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Discussion leader's report: Slopes and excavations

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Ladies and gentlemen, to open this discussion session I will very briefly introduce the 24 papers forming the basis of the discussion and classify these into subject areas to give structure to the discussion. The papers are numbered 1 to 24 as follows:

1) A Asaoka et al, Stability analysis of reinforced soil structures introducing some constraint conditions upon the 3-D velocity field

2) D Asbey-Palmer et al, An innovative solution to the stabilisation of the Cairmuir landslide incorporating reinforced earth

3) S Bang et al, Deep seated stability of soil nailing walls

4) B Berardi, A design method for the reticulated pile structure for the stabilisation of slopes and excavations

5) E C Drumm et al, Instrumentation and monitoring of a nailed mine waste slope

6) M Ehrlich et al, Parametric numerical analysis of soil nailing systems

7) S Ghalib et al, Earth reinforcement applications for hazardous waste containment

8) E Guler, Comparison of different design concepts in slope stability analysis of geosynthetic reinforced slopes

9) T S Ingold and B Myles, Ballistic soil nailing

10) M J Kenny and Y Kawai, The effect of bending stiffness of soil nails on wall deformation

11) J S Kim et al, A large-scale experimental study of soil-nailed structures

12) R Kitamura et al, In-situ test of reinforced volcanic ash with steel bars and panel facings

13) M Kulczykowski, Stability analysis of reinforced slopes based on apparent cohesion method

14) D Y Lin et al, Predicting seismic performance of geogrid reinforced slopes

15) H I Ling et al, A new concept of seismic design of geosynthetic reinforced soil structures: permanent-displacement limit

16) H Matsuoka and Y Sugiyama, Failure mechanism and effective reinforcement of granular soil slope

17) R L Michalowski, Instability patterns of reinforced soil structures

18) K Nishida and T Nishigata, Reaction of reinforcing force and restrainment effect on soil nailing

19) N Sabhahit et al, Seismic analysis of nailed soil slopes - a pseudo dynamic approach

20) F Viel and A Jenne, Repairing the landslide Heroldsberg/Germany

21) M Vucetic et al, Dynamic failure of soil nailed excavation in centrifuge Vucetic...

22) R Yatabe et al, Stability analysis of slopes reinforced by root network

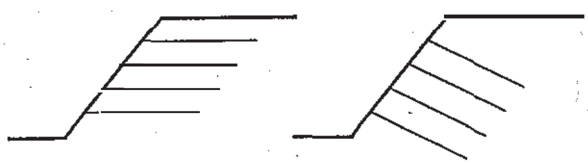
23) J M Zhou et al, In-situ test of steel nailing reinforcement for cut slope with alternating sandstone and mudstone

24) T F Zimmie and M B Mahmud, Instrumentation for centrifuge modelling of geotextile reinforced slopes

To give structure to the discussion the above papers have been divided into the two broad categories of those dealing with conventional reinforced soil, in which reinforcement is incorporated into successive layers of fill during construction, and those dealing with soil nailing.

From the point of view of internal stability this is a very important demarcation since with conventional reinforced soil the engineer has control over the quality of the fill which can be specified to have the required properties. In contrast, soil nailing has to be designed to suit the existing natural ground, or previously placed fill, which is to be reinforced. This of course requires appropriate site investigation to determine what soil or fill properties are available to the engineer.

CONVENTIONAL NAILING



	NUMERICAL ANALYSIS	1, 6, 10
4, 8, 13, 17	EQUILIBRIUM ANALYSIS	3
2, 7, 20	CASE HISTORIES	5, 9, 12, 23
16, 24	EXPERIMENTS TRIALS	11, 18, 21
14, 15	SEISMIC	19
22	NATURAL	22

The above table categorises the 24 papers as dealing mainly with conventional reinforced soil or with soil nailing. The papers are numbered as in the program and the above summary of paper titles. Under these two categories the papers are further classified as dealing mainly with numerical analysis, equilibrium analysis, case histories, experiments or trials, seismic considerations or natural reinforcement in the form of plant roots. It is interesting to note that of the 24 papers 50% are authored by academic organisations, 33% by joint academic and commercial organisations and 17% by practitioners.

Under the classification of numerical analysis, paper 1 presents a 3-D finite element analysis of reinforced soil in which the reinforcing mechanism is modelled by employing a no length change in energy functions. Unlike 2-D analysis, where reinforcement is modelled as equivalent continuous plates, this 3-D approach allows reinforcement to be modelled as linear elements.

Paper 6 presents a parametric study of the influences of construction processes including soil removal, nail and facing installation. The paper addresses important practical considerations. Paper 10 presents the results of finite element analyses and field trials of the influence of nail bending stiffness on wall deformation and concludes that bending stiffness has an insignificant effect. The trial used 23 mm diameter nails in a 45 mm diameter hole which is uncommon outside Japan. See papers 5 and 6.

Under the classification of equilibrium analysis, paper 3 considers deep seated stability of nailed slopes and particularly the effect of face slope angle where the dominant failure mode changes from deep seated failure to toe failure. This paper gives interesting pointers for future directions. Paper 4 presents a rational procedure for assessing raking piles which helps to quantify the benefits and mechanisms of a complex system.

Paper 8 presents useful design charts for geosynthetic reinforced slopes based on the Federal Highways Administration method for extensible reinforcement while paper 13 presents an analytical method in which the reinforcement is deemed to endow the soil with a pseudo cohesion. This approach may help to introduce the concept of reinforced soil into other slope stability programs where the modelling of discrete reinforcing elements difficult. Paper 17 presents a kinematical limit analysis approach based on log-spiral failure surfaces. Although this type of approach has been current for some time it has not gained wide acceptance.

Case histories were the broad topic of 29% of the papers with paper 2 which records reinforced soil used in remedial works to a huge landslide involving 8 Mm^3 of schist rock. Paper 5 recounts the use of 25 mm diameter nails in 200 mm diameter grouted holes to stabilise a mine waste slope built on a mountain slope. The design and construction of conventional geogrid reinforced slopes to retain hazardous waste are reported in paper 7 while paper 9 presents four projects completed using ballistic soil nailing in some cases complemented by no-fines concrete buttresses at the toe of the slope. Versatility of the technique is exemplified by the facility to use the nail launcher suspended from a crane, rather than mounted on a hydraulic excavator, and speed of construction by the installation of nails at the rate of one per two minutes.

Case histories continue with paper 12 which presents a large scale in-situ test on volcanic ash reinforced with steel bars and facing units. A comprehensive monitoring system was used, for more than ten months, to record the axial loads in the bars as well as climatic conditions. Paper 20 presents a remedial works case history involving the use of geogrid reinforcement in stabilising a 10 m deep cut slope which failed shortly after construction due to infiltration of heavy rainfall. Paper 23 gives an interesting account of nailing of a slope comprising alternate layers of sandstone and mudstone.

Experiments were the topic of five papers with paper 11 comparing results obtained from a 2 m high experimental nailed wall with results from finite difference analyses. Paper 16 reports the results of an interesting tilting box experiment in which the surface stability of a soil slope of progressively increasing inclination was studied using the Schneebeli plane strain technique in which soil is modelled by a mass of aluminium rods. Paper 18 recounts model tests, using a 1.5 m high wall backfilled with high density iron ore, and investigates reinforcement intensity related to induced reinforcement tensile strain.

Paper 21 presents results from centrifuge testing used to investigate the failure mechanism and seismic stability of a 7.6 m deep nailed cut slope while paper 24, also based on centrifuge testing, investigated the influence of installing strips of nonwoven geotextile into soft soil slopes to serve the dual function of reinforcement and drainage.

Paper 14 reports a finite element analysis of the seismic stability of a 15 m high geogrid reinforced slope and considers maximum relative slope displacements. Seismic design is the topic of paper 15 which, although based on conventional pseudo static analysis, introduces the concept of designing to a serviceability limit defined by the permanent displacement resulting from direct sliding instability. Paper 19 compares the results of conventional pseudo-static analysis, in which the shear wave velocity is considered to be infinite, analysis with pseudo-dynamic analysis in which the shear wave velocity is considered to be finite.

The effects of natural reinforcement, in the form of tree and plant roots, are considered in paper 22 which concludes that root systems induce an apparent cohesion which should be taken into account in assessing slope stability.

Having briefly introduced the papers comprising this session I now invite questions from the floor

Mr Stevenson of Tensar Corporation to Dr Matsuoka - Can you relate your experiment to the US practice of geogrid reinforced veneers on steep slopes. Your experiment is based on cohesionless soil whereas a veneer on steep slopes is based on cohesive soil. Nonetheless it is a very interesting concept to stabilise these veneers. Can you give design guidelines ?

Dr Matsuoka answers by thanking Mr Stevenson for his question. I am not too familiar with US practice or design but am mainly interested in the mechanisms of surface sliding. Once the mechanisms are defined then these give a basis for design.

Professor Klosek of the Technical University of Silenic asked Professor Vuceti - What is the influence of sand friction on the wall of the box and what are the differences in 2-D and 3-D models ?

Professor Klosek responded by agreeing friction is a problem. However, side friction can be eliminated by using an isolating composite, comprising two sheets of rubber with a water based gel lubricant between the two layers, installed between the walls of the box and the soil. That this eliminated friction is verified by the fact that transverse tension cracks which developed in the soil ran the full width of the box and were perfectly perpendicular to the side walls. Had there been friction between the soil and the walls then the cracks would have curved as they neared the walls of the box. I have to give credit to Professor Tatsuoka who suggested this idea.

Professor Madhav of IIT Kanpur addressed Professor Bang - You seem to have used nails of equal length. If variable length is used it seems to be optimal in terms of overall economy. Can you give your views on this type of optimisation ?

In answer, Professor Bang agreed that variable length is a parameter to be investigated because in many cases equal lengths, although convenient, do not give optimal economic performance; its just a matter of convenience and workability.

However, to optimise performance, length has to vary from top to bottom with constant variations in length and, as far as I know, workability then becomes a critical problem. Nail length might be varied in steps. For example, a block variation can be used in which a given block comprises nails of a constant length. Nail length can be varied over the height of the slope by using three or four blocks of different block nail lengths, but in terms of static and dynamic performance the length variation could be different depending on how you consider it and which one is more critical.

Professor Madhav recounted that in optimisation work he found nails around mid height longer than those at the top or bottom, do you have a similar experience ?

Professor Bang replied that longer nails in the middle makes the problem difficult to optimise and the case for longer nails in the middle would need to be studied.

Professor Chang of Oxford University asked Professor Ehrlich were the nails connected rigidly to the facing or were they unconnected ? My opinion is that nail tension would be different depending on the connection to the facing.

Professor Ehrlich confirmed that the facing was free to move and there was no connection between nail and facing. Professor Chang then stated that if there is a strong connection between facing and nail then the facing acts as though it were anchored. However, with no connection there is a difference. Professor Ehrlich responded that in the case of conventional reinforced soil there may be rotation of the facing, however, with soil nailing construction is step-wise and any movement occurs before the facing is connected. I think my results correctly model behaviour.

Dr Gurung of Hiroshima University then asked Professor Vucetic to elaborate on how the facing panel in the soil model was set to support the excavation. If I understand correctly, as the depth of the soil model increases so stress also increases. Did this produce any lateral or vertical displacements while accelerating the centrifuge from the 1G level to the 50G level before shaking the model. If yes, how did you incorporate this in your test results ?

Professor Vucetic replied that this is a two part question. First how did we install the facing and, second, what was the rotation of the facing and movement in spinning the centrifuge up to 50G. We built the soil in the box in layers of different colours and at predetermined locations we placed the nails and filled the box completely with sand, including the part which was the excavation. While doing this we compacted the soil together with the nails. Then we put weights on top of the box, covering the surface of the sand, put it in the centrifuge, spun it and shook it so as to densify the model without excavation. Then we stopped the centrifuge, removed the weights and excavated the excavation part so that the tips of the nails that were buried there were left sticking out. Then we custom made the facing, glued the same sand on the facing and then lightly pressed the facing against the nails and then glued the nails to the facing. Then the assembly was returned to the centrifuge for testing. Rotation of the facing occurred during the spin-up and the magnitude of rotation, which was very small, corresponded to field values reported in the literature. We did measure the rotation, which I cannot recall, but it was small. We then shook the model and it failed as we described.

Professor Gassler of EH Munich then asked Professor Ehrlich if Dr Jewell was right, or not, to say that the bending stiffness of nails is a second order effect. In my opinion Dr Jewell is right, at least for near vertical walls. This is something I discovered from field tests in 1976. The fact should be considered that bending moments are mobilised too late and that you can only put in your calculation things that are mobilised simultaneously. No doubt, after a larger movement, in the post failure moment, some resistance from bending moments might prevent the full collapse of a wall but before this failure has already occurred and you might try to simulate this in your FEM analysis.

Professor Ehrlich responded that what he was modelling was the working stress condition, not the failure condition, and so you do not consider the large strains necessary to mobilise the bending moment influence. The stiffness is quite important as the results have shown.

Professor Gassler responded that stiffness helps a little, even to reduce deformation in the serviceability state, but it is very very little. Using FEM analysis is still today problematic in modelling moment failure, so, your results should be compared with field tests. At the moment it is better to err on the conservative side in giving advice to practical engineers otherwise stability could be overestimated. Thank you.

Professor Bang, in adding to the view of Professor Gassler, commented that centrifuge work was conducted in 1994 and reported in the Singapore conference in a paper by Sam

Freedman. This experimental work used two types of nail; soft lead and steel. No difference was seen in the bending moment until failure. Once failure was approached the moment effect took place. I think this coincides with what Dr Kim was reporting here.

Professor Ehrlich agreed that field studies are quite important, but lets see what numerical analyses say. Numerical work is important in giving us direction in future studies, if we do not know what we are looking for we cannot instrument properly. The yielding regions will be different depending on bending stiffness. What we want to point out in our paper is that bending stiffness should be taken into account in research.

Professor Gassler then asked Professor Leshchinsky if he had investigated the two part wedge mechanism in rotation for reinforced walls near to the vertical. This could be an unsafe mechanism, particulary for seismic loading.

Professor Leshchinsky replied that the difference between mechanisms is a question of semantics, we are talking about the same mechanism. I looked at all possible failure mechanisms and failure is basically sliding along planes. In geosynthetics it is sliding along the weak plane namely the interface between the soil and geosynthetic. Its an equilibrium approach.

Professor Gassler commented that maybe there is a misunderstanding. The sense of rotation is different in the simple circular slip line and the double wedge mechanism in rotation. We have observed from the slides of Professor Tatsuoka that the overturning moment, or toppling, seems to have happened very often during the last heavy earthquake in Japan. At the end, I agree with you that you can replace the two wedge failure mechanism in rotation by the two wedge mechanism in translation, for the practical engineer, since the latter one is much easier to handle. However, theoretically, you should also investigate rotation and maybe you will come to the same result that I have that about 15% depends on the ratio of acceleration to gravitational acceleration and on some other boundary conditions. The rotational mechanism seems to be more critical, however, from a practical point of view, 15% is not very much in soil mechanics, for example there can be that much scatter in results for soil friction. At the end perhaps we should apply a model factor of 1.1 or something like that. We will agree, no doubt, but before giving things to practical engineers, we should be absolutely sure that things are theoretically correct. Thank you.

Professor Leshchinsky responded that he investigated two types of log spiral; one very deep, which is more critical than the two wedge in rotation, so I looked at that mechanism. Indeed, it has a significant effect on vertical walls or slopes up to 70° and it is that which controls the failure, no doubt. When you increase seismicity above 0.2 then the direct sliding mechanism, the two part wedge, starts taking place. So, it might be dangerous to generalise completely. We looked at the rotational mechanism, first using the simple log spiral to find the reaction force in each reinforcement layer and therefore what is the required strength. The other one, I call a compound failure, is a rather deep log spiral which extends back into the un-reinforced soil and you can very easily fit it with a bi-wedge and get a difference of perhaps 5%. So, in this case the spiral is more critical that the bi-wedge.

Mr Zhao of the Tenax Corporation commented that upper bound analyses of heavily loaded slopes indicate that the translational failure mechanism governs while for lightly loaded slopes the rotational mechanism is more critical.

Dr Koseki of the Institute of Industrial Science, University of Tokyo, then asked Dr Pokharel to explain the assumptions behind his "no length change" analyses. Is it the same as assuming the reinforcement to be infinitely rigid ?

Dr Pokharel confirmed that this was so. This concept came from undrained analysis in which there is no volumetric change. The volumetric stiffness of the soil and water is different. We had no volume change under undrained conditions. There is some elastic volume change in the water which we neglected. Reinforcement stiffness is quite big so that is why we had "no length change" based on plastic flow and undrained analysis.

Dr Koseki then asked if it is possible to formulate the effect of rigidity in your approach. Dr Pokharel responded that the rigidity is infinite. The EI value is not considered and the length between two reinforcement nodes is constant.

Mr Lawson of Royal Ten Cate then commented, in reference to the presentation by Professor Gassler, that in his own experience Eurocode 7 was that it is a poor document for reinforced soil design. Before I give two example of this I just want to say that its important that any new code developed for reinforced soil should provide results which are consistent with existing good practice in terms of the quantities and strengths of reinforcement employed. One good example from

Eurocode 7 is the partial factor of 1.25 used on shear strength of soils. When such a partial factor is applied, one practical implication, particularly for reinforced soil walls, is that it penalises the contractor for using good quality, highly frictional, fill. Factoring down design shear strength automatically increases reinforcement design load and so there is no real incentive for the contractor to use high friction fills. When it comes to basal reinforcement of embankments on soft foundations, again, use of a partial factor of 1.25 on the frictional characteristics of soil is prescribed in Eurocode 7. In this case, when it comes to calibrating against existing good practice, using this value of 1.25, as the ratio of the disturbing moment to the resisting moment changes then it is necessary to use unique partial factors on the loads, the driving forces, to result in consistent designs. It is much better to use a partial factor of 1.0, of unity, on the soil shear strength and a higher partial factor on the driving forces, eg the loads. Then designs results become consistent with past good practice.

Professor Gassler commented that Eurocode 7 is a general code for normal applications of geotechnical work. It cannot work for reinforced soil systems. It is better to make use of the British standard BS 8006. For example, you will learn a lot more about reinforced soil reading this. It could not have been the objective of Eurocode 7 to cover reinforced soil systems in every aspect. Its only the aspect of using partial safety factors in general. All the other details have to be looked up in other codes such as BS 8006.

Finally, Professor Vuceti of UCLA asked Mr Myles, the discussion leader, has any real soil nailed structure in the field, not a model, failed to the extent that one can claim that the geometry of the failure surface is known. If yes, what type of failure mechanism was involved; was it parabolic, circular or bi-linear ?

Mr Myles responded that the reality is that in a lot of failures in soil nailed structures there is not a well defined, simple failure surface; nothing as clear as seen in centrifuge tests. There are a lot of reasons for this. One of the major problems is failure of the toe and in many cases this is not particularly appreciated in design. It is possible to get long term bearing failures, tilting and cracking, because the toe is over stressed, although I have seen, in one case, a large circular global failure which passed outside the nails. I cannot recall failures of the nails themselves;it tends to be pull out or facing failures. I do not believe there is a well defined failure mechanism, it tends to be a whole series of things which go wrong which perhaps masks the situation.

Professor Leshchinsky commented that with geosynthetic reinforced soil walls failures sometimes occur and the failure mechanisms are not too far from those used in analysis. However, it is extremely dependent on boundary conditions, and type of reinforcement, eg the spacing, stiffness etc. In fact I have just completed some research work on a full scale wall, 6 metres high with very short reinforcement, and we could not generate failure within the reinforced soil. So, if such failure does not generate, perhaps we should develop a different design methodology within the parameters of the problem we are considering. At the moment, the approach of failure mechanisms is very common in soil mechanics and quite safe.

Mr Myles, the discussion leader, finished by thanking the contributors and asking them to submit their questions in writing.