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Summary of discussions

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Dr Gassler asked, for the purposes of limit analyses of reinforced soils, which direction of T_{max} is the correct one, the initial reinforcement direction or the direction of the inclined slip surface which later develops. Prof Gourc remarked that the ultimate tension in biaxial tests was generally closer to the shear band direction, but depending on the relative stiffness of the soil. Dr Leschinsky reported that he had published a study in granular soil which showed that the inclination effect was not worth more than about 10% of extra strength when associated changes in the geometry of the slip surface were considered. Dr Gassler expressed some surprise, since he perceived that inclination along the shear band would offer a much bigger lever arm against rotation.

Prof Akagi raised the question of whether there was an optimum amount of deformation of reinforcement materials, or a practical maximum extensibility? Dr Bolton remarked that strength had to be mobilised, but that clients would expect some limit to be placed on service displacements, perhaps 1% of the height of the structure. Prof Jones expected that deformation should be taken into account in determining earth pressure coefficients, K_a for synthetic materials or K_o for metallic reinforcement, but he also noted that any material can be used to create a stiff structure depending on the proportion of reinforcement. Prof Ehrlich spoke of the link between compaction and the reduction of future deformation; compaction acts like a pre-stress. Dr Bolton agreed, and reminded listeners about the generally undeformed state of Reinforced Earth walls after earthquakes, as shown by Prof Tatsuoka earlier; he expected that they remained relatively undamaged because the lateral earth pressure increment of the earthquake was no worse than the original compaction machine. Prof Leschinsky underscored the need for compaction of fill to reduce the vertical shearing at reinforcement connections with wall. Dr Miles pointed out the distinction between reinforcement systems which extend initially during construction, and the long term extension of polymers which creep; he felt designers ought to monitor construction.

Prof Fukuoka drew attention to the strong reduction in soil stiffness and strength which could occur in fine grained soils by water infiltration after construction, leading to unusual displacements if that effect had not been allowed for. He felt that drainage could not always avoid the accumulation of high pore water pressure, so that a better plan was to place a geomembrane to avoid water ingress.

Prof Fukuoka also responded to the Chairman's discussion topic "Why are field tensions so small?" In the case of soft ground and embankments he showed that large tensions were induced in steel bars with steel plates. Prof Gourc said that it was necessary to remember that we have a passive reinforcement technique; it will be very difficult to correlate design values with measurements due to differences between construction methods. He also pointed out that current designs with factors of safety do not solve for the stress distribution in the various components, just the global equilibrium. Dr Bolton remarked that field structures are not necessarily being challenged as the designer assumed in the design scenario, so some component will be under-mobilised and this is likely to be the reinforcement, since the soil must move first. Prof Bathurst noted that boundary conditions are often not allowed for, eg the constraint of footings below the facing of a wall. Dr Lo had used non-linear FE analysis which showed that friction at the base cut tensions in the bottom third of a reinforced soil retaining wall, and noted that suction in compacted soils creates apparent cohesion and reduces also tensions.

Regarding soil nails, Dr Chang showed that there was considerable uncertainty on nail-soil bond, due to unknown radial effective contact stresses after construction, as modified by dilation during shearing as tension develops. There was a need to measure contact stress in some field trials, perhaps using Cambridge contact stress transducers. Dr Gassler doubted whether dilation was practically important since all movement is on the shear band, not around the nails.

Dr Sharma commented on FE analysis for design purposes. He said that there had been much development of PC-based FE packages, which include the ability to model collapse and construction sequence. Although such programs need an expert "driver", universities are producing young engineers who can do the job. Prof Leschinsky noted that design has to be safe and economical, and that reinforcement presently costs 5% to 10% of the overall project cost. If FE analysis is used he felt that overall costs would rise above 10%, so this was not practically applicable, even if it was good in research. Prof Gourc recognised that it was possible to model very complicated geometries, but wondered how to model compaction. Dr Bolton wondered whether we know enough to insert compaction stresses during layer building in FE analyses. Prof Ehrlich said that his paper with Prof Mitchell in April 1994 covered this point. Dr Pokharel warned that axisymmetric and plane-symmetric analyses can be flouted by shear bands; there was a need to model failure without assumed symmetry. Dr Bolton agreed that certain problems appeared to be symmetrical before instability set in, and recalled the Tower of Pisa.

There was a discussion about soil parameters and partial factors used in the UK design Code for reinforced soils. Prof Jones responded to the criticism of the partial factors in BS 8006 which had been made by Dr Bolton in his panel presentation. Any Code, such as BS 8006, had to be used with other Codes of Practice, eg BS 5400 Bridges, so the partial factors have to be compatible between Codes. The partial factors in BS 8006 were chosen to reproduce current designs; they can be changed at some future time within the same framework of ideas laid out in the Code. Dr Bolton had shown a worked example based on a maximum angle of soil internal friction of 45°, but this is not practical since the designer would select a lower value such as 35° since he will not know what material the contractor will obtain. Dr Bolton responded to these three points. If other Codes of Practice are not compatible with common sense, he hoped that they would also be changed. He felt that the factor on density in BS 8006 should certainly be removed, and replaced by a mobilisable strength approach to selecting earth pressures and specifying reinforcement strengths. Dr Bolton pointed out that the designer can specify densification by compaction, and that the UK Retaining Wall Code BS8002 offers advice which will lead to the recognition of the existence of high peak friction angles such as 45°. Prof Jones' advice to designers to select 35° in any event, was exactly Dr Bolton's point: this lower value corresponds to a typical critical state angle of residual strength, which is the design parameter recommended in BS 8002. If a designer makes the mistake of measuring ϕ_{max} and then using it, he could get into a lot of trouble following BS8006. Mr Lawson explained that the logic of BS 8006 was for the partial factors and ϕ_{max} values to go together; he felt that the package was OK as a calculation tool. He was concerned that ϕ_{crit} as basis of design wipes out the incentive for the contractor of using good granular fill. Dr Bolton asked whether that meant that can we utilise cheaper fills? Mr Lawson felt that poor drainage would then become a problem. Dr Bolton recommended that permeation properties then be addressed directly, rather than by hoping that the use of ϕ_{max} would somehow protect you.

Finally, Prof Leschinsky had a comment on creep reduction factors in the design of reinforcement. $T_{allowable}$ is T_{ult} x creep reduction factor x damage factor, and the creep reduction factor is significant. In order to assess this factor we keep sustained load on a strand of reinforcement in isolation in the laboratory. But in real applications, load redistribution will occur, and overstressed layers will relax, as he had demonstrated in a simple experiment. He felt that the creep reduction factor could safely be reduced in its effect.