Geotechnical Investigation of an Embankment Slope Failure on the Campus of James Madison University, Harrisonburg, VA

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Abstract

On March 13, 2013, an embankment slope on the campus of James Madison University began to fail and was eventually in need of repair requiring the removal of the section of the embankment that failed, and the construction of a retaining wall in its place. An embankment slope should be designed in such a way that its factor of safety against failure is greater than 1, resulting in a stable and long-standing structure. The embankment in question has a gentle slope angle of 16.8° which is expected to have a high factor of safety with failure unlikely. This project is a geotechnical investigation to identify the causes of failure of such a gentle embankment slope. Intact samples of the embankment soil were collected and classified as SW-SC with 30%-40% gravel. Cohesion (c′) and angle of internal friction (ϕ′) values of 1665 lb/ft^3 and 13°, respectively, were determined using the direct shear test. After surveying the embankment, Slide 6.0, from the RocScience suite of geotechnical software, was used to determine the factor of safety based on Bishop's Simplified Method. Initial analysis resulted in a factor of safety of 7.6, suggesting other factors might have caused the failure. After obtaining precipitation data for the city of Harrisonburg from NOAA's National Climatic Data Center, it was found that a large amount of snow fell one week before the slope failure occurred and was piled from a nearby parking lot onto the head of the slope that would eventually fail. Along with snow increasing the load applied to the slope, a rise in the water table was also considered, but the resulting FS was still as high as 5.8. Additional scenarios such as the presence of a horizontal boundary with low c′ and ϕ′ values along the fill/residuum material contact at a depth of ~23ft, uplift caused by the infiltration of water into unrecognized tension cracks, and repeated stress applied to the head of the slope are possible causes of failure.

Data Collection

-Intact soil samples were obtained from the site and analyzed to find the properties used for USCS soil classification.

-An average unit weight, moisture content, percent of saturation and void ratio were calculated; Atterburg limits were determined and grain size analysis was conducted, indicating a well-graded clayey sand (SW-SC) with 30%-40% gravel (Fig. 1).

-Soil samples were subjected to direct shear testing to evaluate the shear strength of the soil. Three samples were tested using 4000, 12000 and 20000 lb/ft^2 of normal stress (σ_n). The σ_n and τ were plotted and showed a cohesion (c′) of 1664.9 lb/ft^2 and an angle of internal friction (ϕ′) of 13.84° (Fig. 2).

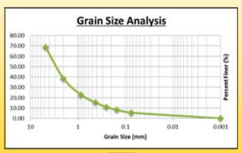

Fig. 1

Fig. 2

RocData (2010)

Lab Data Collected						
Property	Trials					Results
Unit Weight (lb/ft3)	110.13	111.09	119.83	120.57	n/a	120.57
Saturation (%)	60.1	64.3	70.1	70.9	n/a	70.09
Water Content (%)	17.53	18.89	16.17	16.04	n/a	16.04
Void Ratio	0.8	0.8	0.6	0.6	n/a	0.7
Liquid Limit (%)	29.39	30.13	28.83	29.51	29.64	29.5
Plastic Limit (%)	20.03	19.86	20.24	21.33	21.70	20.63
Plasticity Index	9.36	10.27	8.59	8.18	7.94	8.87
USCS Classification	SW-SC w/ gravel	SW w/ gravel	SW w/ gravel	SW-SC w/ gravel	SW w/ gravel	SW-SC w/ gravel

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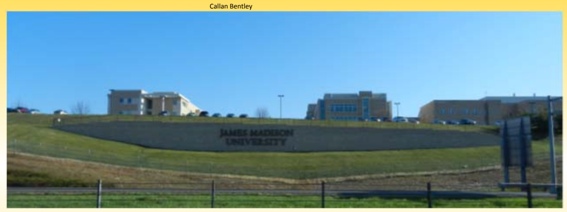

Analysis

-Analysis focused on determining likely variables present during failure and applying them to the slope stability calculation using Slide 6.0. Bishop's Simplified Method was used to determine the factor of safety.

-Cohesion (c′), angle of internal friction (ϕ′) and the unit weight (γ) were used to evaluate the soil strength based on Mohr-Coulomb criteria.

-The pre-defined failure surface was based on a photograph taken right before the major failure occurred.

-Factors of safety were calculated for four models:

1) Without the effect of surcharge or uplift due to saturation from ground water
2) A 270 lb/ft^2 load applied to the head of the slope to account for the snow pile
3) A raised water table to evaluate the worst possible scenario in terms of saturation
4) A model that included both scenarios 2 and 3

Results

Results using a non-circular (pre-defined) failure surface	
Models	Factor of safety
No effect due to surcharge or ground water	7.5 (Fig.3)
Water table raised to just under the surface of the slope	6.9 (Fig. 4)
270 lb/ft^2 load applied to head of slope by snow pile	6.4 (Fig. 5)
Inclusion of both scenarios	5.8 (Fig. 6)

The factor of safety is still too high to consider the slope dangerous or to explain why failure occurred.

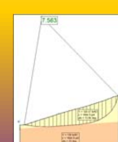

Fig. 3

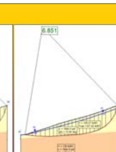

Fig. 4

Fig. 5

Fig. 6

Slide 6.0 (2010)

Conclusions

- The embankment in question is not steep enough to fail under normal conditions. Even when surcharge due to snow is applied and the slope is thoroughly saturated by a rising water table, the analysis still shows a high factor of safety. This means other factors contributed to its instability and eventual failure.

Possible Causes of Failure

- Standard penetration data provided by Froeling and Robertson, Inc. helped indicate a boundary between the fill that was used to construct the embankment and the underlying residuum soil (Fig. 7 and Fig. 8). The residuum is much denser than the overlying soil and has a higher angle of internal friction. The failure surface could have followed this boundary due to possibly weak residual strength.

-Repeated loading each winter from snow piles could have destabilized the slope and created tension cracks. When the soil became saturated in March 2013 after days of high precipitation (Fig. 9), water could have filled the tension cracks and created uplift between the fill and residuum. This uplift would substantially lower friction between the two materials and, combined with the vertical stress applied by the snow pile at the head of the slope, could be the most likely cause of failure.

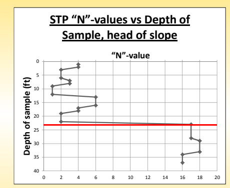

Fig. 7

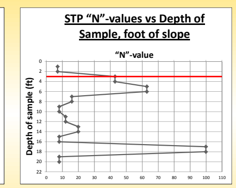

Fig. 8

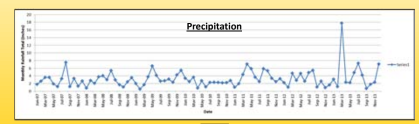

Fig. 9

National Climatic Data Center. NOAA

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