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SLOPE STABILIZATION USING LOW DENSITY POLYETHYLENE

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Landslides still concern transportation agencies. In 2017, the Big Sur coastline roadway in Monterey, California was buried under a landslide that displaced over 6 million cubic yards of mud. Though slope stabilization techniques have been successfully used in the past, the Big Sur landslide has highlighted the necessity for innovation. Through this paper, a new slope stabilization technique is proposed using Low Density Polyethylene (LDPE) pins, used tires and vetiver grass. The paper includes a comparison of a retaining wall (a traditional slope stability alternative) with the proposed new technique. This includes stability analyses considering traditional and the proposed method. The analysis includes checking for overturning, sliding and bearing capacity failure for retaining wall and slope stability analysis for the proposed slope stabilization. The paper also includes cost comparison between the two alternatives. The results indicate that the proposed technique is stable and very comparable to traditional methods. Because the method uses waste material the proposed method costs significantly less than traditional approaches.

Keywords: Retaining walls, Vetiver grass, Used tire, Landslide.

1 INTRODUCTION

Rockfall, slope failure, shallow debris movement, or a combination of all three disturbances can be deemed a landslide. Natural and man-made factors can trigger landslides, including but not limited to, gravity, earthquakes, weather changes, erosion, and mining. Landslides can inflict significant economic losses, damage to infrastructure, loss of life and property, altering natural landscapes and impacts to various ecosystems.

In this research, special emphasis has been made on promoting green alternatives. Millions of tires need to be managed to be recycled as reusable products, but a significant portion of those unrecycled used tires end up in landfills. Similarly, plastic waste needs treatment to be transformed in to reusable form to ensure that they do not end up untreated and eventually affect the environment. Agencies are concerned about dealing with such waste. In this research, the waste materials are being proposed for use to help agencies deal with waste and replace the traditional material to reduce cost.

In this research, an innovative approach is proposed to stabilize slopes in landslide-prone areas. This paper includes stability analyses of the proposed technique to ensure stability and appropriateness of the proposed method. The proposed method uses Low-Density Polyethylene (LDPE) pins and vetiver grass to stabilize slopes and tire wall for retaining slopes. Big Sur landslide is used as a case study which occurred between Carmel Highlands and Santa Lucia Mountain moving about a million tons of rock and dirt on a coastal highway and into the sea.

The results indicate that the proposed method is stable and economically cheaper than the traditional method.

1.1 Components of the Proposed Technique

The proposed method has three components as follows:

(i) LDPE Pins: LDPE is made out of waste plastic. The material is inert and does not react easily with the natural environment. The pins can be nailed using special equipment such as drilling rigs (by Davey-Kent) and hammer drills (by Krupp HB28A Hydraulic). This equipment have been used in Texas for Red and Beaumont clays in Texas (Khan, 2013) Driving LDPE pins displace soil particles to densify treated soil mass (Loehr *et al.* 2013).

(ii) Tire Walls: A wall made by arranging used tires against the sloped surface can withstand earth pressure from behind the wall (lwhome.org). Constructing tire retaining wall will require filling tires with high-density clay and then compacting each tire with a sledgehammer or pneumatic tamper.

(iii) Vetiver Grass: These are a special species of grass and characterized by deep roots. These grasses can be helpful in several ways including sloe stabilization (Truong *et al.* 2008, Gordon and Sherar 2018) that can be used to benefit the engineering community. These grasses will be able to hold the top layers of soil and prevent soil erosion and slope stability (Ni *et al.* 2018).

2 LITERATURE REVIEW

Literature review shows that several slope stabilization methods are proposed. Harabinova (2017) conducted a slope stability assessment and found the most unfavorable slip surface. The researcher proposed reinforcing method using geogrids and ground anchors. Pons *et al.* (2018) assessed the stability of earth retaining wall and suggested gabion walls for heights 1m to 6m. For retaining earth with heights greater than 4.5m, the authors recommended cantilever retaining walls. Zamiran *et al.* (2018) analyzed the seismic response of cantilever retaining wall. They used the finite difference method and Newmark sliding block method for their research. They found that the displacement of a retaining wall is dependent on the cohesive property of backfill material and even a small variation in cohesion will influence displacement of retaining walls. Tang *et al.* (2018) investigated stabilizing slopes using porous concrete and implanting grass and found that the method was very effective under tension and stresses, which prevented slope failure. Broda *et al.* (2016) researched the effectiveness of wool geotextile for protecting steep slopes. The geotextiles provided protection against water erosion and landslides. However, degradation of geotextile caused the reduction of mechanical strength and led to the deterioration of geotextile. This research builds upon the existing body of knowledge and proposes a method that replaces traditional retaining walls with the used tired wall, LDPE and vetiver grass.

3 STABILITY ANALYSIS

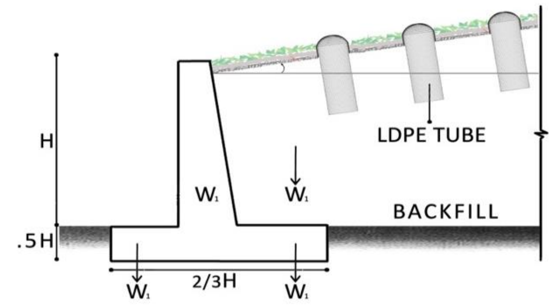
In this research, the analysis is based on the details provided by Arora (2005) and Das (2016). The overall analysis can be divided into three parts; a) overturning, b) sliding, and c) bearing capacity failure analysis for tire wall retaining wall. The analysis is also conducted for slope stability considering natural slope and reinforced slope. The overturning analysis ensures that the structure overcomes the overturning moment created by the soil pressure behind it. The sliding analysis enables ensuring that a retaining structure does not slide due to backfill pressure. The bearing capacity failure analysis ensures that the vertical load exerted from the wall and the backfill is not excessive. The slope stability analysis tells us if the slope is stable against failure.

For conducting the analysis, soil is tested for index properties, and slope profile is obtained. This includes determining the internal angle of friction (ϕ), cohesion (c) and the angle of backfill slope (*i*). Further, horizontal and vertical stresses in the backfill soil mass are required. This needs determining horizontal stress (σ_h) and vertical stress (σ_v) on backfill soil particles. As per Das (2016), vertical stress can be calculated as $\sigma_v = \gamma Z \cos(i)$ where γ is the unit weight of the soil, Z is the height and *i* is the angle of backfill slope. Horizontal stress can be calculated as $\sigma_h = K_a \sigma_v$, where K_a is the coefficient of lateral earth pressure and can be calculated as $K_a = \left(\frac{1-\sin\phi}{1+\sin\phi}\right)$ for backfill slope greater than 15^0 (Das 2016). For overturning analysis, moments must be calculated that could topple a retaining structure. All the overturning moments ($M_{O1} + M_{O2} + ... + M_{On}$) acting on a retaining structure are added to obtain Overturning Moment M_O (i.e., $M_O = M_{O1} + M_{O2} + ... + M_{On}$) (Das 2016). Similarly, resisting moments are calculated and added to obtain M_R (i.e., $M_R = M_{R1} + M_{R2} + ... + M_{Rn}$). Taking a ratio as M_R/M_O provides a Factor of Safety for Overturning (FOS_O) (Das 2016). As per Das (2016), FOS_O of 2 to 3 is considered safe. For bearing capacity analysis, the distance ($\overline{X}$) can be calculated as $\overline{\mathbf{X}}=\frac{\sum \mathbf{M}\text{-}\mathbf{P_h}*\bar{\mathbf{y}}_\mathbf{n}}{\sum \mathbf{V}}$, where M is summation of total moments, P_h is horizontal pressure acting on the retaining structure ($P_h = P_a\cos(i)$), $\bar{y}_n$ is distance of load acting from the base and $\sum V$ is summation of all vertical forces. Further, eccentricity (*e*) can be obtained as $e=\frac{B}{2}-\frac{M_R-M_o}{\sum P_V}$, where B = top width of the retaining wall and P_v is the vertical pressure (Das 2016). The eccentricity obtained is compared with B/6 to determine if the bearing capacity is less or greater than desired. If it comes less, the allowable maximum bearing capacity (q_{max}) can be calculated as $q_{max}=\frac{\sum P_V}{B}\left(1+\frac{6e}{B}\right)$ (Das 2016). The FOS for bearing capacity (FOS_B) can be obtained as FOS_B = (Safe Bearing Capacity)/q_{max} and a value of FOS_B between 2 to 3 is considered safe (Das 2016).

The sliding analysis requires calculating all the resisting forces (F_R). The total F_R forces collectively resist all the driving forces (F_D) generated by the backfill in the horizontal direction. This can be done by using the formula $F_R = \sum F_r$ generated from different weight component taken into consideration. The factor of safety for sliding can be calculated as $FOS_S = \frac{\sum F_R}{\sum F_D}$. As per Das (2016), the FOS_S should be greater than 1.5.

Lastly, the stability analysis of natural slopes includes finding FOS using infinite slope method. FOS against sliding can is given by $FS = \frac{s}{\tau.} = \frac{c+((\gamma H^* \cos 2i)\tan\phi)}{\gamma H^* \cos i * \sin i}$ (Arora 2005). For determining FOS for reinforced stabilized slopes the approach proposed by Bhuiyan (2014) has been used $\frac{Fs = cL + h L \gamma \cos 2i * \tan\phi + (\frac{L}{s}+1)*P}{hL*\sin i*\cos i*\gamma sat}$ where L is the length of slip surface, s is the LDPE spacing, P is mobilized load and h is depth of slip surface = $\frac{D}{\cos i}$

For this research, data was assumed to match the Big Sur area that failed in 2017. For the tire wall stability analysis ϕ was assumed to be 30^o. Other assumptions were made considering that a traditional RCC retaining wall is constructed in the area to prevent landslides. The assumptions include backfill slope angle (i) = 16, soil-wall friction angle (δ) = 25, top width of the retaining wall (W) = 0.984 ft, height of retaining wall (H) = 16.404 ft, width of base slab (2/3H) = 10.941 ft, depth of cantilever base (0.1H) = 1.640 ft, unit weight of soil (γ) = 375.93 psf, unit weight of concrete = 501.25 psf, width of stem at base = 1.6404 ft, extension of base slab = 1.6404 ft, depth (D) of base wall below ground = 2.64 ft, extension of base slab at toe = 7.660 ft, height of backfill beyond structure = 2.076 ft, allowable soil pressure = 10445 psf. The assumed details are displayed in Figure 1.

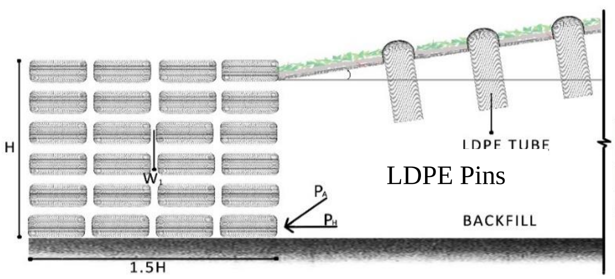


Item	Forces	Leverage	Moments Overturning	Moments Resisting
W1	36	0.85		30.60
W2	12	0.63		7.60
W3	40.02	1.67		66.73
W4	210.15	2.17		455.50
W5	13.36	2.56		34.16
Pv	23.53	3.34		78.48
Ph*	82.07	1.88	154.17	
		Total	154.17	673.08

* represents horizontal force, all others are vertical forces

Figure 1. Traditional retaining wall and forces calculation.

As an alternative, a new soil stabilization method was proposed for the same location. The assumptions made for the proposed rectangle shaped tire-wall slope stabilization include height of tire wall = 16.404 ft, base of tire wall = 16.404 ft, backfill slope angle (j) = 16^{o}, top width of tire wall = 2.833 ft, depth of tire base = 1.6404 ft, unit weight of soil for filling tire = 375.93 psf, angle of tire wall friction (δ‘) = 27, allowable soil pressure (qna) = 10445 psf.



FOR RECTANGULAR SECTION

Item	Forces	Leverage	Moments Overturning	Moments Resisting
W1	450.00	2.50		1125.00
Pv	23.53	5.00		117.66
Ph*	82.07	1.83	150.45	
Total			150.45	1242.66

* represents horizontal force, all others are vertical forces

Figure 2. Proposed rectangular tire wall & force calculation.

For the slope stability analysis slope height is assumed to be 40 ft giving us L=126.5 ft, s is considered to be 3 ft, and P is 725 lb/ft.

4 RESULTS

Both the proposals were compared by conducting the overturning, sliding and bearing capacity calculations. These are detailed in Table 1. Also, the slope stability analysis of natural slope gave us a FOS of 0.76 against sliding, but with the RPP reinforcement, the FOS improved to 3.99. Table 1 shows that the proposed tire wall with a rectangular cross-section (shown in Figure 2) passes the required checks. When implemented, the wall will appear as shown in Figure 3.

The tire wall can be constructed by placing used tires in any masonry bond patterns and filled with dense earth. This approach of constructing tire retaining wall pursued at a few places in the US (Source: lwhome.org) and in order to ensure that the tires act monolithically the tire walls can be treated with methods such as shotcrete, stucco, vegetative covering, geo-fabric, concrete blocks, and concrete blocks (Hossain and Jayawickrama 2000).

From calculations in Table 1, the tire retaining wall will support the backfill material. Also, it is believed that the backfill soil will be loosely packed and will require densification. This can be achieved by nailing LDPE pins into the loose soil. This approach has been used successfully by (Loehr *et al.* 2013). In addition, vetiver grass (a deep rooted grass and a xerophyte that requires relatively low water to sustain (Mekonnen, 2000)) is proposed to be sown to impart extra strength by holding the soil particles and to be able to prevent soil erosion in case of precipitation (Truong *et al.* 2008). The grass will also act as a natural barrier to soil erosion due to the wind.

Table 1. Comparing the RCC retaining wall with the proposed tire retaining wall.

Steps	**RCC Retainting Wall**	**Rectangular Section, Tyred Retaining Wall**
Determining Ka	0.379	0.38
Overturning Check Calculations		
Active Pressure (kN), $Pa = 0.5Ka\gamma H^2$ =	85.373	85.37
Active Pressure (kN), Ph = Pacos(i)=	82.066	82.07
Active Pressure (kN), Pv = Pasin(i)=	23.532	23.53
Overturning Moments =	154.170	150.45
Resiting Moments =	673.076	1242.66
Factor of Safety (FOS_O) =	4.366	8.26
Sliding Check Calculations		
Summation of Vertical Forces =	335.064	473.53
Summation of Horizontal Forces =	82.066	82.07
Factor of Safety (FOS_S) =	1.904	2.94
Bearing Capacity Check Calculations		
Xbar = ∑M/∑V =	1.549	2.31
e = (b/2) - Xbar =	0.119	0.19
b/6 =	0.556	0.83
e < b/6	Yes => OK	Yes => OK
pmax =	121.947	116.70
pmin =	78.991	72.72
Factor of Safety (FOS_B) =	4.100	4.28

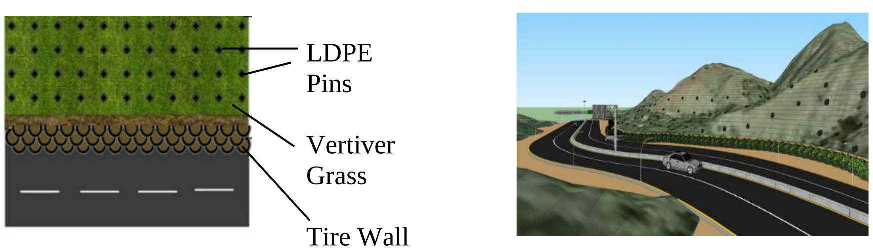


Figure 3. Top view and axonometric view of the proposed slope stabilization.

The cost of the tire wall is found to be lower than traditional retaining wall. For a one mile long and 16.404 ft high RCC retaining wall, the cost of construction will be $2,956,800 (i.e. 5280 ft x 16.404 ft x $35/sq ft). Conversely, a used tire costing $1 (sold at scraptire.net) will cost $74,895 for the same area needing 74,895 tires (i.e. (5280 ft /1.41 ft dia)* 20 layers). Assuming that we use 70,000 LDPE pins at a spacing of 3 feet in XY direction and considering a slope height of 40 ft, an area of approximately 211,200 sq. ft can be stabilized along the 5280 ft stretch of tire retaining wall. This will cost us $340,900 at the cost of $4.87 per sqft. Lastly planting vetiver grass will cost $7000 (at $3 per pound (available at Molokai Seed Company) and used at a rate of 10 pounds per 1000 sq ft at an area of 211,200 sqft). This totals to $422,795 (i.e. 74,895 +

340,900 + 7,000) which is just about 80% cost saving when compared with the cost of traditional retaining wall.

5 CONCLUSIONS

A landslide can trigger tremendous loss to life and property. Government agencies have successfully stabilized slopes in the past. However, some landslides like the case of Big Sur have highlighted the need for innovation. The new method should be reliable and cost-effective and should be able to deal with all the issues. In this research, a new method is proposed which uses LDPE, used tires and vetiver grass. The proposed design was primarily focused on preventing landslides using waste materials. Theoretically, the research results suggest that the proposed retaining wall will be able to safely retain slopes safely. It can be observed from the provided calculations that the stability and factor of safety are relatively good when compared with traditional retaining walls. The proposed model in the research is cost effective and can be used as an alternative to the traditional methods.

While the method is theoretically acceptable, further research is required to determine the effect of pore pressure on overall stability. Also, the use of tires could be unpleasant for some and may require additional methods to cover it. Weathering effects on tire such as erosion, excessive heating, rubber smell, and leaching are yet to be studied. All these will require conducting a pilot project and testing the outcomes in real life. From an application perspective, the proposed method has a lot of future potential

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