Journal of Himalayan Earth Sciences Volume 47, No. 1, 2014, pp. 131-140

Slope stability hazard evaluation and mitigation scheme for Sohbat Charra slide zone, district Battagram

Mohammad Abid Khan[1], Khan Shahzada[1], Bashir Alam[1], Muhammad Fahad[1], Akhtar Naeem Khan[1], Muhammad Javed[1], Kaffayatullah Khan[2] and Hassan Khan[1]

[1]Department of Civil Engineering, UET, Peshawar

[2]Department of Civil Engineering, Iqra National University, Peshawar

Abstract

In the wake of October 8, 2005 Kashmir earthquake, the emergency response to Allai and its surrounding areas was severely affected due to the hazard caused by the Sohbat Charra slide zone. This study focuses on the stability of slopes at Sohbat Charra slide zone at Allai District Battagram. Soil and rock samples were collected and tested in the laboratory. The input parameters needed for the analysis mainly included the shear strength parameters that is, cohesion, angle of internal friction and unit weight of the formation materials, these values were obtained from tests conducted in laboratory. Software Slope/W part of Geo-Studio, 2007 and standard charts were used for the slope stability analysis. On the basis of soil properties and slope stability analysis of the site, suitable measures are suggested for stabilizing the Sohbat Charra slide zone. It is hoped that such measures will help mitigate future problems caused by earthquakes in the area.

Keywords: Sohbat Charra; Slide zone; Hazard; 2005 Kashmir earthquake; Slope stability.

1. Introduction

This research deals with the Hazard Assessment of the Sohbat Charra Slide Zone located along the Thakot-Allai road District Battagram. WAPDA (Water and Power Development Authority) High Head Hydropower Project was initiated in Besham. Work on up-gradation and opening of the Thakot-Allai road to make it for hazard free movement for all weather conditions, not only for their equipment mobilization to the site but also to improve the means of communication for the inhabitants of the area. Up-gradation of this road for all weather conditions is not only necessary for WAPDA's project but also it is the utmost necessity of the two hundred thousand people residing in the area. Whenever this road is blocked for any reason, the inhabitants of the Allai valley suffer great hardships in their routine life and shortage of food frequently occurs. This is the only source of communication of Allai valley with main KKH (Karakoram Highway). The Thakot-Allai road passes through several weak geological features/zones known as the Thakot Shear Zone. However, this study is focused on the Sohbat Charra slide zone where heavy land slide occurs due to its poor geology. Along this stretch of the road heavy land sliding occurs in response to even small showers, causing blockage of the road for all type of transport and even pedestrian cannot cross it due to the continuous sliding. This phenomenon occurs even during dry weather conditions. The location is very perilous for human life as well as for the road which is the only mean of communication for the inhabitants of the Allai valley.

Communication plays an important role in the development of an area. Road is the basic element of all communication ways having key role in the uplifting of socioeconomic activities of an area. WAPDA planned a hydropower project on Allai Khwar in District Battagram in 2002-03. Therefore it was necessary to upgrade the existing road for the mobilization of machinery, to facilitate the two hundred thousand people residing in the area and to provide a hazard free movement for all weather conditions. This study deals to assess the different hazards faced by the people of Allai valley due to heavy slide/closure of the Thakot-Allai road.

In 1980's road was constructed by Khan of the Allai valley which passed through this location to facilitate his people.

The study area stretches between RD 17+825 to 17+875 on Thakot Allai road, extents upstream up to village Baab as shown in Figure 1. It is bounded by high ridges in the South, West, East and somewhat low ridge in the North. Talus deposits occupy the central part of the area.

Slope consists of hard rocks, loose soil/disturbed soil and fractured rocks etc. Its failure can be due to the shaking of earth caused by the seismic waves below the earth's surface, upward movement of magma through internal pressure developed by dissolved gases, down slope transport of soil and rock by natural vibration, changes in direct water content or removal of lateral support and river and coastal rising of water due to intense rainfall. Natural slopes that have been stable for many years may suddenly fail because of changes in the topography, seismicity, ground water condition, loss of strength of the slope materials, stress changes, and weathering. Generally, these failures are not understood well because almost no study is made until the failure of the area makes it necessary. In many instances, significant uncertainty exists relating the stability of a natural slope. This has been emphasized by Peck (1967), who said:

"Our chances for prediction of the stability of a natural slope are perhaps best if the area under study is an old slide zone which has been studied previously and may be reactivated by some human operations such as excavating into the toe of the slope. On the other hand, our chances are perhaps worst if the mechanism triggering the landslide is (1) at a random not previously studied location and (2) a matter of probability such as the occurrence of an earthquake."

During the period from 1993 to 2002, 6031 people were killed and 8,989,631 were affected by the natural disasters in Pakistan which shows a great impact on human life (World Disaster Report, 2003). In Pakistan the Oct, 2005 earthquake has brought changes in reality that the risk is increasing and there is no management to contain it. As per United Nations Development Program, most of the countries do not have clear guidelines as how to control the risk and hazard in the country (United Nations Development Program, 2004). The slopes made by human due to excavation through natural topographic surfaces or filling in the natural topographic surface for different construction purposes are known as engineered slopes. Engineered slopes may be classified in three main categories: Cut slopes, embankments, and retaining walls. Due to the combination of some triggering factors i.e. deformation, dissolution and rupture by the action of static and dynamic loads, the movement of a slope vary in shape and size. These movements of the slope can be controlled by the topography of the slope, by the geo-mechanical characteristics, by pore water pressure and by the structural geology of the slope. To analyze the hazards and risks, a multi hazard approach is required for the spatial planning.

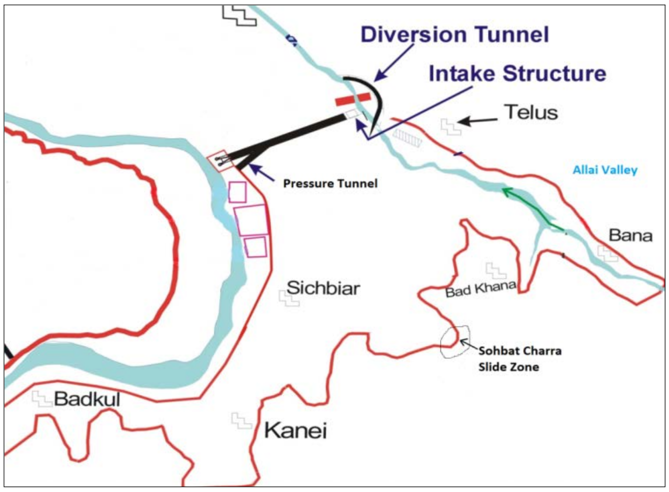

Fig. 1. Road map to Allai Valley showing Sohbat Charra slide zone.

2. **Site condition**

2.1. Site geology

The geological setup of the study area is comprised of exposed rock quartzitic-schist underlain by talus deposits in upper reaches. The talus deposits are further composed of silty gravel, clayey silt and boulders of quartzitic-schist. The bedding plane of the exposed rocks is in north-east direction and talus deposits are lying as alluvial fan.

2.2. Surface conditions

The smooth surface on the bedding plane of these rocks facilitates slips over the slopes when the overburden material becomes saturated due to rainwater. The rain water percolates to the bedding plane develops pore water pressure and pushes the talus deposits onward for sliding. The same phenomenon is observed in the study area.

2.3. Subsurface conditions

A deep channel running perpendicular to the bedding plane was also observed, developed almost in center of the talus deposits during heavy rains. The western part of the talus deposits is badly affected by the heavy rains. The channel starts from the toe of the high peaks where an outcrop of bedrock is exposed, gets terminated little bit upstream of the existing road. The channel is developed at the contact line between the exposed outcrop and talus deposits. It is assumed that at the point of termination of channel, the bedrock has cracks, fissures and joints.

2.4. Rain water conditions

Water is the single most important factor in triggering landslide event at Sohbat Charra area. The rising water pressure is contributory to more slopes failure in the study area. Repeatedly heavy landslides took place in the study area during rains which was due to water pressure developed in the talus deposit during rainfalls.

2.5. Slope geometry of landslides

The movement of earth mass, rock mass and soil is denoted as landslide. Most of the landslides occur due to changes made to the natural surfaces. Landslides are responsible for loss of lives and money causing huge problems to humans. Landslides are classified according to their type of movement of a mass, type of the disturbed material/mass as well as the rate of development over a period of time (Varnes, 1978; Dikau et al., 1996; Cruden and Varnes, 1996). According to the type of movement of a landslide its affects are distinctly dissimilar or unlike.

2.6. Geological study of slope material

As proposed by Cruden and Varnes (1996) and Dikau et al. (1996), five different types of movements are classified according to geomorphologic classification. Fall is the movement of the slope in which the heavy mass travels most of the distance through air. Topple is an overturning movement of a slope about a pivot point due to the forces generated in the slope. Spread is the movement of a slope which is qualified by the lateral extension of a rigid mass over a softer underlying material. Slide is the movement of a slope in which the mass is moved coherently along a recognized well defined surface. Flow is the movement of a slope due to the differential movements which are distributed in the whole disturbed mass and in which the particles move individually within the mass.

2.7. Causes of landslides

1. The loading unloading, slope angle, excavations made by man and surface erosion are the geometric causes of landslide.
2. Nature of soil/rock, its properties, its shear strength parameters are the geological causes of landslide.
3. Surface and subsurface conditions which include underground water and its effects on strength of soil or rock.
4. Changes in temperature, earthquakes and vibrations also causes landslide.
5. Cutting of trees and plants can badly affect the stability of slopes resulting in the occurrence of landslide.

These factors were considered in detail for the Sohbat Charra slide zone and it was observed that most of the landslide occurs due to sliding down of the soil/rock material after saturation due to heavy rains. It was also observed as the main factor of land sliding is the Oct 8, 2005 earthquake, which has disturbed the entire area badly. Poor vegetation was also observed at the study area which causes land sliding.

2.8. Mode of failure

Plane failure: When a geological discontinuity such that the bedding plane strikes parallel to the slope face and dips into the excavation at an angle greater than friction angle (ϕ).

Wedge failure: When two discontinuities strike obliquely across the slope face and their line of intersection daylight in the slope face. The wedge of rock resting on these discontinuities will slide down along the line of intersection provided that inclination of this line is greater than (ϕ).

Circular failure: When the material is very weak as in case of soil or when the rock is heavily jointed as in case of rocks. In such cases failure cannot be defined by a single discontinuity and will be termed as circular failure.

A circular failure was observed in the slope of study area where the material is very weak and the rock is heavily jointed. Water input to a slide mass also has the long term effect of internal weathering; loading by water in a slide mass may increase the driving force. Water does not act as a lubricant, the only material approaching the properties of lubricant in a slide is clay softened by increased water content. Water is the most important single factor in triggering landslide event at Sohbat Charra area. The rising water pressure is contributory to more slopes failure in the study area. Repeatedly heavy landslides took place in the study area during rains which was due to water pressure developed in the talus deposit.

2.9. Evaluation of potential landslide hazards

During the sudden, rapid and intermittent landslides such as mudflow or debris flow, the populations are more assailable to hazard. If the movement of a landslide is slow and imperfect then it does not show risk for a human life but in the case of unstable situation of the land mass it has large impacts on buildings, roads and other infrastructures. According to the type of movement of a landslide its affects are distinctly dissimilar or unlike. A Structure can confront many types of allurements of different magnitudes; approximating its potential damage and its exposure with engineering vulnerability functions is therefore a composite task difficult to apply in practice and demanding detailed engineering databases. Due to these damages with high repair and maintenance cost, an indirect cost link can interfere in the socioeconomic activities of the state.

2.10. Mitigation of landslide hazards

In order to reduce the hazards of landslides or to stabilize the potentially unstable slope sometimes it is necessary to change the existing profile of the area by cutting or filling at the toe of the slope, by decreasing the slope height or by decreasing the slope angle and by removing the loose or unstable material lying on the slope. Filling is more effective than cutting at the toe of the slope which creates step berms at the toe, giving more stability to the slope. If water is present in the joints of rocks or soils then it is necessary to consider pore water pressure in the analysis. An underground drain or drainage pipes should be provided to reduce the pore water pressure.

3. Data collection

Three (03) No. pits were dug at site for the collection of samples to study and observe in detail the formation, type of the rocks and structural geology of the Sohbat Charra slide zone with respect to slope hazard assessment and to get an idea of the ground water condition along the alignment of the components by observing snow fall, springs and streams etc. Local labors were hired for digging and transportation of soil samples. Each pit was dug up to the maximum depth of 6ft. Samples from top i.e. at a depth of 6-8 inches were collected to study the nature of soil at the top. Samples from 3ft and 6ft were also taken to closely determine the type and nature of soil. Required quantities of soil were collected from required depths and were carried in empty cement bags. These samples were then transported to the laboratory of University of Engineering and Technology Peshawar for testing and analysis.

4. Data analysis

Soil samples were collected from study area and were tested for the following parameters in the soil mechanics laboratory of University of Engineering and Technology Peshawar.

1. Shear strength parameters
2. Density and natural moisture content
3. Grain size analysis

Pictorial view of tests conducted in the laboratory for analysis of samples is shown (Figs. 2-4).The tests results are presented in table 1, which shows the calculated shear strength parameters of the tested soils.

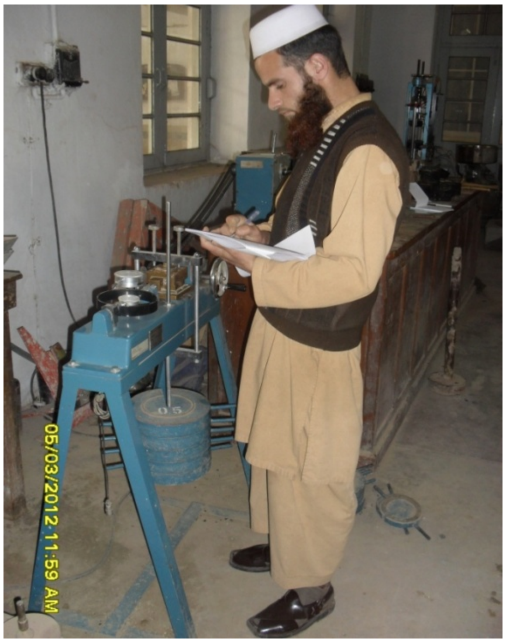

Fig. 2. Direct Shear Test.

5. Test results and design of slopes

On the basis of analyzed data and test results shown in table 1, a methodology both from operational and stability point of view was developed. Slope was accordingly designed, for which computer aided program / Geo slope software was used. For stable slopes a software SLOPE/W and design charts were used for the analysis as per site conditions. For an elaborated/detailed design and analysis, Computer programs are used. For rapid analysis design charts are used which requires simplified approximations for application to actual conditions of slope.

Fig. 3. Liquid & Plastic limit Test

Fig. 4. Sieve Analysis

6. Introduction to SLOPE/W

SLOPE/W (Part of a Geo studio 2007) can effectively dissect both simple and complex problems for a variety of slip surface shapes, pore-water pressure conditions, soil properties, analysis methods and loading conditions. SLOPE/W is the leading slope stability CAD software product for computing the factor of safety of both earth and rock slopes. SLOPE/W can solve heterogeneous and complex soil and rock geometry problems. It can also solve the problems of different pore water pressures and different loading conditions. Due to its vast applications, SLOPE/W part of Geo studio 2007 was used to analyze the slope stability problem of Sohbat Charra slide zone. Basic parameters which are used in SLOPE/W analysis are angle of internal friction, cohesion and unit weight of the selected material.

7. Calculation of factor of safety (FOS)

Two different charts were used in the analysis to compute prompt/quick results. Keeping the factor of safety and height constant, calculated values from the given formulae are plotted on the chart 01 as shown in figure 5 to find the approximate value of slope angle. The following expressions are used to determine the required values from chart 01 in figure 5, in which factor of safety is kept constant.

$C/ \Upsilon H \tan\phi$ …… (1)

$C/ \Upsilon H F$ ……. (2)

$\tan\phi/F$ ……. (3)

Where "C" is cohesion, "ϒ" is unit weight of material, "H" is height of slope, "F" is factor of safety and "ϕ" is angle of internal friction.

After finding the approximate slope angle shown in Table 2 by plotting the values calculated from above formulae on chart 01 and height of slope, another design chart for circular failure which includes several factors of safety gave the factor of safety for the used angle of slope and height shown in table 2. Values of the slope angle functions, horizontal (X) and vertical (Y), can be plotted on the chart and respective factor of safety can be calculated. The functions of (X) and (Y) are presented below:

$X = i - 1.2\ (\phi)$ …………….. (4)

$Y = \Upsilon H/c$ …………….. (5)

Table 1. Analyzed Data in Laboratory

S. No	Material	Sample Description	Cohesion (KN/m^2)	Angle of internal friction (Degree)	Unit wt (KN/m^3)
1	Soil	01 (3ft)	33.09	32.6	18.81
2	Soil	01 (6ft)	33.13	34.80	19.03
3	Soil	02 (3ft)	16.45	34.90	18.35
4	Soil	02 (6ft)	4.30	42	19.01
5	Soil	02 (Top layer)	3.29	32	13.76
6	Soil	03 (Top layer)	7.60	33.10	15.23

Table 2. Calculated Values of Approximate Slope Angle & F.O.S using Failure Charts.

S. No	Sample taken from	Avg. value of "C" (KN/m^2)	Avg. value of "ϒ" (KN/m^3)	Avg. value of "ϕ" (Degree)	C/ ϒHTanϕ	C/ϒH F	Tan ϕ/F	Approx Slope Angle "i"	Slope Angle function (X) = i – 1.25 (ϕ)	Slope Angle function (Y) = ϒH/C	F.O.S from chart
1	RD 17+825	33.11	18.92	33.70	0.18	0.08	0.44	50^o - 60^o	17.875	8.571	1.5
2	RD 17+850	7.60	15.23	33.10	0.05	0.022	0.43	30^o - 35^o	- 06.375	30.06	1.5
3	RD 17+875	8.01	17.04	36.30	0.04	0.02	0.49	35^o - 40^o	- 05.375	31.55	1.5

Keeping H = constant = 15m and F.O.S = constant = 1.5

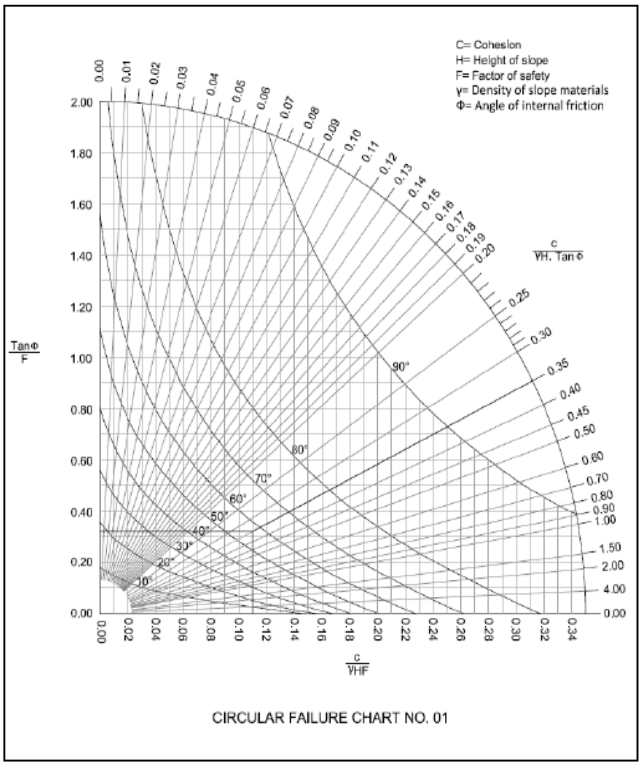

Fig. 5. Circular Failure Chart No. 01 (Hoek and Bray, 1981)

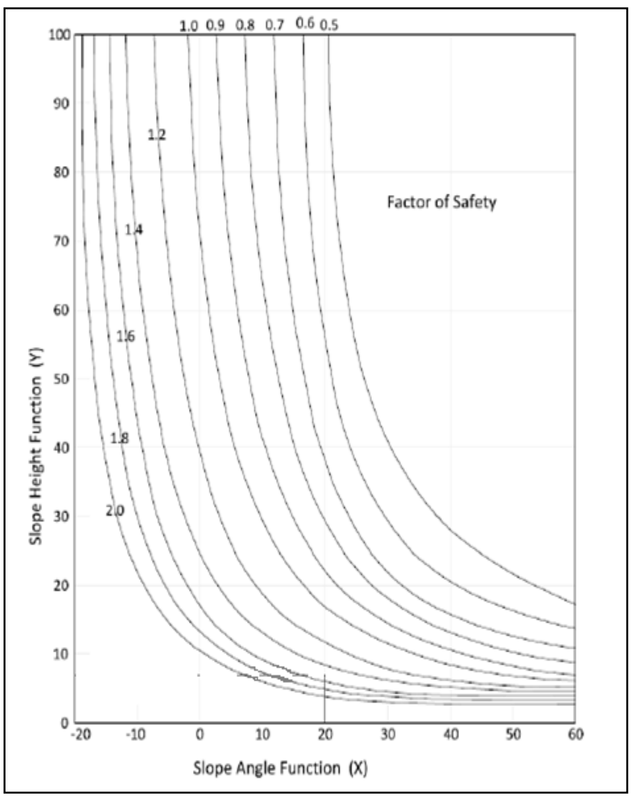

Fig. 6. Design Chart for Plain failure (Ramamurthy, 2010)

8. Preparation of models

After using these charts, preparation of models in SLOPE/W for analysis becomes very easy for optimum results. Average values of cohesion, angle of internal friction and unit weight for each sample were taken for analysis. Model of each sample was prepared in AutoCAD by using these charts and was shifted to SLOPE/W for detailed analysis and design. Models and respective results are presented in (Figs. 7-9).

9. Results and discussions

According to the analysis from SLOPE/W, the maximum slope height for RD 17 + 825 is approximately 22.45 meters with width of the cut slope equal to 15.90 meters. The stable slope angle for that portion is 55 Degree which corresponds to an average factor of safety of 1.47, approximately taken as 1.5. For these values, the slope will be stable at that portion. This area consists of talus deposits with silty clay properties. The parameters of that area are; cohesion = 33.11 KN/m^2, Angle of internal friction = 33.70 Degree and Unit weight of soil = 18.92 KN/m^3.

For portion at RD 17 + 850, the maximum slope height is approximately 19.17 meters with width of cut slope of 29.67 meters. The stable slope angle for that portion is 33 Degree for which average factor of safety is approximately equal to 1.5. For these values the slope will be stable at that portion. This portion mainly consists of silty clay deposits. Most of the slide occurs at that area and it badly damaged the existing road by slipping down of heavy boulders. This portion has a very loose soil and material slide down even in dry conditions. The parameters of that area are; cohesion = 7.60 KN/m^2, Angle of internal friction = 33.10 Degree and Unit weight of soil = 15.23 KN/m^3.

For portion at RD 17 + 875, the maximum slope height is approximately 17.62 meters with width of cut slope of 24.97 meters. The stable slope angle for that portion is 35 Degree for which the Average factor of safety is 1.5. For these values the slope will be stable at that portion. This portion mainly consists of talus and silty clay deposits. This portion is a bit stable as compared to RD 17 + 850 but the road at this portion is also damaged due to sliding down of big boulders. The parameters of that area are; cohesion = 8.01 KN/m^2, Angle of internal friction = 36.30 Degree and Unit weight of soil = 17.04 KN/m^3.

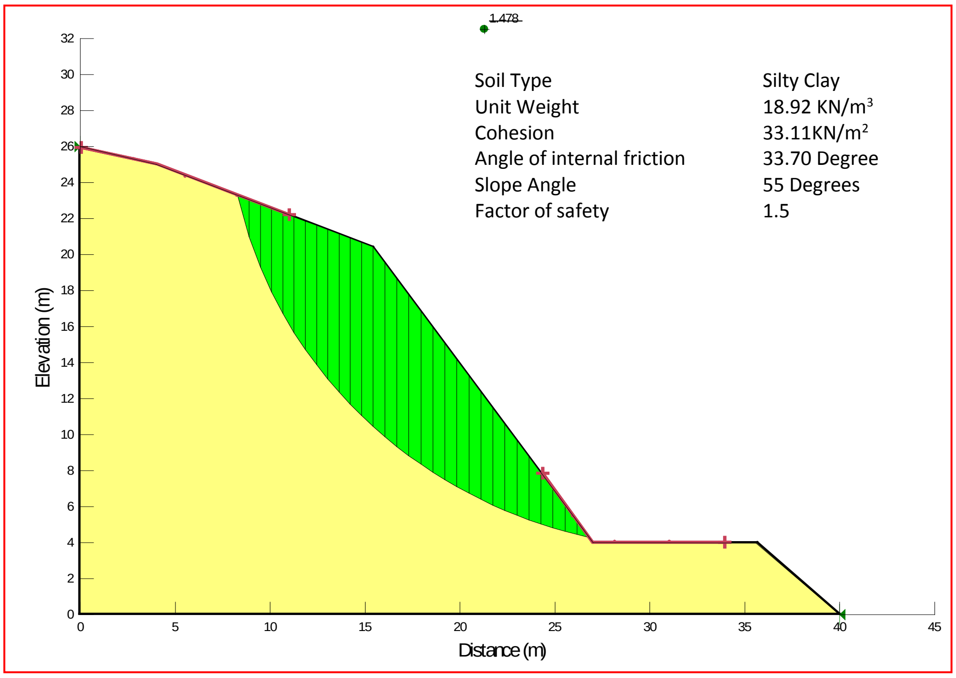

Fig. 7. Slope W Model with FOS and Slope angle of 55 Degree.

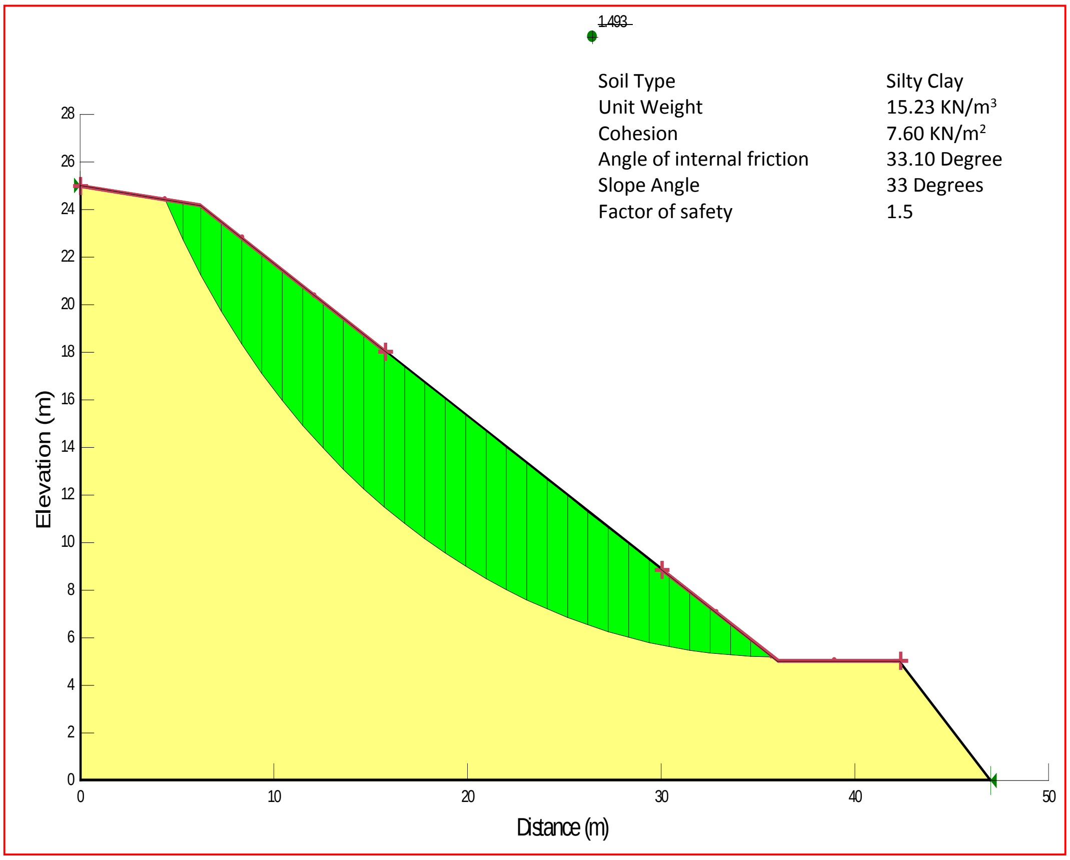

Fig. 8. Slope W Model with FOS and Slope Angle of 33 Degree

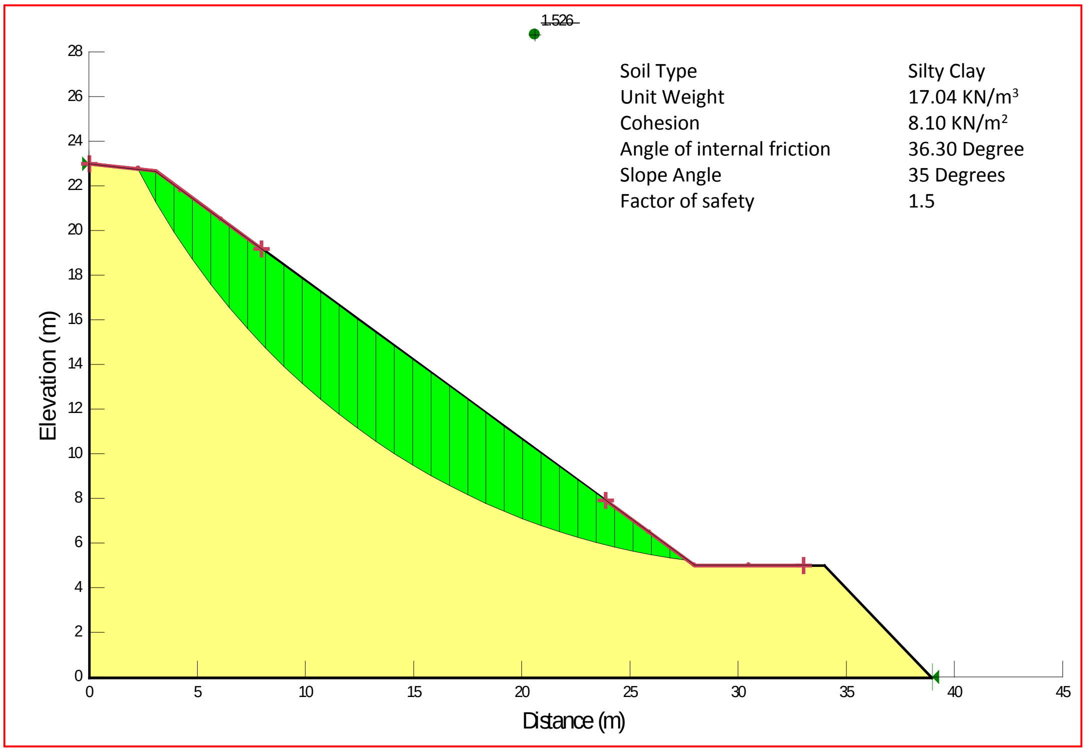

Fig. 9. Slope W Model with FOS and Slope Angle of 35 Degree

10. Conclusions

On the basis of above discussion it is concluded that:

1. The road at Sohbat Charra is mostly blocked due to heavy slide creating difficulties in movement/travelling to the people of Allai valley.
2. The existing Retaining structure constructed at Sohbat Charra Slide zone is badly damaged due to heavy slide which can be redesigned according to the calculated shear strength parameters.
3. The road should be constructed at Sohbat Charra slide zone such that the stable cut slope can be achieved.
4. The soil type at the Sohbat Charra location is very weak and loose. So a cut slope of 33 Degree is safe at RD 17 + 850 to stabilize the slope.

11. Recommendations

On the basis of discussions and conclusion following recommendations have been made:

1. Results from SLOPE/W software shows that a low slope angle i.e. 33 Degree slope is required with a greater cut slope width equal to 29.67 meters.
2. Berms along the slope should be constructed at Sohbat Charra slide zone for stability of slope.
3. The slope should be provided with wire mesh of 3/8 inch diameter steel bar with 15 inch spacing in both directions.
4. Shotcrete of thickness 4-6 inches thick on the berms should be provided for the stability of the Sohbat Charra slide zone.
5. After shotcrete rock bolts each of 2m length and 3m c/c spacing in both directions should be drilled and should be fully grouted.
6. It is recommended that a proper redesign of existing damaged retaining structure should be done in future for construction of the access road through this location.
7. Proper pipes should be provided before shotcrete for drainage.

References

Cruden, D.M., Varnes, D.J. 1996. Landslide Types and Processes. In: Turner, A.K., Schuster, R.L. (Eds.), Landslides: Investigation and Mitigation, transportation research board. National research council, USA (Special report), 247.

Dikau, R., Brunsden, D., Schrott, L., Ibsen, M., 1996. Landslide recognition, identification, movement and causes, Chichester, UK.

Hoek, E., Bray, J.W., 1981. Rock slope engineering, third Edition, B.C., Canada.

Ramamurthy, T., 2010. Engineering in rocks for slopes, foundations and tunnels (2nd edition), New Delhi, India.

United Nations Development Program, 2004. Reducing Disaster Risk-A challenge for Development, United Nations Development Programme, bureau for crisis prevention and recovery, New York, USA.

Varnes, D.J., 1978. Slope movements and types and processes, in landslides analysis and control, Washington D.C. Transportation research board (Special report), 176, 11-33.

World disaster Report, 2003. Focuses on ethics in aid, international federation of Red Cross and Red Crescent societies.