Slope Stability Analysis of Mass Wasting Prone National Road Cuts in Samar, Philippines

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Abstract: Landslides in Samar are more frequent along road cuts or altered natural slopes. This paper explores some of the identified landslide prone roads sections from Catbalogan City to Sta. Rita, Samar. Road cut profile was determined through survey and soil analysis. This information was used in a computer aided slope stability analysis. Of the three sites examined, only the road in the vicinity of Laygayon, Pinabacdao, Samar was identified to have potential for another road slip specifically when soil has high saturation and road is receiving heavy surcharge load. The other two sites low susceptibility to a massive landslide. There is a need to validate the leading causes of previous landslides along the national road at Brgy Silanga, Catbalogan City and Jia-an, Jiabong, Samar. A thorough geotechnical investigation for Laygayon, Pinabacdao area is needed to identify the best intervention before introducing slope stability intervention.

Keywords: precipitation, rain-induced landslides, slope alteration, slope protection, road design

1. Introduction

Mass wasting (more commonly known as landslide) is one of the most damaging types of disasters and has caused a large number of casualties, and economic loses (Dai et al., 2002). Landslides are observed along sloping terrains, and many factors trigger the risk for its occurrence. The triggering agents are both natural and human-induced. Some of the natural triggering agents include rainfall, earthquakes, and undercutting of slopes by fluvial, coastal or weathering processes. Landslides attributed to human activity include explosions, slope cutting, slope loading (with buildings, materials or water) or drainage systems that lead to a change of soil moisture regime (Crozier & Glade, 2005). There is a significant number of landslide occurrences because of human alterations of slopes such as those made for roads (Erginal et al., 2008; Nayak, 2010). At the start, the slopes may be stable, but due to the confluence of other triggering factors such as precipitation and earthquakes, soil fails. The instability is because saturated soils have lower shearing strength capacity, making it easier to fail (Zydron, & Dqbrowska, 2012; Dafalla, 2013; Blahova et al., 2013).

The Philippines being a tropical country receive so much precipitation especially during inclement weather like during typhoons. There were two days in December 2014 where rain was more than 300mm (Orale, 2015). There were occasions when continuous rains would have cumulative precipitation of more than 700mm rain. Extreme precipitation results into landslides such as what happened in Leyte and Southern Leyte which claimed more than 5,000 from landslides (Jadina, 2012). Road cuts are specifically landslide susceptible. Sometime in September 2018, a
total of 30 road sections in Regions I, III and Cordillera Administrative Region (CAR) in the Philippines remained closed due to landslides with a total estimated cost of about PHP 2.273 billion (DPWH, 2018). In the case of Second District of Samar, Philippines, landslides are triggered mainly by continuous and heavy rainfall. Last December 2014, a road cut failed killing 23 people in the aftermath of Tropical Storm Jangmi (NDRRMC, 2015).

Some landslide risks can be mitigated using engineering solutions. In many parts of the country, some roads keep on failing due to mass wasting despite millions-worth of slope protection. Most slope protection strategies are costly that a thorough investigation is necessary to design a more effective strategy.

2. Objectives

The study aimed to list road sections in the Second District of Samar that have slip failures or encountered landslides, characterize selected sites and determine slope failure susceptibility.

3. Methodology

3.1 Research Design.

This paper deals with the investigation of geotechnical properties of soil that are prone to landslide. The profile of the landslide-prone areas was examined through actual site visits. All soil samples were subjected to laboratory testing to determine geotechnical characteristics of soils. Secondary data were used to explain phenomena and capture other sites’ conditions. Maps were taken from Google Map, NAMRIA and DPWH. Interview with some engineers who have knowledge about road design and implementation were also performed. Slope stability analysis used GEO5 software.

3.2 Locale of the Study

The field studies were along National Highway from Catbalogan City, Samar to Sta. Rita, Samar. The sites considered are the top three with the most number of recorded failures according to DPWH. The report showed that road sections with the most number of slope failures documented are in Silanga, Catbalogan City, Jia-an, Jiabong, Samar and Laygayon, Pinabacdao, Samar as shown in Figure 1.

Figure 1. The Three Mass Wasting Cases of the Study (Catbalogan, Jiabong, and Pinabacdao Samar)

3.3 Sampling Procedure and Data Gathering

Data collected about the site are both primary and secondary. A site evaluation was performed which involves topographic survey, soil sampling, and soil testing. Data from the survey was used to determine sites’ profile. Soil tests were carried out to determine the physical and geotechnical properties of representative soil samples. The test samples were prepared following
different ASTM codes as per the test requirement. Two sets of soil samples (disturb and undisturbed) in every location extracted at a depth of 0.5m – 0.8m for the disturbed and 0.8m – 2.2m for the undisturbed. Samples were brought to a DPWH registered soil laboratory and to SSU Soils and Materials Testing Laboratory. Properties like cohesion, the angle of friction, permeability coefficient, density (unit weight) of soil, water content, liquid limit, plastic limit and plasticity index, specific gravity, porosity, and grain size distribution were determined. Soil testing standards used are ASTM D 2216-90 for moisture content, ASTM D 4318-95a for Atteberg limits, ASTM D 854-92 for specific gravity, ASTM D 2937-92 for density test, ASTM D 2434-68(2006) for permeability test, and ASTM D 3080 / D 3080M-11 for the direct shear test.

3.4 Data Processing and Presentation

Data from the survey and soil testing were used as inputs Geo5 Slope Stability software. This program is capable of analysis of embankments, earth cuts and many others using various methods. Bishop analysis was used to determine the factor of safety of the identified slope. Data were presented in terms of tables and diagrams. Print screen of the report made via the Geo5 software was also shown.

4. Results and Discussion

Samar is expected to experience landslides specifically along road cuts (Orale, 2006). There are about 50 recorded occurrences of mass wasting events in (Western) Samar according to DPWH Samar Second District Engineering Office from the year 2014 to 2017. These are found along K0786+000 (Catbalogan Samar) to K825+000 (Sta. Rita, Samar) as shown in Figure 2 and enumerated in Table 1.

Figure 2. Mass Wasting Cases in Samar

4.1 Engineering Profile of Road Cuts.

Samar is mountainous; most of its roads are constructed along slopes or on top of the hills. The governing authority when it comes to design standards in the Philippines is the Department of Public Works and Highways (DPWH). According to DPWH (2017), the slope ratio shall be 1:1 to 1.5:1 (45° to 34°) for common type of materials, 0.5:1 to 1:1 (63° to 45°) for soft/rippable rock and 0.25:1 to 0.5:1 (63° to 76°) for hard/solid rock and the minimum fill slope is 1.5:1. Distinguishing what is a common material, soft or hard and intact rock is left to the appreciation of the design engineer. This information can only be based on
actual soil Testing to determine soils properties including soil strength parameters which are crucial in identifying what is the stable slope. The DPWH Standard Specifications for Highways, Bridges, and Airports does not explicitly provide a categorization of the different type of rocks/soil. Soil exploration is not a widely practiced activity in road construction primarily because of the cost, say's one

Table 1. Mass Wasting Occurrences Along Road Cuts in 2nd District of Samar

<table>
<thead>
<tr>
<th>Location</th>
<th>Address</th>
<th>Description</th>
<th>Rating (Intensity and Frequency)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. K0790+746 – K0790+808</td>
<td>Brgy. Iguid, Catbalogan City, Samar</td>
<td>Major Road Slipped</td>
<td>4</td>
</tr>
<tr>
<td>2. K0793+500 – K0794+231</td>
<td>Brgy. Silanga, Catbalogan, City, Samar</td>
<td>Major Road Slipped</td>
<td>6</td>
</tr>
<tr>
<td>3. K0795+300 – K0795+545</td>
<td>Brgy. Pupua, Catbalogan, City, Samar</td>
<td>Road Slipped</td>
<td>4</td>
</tr>
<tr>
<td>4. K0801+000 – K0801+035</td>
<td>Brgy. Mercedes, Catbalogan, City, Samar</td>
<td>Large volume of landslide</td>
<td>1</td>
</tr>
<tr>
<td>5. K0801+000 – K0801+035</td>
<td>Brgy. Guindapunan, City, Catbalogan, Samar</td>
<td>Major Road Slipped</td>
<td>2</td>
</tr>
<tr>
<td>6. K0805+350</td>
<td>Brgy. Socorro, Catbalogan, City, Samar</td>
<td>Road shoulder slip</td>
<td>1</td>
</tr>
<tr>
<td>7. K0806+680</td>
<td>Brgy. Lagundi, Catbalogan, City, Samar</td>
<td>Road shoulder hanging</td>
<td>1</td>
</tr>
<tr>
<td>8. K0811+000 – K0811+035</td>
<td>Brgy. Jia-an, Jiabong, Samar</td>
<td>Large volume of landslide</td>
<td>5</td>
</tr>
<tr>
<td>11. K0835+000 – K0835+006</td>
<td>Brgy. Mogdo, Hinabangan, Samar</td>
<td>Major road slip</td>
<td>1</td>
</tr>
<tr>
<td>12. K0842+020 – K0842+024</td>
<td>Brgy. Inobangan, Hinabangan, Samar</td>
<td>Major road slip</td>
<td>1</td>
</tr>
<tr>
<td>15. K0863+150 – K0869+000</td>
<td>Brgy. Pahug, Sta. Rita, Samar</td>
<td>Minor road slip</td>
<td>2</td>
</tr>
</tbody>
</table>
DPWH engineer. If it does, the number of test sites is limited; decision is again left to the appreciation of the designers/engineers. Most often than not, slope protection is based on the perceived need and not based on scientific evidence and engineering design. The need for geotechnical exploration today is far more practiced than before, shared by another engineer.

![Figure 3. Cross-sectional Profile of Site 1 (Brgy. Silanga, Catbalogan City)](image)

Figure 3. Cross-sectional Profile of Site 1 (Brgy. Silanga, Catbalogan City)

![Figure 4. Cross-sectional Profile of Site 2 (Brgy. Jia-an, Jiabong, Samar)](image)

Figure 4. Cross-sectional Profile of Site 2 (Brgy. Jia-an, Jiabong, Samar)

![Figure 5. Cross-sectional Profile of Site 3 (Brgy. Laygayon, Pinabacdao, Samar)](image)

Figure 5. Cross-sectional Profile of Site 3 (Brgy. Laygayon, Pinabacdao, Samar)

The road cut in Brgy. Silanga is shown in Figure 3. It has a 10 meters road width, a cut slope ranging from 50° to 59° and 11 meters height following the DPWH order. Part of the soil cut was used as a filling material on the other side of the slope which is steeper. The slope of the fill section of the road is approximately 60°. The road cut of Site 2 is shown in Figure 4. It has a 10 meters road path; a cut slope ranges from 45° to 55° and 11 meters height of cut slope following the DPWH order. A smaller fill section was noted. Site 3 (Brgy. Laygayon, Pinabacdao, Samar) road cut is shown in Figure 5. It has a 10 meters road path; a cut slope ranges from 45° to 50° and 5 meters height of fill area following the DPWH order. This site has experienced multiple failures in the past.

4.2 Topography of the Study Sites

Samar province is hilly and mountainous ranging from 200 to 800 meters high. Slopes are generally steep and bare of trees, mostly covered with grasses. Run-off rainwater on these slopes is substantial and can cause substantial flooding in lowland areas. Most of the roads are found along slopes or on top of it.

Shown in figures 6 to 11 are the study sites and pictures of the road cuts. Site 1 is a coastal zone where one side of the road is a ravine subjected to the action of the waves. A retaining wall has supported the zones that have experienced mass wasting. Shown in Figure 7 is the first site situated 11°49’11.54” N and 124°50’19.63” E. The east side of the road is a cut portion with a slope greater than 60°. From the base of the road to the top of the slope is more than 11m, higher than what was stated in the DPWH order. The current slope is a product of constant erosion of the area, specifically because it is facing the sea. The road surface is about 8 meters above sea level. On the west side is a near vertical retaining wall made of concrete that extends to the beach floor subjected to constant wave action. The beach floor has a very gentle slope (average of 2 to 5°). The beach floor has an almost similar type of rock eroded by wave action.
Study site number 2 is within the vicinity of Brgy. Jia-an, Jiabong, Samar. The site is about 2.2 km from Jiabong proper, with an elevation of approximately 88 m from sea level and coordinates of 11°45′46.74″ N, 124°56′15.63″ E. The slope on the east side is relatively gentle. The site has been identified as a landslide-prone area, but no recent recorded failure. The average site slope (yellow line in Figure 9) of the entire hill (from the lowest level to elevation 155) ranges from 4.76° to as high as 23.96°. The road is found at an elevation 88 with slopes on both sides of about 18° to 19°. Other than the landslide-prone marker on the roadside, no other indicator was noticed during the assessment. The area is mostly covered with grasses and very few trees.

Study site number 3 is within the vicinity of Brgy. Laygayon, Pinabacdao, Samar. The study area is located about 10.8 km from Pinabacdao proper. It is situated at 11°32′14.79″ N, 125°01′12.14″ E with an elevation of approximately 138 meters from
sea level. The site is relatively flat with a little hill on the east side. The road had failed six times according to DPWH records due to mass wasting. To date, the road has been moved at least three times as one of the approaches used to manage road foundation problem.

Figure 11. Line AA of Figure 10 (Site 3: Brgy. Laygayon, Pinabacdao, Samar)

4.2 Soil Profile of the Study Sites

Topsoil of Brgy. Silanga, Catbalogan (S1) was found to be clay loam over a thick silt rock layer (see Figure 12). The soil in Brgy. Jia-an, Jiabong, Samar (S2) was also considered to be a clay loam while in Brgy. Laygayon, Pinabacdao, Samar (S3) the soil present is Faraon clay.

The topsoil in S1 is less than one meter thick categorized as clay-loam. The soil is held up by some vegetation adding a certain level of stability. The clay-loam layer sits on top of a thick layer of greyish shale. Shale rock is a type of sedimentary rock developed through compaction of clay and silt types of soil. Depending on the volume of materials in the rock matrix, the shale may be classified as clayey shale, silty shale, sandy shale or a black shale (Yagiz, 2001). Compacted shale is a soil-like rock that easily breaks along thin bedding planes (Schon, 2015; Asef & Farrokhrouz, 2013). The shale in the study area has Jar Slake Index of 2 (out of 6 levels), meaning, the rock slowly break and forms many chips or both.

Shale creates more landslide problems than other earth materials as it absorbs the excessive volume of water and in slopes resulting in the reduction of soil shear strength causing it to fail (Yagiz, 2001). This phenomenon is true to Samar as observed in many parts of the National Highway. The study site is regularly filled with eroded debris, first from the slaking of the shale then followed with the top-soil fall.

Figure 12. Soil Profile (L-R; S1, S2 and S3)

Table 2. Geotechnical Properties of Soil

<table>
<thead>
<tr>
<th>Site</th>
<th>γ (kN/m³)</th>
<th>φ (kN/m³)**</th>
<th>C (kN/m³)**</th>
<th>k (cm/sec)**</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1*</td>
<td>14.48</td>
<td>3.29</td>
<td>2.55 x 10⁴</td>
<td>2.07</td>
<td>2.20</td>
</tr>
<tr>
<td>S2</td>
<td>14.29</td>
<td>36</td>
<td>2.55 x 10⁴</td>
<td>2.12</td>
<td>2.12</td>
</tr>
<tr>
<td>S3</td>
<td>14.62</td>
<td>34</td>
<td>4.14 x 10⁴</td>
<td>2.07</td>
<td>2.07</td>
</tr>
</tbody>
</table>

*of the eroded soil only
**undisturbed sample

The cohesion of the soil from S2 and S3 are typically clay, but its angle of friction is slightly higher than normal clay. There were no C, K for the shale layer of S1. The clayey soils from S2 and S3 are more permeable than a typical clay, silt, silty sand, silty clay, or silty sand which usually have
permeability between $10^{-9}$ to $10^{-5}$ cm/sec. These suggest that the soil is capable of receiving more water which has an adverse effect on soils shear capacity.

4.2 Slope Stability Analysis of the Study Sites

Identified causal factors to landslides include ground conditions, geomorphological processes, physical processes and man-made processes (Aydilek & Ramanathan, 2013). Under these broad categories includes vegetation removal, erosion, steady seepage, sudden drawdown, intense rainfall, earthquakes, external loading, and construction activities (Aydilek & Ramanathan, 2013; The Contractor, nd). Unlike in gently sloping areas, hilly or mountainous regions will require alteration of natural slopes. A slope remains stable until the factors that make it stable is altered (Zabuski, L et al., 2017; Picarelli & Abolmasov, 2014; CDC, 2003).

Site 1 is a typical road cut in Samar. It is composed of gray shale and capped with a thin layer of clayey soil (left picture of Figure 12). According to DPWH engineer, this type of rock is categorized as intact rock and with recommended slope ranging 50-59°. But due to constant weathering, the slope has changed. This constant weathering will eventually lead to the creation of an overhang, which later may collapse as shown in Figure 13.

Site 2 and site 3 is different from site 1. These sites are made of loose materials (see the middle and right picture of Figure 12) which can readily absorb water thereby weakening its shear strength. Slope stability analysis for site 2 showed that even during maximum saturation (90%) and with a pressure load from a heavy truck of about 800 KPa, the site will not fail. The calculated Factor of Safety (FOS) of an optimal analysis is about 2.63, which means slope is stable. There is a need to further the investigation of why the site in the past has failed. Based on DPWH records, there were at least five times the site had a "large volume landslide." A soil exploration to discover soil layers in the area is necessary to discover the cause of previous landslides.

Site 3 found along km 0862+750 have recently failed. Based on records of DPWH, there have been six occasions that the site has a "major road slip." Based on the analysis, this site is still unstable given the existing conditions available. An optimal analysis revealed that the FOS is critical with the head of the slip circle found within the road section itself (see Figure 15) near the road itself. The simulations take into consideration a saturation level of 90%. These simulations did not consider the likelihood of reduced soil shear strength due to previous landslides. There were several sites in Pinabacdao, Samar with similar

Figure 13. Most Likely Type of Failure in Site 1
Figure 14. Slope Stability Analysis for Site 2, Jia-an, Jiabong, Samar. (Top Picture: Optimal Analysis, Rest: Other Failure Scenarios)

Figure 15. Slope Stability Analysis for Site 3 (Optimal Analysis)
characteristics which were also subject to landslides recently that were not in the list. This means that the site will likely fail again unless a well-designed intervention is implemented. Figure 16 shows that interventions such as construction of retaining wall as well as piles but the same was not enough to prevent road failure.

![Retaining wall & piles](image)

Figure 16. Previous Intervention at Site 3 (Laygayon, Pinabacdao, Samar)

The kind of intervention must take into consideration other parameters such as the extent of damage to soil profile/structure due to previous failures, the subsurface water conditions specifically the presence of weak layer and the aquifer systems. It can be noted that Site 3 and other sites in Calbiga, Samar to Pinabacdao, Samar have failed even with support infrastructures such as piles and retaining walls. Surcharge load from passing vehicles which are dynamic in nature may be considered in the analysis. The dynamic load may pose additional stress not commonly included in road slope stability analysis.

5. Conclusion and Recommendation

Because of the topography, geology, and climate of Samar, landslides or slope failures of roads are very much likely. There are identified areas to have experienced the massive type of road slope failures but are not very evident. Of the three highest number of road-slip failures, only one appears to have the ideal conditions to fail. The Laygayon, Pinabacdao, Samar road slip, for example, has been the subject to several significant interventions such as piles and retaining walls but still has failed.

There is a need for further analysis of the leading causes of landslides in site 1 and 2. A review of interventions made is necessary for site 3, and a more comprehensive geotechnical analysis is required before the identification of the next response to be recommended.

6. Bibliography


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