Investigation and Design of Remedial Measures for Landslide in Hunthar Veng, Mizoram—A Case Study

M. Vinoth, P. S. Prasad, Sudhir Mathur, and Kishor Kumar

1 Introduction

Aizawl city is the capital of Mizoram and Hunthar Veng is one of the important areas of Aizawl town. Hunthar Veng is situated in the Western limb of Aizawl anticlinal ridge, which is below Chanmari West [1]. The area is located at a height of 1188 m above Mean sea level (MSL). The proposed problematic area, i.e. landslide and sinking area below Vaivakawn, Hunther Veng, Aizawal, is located on NH-54 at Km 179.50. The Hunthar landslide area, as informed by neighbouring people of the area and reported by PWD Mizoram, has started during the years 1993 (June), continued in 1995 (June), 2009 (July) and 2012 (August); the road formation had sunk for a length of 100 to 120 m. (Approx.). However, in the year 2016 alone it has sunk up to 2 m. It gets reactivated every year after the torrential rain. On August 2016, landslide took place due to heavy and incessant rains. The area currently affected by landslide covers 126886 sqm, affecting more than 100 houses as shown in Fig. 1. The total affected length is about 490m and with a width of 185m at the top and gradually tapering at toe portion. If this landslide remains unchecked even for one more monsoon, it could result in total blockage of highway which would result in shortage of food and essential daily basic needs of Aizawl city. In order to ensure safety of the people living near the slide area and for people travelling through this area daily and also for the entire economy of Mizoram, it was decided to stabilise the slope with suitable remedial measures with no further delays. This paper describes the complete analysis as carried out on the affected slope and remedial measures for mitigating the landslide. Remedial measures were worked out especially to stabilise the upper thick layer of debris that are located along the affected area as no bed rock

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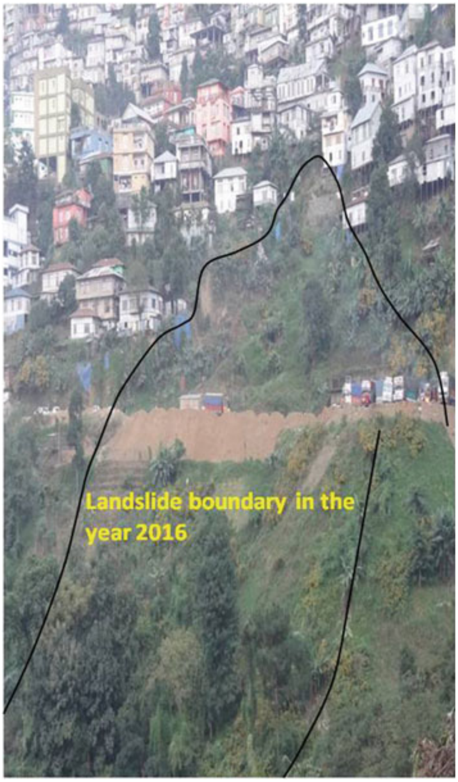


Fig. 1 Hunthar landslide and sinking area (Ch: 179/500 km on NH-54)

has been observed in the subsidence zone. Another major factor considered in the stability analysis was water table, because most of the landslides in the region are found to occur during the monsoon period. During monsoon, overburden material gets saturated, resulting in the reduction of its shear strength and increase in pore water pressure, which decreases the slope stability.

2 Geology

The soil formation in the Hunthar Veng area, in general, is of loose sedimentary type with high porosity and permeability. The top of hills being capped by sandstone having sufficient porosity, rainwater infiltrates down to interface with impervious clayey shale layers (Fig. 2) and exit to the surface due to gravity. While coming out through the shale/silty soil layers, the water carries with it the slope forming material from down below. It results into the subsidence of the area. It was also indicated that there are lot of water channels in the landslide affected area, out of which some are visible and some of them are required to be unearthed.

Fig. 2 Shale and interbedded siltstone–shale at the road section of NH-54

3 Site Description and Assessment of Causative Factors for Landslide

In order to investigate the causes of the sinking/sliding area and to suggest suitable measures for permanent stabilisation of the sinking/sliding area, which affect Vaivakawn, Chandmary West and Hunther Area of Aizawal City by designing the suitable scheme of remedial measures in form the of appropriate structures and a network of drainage systems, the entire area was surveyed by the investigating team. The photograph of the affected slide above the National highway is shown in Fig 3. It was observed that the total affected area due to the landslide was 1,21,107.00 sq.m, however, the length of NH affected was 420 metres. Fig 4 shows the affected area on the down side slope of the highway. It can be seen that the down side slope almost sank by 2 m from the existing road level. In order to drain out the surface

Fig. 3 Affected area above national highway

Fig. 4 Sinking/sliding of national highway

runoff water from the uphill side of the slope, two water channels as shown in Fig. 5 were provided but it was observed that it was choked and broken and therefore not very effective in draining out surface runoff.

Based on the site visit and preliminary investigations, the following factors were found to be the causative factors triggering landslide:

- **Hydrological condition**: It is one of the most important parameters for triggering landslide and slope instability. Most of these landslides occur during the monsoon period. During monsoon, the rock and overburden material gets saturated, resulting in reduction of its shear strength and increase in pore water pressure, which decreases the slope stability.

Fig. 5 Condition (eroded and broken) of side drains adjacent to affected slide

- **Surface water**: During investigation, it was observed that the area is lacking improper road side and surface drainage system and also sewage system which induced instability of slopes that triggered landslides.
- **Toe erosion by nala**: During monsoon season/periods of intense rain, heavy discharge of rainwater in the Vaivakawn stream and Biakin (Church) Kawr nala scours the toe of nala bank slopes and induces slumping tendency in the overburden material which causes the instability (subsidence) in the area.
- **Gully erosion**: The subsidiary drains/gullies formed in the slide/subsidence zone have also contributed instability in the area due to erosion along slope.
- **Habitation**

  (a) Existence of massive multi-storey buildings at the crown and side part of the slide.
  (b) Construction of buildings without taking into account the natural slope factors.
  (c) Foundation of the houses/building, are found to be anchored in the overburden material, which has a higher risk of sliding down.
  (d) Loads of the buildings reduce the bearing capacity as well as shear strength of the overburden material resulting in development of ground cracks and distresses in the houses.

- **Anthropogenic activities**

  (a) Changing the existing slope by cutting slopes unscientifically.
  (b) For construction of Civil Structure and houses, existing slope angle has been cut steeply.
  (c) Over large area vegetation cover has been removed, which lead to high surface runoff.
  (d) NH is constructed through the slide area where some portion is cut and filled which is not well compacted.

4 Subsurface Profile and Design Parameters

Sub-soil investigation in Hunthar Veng area was carried out through three bore holes (BH-1, BH-2 and BH-3) as shown in Figure 6. Table 1 shows the typical sub-soil profile obtained from BH-3. The sub-soil profile in the region consists of two types of materials, top loose debris and followed by Highly Weathered Rock (HWR) (Fig. 7). Survey has been carried out in landslide area and the typical cross-section of affected landslide area is shown in Fig. 8. The entire stretch has been split into three sections (top, middle and lower). The vertical and horizontal depth of debris varies along these sections which are given in Table 2.

Choosing proper input parameters is an important step in slope stability analysis. Therefore, input parameters like shear strength of the soil and rock, bulk density and degree of saturation for different sub-soil layers needs to be selected meticulously.

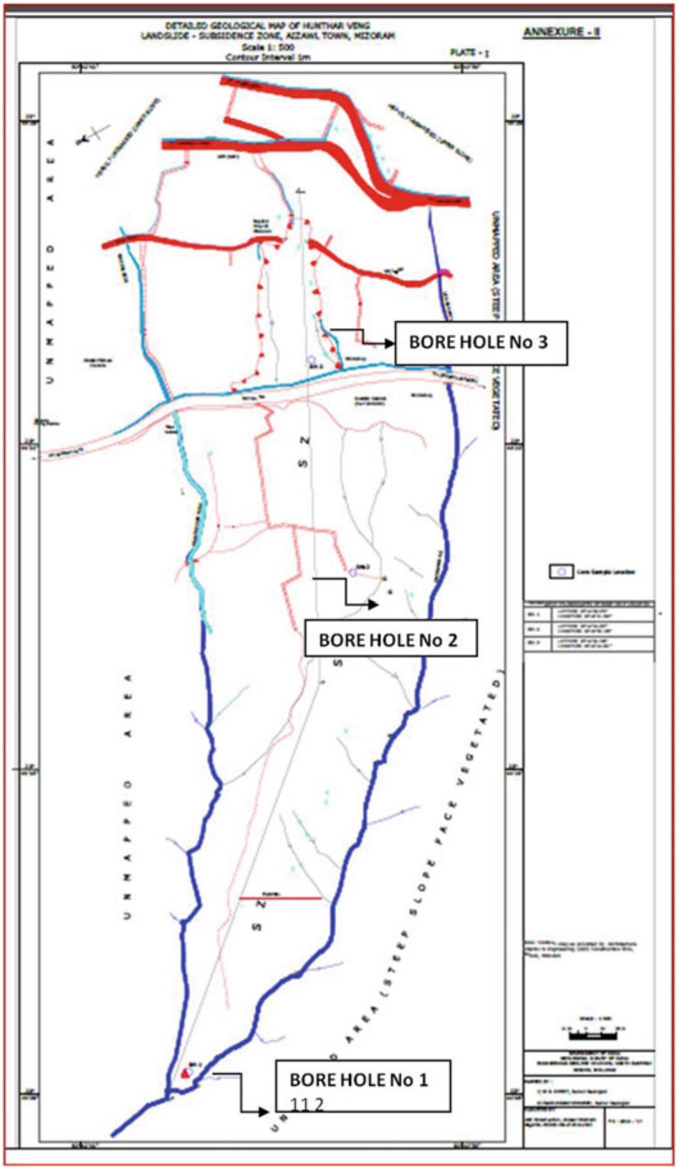


Fig. 6 Location of boreholes

Table 1 Sub-soil profile in the landslide area

Depth, m	Rock type
0.0–1.50	Sandy soil + shale type rock
1.50–3.00	Silt + shale type rock
3.00–4.50	Greyish silt + fine silty stone
4.50–6.00	Greyish silt + fine silty stone
6.00–7.50	Reddish silt + weathered silty stone
7.50–9.00	Greyish silt + silty stone
9.00–10.50	Greyish silt + silty stone + fine grained sandstone
10.50–12.00	Reddish silty + weathered sandstone
12.00–13.50	Reddish sandy clay + partly weathered sandstone
13.50–15.00	Partly weathered sandstone
15.00–16.50	Partly weathered sandstone
16.50–18.00	Weathered sandstone + fresh sandstone
18.00–19.50	Fresh sandstone
19.50–21.00	Partly weathered sandstone
21.00–22.50	Partly weathered sandstone + Fresh sandstone
22.50–24.00	Partly weathered sandstone
24.00–25.50	Partly weathered sandstone
25.50–27.00	Partly weathered sandstone
27.00–28.50	Partly weathered sandstone
28.50–30.00	Fresh and partly weathered sandstone

Existing shear properties were available only for top loose debris layer and not available for HWR. In order to obtain the HWR shear parameters, back analysis was carried out using Geo5 software [2–4]. Back analysis was carried out on the basis that slope is just safe (say FoS is 1) under dry condition. In back analysis, rock shear parameters were varied in order to get a FoS of 1 under dry condition. The results from the back analysis are given in Table 3.

From the back analysis, HWR shear parameters were determined. The parameters used in the slope stability analysis are given in Table 4. All the analysis was carried out under the following conditions:

- Water table at the surface of the slope (i.e. Fully saturated condition).
- Dry density condition (i.e. without water table).

As per IS 1893 (Part-1): 2016, Aizawl city falls under seismic zone category V. Hence, earthquake factors (EQ) were also included in the analysis.

Fig. 7 Rock showing poor core recovery

5 Stability Analysis

After finalising the shear parameters for debris and highly weathered rock (HWR), stability analysis of the existing slope was carried out at saturated condition and it was found prone to slide. Therefore, attempts were made to stabilise the saturated slope with various possible techniques [5]. The following options were tried to stabilise the slope and the results of the same are given in Table 5. All these options were carried in the Geo 5 Software.

- **Option 1:** Inclined and Vertical Grouted Nails.
- **Option 2:** Removal of Debris and Installation of Grouted Nails.
- **Option 3:** Stepped Slope with Cut-off Wall.

Some of the common design details adopted in all the options are given below,

- Top section was installed with both inclined and vertical grouted nails.

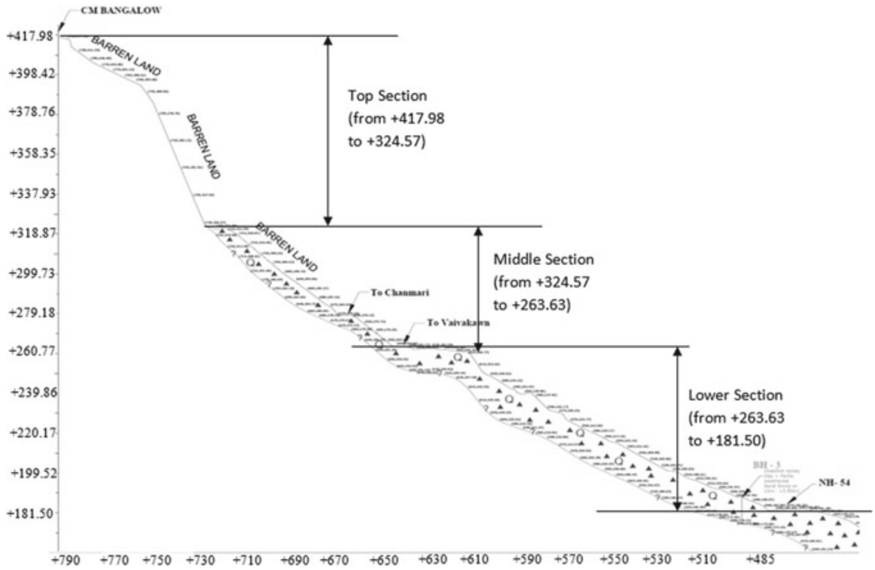


Fig. 8 C/s of affected landslide area

Table 2 Thickness of debris along affected area

Section	Thickness (m)	
	vertical	Horizontal
Top	3.0–12.0	10.0–15.0
Middle	6.0–11.0	10.0–35.0
Lower	11.0–19.0	15.0–35.0

Table 3 Back analysis results

$\varphi'_{ef}{}^{\circ}$	Cohesion, kPa	FoS
20	150	0.77
25	150	0.88
35	100	0.93
36	75	0.85
36	100	0.95
37	75	0.87
37	100	0.98
38	50	0.76
38	75	0.89
38	100	1

Table 4 Design parameters

Description	Debris	HWR
Unit weight, γ (kN/m^3)	20	22
Angle of internal friction, φ'_{ef}°	11	38
Cohesion of soil, c_{ef} (kPa)	20	100

Table 5 Stabilised slope stability analysis results

Options	Length of nail, m	Force, kN	FoS	Stabilisation measures
1	24/36	1000/500	1.02	Grouted nails
2	36	1000/500	1.05	Berms + Grouted nails
3	24	1000	1.31	Grouted nails in top portion + cut-off walls at middle and lower portions

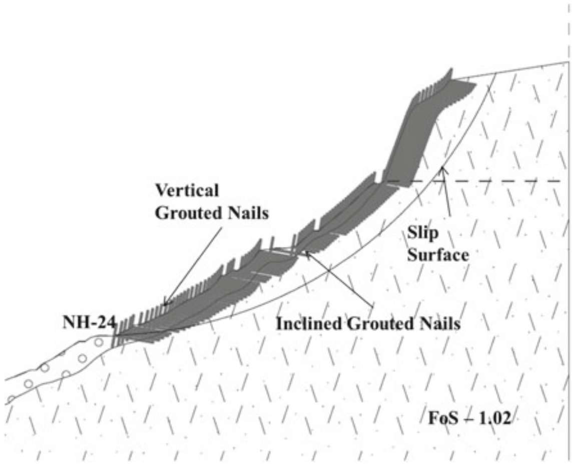


Fig. 9 Slip surface for option 1

- The length of grouted nails installed in the top section is 24m.
- Horizontal and vertical spacing adopted for grouted nail were 2 × 2 m.
- Inclined grouted nails were installed at an angle of 10° to the horizontal surface.
- 100mm diameter grouted nail was considered for the analysis.

Based on the length of nail embedment into HWR, the bond strength was considered. For top section (+790m to +730m) of the slope, HWR is located at the surface itself; hence, nail forces were considered to be 1000kN. Middle section (+730m to +645m) and lower section (+645m to +480m) of the slope debris are found at the surface; hence, nail force has been reduced accordingly to 500kN and 250kN, respectively. The above-mentioned nail forces are valid for nail lengths of 24m, when 36m long nails are used in lower section, forces in this section are increased to 500kN.

Figure 9 presents the stabilisation measures in option 1 (Inclined and Vertical Grouted Nails) with grouted nails. It can be seen that the Factor of Safety (FoS) is still less than the required limit set by the standards (1.25 [6]). Slip surface passes well below the reinforced region and it starts from the crown of the affected area and ends at the toe of the affected area; they still lead to a translational failure.

In order to improve the stability of the slope, in option 2 (Removal of Debris and Installation of Grouted Nails), it was further thought to remove the debris by 5m in vertical direction from bottom to top and making berms of suitable width, and nails were installed on the slopes created in such a manner. The results of the analysis are shown in Fig. 10. It may please be noted that even with such an arrangement, the factor of safety was found to be less than 1 as face failure occurs.

Figure 11 presents the final option 3 (Stepped Slope with Cut-off Wall). In option 3, cut-off walls were provided in the form of continuous piles (very close to each

Fig. 10 Slip surface for otion 2

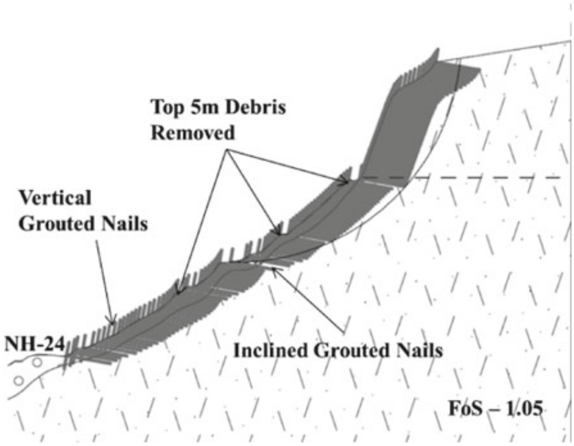
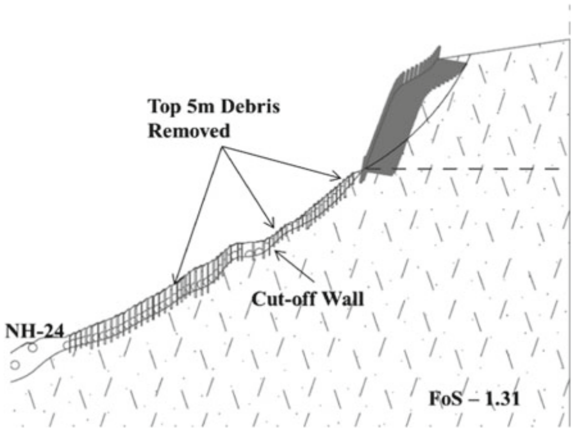


Fig. 11 Slip surface for option 3



other horizontally so that it forms a wall). They were provided from middle portion to lower portion at a vertical distance of 3m and up to a depth, where the piles are embedded into HWR at least up to a depth of 3D to 5D. Only with this arrangement a factor of safety greater than 1.2 could be obtained. All the above slope stability analysis results are indicated in Table 5.

6 Conclusions

Based on the stability analysis, it was found that the slope above the National Highway-54 is highly unstable. The factor of safety of the slope after applying different measures was not adequate except in one condition, where cut-off walls of large depth, i.e. up to 20m in depth at a spacing of 2.5–3 m from top to bottom was provided. Such a solution though analytically appears to be satisfactory would involve high cost. This may also invite many unforeseen construction related problems for which highly experienced professionals may be required to be involved.

In view of the above detailed analysis, it is opined that the remedial measures such as provision of drainage (Longitudinal and Transverse drains, RCC tube wells), vegetation and turfing, construction of retaining wall at the toe of the slope, etc., including evacuation of population close to the affected slide area be implemented.

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