Perspective slope stability assessment along Aizawl – Variengte Sector of NH 54, Mizoram, India

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Abstract

Perspective slope stability assessment along selected stretches of National Highway corridor between Aizawl – Variengte, Mizoram, revealed that the slope mass at a number of locations may experience different degrees of slope instability of varying dimensions within the excavated slope in the event of any high anomalous monsoon discharge. Though major part of the road stretch during the pre-monsoon drier period was found to be self-supporting, yet, probability of slope failures at saturated condition at places may be anticipated due to general disposition of the litho-variants, intense weathering, occasional presence of sheared zones and presence of variably compacted older debris. Further, the variable nature and thickness of overburden, presence of seepage and flowing condition at places, identification of crown cracks of varying dimension and creep movement at places further emphasizes the presence of indicative revealing condition for future initiation of slope failures. The bedrock in the studied sector is found subjected to intense weathering and as a result at many stretches competent bedrock is not encountered at shallower level. Due to intense weathering and past slope failures the bedrock is found to be overlain by thin to thick (1-5 m) overburden material like that of older well compacted debris, insitu clay to silty soil (occasional sandy pockets at places), younger loose debris, scree and slope wash materials. Further due to earlier mass wasting the slope mass along the studied stretches exhibits large spatial and temporal variations in respect of slope morphometry. The dominant siltstone-sandstone sequence underwent folding and fracturing, which facilitated the weathering and reduction of rock mass strength (RQD estimated to be varying from 15 to 40). The rock mass at places is also found to be traversed by high angle shears which reduce the rock mass strength considerably (RQD values 10-30). The disposition of the bedding with respect to the natural and modified slope at many places indicated a condition favourable for planar failure in the bedrock and shallow translational failure in the thin overburden above the bed rock. Further because of the development of joints and fractures related to the folding and deformation at places, intersecting joints and bedding in the slope day-lighted and favoured a condition of wedge failure. The heavy monsoon discharge acted on the variable slope forming material flows along the slopes by way of surface drainage network, which changes at places due to sudden variation in the lithology and slope. Along with surface drainage network, the major part of the percolated water also moves along a variable sub-surface network which interacts with the slope and slope forming material in a complex and varied way. Further due to the higher porosity and reduced permeability of the weathered soil (dominantly fine grained silt to clay), local development of pore water pressure was observed at places. During the period of study (pre-monsoon dry period) a significant part of the slope proximal to the road bench exhibited flowing, wet and damp condition, especially in the overburden slope. These clearly indicate that sub-surface drainage network could be active for a longer period and can act on the slope forming material. One of the significant observations made during the study is the identification of loci of hydrostatic pressure behind the cut slope even during dry season and consequent bulging and fracturing of the slope. Further active removal of clay material by the surface run-off and deposition of the same at places indicated piping condition. These clearly reflect pre-condition of failures in the event of further anomalous rainfall and anthropogenic intervention. The perspective studies may help in overall assessment of the cut slope stability and identification of areas of further studies for this important National Highway corridor.

1. Introduction:

During the last few decades due to the rapid growth of population and augmentation of infrastructures, various parts of North East India has been experiencing large scale excavation of natural slope for the expansion of the existing road network and laying of new roads. The excavations of the natural slope for the same which at many places acted on the fragile geomorphological and geological set up led to the recurrent slope failures particularly during high precipitation. Further, since the region is one of the most active geodynamic domains of the crust and has significant recorded seismicity of social relevance, the probability of seismic induced slope failure in the event of a shallow focus/high magnitude earthquake on the excavated slope is very high. Therefore, it is imperative that any major infrastructure developmental work like that of expansion of existing roads /laying of new ones which involve large scale excavations warrants sustainable planning involving use of the existing geological, tectonic and landslide susceptibility maps prepared on various scale. If no such susceptibility maps of required scale are available, perspective slope stability assessment of the area based on landslide inventory and identification of the revealing condition for likely failures may help in planning and required mitigation. A major part of the National Highway corridor between Aizawl-Variengte, Mizoram are presently undergoing expansion and consequent excavation of the slope. Though major part of the road stretch as observed during the pre-monsoon drier period was found to be self-supporting, yet, at places, probability of slope failures at saturated condition cannot be ruled out due to general disposition of the litho-variants, intense weathering, occasional presence of sheared zones and presence of variably compacted older debris. Field based perspective slope stability assessment along part of the National Highway corridor, therefore, carried out for a general understanding of the probable stability condition of excavated slopes during saturation in active monsoon. The studies undertook includes documentation of the past slope failures and identification of revealing geo-factors pertaining to the slope stability.

2. Geological set up:

The studied corridor of Mizoram is part of the tertiary sedimentary sequences which exposed folded sandstone and shale dominated sequences of upper and middle Bhuban formation of Surma Group. The various litho units are folded and a part of the large anticline structure. The present day geomorphic expression in the form of number of lineaments is result of post depositional structural adjustment as well as concurrent geomorphic evolution (figure 1). Towards the SE part the tertiary sediments are affected by Eastern Boundary fault and Mat fault. Apart from the regional folding, the rocks are found locally affected by high angle shears which has direct bearing on the strength character and stability of the rock mass during the excavation.

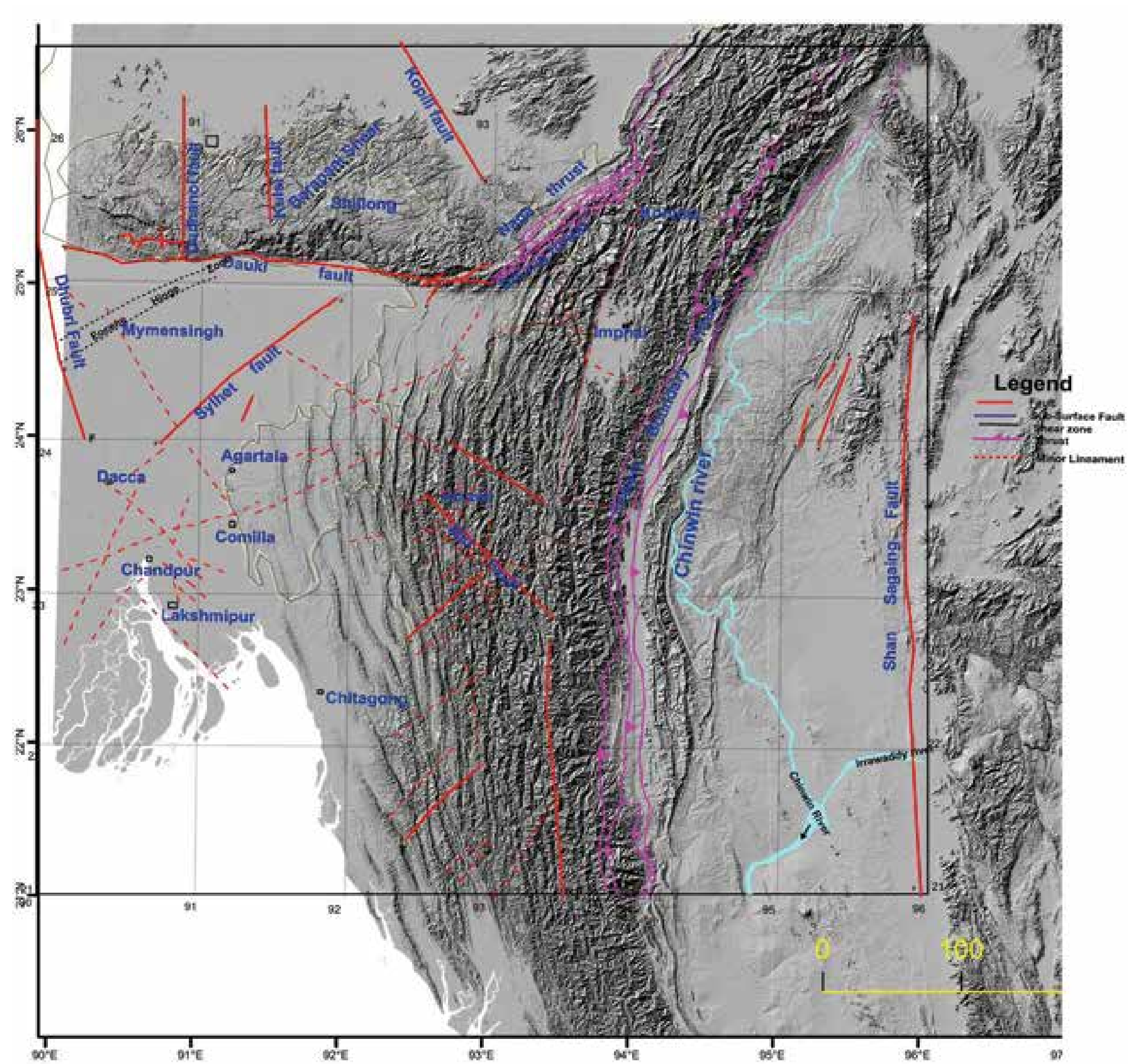

Figure 1 Regional relief map showing disposition of prominent lineaments

3. Methodology:

The studies undertaken are field based in which following things were attempted:

i. Identification and documentation of the geo-factors like bedrock, surficial geology, slope morphometry etc.
ii. Assessment of surface and subsurface hydrological network operating on the natural and excavated slope mass.
iii. Inventory of the recognisable slope failures and documentation of the slope attributes both in natural and excavated slope.
iv. Identification of the various revealing conditions in the slope mass indicative of probable failure condition.
v. Perspective assessment of the slope stability based on the above.

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4. Results:

The various documented attribute of the slope mass required for evaluation of the perspective slope stability assessment are enumerated below:

***Bed rock*:** The bed rock encountered in the exposed part is largely argillaceous dominated sequence in which siltstone is the major component along with variably thick sandstone and shale at places. The alternate sequence of rock sometime clearly shows different competence and strength character as exhibited by presence of thin layer of crumbled shale within more competent sandstone/siltstone (figure 2 & figure 3).

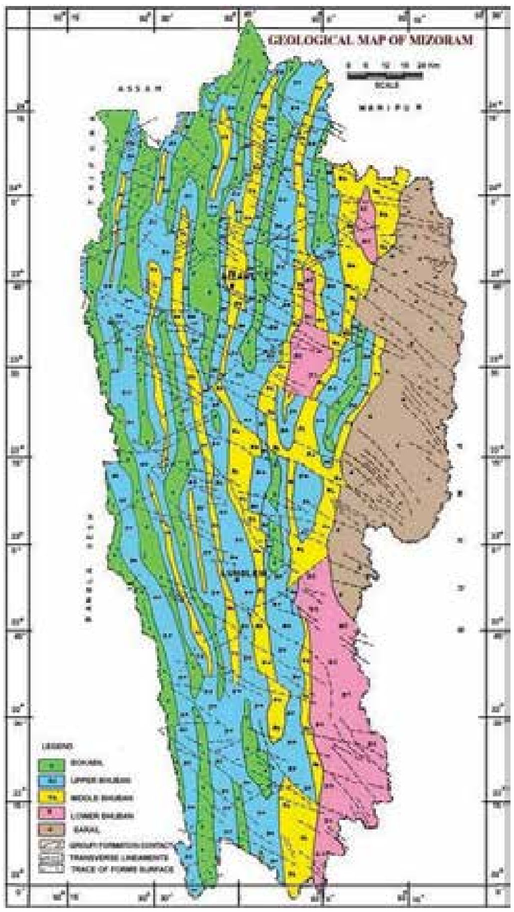

Figure 3 Interbanded sequence of litho units in the area

Figure 2 Regional Geological map of the area

The bed rock is found to have experienced variable degree of differential weathering and consequent reduction of the strength character.

The weathering is facilitated by fractures, especially through percolation of water (figure 4) through the axial plane regions of the folds (figure 5) which shows higher density of fractures.

Figure 4 Seepage of water in the loose overburden

The rock mass strength is highly variable (RQD estimated to be varying from 15 to 40). The reduction of rock mass strength is evident from diffusion of the bedding and sometime discontinuity in the exposed cut face (figure 6). The rock mass at places is also found to be traversed by high angle shears which reduce the rock mass strength considerably (RQD values 10-30).

Figure 5 Steepening of the dip and seepage of water

Figure 6 Diffusion of bedding in the exposed section near the axial zone of the antiforms

Near the shears the rock mass is fragmented and become powdery at places (figure 7). The primary bedding is the major discontinuity plane. Apart from bedding discontinuity a number of variably disposed fractures and joints were also identified in the bed rock which is resulted due to deformation. The secondary fractures and shears at places indicated local slip and further reduction of the strength character of the rock mass (figure 8).

Figure 7 Fragmented and powdery rock mass exposed

Figure 8 High angle shears traversing the rock mass in the cut slope

***Surficial Geology*:** The bed rock encountered along the highway corridor and adjoining slope is largely made up of thickly bedded siltstone with subordinate shales and sandstone belonging to Tertiary Surma Group. However, since the bedrock is subjected to intense weathering, at many stretches competent bedrock is not encountered at shallower level. Due to intense weathering the bedrock is found to be overlain by thin to thick (1-5 m) overburden consist of highly weathered rock mass, insitu clay to silty soil (occasional sandy pockets at places). Because of the primary compositional differences, the weathering profile has variable nature and thickness. Further, because of the past and paleo mass wasting, surficial materials like that of older well compacted debris, younger loose debris, scree and slope wash are encountered in the slope. The surficial material, at places, especially proximal to the accumulation zones of past failures is found to be highly heterogeneous and unevenly distributed. The surficial material, therefore, shows variable volumetric proportion, size fractions and variation in permeability. Since the area experiences heavy monsoon discharge on the said variable slope forming material, therefore the response of the slope on the hydrological situation, is largely variable and complex in nature. Further due to the weathering of the siltstone, the derived soil shows higher porosity and reduced permeability (dominantly fine grained silt to clay). Along with the natural material the slope also hosts at places large volume of loose excavated unconsolidated material. Hence, the large scale excavation has not only modified the slope but the slope forming surficial material (figure 9). At many places long rectilinear to curvilinear cracks of 1 to 8 m observed in the surficial material.

Figure 9 Loose unconsolidated overburden mass in the excavated slope

***Slope morphometry*:** The natural slope which is largely low to moderate is largely modified proximal to the road bench due to excavation and adjacent to the road bench shows variable slope amount, aspect directions and convexity The steepening of the slope and removal of the overburden exposed the weathered bed rock and geometrical relation with the discontinuity in the rock mass.

***Hydrology*:** The area is one of the high rainfall regions of the country and experiences heavy monsoon discharge. Much of the monsoon discharge flows along the slopes by way of surface drainage network, which changes at places due to sudden variation in the lithology and slope. Along with surface drainage network, the major part of the percolated water also moves along a variable sub-surface network which interacts with the slope and slope forming material in a complex and varied way. Further due to the higher porosity and reduced permeability of the weathered soil (dominantly fine grained silt to clay); local development of pore water pressure was observed at places. During the study in pre-monsoon dry period, a significant part of the slope proximal to the road bench exhibited flowing, wet and damp condition, especially in the overburden slope (figure 10 & figure 11).

Figure 10 Flowing condition in overburden mass during the dry period

Figure 11 Extensive damp patches in the exposed rock mass as observed during dry period

These clearly indicate that sub-surface drainage network could be active for a longer period and can act on the slope forming material. One of the significant observations made during the study is the identification of loci of hydrostatic pressure behind the cut slope even during dry season and consequent bulging and fracturing of the slope. Further active removal of clay material by the surface run-off and deposition of the same at places indicated piping condition (figure 12). These clearly reflect pre-condition of failures in the event of further anomalous rainfall and anthropogenic intervention.

Figure 12 Prominent seepage and clay deposition in the basal overburden slope (Inset shows deposited moulded finer material)

Since the area experiences heavy monsoon discharge on the said variable slope forming material, therefore the response of the slope on the hydrological situation, is largely variable and complex in nature. It is pertinent to add that large scale excavation in the slope adjoining to the existing road bench not only modifies the slope but interferes in the subsurface hydrological network by exposing them to the loose surficial material in a diffusive way.

5. Inventory of past failures and identified revealing conditions:

During the study a number of slope failures have been observed in natural slope and also in cut slope adjacent to the road involving bed rock and overburden material. The attribute data of many of them as such cannot be documented in detail because of the obliteration of the scarps, However, identification of concavo-convex slope, relict scars, diffused hydrological scenario, visible creep movement at a number of places pointed towards dynamic nature of the slope mass. Detailed field studies along the road corridor reveals that within the inter-banded siltstone-sandstone-shale sequence, the disposition of the bedding with respect to the natural and modified slope at many places indicated a condition favourable for planar failure in the bedrock and shallow translational failure in the thin overburden above the bed rock. Further because of the development of joints and fractures related to the folding and deformation at places, intersecting joints and bedding in the slope day-lighted and favoured a condition of wedge failure.

However, detailed inventory of two slope failures in rock and over burden which are recently initiated or reactivated are documented. The two most prominent among them are at Variengte (24° 30' 35.8": 92°46' 70"), (figure13) and that of Mama cement factory (23°55'22.6": 92°39'25.3"), (figure14). At Variengte a small (600 sq m) but prominent rock slide initiated in 2013 within the variably weathered interbedded sequence of sandstone was identified. The disposition of the discontinuity with respect to the slope is responsible for both planar and wedge failure. The rock slide is interpreted to be suspended one and is both retrogressive and enlarging. Since the rock slide is adjacent to National Highway and it is found that accumulated debris mass released during mass movement contain big size boulder, therefore in the event of subsequent surface runoff, the same may come down suddenly and may strike the Silchar bound vehicular traffic and consequent hazard. Above the crown there is human settlement in the form of few hutments. In the event of further retrogression of the rock slide, the habitation will be affected. Therefore the road bench, the Silchar bound traffic and the hutments are the elements at risk. Though the dimension of the rock slide is not significant, however, due to its susceptibility for further reactivation within a short period and influencing the element of risk, makes it a threat and therefore need to be mitigated at the earliest.

Figure 13 Prominent rock slide showing released boulder at vulnerable slope, Variengte

The slope failures near Mama cement factory (figure 14) is a reactivated one involving 2080 sq m area and an estimated volume of 12480 cu m affecting the insitu silty soil and older debris material. Rotational failures were identified and the failure plane is found to be both retrogressive and enlarging. Adjacent to the sites of active mass movement prominent creep movement was identified through differential bending of tree trunk. The slope mass exhibited prominent seepage condition even during the dry month of January. Both active hydrological condition and anthropogenic interferences on slope mass are accounted for the failure. Apart from the sites of prominent past mass movements at a number of locations creep movements in side slope and prominent subsidence of road bench were also seen and documented.

Figure 14 Rotational failure in the cut slope near Mama Cement Factory
(Identifiable creep movement in the adjoining slope evident from bending of tree trunk)

The study further reveals that there are locations along the studied corridor where predisposing condition in the slope indicates probable initiation of failure in the event of triggering either due to anomalous high rainfall or due to seismicity. One such location (23º53'54.6": 23º53'54.6") identified along the road corridor reveals probable shallow translational movement along the interface of weathered bed rock and 4 m thick overburden (figure 15).

Fig. 15 Inclined rock soil interface – a site of probable
translation failure during lubrication

The same is interpreted from the slope features like (a) visible bulging of the slope mass (figure 16). (b) Presence of a number of transverse burrows and discreetly bouldery units facilitating seepage and removal of finer material (c) flowing hydrological condition iv) dampening of the slope, the same dampening of the slope mass even during dry season pointed towards development of pore water pressure at the back of the rock face. d) Prominent curvilinear fractures, (e) well defined irregular furrows.

Figure 16 Prominent bulging of slope probably indicating pore water pressure development

There is no history of failure in the area as of now. But the increase of pore pressure as evidenced by bulging of the lower slope and the flowing condition in parts of the slope even during driest month of January suggests that it is prone to failure, especially if interfered by anthropogenic activity such as cutting of the toe of the slope. Presently the slope is self supporting however in the event of any small/large scale anthropogenic intervention, the slope failure is expected. The slope attribute documented may suggest that the slope face may experience failure during next five years naturally and if interfered further in the next monsoon. Therefore, probability of the occurrence of failure is 20%. Apart from the above, due to the action of subsurface water at a number of places removal and deposition of fine clay fractions at the base of the cut slope and also in vegetated natural slope were observed.

6. Discussion:

The observation along the road sector indicate appreciable signature of past mass movement and also present day dynamicity of the slope mass. Further, at a number of places the revealing conditions suggest probable failure in the event of any rainfall, seismic and anthropogenic triggering. Since the slope mass is being modified and hence the geometrical relation between discontinuity in rock and that of excavated slope at places are being changed to favour both planar and wedge failure consequent to the lubrication during monsoon. Further, the bed rock- overburden interface between 1- 5 m depth are also exposed at many places due to excavation. The said exposed interface is the probable loci of shallow translational movement of varying dimensions due to lubrication in the event of any high anomalous monsoon discharge. At a number of location the exposed slope reveals presence of rectilinear to curvilinear cracks, prominent signature of creep movement, local slump, piping and consequent deposition of finer clay in pockets which clearly indicate that slope mass is under dynamic state and experiencing stress at various intensity. A number of subsidence zones of varying dimension both along the road bench and also in the side slope corroborate the above contention. Identification of prominent bulging at places clearly indicates the development of hydrostatic stress behind the cut slope. Though the major part of the road is found to be self supporting under the pre monsoon dry period but further enhancement of stress at saturated condition may be interpreted due to combination of hydrological scenario and toe cutting of the slope by artificial means. The said stress acting on the slope forming material may induce slope failure of varying nature and magnitude. Since the area experiences heavy monsoon discharge on variable slope forming material, therefore the response of the slope on the hydrological situation, is largely variable and complex in nature. Much of the monsoon discharge flows along the slopes through surface drainage network path, which is regulated by variation in the lithology and slope. Along with surface drainage network, the major part of the percolated water also moves along a variable sub-surface network which interacts with the slope and slope forming material in a complex and varied way. Further due to the higher porosity and reduced permeability of the weathered soil (dominantly fine grained silt to clay), local development of pore water pressure was observed at places. During the study in pre-monsoon dry period, a significant part of the slope proximal to the road bench exhibited flowing, wet and damp condition, especially in the overburden slope. These clearly indicate that sub-surface drainage network could be active for a longer period and can act on the slope forming material. Therefore it emerges that large scale excavation for widening and expansion of the road bench in the prevailing geological and hydrological scenario need to be undertaken considering the slope features discussed above and wherever required are to be executed through required engineering support. Otherwise, the excavation may act as an triggering factor during heavy monsoon discharge for inducing slope failures and consequent hazard to the road bench. The perspective studies may help in overall assessment of the cut slope stability and identification of areas of further studies for this important National Highway corridor.

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