Discussion of "1907 Static Liquefaction Flow Failure of North Dike of Wachusett Dam" by Scott M. Olson, Timothy D. Stark, William H. Walton, and Gonzalo Castro

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The authors of the paper have presented an interesting case history of static liquefaction and a rational method of back-calculating the shear strength of liquefied material. The discussers would like to address "modeling" uncertainty in back-calculating shear strength of liquefied materials using currently available kinetics models. The modeling uncertainty addresses differences between the actual physical process of flow slide and the numerical analysis to "simulate" the process.

A kinetics model similar to the method described by the authors of the paper was developed prompted by a project involving a tailings dam failure. This model, called the dynamic run-out analysis methodology (DRUM), satisfies Newton's second law of motion ($F=ma$) and uses reasonably idealized kinematic boundaries, where the bottom of the sliding mass is controlled by the observed or postulated slide surface and the ground surface, and the top of the sliding mass is assumed to form a straight line as the sliding initiates, but preserving the total sliding cross-sectional area and, therefore, the total sliding mass. Although the sliding mass is assumed rigid for each time increment, its shape is changed at each time increment as the kinematic boundaries described above force a change in the geometry of the sliding mass as the mass moves downward and outward. The DRUM model was "calibrated" using a number of flow slide case histories and the actual tailings dam failure. The methodology and some results of the case history calibration were presented elsewhere (Tan et al. 2000).

Although the DRUM model was used to back-calculate residual shear strengths using case histories of flow slides, it was also used to estimate the run-out distances of postulated tailing dam failures, using various assumptions regarding residual shear strength and sliding surfaces. Thus, the DRUM model is considered a reasonable kinetics (and to some extent kinematics) model and similar to the one described by the authors in the paper.

Using the DRUM model and the input parameter values presented in the paper, we back-calculated the residual shear strength of the liquefied material from the north dike failure of the Wachusett Dam by force matching the postfailure geometry. The postfailure geometry from our calculation is shown on Fig. 1. The back-calculated values of residual shear strength ranged from 13.8 kPa (assuming 57.4 kPa or a ϕ of 35° for the nonliquefied zone) to 15.1 kPa (assuming 47.8 kPa or a ϕ of 30° for the nonliquefied zone). These values are somewhat lower than the 16 kPa value reported in the paper.

The back-calculated values reported in the paper using static slope stability analysis and the postfailure and prefailure geometries clearly indicate the importance of reflecting Newton's second law of motion in back-calculation. However, given these somewhat different back-calculated values using the two kinetics models and given the "crudeness" of the current kinetics models, it appears that at this time the "modeling" uncertainty of 10–20% should be reflected in the back-calculated residual shear strength of liquefied soils using kinetics models.

References

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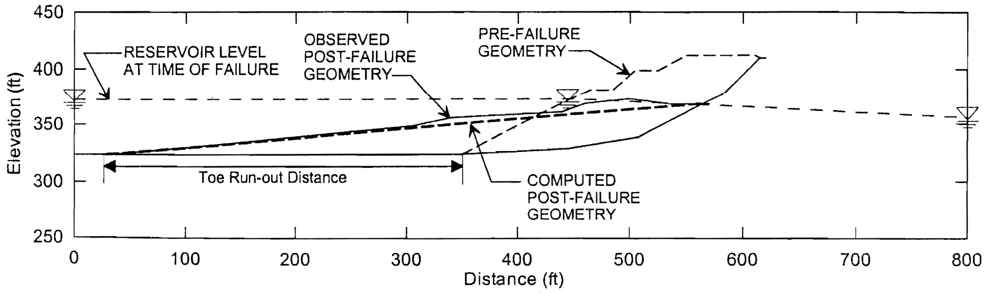

Fig. 1. Observed postfailure geometry and calculated postfailure geometry using the DRUM model

Closure to "1907 Static Liquefaction Flow Failure of the North Dike of Wachusett Dam" by Scott M. Olson, Timothy D. Stark, William H. Walton, and Gonzalo Castro

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The writers welcome and thank the discussers for their interest in the paper. The discussers briefly present the results of a back-analysis of the North Dike failure using a kinetics model that they developed (Tan et al. 2000). As indicated by the discussers, their analysis is also based on Newton's second law of motion and is similar to the kinetics analysis presented in the paper. However, the discussers' back-analysis yielded a value of liquefied shear strength that is 6–14% smaller than the writers' "best estimate," depending on the value of shear strength used for the nonliquefied soils. Based on this difference, they suggest that a "modeling" uncertainty of 10–20% should be reflected in shear strengths back-calculated using kinetics models.

The writers would like to point out that a number of uncertainties exist in the back-analysis of the North Dike of Wachusett Dam. Olson (2001) identified the following uncertainties in estimating the liquefied shear strength: (1) the limits of the zone of liquefaction; (2) the shear strength of the nonliquefied soils; (3) the location of the final sliding surface; and (4) the effects of hydroplaning (slide material "riding" on a layer of water), mixing with water, and an increase in void ratio of the soils near the toe as they slid farther into the reservoir. Of these uncertainties, the effect of hydroplaning and mixing potentially has the largest effect on the back-calculated liquefied shear strength.

As described in the paper, the writers accounted for the effect of hydroplaning by setting the shear strength mobilized along the failure surface in the reservoir (beyond the limits of the prefailure geometry) to 50% of the shear strength mobilized within the prefailure geometry limits of the dike. This hydroplaning strength factor (h) is used as follows:

$$s_u(\mathrm{LIQ})_{\text{beyond prefailure geometry}} = h \times s_u(\mathrm{LIQ})_{\text{within prefailure geometry}} \quad (1)$$

Factors of 25 and 100% also were used to ascertain the sensitivity of the liquefied shear strength to the effect of hydroplaning. Using these hydroplaning strength factors and the range of shear strength of the nonliquefied soils, the writers back-calculated the values of liquefied shear strength shown in Table 1.

The writers would like to highlight three pertinent details. First, as indicated in Table 1, the discussers' range of back-calculated shear strengths (13.8–15.1 kPa) fall well within the range of liquefied shear strengths reported by the writers (10.4–19.1 kPa).

Table 1. Evaluation of Potential Range of Liquefied Shear Strength Back-Calculated for 1907 Flow Failure of North Dike of Wachusett Dam

Case	Hydroplaning strength factor, h	Shear strength of non-liquefied soils (kPa)	Back-calculated liquefied shear strength (kPa)
"Best estimate"	50%	47.8	16.0
Lowerbound	100%	57.4	10.4
Upperbound	25%	47.8	19.1
Comparison to discussers' back-calculation	60%	47.8 to 57.4	13.8 to 15.1

Second, Tan et al. (2000) used a maximum shear strength reduction of 40% to account for hydroplaning. This is equivalent to $h = 60\%$. The writers back-calculated the liquefied shear strength for the North Dike using $h = 60\%$ and obtained liquefied shear strengths identical to those reported by the discussers, as indicated in Table 1.

Finally, both the writers' and the discussers' models evaluate the kinetics of the sliding mass center of gravity. Because Newton's second law of motion is a vector equation, only the center of gravity is pertinent. The shape of the sliding mass is irrelevant to the kinetics analysis. As such, the writers' and discussers' independently developed analyses should provide identical results provided that the same input values of initial and final coordinates of the center of gravity and center of gravity travel path are used. However, the writers' model allows additional factors, e.g., hydroplaning, buoyancy, change in sliding surface length, and shear strengths of nonliquefied soils, to be considered in the analysis.

In summary, the uncertainties related to our understanding of soil behavior during rapid flow (e.g., hydroplaning) are much greater than any potential differences in the two kinetics models based on the same physical principles. Although some progress has been made, e.g., Iverson and LaHusen (1993) and Iverson et al. (1997), soil behavior during rapid flow remains a significant uncertainty in back-analysis of flow failures.

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