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Monitoring the stability of highway cut slopes utilizing drone photogrammetry

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ABSTRACT

Roads have long been an integral asset for civilization. A lot of things have been said, drawn and shown regarding what and what not to do while drafting the routes. No matter how conscientious they are planned and laid out, mishaps occur while placing them on terrain. The demand to tie two points with the shortest possible route, create cut slopes and embankments. They both are bolstered with engineering reinforcements, however the cut slopes, which are always in sight while driving through, gave way in majority of time if those engineering principles are not sufficiently applied. Slope failure occurs when the downward movements of material due to gravity and shear stresses exceeds the shear strength. Therefore, factors exploiting these critical dynamics, increase the chances of slope failures. Six crumbling cut slopes en route to Karabuk from Kastamonu province were investigated in terms of the stability dynamics. Through stereo photogrammetric evaluation, digital surface models, which were sensitive to 0.08 to 0.22 m ground resolutions were constructed. Additionally, soil samples to understand the physical and chemical compositions of the cut slopes were taken from two depths; 0-15 cm and 15-30 cm. Analyses of the models showed that the considerable parts of all of the cut slope areas were graded over 87%, which was the collapse threshold for unprotected or untreated soil surfaces. Lab analyses showed that the binding agents e.g. organic matters, lime, etc. were rather weak because no vegetation to stabilize the already steep cut slopes was present on any of them.

1. INTRODUCTION

Roads are the foremost infrastructural need for the societies to establish secure transportation and commerce. The principle road building approach is to connect two points with the shortest possible route ((Umrao et al. 2015), however, geologic and topographic conditions are not always favorable for this principle to be laid down, flawlessly. In order to draft and materialize a road route, the mentioned difficulties must be eliminated so that a reasonably through right of way is constructed (Gorcelioglu, 2004). Due in fact to the geologic and topographic terrain conditions faced in majority of our country, the routes are planned and constructed over not so ideal ground, thus many cut-slopes and the corresponding embankments have to be devised to finalize the roadbed, effectively. In order to control the slope stability problems resulting from the steep slopes during construction, engineering solutions must be entegrated into the projects (Senturk, 1989). Six such cut slopes, which have long been eroding especially during wet seasons, were investigated to determine the underlying reasons trigerring the mass movements year after year. Drone photogrammetry was used to efficiently model the slopes along with the soil analses for composition and physical characteristics.

2. STUDY AREA

Six cut slopes varying in size on Kastamonu-Karabük intercity road were investigated for slope failure in this study.

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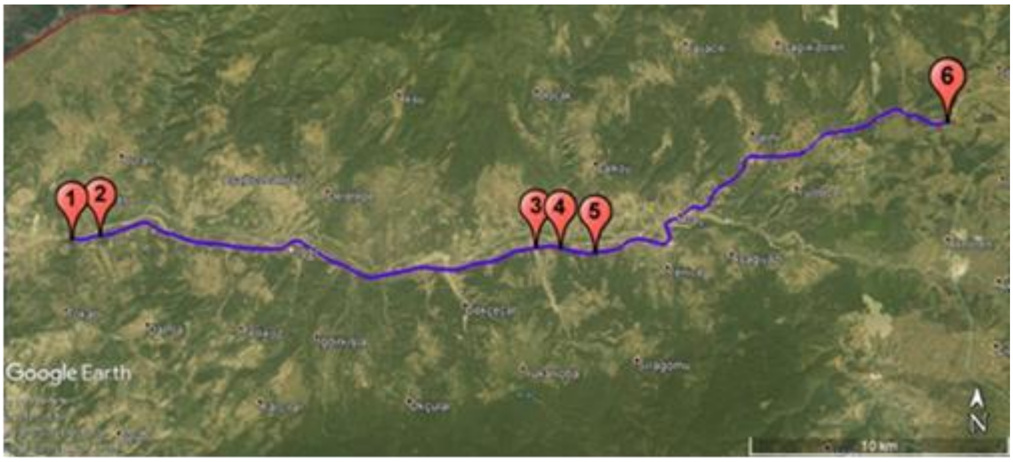

Figure 1. Studied cut slope locations on the intercity road en route to Kastamonu from Karabuk

3. METHODOLOGY

Each cut slope was individually flied over utilizing a preprogrammed drone, DJI Phantom 3 Professional, to model the surface(s), meticulously. Simultaneously, soil samples were collected from the upper undisturbed edges of the slope areas. The samples were taken from two depths, 0-15 cm and 15-30 cm to analyze the physical and chemical compositions of the slope surfaces. In majority of the studies conducted to assess the slope stability, the term, factor of safety, (FS), is rather important in better understanding and definition (Duncan et al. 2014). When FS is explained in terms of the slope gradient intervals; "stable", "critical range" and "fail certain", can be grouped as followed: < 87%, 87% < x < 148% and 148% < , respectively (Zakaria et al. 2018) (Figure 2).

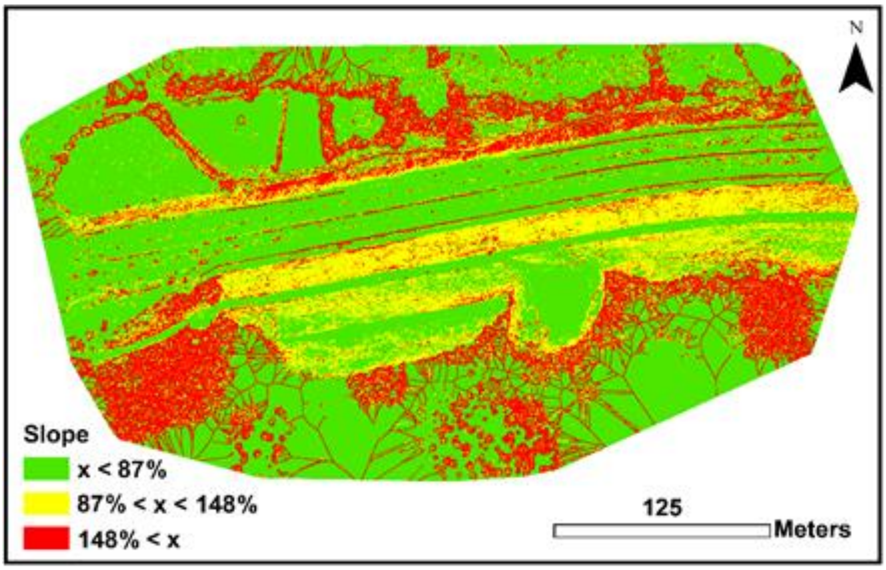

Figure 2. Site 2 slope classification resulting from 0.09 m DSM

4. RESULTS

Six digital surface models (DSM) with relatively high spatial resolutions; 0.22 m for site 1, 0.09 m for site 2, 0.08 m for site 3, 0.1 m for site 4, 0.14 m for site 5 and 0.15 m for site 6, were constructed for slope classification analyses. Slope classes were generated as a function of the vertical elevation gain/loss within a given horizontal distance, thus each slope area was dissected according to the slope classes specified above, and the acreages were calculated, accordingly (Table 1).

As clearly visible and suspected from the visual observations, the cut slopes were unfortunately not constructed to stay stable in the long run. The acreage amounts regarding the "critical" and "fail certain" slope classes were obviously less than the ones aggregated in "stable" slope class in all cut slope surfaces, however, we all know how erosion which might innocently start in a rather small part of a catchment, could trigger large mass movements when the favorable conditions materialize. When the acreages were compared percentagewise, stable parts vs. unstable parts, the results were nowhere near innocent. The worst was in site 6 in which exactly one third of the entire slope area was on the unstable slope classes. The least affected one still amounting almost one fifth of the entire slope area on the unstable slope classes was site 5. It was not clear from the results of this study that the very existence of these dangerous slope classes was initially there or were gradually developed due in fact from the relentless atmospheric effects hammering on the bare slope surfaces. However, if this conclusion was the result of the imperviousness during the construction or unavoidable circumstances due to some other constrains e. g. the need to remove more vegetation beyond the upper reaches of the slopes to lengthen the slope surfaces, and the excessive amount of surface stripping needed to compensate the steepness, the current situation in the studied cut slopes or in many others alike has not been good in terms of the functions assigned to them in the first place.

Soil analyses conducted on all of the cut slope surface areas showed that clay heavy two investigated depths lacked rather less binding agents, organic matter and lime. The vegetation removed during the grading left the slope surfaces vulnerable to precipitation. The already weak organic matter formed under the coniferous stands was quickly washed away when the slope surfaces were prepared, terraced or graded. Generally, sponge like this top coat on soil surfaces limited the surface runoff better dissipating the water. The same organic matter on unstable slopes, on the other hand, was quickly ravaged by the same water.

Table 1. Cut slope surface area classifications based on the “stable”, “critical” and “fail certain” slope percentages

	Site 1 classification	Site 2 classification	Site 3 classification
Slope (%)	Acreage (m^2)	Acreage (m^2)	Acreage (m^2)
x < 87	214144.72	86265.87	53830.06
87 < x <148	21279.15	8250.08	4822.65
148 < x	37574.47	9693.67	7132.64
Total area (m^2)	272998	104210	65785
	Site 4 classification	Site 5 classification	Site 6 classification
Slope %	Acreage (m^2)	Acreage (m^2)	Acreage (m^2)
x < 87	61416.33	119506.33	70197.90
87 < x <148	6707.54	8687.10	7343.13
148 < x	11507.16	13875.62	15692.90
Total area (m^2)	79631	142069	93234

5. DISCUSSION and CONCLUSION

When the cut slopes were left to stand on their own, they were mostly furnished with engineering reinforcements to keep them from crumbling if the gradients were steeper than the proven safe. However, these have been rather expensive protective measures, which have been overlooked frequently. When either the cut slopes or the embankments were left untreated, they would eventually erode jeopardizing the lifespan of the main infrastructure that they had actually been erected to protect. Whenever vegetation was removed on flat or inclined surfaces, erosion has become a problem varying in severity depending on the steepness. Six cut slopes investigated in this study were just manifesting the types of such adversities. The soil eroding from the slope surfaces was overflowing the retaining walls installed at the slopes’ bottom heels. Although furnished with some terracing, they were all on bare soil without any protective measure. Such slopes must first be seeded immediately after construction to form a perennial shrub cover with long root systems. A balanced mix of deciduous and coniferous tree species must also be planted to bolster the protection in the long run. Drones have been very powerful and practical in purpose build such case studies. The precision they provided, was only surpassed by light detection and ranging (LIDAR). For periodic status monitoring, there is no better priced alternative to drone remote sensing today. All considered, the cut slopes and embankments must be built with the utmost attention they deserve because there are means to capture the misdeed, flawlessly.

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