depending on directions of retaining wall moving).

In Paper No. US-16 by *Huang et al.,* a case study of a geosynthetic reinforced pile-supported embankment constructed in Germany by others was selected and a 3D numerical analysis was conducted to investigate the stress levels and the displacements of this embankment. The numerical analysis demonstrates that a simple linearly elastic perfectly plastic constitutive model can reasonably predict the performance of this embankment system as compared with the measured results. The analysis also indicates that a concentration of stress develops above the pile caps and the edge piles are subjected to large bending moments. The maximum tension in the lower geogrid reinforcement occurs between the pile caps, while that in the middle and the upper reinforcements occurs near the edges of the pile caps. A tilting of the pile caps exists in the cross-section direction to the embankment. This paper also investigates the effect of foundation soil on the stress levels and the vertical displacements above and between the pile caps, the maximum tension in the geogrid sheets, and the bending moments along the piles. Within the range of the elastic modulus of the foundation soil from 2MPa to 8MPa, the effect of the foundation soil is not significant.

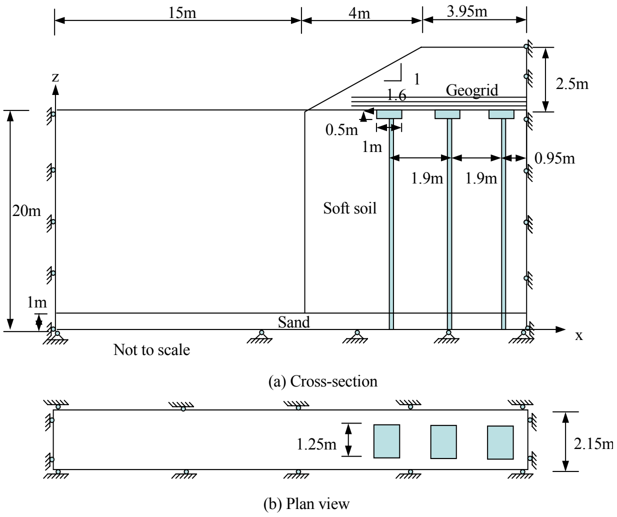


Figure 7. Design sections and model for the analysis (*Huang et al.*)

Paper No. RU-11 by *Paramonov et al.* investigates subsoil–superstructure interaction by means of changes in the stress-strain condition of the bearing elements of a building different to the stress-strain values predicted through traditional calculations for different interactions between the building and the natural subsoil, the superstructure, and the piled foundation under static and dynamic loading.

Paper No. UK-22 by *Rouainia et al.* tries to apply a particular elastoplastic model, i.e., the Advanced Linear Interpolation Model (ALIM) to the prediction of loads on a buried pipe due to the relative movements of the soil under plain strain conditions by incorporating the model into the CRISP program. The ALIM model provides a more rational prediction for the force-displacement responses than that of the conventional Mohr-Coulomb model.

Paper No. FR-10 by *Thépot and Frank* concludes that the elastoplastic model with nonlinear elasticity is highly capable of representing both the high stiffness around the pipe and the significant decrease in stiffness below the foundation through the finite element analysis and the interaction between a shallow foundation and a buried pipe.

2.5 *Review of the Group E papers: Seismic responses of soil/structures*

In Group E, the seismic responses of soil improvement with geosynthetics, cantilever retaining walls and far fields are analytically examined. Paper No. MA-02 by *Dimitrievski and*

Tomov and Paper No. IR-08 by *Akhlaghi and Nakhodchi* carry out finite element analyses for different problems.

The former paper deals with the problem of soil improvement using geosynthetics and the substitution of loose sand and soft clay with coarse gravel below a 12-story building in Macedonia. An analysis using the PLAXIS program is conducted under static as well as earthquake conditions to examine the efficiency of the geogrids.

The latter paper employs the finite element analysis, using PLAXIS software, to investigate the effects of the mechanical properties of the soil and the wall on the dynamic behavior of a cantilever retaining wall. In addition, the effects of the amplitude and the frequency of the source vibration on the response of the walls are studied and discussed. The results show that the wall displacement increases when the soil density and the amplitude of the harmonic load increase, while the dynamic response of the wall decreases with an increase in the values of the friction angle, the cohesion, the elasticity, and the damping of the soil, and the response increases when the stiffness of the retaining wall increases. It is also shown that amplification occurs when the input motions coincide with the natural period of the backfill and produce considerably permanent displacements.

In Paper No. IN-11 by *Maheshwari*, the effect of the material nonlinearity of soil on the seismic response of the free field is investigated. When the properties of soil are homogeneous in a lateral direction, a layered soil stratum can be used. However, a finite element model is required to properly account for the inhomogeneous nature of soil. The model can be used for a layered soil stratum as well as for a soil stratum in which the material properties are varying in all three directions. To introduce the plasticity of soil, two advanced plasticity-based models, namely, Drucker-Prager and HiSS (Hierarchical Single Surface) are used.

2.6 *Review of the Group F papers: Numerical techniques*

Group F is comprised of three papers concerning numerical techniques, e.g., the embedded stiffness approach, the ground loss theory, and the mesh-free method, for overcoming the difficulties in the existing methods. Paper No. BR-03 by *Farias et al.* provides the use of the embedded stiffness technique in the FEM analysis to consider the effect of reinforcements, while avoiding the mesh dependency due to a different arrangement of the reinforcements, and the dependency of the solid element type and domain discretization or a constitutive model of the solid element. Figure 8 depicts that the stiffness of the bar which intersects the solid element must be initially transformed in that of an equivalent solid, which is then added to the stiffness of the real solid element, thus obtaining a total stiffness.

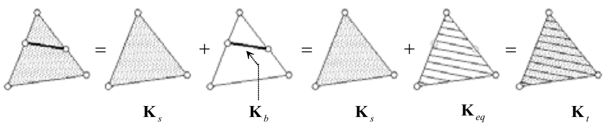


Figure 8. Illustration of the embedded stiffness approach (*Farias et al.*)

The technique is applied to the problem of soil nailing and its results emphasize the importance of the constitutive model under these conditions, mainly when the extension stress paths are predominant. It is revealed that the use of the Cam-clay model under these circumstances is highly unsafe, because the Cam-clay model overestimates the strength in addition to underestimating the soil displacements and the axial forces in the bars.

In Paper No. ME-01 by *Rojas et al.,* the process and the evolution of soil cracks due to water depletion is studied by means of the ground loss theory applied to a compressible soil over an irregular rock basement. With this procedure, the vertical and the horizontal displacements as well as the strains of the soil mass due to water withdrawal can be obtained.

This analysis shows that cracks on the soil surface may develop when the following conditions are satisfied:

1) The rock basement is highly irregular
2) Important declines in the water table are taking place
3) Soil sediments show medium to high compressibility and low plasticity.

The analysis also shows that, for a sinusoidal buried graben, surface cracks are more likely to appear close to the inflexion point. When a crack has completely developed from the soil surface to the rock basement, and a decline in the water table continues, the phenomenon may evolve into a faulting process evidenced by the presence of a growing step on the soil surface. The evolution of the step depends on the thickness, the compression factor and the plastic index of the soil layers as well as on the water extraction rate.

The so-called the mesh-free technique, e.g., the Element-Free Galerkin Method (EFG) proposed by Belytschko *et al.* (1994), is incorporated into the computation of the soil-water coupled analysis within the framework of a large deformation in order to avoid the mesh dependency on the solutions for several particluar problems. The results obtained from the numerical tests show that the use of Delaunay triangles as background cells leads to a higher accuracy of the numerical solutions than those under the usual square background cells. It is also revealed that the particular type of weight functions to be adopted in the moving least-square approximation and the density of the nodal points can determine the resultant shape functions of the EFG for both the pore water pressure and the displacement field such that they are advantageous in avoiding spatial instability in the numerical solutions of pore water pressure under the undrained conditions appearing in the patch tests.

2.7 *Review of the Group G papers: Observed and predicted behavior*

The *in situ* observed behavior during the construction of embank-ments and the installation of pile walls is examined and compared with the predictions for the papers involved in this category. The behavior of motorway or highway embankments is addressed both in Paper No. AS-17 by *Rankine et al.* and in Paper No. BA-02 by *Siddique et al.*

In the first paper, the findings of a fully instrumented trial embankment of three different sections in Area 2A of the Sunshine Motorway, South East Queensland in Australia, where two of these sections are installed with drains in a triangular grid arrangement of differing drain spacings and another section is left as a control case and no method of ground improvement is installed within it, are monitored to observe the foundation response upon loading, and the effectiveness of the various ground improvement techniques on the soft, organic clays characteristic of this region is monitored. The principal focus is to compare the numerical predictions obtained from the finite difference analysis using the FLAC code with the field data obtained during the construction phase. A sensitivity study carried out on each of the models using the coefficients of permeability back calculated from the field measurements suggest that both the vertical and the horizontal permeability values are lower than those derived from laboratory testing.

The second paper investigates the causes of the failure of an embankment along the Bhanga-Bhatiapara section of the Southwest Road Network Development Project (Contract No. 3) at 5+540 km. Using the available soil reports, additional soil investigations and survey data, a series of stability analyses are conducted for the failed section of the embankment. The investigation reveals that a very soft clay layer exists below the embankment fill. Stability analyses reveal that the failure of the embankment is attributed to the existence of this very soft subsoil layer over which the fill has been placed.

Paper No. SL-01 by *Zvanut et al.* describes that the step-by-step back analyses of four large diameter bored-pile walls with a free height ranging from 9 to 18 m and supported by prestressed geotechnical anchors in Slovenia reveals a sufficiently accurate numerical model which could be obtained in the early stages of the construction sequence. It is shown that even with the use of a simplified model the final results are very good. This makes the use of back analyses and the observational method even more attractive for practicing engineers. The FEM prediction of the behavior of another retaining wall under similar ground conditions, using suitable material parameters from previous back analyses, is in good agreement with the observed behavior.

2.8 *Review of the Group H papers: Hydraulic fracture, flow and drainage*

This group includes problems related to 1) hydraulic fracture, i.e., the process of the initiation and the propagation of cracks due to fluid pressure at relatively high flow rates in cohesive soil, 2) the groundwater flow and pollutant transport, and 3) mine drainage within a hydraulically filled stope.

Paper No. IR-04 by *Sadrnejad* presents a multi-plane elastic-plastic model to describe hydraulic fracture propagation through the application of the model to San Fernando dam failure. The finite element analysis, in which the model is incorporated, identifies two forms of failure based on the shear and the tension of the defined sample planes.

Paper No. PL-04 by *Koda and Wienclaw* presents the numerical modeling of groundwater flow and pollutant transport for an old sanitary landfill surrounded by a vertical bentonite barrier, where the leachate re-circulation system is applied. The aim of the modeling is an assessment of the vertical barrier influence on the shaping of the groundwater level in the surroundings as well as the determination of the time infiltration of the leachate in the waste body during re-circulation. The influence of the vertical barrier and the leachate re-circulation system on the shaping of the groundwater flow on the surroundings is also analyzed.

Flow and transport modeling is performed for the Radiowo sanitary landfill located near Warsaw. This object has existed since 1962, and permission for its exploitation is valid up to the end of the year 2005. Remedial works on this landfill have been conducted since 1994 and they include a vertical bentonite barrier, a leachate drainage system, a leachate re-circulation system, technological roads, and a landfill shape, mineral cover, a degassing system as well as regulations on the water relations in the surrounding area. Along the perimeter of the landfill, a one-phase cut-off wall barrier is constructed to minimize the spread of pollutants into the surrounding groundwater environment. The depth of the vertical barrier wall was 5-22m. The protection of the groundwater against leachate from the Radiowo landfill is effected by the system consisting of a cut-off wall barrier and peripheral drainage, additionaly completed by the leachate re-circulation system. The modeling results were used for the design of proper preventive measures.

Paper No. AS-05 by *Rankine et al.* utilizes the two-dimensional finite difference package, FLAC, to investigate various factors affecting mine drainage, including the effects of anisotropy, ancillary drainage, and geometry on the flow through the hydraulic fill mine stopes. Through the use of a two-dimensional model developed in FLAC, this paper illustrates that the use of ancillary drainage behind barricades is effective for accelerating the drainage process within a hydraulically filled stope. Consequently, the build-up of pore pressure behind the barricades is reduced. It was shown that the horizontal ancillary drain, provided at the bottom of the stope, reduces the pore water pressure at all points within the fill, with the reduction being proportional to the length of the drain. The ancillary drain also increases the hydraulic gradient, and the rate of flow, resulting in quicker drainage of the stope.

From the results of the numerical modeling, it is evident that the anisotropic permeability has a significant effect on pore pressure development and discharge within the stope. As the anisotropy in the permeability is increased, there is a substantial reduction in pore pressure. A number of design charts were created to quantify the effect of the varying anisotropic ratios and geometries on pore pressure and discharge within the stope.

3 TOPICS TO BE DISCUSSED BY THE PANELISTS AT THE TECHNICAL SESSION

The Technical Sessions are intended for discussions and debates on issues of importance and interest arising from the papers submitted to the proceedings. The following six main themes have been chosen from the contents of the thirty accepted papers in TS 1e to cover the subjects of the accepted papers.

1) Newly-proposed methods: analytical solutions, constitutive models and numerical algorithms formulations, performance, and validation.
2) Deformation and failure of geomaterials: strain localization and instabilities, large strain vs small strain, drained vs undrained.
3) Soil-structure interaction problems: foundations, embankments, retaining walls and underground works; ground improvement and geosynthetics, and modeling of soil-structure interface.
4) Dynamic, soil-water coupled, and environmental problems.
5) Predictions of soil-structure behavior in the field: the selection of proper constitutive models for the problems, parameter determination from laboratory and field tests.
6) Practical designs with numerical analyses, the making of design charts with numerical analyses, the direct use of numerical analyses for practical designs.

Five panelists propose that the following topics be discussed at the session as they are related to one of the chosen topics.

- Prof. M. Rouainia (University of Newcastle, UK): 'Constitutive modeling of anisotropy and destructuration of natural soils' related to Theme 1;
- Prof. P. Delage (Ecole Nationale des Ponts et Chaussees CERMES, France): 'THMC couplings in geoenvironmental engineering' related to Theme 4;
- Prof. A. Gens (Technical University of Catalonia, Spain): 'Coupled analysis for materials with double structure' related to Theme 4;
- Prof. J. Pestana (University of California, Berkeley, USA): 'Importance of objective parameter determination for constitutive soil models' related to Theme 1 or 5.
- Prof. D.V. Griffith (Colorado School of Mines, USA): 'Probabilistic methods applied to classical geotechnical analysis' related to Theme 6.

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