very good point that the disturbance factor "D": introduced by Hoek et al. (2002) and which is related to blasting, caused damage and stress relief; it may also be considered in the estimate of rock mass modulus from intact rock modulus. The recommendations of "D" values for tunnel and slope applications were provided by Hoek et al. (2002). Unfortunately, no guidelines were provided for deep foundation application. The discussers related the disturbance factor to weathering and degradation of rock during drilled shaft construction, which was not originally discussed by Hoek et al. (2002). Slake may cause weathering of rock and separation of rock pieces away from rock mass during drilled shaft construction at I-85 site. However, it may not necessarily cause reduction of rock mass modulus since slake does not necessarily damage the rock mass, which still remains in place, or cause additional stress relief other than the stress relief due to excavation itself. It is certainly worthwhile to investigate the disturbance factor for drilled shaft installed in slake susceptible rock.

3. Thank you for pointing out the typographical error. A modulus value of 146 MPa was used for the I-40 short shaft at depth of 2.3 m.

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Discussion of "Analysis of a Large Database of GCL-Geomembrane Interface Shear Strength Results" by J. S. McCartney, J. G. Zornberg, and R. H. Swan Jr.

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The authors have presented an extensive and valuable study on the interface shear strength between geomembranes (GMs) and geosynthetic clay liners (GCLs). The discussers have performed shear tests using similar materials and can provide comment on an important topic discussed in the paper—the difference between GCL internal and GM/GCL interface shear strengths and which strengths are critical for design. We will limit discussion to hydrated needle-punched (NP) GCLs and textured geomembranes (GMXs) as these materials are most relevant to U.S. practice.

The authors conclude that: (1) GCL internal peak shear strengths are generally larger than GMX/GCL interface peak strengths, and (2) GCL internal large displacement strengths are often similar to those of GCL/GMX interfaces. The first conclusion is well-supported by published test results at low to moderate normal stress levels (Triplett and Fox 2001; Chiu and Fox 2004) and by the authors' database in which failure always occurred at the GM/GCL interface and no internal GCL failures were observed for 534 tests. Published test results do, however, contradict the second conclusion; GMX/GCL interfaces can be expected to have higher shear strengths at large displacements than GCLs sheared internally. This does not obviate the need for product-specific testing under project-specific conditions but the trend is consistent. The authors' second conclusion undoubtedly reflects data variability from the large number of tests that were conducted over a considerable time period using different product types and manufacturing lots, but may also result from the displacement termination limits used in the study (typically 75 mm or less). When sheared internally to 200 mm, hydrated GCLs consistently yield a secant residual friction angle of 4° to 5° (Fox et al. 1998). By comparison, the secant large displacement friction angle for smooth GM/GCL interfaces is at least 7° (Triplett and Fox 2001)—9° in the authors' database—and GMX/GCL interfaces will have still higher values.

With regard to design of liner systems, shear failure will occur at the interface with the lowest peak shear strength. Design for peak strength conditions should be based on the lowest peak strength interface and design for large displacement conditions should be based on the residual strength of the same interface (Gilbert 2001; Fox and Stark 2004). Design for large displacement conditions should therefore be based on the residual strength of a GCL or GCL interface only if the GCL or GCL interface exhibits the lowest peak strength in a liner system. At low to moderate normal stress levels, large displacement design is unlikely to be governed by the internal residual shear strength of a NP GCL because it is unlikely that the NP GCL will fail internally.

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Closure to "Analysis of a Large Database of GCL-Geomembrane Interface Shear Strength Results" by John S. McCartney, Jorge G. Zornberg, and Robert H. Swan Jr.

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The writers would like to thank Dr. Fox and Mr. Ross for their interest in the paper and for raising important issues concerning the trends in large displacement and residual shear strength values for hydrated needle-punched geosynthetic clay liners (GCLs) sheared internally and along the interface with a textured geomembrane (GM). The discussers concur with the writers that the GCL internal peak shear strengths are generally larger than GCL-GM interface peak strengths. However, unlike the writers' observation that GCL internal large-displacement strengths are often similar to those of GCL-GM interfaces, the discussers expect a higher GCL-GM residual shear strength values. The discussers also point out that design for large-displacement conditions should be based on the residual shear strength of the interface with the lowest peak shear strength. The writers reached the conclusions under discussion regarding the large-displacement shear strength values through a statistical comparison of GCL internal and GCL-GM interface peak and large-displacement shear strength values in a large database of tests. The tests in this database included different GCL and GM manufacturers, hydration procedures, and test conditions. On average, the statistical comparison indicated that the GCL internal peak shear strength was generally larger than GCL-GM interface peak strength, and that GCL internal large-displacement strengths were similar to those of GCL-GM interfaces. However, the writers agree with the discussers that these observations are not general, and are an artifact of both the variety of conditions evaluated in the database and the fact the direct shear tests evaluated in this study were not performed to reach residual conditions.

Analysis of a series of tests performed on the same GCL and GM materials present in the writers' database, performed with consistent test conditions, indicate consistent trends in large-displacement shear strength with the trends in residual shear strength reported by the discussers. Specifically, the large-displacement shear strength data (i.e., the shear stress defined at a displacement of 75 mm) shown in Fig. 1 indicates that the average GCL internal large-displacement shear strength is similar to that of the GCL-GM interface. However, the lowest GCL internal large-displacement shear strength is clearly lower than that of GCL-GM interfaces under relatively high normal stresses. The lower-bound friction angle for GCLs sheared internally is 6.6°, while the lower-bound friction angle for GCL-GM interfaces is 9.9°. Although these friction angle values are larger than the residual shear strength friction angles reported by Fox et al. (1998) and Triplett and Fox (2001), the overall trends between GCL internal and GCL-GM interface large-displacement shear strength are the same as for the residual shear strength values reported in these papers. The greater friction angle for the GCL-GM interfaces in relation to the internal GCL friction angle is likely due to the plowing of textured GM asperities through extruded bentonite along the carrier geotextile of the GCL. On the other hand, the lower friction angle of the internal GCL results from shearing through unreinforced sodium bentonite.

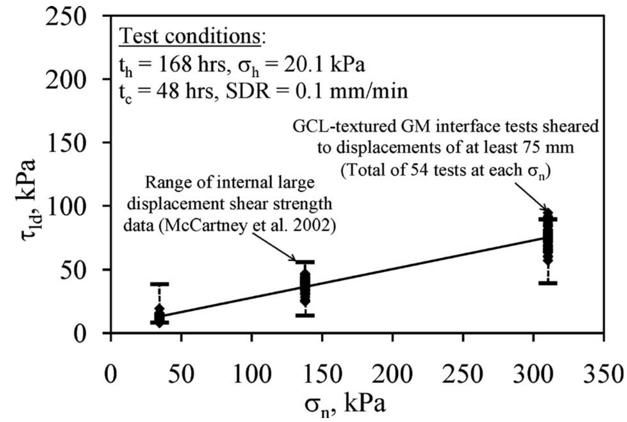

Fig. 1. Large-displacement shear strength values for GCL-GM interfaces with the same test conditions, along with ranges in large-displacement shear strength for GCLs sheared internally under the same test conditions

Evaluation of variability in the GCL internal and GCL-GM internal large-displacement shear strength data leads the writers to believe that similar variability may also be present in the GCL internal and GCL-GM interface residual shear strength (McCartney et al. 2002). Although this belief needs to be justified experimentally, some insight may be gained through evaluation of the correlation between GCL internal and GCL-GM interface peak and large-displacement shear strength data, as shown in Fig. 2 [data in this figure are from Fig. 11(a) of the paper under discussion and from Fig. 1 herein]. This figure indicates a strong positive correlation between peak and large-displacement shear strength, which implies that post-peak shear strength behavior is

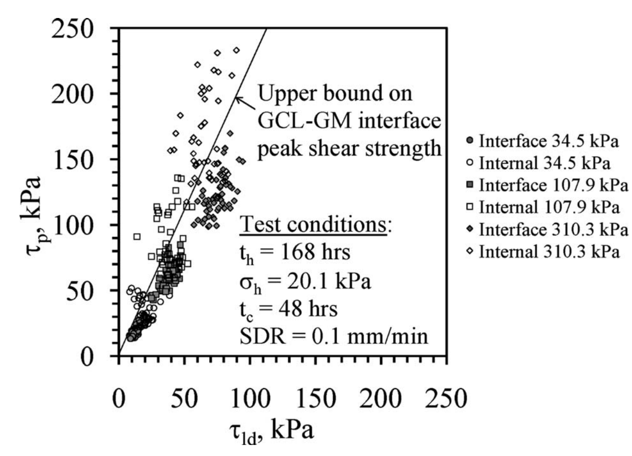

Fig. 2. Comparison between GCL internal and GCL-GM interface peak and large-displacement shear strength data from direct shear tests performed under different confining pressures

not independent of the peak shear strength for interfaces involving GCLs. The strength of this correlation for shear strength values at a displacement of 75 mm may not extend to the correlation for shear strength values at residual displacements of 200 mm or more. Nonetheless, the failure plane in GCLs sheared internally to post-peak conditions typically contain varying amounts of ruptured and pulled-out fiber reinforcements, which can lead to variable residual shear strengths. Accordingly, the writers believe that the scatter in the large-displacement shear strength values in Figs. 1 and 2 suggests that similar scatter may also be present in the residual shear strength.

The writers agree with the discussers that designs based on peak or large-displacement conditions should focus on the interface with the lowest peak shear strength. The writers would like to emphasize that it should not be assumed that a GCL sheared internally will always have greater peak shear strength than a GCL-GM interface under the same conditions. The results in Fig. 11(a) of the paper under discussion indicate that, due to inherent material variability, the GCL internal peak shear strength is occasionally smaller than the GCL-GM interface peak shear strength. With the exception of data from tests performed under relatively low normal stresses (34.5 kPa), the GCL internal and GCL-GM interface large-displacement shear strengths shown in Fig. 2 are similar when the GCL internal peak shear strength is less than the upper bound on GCL-GM interface peak shear strength. The variability noted in the peak and large-displacement shear strength data shown herein adds emphasis to the need for probabilistic consideration of the weakest interface in design. Specifically, variability in the shear strength of GCLs and GCL-GM interfaces has been considered using reliability-based methods for slope design involving GCLs and GMs (McCartney et al. 2004; Dixon et al. 2006). McCartney et al. (2004) provides guidance on selection of representative coefficients of variation for the peak shear strength of GCLs and GCL-GM interfaces for use in reliability-based slope design.

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Discussion of "Singularities of Geotechnical Properties of Complex Soils in Seismic Regions" by Ramon Verdugo

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Professor Verdugo has presented a very interesting paper on two highly unusual soil groups, namely volcanic ash clays and diatomaceous soils. In general they exist separately from each other, as is to be expected from their distinct formation processes. However, as the author points out, in particular situations, their formation processes are such that they can still occur together, and he describes a number of situations where they are found together. The purpose of this discussion is add to the database of these soils by describing one further location known to the discusser where the two soils occur together.

The situation where the soils are likely to be found together is the lake environment illustrated in Fig. 1. Deposits entering the lake may consist of a variety of materials. First, there is relatively coarse pyroclastic material deposited directly at the time of eruptions, or flowing into the lake as lahars. Second, there is fresh airborne ash falling into the lake shortly after the eruption. Third, there is soil eroded from surrounding hillsides and carried by streams or rivers into the lake. This soil is likely to be rich in the clay minerals allophone, immogolite, and halloysite, especially if the volcanic activity is predominantly andesitic.

In addition to these materials entering the lake and forming deposits, there is the possibility of the formation within the lake itself of diatomaceous silts, since the volcanic environment may provide the special conditions needed for their formation, namely an adequate supply of water rich in dissolved silica. As the author points out, the form and size of diatoms are extremely variable, there being many thousands of different species of diatom existing worldwide.

The site known to the discusser where the above conditions existed in the past is the plateau found in West Java, Indonesia, immediately south of the city of Bandung. This low-lying area, which extends to the Citarum River, was a fresh water lake during the Quarternary period, the level of which varied with the volcanic activity coming from the enclosing mountains, especially Mt. Tangkuban Perahu, which is located about 25 km to the north of Bandung. Eruption materials gradually accumulated in the lake, forming a soft, highly compressible clay, which at its deepest part is about 30 m thick.

In the 1980s a bypass road (the Padalarang–Cileunyi toll highway) was built to the south of Bandung, and a substantial section of it passed through this area of deep volcanic alluvial soil, which came to be known as Bandung clay. The geotechnical properties of this clay were investigated in considerable detail as part of the planning of the highway; they have been described in papers by