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ANGLE OF REPOSE AND SLOPE STABILIZATION IN HIMALAYA

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ABSTRACT

India is a unique geographical country, having all type of topography and climate. Himalaya is major geographical feature of India. About 16.2% of total area of India (5 lacs sq km) is covered by Himalaya. Slope failure, ground shrinking, landslide, avalanches are natural disaster happens due to disturbance in slope angle (angle of Repose). Now days due to international security and best connectivity at higher altitude, road and railways work is under progress and it is observed that frequency of landslide, rock fall increases due to hill cutting. After the hill cutting as per best engineering practices, protect the hill slope. Apart from slope protection, landslide and ground shrinking cases frequently happened. Many landmarked infrastructure projects are failed to maintain the hill slope and facing economic losses. In this paper we have tried to discuss the role of angle of repose on hill stability in view of slope angle, geological strata, vegetation cover, hydrological and climatic factors.

Keywords: Angle Of Repose, Hill Slope, Landslide, Hydrological Factors, Infrastructure Projects, Slope Protection.

I. INTRODUCTION

Every material has natural property to maintaining its slope, depends on grain size and strength. The angle formed between slope and horizontal is called, angle of repose. At this angle, the material on the slope face is on the verge of sliding. The angle of repose can range from 0° to 90°. The angle of repose can also be affected by additions of solvents. Angle of repose is indirectly proposal to particle size.

A material's angle of repose is influenced by other factors such as cohesive forces, friction forces, and steric repulsions. Additionally, liquid bridge formation, electric static charge generation, van der Waals forces, and magnetic forces can also influence the material's cohesiveness. Refer Table 1 and figure 1 for more information about angle of repose with respect to particle size.

Nature Earth has created its own angle of Repose for different topography depending on geological and climatic condition. Variation in external environmental condition, nature Earth trying to maintain its stability and excess mass should remove naturally, called Land/rock slide. Figure 2 & 3 showing the unstable condition.

II. ANGLE OF REPOSE IN HIMALAYA WITH AFFECTING FACTORS

Himalaya is youngest tectonic mountains, formed about 50 million years ago due to collision between the Indian Plate and Eurasian Plate and process is still going on. Geologically Himalaya can be divided on the basis of rock, topography and different fault and thrust; terms as Shiwalik or Outer Himalaya, Lesser or Middle Himalaya, Greater Himalaya and Tethyan Himalaya from South to North direction. Apart from geology, Himalaya has variable climate, height, vegetation, precipitation pattern and other physical factors. The geological challenges are also varies different Himalayan zone wise.

For better understand the geological challenges, summarized the type of rock, average elevation, geological age, average rock class, type of overburden, geological challenges, have comprises in tabular form according to part of Himalaya and shown in south to North direction, given below in table 2.

Table 1: Different material with angle of Repose

Material (condition)	Angle of Repose (degrees)
Ashes	40°
Asphalt (crushed)	30–45°
Chalk	45°

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Clay (dry lump)	25–40°
Clay (wet excavated)	15°
Clover seed	28°
Granite	35–40°
Gravel (crushed stone)	45°
Gravel (natural w/ sand)	25–30°
Sand (dry)	34°
Sand (water filled)	15–30°
Sand (wet)	45°
Snow	38°

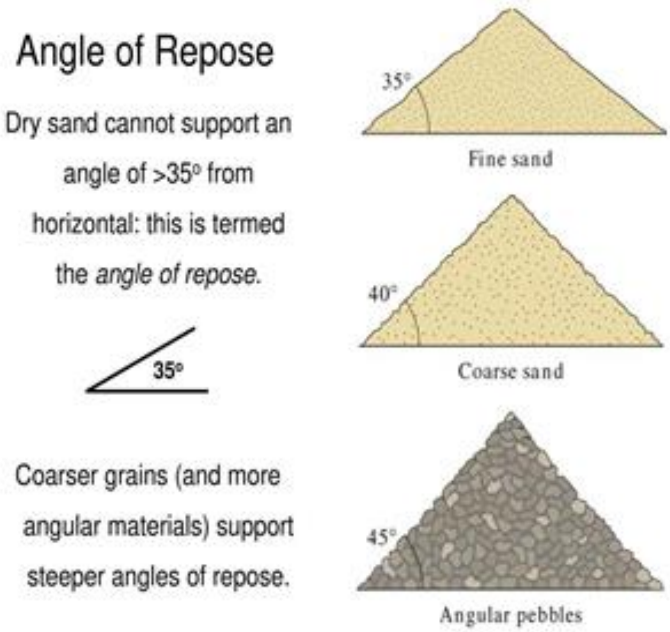

Fig 1: Angle of Repose

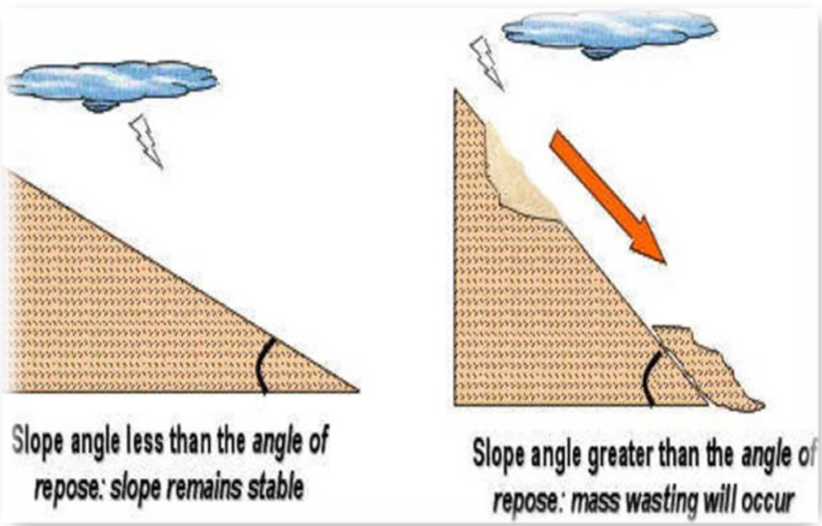

Fig 2: Condition of landslide and role of angle of Repose

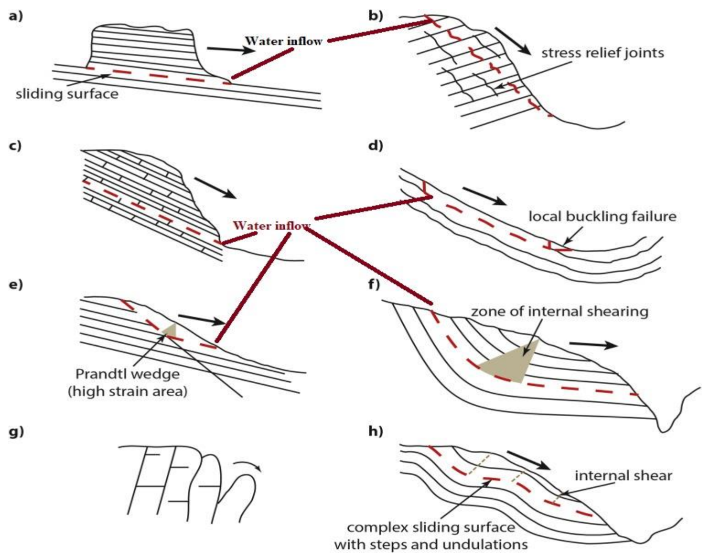

Fig 3: External forces disturbing the stability

Table 2: Features of Indian Himalaya and Geological challenges

S No	Division of Indian Himalaya with geological age	Main Rock type Elevation, hydrology, Vegetation	Average Rock class as per RMR and slope angle	Type of Overburden	Main Geological challenges	Landslide Probability	Remarks
1	Shiwaliks or Outer Himalayas Age: Miocene to recent.	Sedimentary rock (sandstone, Lime stone and mudstone/ claystone). > Monsoon, good drainage system. > Elevation varies from 600 to 1500 meters. > Dense Vegetation	V-III 20°-45°	Consolidated sands, gravels and conglomerate deposits (Alluvial fans) which were brought by the rivers flowing from the higher ranges.	Hill Slope stability, ground subsidence, difficult to get competent rock strength for project component, tunnel collapse, water ingress, shear zone, overburden material protection.	Very High	> Its falling between Himalayan Frontal Fault (HFF) and Main Boundary thrust (MBT).

2	Lesser or Middle Himalayas Age: Paleozoic to Mesozoic	Fold-and-Thrust belt (low-grade, Metasedimentary rocks, Metavolcanic strata and augen gneiss). > Monsoon, good drainage system. > Average Elevations vary from 3500 to 4500 m. > Medium Vegetation.	IV-III 30°-75°	The synclinal basin of the valley is floored with alluvial, lacustrine, fluvial and glacial deposits.	Hill Slope stability, ground subsidence, liquifraction along joints, highly jointed rock, tunnel collapse, tunnel rock burst, water ingress, shear zone, overburden material protection	Very High to High	> Its falling between Main Boundary thrust (MBT) and Main Central thrust (MCT).
3	The Greater Himalaya. Age: Proterozoic-Cambrian	Mainly formed of the central crystallines (granite and gneisses) overlain by metamorphosed sediments schist. > Snowfall, Less precipitation. > An altitude varies from 3000 m to over 8000 m. > Low vegetation mostly grass and small height vegetation.	III-II 45°-65°	The valley is floored with alluvial, fluvial (river action) and glacial deposits (Fluvial Land forms, Glacial Land forms).	Hill Slope stability, liquifraction along joints, highly jointed rock, tunnel collapse, tunnel rock burst, water ingress, shear zone, overburden material protection.	High to Moderate	> Gentle north slope giving a long, steep hill, topography. > Its falling between Main Central thrust (MCT) and South Tibet Detachment Fault (STDF).

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4	The Tethyan Himalaya Age: Cambrian to Eocene	>The Tethyan Himalaya sedimentary units, (sandstone, shale and limestone) which were deposited on the continental shelf of the Tethys Ocean. > Altitude varies from 3000 m to over 8000 m.	IV-III 30°-60°	The valley is floored with alluvial, fluvial (river action) and glacial deposits (Fluvial Land forms, Glacial Land forms)	Hill Slope stability, liquifraction along joints, highly jointed rock, shear zone, tunnel collapse & rock burst, water ingress, shear zone, overburden material protection , Karst topography.	Moderate to Low	> Its falling between South Tibet Detachment Fault (STDF) and Indus Suture Zone (ISZ).

From the table no 2 we can easily observed that angle of Repose in outer Himalaya is 20°-45° as it made up of various sedimentary rock (sandstone, Lime stone and mudstone/ claystone), Lesser or Middle Himalayas having 30°-75° due to made up of low-grade, Metasedimentary rocks, Metavolcanic strata and augen gneiss, the Greater Himalaya is 45°-65° and made up of granite and gneisses overlain by metamorphosed sediments schist and Tethyan Himalaya is 30°-60°and made up of sandstone, shale and limestone. Mandal N et al, 2015 has prepared the topographical slope of Himalaya in various cross section and given below as figure 4, showing that slope are gentle in outer Himalaya. A number of landform elements such as terraces (Bowles and Cowgill, 2012; Demoulin et al., 2007), valley bottoms (Gallant and Dowling, 2003; Straumann and Korup, 2009; Williams et al., 2000), or general landform classification (Dragu and Blaschke, 2006; Klingseisen et al., 2008 and Jan Henrik Blöthe, 2013) of Himalayan river have studies and prepared the topographic gradient map shown in figure 5, which showing the high gradient at Upper part of Outer Himalaya and Middle Himalaya and having very prone to landslide. The Natural slope variation is observed Himalaya due to different material, hydrology, vegetation cover and rainfall pattern.

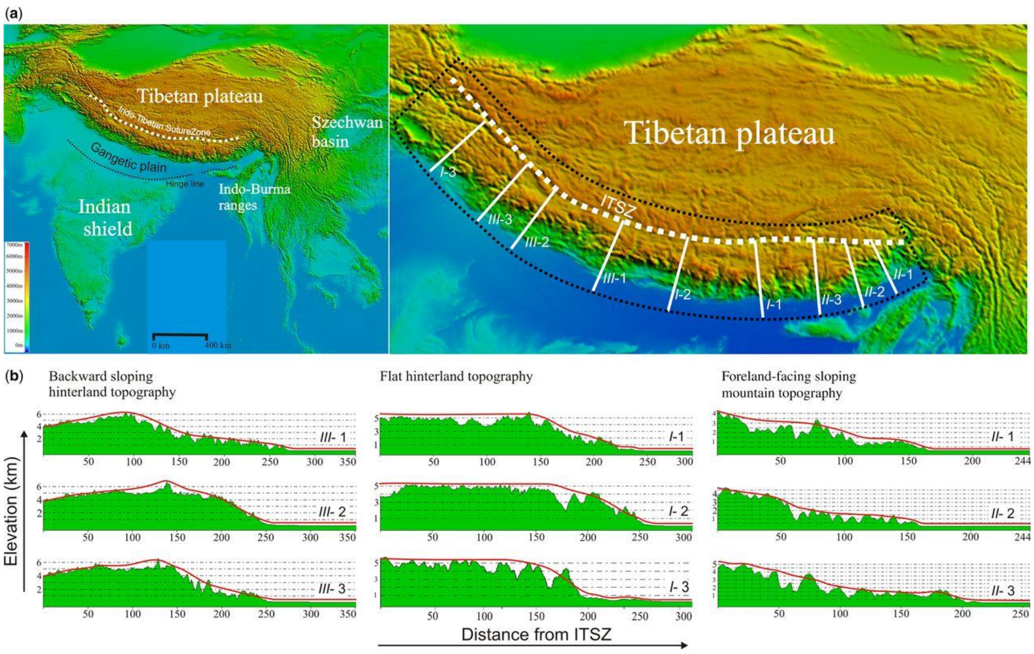

Fig 4: Himalaya Topographical slope (Nibir Mandal et al, 2015)

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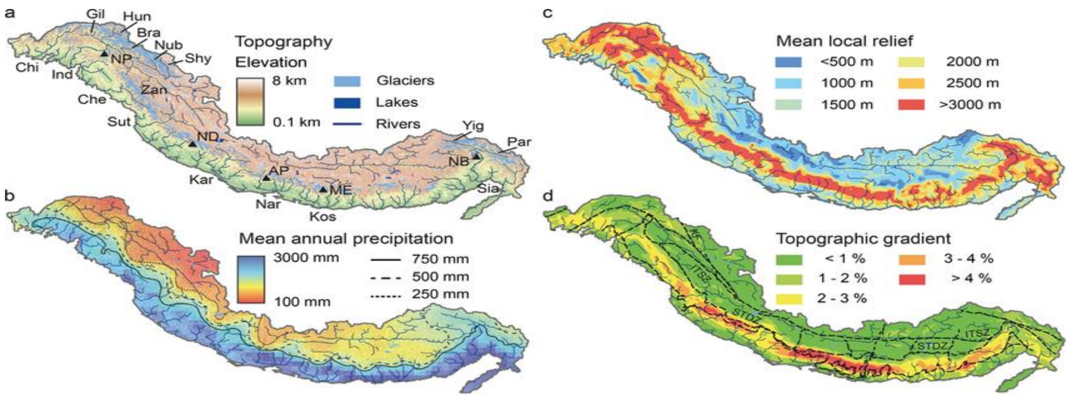

Fig 5: Himalaya topographical features (Jan Henrik B.& Oliver K, 2013)

III. INFRASTRUCTURE PROJECTS AND CHALLENGES IN HIMALAYA

About 5 lacs square kilometer of Indian geographical area (16% to total area) is been covered by Himalaya Mountain belong to 10 states from Jammu & Kashmir to North Eastern states. For better connectivity and national security, government of India has started various infrastructure projects such road, railway, Airports/helipads etc. project in Himalayan region; which comprises of hill cutting, filling the valley areas, tunnels, minor & major bridges etc.

Some Infrastructure projects are listed below:

1. Jammu- Srinagar & Srinagar- Leh Road project (Chennani- Nashri tunnel -9.2 km Completed (more than 1000 m overburden), Benihal- Qazigund road tunnel (Under Pir Penjal range)- 8.5 km (more than 1000 m overburden), and Zojila Tunnel- 14.31 KM and Z-Morh Tunnel- 6.5 km
2. Jammu- Udhampur- Katra- Srinagar-- Kargil-Leh Rail Project (World highest rail bridge on river Chenab- 359 m height from river surface, Bridge length: 1,315 m (4,314 ft), including the 650 m (2,130 ft) long viaduct on the northern side), T-80 tunnel Pir Penjal tunnel length is 10.96 km, under operational. Total 262 kms of approach roads to work site have constructed.
3. Rohtang to Leh road project (Atul tunnel- 9.02 km long at 3,000–3,100 m altitude of tunnel and longest tunnel above 10,000 feet in the world).
4. Bilashpur Leh railway line (Total 458 km long and Taglang La railway station at elevation of 5,359 m i.e. 17,582 ft, and proposed the world highest railway station in this section).
5. Chardam Road and Railway project
6. Sevok- Gangtok Railway project.
7. Two Tunnels at Sela Pass in Arunachal Pradesh
8. Indian Railways Jiribam-Tupul-Imphal line (45 tunnel, longest tunnel is 10.28 km long with world tallest pier height of 141 metre at the valley of river Ijai near Noney).
9. Imphal- Moreh road and Moreh bypass road will facilitate trade with Myanmar.

For propose and construction of infrastructure projects in Himalaya; topographical, geological, remote sensing & aerial imagery interpretation studies used in primary stage and finalized the project components (road, tunnel & bridges alignment) as well as basic civil construction details. Geological mapping along the project alignment helpful in design and planning of hill excavation and slope protection, bridge foundation as well as geotechnical investigation provide the subsurface strata along the project alignment. Hydro geological & meteorological studies should be done for mitigate the project from natural calamities such as landslide, flood, cloud burst etc.

IV. CHALLENGES

During the project finalization stage, project approving authorities have consider the various aspect of project and prefer the best techno-commercial and environmental friendly option and considered the general angle of slope cutting which may be not suitable for the whole project section due to geological strata. Such as Outer Himalaya is made up of Sedimentary rock and highly prone to landslide, angle of repose is 20°-45° but after the hill cutting slope angle becomes more than 60° due to acquired land limitation. In that area, government body proposed for slope protection measures, but slope failure happens in such a large scale that protection measure seems like good for nothing.

Main challenges during hill cutting due to unavailability of land for maintaining angle of repose are following:

- Construction work hampered due continue landslide
- Chances of casualty and damage of man power and machineries
- Local public problem, when slide started beyond the project land
- Delay in project time line and wastage of project funds
- Loss/damage of project and civil structures
- Loss/damage of slope protection measures
- May create disaster during heavy rain in form of shrinking of area, flash flood, mud flow and other.

One conceptual plan is shown in figure 6, considering the hill slope respect to hill cut. Hill natural slope is 44°, hill cut width is 14 m, excavated hill slope is 77° and protected with rock bolt/anchors with breast wall, wire mess and other precautionary measures. Applied slope protection measures are sufficient respect to hill cutting but may not be viable respect to large scale hill slope failure. One gentle angle hill cut has shown along the road are more stable for large scale hill slope failure. Definitely more land required for maintaining the hill slope but we can avoid the probability for the future land mass movement.

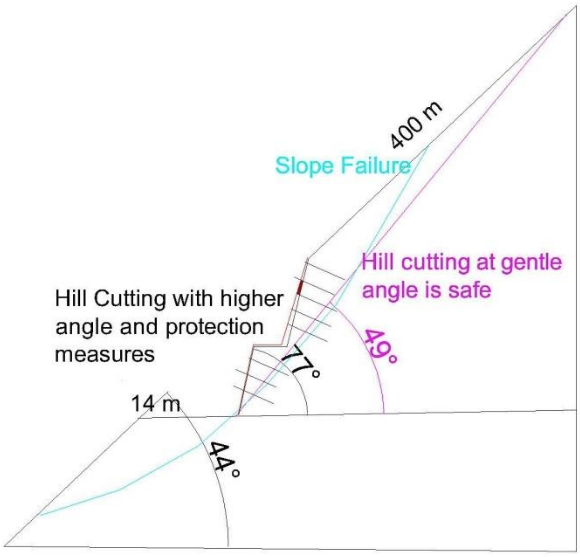

Fig 6: Conceptual plan for gentle hill cutting

Various hill slope failure cases

One best example for failure of slope protection measure is South and North portal of Chenani- Nashri tunnel, where authorities had applied huge slope protection measures but most protection measures are damaged several times apart from slope south portal road is also shrinking due to toe erosion (Figure 8).

Slope failure due to hill cutting with taking all precautionary measures happened worldwide. Fang Wei (2019) has described the slope failure due after taking the all slope protection precautions in Taizaifu Area, Fukuoka, China. Slope failure at Fukuoka, China has shown in figure 9.

Failure Landslide in Char Dham road, Uttarakhand, Paonta-Shilaai road, Sirmore, Himachal Pradesh, Sevok More 29th mile, West Bengal, NH 31 A Rampoo- Sevok road, Sikkim, Gangtok, Sikkim (figure 10) Malli-Jorethang road, Sikkim, Reshi Legship road, West Sikkim and many more landslide in Himalayan region which are happening due unstable slope and geological factors. Many active tectonic faults, folding and sheared zone increased the probability of landslide and slope failure during hill cutting. Ashok K Singh et al (2018) has studied the slope failure along the National Highway (NH)-5 in Jhakri region of Himachal Pradesh, India draws frequent concern due to heavy damage and traffic disruption almost every year, after the detailed

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studied and find that a high vulnerable slope due to steep slope angle. Refer figure 11. If compared with old roads, where hill slope is equal to or less then angle of repose, roads are safe such as Kalka- Simla- Narkanda road, Haldwani – Nainital Road, Siliguri- Darjelling road and other old roads. Slopes are gentle, water channelized and vegetation on slope.

Fig 7: Slope Protection failure at North and South Portal of Chenani- Nashri Tunnel, J&K, India

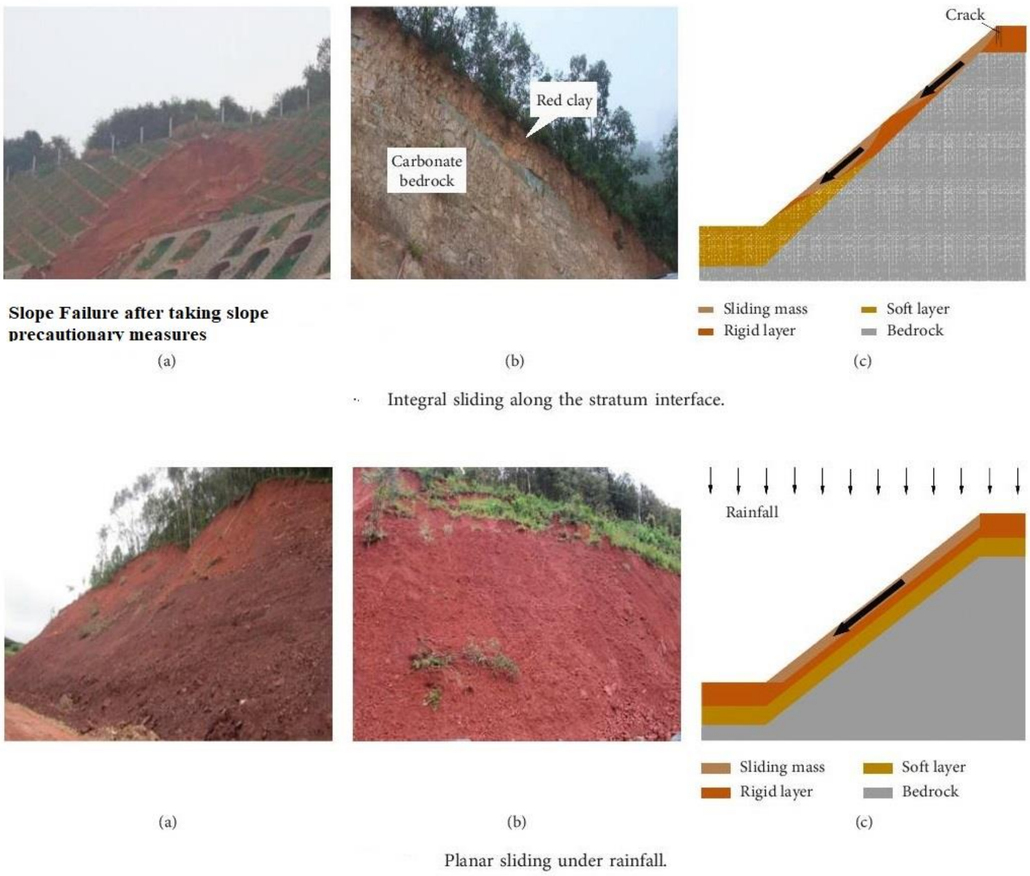

Fig 8: Slope Failure after the hill cutting and slope precautionary measures in Fukuoka, China (Fang Wei, 2019)

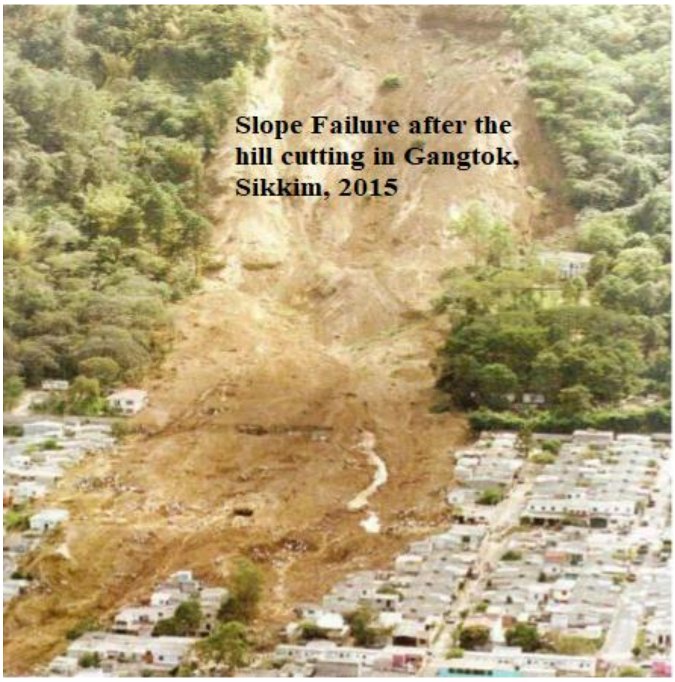

Fig 9: Slope Failure after the hill cutting in Gangtok Sikkim, year 2015.

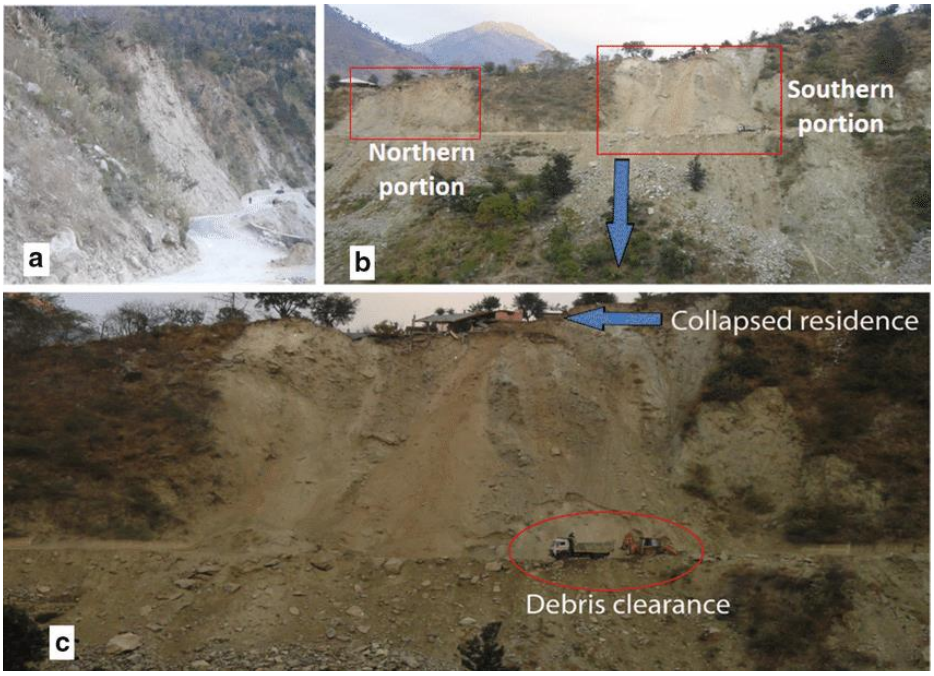

Fig 10: Slope failure due to step angle hill cutting at NH -05 Jhakri, Himachal Pradesh

V. CONCLUSION

Nature has its own engineering and much perfect than modern engineering. Angle of Repose plays important role in natural slope stability. For protection of hill slope we have to maintain sufficient slope angle depends on rock type and geological factors. Slope protection for small area in hilly terrain depends on bedding, joint orientation, ground water flow, vegetation and angle of repose. We have many examples that slope protection is good for nothing if angle of repose is not maintain during hill cutting. It is suggested to be acquired sufficient land for maintains the natural angle of repose (min 45° for outer Himalaya and 60° for Middle Himalaya) by the authorities. Less land acquisition is cheaper during initial stage of project but challenges faced during the construction and operational stage of project become much higher. Modern engineering have to understand the hidden cost of landslide and maintenance cost with respect to time and take early steps regarding angle of repose in developing infrastructure projects in Hill area.

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