*University of Idaho NCATT (National Center for Advanced Transportation Technology) and Idaho Transportation Department Cooperative Transportation Research Program*

**Research Brief**

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# *Back-Analysis of Failed Roadway Slopes*

The primary goal is to investigate shallow slope failures that occur on roadway slopes. Laboratory direct-shear testing and the back-analysis of field-mapped, shallow soil slips have been used to study soil shear-strength modeling procedures, translational failure modes approximated by the *infinite slope model*, and the influence of perched ground water on such slope failures.

Shallow soil slips (less than 1 meter thick) commonly occur on roadside slopes steeper than 2:1 and comprised of native clay or silt soils. These slope failures often occur in the winter or early spring when the ground is prone to repeated freeze-thaw cycles and when rain events occur during otherwise cold weather. An engineering analysis of these translational slope failures often is based on the *infinite slope model*, which is appropriate when the length of the failure mass is more than 10 times its thickness (Figure 1).

*Direct-Shear Testing*

A Wykeham-Farrance laboratory direct-shear apparatus with a 2.5-in. (63.5-mm) diameter shear box was used to test remolded soil samples collected from glacial silts near Sandpoint and from Palouse silty clays of the Moscow area. The water content of remolded specimens was varied to determine how shear strength would change as a function of moisture. The shearing rate was 0.3 mm/minute, and normal loads ranged from 640 to 3,160 psf (30.6 to 151.3 kPa). Results from the testing program, as summarized in Table 1, clearly show that the shear strengths of Palouse silty clays are much more sensitive to moisture than are the Sandpoint soils. For the Palouse samples, a power shear-strength envelope was fitted to the test results, as well as the traditional linear Mohr-Coulomb model. The power model is a curved function that rises steeply from the origin and then flattens as the normal stress increases (Figure 2). It commonly represents actual field conditions better than a linear model, especially when describing the shear strength that results when normal stresses are small (i.e., for shallow slope failures).

**Table 1.** Results of laboratory direct-shear tests of remolded soils from highway slopes.

| Soil Type | Water Content (%) | Shear Strength Model (tonne/sq.m) | Regression Coef. | Friction Angle |
|---|---|---|---|---|
| Sandpoint glacial silt | 1.4 | linear: $\tau = 0.7775\sigma + 0.739$ | R=0.991 | 38° |
| | 10.0 | linear: $\tau = 0.7964\sigma + 0.133$ | R=0.982 | 38° |
| | 15.0 | linear: $\tau = 0.6940\sigma + 0.612$ | R=0.999 | 35° |
| | 21.0 | linear: $\tau = 0.5352\sigma + 1.147$ | R=0.932 | 28° |
| | 21.0 | power: $\tau = 1.496\sigma^{.565} + 0.0$ | MAD=0.182 | |
| Palouse loess silty clay | 6.5 | linear: $\tau = 0.8357\sigma + 1.010$ | R=0.963 | 40° |
| | 6.5 | power: $\tau = 1.799\sigma^{.627} + 0.012$ | MAD=0.181 | |
| | 20.8 | linear: $\tau = 0.6276\sigma + 0.684$ | R=0.997 | 32° |
| | 20.8 | power: $\tau = 1.251\sigma^{.674} + 0.0$ | MAD=0.125 | |
| | 25.4 | linear: $\tau = 0.2219\sigma + 0.536$ | R=0.958 | 13° |
| | 25.4 | power: $\tau = 0.731\sigma^{.476} + 0.0$ | MAD=0.109 | |

Note: R=linear correlation coefficient; MAD=mean absolute deviation.

Project: Integrated Erosion Control Methods for Highway Construction and Slope Maintenance
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*(Continued)*

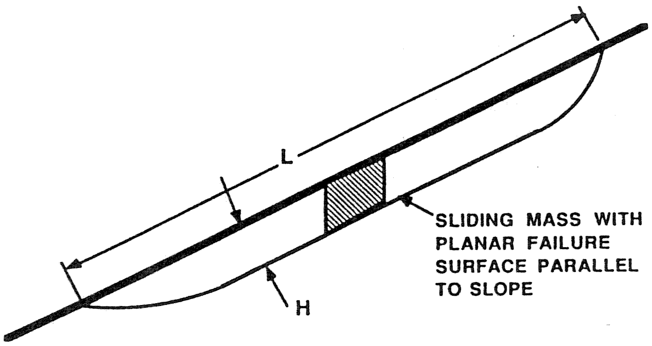


**Figure 1.** Translational, infinite slope failure model.

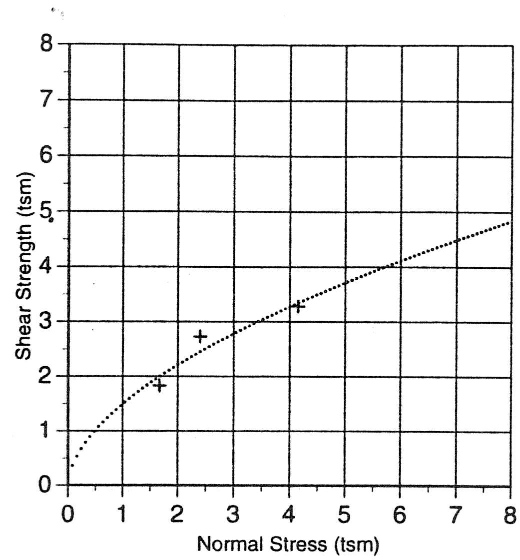


**Figure 2.** Power (curved) shear-strength model.

*Engineering Back-Analysis of Translational Slope Failures*

Field work for this project included the mapping of roadcut failures in the Palouse area during the summer and fall of 1996. Of the 15 sites described, three of the translational failures were selected for engineering back-analysis using the infinite slope method. Based on previous experience with Palouse silty clay soils, a dry unit weight of 89.3 pcf (1.43 tcm) and a specific gravity of 2.65 were assumed for the soils. Soil shear strengths for water contents of 20% and 25% (see Table 1) were used in the stability calculations. Results are summarized in Table 2.

The calculated safety factors indicate that application of a linear shear strength model does not accurately reflect field conditions. When soil cohesion values are used, the SF values all exceed 1.0. When they are reduced to zero, as is sometimes done in geotechnical engineering practice, the resulting SF values are all too low. However, when a power shear strength model is applied, the calculated SF values seem much more reasonable. Except for the very thin failure (0.18-m thick), the stability results for soil moisture at 25% indicate calculated SF values above 1.0 for unsaturated conditions and values dropping below 1.0 when perched ground water rises in the potential failure mass.

The effects of seepage forces have not been included in this analysis, but they will be incorporated into the next phase of the research study.

**Table 2.** Summary of back-analysis results for roadcut failures

| | | | | Calculated Factor of Safety | | | |
|---|---|---|---|---|---|---|---|
| | | | | Linear Model | | Power Model | |
| Location | Avg. Slope Angle (deg.) | H, Failure Thickness (m) | $H_W$, Height of Ground Water | w=20% (c=0) | 25% (c=0) | w=20% | 25% |
| US 95 S. of Eid Rd. | 37 | 0.64 | 0.0 | 2.13 (0.83) | 1.27 (0.29) | 1.86 | 1.14 |
| | 37 | 0.64 | 0.5H | 1.84 (0.60) | 1.16 (0.21) | 1.47 | 0.97 |
| | 37 | 0.64 | 1.0H | 1.57 (0.39) | 1.06 (0.14) | 1.09 | 0.78 |
| US 95 at Rudd Rd. | 38 | 0.46 | 0.0 | 2.60 (0.39) | 1.64 (0.28) | 2.02 | 1.34 |
| | 38 | 0.46 | 0.5H | 2.29 (0.39) | 1.52 (0.21) | 1.60 | 1.13 |
| | 38 | 0.46 | 1.0H | 2.01 (0.39) | 1.41 (0.13 | 1.18 | 0.91 |
| Eid Rd. at Lenville Rd. | 42 | 0.18 | 0.0 | 5.15 (0.70) | 3.60 (0.25) | 2.47 | 2.01 |
| | 42 | 0.18 | 0.5H | 4.74 (0.50) | 3.44 (0.18) | 1.96 | 1.70 |
| | 42 | 0.18 | 1.0H | 4.37 (0.33) | 3.28 (0.11) | 1.44 | 1.36 |