**Discussion and Response**

# PEAK VERSUS RESIDUAL SHEAR STRENGTH IN GEOSYNTHETIC-REINFORCED SOIL DESIGN

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Zornberg, J.G., 2002, "Response to 'Peak Versus Residual Shear Strength in Geosynthetic-Reinforced Soil Design' ", *Geosynthetics International*, Vol. 9, No. 4, pp. 392-393.

## Discussion by R.B. Gilbert

Sorry to jump into the fray late. There are four issues that I would like to open up for discussion.

First, my intuition supports the conclusion that the peak strength would be mobilized for an active failure like this because generally very small displacements are required to mobilize the full active pressure. However, if this were a passive mode of failure, then I would be more concerned about strain softening.

Second, Jorge's test walls failed through the reinforcement. If the failure mechanism had involved pullout of the reinforcement, I am not sure that the results would have been the same. Also, reinforced walls are typically designed in practice so that the critical failure surface is pushed outside of the reinforced zone because we use large factors of safety on the reinforcement capacity to limit deformations for serviceability.

Third, I wonder whether the centrifuge scaling would work for tests with interfaces. For example, the peak interface shear resistance along the reinforcement is mobilized at several tenths of an inch regardless of the normal stress. However, several tenths of an inch in a centrifuge test could mean failure of the wall where several tenths of an inch of displacement in an actual wall would not even be detected. As another example, I do not think a model of Kettleman Hills would have failed in the centrifuge test at the height that it failed in the field because the shear displacements in the centrifuge would have been much smaller relative to the peak displacement. Essentially, I am questioning whether the relationship between compressive strains (within a material) and shear displacements (at an interface) is properly represented in a centrifuge test.

Finally, the boundary effects at the sides of the wall in the centrifuge may be significant and may affect any conclusions that can be drawn. For example, a dense sand would tend to dilate and develop more resistance along the boundaries than a loose sand. Therefore, I would expect the wall with the dense sand to be more stable than that with the loose sand in the centrifuge test even if they had the exact same peak strength.

## Response by J.G. Zornberg

Many thanks to Professor Gilbert for joining the discussion. In addressing the four important issues he posed, it should be kept in mind that failure of the models was not progressive. That is, failure initiation and final collapse took place under a single g-level increment. Progressive failure would have led to failure initiation at a g-level below that corresponding to model collapse. The following are my answers to each issue raised by Professor Gilbert.

First, I support Professor Gilbert's intuition supporting that the peak strength is mobilized for an active failure surface of earth retaining structures. Accordingly, the results of this investigation should not be extended to failure surfaces other than those through soil within the reinforced soil mass (e.g., failure involving passive modes and failure through soil-geosynthetic interfaces).

Second, I agree that the results should not be generalized to pullout failure mechanisms (which is a failure through a soil-geosynthetic interface). Although pullout does not govern the design of geosynthetic-reinforced soil structures, it may be relevant for structures reinforced with steel strips or nails.

Third, this an important issue in centrifuge modeling: is peak shear strength characterized by a "displacement at peak" or by a "strain at peak"? Without getting into details, I should state that centrifuge scaling laws are different depending on the answer to this issue. A discussion on this issue is provided by Zornberg et al. (1997). Proper scaling of the displacement in centrifuge models is particularly important if the objective of centrifuge modeling is to assess the deformability of earth structures. However, this issue may not be so relevant in stability evaluations. As mentioned, the models failed through a distinct failure surface, but this distinct surface did not develop progressively.

Fouth, certainly, dense sands will dilate (leading to peak strength values higher than the residual shear strength). Significant effort was made in the centrifuge testing program to minimize boundary effects in the centrifuge models (low friction interfaces). The success of these efforts could be verified by the good comparison between the location of tears in the reinforcements (within the soil mass) and the location of the failure surface (monitored at the model boundary).

In summary, while recognizing that centrifuge modeling cannot solve all our geotechnical problems, I believe that centrifuge studies are particularly useful in identifying failure mechanisms in geotechnical systems.

## REFERENCE

Zornberg, J.G., Mitchell, J.K., and Sitar, N., 1997, "Testing of Reinforced Soil Slopes in a Geotechnical Centrifuge", *Geotechnical Testing Journal*, ASTM, Vol. 20, No. 4, December 1997, pp. 470-480.