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Principal Investigator	Co-Principal Investigator	Co-Principal Investigator
Prof. Talat Ahmad ***Vice-Chancellor*** Jamia Millia Islamia Delhi	**Prof. Devesh K Sinha** Department of Geology University of Delhi Delhi	**Prof. P. P. Chakraborty** Department of Geology University of Delhi Delhi
Paper Coordinator	**Content Writer**	**Reviewer**
Dr. Shashank Shekhar Department of Geology University of Delhi Delhi	**Dr. M. Masroor Alam** Department of Civil Engineering Aligarh Muslim University Aligarh	**Prof. Vinay Jhingran** Department of Geology University of Delhi Delhi

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1. Learning outcomes

After studying this module, you shall be able to:

- Know about different types of pavement and materials used for their construction.
- Geological and geomorphological investigations for the alignment of highways.
- Learn about geological and geomorphological investigations for alignment of railway tracks and usage of rail ballast.
- Tell functions of super and sub structures of bridge and other components.
- Different geological investigations for construction approach of a bridge at different reaches of a river.

2. Introduction

Road and rail networks and bridges are the lifeline infrastructures facilities for any region or country. Roads being the oldest and most important element of transport have played a pivotal role in the evolution of civilizations. With the beginning of Industrial era and the advent of steam engine, railways have supplemented the transportation of people and goods in a big way and are still vital for modern day industrial growth. The bridges being the integral part of the road and rail networks spanning not only over rivers but also over arms of sea to provide all season connectivity. The understanding of topography, geomorphology and geology of the area being traversed by these transportation elements is important for safe design, longevity and economy. As huge amount of construction material in form of earth and rocks will be required in laying of roads, rails and construction of bridges. Hence, their availability must also be ensured keeping in view its quality and haulage cost. The emphasis in this module is given to geology of highways and railways for rocky terrains as in plain and alluvial areas most of the geotechnical investigations will come under the preview of soil mechanics, hence not considered here.

3. Road and Rail Network

From time immemorial, the construction material and methods have developed from *stone pavements* in the beginning during ancient period, through *kankar* and *lime-surkhi-pitch* roads in medieval period to modern day *tar* and *concrete* roads with state of the art construction technology. Nowadays the quality and connectivity of road network not only forms the basis but also is one of the indices to show infrastructural development of a country. There are two types of roads termed as *Flexible Pavement* and *Rigid Pavement*. Flexible pavement, is said so because of the fact that part of road may flex down or raised up due to differential compaction of founding soil or rocks. It is laid on original founding soil called as sub grade, followed by earth used for raising the level termed as sub base course, followed by different layers of rock aggregate as base course, surface course and wearing course. In the upper most layer, termed as wearing course, coarse sand or rock powder of same size is sprayed over to fill the small pores with the help of *tar*. Flexible pavements are the most versatile and prevalent road type, all over the world. The rigid pavement gets its name from the cast concrete (CC) or reinforced concrete layer (RCC), founded over soil or rock foundation and sub base made of rock aggregate. The CC or RCC layer acts as slab, does not allow any settlement, and normally constructed in areas having problem of water logging. The flexible pavements are cheaper and can be maintained at low cost while CC and RCC roads may be more durable but involves high construction and high maintenance cost.

The railways are also laid on raised ground over the founding ground with borrowed earth compacted at optimum moisture condition. It is then covered by rail ballast of 40-80 mm size for 40 to 60 cm thick apron followed by 40 to 50 mm ballast for shoulder of rail tracks. Highways and railways both usually pass through different kinds of terrains and varied founding substrate. In plains, it is usually or alluvial or at the most Aeolian soil deposits with very gentle slopes. In plateaux topography, they may come across with both earthy and rocky ground with low to moderate angle slopes. However, when it comes to hilly areas it has to negotiate high angle slopes over different types of rocks with differing attitude. Especially in case of railway tracks, sharp bends and sudden slope change cannot be allowed as against roads, which rise on slopes with sharp *hairpin bends*. In this way, railway tracks need more space sideways and also more number of bridges as compared to roads. The long-term stability of roads and railways is of prime importance especially on rocky slopes whose failure can have serious consequences. In the following section problems faced by roads and rail-tracks in hills are discussed.

3.1. Route Alignment: The route alignment between destination to destination is the most important factor as it will not only decide the length of the route but also the slope it has to negotiate, bridges and tunnels to be made and rock sequences it has to come across. Normally in case of laying new road or railways, many different alignments have to be studied thoroughly by taking into account all above factors, logistics involved in terms of availability of construction material, machine and economy. The important investigations involved along highway and railways include following:-

- **a)** The total running distance is studied to assess geotechnical properties for deciding the alignment, to identify problematic areas, and to decide its mending or bypassing.
- **b)** The volume of cutting and filling required, identification of borrowed areas for getting earth and rocks.
- **c)** Assessment of instability of slopes along the alignment and measures to be taken for its stability.
- **d)** Identification and of organics rich soil, swamps, palaeo-channels, cavities and peat deposits to ascertain there effect on stability.
- **e)** Making of detailed geological maps incorporating the road and its sides showing different types of soil, thickness of soil cover, rocks and its attitude.

Remote sensing imageries, aerial photographs, Survey of India topographic maps and existing geological maps are used to decide different possible alignments, identification of potential areas of land sliding, number of rivers to come across and to mark major topographic obstacles to decide construction of tunnels along the route. The ground study and surveys are then taken up to decide final one, from the above alignments.

4. Factors Influencing stability of Roads and Railways

The stability of a particular rock slope is governed by natural geomorphic and geological factors as well as on excavation methods employed during construction. The most important geomorphic factor is nature of slope, while important geologic factors include lithology, its structure and weathering grade. The construction of roads invariably involves excavations of rocky slopes to make benches for laying roads. As slopes created for roads will be subjected to various kinds of mass movements, their stability will be controlled by (i) type of rocks, its strength, density, cohesion (ii) alignment of cut slope and bench with respect to attitude of bedding, foliation, (iii) angle of slope and ratio of slope height with that of bench width termed as *batter*, (iv) presence and orientation of joints, shear zones, fault and fault zones and (v) flow pattern of surface and ground water.

4.1. Rock Types: The overall behavior of rock mass will depend on its intrinsic properties such as density, porosity, strength, cohesion a factor of mineral composition and texture of rocks as well as on the presence of joints and shear zones in a rock mass. Igneous rocks and non-foliated metamorphic rocks with interlocking texture with homogenous mineralogy will be the most favorable rocks. The roads in regions with sedimentary and foliated metamorphic rocks are more likely to suffer by landslides as they are intrinsically layered.

Ultramafic igneous rocks pyroxinite, serpentine; sedimentary rocks such as evaporites, marl, shale, chalk and metamorphic rocks such as schist, phyllite and slate are to be specially watched if they come along the route alignment as they are known weak rocks. The rocks are subjected to change by weathering specially if rocks are geologically very old, lying in regions with humid tropical climate, will be prone to landslides for example railroads in Konkan area.

Similarly, roads and railways in geo-tectonically active areas (Himalayan Mountain) are subjected to landslides due to high angle slopes, sudden heavy downpours and earthquakes, as in Uttarakhand and Himachal Pradesh.

4.2 Attitude of Rocks: The strike and dip of layers in rocks such as volcanic flows, bedding, lamination and foliation planes with respect to slope cut and bench plays a very important role. Horizontal rocks will provide moderate to good conditions while vertical rocks will pose problems on cut slope and bench. The most favorable situation is when rocks dipping against the slope, while most unfavorable condition will be when rocks dip towards slope. If the hills have horizontal or vertical rocks, the slope created will have almost similar conditions all around the hill. The dipping rocks will have different conditions around the hill i.e. in hill face perpendicular to strike of rocks will dip towards the slope, opposite to this face rocks will dip against the slope while in rest of the sections, rocks will show varying angles of dip (apparent dips) and may look apparently horizontal on slopes running parallel to its strike. In such cases it is prudent to have roads on the slope wherein rocks dip opposite to slope by having hair pin bends (Fig. 1) as against on slopes with rocks dipping towards it.

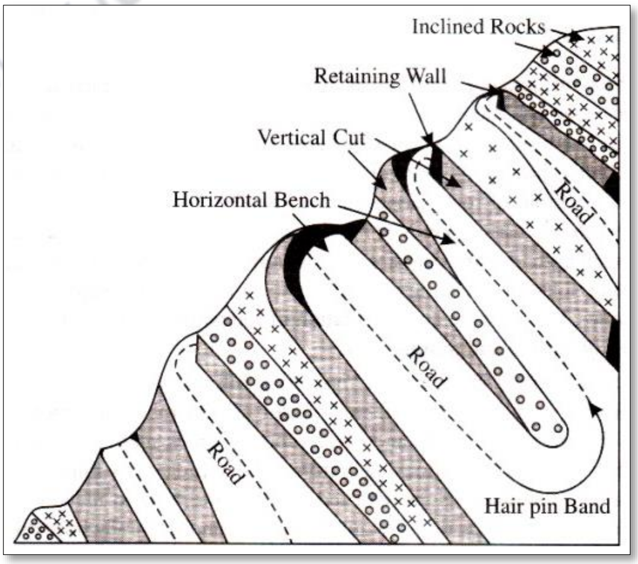

Fig. 1 Road on a hill with rocks dipping opposite to slope, forming hairpin bands. Also, see the vertical and horizontal cut to form bench for laying road.

4.3 Batter and Slope Angle: Construction of roads on slope requires creation of benches to seat it. The width of bench will depend upon the proposed width of road and associated elements such as side slope, provision of drain, parapet and retaining wall etc. The ratio of vertical cut height with that of horizontal bench width termed as batter is very important for stability of the roads, which depends upon the rock type and its overall strength (Fig. 2).

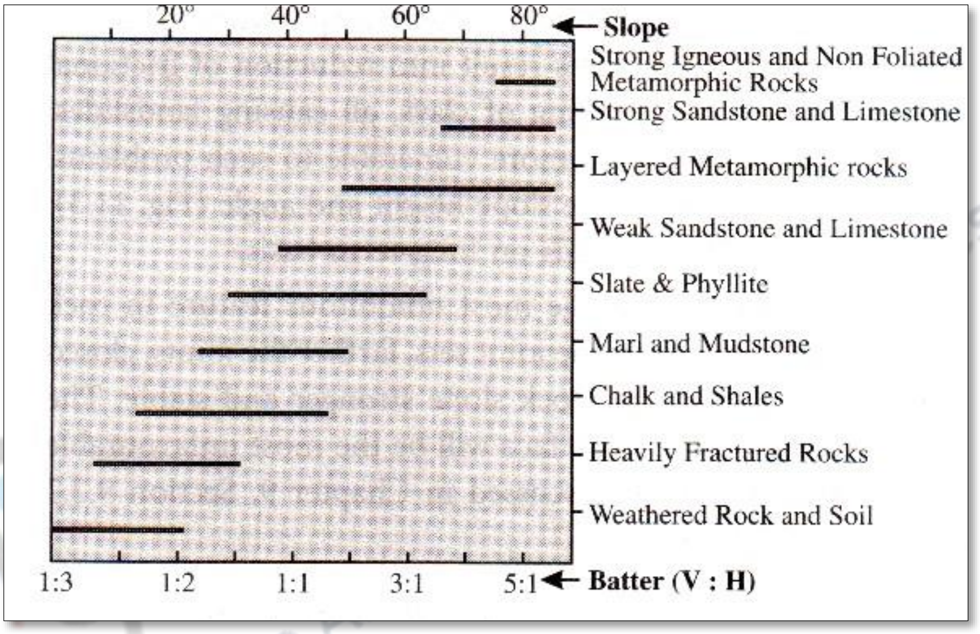

Fig. 2 The ratio of vertical to horizontal cut to create road space on hill slopes for different rocks.

The inclination and height of side slope (Fig. 3) are also important as they are going to control the space, would be available after cut and fill for laying the road. Weathered and weak rocks will offer low height vertical cut and low angle slopes while strong rocks can afford to have high slopes with high angle of inclination. Steep and high slope cut economize the space hence lesser excavation. Sound rocks can be cut to almost vertical faces, raked back by 10^0 for safety and can be benched at every 5 to 10m height intervals.

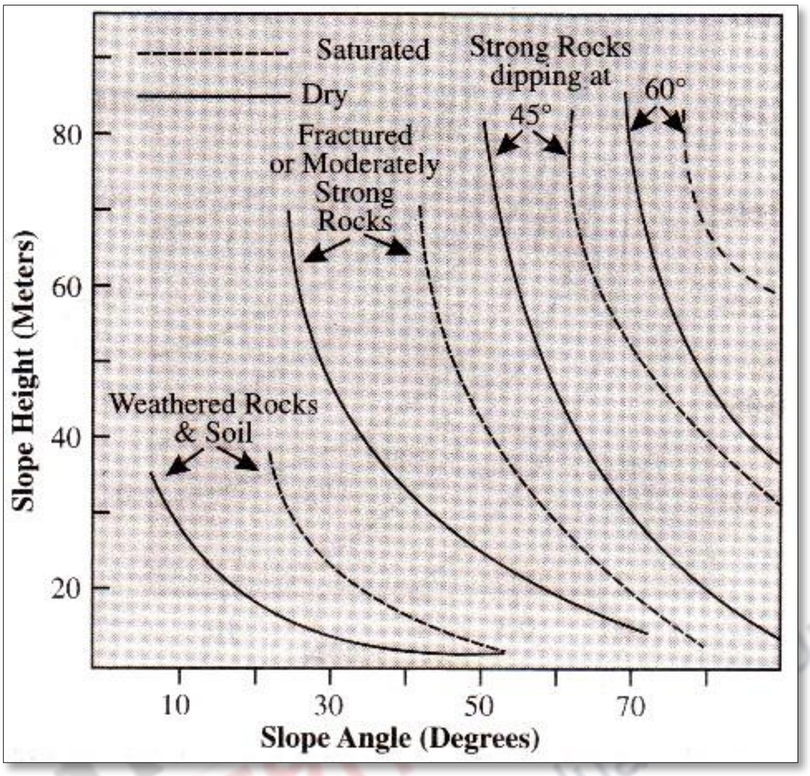

Fig. 3 Rocks of different strength and attitude on different slope height, angle and saturation level.

4.4 Surface and Groundwater: Water is the most important factor in aiding and triggering the landslides. Surface runoff caused by rainfall result into sudden mass transportation of debris on the slopes. Infiltration of water through pores and fractures result in to reduction of frictional resistance along fractures, increased pore pressure and swelling of clays all causing landslides. Freshly exposed slopes and benches cut for making roads are more vulnerable to such problems. The presence or absence of groundwater in rocks too influence slope height and angle (Fig. 3) Proper and improved drainage can ensure the stability of roads on long-term basis.

4.5 Joints, Shear Zones, Fault and Fault Zone: Joints the most ubiquitous feature in rock mass will control the overall rock mass characteristics. Lesser the joint sets, farther the joints, closed joint apertures and high degree of asperities will make the rock slope stronger and stable. The joint sets dipping with 45 to 75^0 and day lighting on the slope face will be the most unfavorable and need to be taken into account. Slope Mass Rating as discussed in Module 12, Section 3.6, should be employed for proper construction of hill roads.

5. Excavation to create Bench and Slope for Motor and Railway

To create space for laying road or railways on the shoulder of hills we need to create benches having different batter based on the rock mass conditions. For this different excavation techniques can be employed depending upon the rock types. Direct excavation by face shovel or by backhoe can be used for weathered and weak rock mass (Class V). Ripping can be employed for moderately weathered rocks of class IV using tractor mounted rippers or by breaking rocks using pneumatic hydraulic pecker. The old and most common technique has been the blasting if rocks are fresh, less fractured and strong. The different methods of excavation can be related to different rock mass parameters such as Rock Quality Designation, Unconfined Compressive Strength, Point Load Strength and fracture spacing (Fig. 4).

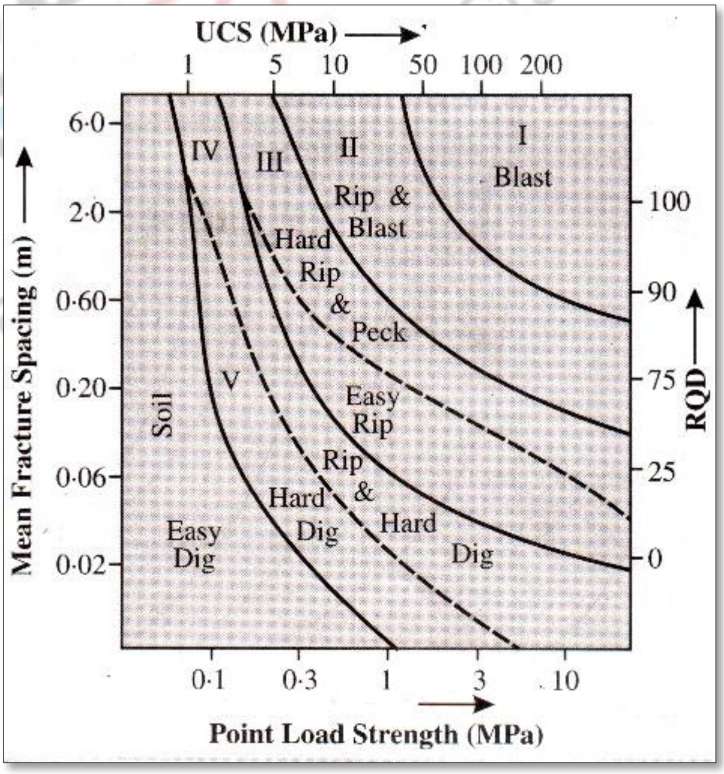

Fig. 4 A graph to show different excavation method for different rock mass classes (I – V), based on various rock and rock mass parameters.

5.1 Open Face Blasting: A generalized schematics is shown in figure (11.5) for blasting and excavation. It involves drilling of holes of 50 to 100mm diameter (D) usually raked at 10 to 15^0 of angle from the vertical. The rocks over the hole up to free face is called as burden (B) and ideally should be 30 to 40 times the D which may come to be 1.5 to 4.0m. Spacing between the drills holes are kept at 50 times the D, generally comes to be 3 to 5m. To make excavation smooth and to protect the slope from getting weak due to explosion few drill holes at a distance of 10 to 20 times D are kept with 10% less explosives that too decoupled i.e. not fully compacted.

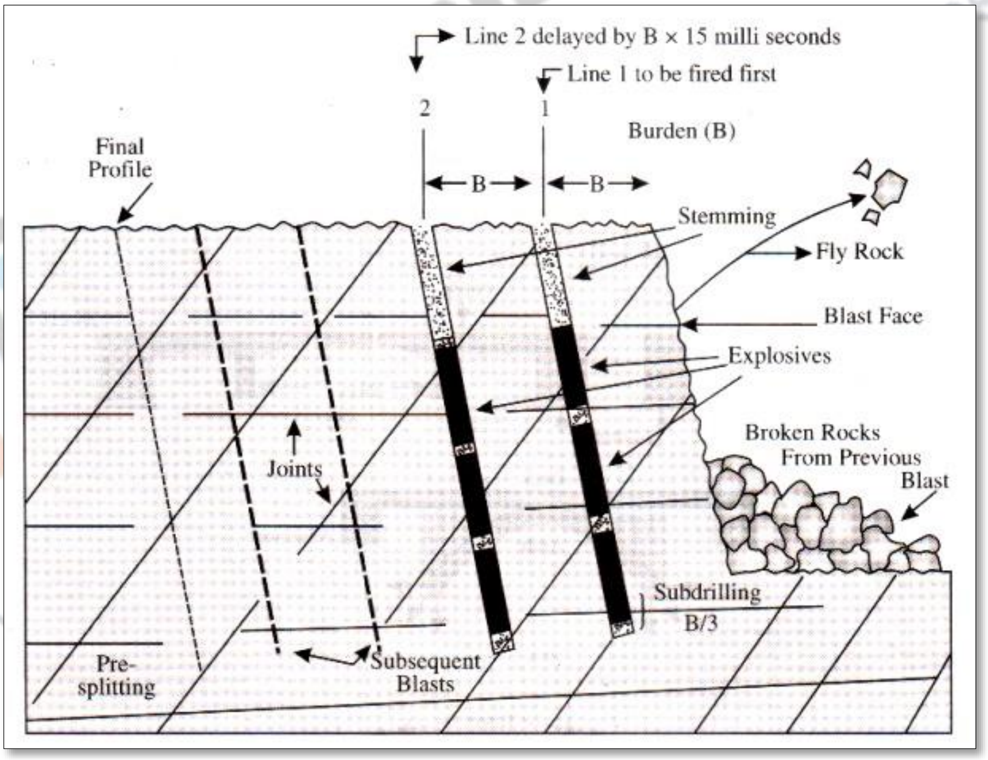

Fig. 5 A pictorial representation of drilling and blasting for open face excavation.

5.2 Explosion Material and Method: Black Powder also known as Gun Powder composed of KNO_3 with S and C is used for low magnitude blasting. Nitro-glycerin with Ammonium Nitrate called as Dynamite is used for powerful explosion. Ammonium Nitrate (94%) with Fuel Oil

(6%) termed as ANFO is cheap and safe to use for weak and fractured rock. The method involves charging where in explosive is kept in drill hole, is rammed tightly for good results the upper most part of the hole almost equal to burden, is left without explosive and is filled by sand termed as, stemming. Explosives are fired by using electric detonator by giving a delay, equal to 5 milliseconds/m of burden.

6. Engineering Geology of Bridge Site

Bridges are an integral part of road or rail track. In hilly areas, the number of bridges increases many times due to presence of numerous valleys with or without streams or rivers, as compared to their numbers in plain areas where they have to cross them occasionally. An engineering geologist ordinarily may not suggest the particular site for the bridge, as its location, height, span and type will be controlled by grade (slope) and alignment of the route and nature of traffic which are usually decided during the planning and designing stage. Though, he is very much involved in working out the geology of the bridge site, depth and condition of bed rock, thickness of overburden in river section, presence of buried channel, and correlation of rocks exposed on the two banks of the river where terminal support i.e. abutment of bridge will be placed.

6.1. Types of Bridges: A bridge consists of a superstructure placed on substructure, which is founded on a substrate comprising soil or soil and rock or only rock(s). The superstructure mainly consists of *deck*, placed on substructure either directly upon abutment or on last piers, which in turn are placed on foundation. (Fig. 6). There are four common types of bridges termed as (a) Girder Bridge, (b) Cantilever Bridge, (c) Arch Bridge and (d) Suspension bridge (Fig. 6a - d).

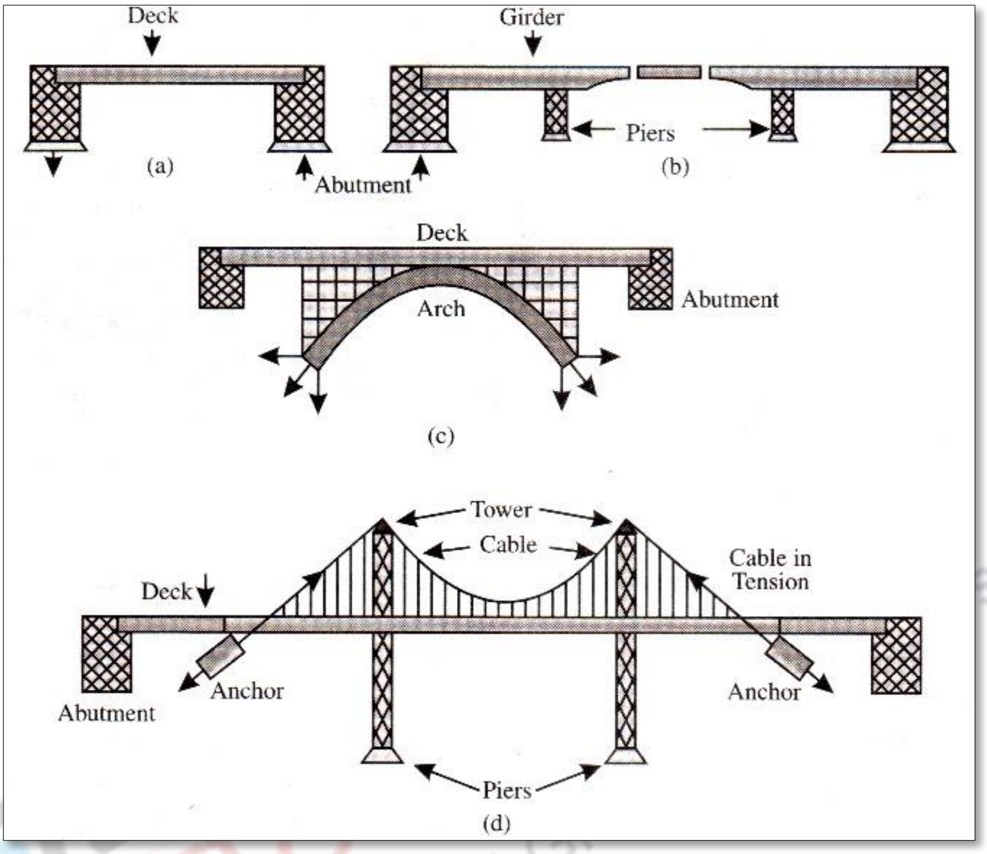

Fig. 6 Identify deck, abutments, piers and foundation part of bridges. (a) Simple beam or Girder bridge on end terminals/abutments; (b) Cantilever or truss bridges with end and mid pier supports; (c) Arch Bridge, see the orientation of forces; (d) Suspension bridge supported by cables anchored in rocks.

6.1.1. Simple Beam or Girder Bridge is made up of one span supported by abutments at their ends. When more than one span is required, piers are used to provide support in middle parts. Now days beam bridges are replaced by *Box Steel Girder* bridges.

6.1.2. Cantilever or Truss Bridge is made up of more than one span with intermediate support of piers. Mainly Consist of assembly of triangles using steel bars where in rigid steel arms extend from both side of the piers and steel tubes projected from top and bottom of each piers hold the arm in place. The arms projecting in the mid part are supported at one end only called cantilever, which supports the central span.

6.1.3. Arch Bridge has its deck supported by arch action, in earlier days were made up of stones but now are made of steel or concrete.

6.1.4. Suspension Bridge can have very large span i.e. 200 to 2000m largest of all bridge types consist of two strong steel cables, resting on saddles, fixed on steel or masonry towers and anchored in rocks at both ends, while deck is suspended on cables.

7. Geomorphological Factors

Any bridge on a river will affect the geomorphological process of a river; hence, basic knowledge of *Fluvial Geomorphology* is very important. The geomorphology of a river system can help in understanding the hydrodynamics and dynamic equilibrium of a river system at and around the bridge site. Normally a bridge negotiates a river at 90^0 to keep the length of bridge to its minimum. For this, the orientation of road has to be changed as it approaches the river. Depending upon the stages of river system the river may have different sizes in terms of its width, depth and cross section. Similarly, river may show different hydrodynamic character depending upon the gradient, discharge, nature and amount of sediment it is carrying with it. In addition, the order of a river system, catchment area, rainfall characteristics and drainage basin shall control how fast and how much of water comes into river in an event of sudden rainfall.

7.1. Fluvial Geomorphology: A river termed as *Anastomosing River* when it flows in hilly areas and is said to be in its *Nascent Stage*, where rate of erosion is much faster than the deposition of sediment. The sediment deposit is usually thin channel lag deposit over bedrock, comprising mostly of gravels of all sizes with coarse grain sand being transported very quickly due to high velocity currents. The river depth is more as compared to its width and usually has 'V' shape unless it is not carved out by glaciers in which case 'U' shape valley is common. The river may have tortuous route in deeply carved out entrenched valleys. The rivers once come out of hilly tracts in adjoining plain are said to be in *Young Stage*, where erosion almost equals the deposition and rivers show straighter route. The valleys become very broad with thick sediment deposit of medium to fine size gravel and sand. The river may consist of multiple channels, called as *Braided Rivers* with intervening braid bars in valleys having breadth more than depth. The current velocity, nature and amount of sediment vary with amount of water during rainy and non-rainy season and at the same time, the location of main or active channel may also change.

The rivers in plain areas flow with tortuous route having meanders of different sizes and shapes and called as *Meandering River*. This stage is termed as *Mature Stage* where rate of erosion becomes much less than the rate of deposition due to very low current velocity, except during rainy season. The river changes its course due to erosion on outer bend and deposition on inner bend of river channel and may also make new course by leaving its own meander loop called as *Ox Bow Lake*. The valley or flood plain becomes very broad as compared to its depth. The sediment deposit includes gravels in channel section, sands as point bars, silt and clay on flood plain.

As river approaches its mouth and ends at sea or lake, it forms delta through number of distributaries. Such *Deltaic River* is in its *Old Stage* where its erosive power is at its minimum, deposition of sediments take place in and around delta while remaining sediment goes into sea. The flood plain becomes extremely wide and is inundated time and again by floods either due to rain in its upper reaches or due to sea tides.

The bridges made on rivers with different stages of flows will create hindrance in natural geomorphic processes operating and will not only restrict river flow but also the dynamics of erosion and deposition. The bridges over rivers of nascent or young stage may have lesser length but will have great heights and may be subjected to flash floods and overtopping. The foundation in all probability will lie on rocks. The nature and thickness of valley fill will show lot of heterogeneity. The bridges on mature stage rivers may have moderate length and height. The problem of flash flood and over topping gets less severe but the current velocity may become very high in rainy seasons as water coming from restricted valleys may spill laterally in these open channels. Hence, the embankments have to be strong and there should be enough space through the bridges, in terms of height of the deck and spacing between the piers to drain off the floodwaters. The foundation rock may or may not be exposed but can be found at varying depths and can be approached through pile foundations. The bridges on mature or old staged rivers may have great lengths due to broad flood plains but may have comparatively lesser heights. The foundation in this case may have to be provided on river deposits itself as rocks may be found at very deep levels. It is common to have well foundations in such cases. The problem of flash floods and overtopping is minimized.

7.2. Problem of Impoundment and Scouring: The height of a bridge is a very important element as for as proper functioning and life of bridge is concerned. During the construction of bridges, roads have to be elevated to the levels of bridge from fairly a long distance and act as barrier to flow of water during flood stage. This results into impoundment of water as in reservoirs causing increased floodwater levels as compared to levels, prior to the construction of bridge at that very place and probable overtopping, which may cause increased buoyancy forces. Similarly, the piers supporting the bridge deck occupy the space of river channel, which in turn will result into raising of water level during lean periods also. During the flood the raised embankment for road and railway to achieve deck height, abutment and piers will also cause damming of flood plain and act as impediment, causing rise in flood water levels as compared to pre bridge construction flood levels. Hence, before deciding the height of the bridge maximum flood water level is to be worked out by taking into account the probable increase in flood water levels due to construction of road embankment and bridge.

Apart from above problem of rise in water level the movement of waters are impeded in channel section, by abutments and piers resulting in to the generation of eddies which causes erosion at the base of abutments and around piers called as *scouring*, resulting in weakening of their foundation.

8. Geological Factors

The geological factors play important role where abutment and foundation ground is made up of rocks which is normally a case in hilly areas and rocky areas. The important design factors of a bridge includes total *Vertical Load* acting downward (*Dead Load* and *Live Load* or *Load of Rolling Stock* i.e. train), *Vertical Load* acting upward (*Buoyancy* and *Pore Water Pressure*), *Lateral Forces* (*Wind Forces, Thrust Forces* by running and impounded water) and *Dynamic Forces* (Vibrations due to movement of four wheelers and trains, Creeping Slopes, Landslides, Earthquake). To address these issues important geological factors to be investigated include type and strength of foundation rocks, thickness and attitude of rocks, structural characteristics of rock mass, groundwater levels, slope strength and earthquake for deciding the site, size, type and design of bridge.

8.1. Type and Strength of Foundation Rocks: Depending upon the geology of the area and size of the bridge, foundation rocks at abutment and below piers may remain same or may differ. The former situation is ideal as compared to the later one. Spatial similarity of rocks all through foundation will ensure similar strength, rock mass characteristics and will limit differential settlement. It is the compressive and shear strength of rocks, which are important for deciding types of foundation. Usually all kind of igneous rocks being bodies of large dimension will cover entire foundation area and will have high compressive and shear strength. Only in the case of volcanic rocks inter bedded with weak volcanic ash deposits, care should be taken. Non-foliated metamorphic rocks are as good as igneous rocks as for as their strength and areal coverage is concerned but foliated metamorphic rocks have to be properly investigated, as foliation will impart weakness. If vertical load is incident perpendicular to foliation planes then rock may show comparatively good compressive strength but still shear strength will be low and care should be taken while designing. Sedimentary rocks are in general show lower strength as compared to the other two major groups primarily due to inherent weakness as well as presence of bedding and lamination planes. Only sandstone with silica and ferruginous cements can be used as foundation ground safely, rest of the rocks such as conglomerate, siltstone, shale etc. may not fair good as foundation rocks especially for medium to large sized bridges. Limestones and other calcareous rocks despite being very strong in dry conditions get deteriorated when in contact with water. Water can dissolve calcareous rocks leading to the formation of cavities. Hence, limestone terrains should always be seen with extra caution and construction of bridge may be undertaken only after thorough investigations involving geophysical and drilling methods. The *karstic* limestone foundation rocks should be treated for its cavities by filling of cement-concrete for safety of a bridge.

8.2. Thickness and Attitude of Rocks: Greater is the thickness of rocks, rock foundation will much sounder, as pressure bulb formed due to loading will remain within a particular rock. The natural disposition of rocks may be horizontal, vertical and inclined. The thick horizontal rocks and vertical rocks with different strike directions may fair well as for as foundation of bridges are concerned. The attitude of rocks with respect to bridge alignment becomes important if rocks are inclined wherein the strike direction of rocks will be parallel, perpendicular or diagonal to the bridge alignment. The rocks striking parallel to bridge will have rock dips towards up stream or downstream, the former is a best, while later one is a poor situation. Rocks with high angle dips ($>45^0$) fair good as compared to rocks with low angle of dip ($<45^0$). In the case of rocks striking perpendicular to bridge the rocks may dip either towards left bank or right bank, both the conditions are fair. The rocks with strike oriented diagonally to bridge alignment will also fair good.

8.3. Structural Characteristics of Rock Mass: Depending upon the geological evolution of an area, rocks must have undergone natural deformation resulting into development of fractures, shear zone, fault and fold. The number of joints present, their spacing, aperture, alteration etc. will decide the overall strength of rock mass and its engineering behavior. Presence of shear zones in abutments and below piers should be treated by excavation and back filling by reinforced concrete. It has been seen more than often that in hilly areas rivers follow anticlinal fold axis or fault plane/zone because it is easier to erode rocks along them. Depending upon the wavelength and type of fold and overall length of bridge the rocks may get repeated with changing dips resulting into different rocks below different piers and abutments. Similarly, presence of fault along or across the river will result into dislocation of rocks and bringing different rocks at different foundation points apart from forming a deep valley with lot of debris and buried channel (Fig. 7). In the geologically active areas, the faults may still show some movement and displacement along them, termed, as *Active Faults* should be identified as the movement along them may cause failure of the bridge founded over faulted rock mass.

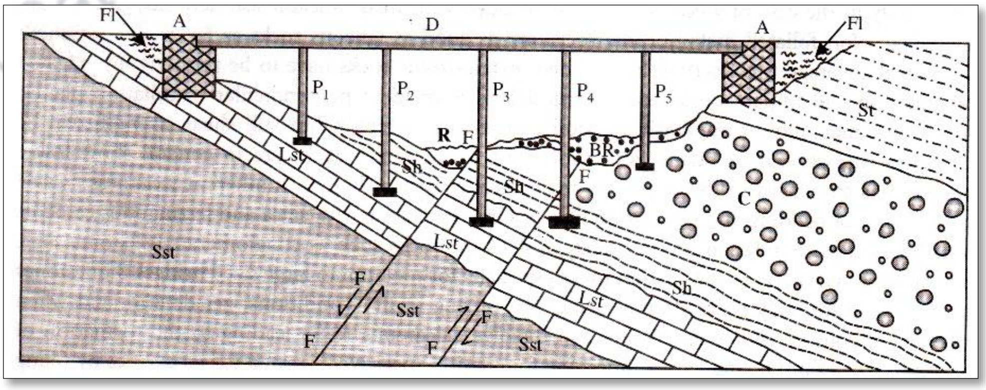

Fig. 7 A bridge crossing a river (R) in valley showing faults (F-F) with buried channel (BR) and different rocks. The Abutments (A) and piers (P – P) are placed in different rocks (Sst-sandstone, Lst-limestone, Sh-shale, C-conglomerate, St-siltstone, Fl-earth fill, D-deck).

8.4. Groundwater Levels: It is very normal to have groundwater in foundation part of bridge made over a river. The presence of groundwater will result into lowering of shear strength of rocks, increased pore pressure, solution and corrosion of foundation material. If clays are present, in rocks (sedimentary rocks) or as alteration product present in joints they may cause swelling in wet conditions and shrinking during dry seasons may lead to differential settling. Similarly, salts may be found in rocks as minor component in association with calcareous rocks; its dissolution will play havoc with time and may result in the failure of bridge. That is why it will not at all be prudent to have bridge foundation over evaporites, a rock full of salts. Some times during the laying of foundation dewatering is done to lower down the groundwater table well below the foundation and moisture still left is drawn out by injecting hot steam through holes or conducting electro-osmosis by installing electrodes into soil or rocks wherein perforated pipes are as anodes and cathodes to collect water.

8.5. Slope Strength: A bridge in hilly areas over a river will definitely be subjected to problems of mass wasting and mass movement may it be very slow termed as creep or fast termed as landslides. In both the cases different elements of bridge will be in danger. There are many instances when landslide in a river valley results into natural damming of river and formation of natural reservoir. The breach of such reservoirs result into flash floods and many times bridge washouts a common feature in Himachal Pradesh and Jammu and Kashmir. To mitigate this problem we have to employ different methods to strengthen the slope as per the need and economy.

8.6. Earthquake: For bridge design first of all one has to take into account the seismic zone in which lies the site. The Peak Ground Acceleration (PGA) and probability of earthquakes of different magnitude based on the history of region needs to be considered. The possible return periods of earthquake for

50, 100, 200 years should also be worked out as long-term measures. Apart from this, seismic dampers such as synthetic sheets (Fig. 8) or ball bearings are placed between the deck and piers to provide base isolation (Fig. 9).

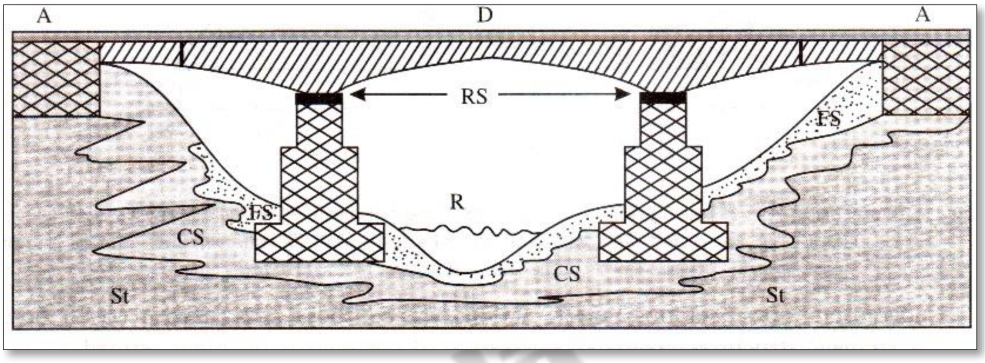

Fig. 8 A bridge showing synthetic sheet (RS) between deck and pier (P) to absorb seismic vibrations.

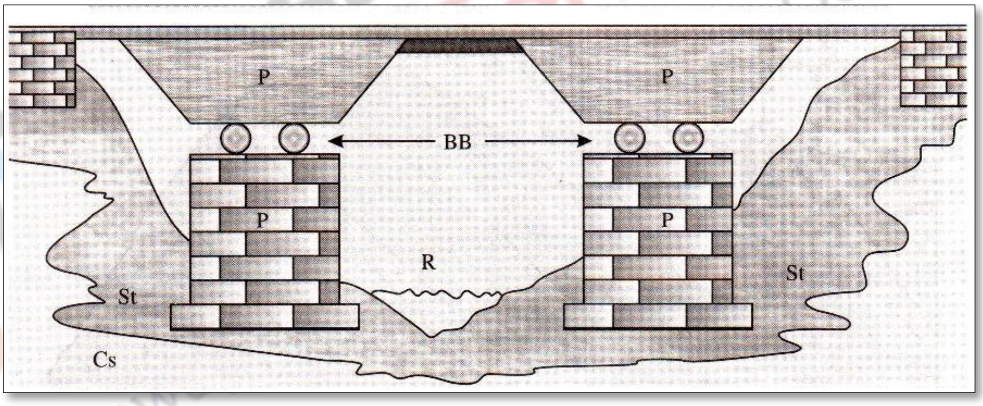

Fig. 9 A bridge showing ball bearing (BB) between pre stressed bridge blocks and pier to absorb seismic vibrations.

9. Summary

Road and rail networks and bridges are the lifeline infrastructures facilities for any region or country. The bridges being the integral part of the road and rail networks constructed over rivers and arms of sea to connect two sides. The understanding of topography, geomorphology and geology of the areas being traversed by these transportation elements is important for safe design and longevity, especially in rocky or hilly terrains. Huge amount of quality construction material in form of earth and rocks are required from nearby sources to keep cost within permissible limits.

The construction of roads started with *stone pavements* in ancient period, followed by *kankar* and *lime-surkhi-pitch* roads in medieval period to modern day *tar* and *concrete* roads with state of the art construction technology. There are two types of roads termed as *Flexible Pavement* and *Rigid Pavement*. Flexible pavement, is said so because of the fact that part of road may flex down or raised up due to differential compaction of founding soil or rocks is the most prevalent road type, all over the world. It is laid on original founding soil called as sub grade or on raised ground using borrowed earth, termed as sub base course, followed by different layers of rock aggregate as base course laid mixed with earth and water, surface course and wearing course mixed with hot tar. The rigid pavement gets its name from the cast concrete or reinforced concrete layer, which acts as slab and does not allow any settlement, founded over soil or rock foundation with sub base made of rock aggregate. Rigid pavement are constructed where soil strata is weak and there is a perpetual problem of water logging. The flexible pavements are cheaper and can be maintained at low cost while rigid pavements though durable but involves high construction and high maintenance cost.

The railways are also laid on raised ground over the founding ground with borrowed earth compacted at optimum moisture condition. It is then covered by rail ballast of 40-80 mm size for 40 to 60 cm thick apron followed by 40 to 50 mm ballast for shoulder of rail tracks. Highways and railways both usually pass through different kinds of terrains and varied founding substrate. In plains, it is usually or alluvial or at the most Aeolian soil deposits with very gentle slopes. In plateaux topography, they may come across with both earthy and rocky ground with low to moderate angle slopes. However, when it comes to hilly areas it has to negotiate high angle slopes over different types of rocks with differing attitude. Especially in case of railway tracks, sharp bends and sudden slope change cannot be allowed as against roads, which rise on slopes with sharp *hairpin bends*. In this way, railway tracks need more space sideways and also more number of bridges as compared to roads. The long-term stability of roads and railways is of prime importance especially on rocky slopes whose failure can have serious consequences.

The route alignment between destination to destination is the most important factor as it will not only decide the length of the route but also the slope it has to negotiate, bridges and tunnels to be made and rock sequences it has to come across. Normally in case of laying new road or railways, many different alignments have to be studied thoroughly by taking into account all above factors, logistics involved in terms of availability of construction material, machine and economy. The important investigations involved along highway and railways include following:-

f) The total running distance is studied to assess geotechnical properties for deciding the alignment, to identify problematic areas, and to decide its mending or bypassing.

g) The volume of cutting and filling required, identification of borrowed areas for getting earth and rocks.

h) Assessment of instability of slopes along the alignment and measures to be taken for its stability.

i) Identification and of organics rich soil, swamps, palaeo-channels, cavities and peat deposits to ascertain there effect on stability.

j) Making of detailed geological maps incorporating the road and its sides showing different types of soil, thickness of soil cover, rocks and its attitude.

Remote sensing imageries, aerial photographs, Survey of India topographic maps and existing geological maps are used to decide different possible alignments, identification of potential areas of land sliding, number of rivers to come across and to mark major topographic obstacles to decide construction of tunnels along the route. The ground study and surveys are then taken up to decide final one, from the above alignments.

The stability of a particular rock slope is governed by natural geomorphic and geological factors as well as on excavation methods employed during construction. The most important geomorphic factor is nature of slope, while important geologic factors include lithology, its structure and weathering grade. The construction of roads invariably involves excavations of rocky slopes to make benches for laying roads. As slopes created for roads will be subjected to various kinds of mass movements, their stability will be controlled by (i) type of rocks, its strength, density, cohesion (ii) alignment of cut slope and bench with respect to attitude of bedding, foliation, (iii) angle of slope and ratio of slope height with that of bench width termed as *batter*, (iv) presence and orientation of joints, shear zones, fault and fault zones and (v) flow pattern of surface and ground water.

The overall behavior of rock mass will depend on its intrinsic properties such as density, porosity, strength, cohesion a factor of mineral composition and texture of rocks as well as on the presence of joints and shear zones in a rock mass. Igneous rocks and non-foliated metamorphic rocks with interlocking texture with homogenous mineralogy will be the most favorable rocks. The roads in regions with sedimentary and foliated metamorphic rocks are more likely to suffer by landslides as they are intrinsically layered.

Ultramafic igneous rocks pyroxinite, serpentine; sedimentary rocks such as evaporites, marl, shale, chalk and metamorphic rocks such as schist, phyllite and slate are to be specially watched if they come along the route alignment as they are known weak rocks. The rocks are subjected to change by weathering specially if rocks are geologically very old, lying in regions with humid tropical climate, will be prone to landslides for example railroads in Konkan area. Similarly, roads and railways in geo-tectonically active areas such as in Himalaya are subjected to landslides due to high angle slopes, sudden heavy downpours and earthquakes.

The strike and dip of layers in rocks such as volcanic flows, bedding, lamination and foliation planes with respect to slope cut and bench plays a very important role. Horizontal rocks will provide moderate to good conditions while vertical rocks will pose problems on cut slope and bench. The most favourable situation is when rocks dipping against the slope, while most unfavorable condition will be when rocks dip towards slope. If the hills have horizontal or vertical rocks, the slope created will have almost similar conditions all around the hill. The dipping rocks will have different conditions around the hill i.e. in hill face perpendicular to strike of rocks will dip towards the slope, opposite to this face rocks will dip against the slope while in rest of the sections, rocks will show varying angles of dip (apparent dips) and may look apparently horizontal on slopes running parallel to its strike. In such cases it is prudent to have roads on the slope wherein rocks dip opposite to slope by having hair pin bends as against on slopes with rocks dipping towards it.

The width of bench will depend upon the proposed width of road and associated elements such as side slope, provision of drain, parapet and retaining wall etc. The ratio of vertical cut height with that of horizontal bench width termed as batter is very important for stability of the roads, which depends upon the rock type and its overall strength.

The inclination and height of side slope are also important as they are going to control the space, would be available after cut and fill for laying the road. Weathered and weak rocks will offer low height vertical cut and low angle slopes while strong rocks can afford to have high slopes with high angle of inclination. Steep and high slope cut economize the space hence lesser excavation. Sound rocks can be cut to almost vertical faces, raked back by 10^0 for safety and can be benched at every 5 to 10m height intervals.

Water is the most important factor in aiding and triggering the landslides. Surface runoff caused by rainfall result into sudden mass transportation of debris on the slopes. Infiltration of water through pores and fractures result in to reduction of frictional resistance along fractures, increased pore pressure and swelling of clays all causing landslides. Proper and improved drainage can ensure the stability of roads on long-term basis.

Joints being ubiquitous in rock mass will control the overall rock mass characteristics. Lesser and fewer joint sets will make slope less vulnerable to failure. The joint sets dipping with 45 to 75^0 and day lighting on the slope face will be the most unfavorable and need to be taken into account.

Creation of space for laying road or railways on the shoulder of hills we need to create benches having different batter based on the rock mass conditions. For this different excavation, techniques can be employed depending upon the rock types. Direct excavation by face shovel or by backhoe can be used for weathered and weak rock mass (Class V). Ripping can be employed for moderately weathered rocks of class IV using tractor mounted rippers or by breaking rocks using pneumatic hydraulic pecker. The old and most common technique has been the blasting if rocks are fresh, less fractured and strong. The different methods of excavation can be related to different rock mass parameters such as Rock Quality Designation, Unconfined Compressive Strength, Point Load Strength and fracture spacing. Open face control blasting with presplitting can create good slope using KNO_3 with S and C for low and dynamite for high magnitude blasting giving proper delay in detonation. Ammonium Nitrate (94%) with Fuel Oil (6%) termed as ANFO is cheap and safe to use for weak and fractured rock.

Frequently Asked Questions-

Q1. Enumerate different stages of investigations for road and rail network in hilly terrains?

Ans. Highways and railways are the lifelines of any country. In hilly areas, they are to be constructed through different kinds of terrains with varied founding ground. In plateaux topography, they may come across with both earthy and rocky ground with low to moderate angle slopes. However, when it comes to hilly areas it has to negotiate high angle slopes over different types of rocks with differing attitude. Especially in case of railway tracks sharp bends and sudden slope change cannot be allowed as compared to roads, which can rise on slopes with sharp *hairpin bends*. Hence, railway tracks need more space sideways and also more number of bridges as compared to roads. The long-term stability of roads and railways is the prime consideration.

After alignment is finalized we come to know about type of slope is to be negotiated and how much cutting and filling will be required. In hilly terrains, it is common to have many valleys and rivulets hence it is ensured that how many bridges and tunnels will be required. Now a days many existing roads are being widened in our country and at places new alignment are by passes are required to avoid areas of population. The important investigations involved along highway and railways include following:

i) Making of detailed geological maps incorporating the road or rail alignment and its sides showing different types of soil, thickness of soil cover, rocks and its attitude. ii) Geotechnical properties all along the alignment of the road to identify problematic areas and to decide its mending or bypassing. iii) The volume of cutting and filling required, identification of areas for borrowing earth and rocks. iv) Assessment of instability of slopes along the alignment and measures to be taken for its stability. v) Identification and of organics rich soil, swamps, palaeo-channels, cavities and peat deposits to ascertain there effect on stability.

For these modern methods such as remote sensing imageries, aerial photographs, Survey of India topographic maps and existing geological maps are used to decide different possible alignments, identification of potential areas of land sliding, number of rivers to come across and to mark major topographic obstacles to decide construction of tunnels along the route.

Q2. Describe important geomorphological and geological factors for safe laying of roads and rail network on rocky slopes?

Ans. The stability of a particular rock slope is governed by natural geomorphic and geological factors as well as on excavation methods employed during construction. The most important geomorphic factor is nature of slope, while important geologic factors include lithology, the structure inbuilt and weathering grade. The construction of roads or railways invariably involves excavations of rocky slopes to make benches for laying roads. As slopes created, they will be subjected to various kinds of mass movements; their stability will be controlled by following factors:

i) Type of rocks, its strength, density and cohesion wherein mineral composition and texture of rocks will play an important role. Igneous rocks and non-foliated metamorphic rocks with interlocking texture with homogenous mineralogy will be the most favorable rocks. The roads in regions with sedimentary and foliated metamorphic rocks are more likely to suffer by landslides as they are intrinsically layered. Slopes with presence of even less amount of serpentine; evaporites, marl, shale, chalk and weathered metamorphic rocks such as schist, phyllite slate etc. are to be specially watched if they come along the route alignment as they are known weak rocks.

ii) Alignment of cut slope and bench with respect to attitude of bedding, foliation or flowage planes play a very important role. Horizontal rocks will provide moderate to good conditions while vertical rocks will pose problems on cut slope and bench. The most favorable situation is when rocks dipping against the slope, while most unfavorable condition will be when rocks dip towards slope. If the hills have horizontal or vertical rocks, the slope created will have almost similar conditions all around the hill. The dipping rocks will have different conditions around the hill i.e. in hill face perpendicular to strike of rocks will dip towards the slope, opposite to this face rocks will dip against the slope while in rest of the sections, rocks will show varying angles of dip (apparent dips) and may look apparently horizontal on slopes running parallel to its strike.

iii) Angle of slope and ratio of slope height with that of bench width termed as *batter*, is very important for stability of the roads, which depends upon the rock type and its overall strength as it is going to control the space, would be available after cut and fill for laying the road. Weathered and weak rocks will offer low height vertical cut and low angle slopes while strong rocks can afford to have high slopes with high angle of inclination. Steep and high slope cut economize the space hence lesser excavation. Sound rocks can be cut to almost vertical faces, raked back by 10^0 for safety and can be benched at every 5 to 10m height intervals.

iv) Presence and orientation of joints, shear zones, fault and fault zones will control the overall rock mass characteristics. Less number of joints, farther with closed joint apertures and high degree of asperities will make the rock slope stronger and stable. The joint sets dipping with 45 to 75^0 and day lighting on the slope face will be the most unfavorable and need to be taken into account. Shear zones and fault zones will not only displace the rocks but will make the rock mass pulverized and weak.

v) Flow pattern of surface and ground water as it is the most important factor in aiding and triggering the landslides. Surface runoff caused by rainfall result into sudden en mass transportation of debris on the slopes. Infiltration of water through pores and fractures result in to reduction of frictional resistance along fractures, increased pore pressure and swelling of clays all causing landslides. Freshly exposed slopes and benches cut for making roads or rails are more vulnerable to such problems. Proper and improved drainage can ensure the stability of roads on long-term basis.

Q3. What are the different methods of excavation required for creating benches to lay road and railways in hilly tracts?

Ans. To create space for laying road or railways on the shoulder of hills we need to create benches having different batter based on the rock mass conditions. For this different excavation, techniques can be employed depending upon the rock types. Direct excavation by face shovel or by backhoe can be used for weathered and weak rock mass (Class V). Ripping can be employed for moderately weathered rocks of class IV using tractor mounted rippers or by breaking rocks using pneumatic hydraulic pecker. The old and most common technique has been the blasting if rocks are fresh, less fractured and strong. The different methods of excavation can be related to different rock mass parameters such as Rock Quality Designation, Unconfined Compressive Strength, Point Load Strength and fracture spacing. Mostly open face blasting is carried out which involves drilling of holes of 50 to 100mm diameter (D) usually raked at 10 to 15^0 of angle from the vertical. The rocks over the hole, up to free face is called as burden (B) and ideally should be 30 to 40 times the D which may come to be 1.5 to 4.0m. Spacing between the drills holes are kept at 50 times the D, generally comes to be 3 to 5m. To make excavation smooth and to protect the slope from getting weak due to explosion few drill holes at a distance of 10 to 20 times D are kept with 10% less explosives that too decoupled i.e. not fully compacted.

Black Powder also known as Gun Powder composed of KNO_3 with S and C is used for low magnitude blasting. Nitro-glycerin with Ammonium Nitrate called as Dynamite is used for powerful explosion. Ammonium Nitrate (94%) with Fuel Oil (6%) termed as ANFO is cheap and safe to use for weak and fractured rock. The method involves charging where in explosive is kept in drill hole, is rammed tightly for good results the upper most part of the hole almost equal to burden, is left without explosive and is filled by sand termed as, stemming. Explosives are fired by using electric detonator by giving a delay, equal to 5 milliseconds/m of burden.

Q4. What are the important geomorphological factors for safe design of bridges?

Ans. The bridges made on rivers with different stages of flows will create hindrance in natural flow of rivers and alters the process of erosion and deposition. The bridges over rivers of nascent or young stage in mountains and hills may have lesser length but will have great heights needing very high piers giving excessive load on foundation rocks. The slopes here will be amenable to slope failures and probably vibrations due to earthquakes and wind forces.

The bridges on mature stage rivers may have moderate length and height. The nature and thickness of valley fill will show lot of heterogeneity. The problem of flash flood and over topping may be less probable but the current velocity may be very high in rainy seasons as water coming from restricted valleys may spill laterally in these open channels. Hence, the embankments have to be strong and there should be enough space through the bridges, in terms of height of the deck and spacing between the piers to drain off the floodwaters. The foundation rock may or may not be exposed but can be found at varying depths and can be approached through pile foundations.

The bridges on mature or old staged rivers may have great lengths due to broad flood plains but may have comparatively lesser heights. The foundation in this case may have to be provided on river deposits itself as rocks may be found at very deep levels. It is common to have well foundations in such cases. The problem of flash floods and overtopping is minimized.

During the construction of bridges, roads have to be elevated to the levels of bridge from fairly a long distance and act as barrier to flow of water during flood stage. This results into impoundment of water as in reservoirs causing increased floodwater levels as compared to levels, prior to the construction of bridge at that very place and probable overtopping, which may cause increased buoyancy forces. Similarly, the piers supporting the bridge deck occupy the space of river channel, which in turn will result into raising of water level during lean periods also. During the flood the raised embankment for road and railway to achieve deck height, abutment and piers will also cause damming of flood plain and act as impediment, causing rise in flood water levels as compared to pre bridge construction flood levels. Hence, before deciding the height of the bridge maximum flood water level is to be worked out by taking into account the probable increase in flood water levels due to construction of road embankment and bridge.

Apart from above problem of rise in water level the movement of waters are impeded in channel section, by abutments and piers resulting in to the generation of eddies which causes erosion at the base of abutments and around piers called as *scouring*, resulting in weakening of their foundation.

Q5. What are the important geological factors for safe design of bridges?

Ans. The geological factors play important role where abutment and foundation ground is made up of rocks which is normally a case in hilly areas and rocky areas. The important design factors of a bridge includes total *Vertical Load* acting downward (*Dead Load* and *Live Load* or *Load of Rolling Stock* i.e. train), *Vertical Load* acting upward (*Buoyancy* and *Pore Water Pressure*), *Lateral Forces* (*Wind Forces*, *Thrust Forces* by running and impounded water) and *Dynamic Forces* (Vibrations due to movement of four wheelers and trains, Creeping Slopes, Landslides, Earthquake). To address these issues important geological factors to be investigated include:

i) Type and strength of foundation rocks as at abutment and below piers may remain same or may differ depending upon the geology of the bridge site. Depending upon the length of the bridge and number of piers involved similarity of rocks all through foundation will ensure similar rock mass characteristics especially the strength. It is the compressive and shear strength of rocks, which are important for deciding types of foundation. Usually all kind of igneous rocks being bodies of large dimension will cover entire foundation area and will have high compressive and shear strength. Only in the case of volcanic rocks inter bedded with weak volcanic ash deposits, care should be taken. Non-foliated metamorphic rocks are as good as igneous rocks as for as their strength and areal coverage is concerned but foliated metamorphic rocks have to be properly investigated, as foliation will impart weakness. If vertical load is incident perpendicular to foliation planes then rock may show comparatively good compressive strength but still shear strength will be low and care should be taken while designing. Sedimentary rocks are in general show lower strength as compared to the other two major groups primarily due to inherent weakness as well as presence of bedding and lamination planes. Only sandstone with silica and ferruginous cements can be used as foundation ground safely, rest of the rocks such as conglomerate, siltstone, shale etc. may not fair good as foundation rocks especially for medium to large sized bridges. Limestones and other calcareous rocks despite being very strong in dry conditions get deteriorated when in contact with water. Water can dissolve calcareous rocks leading to the formation of cavities. Hence, limestone terrains should always be seen with extra caution and construction of bridge may be undertaken only after thorough investigations involving geophysical and drilling methods. The *karstic* limestone foundation rocks should be treated for its cavities by filling of cement-concrete for safety of a bridge.

ii) Thickness and Attitude of rocks: Greater is the thickness of rocks, rock foundation will much sounder, as pressure bulb formed due to loading will remain within a particular rock. The natural disposition of rocks may be horizontal, vertical and inclined. The thick horizontal rocks and vertical rocks with different strike directions may fair well as for as foundation of bridges are concerned. The attitude of rocks with respect to bridge alignment becomes important if rocks are inclined wherein the strike direction of rocks will be parallel, perpendicular or diagonal to the bridge alignment. The rocks striking parallel to bridge will have rock dips towards up stream or downstream, the former is a best, while later one is a poor situation. Rocks with high angle dips (>45^0) fair good as compared to rocks with low angle of dip (<45^0). In the case of rocks striking perpendicular to bridge the rocks may dip either towards left bank or right bank, both the conditions are fair. The rocks with strike oriented diagonally to bridge alignment will also fair good.

iii) Structural characteristics of rock mass: Depending upon the geological evolution of an area, rocks must have undergone natural deformation resulting into development of fractures, shear zone, fault and fold. The number of joints present, their spacing, aperture, alteration etc. will decide the overall strength of rock mass and its engineering behavior. Presence of shear zones in abutments and below piers should be treated by excavation and back filling by reinforced concrete. It has been seen more than often that in hilly areas rivers follow anticlinal fold axis or fault plane/zone because it is easier to erode rocks along them. Depending upon the wavelength and type of fold and overall length of bridge the rocks may get repeated with changing dips resulting into different rocks below different piers and abutments. Similarly, presence of fault along or across the river will result into dislocation of rocks and bringing different rocks at different foundation points apart from forming a deep valley with lot of debris and buried channel. In the geologically active areas, the faults may still show some movement and displacement along them, termed as *Active Faults* should be identified as the movement along them may cause failure of the bridge founded over faulted rock mass.

iv) Groundwater levels: It is very normal to have groundwater in foundation part of bridge made over a river. The presence of groundwater will result into lowering of shear strength of rocks, increased pore pressure, solution and corrosion of foundation material. If clays are present in rocks (sedimentary rocks) or as alteration product present in joints they may cause swelling in wet conditions and shrinking during dry seasons may lead to differential settling. Similarly, salts may be found in rocks as minor component in association with calcareous rocks; its dissolution will play havoc with time and may result in the failure of bridge. That is why it will not at all be prudent to have bridge foundation over evaporites, a rock full of salts. Some times during the laying of foundation dewatering is done to lower down the groundwater table well below the foundation and moisture still left is drawn out by injecting hot steam through holes or conducting electro-osmosis by installing electrodes into soil or rocks wherein perforated pipes are as anodes and cathodes to collect water.

v) Slope Strength: A bridge in hilly areas over a river will definitely be subjected to problems of mass wasting and mass movement may it be very slow termed as creep or fast termed as landslides. In both the cases different elements of bridge will be in danger. There are many instances when landslide in a river valley results into natural damming of river and formation of natural reservoir. The breach of such reservoirs result into flash floods and many times bridge washouts a common feature in Himachal Pradesh and Jammu and Kashmir. To mitigate this problem we have to employ different methods to strengthen the slope as per the need and economy.

vi) Earthquake: For bridge design first of all one has to take into account the seismic zone in which lies the site. The Peak Ground Acceleration (PGA) and probability of earthquakes of different magnitude based on the history of region needs to be considered. The possible return periods of earthquake for 50, 100, 200 years should also be worked out as long-term measures. Apart from this, seismic dampers such as synthetic sheets or ball bearings are placed between the deck and piers to provide base isolation.

Multiple Choice Questions-

1. Rigid pavements are made using

(a) Earth
(b) Lime
(c) Tar
(d) Concrete

2. Batter for strong rocks such as granite will be

(a) 1:5
(b) 5:1
(c) 2:4
(d) 1:3

3. The safe angle of vertical slope in rocks with batter 1:5 will be

(a) 80°- 90°
(b) 70°- 80°
(c) 10°- 20°
(d) 45°- 55°

4. The best kind of rail ballast will be of rock

(a) Quartzite
(b) Sandstone
(c) Slate
(d) Limestone

5. Which of the rock attitude will provide most favorable slope condition

(a) Vertical Rocks
(b) Rocks dipping in to slope
(c) Rocks dipping away from the slope
(d) Horizontal Rocks

Suggested Readings:

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