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TACKLING LANDSLIDES DURING EXTENSION OF KKH

Engr. Sohail Kibria, Basit Masud

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SYNOPSIS

The Karakoram Highway (KKH) linking Pakistan with China traverses through one of the most difficult mountainous ranges in the world. There are many notorious landslides enroute its 840 km long stretch (Figure-1). These landslides pose the most challenging geotechnical problems to the civil engineers and engineering geologists.

Recently the 462 km long stretch of KKH from Havelian to Raikot has been studied extensively for the rampant landslide problem and their mitigation, as a part of its widening program. The study involved topographic surveys, geological mapping, interpretation of satellite imageries, rock joint measurements followed by stereonet analysis, on-site rock mechanics testing and slope stability analysis.

The 322 km length of the study involves widening of the road from 4.5 m to 7.0 m, whereas 140 km length of the study comprises relocation of the road to a higher level because of future inundation in the reservoir of a major dam. The studies have concluded that minimum disturbance should be caused to the barely stable mountains during extension of the road, which should be planned on the valley side, as much as possible. Besides, rock fall has been determined as the major hazard enroute. The mitigation measures include modification of drainage, provision of benches, removal of overhangs, provision of rock trap ditches, construction of protection walls, construction of retaining/breast walls along with a well-planned round-the-clock maintenance strategy to keep the road operational. A blend of these measures is considered to have optimum impact on the cost of the project and will ensure safety against any life hazard.

This paper describes the details of the geotechnical studies carried out for addressing landslide problems and the optimum remedial measures conceived for extension of KKH.

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INTRODUCTION

Landslides and other types of slope movements (rock falls, topples, debris falls, debris slides, debris flows, mud flows) constitute a major environmental hazard along the entire length of KKH. They pose a serious threat to the safety of the travelers, damage the highway at numerous places, and frequently interrupt traffic. The maintenance and remediation costs for the highway have been rising astronomically ever since its construction in the seventies. The various factors contributing to slope movements include steep slopes, highly weathered and fractured rock masses, abundance of unconsolidated material (residual and colluvial soils, terrace deposits, glacial moraines), steep contact between unconsolidated material and bedrock, abundance of overhangs due to uncontrolled blasting, severe climatic conditions, abundant supplies of water from rainfall and snow melt, and seismically active nature of the region.

For safe construction of the proposed Basha Diamer Dam, it is imperative that the existing section of KKH from Havelian to damsite be upgraded and the section from dam site to Raikot, that will be submerged in the reservoir, be relocated (Figure-2). Both of these tasks require a detailed evaluation of landslide hazards along KKH. The following objectives were set forth for carrying out the landslide study:

1. Identify the types of slope movements that frequently affect KKH, investigate the factors that contribute to these slope movements, and evaluate their hazard potential.
2. Conduct a more detailed study of selected problematic landslide areas.
3. Recommend appropriate, cost-effective, remedial measures, including design of cut slopes that should be undertaken to minimize the hazard associated with slope movements and to obtain the necessary pavement width.

Subsequently, a reconnaissance field trip was undertaken in May-June, 2003 during which various modes of slope failure, and the associated hazards, were identified, five areas of major landslide activity were selected for further investigation, and 29 locations were chosen for collection of discontinuity orientation data by the detailed line survey method. This was followed by recording a detailed inventory of lithologic units, slope movements, and hazard potential evaluation for various sections (Havelian to Mansehra, Mansehra to Thakot, Thakot to Dasu, Dasu to dam site, dam site to Raikot), of the highway as well as an investigation of the five areas designated for detailed study. The discontinuity orientation data were analyzed to determine the principal joints sets and various modes of failure using GEOrient™ and ROCKPACK™ softwares. Based on field observations and subsequent office work, both general and specific remedial measures and typical cut-slope sections were conceived.

PROJECT AREA

The KKH starts from Hasanabdal, a town about 45 km from Rawalpindi on the main G.T. Road, but the section of the highway pertinent to the project starts from Havelian which is located at a distance of 56 km from Hasanabdal. The project section ends at Raikot Bridge, the end point of the section that needs relocation due to submergence in the dam reservoir.

The project area falls within latitudes 33.45^{o} to 36.50 ^{o} N and longitudes 72.41 ^{o} to 75.27 ^{o} E. The project section of the highway passes through alluvial plains and loessic deposits, with a few rock outcrops, near Abbottabad and Mansehra, trailing through Shinkiari and the higher Pakhli Plain. It descends from Sharkul down to Batgram on mostly schistose rocks and then follows the Nandhiar valley upto Thakot. After crossing the Thakot Bridge on the Indus River, the highway runs along the right bank of the Indus River upto Kamila and then follows the left bank upto Raikot Bridge. As the highway passes through fertile plains like Rush, Chattar, Pakhli, and Nandhiar, the cultivation along it is extensive. Besides these plains, residual soil terraces are also seen along the highway in this section. The presence of flood plains, gentle slopes with rare cliffs, and lack of waterfalls along the river indicate the mature stage of erosional geomorphic cycle for this stretch of the highway.

From Thakot to dam site, steep slopes and deep gorges characterize the highway section. The topography is rough and rugged. The Indus Valley widens at certain places forming wide terraces where cultivation is practiced. The Thakot-Basha section of the highway passes through mainly metamorphic rocks of low to high grade. The high-grade metamorphism of both igneous and sedimentary rocks has resulted in the formation of schists, amphibolites, granulites, and quartzites. The low-grade metamorphic rocks consist of slates and phyllites. Some amphibolites gneisses are also seen in this section.

The relocation section of the highway passes through a U-shaped portion of the Indus Valley. The slopes in this section are steep as the Indus River passes through very high mountains. The major valleys are frequently occupied by perennial streams carrying snowmelt water. The rocks exposed are mainly of igneous origin along with small outcrops of metamorphic rocks.

BASIC APPROACH

The basic approach of this study has been to control and minimize the hazard potential associated with slope movements, not to eliminate the hazard completely. An important element of this approach is to utilize the most cost-effective remedial measures , based on locally available resources. The ultimate objective of the approach is the safety of the travelers and the hazard-free hauling of equipment and machinery.

The following broad philosophy was adopted to rationalize the landslide study:

i) Slope movements along KKH are triggered by natural factors including the presence of well-developed discontinuities, extensive unconsolidated deposits (valley fills by glacial activity, terrace deposits, alluvial/colluvial soils, and sheared rock masses), high relief and steep natural slopes, occurrence of torrential rains, and seismically active nature of the region. These factors suggest that slope movements in the area, particularly the large destructive debris flows, will continue to occur and pose hazard to the highway despite the remedial measures.

ii) Although the hazards associated with slope movements cannot be completely eliminated, they can be significantly minimized by employing a variety of protective and remedial measures.

iii) In addition to remedial measures, continual maintenance of the highway is essential for smooth and safe flow of traffic.

iv) Although there are numerous instances of slope instability along the highway, many steep slopes have reached their natural state of equilibrium. Excavating the toes of these slopes for the purpose of widening the highway can result in instability, triggering new landslides. This will be particularly true for the areas where unconsolidated materials are prevalent. Therefore, the best approach for widening the highway would be to consider fill embankments supported by retaining structures before undertaking any excavations to gain the required width of the highway.

v) Considering the huge nature of this project, the extensiveness of the work involved, and the limited resources of our country, it was considered to select the most cost-effective methodologies for construction and successful completion of this project in which handling of landslide hazards is one of the most important considerations.

vi) The magnitude of the landslide problems along the highway is so enormous that in certain instances, the hazard has to be accepted and to be learnt as how to best live with the problem.

METHODOLOGY OF STUDIES

The detailed landslide studies comprised the following tasks:

- Reconnaissance Field Trip
- Detailed Line Survey
- Detailed Inventory of Lithologic Units, Slope Movements, and Hazard Potential Evaluation
- Discontinuity Data Analysis
- Remedial Measures and Design of Cut Slopes

- Evaluation of Instability of Slopes with Reservoir Impoundment
- Mitigative Measures to Save KKH in Relocated Section

GEOLOGY AND GEOMORPHOLOGY ALONG KKH

As a result of the past and present geomorphologic processes, a variety of landforms are present within the Indus Valley. Pakistan's most exotic geomorphic features are the mountains. Northern Pakistan contains spectacular mountains capped by some of the highest peaks on earth. The mountainous terrain includes the Lesser Himalayas in the south and the Trans-Himalayas in the north. The Himalaya region contains three roughly parallel and arcuate mountain ranges: the Karakorum Range (Northern Baltistan, Hunza, Iskuman, Yasin), the Kailas Range (Haramosh-Rakaposhi-Masherbrum chains), and the Hinduraj Range (easterly extension of the Hindu Kush). These mountain ranges contain twelve of the thirty highest mountain peaks in the world, with heights greater than 8,500 m. The mountain peaks show typical ice skittled sharp features with steep slopes, occasionally covered by sparse vegetation. The Indus River is the major drainage artery. The bedrock geology along the project section of KKH is shown on Figure–3.

The landform between Hassanabdal and Thakot mainly consists of reworked loess and alluvial deposits. These deposits occur in the form of terraces and flood plain deposits along the valley slopes and banks of the main stream in the area. These alluvial plains are well developed in the low lands of Haripur, Abbottabad, Hassanabdal, and Batgram areas, but poorly developed in the uplands between Mansehra and Shinkiari. The loess is partly consolidated and interlayerd with sandy gravel. Small alluvial patches present along the highway are composed of gravel and boulder deposits. The alluvial deposits of Batal are composed of slightly reworked and weathered material derived from the Mansehra granite.

The Thakot to Gilgit section of the highway is characterized by steep slopes and deep gorges. The topography is rough and rugged. A wide variety of igneous and metamorphic rocks is exposed in the area that have undergone extensive deformation due to the high degree of tectonic activity characteristics of the region. The region has been glaciated one or more times. Glacial sediments comprise interbedded glaciofluvial and morainic deposits with less frequent occurrence of glaciolacustrine material. Surficial materials occur to a large degree in glacially deposited terraces in the river valleys, as alluvial fans at the confluence of the Indus River and its tributaries, and as recently deposited alluvial material in and along the riverbed.

The glaciation in the past has played a vital role in development of Indus Valley. From the confluence of the Indus and Gilgit rivers to a few kilometers upstream of Basha, except for a short stretch upstream to Raikot Bridge, the Indus River flows in a comparatively wide U-shaped valley section. The Chilas Plain between Basha and Raikot forms the major part of Basha reservoir. The width of the valley ranges from 0.5 to 2 km in this reach. It is infilled with extensive deposits of glacial sediments through which the present river channel has carved its way down to the present level. The meandering of the river in this section appears to be controlled by the regional structure and joint pattern developed in the rocks. The valley narrows somewhat between Basha and Sazin with some wider areas near Shatial and Sazin. Just below Sazin, the river bends and flows in a general southerly direction. The valley configuration changes to a V-shaped, steeper, narrow, and apparently non-glaciated form. This configuration continues from Sazin to Besham Qila with occasional wider sections such as the one at Pattan.

The individual geomorphic forms of the region include natural rock slopes, scree and debris covered slopes, debris-flow fans, alluvial fans, river terraces, and moraines. Natural rock slopes vary in form depending upon the lithology and discontinuity patterns. They vary from 40^o slopes in highly fractured slates to sub-vertical slopes in unweathered massive igneous rocks. Some slopes are seasonally snow covered and subject to severe freeze-thaw action and chemical weathering. Long sections of natural rock slopes are exposed from Sharkul to Sazin along a steep sided gorge.

The scree slopes and debris slopes result from accumulations of rock fragments (scree) and debris. The scree is a result of in-place mechanical weathering whereas the debris comes from rock falls and glacial moraines. Slope angles vary from 25^o to 40^o. In general, scree slopes consist of coarser pieces of intact rock with a highly permeable structure whereas debris slopes contain a significant proportion of fine-grained material that gives rise to a lower permeability. The coarser scree slopes are typically subject to localized avalanching, whereas debris slopes with a lower permeability are susceptible to the formation of debris flows. Scree and debris slopes of varying heights and extents are present along many sections of the highway.

Debris-flow fans are result of runoff water from either rainfall or snow melt. They consist of a mixture of unsorted material from fine silt to boulders, exhibiting a rough surface of levied gullies. The typical slope angle ranges from 7^o -20^o.

Alluvial fans occur typically as low-angle fans, in the range of 2^o to 7^o, at the confluence of mountain streams and the Indus River. They only form where the valley is large enough and the Indus River does not actively erode the deposited sediments.

River terraces, characterized by flat to gently sloping land situated at a level above the present flood plain, represent previous levels of the Indus River. These terraces consist of a variety of valley infill materials intermixed with glaciofluvial deposits.

Irregular mounds and ridges of unsorted glacial moraines can be encountered on the higher slopes. Evidence suggests that previous glacial activity extended down the Indus Valley as far as Shatial. These deposits include various types of glacial to fluvio-glacial material.

LANDSLIDE TYPES ALONG KKH

The various modes of slope failures that affect the KKH include rock falls, topples, plane failures, wedge failures, debris slides, debris flows and mud flows.

Because of the earthquake activity and frequent heavy rains annually, there is hardly any section of the highway that has not been affected by these slope failures.

Figures 4 to 7 depict various landslide formations.

Various modes of slope failures observed along KKH have been noticed as described below:

Rock Falls

In rock falls, a block of rock is detached from the surrounding mass along a steeply dipping discontinuity and falls under the influence of gravity, traveling most of its distance through air. Along KKH, rock falls constitute the most common mode of failure and they occur both in rocks as well as unconsolidated materials (valley fills, terrace deposits, etc.). In rocks, the falls are promoted by various discontinuities and overhangs, resulting from uncontrolled blasting, whereas in unconsolidated materials they occur mostly in the form of boulders of various sizes detaching from the surrounding matrix and falling down. Depending upon the gradation of unconsolidated materials and the joint spacing in rocks, the sizes of rock falls along KKH are highly variable, ranging from small boulders to extremely large rock blocks. Because of their extremely rapid speed and the suddenness of their occurrence, rock falls can be categorized as the most hazardous mode of slope failure. Any mitigation measure for this purpose must address the hazard associated with rock falls.

Topples

Topples occur along those discontinuities that dip into the slope face at steep angles. Toppling is also a common mode of failure along the highway. Many of the negative slopes along the entire length of the highway are a consequence of these toppling failures.

Plane Failures

Plane failures are associated with moderately to steeply dipping (more than 40 degrees) discontinuities that strike more or less parallel to the slope face or daylight on it. Plane failures are a less frequent mode of failure than rock falls and topples.

Wedge Failures

Wedge failures are found to occur where two sets of joints intersect each other with their lines of intersection daylighting on the slope face at angles greater than the friction angle. These are found to be more frequent than topples and plane failures. However, many rock falls along KKH initiate as plane and wedge failures in upper portions of the cut slopes and descend as falls, making rock falls as the most common mode of failure.

Debris Slides/Debris Flows

Debris slides and debris flows are the largest and extremely hazardous slope failures along the highway. These failures are confined to valley fills, terrace deposits, alluvial/ colluvial soils, and crushed rock materials associated with shear zones. In many cases the movement is confined to shallow depths. The moving mass generally covers the roadway and hinders or interrupts the traffic flow. Debris slides and debris flows constitute the most problematic failures along the highway and the most difficult to handle during upgradation and relocation phases of the highway.

Mud Flows

Mudflows are much less frequent than debris flows. They involve large quantities of nearly saturated and viscous material along existing drainage courses. They usually occur after heavy rainfall and are known to have caused serious damage to the area bridges. They are differentiated from debris flows by the predominance of fine-grained material (more than 50 percent silt and clay size material).

The above-described modes of failure have greatly deteriorated the highway condition, making it almost unusable without continual clearance and maintenance. Furthermore, these failures pose a serious threat to the safety of travelers along the highway. This situation necessitates the development of a hazard potential map for the entire length of the highway.

FACTORS CAUSING SLOPE MOVEMENT ALONG KKH

There are many factors that contribute to landslides and other types of slope movement along KKH. These include:

- Extremely high relief and very steep slopes.
- Nature of geologic formations exposed along the alignment (abundance of unconsolidated material, highly weathered and fractured rock masses).
- Well-developed rock discontinuities as a result of tectonic activity.
- Abundance of Overhangs due to uncontrolled blasting.
- Highly shattered rock masses due to Main Mantle Thrust (MMT) and the associated faults and shear zones, further exacerbated by uncontrolled blasting during KKH construction.
- Precarious locations of alluvial and morainal deposits.
- Presence of loose rock blocks of variable sizes on natural slopes as a result of weathering.
- Severe climatic conditions leading to rapid weathering.
- Poor drainage conditions
- Scarcity of vegetation.
- Seismically active nature of the region

MAIN INSTABILITY PROBLEMS

The main instability problems observed on the five main reaches, namely Havelian to Mansehra, Mansehra to Thakot, Thakot to Dasu, Dasu to Dam Site and Dam Sit to Raikot Section of KKH along with the Condition and types of rock present are listed in Table -1.

POSSIBLE REMEDIAL MEASURES

An inventory of possible remedial measures at a few of the notorious landslide prone areas along KKH, namely Thakot, Dandai, Jijal, Harban and Tatta Pani is presented in Table - 2. The Table also lists the principal geological materials, slope angles along with the main reasons for sliding for these areas.

SECTION	MAIN ROCK TYPES	CONDITION OF ROCK	MAIN INSTABILITY PROBLEMS
Havelian to Mansehra Section (Chainage 0+000 km to 40+550 km)	Slate, Shale, Phyllites, Greywackes and Lime Stone	Slates and Shales are medium grained and unfossiliferous Greywackes thick bedded and poorly sorted Limestone layers are nodular, hard and compact Slates, shales and phyllites are highly jointed	No major problems expected
Mansehra to Thakot Section (Chainage 0+000 km to 93+660 km)	Granite, Slate, Phyllite, Schist and Gniess	------------------------	Signs of Instability due to seepage water from the irrigated terraces
Thakot to Dasu Section (Chainage 0+000 km to 101+700 km)	Schist, Gniess, Amphibolite, Granite and Gabbro	Shattered rock due to blasting	Accumulation of scree due to steep gradient
Dasu to Dam Site Section (Chainage 0+000 km to 85+250 km)	Schist, Amphibolite, Diorite and Norite	Shattered rock due to blasting	Blockage of road due to debris and rockfall Accumulation of scree due to steep gradient Instability caused due to rains and require continous removal of fallen material
Dam Site to Raikot Section (Chainage 0+000 km to 140+725 km)	Behrain Pyroxene Granulite	Highly metamorphosed,foliated, layered and banded	Slope failures

LANDSLIDE AREA	PRINCIPAL GEOLOGICAL MATERIALS	DIP ANGEL (Deg)	SLOPE ANGLE (Deg)	MAIN REASON FOR SLIDING	POSSIBLE REMEDIAL MEASURES
Thakot (RD 185+000 and RD 185+200)	Schist rock exposed, moderately weathered, moderately jointed covered with colluvial soil. Boulders comprising the colluvial material belong to bedrock.	60 to 70	50	Low shear strength of colluvial material. High slope angle. Sudden shaking of ground during earthquakes and erosion of bedrock and colluvial material exposed in nullah.	Existing retaing wall to be reinforced. 200 m long and 3.5 m wide stone-pitched rock trap ditch to be provided along the slope. 200 m long and 2.5 m high gabian protection wall along the road side. 200 m long plum concrete retaining wall on sound bedrock on valley side. A culvert near toe of slope. Two gabian spurs against nullah erosion. Interceptor drain to safely transmit surface water from the crown of the landslide to stable area.
Dandai (RD 194+385 to RD 194+420)	The landslide area can be classified as a debris flow surrounded by metamorphic rocks of schist grade inclined at steep angles. The loose deposits comprising the debris flow are the phyllitic schists from the upslope area.			Surface water perculating downward into unconsolidated materials. Low grade schist rock disintegrates upon exposure to water.	Gabian check dams on upslopes. 2 to 3 m wide culvert to clear debris. Breast wall along with road side drain. Constant maintenance and clearance of roadside drain.
Jijal (RD 48+800 and RD 51+800)	This falls in earthquake active zone. The predominent rocks are serpentinites and pyroxinites. Fractured nature of rock, weathering and disintegration have produced large amounts of scree on slopes.		70 to 75	Rain water and gravitational forces mobilize the rock falls, scree slides and disintegrated bedrock material into debris flows.	Gabian wall to be provided between rock trap ditch and road pavement. Road to be shifted 4 to 5 m towards valley side by provision of a series of masonary retaining walls. 3 m wide culvert to be provided at the area susptible to gully flow. A 2-3 m wide rock trap ditch to be provided at the toe of the hills.

LANDSLIDE AREA	PRINCIPAL GEOLOGICAL MATERIALS	DIP ANGEL (Deg)	SLOPE ANGLE (Deg)	MAIN REASON FOR SLIDING	POSSIBLE REMEDIAL MEASURES
Harban (RD 361+000 and RD 363+000)	Massive, slightly to moderately weathered Peridotite forms the bedrock. Bedrock covered with residual soils		45	Steep angle of unconsolidated residual material Considerable surface runoff is likely to occur in rainy season which also promotes rock disintegration. Moderate intensity earthquakes	One of the options is removal of residual material Another opion is to provide retaining wall on both upslope and down slope. Rock trap ditch between retaining walls and the road pavement.
Tatta Pani (RD 275+000 and RD 276+000)	Rock type exposed are Gneiss and Quartzites. Holocene fan gravels are also present. Slickensides are well developed in the brecciated zone of 5 to 10 m thickness in these gravels. A fault scarp is observed in the fan gravels associations. Trace of fault is delineated by a line of hot springs.			Rock disintegration and scree formation due to extreme tempratures. The sporadic movement along the fault activate sliding Fault beccia is intensely sheared and mylonised, providing suitable environment for slippage of fault blocks. Presense of hot water springs results in disintegration, decay and generation of pore pressure. The contact between parent rock and loose overburden material is very steep	Most cost effective option would be to bypass the landslide area by shifting the KKH alignment to the right bank of the indus river.

POTENTIAL INSTABILITY ALONG RELOCATION SECTION

The alignment of relocation section of KKH will be constructed in the upper reaches of the Indus valley between the proposed Basha Diamer Dam site and Raikot Bridge. In this section about 52 % of the alignment passes through unconsolidated deposits and 48% through rocky reaches.

Among the unconsolidated materials, moraines are extensively spread over the whole length of the relocation section of KKH, which overlies the bedrock, generally Norite. The heterogeneous nature of these deposits, both laterally and vertically, is quite evident from the exposures along the existing KKH. Similarly, the lithology of the materials ranges from silt to poorly graded gravels, cobbles and large boulders. Localized lenses of clayey silt and layers of gravel and cobbles can also be distinguished in the natural steep slopes and lead to its further subdivision into coarse and fine moraines. The thickness of these deposits is quite variable and exceeds even 100 meters at places. Similarly, the natural slopes also vary from less than 30º to almost vertical. Most of the deposits however have slopes up to 45º or less. With the construction of Basha Diamer Dam and impoundment of its lake, these deposits will be partially submerged in the reservoir. Once these deposits are inundated, these will undergo slope instability or failures, depending upon the existing slope angles. This may result in collapse or destruction of the KKH in such reaches.

Thus the approach adopted focused on the following tasks:

- Identification of critical reaches using GIS techniques, where relocated alignment of the KKH passes in close vicinity of the reservoir rim in moraines, which would be partially or fully submerged by the reservoir.
- Preparation of geologic cross - sections at the identified critical reaches.
- Determination of engineering characteristics of the deposits in the critical reaches through limited field and laboratory tests, state of the art literature and using best engineering judgment.
- Determination of the mode of slope failure and its extent through stability analysis and identification of possible hazards to the relocated section associated with the expected slope failures.
- Proposing remedial measures i.e. shifting of alignment of the relocated section away from the reservoir rim at a safe distance, so as to mitigate the undesirable effects of hazards associated with the expected slope failures.

Critical reaches were identified using the reservoir area geologic map and reservoir area slope map. These maps had been prepared through interpretation of 0.6m resolution satellite imageries and digitizing SOP topographic map at scale of

1:7500. The topographic survey carried out for the proposed route for relocation of the KKH using SOP reference, has been superimposed on these maps.

The available geotechnical data of moraines mainly comprised the insitu dry density and compaction data as well as insitu shear strength parameters (both in dry and saturated conditions) of moraines.

The above data together with the state-of–the–art, literature and engineering judgment helped to evolve soil parameters, which were used in the slope stability analysis.

The following soil parameters were adopted for the stability analyses of moraine slopes:

Material	ϕ (Deg)	C (KPa)	Bulk Density (kN/m^3)
Fine Moraines	35	150	20
Coarse Moraines	40	100	20
Sandy Gravel	38	0	20
Talus/ Scree	40	0	20

Slope stability analyses were carried out by Morgenstern-Price Method using computer software SLOPE/W.

Five typical sections viz. A and B for the design of cut slopes in the unconsolidated materials and C, D and E for the design of cut slopes in rocks have been conceived which are shown on Figures 8 to 12. Typical stereonets to be used in the design are also shown in Figure – 13.

The unconsolidated materials on the slopes are likely to loose their shear strength significantly upon saturation, thereby resulting in the slope failures. The phenomenon of the slope failure will in the form of progressive failures, continue till an equilibrium state is achieved. Thus, the highway passing over steep slopes and in the close proximity of the likely failure zones will have the risk of collapse thereby posing extreme hazard to life and property. Besides, the maintenance cost will also increase tremendously. Finally, uncontrolled failures of certain reaches of the KKH will also result into its closure for long periods in the aligned portions, thereby causing a number of additional economical and unquantifiable losses.

CONCLUSIONS AND RECOMMENDATIONS

The landslide study along KKH has led to the following conclusions:

i) Various types of slope movements that affect the Karakorum Highway include rock falls, debris falls, topples, rockslides (plane failures and wedge failures), debris slides, debris flows, and mud flows.

ii) Rock falls and debris falls are the most common and the most hazardous of all types of slope failures whereas debris slides and debris flows are the largest and the most difficult to control. Many rock falls in the area initiate as plane failures, wedge failures, or toppling failures in the upper portions of the slopes and descend as falls.

iii) Rock falls and debris falls can be best controlled by the provision of 2-3 m wide rock trap ditches, with a 2 m high gabion wall or safety fence on the highway side of the ditch, by regrading the steep slopes in the unconsolidated material, and by removing the overhangs in rock through controlled blasting.

iv) Because of their large size, debris slides and debris flows are generally more difficult to control. However, the hazard posed by these movements can be minimized by utilizing a combination of options including removal of unconsolidated material, provision of retaining walls along the toes at the highway level and along the valley side of the highway to provide lateral support and prevent undercutting by the river, provision of drainage galleries / ditches, and provision of catchment ditches. These remedial measures must be complemented by an extensive and continual maintenance programme.

v) The typical sections A and B can be used for the design of cut slopes in the unconsolidated materials and typical sections C, D and E, can be used for the design of cut slopes in rocks.

vi) In relocation section of the KKH, slope stability study has revealed that with the filling of Basha Diamer Dam reservoir, the natural balance of the existing slopes in the moraines would be disturbed. This may lead to large progressive mass movements (landslides) of moraine slopes into the reservoir and as a result, certain reaches of the relocation section, which are situated in the immediate vicinity of reservoir rim, may collapse posing serious hazards to life and property.

The following recommendations have been made for upgradation and relocation of the KKH:

i) Wherever feasible, the widening of the road should be accomplished by extension on the valley side, utilizing fill embankments supported by retaining walls. Cutting back the existing slopes to gain ground for desired width should be kept to the minimum. Disturbing the natural state of equilibrium can add to slope stability problems.

ii) It is important that all the retaining structures not only be founded on sound bedrock but also anchored into it through reinforcement. Every effort should be made to tie back the retaining structures located on the valley side of the highway.

iii) Extensive and continual maintenance, including clearance of rock trap ditches, roadside drains, culverts, and removal of any debris from the pavement, is recommended for safe operation of the highway. Permanently available maintenance crews should be posted at all areas of major landslide activity.

iv) For detailed design of remedial measures at the major landslide areas, detailed subsurface investigations should be carried out. These should include determination of the boundaries of the landslide areas, thickness of the unconsolidated material involved in the landsliding, and depth of bedrock at locations of retaining structures, especially where these structures are supposed to provide lateral support to highway embankment. In addition to the major landslide locations mentioned above, further investigations would be necessary for other areas involving large-scale remediation works.

v) In order to avoid the damage to the relocation section of KKH, it is recommended that, the proposed alignment must be kept away laterally from the reservoir rim at minimum safe horizontal distances, as provided in this report. These distances have to be firmed-up by detailed geotechnical studies.

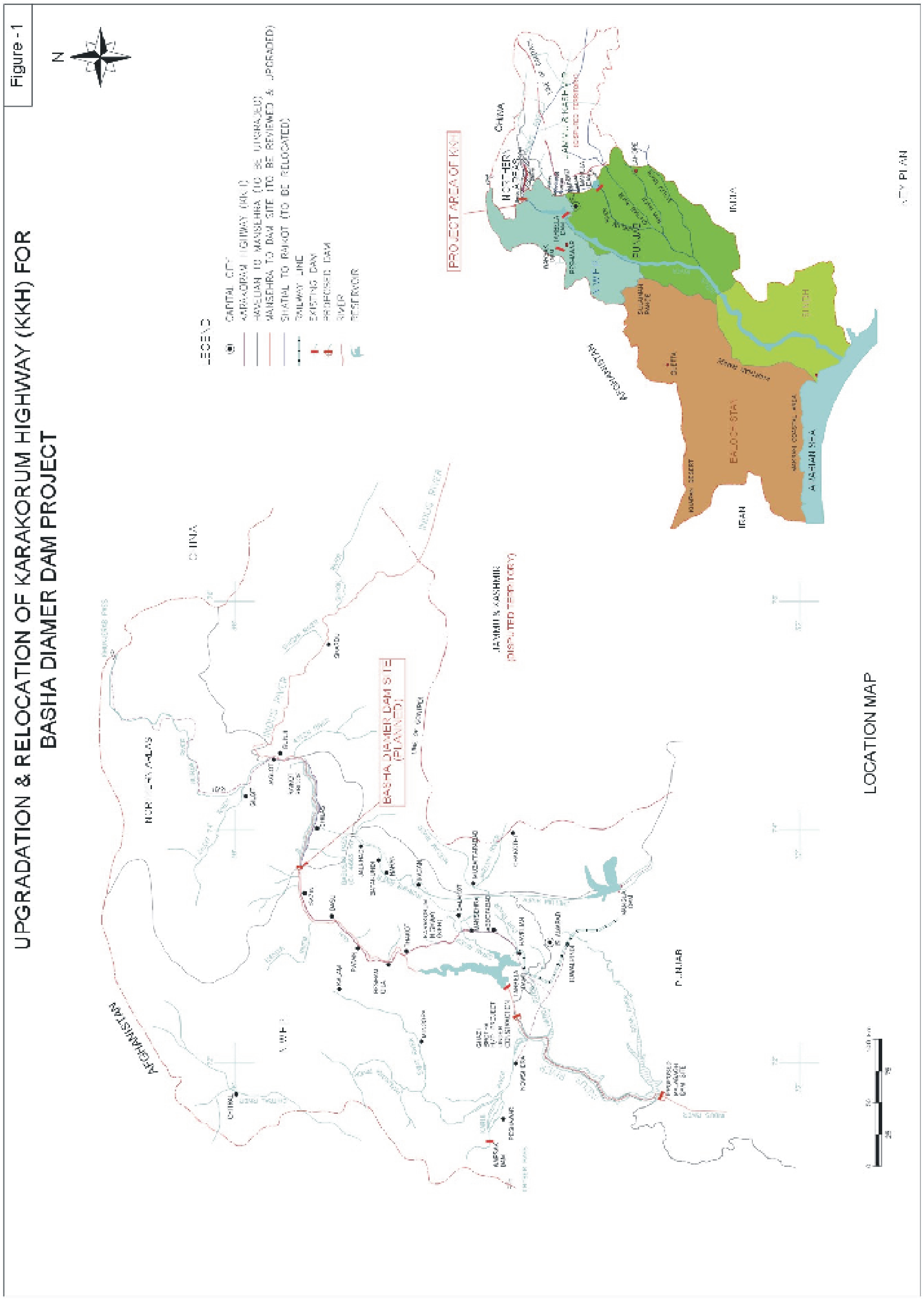
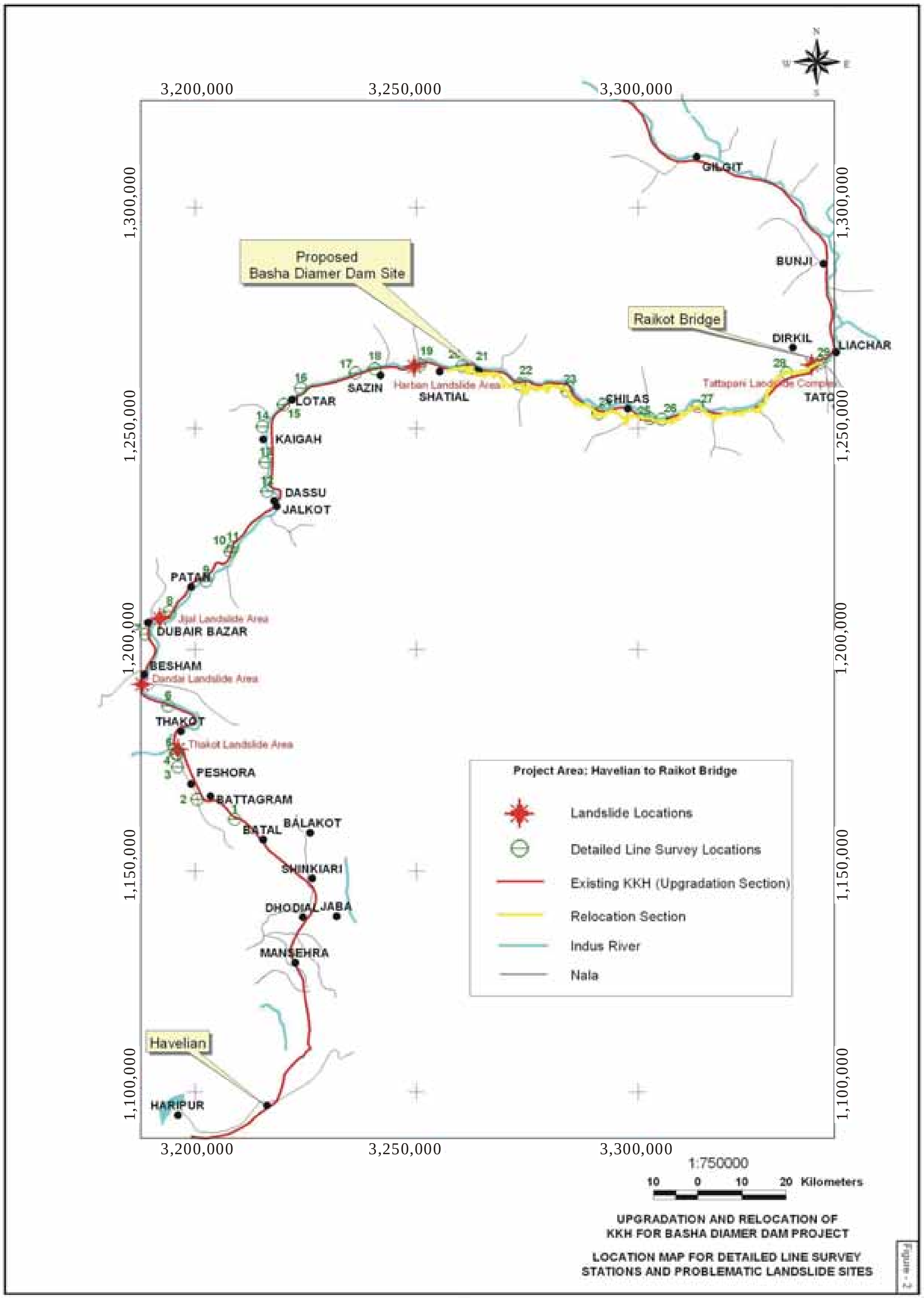


Figure - 1
N
UPGRADATION & RELOCATION OF KARAKORUM HIGHWAY (KKH) FOR
BASHA DIAMER DAM PROJECT
LEGEND
BASHA DIAMER DAM SITE
(PLANNED)
JAMMU & KASHMIR
PROJECT AREA OF KKH
CHINA
INDIA
IRAN
AFGHANISTAN
LOCATION MAP


Proposed
Basha Diamer Dam Site
Raikot Bridge
Havelian
GILGIT
BUNJI
DIRKIL
LIACHAR
TATO
Tattapani Landslide Complex
CHILAS
SHATIAL
Harban Landslide Area
SAZIN
LOTAR
KAIGAH
DASSU
JALKOT
PATAN
Jijal Landslide Area
DUBAIR BAZAR
BESHAM
Dandai Landslide Area
THAKOT
Thakot Landslide Area
PESHORA
BATTAGRAM
BATAL
BALAKOT
SHINKIARI
DHODIAL
JABA
MANSEHRA
HARIPUR
3,200,000
3,250,000
3,300,000
1,300,000
1,250,000
1,200,000
1,150,000
1,100,000
Project Area: Havelian to Raikot Bridge
Landslide Locations
Detailed Line Survey Locations
Existing KKH (Upgradation Section)
Relocation Section
Indus River
Nala
1:750000
10 0 10 20 Kilometers
UPGRADATION AND RELOCATION OF
KKH FOR BASHA DIAMER DAM PROJECT
LOCATION MAP FOR DETAILED LINE SURVEY
STATIONS AND PROBLEMATIC LANDSLIDE SITES
Figure - 2

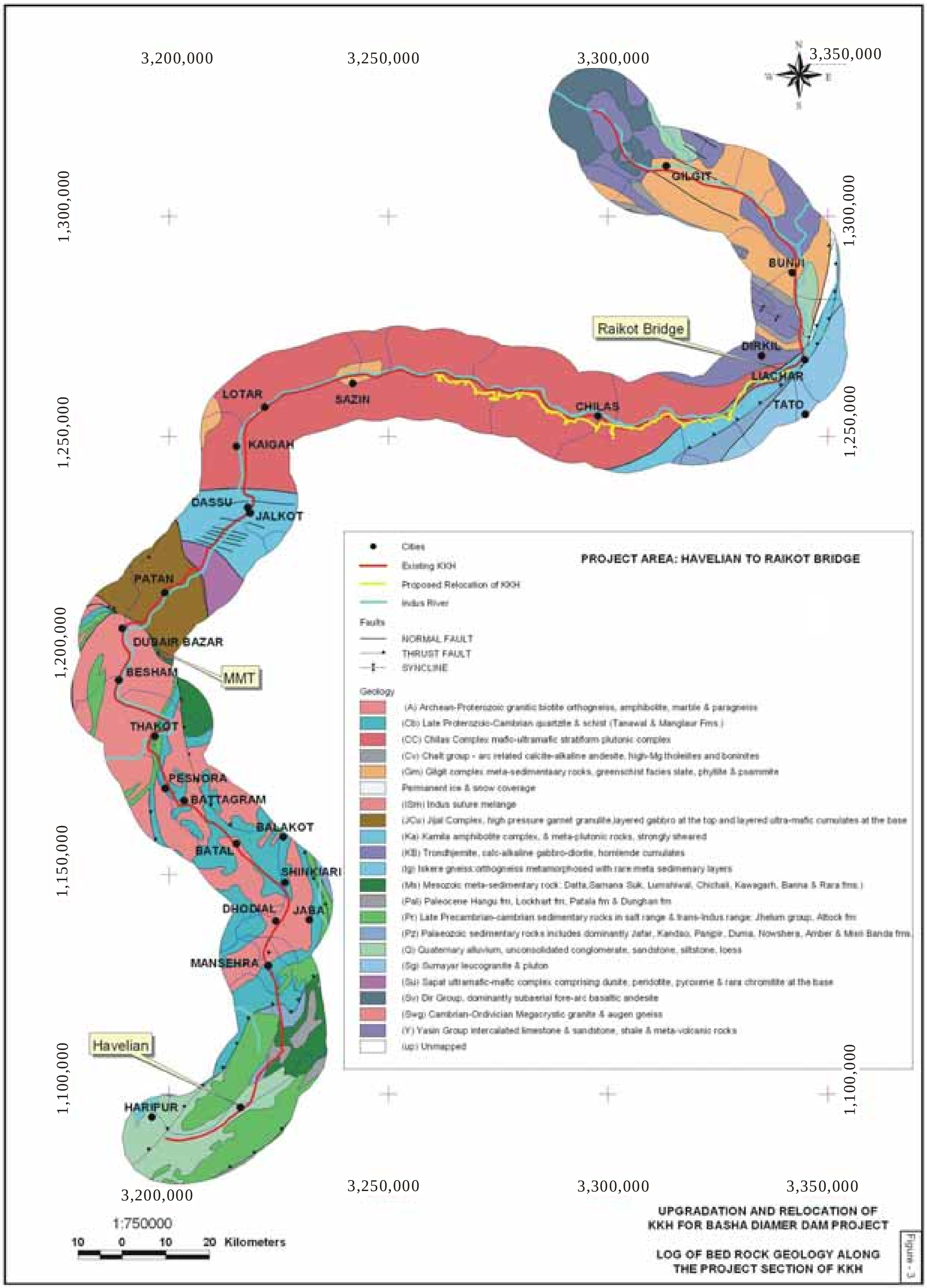

3,200,000
3,250,000
3,300,000
3,350,000
1,300,000
1,250,000
1,200,000
1,150,000
1,100,000
GILGIT
BUNJI
Raikot Bridge
DIRKIL
LIACHAR
TATO
CHILAS
SAZIN
LOTAR
KAIGAH
DASSU
JALKOT
PATAN
DUBAIR BAZAR
MMT
BESHAM
THAKOT
PESHORA
BATTAGRAM
BALAKOT
BATAL
SHINKIARI
DHODIAL
JABA
MANSEHRA
Havelian
HARIPUR
Cities
Existing KKH
Proposed Relocation of KKH
Indus River
PROJECT AREA: HAVELIAN TO RAIKOT BRIDGE
Faults
NORMAL FAULT
THRUST FAULT
SYNCLINE
Geology
(A) Archean-Proterozoic granitic biotite orthogneiss, amphibolite, marble & paragneiss
(Cb) Late Proterozoic-Cambrian quartzite & schist (Tanawal & Manglaur Fms.)
(CC) Chilas Complex mafic-ultramafic stratiform plutonic complex
(Cv) Chalt group - arc related calcite-alkaline andesite, high-Mg tholeiites and boninites
(Gm) Gilgit complex meta-sedimentaary rocks, greenschist facies slate, phyllite & psammite
Permanent ice & snow coverage
(ISm) Indus suture melange
(JCu) Jijal Complex, high pressure garnet granulite,layered gabbro at the top and layered ultra-mafic cumulates at the base
(Ka) Kamila amphibolite complex, & meta-plutonic rocks, strongly sheared
(KB) Trondhjemite, calc-alkaline gabbro-diorite, hornlende cumulates
(Ig) Iskere gneiss:orthogneiss metamorphosed with rare meta sedimentary layers
(Ms) Mesozoic meta-sedimentary rock: Datta,Samana Suk, Lumshiwal, Chichali, Kawagarh, Banna & Rara fms.)
(Pal) Paleocene Hangu fm, Lockhart fm, Patala fm & Dunghan fm
(Pr) Late Precambrian-cambrian sedimentary rocks in salt range & trans-Indus range: Jhelum group, Attock fm
(Pz) Palaeozoic sedimentary rocks includes dominantly Jafar, Kandao, Panjpir, Durria, Nowshera, Amber & Misri Banda fms.
(Q) Quaternary alluvium, unconsolidated conglomerate, sandstone, siltstone, loess
(Sg) Sumayar leucogranite & pluton
(Su) Sapat ultramafic-mafic complex comprising dunite, peridotite, pyroxene & rare chromitite at the base
(Sv) Dir Group, dominantly subaerial fore-arc basaltic andesite
(Swg) Cambrian-Ordivician Megacrystic granite & augen gneiss
(Y) Yasin Group intercalated limestone & sandstone, shale & meta-volcanic rocks
(up) Unmapped
1:750000
10 0 10 20 Kilometers
UPGRADATION AND RELOCATION OF
KKH FOR BASHA DIAMER DAM PROJECT
LOG OF BED ROCK GEOLOGY ALONG
THE PROJECT SECTION OF KKH
Figure - 3

Figure 4: An overview of Thakot landslide area.

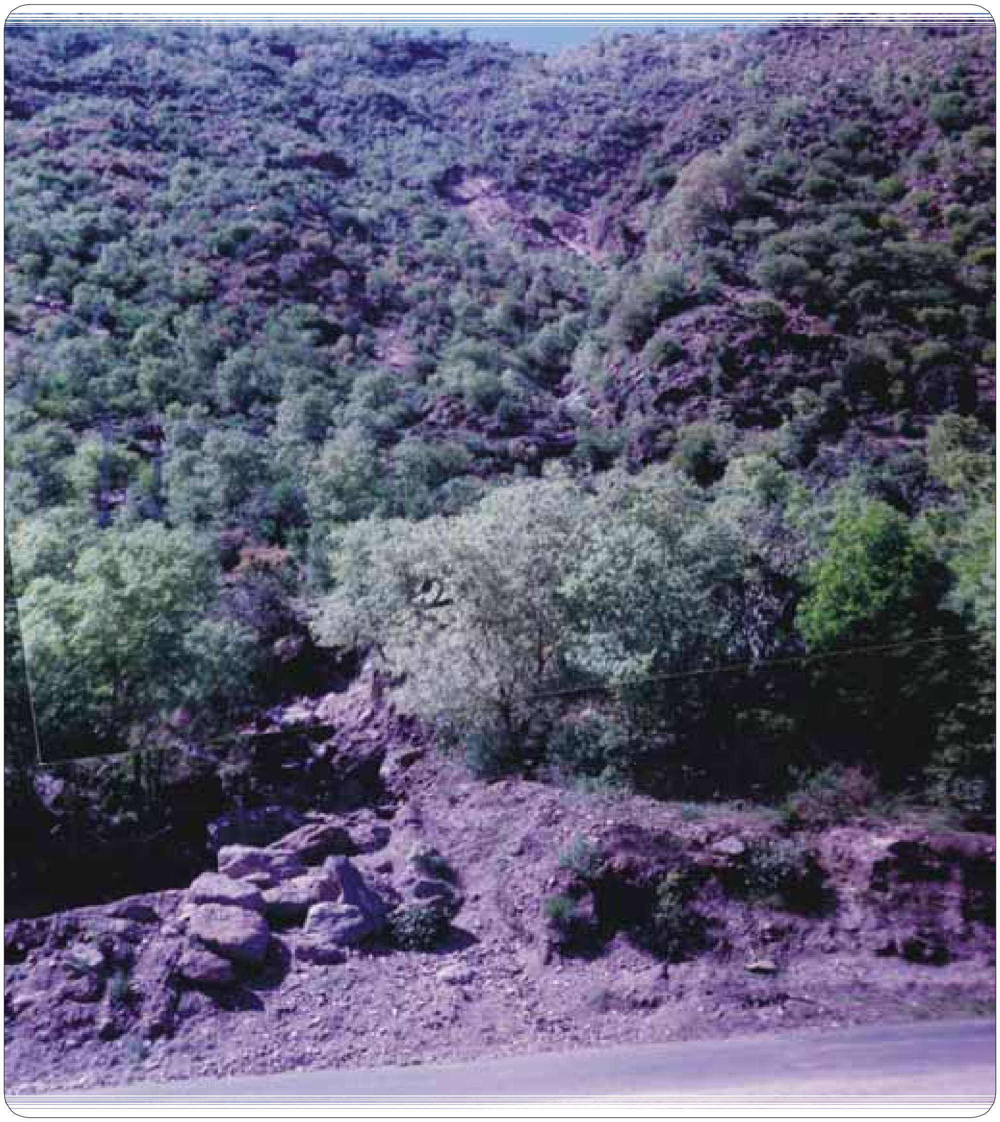
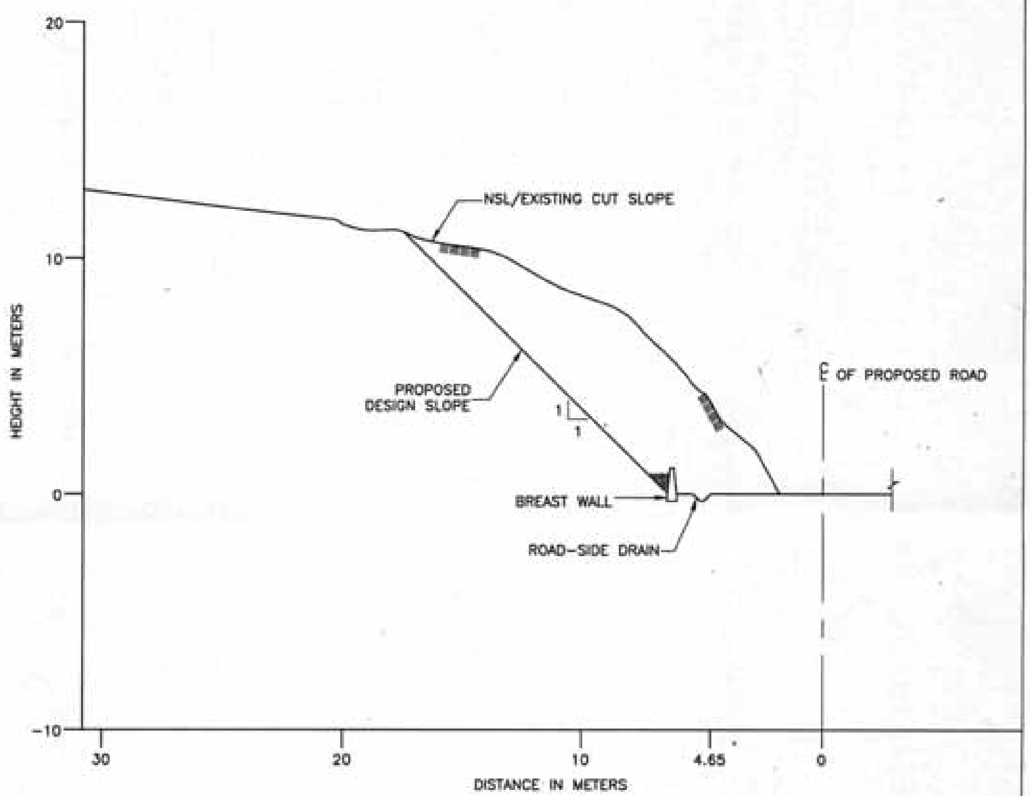


Figure-5: An overview of Dandai debris slide.

Figure- 6: Another example of scree and debris material subject to sliding on both upslope and downslope portions of Jijal landslide site.

Figure 7: Another view of steep slopes at the Tatta Pani landslide site covered with loose and unconsolidated materials.

FIGURE - 8



NOTES

MATERIAL:

FINE MORAINE/TALUS/SCREE COMPRISING CLAYEY SILT/SILTY CLAY/GRAVELLY CLAYEY SILT SOIL.

CUT SLOPE:

1V:1H, WITH A 3 m WIDE BENCH AT EVERY 10 m UPTO 30 m HEIGHT. ABOVE 30 m A CUT SLOPE OF 2V:1H IS RECOMMENDED.

PROTECTIVE MEASURES:

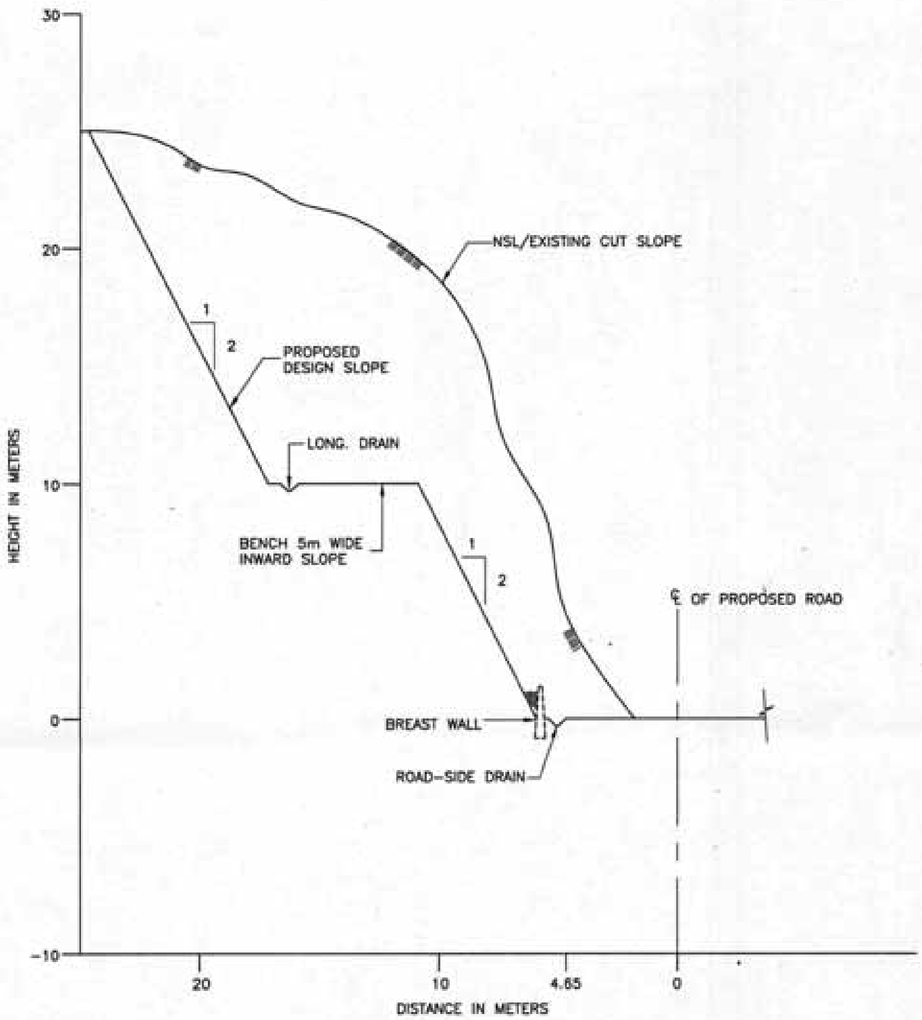
a) ROAD-SIDE DRAIN TO BE PROVIDED AT THE TOE OF HILL.
b) BREAST WALL 2-3 m HIGH.
c) LINED INTERCEPTOR DRAIN TO BE PROVIDED WHEREVER REQUIRED.
d) PROVIDE VEGETATION OVER THE CUT SLOPE.
e) SLOPES BELOW THE ROAD SHOULD BE TREATED AS PER SITE REQUIREMENTS.

SCALE: 1:250

TYPICAL SECTION 'A'
FOR DESIGN OF CUT SLOPES
IN UNCONSOLIDATED MATERIAL

Riaz\F\Riaz\Embankment\2352KKH\cut slope Mansehra-Thakot\Typ. sec. A

FIGURE - 9



NOTES

MATERIAL:

COURSE MORAINE/ALLUVIUM CONSISTING OF ROUNDED TO SUBROUNDED & SUBANGULAR GRAVEL & BOULDERS WITH CLAYEY SILT/SANDY SILT AS MATRIX. (MODERATELY TO WELL CEMENTED.

CUT SLOPE:

2V:1H WITH A 5 m WIDE BENCH AT EVERY 10 m UPTO 30 m HEIGHT. ABOVE 30 m, A CUT SLOPE OF 4V:1H IS RECOMMENDED.

PROTECTIVE MEASURES:

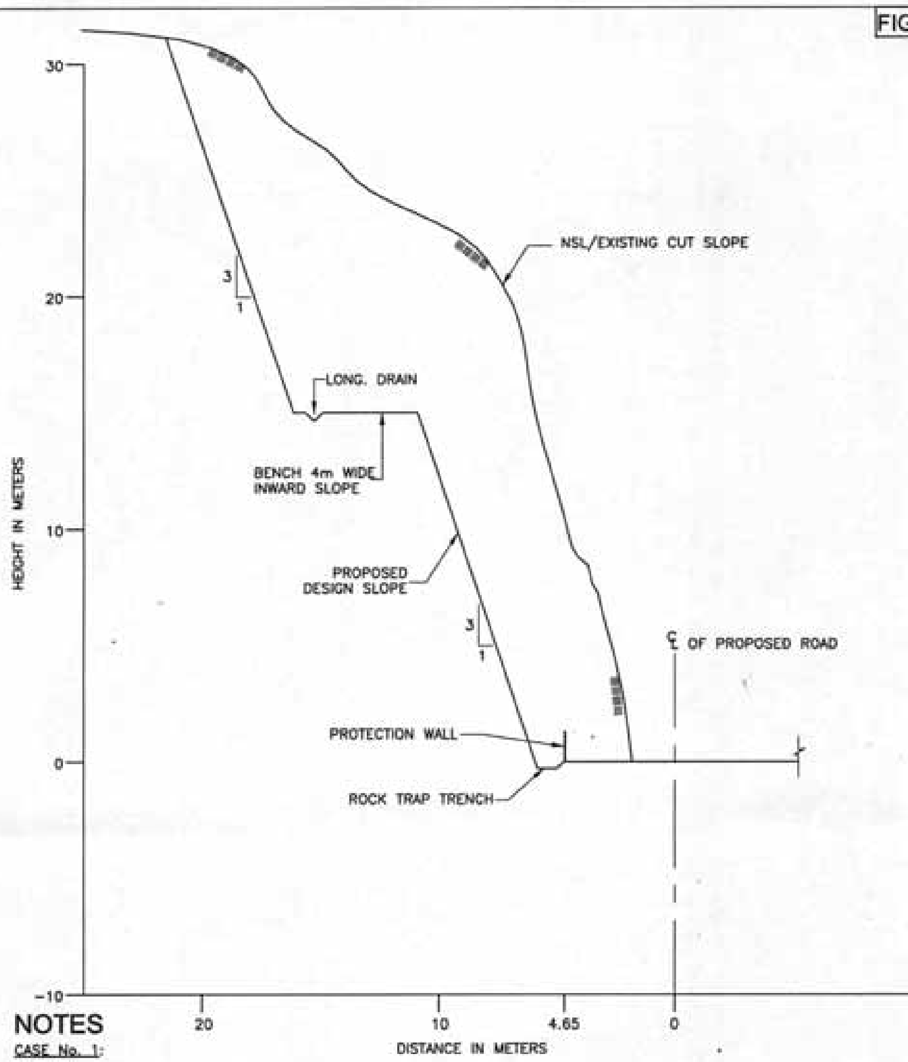
(a) ROAD-SIDE DRAIN TO BE PROVIDED AT THE TOE OF HILL.
(b) BREAST WALL 2m-4m HIGH WHEREVER REQUIRED ACTUAL LOCATIONS AND HEIGHT OF BREAST WALL TO BE DECIDED AS PER SITE CONDITIONS AND AFTER EXCAVATION OF CUT SLOPES.
(c) LINED INTERCEPTOR DRAIN TO BE PROVIDED WHEREVER REQUIRED.
(d) PROVIDE VEGETATION OVER THE CUT SLOPES.

SCALE: 1:250

TYPICAL SECTION 'B'
FOR DESIGN OF CUT SLOPES
IN UNCONSOLIDATED MATERIAL

Riaz\F\Riaz\Embankment\2352KKH\cut slope Mansehra-Thakot\Typ. sec. B

FIGURE - 10



NOTES

CASE No. 1:

MATERIAL

SCHISTOSED ROCK, MODERATELY WEATHERED, FINE GRAINED, MEDIUM SOFT TO MEDIUM HARD, SCHISTOSITY WELL DEVELOPED, CLOSELY JOINTED & FRACTURED.

CUT SLOPE: 3V:1H WITH 4 m WIDE BENCH AT 15 m HEIGHT.

PROTECTIVE MEASURES:

i) CUT SLOPE SHOULD BE PROTECTED WITH WIRENET OR WIRENET AND GUNITE AT SELECTED LOCATIONS IF ESSENTIALLY NECESSARY.

(ii) ROCK TRAP TRENCH 2–3 m WIDE SHOULD BE PROVIDED.
(iii) INTERCEPTOR DRAIN TO BE PROVIDED WHEREVER REQUIRED, AT THE TOP OF THE CUT SLOPE
(iv) PRE-SPLIT BLASTING TO BE ADOPTED.
(v) SCALING OF LOOSE BLOCK FROM CUT SLOPE IF ANY TO BE CARRIED OUT.
(vi) PROTECTION WALL 2 m HIGH SHOULD BE PROVIDED AS PER SITE CONDITIONS.

SCALE: 1:250

CASE No. 2:

MATERIAL

SCHIST, HIGHLY WEATHERED, CLOSELY JOINTED & FRACTURED, AND SHEARED.

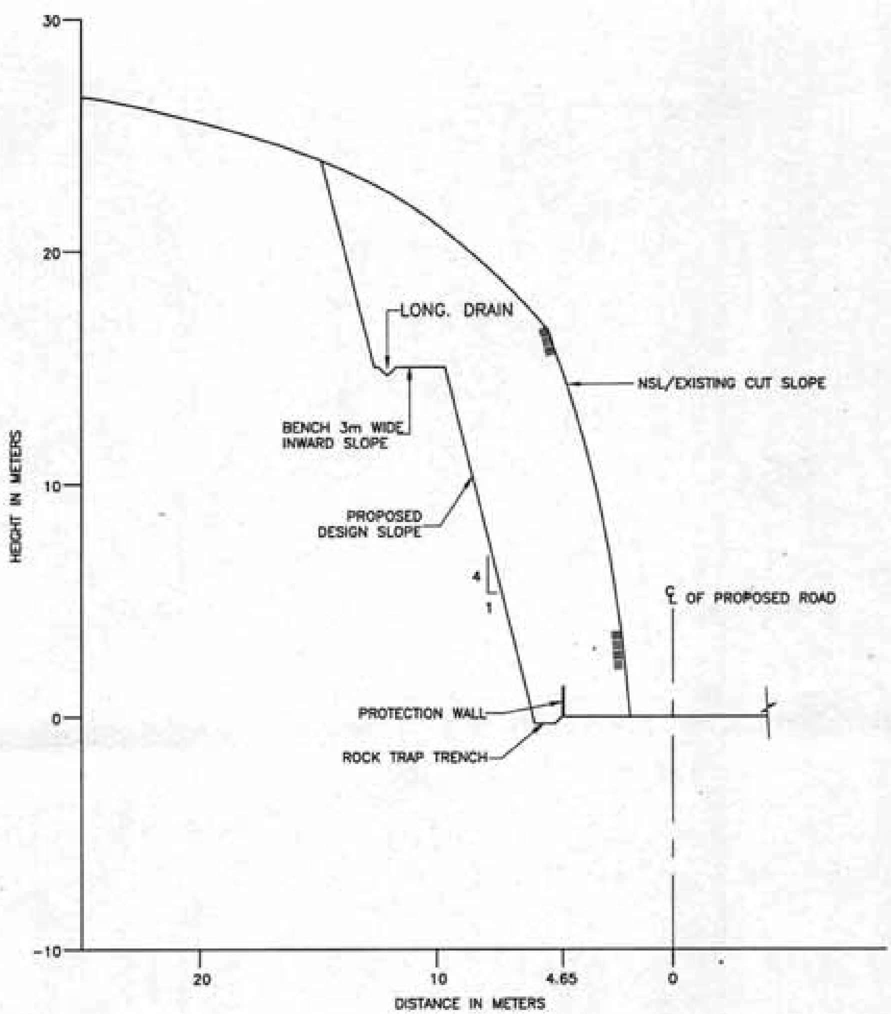
CUT SLOPE: 3V:1H WITH 4 m WIDE AT HEIGHT OF 10 m.

PROTECTIVE MEASURES: SAME AS ABOVE.

TYPICAL SECTION 'C'
FOR DESIGN OF CUT SLOPES
IN ROCK

Riaz\F\Riaz\Embankment\2352KKH\cut slope Mansehra–Thakot\Typ. sec. C

FIGURE - 11



NOTES

MATERIAL:
IGNEOUS AND METAMORPHIC ROCKS, HARD, THICKLY BEDDED, MODERATELY JOINTED AND MODERATELY TO HIGHLY FRACTURED.

CUT SLOPE: CUT SLOPE OF 4V:1H WITH A 3 m WIDE BENCH AT 15 m HEIGHT.

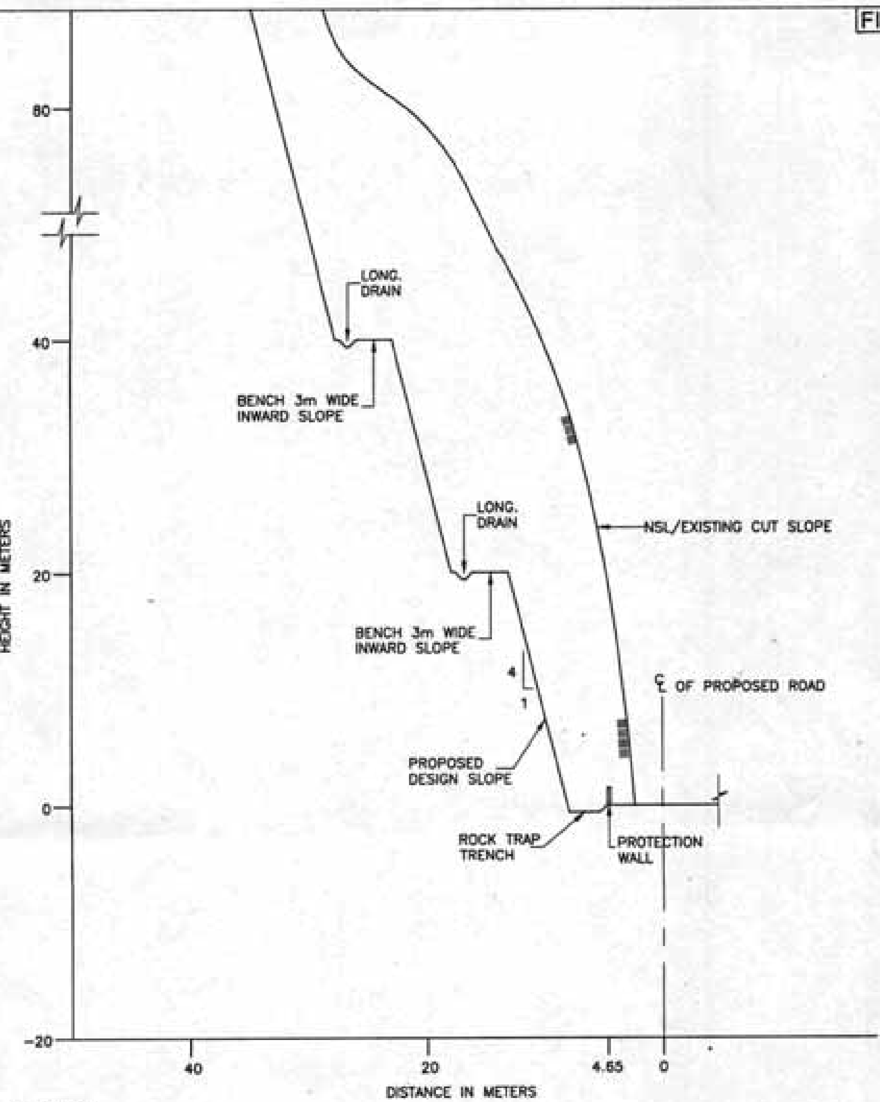
PROTECTIVE MEASURE:
(i) ROCK TRAP TRENCH 2–3 m WIDE SHOULD BE PROVIDED
(ii) INTERCEPTOR DIRAIN SHOULD BE PROVIDED IF REQUIRED.
(iii) SCALING OF LOOSE BLOCK FROM CUT SLOPE, IF ANY, SHOULD BE CARRIED OUT.
(iv) PRESPLIT BLASTING SHOULD BE ADOPTED.
(v) CUT SLOPE SHOULD BE PROTECTED WITH WIRENET OR WIRENET AND GUNITE AT SELECTED LOCATIONS IF ESSENTIALLY NECESSARY.
(vi) PROTECTION WALL 2 m HIGH SHOULD BE PROVIDED AS PER SITE CONDITION.

SCALE: 1:250

TYPICAL SECTION 'D'
FOR DESIGN OF CUT SLOPES
IN ROCK

Riaz\F\Riaz\Embankment\2352KKH\cut slope Mansehra–Thakot\Typ. sec. D

FIGURE - 12



NOTES

MATERIAL:

IGNEOUS AND METAMORPHIC ROCKS, MODERATELY HARD TO HARD, THICKLY BEDDED TO MASSIVE, MODERATELY JOINTED AND BLOCKY, MODERATELY TO HIGHLY FRACTURED. THE ROCK SLOPES ARE AT PLACES COVERED WITH THICK DEPOSITS OF LOOSE ROCK FRAGMENTS AND OR OVERBURDEN MATERIAL, LYING AT UNSTABLE POSITIONS.

CUT SLOPE: CUT SLOPE OF 4V:1H WITH A 3 m WIDE BENCH AT 20 m HEIGHT. IF THE ROCK IS DIPPING TOWARDS THE CUT SLOPE (≥ 60°) THEN THE CUT SLOPE SHOULD BE THE SAME AS OF DIP ANGLE/DIP SLOPE WITH BENCH HEIGHT 15 m.

PROTECTIVE MEASURE:

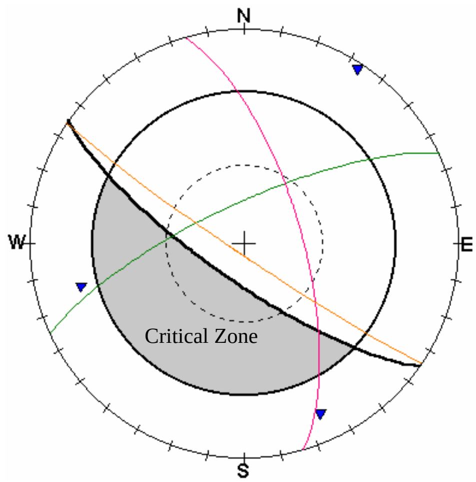
(i) ROCK TRAP TRENCH 3.2 m WIDE SHOULD BE PROVIDED. IN MORE CRITICAL AREAS RTT WIDTH SHOULD BE INCREASED TO 5.0 m.
(ii) INTERCEPTOR DIRAIN SHOULD BE PROVIDED IF REQUIRED.
(iii) SCALING OF LOOSE BLOCK FROM CUT SLOPE, IF ANY, SHOULD BE CARRIED OUT.
(iv) PRESPLIT BLASTING SHOULD BE ADOPTED.
(v) CUT SLOPE SHOULD BE PROTECTED WITH WIRENET OR WIRENET AND GUNITE AT SELECTED LOCATIONS IF ESSENTIALLY NECESSARY.
(vi) PROTECTION WALL 2.0 m HEIGH WOULD BE REQUIRED AT SELECTED LOCATIONS. LOCATIONS TYPE AND LENGTH OF THE PROTECTION WALL WOULD BE DECIDED AFTER CUTTING OF THE CUT SLOPES.
(vii) ROAD MAY BE EXTENDED TOWARDS THE VELLEY SIDE TO AVOID ROCK CUTTING WHERE EVER POSSIBLE AFTER MEETING THE GEOMETRIC REQUIRMENT.

SCALE: 1:500

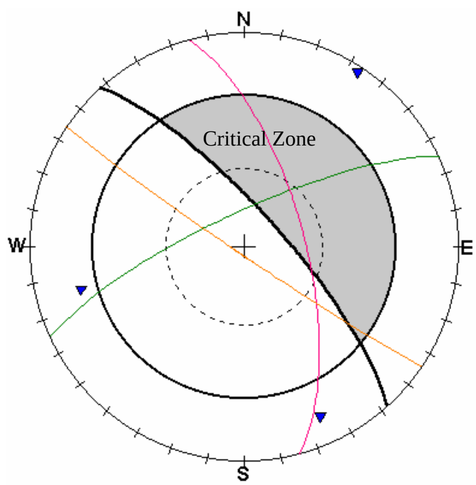
TYPICAL SECTION 'E'
FOR DESIGN OF CUT SLOPES
IN ROCK

Riaz\F\Riaz\Embankment\2352KKH\cut slope Typ. secs. Thakot-Dsu section\Typ. sec. E

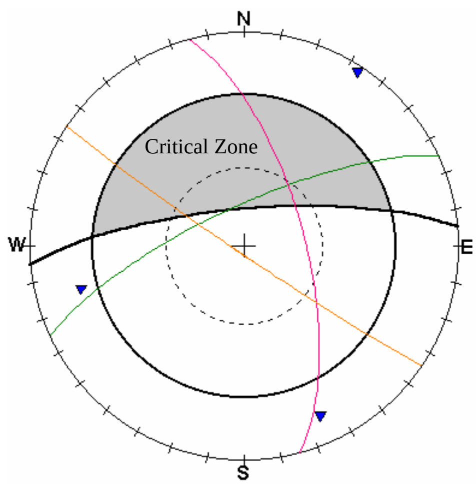
STATION No. 18 **Figure - 13**



Friction Angle = 30º
Slope Orientation = 215º
Cut Slope Angle = 76º
Potential Failure Modes: Stable



Friction Angle = 30º
Slope Orientation = 48º
Cut Slope Angle = 76º
Potential Failure Modes: Toppling, Wedge Failures



Friction Angle = 30º
Slope Orientation = 355º
Cut Slope Angle = 76º
Potential Failure Modes: Plane Failures (Along Dip Slopes), Wedge Failures