Stabilization of Road Slope failure by Soil Nailing Technique with Shotcrete Frame: A Case Study of Right Bank Slope at Telegangchu Bridge Construction Project, Trongsa

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Abstract: Soil nailing is a relatively young concept in Bhutan with not many slides in the country using it as a stabilization measure. The landslide in the right bank slope of Telegangchu bridge project is one of the locations where soil nailing along with grouting and shotcrete frame (200mmx200mm) was implemented. Disturbance in the original slope by excavation, increase in gradient and increase in ground water caused the failure of slope. Conventional methods of stabilization failed to contain the slope after which soil nailing with frame was adopted with proper drainage. The stabilization method proved to be highly effective with drainage playing the vital role in the whole structure's efficiency. This case study and findings paves a way for such strategies to be implemented in similar terrains and soil conditions in Bhutan where conventional methods have failed.

Keywords: Soil-nailing, Shotcrete Frame, Landslide, Ground Water, Drainage, Sub-soil condition.

Introduction

Landslide is a very common phenomenon in the Himalayan region, pre-dominantly during the monsoon season (Chaulagai, 2017). "Bhutan" located at the southern foot of Himalaya is no exception to this naturally occurring hazard. "The majority of the national land is mountainous and difference of elevation is large namely 100m in the southern area to 7561m in the northern region", (MoWHS, 2016). Intense rainfall during the monsoon season triggers landslides on these varying range of mountainous terrain disrupting the livelihood and economy of the country. Preventive measures against landslides are often ignored and not given priority. Raut et al. (2018) recommended that from the planning phase itself the steps for avoiding landslides should be initiated. Adopting the most suitable stabilization method is the key aspect to reliability and safety of any construction. A prevailing trend in Bhutan is the adoption of insufficient slope protection method which often results to failure of slopes incurring repeated losses to the government.

Telegangchu, Trongsa lies in the Nubi Gewog, central part of Bhutan with a population of 3171(NSB, 2017). The location is a Primary National Highway-4 and is one of the most important roads without any alternative route to the Southern region in terms of transportation (MoWHS, 2016). Trongsa Dzongkhag is well-known for road blockages during the monsoon season due to innumerable landslides. In fact, Nubi Gewog is considered to be a medium risk zone in terms of landslide hazard as show in fig 1 (GFDRR, 2007). In 2018, a slope of approximately 20m height originally was cut during widening of the existing highway for construction of girder bridge project. The right bank slope failed from the center point of 18 meter height from the road level with the onset of summer, 2019. Traditional engineering techniques- retaining wall and 1ton bags were used in an attempt to stabilize the slope temporarily. Due to heavy rainfall and uncertain ground water, the slope was further degraded.

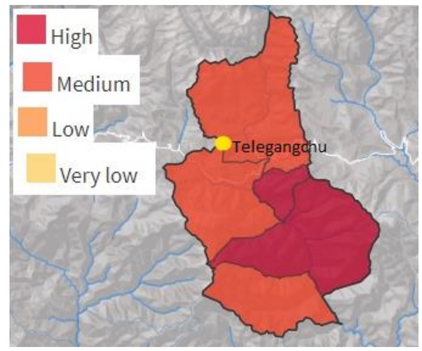


Figure 1. Landslide hazard mapping of Nubi Gewog (Source: GFDRR, 2007)

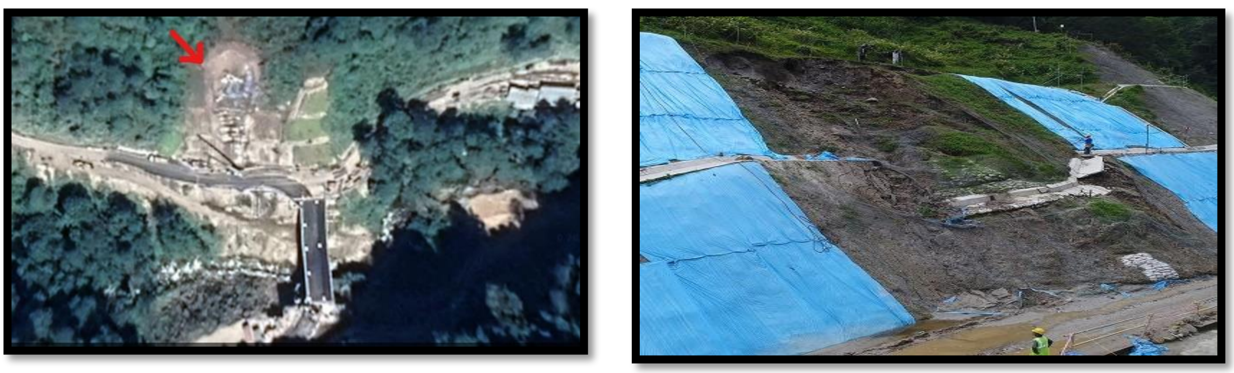
In this context, the paper describes post landslide remedies done in order to gain the stability of the failed slope. In October, 2020 the protection work by use of soil nailing with reinforced shotcrete frame work was adopted to stabilize the critical part of the slope. The main focus of the paper is the methodology of stabilization measure adopted at the right bank slope of Telegangchu Bridge.

Limitation and Scope

The paper is written based on field observation and field tests that were carried out during the investigation period. Practical methodology for construction carried out at site is the main focus of the paper. Designer's intention for using certain specifications could not be resolved due to confidentiality. All the calculations except for the grout and shotcrete mixes have been derived from literature review of research papers and standard code books. The paper provides future scope for studying the post stabilization analysis and implementation at failure sites with similar sub-soil condition.

Location and Geology of the Slide Area

The right slope of the bridge abutment was cut in a slope angle of 1:1.2 and bio- engineering was initially planned as the stability method which will not be discussed in this paper. With the onset of monsoon, a slight crack 18m above the road level was observed. The first crack was approximately 50 cm. This slowly broadened due to continuous precipitation resulting in a rotational slide. As a temporary measure, tarpaulin sheets were used to cover the crest of the slope failure to prevent further seepage of water into the soil.



(**a**) (**b**)

Figure 2. (**a**) Aerial view of the slide area (Source: Google Earth); (**b**) Right bank slope after initial slide

Soil investigation revealed that the slope consisted of colluvium mass which was water laden and saturated (Kalachakra Consultancy, 2020). From the un-disturbed soil sample inspection and SPT test conducted, it was concluded that at an elevation of 2116.606m two layers of material were present: 1) up to 9m a saturated layer of colluvium sediments was identified as the main layer causing the slide, 2) Below 9m a part of the bedded strata was found (Kalachakra Consultancy, 2020). Another boring was done 12m below the first boring hole. Same tests were conducted upon it, thicker colluvium sediments were found and two types of slope material were found: 1) of the recent slide and 2) of an older landslide whose cause could not be traced due to lack of data on the matter (Kalachakra Consultancy, 2020).

The presence of older landslide material clearly shows that the slope was a dormant slide area. It was triggered by disturbance caused due to excavation resulting in increase in gradient as shown in

Table 1, colluvium material with low bonding capacity present throughout the sliding slope and seepage of ground water at various points at the slide area.

Table 1. Comparison of required gradient with the gradient provided at site

Soil Sample No.	G	NMCW(%)	γ_t(KN/m^3)	e	S (%)	i_r	i_p	Remarks
B-1 (Upper Portion, 1- 2m)	2.04	19.18	15.892	0.501	78.14	0.693	0.833	$i_p > i_r$, Slope is Unstable
B-1 (Upper portion, 3-4m)	2.26	15.69	15.99	0.605	58.62	0.785	0.833	$i_p > i_r$, Slope is Unstable
B-2(Lower portion, 2-3m)	2.18	23.38	15.598	0.692	73.67	0.697	0.833	$i_p > i_r$, Slope is Unstable
B-2(Lower portion,3-4m)	2.16	19.23	15.794	0.6	69.24	0.725	0.833	$i_p > i_r$, Slope is Unstable

Where, G- Specific Gravity of Soil, $\boldsymbol{\gamma_t}$ –Wet Unit weight of soil, **e**- Void ratio, **S** = Percentage of Saturation, $\mathbf{i_r}$- required gradient, $\mathbf{i_p}$ – provided gradient

Stabilization Measures

As of September 2020, the whole landslide was a marshy area due to discreet water sources originating from every part of the slope randomly. The colluvium deposits carried to the road side plains spread in a fan shape clearly depicting silty sand(SM) soil type. Manual as well as excavation using backhoe was carried out to remove all the loose deposits and to prevent further wash away, wooden catch basin and water diversion work was done(as depicted in Figure 3).

(a)

Figure 3. (**a**) Fan-Shaped colluvium material deposit at the base of the slope; (**b**) Water diversion using wooden catch basin

Construction facing

Construction facing which consists of wire mesh and shotcrete improves flexibility and provides better air-entrainment for improved freeze thaw protection (Federal highway Administration, 1998). To protect and support the freshly excavated soil, welded wire mesh at an overlap of 100 mm with shotcrete spray of 100mm thickness was provided. The construction facing was not accounted to give structural capacity for frame structure-the final facing.

Soil Nailing and Grouting

Soil nailing is seen to be increasingly adopted stabilization measure on the slopes, especially in hydropower project sites in Bhutan. Soil nailing technique has been used in range of ground conditions from soil to rocks (Galvao et al., 2010). Slope frame coupled with grouted soil nails tend to bind the slope slip surface with the inner resisting zone having higher shear resistance and thereby, reduce the chance of potential soil slip.

A total of 167 number of soil nails along the main slope failure was installed. The length of the nails was 4m with Ø28.5 mm but an initial hole of Ø50mm was drilled with the help of drilling rig machine perpendicular to the slope face. The nails were drilled at a spacing of 1.5m x 1.5m, as the minimum distance between nails of general gravitational soil nailing is 1.5 m (Seo et al., 2014). After drilling, rubber bell sheath 200mm long was fitted from the head of the nail for protection against rusting of the nail and as a base support for square washer which was to be placed at the head of the rubber sheath. Bell washer and nut were fitted on top of the square washer and a bell cap with rust inhibitor was hand tightened as shown in Figure 4.

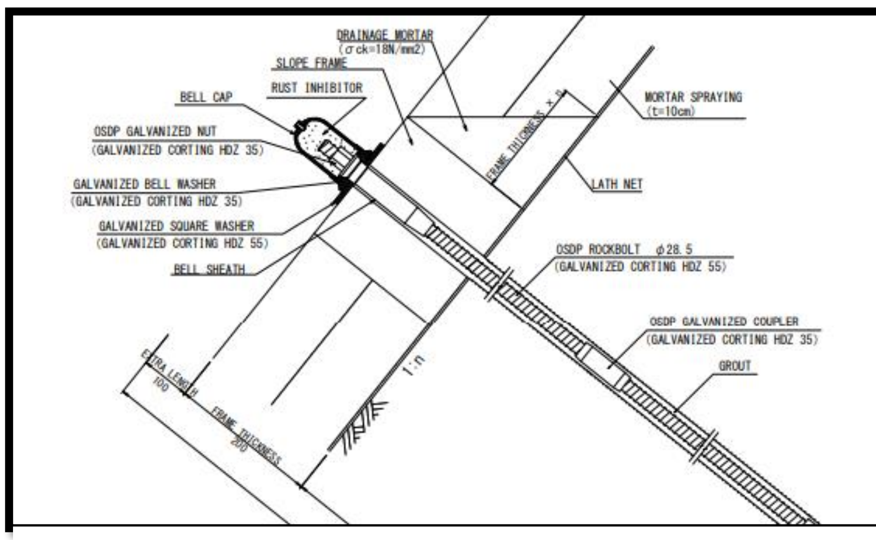


Figure 4. Detail of Soil Nailing Component

According to an experimental study conducted by Mittal (2006), he obtained the following relationship between Length of the soil nail (L) and vertical height of the slope:

L/H=0.8, the most critical slope of the slide had a slope length of 7.7 m and vertical height (H) of 4.5m

L/4.5=0.8, L=3.6 m. Therefore, a nail of 4m length seems most appropriate for use.

On a 7.7 m slope length, 5 nails were driven at an interval of 1.5 m

Seo et al. (2014) in their paper provided:

Number of nails (N) $\leq L/S_{min} * H_{Excavation}/S_{min}$,

Therefore, N $\leq$ 4/1.5*3/1.5 = 5.3

Where, L- Length of Soil Nail,
S_{min}- Minimum distance between nails,
$H_{Excavation}$- Depth of excavation

Hence, 5 nails on a slope length of 7.7m was adequate. Soil nails along with surface protection stitches the sliding surface to the stable stratum below and provides stability to the slope as shown in the Figure 5.

In high rainfall area, nails grouted with cement concrete is more effective than just driven nails (Mittal S., 2006). The grout enhances the shear resistance of nails and also seeps inside soil cracks and solidifies which in turn provides greater stability to the soil. The technique was adopted at site as well. Grouting was done after the drilling and insertion of the soil nail to slope by gravitational method. A grout (Refer Table 2) consisting of water to cement ratio of 50% was used (mix ratio for 1m^3: C=1230kg, W=615L & Admixture=24.6L).

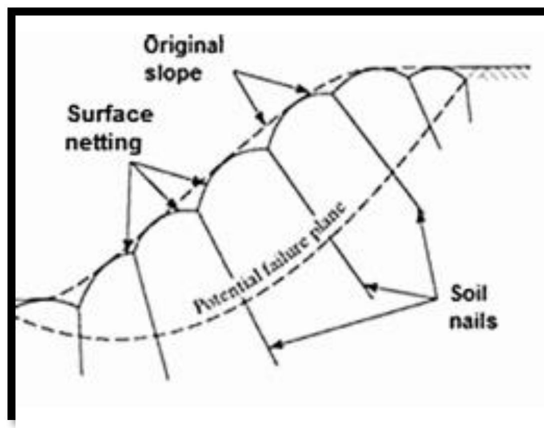


Figure 5. Concept of soil nailing (Koerner, 1984)

Table 2. Grout Mix ratio used for grouting the rock bolt (Soil Nail) is as given below

Design Strength (N/mm2)	W/C (%)	W (l/batch)	C (kg/batch)	Water Reducer (ml/batch)	Mix volume/batch (m3)	Flow (Sec)	28 days compressive Strength achieved (N/mm2)
24	50	25	50	1000	0.041	10~18 sec	31.92

Final Wall Facing

Final wall facing is provided as a counter weight to the earth pressure that the soil mass exerts due to lateral deformation of the soil. The facing is supported by anchors and metal frames which divides the soil mass into compartments limiting the failure (if any) to just the compartment i.e. 1.5 m x 1.5 m in this case as shown in Figure 5. Frame work of size 200 mm X 200 mm at a spacing 1.5

m x 1.5 m c/c was adopted as shown in Figure 6. (a). Four main reinforcement bars of 16 mm diameter were provided inside the frame along with 20 mm diameter, 750 mm long main Anchor and Auxiliary Anchor of 12 mm diameter, 400 mm length. A total length of 1492.5 m horizontal and vertical frame was provided to cover the active slide slope. Mortar spraying (refer Table 3. For mix ratio) was done to construct the frame and construction facing of the slope as shown in Figure 6. (b).

Table 3. Mortar spray mix ratio used for frame spray and construction facing is given below.

Design Strength (N/mm2)	W/C (%)	W (l/batch)	C (kg/batch)	Sand (kg/batch)	Mix volume/batch (m3)	28 days compressive Strength achieved (N/mm2)
21	50	22.5	50	150	0.127	28.39

(**a**)
(**b**)

Figure 6. (**a**) Installation of Rebar and Anchors; (**b**) Mortar spray of the slope frame

Drainage

One critical landslides preventive measures in tropical region is to examine the area for potential surface and subsurface water risk. In almost all the slope protection techniques applied around the globe, high importance is given to drainage system. An indirect remedial measure recommended is to provide adequate drainage system, both surface and sub surficial (IS 14680: Landslide Control- Guidelines). One major cause of slide identified through the soil investigation carried out at site was presence of surface and subsurface water causing up to 78% saturation of the soil as portrayed in Table 1.

As a remedial measure, total of 452 numbers of 3m long perforated pipes were inserted inside the predrilled hole of 1.5 m x 1.5 m concrete frame covering the whole slope of the frame structure to improve the natural drainage system of the slope(refer Figure 7. (a)). This helped in reducing the uplift pore pressure. An average of 1.7 m width was covered with 10cm shotcrete above the crest of the slope to further prevent penetration of any precipitation. Peripheral drainage gutter of 300mm x 300mm was provided to collect the surface water and divert it away from the slope as shown in Figure 7. (b).

(**a**) (**b**)

Figure 7. (**a**) Drilling being done for installation of subsurface drainage; (**b**) Completion of installation of drain pipes for subsurface, periphery drainage gutter and completion of shotcrete work

Comparative Analysis

A BCS (Benefit, Cost and Speed of implementation) comparative analysis matrix was carried out between four stabilization methods as depicted in the table below.

Table 4. Comparative analysis based on BCS Matrix.

Alternatives	**Benefit (70%)**				**Benefit average**	**(10%) Cost (5)**	**(20%) Speed (5)**	**Score**	**Rank**
	Durability (5)	Feasibility (5)	Aesthetic (5)	Safety (5)					
RCC wall	4	4	4	3	3.75	3	2	67%	2
Gabion wall	2	2	2	2	2	4	4	52%	3
Bio-Engineering	1	1	4	1	1.75	5	4	51%	4
Soil nailing	5	5	5	4	4.75	1	2	77%	1

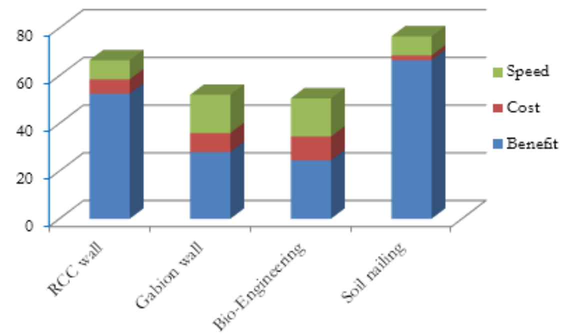


Figure 8. Graph showing comparison between stabilization methods using BCS Matrix

The rating is done in 1 to 5 scale, "5" as the most favorable and "1" as the least favorable to the particular stabilization method against the factors considered to be vital for slope stabilization. The ratings are given based on the approximate calculative designs and a survey from 50 people of different occupation from Nubi Geog. 70% weightage is given to the benefits as it incorporates the vital factors for any slope stabilization. The speed of implementation given 20% weightage as timely completion was important for economic viability and for minimizing the traffic disruption. From the comparison, it was deduced that soil nailing was the most favorable methodology for stabilization under the conditions given in the problem statement.

Recommendations

The following recommendations have been made for stabilization measure of a landslide caused due to ground water and unstable soil conditions:

1) Gradient of a slope plays a very important factor in the stability of slope. Therefore, it is necessary to first take in account the type of underlying soil, their saturation level fixing the slope gradient. If the underlying soil is as weak as it was in this failed slope, even a small disturbance can lead to increase in failure slip of a slope.
2) Drainage is hardly given importance though it is one of the key aspects to stability of soil. Ground water weakens the cohesion of soil grains and ultimately leads to shear failure of soil mass. Understanding the sub-surface water condition and channeling it properly as well as surface protection and drainage is vital in any kind of slope protection work.
3) Field tests and sub-soil investigations are very important prior to any earth work on slope. Many a times sub-soil investigations is given less priority at the initial planning phase of the project. The result is: annual restoration work and ultimately a huge expenditure in the long run. A mitigation measure based on sub-soil investigation should be encouraged to curb recurrent restoration and also minimize the risk to road users, infrastructure and environment.

Conclusion

The Telegangchu right bank slope failed during monsoon of 2019. A thorough geotechnical study was carried out to determine the actual physical parameters of the soil. Colluvium soil with high percentage of saturation was found to be the main sliding layer. Accordingly, importance was given to strengthening the structural aspect of the soil rather than providing retaining structure at the base based on assumptions. It was found that the slope consisted of soil with low bonding capacity with high presence of water which led to the failure of the slope at a slightest disturbance caused.

Soil nailing with grouting and shotcrete was adopted as the stabilization measure with drainage as the key feature. With the method in use, ground water was successfully channelized and the slope visually looks more stable and safe. In comparison to other methods of stabilization, soil nailing with shotcrete frame was the most technically viable solution despite its higher cost. The method is analyzed as the safest and the most pragmatic for slope failure under similar sub-soil condition and terrain.

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Author Contributions

All authors contributed equally to the conceptualization, methodology, implementation, writing, reviewing, and editing of the paper.

Conflict Of Interest: The authors declare no conflict of interest.

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