International Conference on Case Histories in Geotechnical Engineering

(1993) - Third International Conference on Case Histories in Geotechnical Engineering

02 Jun 1993, 2:30 pm - 5:00 pm

Evaluation and Remediation of a Small Landslide in Colluvium

D. T. Mooney
West Virginia University, Morgantown, West Virginia

J. J. Bowdes Jr.
West Virginia University, Morgantown, West Virginia

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 2.17

Evaluation and Remediation of a Small Landslide in Colluvium

D. T. Mooney
E.I.T., Graduate Student, West Virginia University, Morgantown, West Virginia

J. J. Bowders, Jr.
Ph.D., P.E., Associate Professor of Civil Engineering, West Virginia University, Morgantown, West Virginia

SYNOPSIS: A landslide in colluvium near Grafton, West Virginia was evaluated for cause and remediation. Monitoring was conducted for 15 months to observe further movements prior to remediation. The observed failure surface, slide geometry and groundwater conditions were used to back-solution for an effective residual friction angle (ϕ_r'). The ϕ_r' was found to agree well with index property correlations cited in the literature. Slope failure resulted from excessive pore water pressures due to seasonably high groundwater levels. Stability analyses using the back-solutioned ϕ_r' were performed to design and position seepage cutoff drains for slope remediation. As of this writing, September 1992, the drains have performed well and the slope has remained stable for three (3) years.

SITE DESCRIPTION

Site Location and Slide Description

The site of the slope failure is located in Taylor County, West Virginia approximately 1 mi. north of Grafton, on the east side of U.S. Rt. 119, at an elevation of about 1300 ft. A site plan is shown in Figure 1. The failure occurred in the backyard of a local resident, in late December 1987. The owner's residence, a two-story wood frame building, was constructed on a bench cut into the slope.

The slope rises behind the home (south) to an elevation of approximately 1450 ft. and descends northwardly to the stream valley at elevation 1200 ft. The slope averages 3.7(H):1(V). The area of the failure has a slope of 3.3:1, and was grass covered with several trees as shown on Figure 1. Forested areas bordered the slide to the east, south and west.

North of the slide area lay the owner's residence and driveway/parking area. Horizontal slide movement was to the north. A well defined scarp, oriented east to west, was formed on contour and the maximum vertical movement was about 1.0 ft. The scarp was located 50 ft. south of the owner's residence (Fig. 1). The slide area was located between two natural drainage courses. Consequently, infiltration and subsurface sources were the primary means for entrance of water into the slide area. During the investigation, the toe of the slide, near the driveway, was often saturated.

Objectives

The primary objectives of the project were to measure any continuing movements, determine the cause of the slide, its current factor of safety (FS), and finally, to recommend economically feasible remedial measures.

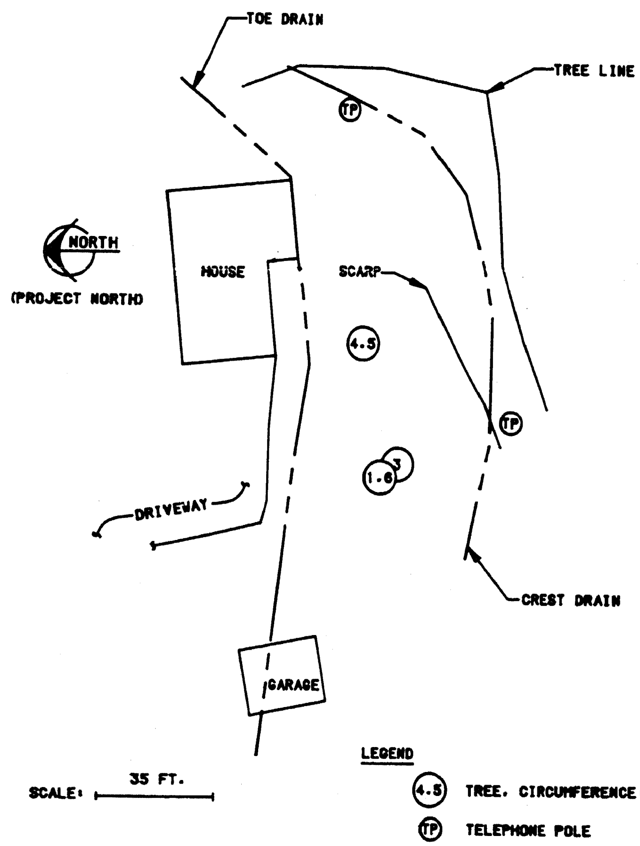


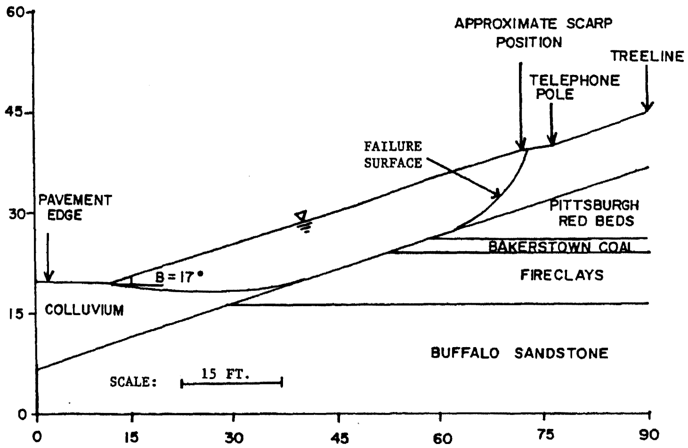
Figure 1: Site Plan

The investigation and analysis were conducted based on a review of pertinent literature, observations at the site, both measured, e.g., survey data, and interpretive, e.g., see Geologic Conditions, and limited sampling and testing.

Geologic Conditions

The slide area is located within the Central Allegheny Plateau Physiographic Province. Geology within this region is characterized by cyclic sequences (cyclothems) of coals, sandstones, shales, siltstones, claystones, and limestones (D'Appolonia, et.al., 1966).

The lithologic profile for the site was constructed from references (Cardwell,et.al., 1968 and Hennen and Reger, 1913) and limited exposures near the site. The profile was typical for the area, consisting of the alternating beds (cyclothems) as described by Cardwell, et.al., (1968), D'Appolonia, et.al., (1966) and Hennen and Reger, (1913). A key feature of the profile was the occurrence of a red shale layer (Pittsburgh Red Beds) near the elevation of the slide area, Figure 2. This sequence has been associated with many slides in WV (Hall, 1974).



EVALUATION

Monitoring for Movement

The first objective was to determine if movement of the slide was continuing. To this end, a surveying program was initiated using both angle intersection and terrestrial non-metric photogrammetry. Thirty-five points were placed in the slide area for monitoring. The conventional survey consisted of the establishment of a base line with endpoints on stable ground. From this reference the monitoring points, styrofoam balls, were located by arbitrarily establishing one baseline endpoint as having xyz coordinates of (5000,5000,500). The styrofoam balls were used to facilitate digitizing the photos during photogrammetric data reduction.

Photogrammetric surveying was conducted using a close-range, non-metric photogrammetric mapping system developed at West Virginia University (Ballantyne, et.al., 1987). Its use in this project was to further evaluate its ability to monitor slope movements. However, during several surveys, irreconcilable difficulties in identifying points on the photographs with those in the field lead to significant inaccuracies. Consequently, only the results of the conventional survey are discussed in this paper.

Four conventional surveys of the monitoring points were made in the fifteen month period (March 1988 to June 1989). Comparison of total movements from these surveys showed only about 0.3 ft. of movement between any two consecutive surveys. This magnitude of movement was approximately equal to the diameter of the styrofoam balls. Such consistent average total movement between any two consecutive surveys indicated that the apparent movement was within the inherent error in attempting to target the center of the styrofoam balls during each survey. Consequently, the data was interpreted as having recorded no further slide movements during the monitoring period.

Soil Investigation, Description, and Testing

Initial sampling was conducted on 22 Feb. and 26 May 1988. Sampling of site soil did not incorporate any soil test borings or auger probes. Initial soil sampling was confined to the upper 3 ft. of the slide mass. Hand and motorized augers were used to collect disturbed samples, neither could penetrate beyond a depth of 3 ft. Samples consisted of mixtures of soil from 1-3 ft.

In August 1990, a 10 ft. cut was made on the adjacent property for a house basement and was utilized as a test pit. A bag sample was collected from this area at a depth of approximately 7.0 ft. Visually, this soil was similar to that sampled earlier. The soil in the cut was clayey silt, slightly mottled with a relatively large fraction of angular gravel to cobble size shale and sandstone fragments. Also evident were small lenses of reddish-brown sand and silt. The lack of any visible structure within the exposed soil mass, the heterogeneity, with regard to grain size distribution and composition, and the morphology of the site indicated that the soil was colluvium.

Testing consisted of index property determinations for the site and adjacent property soils. A series of consolidated-undrained triaxial tests were performed; however, undrained analysis proved invalid and therefore these results are not presented. Table 1 presents the relevant test results.

TABLE 1 : Summary of Laboratory Test Results

	Sample Location	
	Site	Test Pit
Natural Moisture	24%	-
Specific Gravity	2.72	2.70
Optimum Moisture	-	17.2%
Max. Dry Density (pcf)	-	112.6
Liquid Limit	40%	34%
Plasticity Index	13	11
Percent Clay (<2μ)	23	18
Classification (USCS)	ML	CL
In-Situ Dry Density(pcf)*	-	102.5

*In-situ dry density at the site was measured by the liquid balloon method (ASTM D2167).

Stability Analysis

Using the measured undrained shear strength (700 psf), the calculated factor of safety was 3.9 for the observed failure surface (Figure 2). Thus an undrained (ϕ=0) analysis for the site was not valid. An effective stress analysis was conducted by assuming the residual strength ($c_r' = 0$, $\phi_r' > 0$, Skempton, 1964) was acting along the failure surface, then back-solutioning for a residual friction angle (ϕ_r'). This was deemed valid as shear strength in colluvium is often governed by slickensides from previous movements, across which the residual strength can be assumed to be mobilized (D'Appolonia, et. al., 1966; Skempton, 1964).

The failure surface was selected based on the observed scarp and toe position and the fact that failures in colluvium are often bedrock controlled (Jacobson, 1986; Pascucci, 1983; Varnes, 1978; and Hall, 1974). Depth to bedrock (8 ft.) was established based on excavations at the site for drainage installation.

Effective stress analysis for the failure surface was performed using the simplified Janbu method. A range of ϕ_r' was selected and the position of the groundwater table (GWT) over the failure surface was varied for each. The results are summarized in Figure 3.

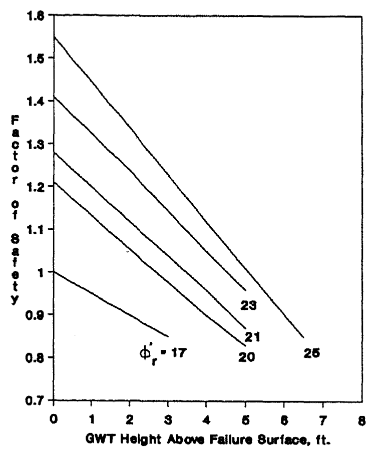


Figure 3: Results of the Effective Stress Analysis

Beverage and Yoakum (1980) gave GWT positions as being generally greater than 3 ft. below the surface in the area of the slide, i.e., the GWT would likely be at least 5 ft. above the failure surface. From Fig. 3 then, it is clear that ϕ_r' must be within the range of 23-25 degrees for marginal stability ($1.1 < FS < 1.2$).

The range of ϕ_r' (23-25 deg.) was checked against several published correlations of Atterberg Limits data and percent clay (<2μ) with residual friction angle. All the correlations could be considered to have given estimates within the margin of error for this study. The correlations with percent clay (<2μ) from Skempton (1964), for various clays and Collotta, et.al., (1989), for Italian Apennine silty clayey soils, produced values closest to the 23-25 degree range. Table 2 summarizes the estimates and Fig. 4 contains plots of the Collotta, et.al., (1989), and Skempton, (1964) data as well as that from Hall (1974).

TABLE 2: Correlation of ϕ_r' with Various Index Properties

Correlation	Estimate	Reference
%Clay (<2μ)	25-30	Skempton,1964
%Clay (<2μ)	24	Collotta et al., 1989
%Clay (<2μ)	28	Hall, 1974
PI	21-22	U.S. Army COE, 1988
PI	26	Voight, 1973
LL	19-20	Swanson & Jones, 1984
CALIP*	18-27	Collotta et al., 1989

* CALIP = $(\%clay,<2\mu)^2(LL)(PI)x10^{-5}$

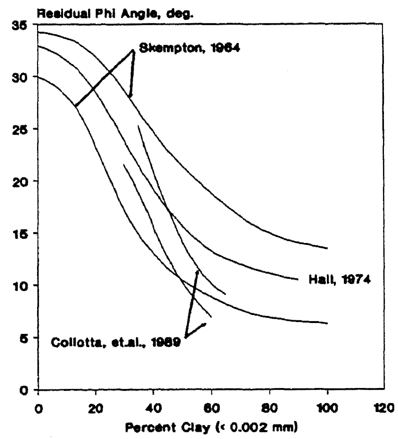


Figure 4: Correlations of Residual Friction Angle with Percent Clay (<2μ)

From the above data it can be concluded that a ϕ_r' of 23-25 deg. was acting at the time of the failure. Failure would have been induced by only a slight rise in the GWT. A similar condition was reported by D'Appolonia, et.al., (1966) for a colluvial slope in Weirton, West Virginia.

REMEDIATION

The proposed remediation included installation of subsurface flow cutoff drains and limited regrading to divert surface runoff. Recommended drain design was either perforated pipe placed into a trench with a geosynthetic drainage composite extending vertically from the pipe into granular backfill or a perforated pipe in granular fill, wrapped in a geotextile. Schematic diagrams of these designs are shown on Figure 5.

The intent of the cutoff drains was to intercept subsurface seepage and maintain the GWT < 5 ft. above the failure surface to obtain stability (Fig.3). It was recommended to install the drains to bedrock and extend the perforated pipes to discharge into the natural drainage courses to the east and west of the site. Figure 1 shows the geometry of the installed drainage. Spatially, the installation was satisfactory; however, the contractor wrapped the filter fabric around the pipe which can expedite geotextile clogging due to the limited surface area. Also, the authors were not consulted as to the selection of the proper fabric. Total cost to the owner was approximately $5600.

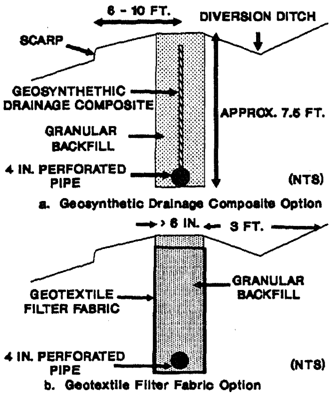


Figure 5: Recommended Cutoff Drain Designs

PERFORMANCE

Remediation was carried out and the slope returned to its original inclination (Fig. 2). Despite the variations from the design recommendations, the slope has remained stable for this geometry. Discussions with the owner indicate that he is satisfied with the slope's performance.

The writer returned to the site on 27 July 1992 during a light rain following a day of heavy showers. Outflow at the drains was measured and the turbidity of the outflow observed. Approximately 2-3 times more outflow was occurring at the east drain outlets than at the western ones. Effluent was very turbid (opaque in color) indicating that the filter fabric was allowing passage of fines. This may be a precursor to eventual clogging of the geotextile.

CONCLUSIONS

The following conclusions are drawn from the observations, testing and analysis performed during the course of this investigation:

1. The back-calculated residual friction angle ranged from 23-25 degrees. This was supported by the demonstration of FS of unity for GWT conditions likely at the time of failure.

2. The back-calculated residual friction angle as a function of plasticity and percent clay fraction agreed well with published values.

3. The remedial drainage system has lowered the groundwater elevation and maintained the slope in a stable configuration.

4. Turbidity in the effluent from the drains indicates some soil fines are migrating through the geotextile.

ACKNOWLEDGEMENTS

The writers would like to thank the owners, Mr. and Mrs. Leonard, for their cooperation in this project and Mike Runner and Bob Baker for the last survey.

REFERENCES

Ballantyne, J.D., Dean, D.R., and Thompson, B.L., (1987), "Monitoring Landslide Movement with a 35-mm Camera", In Transportation Research Record 1119, TRB, National Research Council, Wash., D.C., pp. 47-54.

Beverage, W.W. and Yoakum, T.D., (1980), Soil Survey of Harrison and Taylor Counties, West Virginia, USDA SCS, with WVU Agricultural Experiment Station.

Cardwell, D.H., Erwin, R.B. and Woodward, H.P., (1968), Geologic Map of West Virginia, WVGES, Morgantown, WV.

Collota, T., Cantoni, R., Pavesi, U., Ruberl, E., and Moretti, P.C., (1989), "A Correlation Between Residual Friction Angle, Gradation and Index Properties of Cohesive Soils", Geotechnique, 39(2), pp. 343-346.

D'Appolonia, E., Alperstein, R. and D'Appolonia, D.J., (1966), "Behavior of a Colluvial Slope", Proceedings, ASCE Conf. on Stability and Performance of Slopes and Embankments, U.C. Berkeley, pp. 489-517.

Hall, G.A., (1974), "The Development of Design Criteria for Soil Slopes on West Virginia Highways", Ph.D. Dissertation, West Virginia University, Department of Civil Engineering, 272pp.

Hennen, R.V. and Reger, D.B., (1913), County Reports: Marion, Monongalia and Taylor, WVGES, Morgantown, WV.

Jacobson, R.B., (1986), "Genesis and Distribution of Colluvium in Buffalo Creek Area, Marion County, West Virginia", In Transportation Research Record 1089, TRB, National Research Council, Wash., D.C., pp. 62-67.

Pascucci, V.N., (1983), "Landslides in Soils Overlying Franciscan Assemblage", ASCE Special Publication, Geological Environment and Soil Properties, pp. 167-182.

Skempton, A.W., (1964), "Long-term Stability of Clay Slopes", Geotechnique, Vol. 14, No.2, pp. 77-101.

Swanson, P.G. and Jones, J.S., (1984), "Design and Construction of Slopes in Potomac Formation Deposits", USGS Bulletin 1556, pp. 49-62.

Varnes, D.J., (1978), "Slope Movement Types and Processes", In Landslides: Analysis and Control, TRB Special Report 176, pp. 11-33.

Voight, B., (1973), "Correlation Between Atterberg Plasticity Limits and Residual Shear Strength of Natural Soils, Geotechnique, 23(2), pp. 265-267.