BEFORE THE NATIONAL GREEN TRIBUNAL

SOUTHERN ZONE, CHENNAI

ORIGINAL APPLICATION NO. 261/2024
[EARLIER O.A. NO. 1055/2024 (PB)] .

IN THE MATTER OF;-

Suo Moto matter in respect of news item appearing in The Indian Express dated 02.08.2024 titled "Unscientific work by NHAI led to Shirur landslide, Geological survey of India report" ...APPLICANT

Versus

National Highway Authority of India and Others ..RESPONDENTS

Next Date. 18/02/2026

INDEX

Sr.No	Description	Pages No.
1.	Report on Behalf of Respondent No. 5 (Karnataka State Disaster Management Authority).	1-11
2.	**ANNEXURE-R-1** True Cupy of The Report of the GSI.	12-23
3.	**ANNEXURE-R-2** True Copy The details of types of landslides and causes of landslides in Karnataka.	24-28
4.	**ANNEXURE-R-3** True Copy The details Major causative factor for landslide in Karnataka.	29-33
5.	**ANNEXURE-R-4** True Copy Expert Committee Report on Cost-Effective Long-Term Remedial Measures for Landslide-Prone Areas in Hilly Regions,"	34-96

New Delhi **Filled By: -**

Date: - 18/02/2026

(Mr. DARPAN KM Adv.)
Advocate for the Respondent No.5
Kar/1053/2009.
Office K-6, LGF,Lajpat Nagar-3,
New Delhi - 110024
Mob. 9899125060/9968638862

BEFORE THE NATIONAL GREEN TRIBUNAL
SOUTHERN ZONE BENCH AT CHENNAI
ORIGINAL APPLICATION NO. 261/2024
[EARLIER O.A. NO. 1055/2024 (PB)]

IN THE MATTER OF:

Suo Moto matter in respect of news item appearing in The Indian Express dated 02.08.2024 titled "***Unscientific work by NHAI led to Shirur landslide, Geological survey of India report***"

AND

National highway authority of India and Others …Respondents

REPORT ON BEHALF OF RESPONDENT NO. 5 (KARNATAKA STATE DISASTER MANAGEMENT AUTHORITY)

MOST RESPECTFULLY SHOWETH:

1. That the instant report is being filed pursuant to the order dated 08.09.2025 by way of which this Hon'ble Tribunal in exercise of its *suo moto* powers impleaded the answering Respondent. It is submitted that Karnataka experienced around 86 incidents of varying intensities of landslides, debris flows, and mudflows during July-August 2024. The human casualties due to these landslides were primarily linked to unscientific slope stabilization along National Highway 66. In total, 10 fatalities were reported: 9 in Shiruru (with 2 people still missing) and 1 in Udupi district.

2. **Brief on Shiruru landslide Incident:** From July 1st to July 23rd, Uttara Kannada district recorded 1,389 mm of rainfall, significantly higher than the normal of 751 mm, which is departure of +85%. It is pertinent to note

that Uttara Kannada district typically experiences high rainfall, so an 85% departure translates into a substantial amount of continuous rain over 20 days. The Ankola taluk recorded extremely heavy rainfall of 275 mm on 16the July. The heavy rainfall was also accompanied by strong winds triggering a landslide incident at Shiruru village, Vasarakudrigi village panchayat. Ankola Taluk, Uttara Kannada district. that occurred on 16th July 2024 at approximately 08:30 Hrs. The landslide occurred on the road next to Bommaiah temple by National Highway-66. The precise location of the event is at the left-hand side of Chainage number 148.000 (14.603554°N / 74.371219°E) of NH-66. The landslide was characterized as a deep rotational debris flow with approximate dimensions: Length - 110m, Width - 130m, and Height - 50m. The landslide event obstructed communication through the National Highway-66, with a runout distance exceeding 150m, depositing debris material into the river channel.

a. The heavy influx of debris swept away one fully loaded HP tanker which was fully loaded with LPG gas and fully loaded Benz truck into the adjoining Gangavali river. A total of 11 people lost their lives due to the landslide in Shirur Village.

b. **Expert report on the incident:** The Geological Survey of India, which is the nodal Government agency for landslide studies, investigated the landslide slide on the 17th and 18th of July, with the primary aims of understanding the geogenic causes of the landslide. As per the preliminary report submitted by the GSI submitted on 19th July 2024 "***The steep gradient of the cut slope, presence of highly weathered rock, thick debris, saturation due to rainfall, and lack of toe support are the primary causative factors of the debris flow.***" In essence, the heavy rainfall induced landslide was result of unscientific slope modification by the NHAI.

3. The gist of the GSI preliminary report is as follows:

General Observations about the site:

- The site has a very thick weathered rock and in-situ clay-rich lateritic soil (having thickness ranging from 5-15m) exposed by slope cutting.
- The pyroxenite rock in the area is highly weathered, topped by a thick soil cover. The fresh pyroxenite rock exposed at the toe tapers, providing minimal natural toe buttress or support for the slid zone.
- Natural drainage flows have been disturbed due to slope modifications. The slide area and the left flank are structurally deformed, presenting friable and gouge-like material.
- The landslide movement is extremely rapid and currently active, with the potential for enlargement.
- The adjoining slope on the right of the landslide has a gradient of approximately 40° without benches. Fresh tension cracks present in this area may lead to failure in case of continuous rainfall. The debris thickness here is also considerable. Tension cracks of 2 feet depth were observed in the left flank also.
- Multi-temporal satellite imagery indicates anthropogenic interference on the slopes from Chainage number 147.400 to 148.200 since 2017, with some landslide scars above the cut slopes.
- The 3-day antecedent rainfall in the area was 503 mm, causing saturation of the thick debris material and lithomarge, thereby increasing pore water pressure.
- The steep gradient of the cut slope, presence of highly weathered rock, thick debris, saturation due to rainfall, and lack of toe support are the primary

causative factors of the debris flow. Intense rainfall acted as the trigger for the landslide.

- The high relief and overburden material in the hill slope suggest that retrogression of the slide is probable during prolonged rainfall.

4. Geo-technical cause for the landslide:

- The site has a very thick weathered rock and in-situ clay-rich lateritic soil exposed by slope cutting.
- The pyroxenite rock in the area is highly weathered, topped by a thick soil cover. The fresh pyroxenite rock exposed at the toe tapers, providing minimal natural toe buttress or support for the slid zone.
- Natural drainage flows have been disturbed due to slope modifications.
- The slide area and the left flank are structurally deformed, presenting friable and gouge-like material.
- The steep gradient of the cut slope, presence of highly weathered rock, thick debris, saturation due to rainfall, and lack of toe support are the primary causative factors of the debris flow.

5. Long term remedial measures suggested by GSI:

- The gradient at the slope sector from 147.400 to 148.200 should adhere strictly to BIS codes for slope gradient with benching, based on the geotechnical properties of the soil. The bench width should enable the slope segments to act independently, as prescribed in IS code 14680:1999.
- Benches should be provided with lined ditches or drainage to reduce erosion and infiltration along with slope reinforcement measures.
- The natural drainage path is modified due to extensive slope cutting at the site. A culvert with sufficient diameter pre-cast pipes should be provided to

accommodate water and debris discharge at the toe of the landslide at Ch. No. 148.000.

- Monitor for tension cracks and possible displacement of slope material at the crown area.
- Given the excess subsurface water flow, engineered slopes should include provisions to drain subsurface water, such as perforated horizontal pipes of appropriate diameter, depending on site conditions.
- A comprehensive geotechnical investigation is recommended to determine appropriate slope stabilization strategies for the Shirur site.

The report of the GSI is annexed as annexure 1.

6. Incidences of landslides adjoining to National Highway during the Southwest Monsoon of 2024: One mudslide/landslide occurred on National Highway-69 between Sagara and Honnavara, nine incidents were reported along the Hassan to Mangaluru stretch of National Highway-75, and 25 mudslide/landslide incidents were recorded along National Highway-66 between Mangaluru and Karwar. This includes the major landslide event in Shirur village, detailed earlier.Repeated mudslides and landslides occurred at Shiradi Ghat, Doddathappale village in Heggade, along NH-75 in Hassan district, between 16th July and 31st July 2024. The specific location of the event was at Chainage 234.700 (12.897142°N, 75.732455°E) on National Highway-75. Notably, the major landslides during the 2024 Southwest Monsoon were adjacent to national highways, with the primary cause attributed to unscientific slope stabilization.
7. Geological Survey of India, Government of India is the nodal agency for landslide studies in the country. Since FS 2014-15, GSI has launched and undertook a national programme on landslide susceptibility mapping – Macro-scale (1:50,000)

National Landslide Susceptibility Mapping (NLSM) with an aim to cover the 0.42 million sq. km landslide prone areas of the country. GSI prepared GIS-based seamless Landslide Susceptibility Maps of India on 1:50,000 scale and submitted the following reports to Government of Karnataka during May 2024. Based on National Landslide Susceptibility Mapping (NLSM) by GSI, list of landslide susceptible Gramapanchayats in Coastal (Dakshina Kannada, Udupi and Uttara Kannada) and Malnad (Kodagu, Hassan, Chikkamagalur and Shivamogga) Districts were identified. The details of types of landslides and causes of landslides in Karnataka is annexed as **Annexure 2.**

1. **Macro-Scale (1:50,000) Reports (26 Reports)**
   https://www.ksndmc.org/Default.aspx/Downloads/GeoSurveyMacroscale

2. **Meso-Scale (1:10,000) Reports (14 Reports)**
   https://www.ksndmc.org/Default.aspx/Downloads/GeoSurveyMesoscale

3. **Post Disaster Landslide Studies Reports (13 Reports)**
   https://www.ksndmc.org/Default.aspx/Downloads/GSIPDLS

4. **Site Specific Studies (4 Reports)**
   https://www.ksndmc.org/Default.aspx/Downloads/GSISitespecific

Based on the above, Landslide Susceptible zones for Karnataka is classified as follows:

Details of Total Landslide Prone area in Karnataka

Sl. No	**Landslide Susceptibility**	**Area in sq.km***
1	High Susceptibility	1163.8
2	Moderate Susceptibility	5385.0
3	Low Susceptibility	24682.2
	Total	**31,231.0**

*** Source:** Geological Survey of India, GoI
Link: **https://bhukosh.gsi.gov.in/Bhukosh/Public**

8. LANDSLIDE ON NATIONAL HIGHWAYS

Widening of National Highways in Karnataka is an important developmental project. The highway passes through Coastal (Dakshina Kannada, Uttara Kannada and Udupi) and Malnad (Kodagu, Hassan, Chikkamagalur and Shivamogga) districts are frequently affected by landslides at various places. The landslide occurred information on along National Highways from2006 to 2024 are shown below.

Sl No	National Highway	Stretch	Landslide Numbers
1	NH- 66	Mangalore to Goa	61
2	NH-75	Mangalore to Hassan	23
3	NH-73	Mangalore to Mudigere	98
4	NH-169	Mangalore to Shivamogga	30
5	NH-69	Honnavara to Shivamogga	56
6	NH-52	Ankola to Yellapur	19
7	NH-275	Mangalore to Madikeri	82

Source GSI and KSNDMC

9. **Major causative factor for landslide in Karnataka The details are annexed in Annexure 3.**

10.LANDSLIDE EARLYWARNING SYSTEM

LANDSLIDE BULLETIN BY GEOLOGICAL SURVEY OF INDIA

Geological Survey of India initiated issuing Experimental Regional Scale Rainfall Based Landslide bulletin internally on testing mode for Kodagu district. Following validation of experimental landslide bulleting, the rainfall based landslide bulletin will be given to all landslide vulnerable districts in Karnataka.

11.COLLABORATIVE STUDIES ON LANDSLIDE EARLY WARNING

Karnataka State Natural Disaster Monitoring Center (KSNDMC) is carrying out collaborative studies on landslide in Karnataka with the Geological Survey of India (GSI), National Institute of Rock Mechanics (NIRM) and Amritha Vishwa Vidapeetham.

Sl No	Organisation	Topic	Status
1	Geological Survey of India, Govt. of India	Development of an experimental rainfall threshold-based regional landslide forecasting system for Kodagu district	➢ Pre-field work of collection of landslide inventory data done from various other sources and GSI reports were completed. ➢ Risk assessment of vulnerable wards/ villages are been carried out for Kodagu district. ➢ Collection of Rainfall data for rainfall threshold analysis collected from KSNDMC ➢ GSI has started issuing experimental Rainfall bulletin internally on testing mode. ➢ KSNDMC shared the historical rainfall data to Chikkamagalur and Dakshina Kannada districts to include for

Sl No	Organisation	Topic	Status
			landslide forecasting system
2	National Institute of Rock Mechanics, Govt. of India	Landslide Early Warning system (LEWS) in Chikkamagalur district	➢ 8 villages has been identified by District Administration to take up LEWS. ➢ In phase Gudde Thota village area and Kunkalamane village area are taken up for the detailed investigation. ➢ As the vulnerable sites, require detailed investigations for scientific stability measures, detailed techno commercial proposal will be submitted by NIRM in accordance to the prioritization by KSNDMC and enquiry for the detailed investigations.
3	Amrita Vishwa Vidyapeetham, Kerala	Landslide Early Warning system (LEWS) in Kodagu district	➢ Dynamic risk map for Kodagu. ➢ Landslide Hazard Management Solutions for Kodagu district, Karnataka

12. Landslide mitigation projects: Landslide mitigation projects are taken up in most vulnerable landslide prone village/area under State Disaster Mitigation Fund (SDMF) and National Disaster Mitigation Fund (NDMF). The proposals are formulated in consultation with Geological Survey of India (GSI):

Abstract of the project proposals and estimation is as follows:

Sl No	District	No. of works	Estimated Amount (in.crore)
1	Chikkamagalur	146	66.47
2	Dakshina Kannada	213	85.00
3	Kodagu	104	38.61
4	Shivamogga	84	95.30
5	Udupi	19	17.92
6	Uttar Kannada	99	100.00
7	Hassan	55	63.63
Total		**720**	**466.93**

13.**NHAI mandate on Disaster Risk Reduction:** Sections 36 of the Disaster Management Act, 2005, read with the Disaster Management (Amendment) Act, 2025, specifies the responsibility of the Ministries or Department of the Government of India in regard to prevention, mitigation, preparedness and response pertaining to Disaster Management. Further, Sections 37 of the Disaster Management Act, 2005, read with the Disaster Management (Amendment) Act, 2025, mandates every Ministry and Department of the Government of India to formulate a disaster management plan and to integrate mitigation measures into all development plans. The Ministry of Road Transport & Highways, vide Office Memorandum dated 28th November 2024, has issued the **"Expert Committee Report on Cost-Effective Long-Term Remedial Measures for Landslide-Prone Areas in Hilly Regions,"** which is enclosed as Annexure-4.

14. It is submitted that NHAI is required to scrupulously adhere to the scientific procedures and guidelines set out in the said Expert Committee report to mitigate development-induced landslides and to ensure the integration of Disaster Risk Reduction into all its works.

(HONNAMBA S, IAS)
Commissioner KSDMA & SSP,
Revenue Department

Filed by

Darpan KM
Standing Counsel
State of Karnataka

Date: 17.02.2026

Annexure- I

भारत सरकार
GOVERNMENT OF INDIA
भारतीय भूवैज्ञानिक सर्वेक्षण
GEOLOGICAL SURVEY OF INDIA

Note on the preliminary assessment of landslide at Shirur, Uttara Kannada District, Karnataka, India

एम4एलएस/ एनसी/एसआर/एसमू- केजी/2024/50072
M4LS/NC/SR/SU-KG/2024/50072

कायय सत्र 2024-25
Field season 2024-25

Engg. Geology & Landslide Division
State Unit: Karnataka & Goa
Southern Region

July 2024

Preliminary Note on Shirur Landslide, Uttara Kannada District, Karnataka, India.

Introduction:

The landslide incident at Shirur village, Ankola Taluk, in Uttara Kannada district occurred on 16th July 2024 at approximately 08:30 Hrs. The location of the event is at the left-hand side of Chainage number 148.000 (14.603554°N / 74.371219°E) of NH-66 (**Fig.1**). The landslide is characterized as a deep rotational debris flow with approximate dimensions: Length - 110m, Width - 130m, and Height - 50m. This event obstructed communication through the National Highway, with a runout distance exceeding 150m, depositing debris material into the river channel. Local reports indicate that the substantial volume of debris influx into the river caused an impact wave, resulting in the destruction of four houses on the opposite bank.

The Geological Survey of India investigated the landslide on the 17th and 18th of July, with the primary aims of understanding the geogenic causes of the landslide, assessing the potential for reactivation, and developing temporary remedial measures to restore communication, which can be implemented by the district administration.

NH-66, which passes through the area, makes a left bend at Shirur village and runs parallel to the right bank of the Gangavali River until the Gangavali highway bridge. To facilitate four-lane traffic, the hill slopes in this road section had to be modified. Satellite imagery from Google Earth (**Fig.2**) shows that slope modifications have been initiated in the area since 2017, with modifications up to 40m in height. Local reports indicate that the location of the Shirur landslide was modified with benches measuring 6m x 2m.

Geology and Geomorphology:

The area is part of the Western Ghat mountain ranges and exposes rocks of the Archean age. The rock type at the site is Pyroxenite of the Motimakki Ultramafites, overlain by a thick weathered horizon and soil layer. The hill slope near the landslide is a low dissected hill with an elevation difference of approximately 200m from the ridge top to bottom. Morphometrically, the slope angle ranges from 30° to 40° (**Fig. 3**). The drainage pattern is dendritic, with the drainage map of the study area, prepared from DEM, showing a few first-order drainages along the hill slope.

Susceptibility Status as per NLSM:

The slope sector from Chainage number 147.400 to 148.200 shows Moderate to High susceptibility according to the National Landslide Susceptibility Map of the Geological Survey of India (**Fig. 4**).

General Observations:

- The site has a very thick weathered rock and in-situ clay-rich lateritic soil (having thickness ranging from 5-15m) exposed by slope cutting.
- The pyroxenite rock in the area is highly weathered, topped by a thick soil cover. The fresh pyroxenite rock exposed at the toe tapers, providing minimal natural toe buttress or support for the slid zone.
- Natural drainage flows have been disturbed due to slope modifications.
- The slide area and the left flank are structurally deformed, presenting friable and gouge-like material.
- The landslide movement is extremely rapid and currently active, with the potential for enlargement.
- The adjoining slope on the right of the landslide has a gradient of approximately 40° without benches. Fresh tension cracks present in this area may lead to failure in case of continuous rainfall (**Fig. 5**). The debris thickness here is also considerable. Tension cracks of 2 feet depth were observed in the left flank also (**Fig. 6**).
- Multi-temporal satellite imagery indicates anthropogenic interference on the slopes from Chainage number 147.400 to 148.200 since 2017, with some landslide scars above the cut slopes.
- The 3-day antecedent rainfall in the area was 503 mm, causing saturation of the thick debris material and lithomarge, thereby increasing pore water pressure.
- **The steep gradient of the cut slope, presence of highly weathered rock, thick debris, saturation due to rainfall, and lack of toe support are the primary causative factors of the debris flow**. Intense rainfall acted as the trigger for the landslide.
- The high relief and overburden material in the hill slope suggest that retrogression of the slide is probable during prolonged rainfall.

Immediate Measures:

- Clear the debris in a phased approach, beginning with the lower sections. Use heavy machinery carefully to avoid disturbing the upslope. Employ spotters to monitor any slope movement. Vehicular traffic at night may be restricted/halted till the landslide site stabilizes.
- Refrain from removing debris material, including large boulders, on the hillward side below the landslide for the time being.
- Construct temporary channels to divert water away from the debris-clearing area to prevent further destabilization.
- No further modifications should be made to the hillward slope.

- Debris material may be cautiously removed only from the outer lane of the road. Traffic may resume in the outer lane after debris clearance. Continuous monitoring of the slope using spotters is crucial, and vehicular movement must be halted if any slope movement is detected, especially during prolonged rainfall.

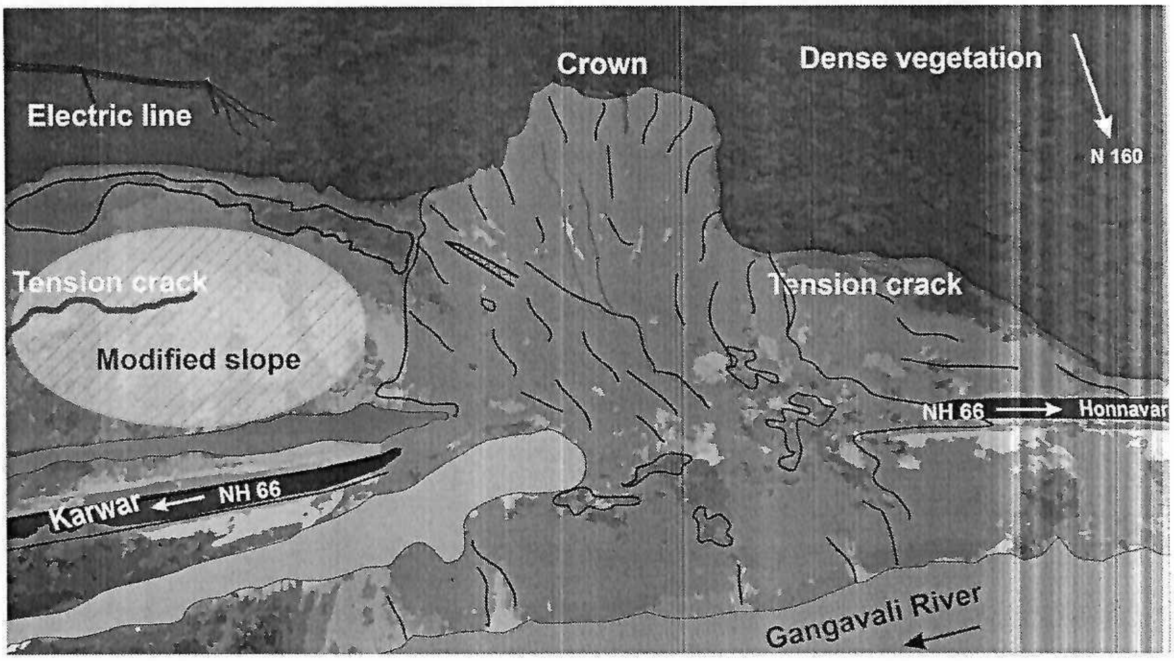


Fig.1: Schematic diagram of Shirur landslide (not to scale)

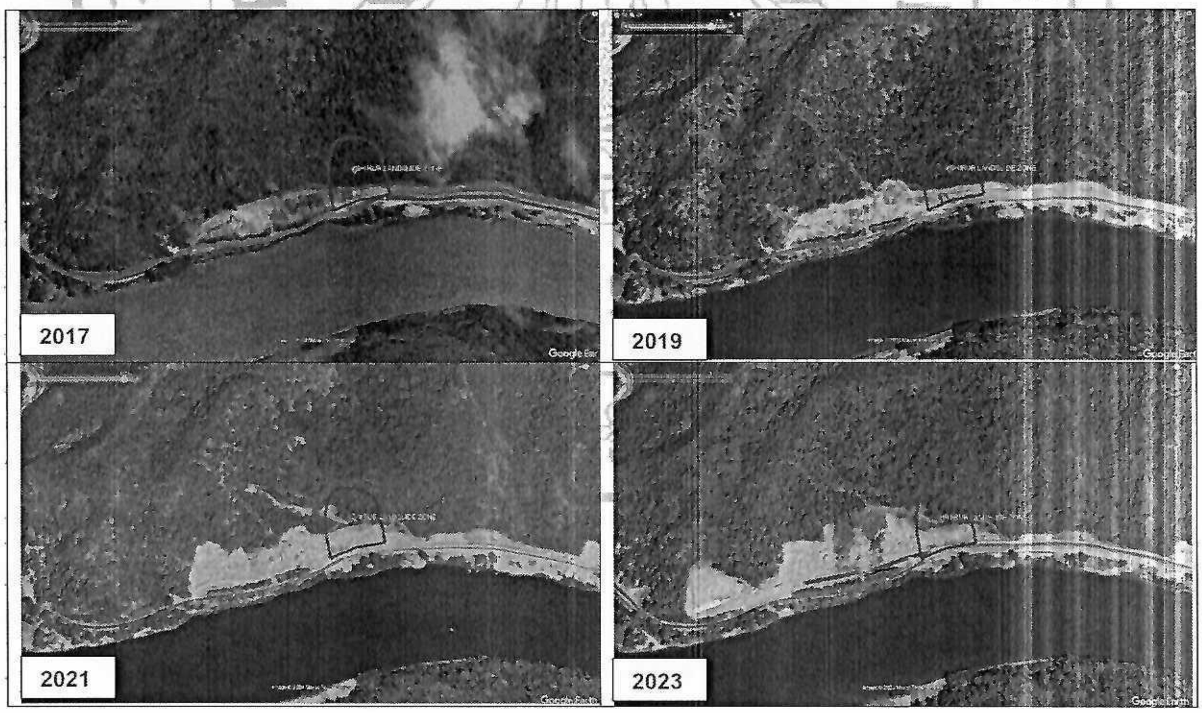


Fig.2 Multi-temporal satellite imageries of the landslide zone.

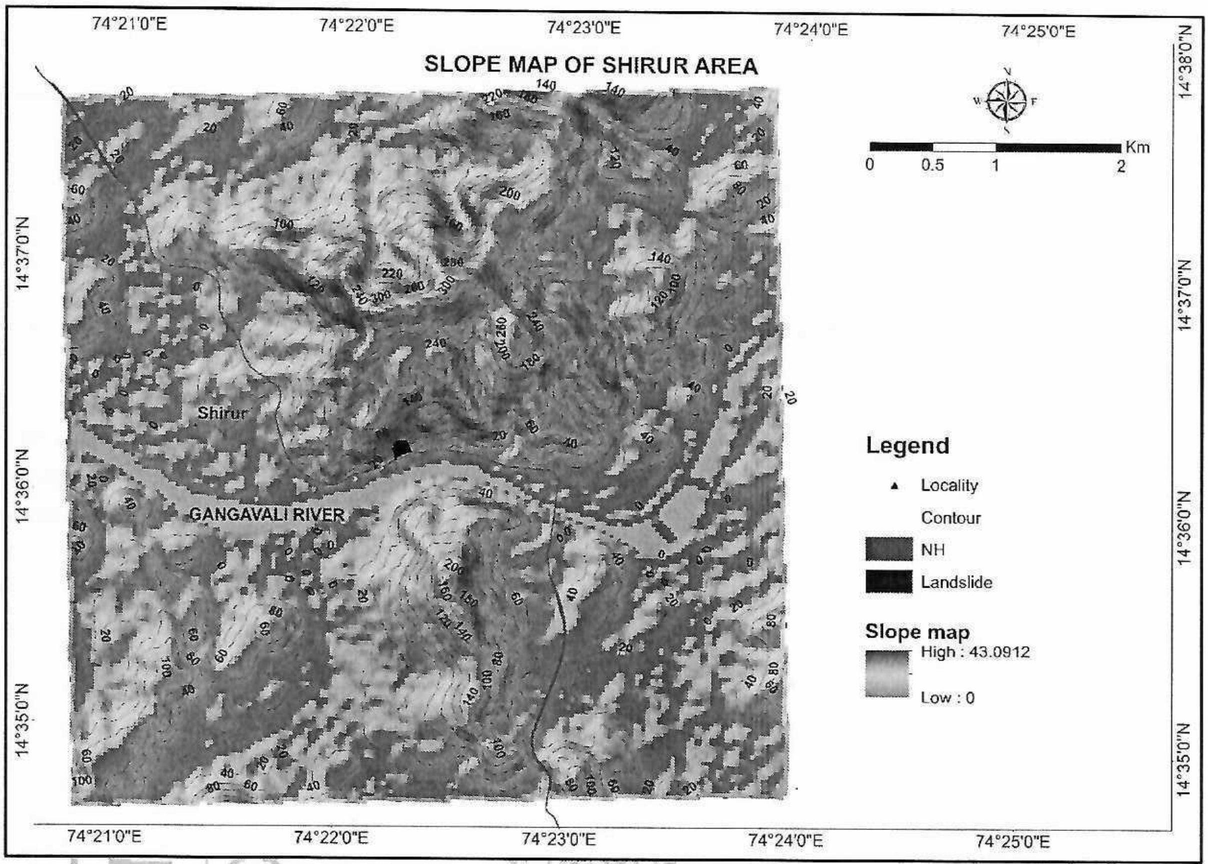


Fig. 3. Slope map of Shirur area derived from SRTM DEM

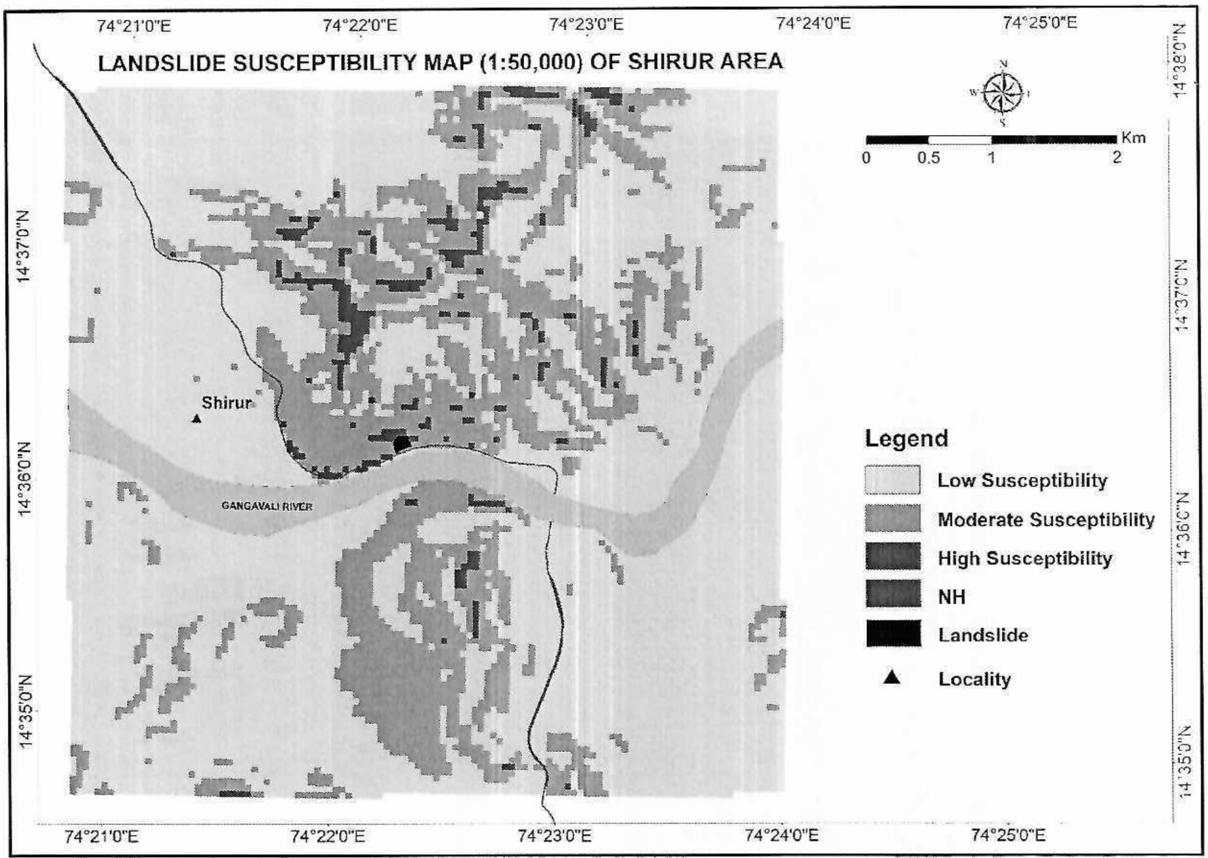


Fig. 4 National Landslide Susceptibility Map of Shirur area, (NLSM GSI)

Fig. 5 Transverse cracks on the right flank of the landslide

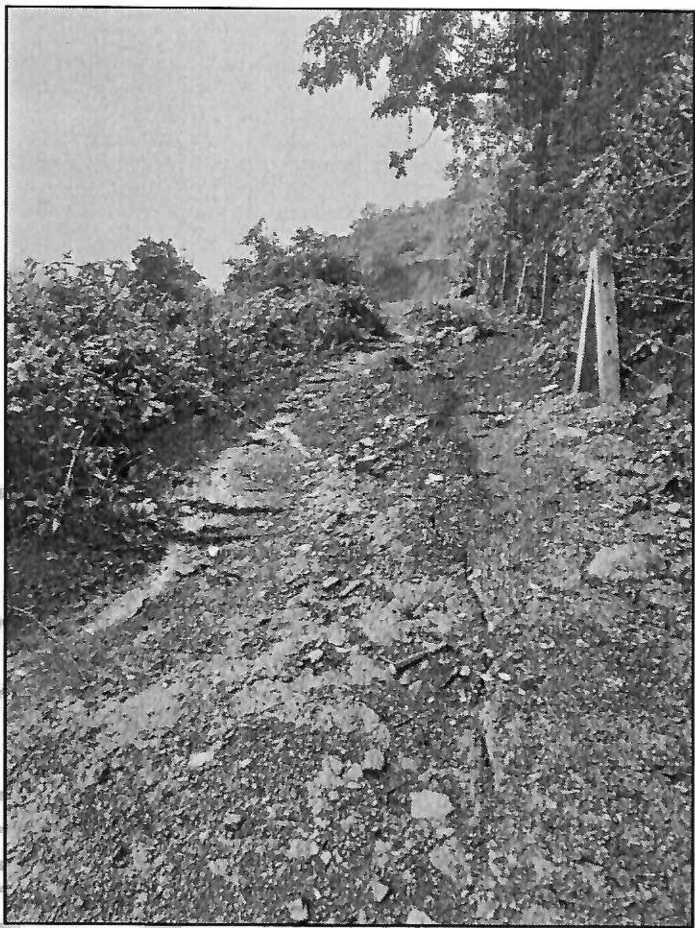


Fig. 6 Transverse cracks on the left flank of the landslide

Long-term Measures:

- The gradient at the slope sector from 147.400 to 148.200 should adhere strictly to BIS codes for slope gradient with benching, based on the geotechnical properties of the soil. The bench width should enable the slope segments to act independently, as prescribed in IS code 14680:1999.
- Benches should be provided with lined ditches or drainage to reduce erosion and infiltration along with slope reinforcement measures.
- The natural drainage path is modified due to extensive slope cutting at the site. A culvert with sufficient diameter pre-cast pipes should be provided to accommodate water and debris discharge at the toe of the landslide at Ch. No. 148.000.
- Monitor for tension cracks and possible displacement of slope material at the crown area.

- Given the excess subsurface water flow, engineered slopes should include provisions to drain subsurface water, such as perforated horizontal pipes of appropriate diameter, depending on site conditions.
- A comprehensive geotechnical investigation is recommended to determine appropriate slope stabilization strategies for the Shirur site.

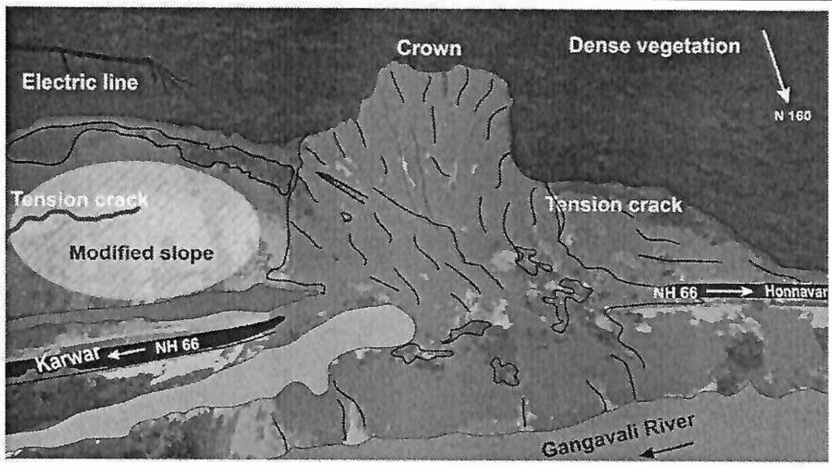
Annexure - I

No	Field	Description
1	Slide No (LS .No.)	KA/UK/48J06/2024/01
2	State	Karnataka
3	District	Uttara Kannada
4	Toposheet	48J06
5	Name of the slide	Shirur Slide
6	NH/SH/Locality	NH-66
7	Latitude	14.603554° N
8	Longitude	74.371219° E
9	Length	110m
10	Width	130m
11	Height	~50m
12	Area	~13000m^2
13	Depth	~10m
14	Volume	~1,30,000m^3
15	Run out distance	170 m
16	Type of Material	Debris
17	Type of movement	Flow
18	Rate of movement	Extremely Rapid
19	Activity	Active
20	Distribution	Enlarging
21	Style	Single
22	Failure mechanism	Deep rotational failure
23	History	Initiation-16-07-2024, 08:00 am
24	Geomorphology	Low dissected hill
25	Geology	Pyroxenite
26	Structure	Foliation - 210°/45°; J1- 35°:30°; J2 – 80°:295°; J3 - 80°:230°
27	Land use/ Land cover	Dense vegetation
28	Hydrological condition	Flowing
29	Triggering Factor	Rainfall
30	Death of persons	7 at the time of investigation
31	People affected	4 people critically injured on the opposite bank
32	Live-stock loss	NA
33	Communication	Road blockage
34	Infrastructure	Road damaged, 4 houses destroyed, one tea stall washed away, two high tension power transmission towers destroyed, two trucks washed away
35	Agriculture/forest/Barren	Forest

Annexure - I

36	Geo-scientific Causes	1. The site has a very thick weathered rock and in-situ clay-rich lateritic soil exposed by slope cutting. 2. The pyroxenite rock in the area is highly weathered, topped by a thick soil cover. The fresh pyroxenite rock exposed at the toe tapers, providing minimal natural toe buttress or support for the slid zone. 3. Natural drainage flows have been disturbed due to slope modifications. 4. The slide area and the left flank are structurally deformed, presenting friable and gouge-like material. 5. ***The steep gradient of the cut slope, presence of highly weathered rock, thick debris, saturation due to rainfall, and lack of toe support are the primary causative factors of the debris flow***
37	Remedial measures	**Immediate Measures:** ▪ Clear the debris in a phased approach, beginning with the lower sections. Use heavy machinery carefully to avoid disturbing the upslope. Employ spotters to monitor any slope movement. ▪ Refrain from removing debris material, including large boulders, on the hillward side below the landslide for the time being. ▪ Construct temporary channels to divert water away from the debris-clearing area to prevent further destabilization. ▪ No further modifications should be made to the hillward slope. ▪ Debris material may be cautiously removed only from the outer lane of the road. Traffic may resume in the outer lane after debris clearance. Continuous monitoring of the slope using spotters is crucial, and vehicular movement must be halted if any slope movement is detected, especially during prolonged rainfall. **Long-term Measures:** ▪ The gradient at the slope sector from 147.400 to 148.200 should adhere strictly to BIS codes for slope gradient with benching, based on the geotechnical properties of the soil. The

Annexure - I

		bench width should enable the slope segments to act independently, as prescribed in IS code 14680:1999. ▪ Benches should be provided with lined ditches or drainage to reduce erosion and infiltration along with slope reinforcement measures. ▪ The natural drainage path is modified due to extensive slope cutting at the site. A culvert with sufficient diameter pre-cast pipes should be provided to accommodate water and debris discharge at the toe of the landslide at Ch. No. 148.000. ▪ Monitor for tension cracks and possible displacement of slope material at the crown area. ▪ Given the excess subsurface water flow, engineered slopes should include provisions to drain subsurface water, such as perforated horizontal pipes of appropriate diameter, depending on site conditions. ▪ A comprehensive geotechnical investigation is recommended to determine appropriate slope stabilization strategies for the Shirur site.
38	Remarks, if any	
39	Photos. Sketch of Plan & section of the slide	
40	Summary/Abstract	*The landslide incident at Shirur village, Ankola Taluk, in Uttara Kannada district occurred on 16th July 2024 at approximately 08:30 Hrs. The steep gradient of the cut slope, presence of highly weathered rock, thick debris, saturation due to rainfall, and lack of toe support are the primary causative factors of the debris flow. As immediate measure*

Annexure - I

		Clear the debris in a phased approach, beginning with the lower sections. Use heavy machinery carefully to avoid disturbing the upslope. Employ spotters to monitor any slope movement. A comprehensive geotechnical investigation is recommended to determine appropriate slope stabilization strategies for the Shirur site.
41	Pdf	Attached
42	Landslide category	I

Annexure - II

1. TYPES OF LANDSLIDES:

Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In low-relief areas, landslides occur as cut-and fill failures (roadway and building excavations), river bluff failures, lateral spreading landslides, collapse of mine-waste piles (especially coal), and a wide variety of slope failures associated with quarries and open-pit mines. The most common types of landslides are described as follows.

Table 1: Types of landslides (Varnes, 1978)

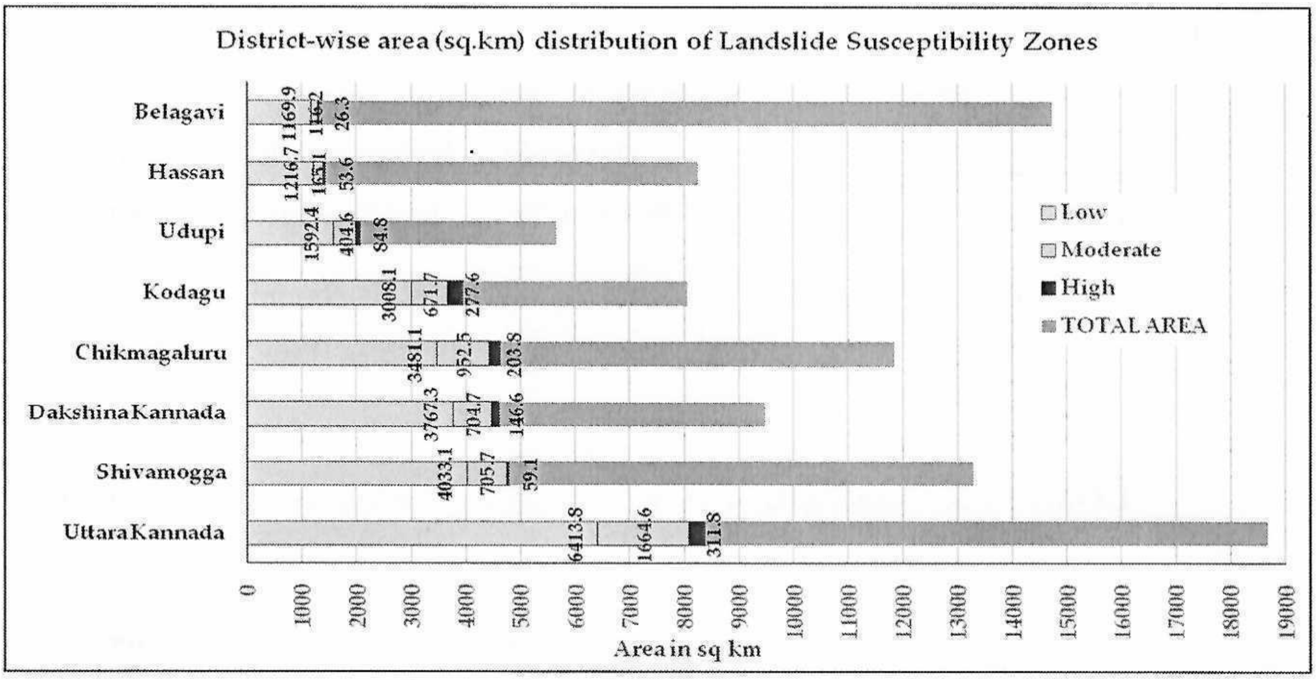
		TYPE OF MATERIAL		
TYPE OF MOVEMENT		**BEDROCK**	**ENGINEERING SOILS**	
			Predominantly coarse	**Predominantly fine**
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow	Earth flow
			(soil creep)	
COMPLEX Combination of two or more principal types of movement				

Table 3: District-wise distribution of landslide Susceptible Zonation

Sl No	**District**	**District total Area in sq. km***	**Landslide Susceptible Zone**			**(A+B+C) Area in sq. km***	**Percentage**
			Low (A)	**Moderate (B)**	**High (C)**		
1	Uttara Kannada	10,291	6413.8	1664.6	311.8	8390.3	81.53
2	Shivamogga	8,495	4033.1	705.7	59.1	4797.9	56.48

3	Dakshina Kannada	4,866	3767.3	704.7	146.6	4618.6	94.9
4	Chikkamagaluru	7,201	3481.1	952.5	203.8	4637.4	64.40
5	Kodagu	4,102	3008.1	671.7	277.6	3957.4	96.47
6	Udupi	3,582	1592.4	404.6	84.8	2081.7	58.11
7	Hassan	6,814	1216.7	165.1	53.6	1435.4	21.0
8	Belagavi	13,415	1169.9	116.2	26.3	1312.4	9.78
Total Area in sq.km		**58,766.0**	**24,682.2**	**5,385.0**	**1,163.8**	**31,231.0**	**482.67**

* **Source:** Geological Survey of India, GoI



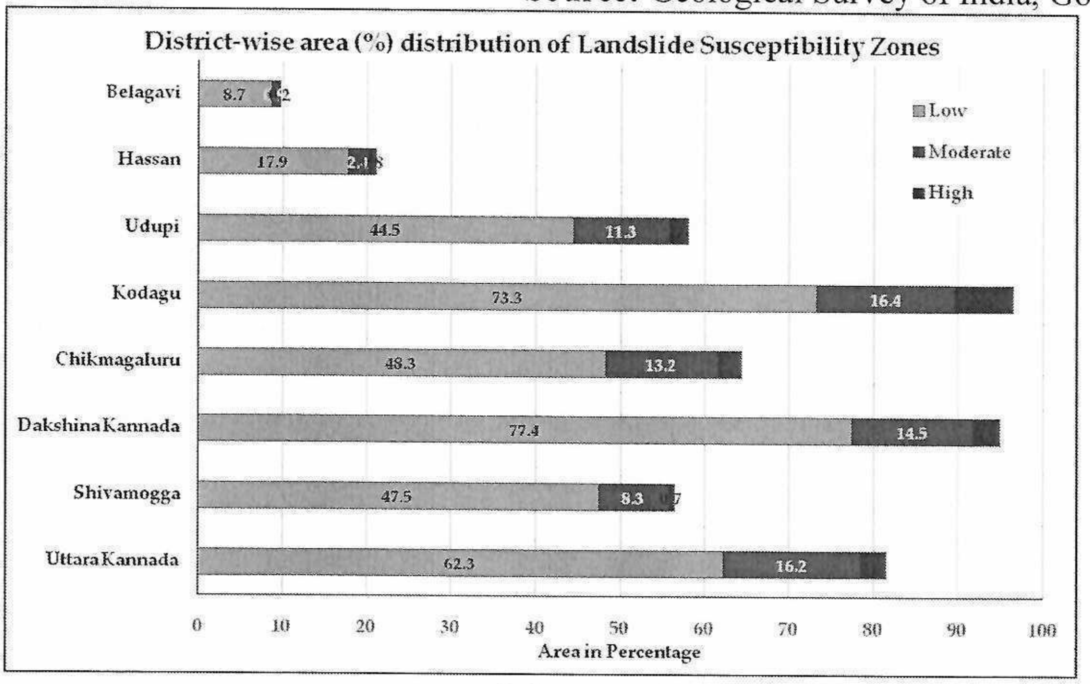
* **Source:** Geological Survey of India, GoI

Table 4: District-wise area in % distribution of landslide Susceptible Zonation

Sl No	Susceptibility	Landslide Susceptibility in %		
		Low	**Moderate**	**High**
1	Uttara Kannada	62.3	16.2	3.0
2	Shivamogga	47.5	8.3	0.7
3	Dakshina Kannada	77.4	14.5	3.0

4	Chikkamagaluru	48.3	13.2	2.8
5	Kodagu	73.3	16.4	6.8
6	Udupi	44.5	11.3	2.4
7	Hassan	17.9	2.4	0.8
8	Belagavi	8.7	0.9	0.2
Total %		**379.9**	**83.2**	**19.7**

* **Source:** Geological Survey of India, GoI



* **Source:** Geological Survey of India, GoI

2. CAUSES OF LANDSLIDES IN KARNATAKA

There are three primary causes of landslides: geological, morphological and human-caused. Sometimes, landslides are caused by a combination of three factors, or worse. According to a detailed study conducted in Karnataka by Geological Survey of India (GSI), Government of India, geo-scientific causes for most of the landslides are known to be some of the most common causes that act as trigger factors for landslides in Karnataka.

i. High intensity/prolonged rainfall
ii. Modification/Cut of natural slopes

iii. Anthropogenic Activity

iv. Toe erosion by stream and removal of toe support

v. Dump on the head part

vi. The rise in hydraulic head due to increase in sub-surface water flow saturated the slope forming material.

vii. Increase in pore water pressure, due to rain

viii. Reduction of strength on normal/super saturation

ix. Presence of weak slope forming material saturated during the incessant rainfall.

x. Weathered jointed rock; slope disturbance

xi. Flash flood due to construction of temporary dam in Nala

xii. Blockage of natural rivers

xiii. Geographical causes (geographical ridges/structures)

The above said geo-scientific causes may differ from location to location due to its slope, aspect, soil, geology, geomorphology, geological structures, river/drainage system network, lulc and rainfall.

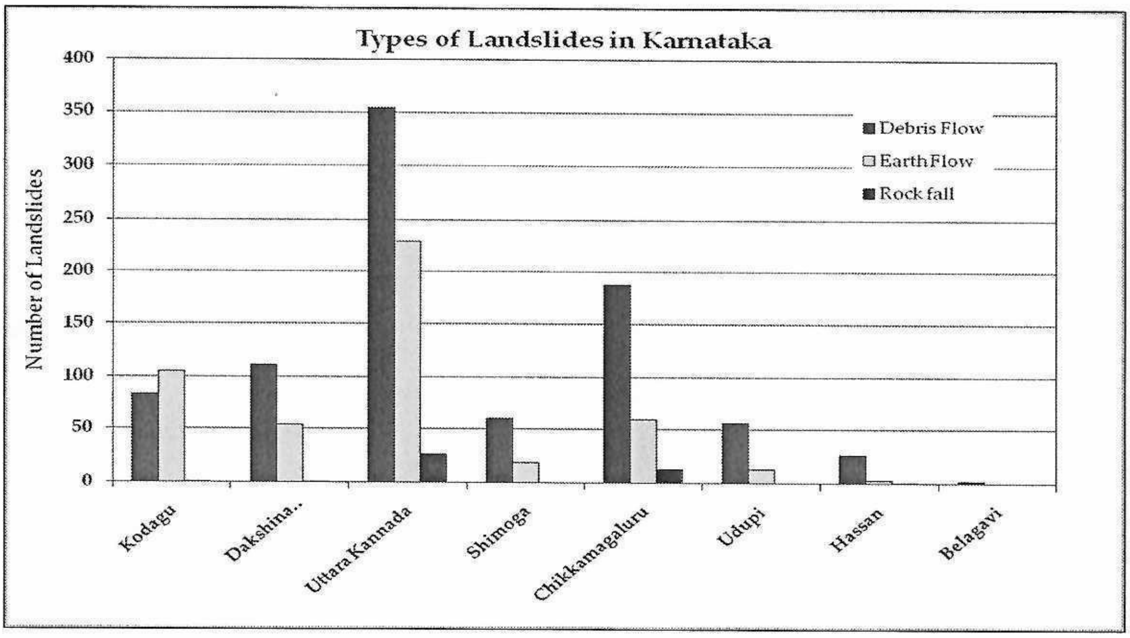
3. CLASSIFICATION OF LANDSLIDES IN KARNATAKA

Karnataka had experienced three types of landslides viz., Debris flow, Earth flow and Rock fall. District wise classification of landslides are shown table.

Table 5: Types of Landslides occurred in Karnataka

Sl. No	District	Debris Flow	Earth/Mud Flow	Rock fall
1	Kodagu	83	104	1
2	Dakshina Kannada	111	54	1
3	Uttara Kannada	354	229	26
4	Shimoga	60	19	0

5	Chikkamagaluru	188	59	13
6	Udupi	56	13	0
7	Hassan	26	3	1
8	Belagavi	2	0	0
Total		**880**	**481**	**42**



District wise Types of landslides

Majority of the landslide types are debris flow followed by earth/mud flow and rock fall. Uttara Kannada, Chikkamagalur and Dakshina Kannada districts recorded highest number of debris flow type of landslides.

Earth/Mud Flow type of landslides are second highest numbers occurred in Uttara Kannada, Kodagu, Chikkamagalur and Dakshina Kannada districts.

Rock falls type of landslides are lowest numbers occurred in Uttara Kannada and Chikkamagalur districts. Remaining districts are recorded least number of rock falls.

Annexure - III

1. RAINFALL - A TRIGGERING FACTOR FOR LANDSLIDES IN KARNATAKA

- The Landslides which are occurring in the State are being triggered by a sporadic high intensity rainfall as captured by the high density Telemetric Rain Gauge stations established by KSNDMC in Karnataka. The comparatively higher rainfall is the factor which is saturating the soil column and becoming sufficient enough to trigger landslides
- This is mainly due to the fact that groundwater conditions are responsible for slope failures and are related to rainfall through infiltration, evapotranspiration, soil characteristics, antecedent moisture content and rainfall history. The rapid increase in rainfall intensity results in a sharp break in the slope of the rainfall cumulative curve
- A rainfall threshold value is the minimum or maximum level of some quantity of rainfall needed for a process to take place or a state to change. A minimum threshold defines the lowest level below which a process does not occur, while a maximum threshold represents the level, above which a 100% process always occurs, whenever the threshold is exceeded
- For rainfall-induced slope failures, a threshold may represent the minimum intensity or duration of rain, the minimum level of pore water pressure, the slope angle, the reduction of shear strength or the displacement required for a landslide to take place. The most commonly investigated rainfall parameters are: (i) Total (cumulative) rainfall; (ii) Antecedent rainfall; (iii) Rainfall intensity, and (iv) Rainfall duration
- Higher rainfall will lead to landslides, however, there exists a lot of variability in terms of exact amount of rainfall, time of the rainfall-

at the beginning of rainy season or later part of rainy season, size of the slide and underlying geological and geotechnical factors. In simplistic term, the critical rainfall is the rainfall measured from the beginning of the event, i.e., from the time when rainfall intensity increases sharply, to the time of the occurrence of the landslide.

Year-wise Rainfall threshold for landslides in Karnataka

Sl. No.	**Year**	**Duration of Rainy Days**	**Rainfall limit (mm)**			**% Dep**
			Min	**Max**	**Avg.**	
1	2018	08-08-2018 to 17-08-2018 ***(10 Days)***	534	1234	884	(+) 289 %
2	2019	01-08-2019 to 13-08-2019 ***(13 days)***	630	1794	1212	(+) 316 %
3	2020	04-08-2020 to 08-08-2020 ***(6 days)***	258	821	539.5	(+) 201 %
4	2021	21-07-2021 to 26-07-2021 ***(6 days)***	72	824	448	(+) 83.5 %
5	2022	26-08-2022 to 31-08-2022 ***(6 days)***	12	326	169	(+) 19 %
6	2023	01-07-2023 to 16-07-2024 (***16 days***)	14	174	92	(+) 68 %
7	2024	**July and August**	12	319	172	(+) 112 %

2. WEATHER FORECAST SYSTEM IN KARNATAKA

Karnataka State Natural Disaster Monitoring Centre (KSNDMC), An Autonomous body affiliated to Revenue Department (Disaster

Management) is the nodal agency to monitor Natural Disasters in Karnataka. In view of this KSNDMC is installed the following network of sensors across the state to monitor Natural Disasters.

Weather Forecast at high Spatial & Temporal Resolution is a pre-requisite for planning and executing Risk reduction program with respect to Hydro-Meteorological Disasters. KSNDMC has been collaborating with Space Application Centre, Ahmadabad and providing Gramapanchayath level Rainfall & Weather forecast at 12, 24, 36, 48, 60 and 72 hrs formats for Karnataka.

Sensors installed to monitor natural disasters in Karnataka

Sl No	Type of Sensors	Numbers
1	Telemetric Rain Gauges (TRG's)Network	6500
2	Telemetric Weather Station	926
3	Lightning & Thunderstorm	11
4	Seismic Monitoring	14
5	Water Level Sensors	182
6	Reservoir Water level & Stream Gauge water level Sensors	9 &12

The observational 15 minutes data collected through KSNDMC's Weather Stations Network is ingested in to the SAC model. The Initiative, first of its kind in the Country, is appreciated by the farmers. Equal Spatial Resolution of Weather Forecast & Monitoring Network is a unique feature and advantageous for validating the Weather Forecast. The Observational data is used to validate the Weather Forecast and the result is incorporated in the Model to improve the output dynamically. This forecasted information will be effectively used for evacuate community during severe weather instances in terms of intensity, time, and geographical span.

3. INFORMATION DISSEMINATION MECHANISM AT KSNDMC

Information Dissemination plays an important role in disaster risk reduction. KSNDMC has employed various Dissemination systems to send Disaster-related information through Alerts, Advisories and Early Warnings to all the Government Executives & Communities at Real time.

High Spatial and Temporal resolution data thus collected from the ground on various parameters are being converted into information. Subsequently, in conjunction with the weather forecast, the meteorological information is used to generate customized weather Advisories and disseminated to the users. This has enabled the stakeholders at all levels to take appropriate decisions atright time. Providing early warnings about possible extreme weather condition, Weather forecast at high spatial and temporal resolution helps the end-users to plan and implement appropriate measures to minimize the adverse impact of extreme weather condition.

The Information Dissemination activities undertaken through: 24X7 Varuna Mitra, DEWS, CAP, SMS, E-mail, WhatsApp, Real time weather dashboards, Dynamic websites, Social Media, Media etc;

Information Dissemination through Help-Desk –VarunaMitra

To disseminate the Agro-Met information, forecast and advisories directly to the farmers, a 24x7 Interactive HelpDesk "VarunaMitra" has been functioning in Karnataka at KSNDMC. It is a common experience that required precise information about the weather is not available, on real/near real time, to the community and response players. It takes longtime to obtain the data and lot more time to integrate and generate information/reports/advisories.

Disaster Early Warning System (DEWS)

KSNDMC has developed a unique integrated public alert and warning system called Disaster Early Warning System (DEWS) to disseminate early warnings to the potentially vulnerable panchayaths effectively.

Common Alerting Protocol (CAP)

National Disaster Management Authority (NDMA) has envisaged a Common Alerting Protocol (CAP) Integrated Alert System for Disaster Management to warnthe Indian public of emergencies and disasters and to address the measures for the prevention of disaster, or the mitigation, or preparedness and capacity building for dealing with threatening disaster situations or disasters.

Through CAP, Alert Generating Agencies (AGAs) such as CWC, IMD, INCOIS, FSI & DGRE along with State Disaster Management Authorities (SDMAs) will issue weather–related alerts in the form of SMS, Web browser, Mobile App, and recently added GAGAN and NAVIC medias to the general public in both English and regional languages.

NDMA has collaborated with Union Ministry of Telecommunication and the Centre for Development of Telematics(C-DoT). SMS alerts are geo-tagged and sent only to defined area.

In Karnataka State; whenever there is any warning/alert drafted by IMD–Bengaluru or any Alert Generating Agency(AGA), that particular warning will be pushed to SDMA to disseminate to the define area.

Annexure - IV

Efile No.RW/NH-33044/55/2021-S&R (P&B)pt. /Hill Slope Monitoring (Computer No.219394)
Government of India
Ministry of Road Transport & Highways
Transport Bhawan, 1, Parliament Street, New Delhi-110001

Dated 28th November, 2024

OFFICE MEMORANDUM

Subject: Expert Committee Report on Cost Effective Long-term Remedial Measures for Landslide Prone Areas in Hilly Regions- Regarding

Expansion of National Highways in hill roads having mountainous/steep terrain involving a lot of hill cutting has resulted in landslides and destabilization of slopes. There are also landslides in hill roads built several years ago. There is need of proper slope stability measures on both hill and valley side.

2. It is desirable to have a matrix of site investigations to be carried out for different slope types as characterized by different geological formations, slope angle, height etc. as revealed from site reconnaissance survey for simple understanding of field engineers. Similarly, there is need to have a matrix of cost-effective protection / mitigation measures to be used for different slope types as determined based on afore-mentioned site investigations. Keeping this in view, a six-member expert committee comprising of academicians, researchers, representative from consultant, representative from concessionaire, technology provider and subject-matter experts was formed by Ministry of Road Transport & Highways (MoRTH) to finalize such matrices.

3. Please find enclosed herewith the Expert Committee Report on Cost Effective Long-term Remedial Measures for Landslide Prone Areas in Hilly Regions. The matrices on investigation and mitigation of landslides serve as a valuable tool for field engineers by providing a structured approach to select appropriate field investigation and mitigation measures and prioritize actions. This systematic framework not only enhances the efficiency of decision making but also ensures that interventions are tailored to local conditions, balancing cost-effectiveness with environmental resilience and long-term sustainability. By integrating scientific investigation with practical mitigation strategies, the matrix empowers field engineers to proactively select suitable cost-effective measures to protect slopes and manage landslide hazards, ultimately safeguarding communities and infrastructure against the devastating impact of landslides.

4. All the stakeholders of MoRT&H are requested herewith kindly use this report as reference/guidance while finalising investigations and mitigation measures.

Enclosure: Expert Committee Report (61 pages)

(Bidur Kant Jha)
Bidur Kant Jha
28/11/2024
Director
(New Technology for Highway Development)
For DG (RD) & SS

To:

1. All Stakeholders

Copy for information:

1. PSO to DG(RD)&SS
2. PPS to ADG(S&R)

Copy for necessary action:

1. Director-NIC: with a request to please upload on MORT&H's website.

Bidur Kant Jha

EXPERT COMMITTEE REPORT ON

COST EFFECTIVE LONG-TERM REMEDIAL MEASURES FOR LANDSLIDE PRONE AREAS IN HILLY REGIONS

Submitted to

Ministry of Road Transport & Highways

Government of India

11 September 2024

Content

List of Figures		3
List of Tables		4
Glossary		6
1.	Introduction	8
2.	Objectives	8
3.	Methodology for Preparation of Matrices	9
4.	Presentation of Lists and Matrices	10
5.	Important Notes	10
	5(a) Applicability of Matrices	11
	5(b) Limitations of Matrices	11
	5(c) Precautions	12
	5(d) Additional Literature	12
	5(e) Discliamer	12
6.	Conclusion	13
Acknowledgement		13
Vote of Thanks		13
Bibiliography		38
Annexure A1.	Steps to Use the Matrix	42
Annexure A2.	Slope Mass Rating (SMR)	46
Annexure A3.	Weathering Grades and Their Meaning	48
Annexure A4.	Back Analysis to Determine Shear strength Parameters	49
Annexure A5.	Estimation of Safe Bearing Pressures	50
Annexure A6.	Check-list for Use in the Field during Mitigation Stage	52
Annexure A7.	Snapshots of Different Mitigation Measures from Hill Road Manual	54
Annexure A8.	Approval of All Committee Members	61

List of Figures

Figure A1. Examples of Drapery Systems used for Rockfall Mitigation Measures 54
Figure A2. Typical Cross-Section of Reinforcing Rock Slope by Anchors/Bolts/Nails 55
Figure A3. Rockfall Embankment to Protect Infrastructure and Roads at Foot of Cliff 55
Figure A4. Site Photograph of Rock Shed 56
Figure A5. Flexible Rockfall Barriers 56
Figure A6. Debris Flow Barrier 57
Figure A7. Indicative Cross-Section of Gabion Retaining Wall 57
Figure A8. Cross-Section of Reinforced Soil Slope with Flexible Facing 58
Figure A9. Cross-Section of Gabion Wall with Launching Apron on River Bed 58
Figure A10. Photograph of Gabion Retaining Wall with Launching Apron on River Bed 59
Figure A11. Cross-Section of Fabric Form Mattress with Launching Apron on River Bed 59
Figure A12. Photograph of Fabric Form Mattress with Launching Apron on River Bed 60
Figure A13. Typical Components of a Ground Anchor 60

* Cover photos show the slope protection using Bally benching with use of Bamboo & Vetiver grass plantations near Deingpasoh village on Shillong bypass highway connecting NH-40 & NH-44 in East Khasi Hill District in Meghalaya.

List of Tables

Table 1. Composition of the Committee 9

Table 2. List of Investigations 14

2(A) Site Inspection or Reconnaissance Survey (Code A) 14

2(B) Topographical Mapping (Code B) 15

2(C) Geological Investigation (Code C) 15

2(C)(i) Geological Categories 15

2(C)(ii) Rock Debris Contact Depth (Code C04) 15

2(C)(iii) Slope Assessment (Code C06) 16

2(D) Hydrological / Meteorological Investigation (Code D) 17

2(E) Geophysical Investigation 17

2(F) Geotechnical Investigation (Code F) 17

Table 3. Investigation Matrices 18

3(A) For Rock Slopes (Code A01a) 18

3(B) For Debris / Soil Slopes (Code A01b) 19

3(C) For Talus Slopes (Code A01c) 20

Table 4. List of Mitigation Measures 21

Table 5. Mitigation Matrices 28

5(A) For Rock Slopes (Code A01a) 28

5(B) For Debris / Soil Slopes (Code A01b) 32

5(C) For Talus Slopes (Code A01c) 35

5(D) For Additional Measures to Curb Instability Issues (Code A06) 36

Table A1. Slope Mass Rating Factors F_1, F_2, and F_3 (IS 13365, Part 3) 47

Table A2. Slope Mass Rating Factor F_4 (IS 13365, Part 3) 47

Table A3. Slope Stability Classes as per SMR Values 47

Table A4. Rock Mass Classification in Terms of Weathering 48

Table A5. Safe Bearing Pressure of Rock Mass Based on Classification (IS 12070) 50

Table A6. Net Allowable Bearing Pressure of Rock Mass Based on RMR (IS 12070) 50

Table A7. Safe Bearing Capacity Values for Different Types of Soils (IS 14458, Part 2) 51

Table A8. Typical Shear Strength Charateristics of Soils (IS 14458) 51

Table A9. Site Assessment Check-List For Field Use 52

GLOSSARY

Term	Definition
Debris / Soil / Earth / Rock	Rock, earth and debris are the terms generally used to distinguish the materials involved in the landslide process. If the weight of the particles with a diameter greater than 2 mm is less than 20%, the material is defined as earth; in the opposite case, it is debris (refer IRC SP 106). Soil includes both earth and debris.
Debris Flow	A form of rapid mass movement involving loose soil, rocks and organic materials along with entrained air and water to form slurry which flows down the slope.
Glaciofluvial strata	Sedimentary formations created by glacial meltwater. These are made up of a variety of materials, including gravel, sand, silt, clay, boulders, and cobbles.
Landslide	Downslope and outward movement of a mass of soil (earth or debris) or rock down a slope.
Planar Slide	A kind of translational movement along a definite plane or a set of discontinuity planes, like joints, beddings, schistosity planes and other such structural features.
RBM (River Borne Material) Strata	An accumulation or deposit of material derived naturally from the disintegration or rocks. These deposits predominantly consist of a mixture of sand and gravel. Some cobble size stones of 80 mm to 150 mm size and some percentage of fine-grained soil may also be present.
Right of Way (RoW)	A width of land acquired for a road along its alignment. It should be adequate enough to accommodate all the cross-sectional elements of the road and should reasonably provide for future development.
Rockfall	A fragment of rock (a block) detached by sliding, toppling, or falling, that falls along a vertical or sub-vertical cliff, proceeds down slope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes.
Rockfall Barrier	A structure built to intercept rockfall, most often made from metallic components and consisting of an interception structure hanged on post-supported cables

Self-Drilling Anchors (SDA)	Special type of anchors generally used in collapsable strata. Self-drilling anchor consists of a sacrificial drill bit, hollow steel bar of an appropriate outer and inner diameter and coupling nuts.
Slope Mass Rating (SMR)	A rock mass classification scheme developed by Manuel Romana to describe the strength of an individual rock outcrop or slope. The system is founded upon the more widely used RMR scheme, which is modified with quantitative guidelines about the influence of adverse joint orientations (e.g., joints dipping steeply out of the slope).
Talus Slide	A downslope movement of overburden soil or debris lying over in-situ rock with the attitude of rock surface dipping roughly towards valley side at an angle less than the inclination of general slope. In this case, the thickness of overburden soil or debris usually ranges between 1m to few meters (less than 5m).
Toppling failure	A failure in which the movement consists of forward rotation of a mass unit or units about a horizontal axis (below the center of gravity of the mass) under the action of gravity and other forces exerted by adjacent units or fluids / ice in cracks.
Wedge Slide	A kind of translational movement that occurs due to intersection of two obliquely dipping discontinuity planes (with respect to slope face) along the line of intersection.

EXPERT COMMITTEE REPORT ON

COST EFFECTIVE LONG-TERM REMEDIAL MEASURES OF LANDSLIDE PRONE AREAS IN HILLY REGIONS

1. Introduction

With expansion of National Highways in hill roads having Mountainous/Steep terrain involving a lot of hill cutting has resulted in landslides and destabilization of slopes. There are also landslides in hill roads built several years ago. There is need of proper slope stabilitymeasures on both hill and valley side. Such kind of treatments are generally provided during project implementation or subsequently as a reactive measure to landslide.

There are several protection / mitigation measures available for stability of slopes, such as natural vegetation, rockfall barrier, surface treatments and structural treatments. Various types of investigations (topographic, geophysical, etc.) are also available to characterize the slope and accordingly, decide the type of treatment measures. Design and construction methods for different types of protection / mitigation measures are available in IRC guidelines (IRC SP 48 and IRC SP 106). However, there is a gap in identifying the type of investigations needed for a particular type of slope and subsequently, the selection of the type of mitigation measures for that slope. As a result, there is lack of consistency in the field investigations performed and the mitigation measures used for similar types of slopes, which sometimes result in very high end structural treatments without proper justification.

For simple understanding of field engineers and consultants working for National Highway projects, it is, therefore, desirable to have a matrix of site investigations to be carried out for different slope types as characterized by different geological formations, rainfall, etc. Similarly, there is a need to have a matrix of cost-effective protection / mitigation measures to be used for different slope types as determined based on afore-mentioned site investigations. Keeping this in view, a Six-member committee was formed by Ministry of Road Transport & Highways (MoRTH) to finalize such matrices. The composition of the committee is given in Table 1.

2. Objectives

The objectives of the committee are given below:

(i) Preparation of matrix of different types of field investigations (i.e., Geotechnical/ Geological investigation, Geophysical investigation, Ground water investigation, etc.) required for different types of soil / rock slopes, geological formations, rainfall, landslide type, rockfall, debris flow, etc. as observed at site during visual inspection.

(ii) Preparation of matrix of most suitable mitigation measures (such as, benching of slope, retaining wall, soil nailing, ground anchor, geosynthetic mat, coir geotextile, jute geotextile, biotechnical slope protection, greening techniques, flexible ring net barriers, check dams, surface water drains, surface protection, subsoil drains, etc.) for different types of slope parameters based on results of field investigations.

Table 1. Composition of the Committee

Sl. No	Name	Designation	Organisation	Position in the Committee
1	Dr. J.T. Shahu	Professor	IIT Delhi	Chairman
2	Dr. P.S. Prasad	Chief Scientist	CSIR-CRRI	Member-Secretary
3	Dr. Sanjay Wakchaure	SE	MoRT&H	Member
4	Colonel Soumendra Banerjee (Veteran)	Vice President	Terre Armee	Member
5	Shri. Niraj Kumar Agarwal	AGM-1 (Design-Civil)	M/s THDC	Member
6	Shri. Sachin Joshi	VP	M/s Highway Concession One	Member

3. Methodology for preparation of Matrices

To prepare the matrices, the committee first prepared the following three lists:

1) A list of site inspection parameters
2) A list of type of field investigations
3) A list of mitigation measures

The matrices were then prepared by intercorrelation of these lists. The details of preparation of these lists and matrices are given below.

a) **Listing of types of field investigation:** The committee members based on the diverse experiences in this field contributed valuable insights into various aspects of landslide investigations. These include root cause analysis, geological mapping, slope stability assessment, and the evaluation of human and environmental impacts. The committee also took note of the various field investigation methodologies in common practice and their efficacy.

b) **Listing of Mitigation measures:** By pooling their collective expertise, taking reference of the mitigation measures available in the codal provision and common practices, an exhaustive list of mitigation measures was prepared. The committee deliberated in detail the efficacy of each system for various slope type and terrain.

c) **Developing the Matrix:** For building the matrices, the slope was categorised into three types, namely, Rock Slope, Debris / Soil Slope (refer IRC SP 106) and Talus Slope (i.e., a combination of Rock and Debris Slopes). Based on this, three matrices each were prepared for both field Investigation and Mitigation measures, making it a total of six Matrices. One special matrix was also prepared for additional mitigation measures to curb the adverse effect of instability issues.

i) **Investigation Matrices**: These matrices have two distinct parts, namely, Site description based on visual inspection and Field investigation. Site description is based on preliminary visual inspection that gives the initial input of basic elements and field investigation is a more detailed field investigation of the affected area. Three matrices are prepared for three types of slopes (Rock, Debris/Soil and Talus) by creating various combinations of the site description parameters.

ii) **Mitigation Matrices:** These matrices have two distinct parts, namely, site assessment and suggested mitigation measures. Three matrices are prepared for three types of slopes (Rock, Debris/Soil and Talus) by creating various combinations of site assessment parameters. Site assessment of slope shall be derived from the above-mentioned investigation matrix. One special matrix was also prepared for additional mitigation measures to curb the adverse effect of instability issues.

4. Presentation of Lists and Matrices

Table 2(A) presents the list of site inspection parameters to be determined by visual inspection or reconnaissance survey. Tables 2(B) to (F) shows a list of field investigations broadly classified under Topographical Mapping, Geological Investigation, Hydrological / Meteorological Investigation, Geophysical Investigation, and Geotechnical Investigation. Tables 3(A), 3(B) and 3(C) present the investigation matrices for Rock slopes, Debris/Soil slopes and Talus slopes, correlating a combination of site inspection parameters with the field investigations to be performed.

Table 4 lists the commonly used mitigation measures along with their IRC/IS/ISO code references. Tables 5(A), 5(B) and 5(C) present the mitigation matrix for Rock slope, Debris/Soil slopes, and Talus slope, correlating a combination of slope assessment parameters determined from field investigations with the mitigation measures to be selected. Additional measures to curb special instability issues, namely, Subsidence/ Sinking, River/Scour action at toe, Road widening towards hill and valley side, Emergency Road Support and Avalanche, are given in Table 5(D).

The use of matrices (Tables 3 and 5) is self-explanatory. Still the steps to use the matrices are given in detail in Annexure A1 for clarity.

5. Important Notes

Important notes related to Applicability of matrices, Limitations of matrices, Precautions, Additional Literature and Disclaimer are given below.

a) Applicability of Matrices

i. The proposed matrices are applicable for rock, debris/soil, and talus slopes. The matrices shall be applicable to all regions, especially the Himalayan slopes in North and North-East India, Western Ghats, etc. It is envisaged that the combination of slope parameters covered in the matrices shall be able to cover 80-85% of slope types. In case of doubt or a different slope type, expert advice should be sought.

ii. In general, the matrices give the mitigation measures for dry slopes. Additional mitigation measures for wet slopes (cases A04a and b) are given at the bottom of each matrix under a separate heading titled 'Additional measures to curb the adverse effect of subsurface water/flowing water over slope'. The user should first choose dry mitigation measures based on slope assessment. The user must then add wet mitigation measures (if slope is expected to have the flowing surface water or subsurface seepage water flow) to these dry mitigation measures.

iii. Additional mitigation measures for special cases are given under other instability issues. These special cases are Subsidence/Sinking zone, Shooting stones, Toe erosion due to flowing water body, Road Widening, Emergency Works and Avalanche (refer Cases A06a-d and A06f-g in Table 2). These additional measures for special cases must be added to dry or wet mitigation measures decided earlier as explained above (refer point - ii above). Stability of unplanned muck disposal (Case A06e) should be evaluated using geotechnical slope stability analysis.

iv. If necessary, a potential landslide site may be divided into 2 or 3 slope types based on Investigation matrix, and the corresponding mitigation measures based on mitigation matrix may be chosen, keeping aesthetics at the site in mind, to achieve overall cost savings.

v. The above matrices can also be used for stabilisation of slope along a proposed long hill road or widening of an existing road, if it is envisaged that the slope may become unstable due to construction activities. In such cases, the existing slope along entire road stretch may be divided into 5 or 6 (or even more) slope types based on investigation matrix and the corresponding mitigation measures be chosen.

b) Limitations of Matrices

i. Once the elements of mitigation measure are chosen from the mitigation matrices, a detailed design must be carried out that may involve the use of commonly used software, such as Slide (Roc Science), Slope/w (Geo slope), Geo 5, etc. Detailed design is beyond the scope of this report.

ii. Each slope site is unique in spite of given classification here. Accordingly, it is possible that all the elements of mitigation measures as decided based on the mitigation matrix might not be needed at some sites. On the other hand, it is also possible that some additional elements of mitigation measures might be needed. In such cases, the final decision should be taken by the relevant authorities based on expert advice / guidance.

c) Precautions

i. Some of the critical slopes may experience failure between the time of investigation and implementation of mitigation measures without any preventive measure and their geometry may get modified. Hence, before implementation of suggested measures, the geometry of slopes should again be verified.

ii. Leaving some of the remedial measures from suggested scheme and implementing only selected ones, may have only partial benefit and may even be failure.

iii. The cracks of various dimensions observed on the surface of the slope during investigation should be sealed immediately so as to prevent the percolation of water on the slope.

iv. Flexible barriers / dynamic rockfall barrier require regular maintenance including removal of collected debris. If the debris is not removed periodically, the protective measures may eventually break and fail.

v. Maintenance of drains and drainage system is another important activity to ensure that run-off water does not infiltrate into the subsoil.

vi. Permanent observation points (Pedestals) should be established on the slopes and the movement of these points should be regularly monitored during service life (operational period) of the road, especially during rainy season through accurate surveying techniques to ensure that there is no hill slope movement.

vii. Most of the aforementioned investigations are kind of specialised jobs and therefore, should be carried out by expert agencies / consultants in similar fields. Similarly, analyses of collected data and design of mitigation measures should be done under the supervision of experts who have adequate experience in this field.

d) Additional Literature

A bibliography of chosen codes related to landslide investigation and mitigation measures from around the world (IRC, IS, ISO, BS, AASHTO, FHWA, ASTM, UNI, WSDOT, CIRIA, EAD, ONR, MoRTH, etc.) is given at the end of the report. For detailed information on the subject, the reader is directed to refer to these codes. The bibliography also contains the IRC and IS codes referred in this report.

e) Disclaimer

Utmost care has been taken in the preparation of matrices. However, users should take appropriate safety precautions while implementing the matrices at site. The committee bears no responsibility for any kind of losses – financial, infrastructural or human – suffered by anyone by following the matrices / guidelines given here.

6. Conclusion

There is crucial need for Cost-effective long-term remedial measures for landslide-prone areas in hilly regions to typically focus on sustainable solutions that mitigate the risk of landslides without imposing excessive financial burdens.

The matrices on investigation and mitigation of landslides serve as a valuable tool for field engineers by providing a structured approach to select appropriate field investigation and mitigation measures and prioritize actions. This systematic framework not only enhances the efficiency of decision-making but also ensures that interventions are tailored to local conditions, balancing cost-effectiveness with environmental resilience and long-term sustainability. By integrating scientific investigation with practical mitigation strategies, the matrix empowers field engineers to proactively select suitable cost-effective measures to protect slopes and manage landslide hazards, ultimately safeguarding communities and infrastructure against the devastating impact of landslides.

Acknowledgment

The committee was well supported by Shri Amninder Singh Nayyar, Geotechnical Engineer, THDC India Limited, throughout this work. The committee gratefully acknowledges his contribution.

Vote of Thanks

All committee members are thankful to MoRT&H for giving this wonderful opportunity.

J. T. Shahu

(J.T, Shahu)

Chairman of the committee

Signed on behalf of all members

Note: Approvals from all committee members are given in Annexure A8.

Table 2. List of Investigations

(A) Site Inspection or Reconnaissance Survey (Code A)

During reconnaissance/site inspection, data corresponding to A01 to A07 are noted and accordingly, investigation process shall be decided.

Code	Category
A01	Slope Mass Type
A02	Slope Height
A03	Slope Angle
A04	Source of Seepage
A05	Area of Affected Slope*
A06	Other Instability Issues
A07	RoW (Right of Way) Restriction

A01 - Slope Mass Type	
A01a	Rock Slope
A01b	Debris / Soil Slope**
A01c	Talus Slope***

A02 - Slope Height	
A02a	Slope Height ≤ 60m
A02b	60m< Slope Height ≤ 100m
A02c	Slope Height >100m

A03 - Slope Angle	
A03a	Slope Angle ≤ 30^0
A03b	30^0< Slope Angle ≤ 45^0
A03c	45^0 < Slope Angle ≤ 60^0
A03d	60^0< Slope Angle ≤ 75^0
A03e	Slope Angle > 75^0

A04 - Source Of Water Flow	
A04a	Natural Nala
A04b	Seepage through Slope in Dry Season

A06 - Other Instability Issues	
A06a	Sinking Zone
A06b	Shooting Stones
A06c	Toe Erosion due to Water Body
A06d	Road Widening
A06e	Unplanned Muck Disposal
A06f	Washed out Road (Emergency Works)
A06g	Avalanche

A07 - RoW Restriction	
A07a	RoW Restriction due to Village on Hill Side Vicinity
A07b	Row Restriction due to Forest Land on Hill Side Vicinity

Note:
* During the reconnaissance survey, to determine the affected area of slope, details regarding its physical features such as crown, main scarp, left & right flanks and toe shall be noted.

** For definition of Debris / Soil slope, refer IRC SP 106.

*** Talus slope are those slopes that have less than 5m thick debris as overburden and bedrock strata lies below that. They undergo translational slide along the contact of overburden and underlying rock. Such slides are often observed in Himalayas.

Table 2 (Continued). List of Investigations

(B) Topographical Mapping* (Code B)

Code	Category
B01	Digital/Infrared Videography; Total Station; Lidar Survey
B02	Digital Terrain Model (DTM) by Drone/UAV with or without Lidar

Note:
* The topographical survey shall be done on the scale of 1:500 to 1:2000

(C) Geological Investigation (Code C)

(i) Geological Categories

Code	Category
C01	Assessment of Slope by Analysing the Google Earth Imagery / Latest Satellite images from ISRO (Bhoonidhi Portal), Digital / Infrared Videography
C02	Study of Physiography and Geomorphology
C03	Study of Regional Geology
C04**	Site Specific Geology
C05	Determining the Causative Factors
C06	Slope Assessment (C06a / C06b / C06c)
C07	Geological Mapping Incorporated with Joint Data

(ii) Rock Debris Contact Depth** (Code C04)

Code	Rock Debris Contact Depth
C04a	0 - 5m
C04b	5 - 10m
C04c	10 - 20m
C04d	>20m
C04e	Cannot Be Interpreted (No Rock Exposure Observed)

Note:

** For the Site-Specific Geology, the Rock Debris Contact Depth is estimated by interpolating nearby Rock-Debris Slope exposures. In case of Code C04e, Seismic Refraction test shall be conducted.

Table 2 (Continued). List of Investigations

(iii) Slope Assessment (Code C06)

Type Of Slope	C06a - Rock Slope		C06b - Debris Slope		C06c - Talus Slope	
	Code	**Category**	**Code**	**Category**	**Code**	**Category**
Determination of Strength Parameter/ Characteristics of Affected Slope Mass^	C06a (i)	SMR* Class - I	C06b (i)	Back Analysis***	C06c (i)	Back Analysis***
	C06a (ii)	SMR* Class - II				
	C06a (iii)	SMR* Class - III				
	C06a (iv)	SMR* Class - IV				
	C06a (v)	SMR* Class - V				
Weathering Characteristics of Slope**	C06a (I)	Weathering Grade - W1				
	C06a (II)	Weathering Grade - W2				
	C06a (III)	Weathering Grade - W3				
	C06a (IV)	Weathering Grade - W4				
	C06a (V)	Weathering Grade - W5				
Type of Slope Composition			C06b (I)	Debris/Soil Strata		
			C06b (II)	RBM Strata		
			C06b (III)	Glaciofluvial Strata		
Type of Failure#	C06a (α)	Planar Failure	C06b (α)	Circular Failure	C06c (α)	Translational Failure
	C06a (β)	Wedge Failure				
	C06a (γ)	Toppling Failure				

Note:

* Refer Annexure A2.

** Refer Annexure A3.

*** The process of back analysis is opted for determination of shear strength parameters, i.e. cohesion and angle of friction, of debris and talus slope mass. In back analysis, the shear strength parameters are selected from various combinations of cohesion and friction angle calculated by considering FOS = 1 for the slope as per engineering judgement and experience. FOS = 1 represents the state when the slope is on verge of failure. Refer Annexure A4.

For rock slopes, the type of failure is to be determined by geotechnical assessment of slope by kinematic analysis.

^For the design of retaining structures, Safe Bearing Capacity shall be assumed as per codal provisions. Refer Annexure A5.

Table 2 (Continued). List of Investigations

(D) Hydrological / Meteorological Investigation (Code D)

Code	Category#
D01	Determination of Catchment Area*
D02	Determination of Peak Discharge**
D03	Determination of HFL***, LWL, RBL, NWL HFL: High Flood Level; LWL: Low Flood Level; RBL: River bed Level; NWL: Normal Water Level
D04	Analysis of Annual Rainfall Data

Note:

#Hydrological / Meteorological Investigation (Code D) shall be analysed for the states having Average annual rainfall greater than 1800 mm as well as for local areas in other states that have had a recent history of cloudburst, i.e., getting more than 100 mm rainfall per hour. Furthermore, investigations to determine all or part of the components (D01, D02, D03 and D04) in any other area can be carried out as per design requirements.

* Delineation of catchment is done by GIS or by using toposheets provided by Survey of India.

** Using the rational formula, i.e., Q = C I A, where I = rainfall intensity and can be taken from the IMD database.

*** Determination of HFL is done (i) by River routing using HEC-RAS or any other relevant software / tool; or (ii) based on analysis of historical events.

(E) Geophysical Investigation (Code E)

Code	Category
E01	Seismic Refraction Tomography / MASW
E02	Electrical Resistivity Tomography

(F) Geotechnical Investigation (Code F)

Code	Category
F01	Borehole Drilling*

Note:

* Geotechnical investigation (FO1) includes field work (boreholes, trial pits, etc.), In-situ tests and Laboratory tests. Standard Penetration Test (IS 2131) shall be conducted on site. For laboratory testing, both disturbed sampling and undisturbed sampling shall be done by process of borehole drilling. Further, various laboratory tests shall be conducted for determination of engineering and index properties.

Table 3. Investigation Matrices

(A) For Rock Slopes (Code A01a)

Site Description Based on Inspection				Detailed Field Investigations To Be Undertaken			
Slope Height	Slope Angle	Water Flow Source	Other Instability Issues	Topographical Mapping*	Geological Investigation	Geophysical Investigation	Any Other Investigation
A02a	+ A03			B01	+ C		
A02b	+ A03			B02	+ C		
A02c	+ A03			B02	+ C		
A02a	+ A03	+ A04b		B01	+ C	+ E02	
A02b	+ A03	+ A04b		B02	+ C	+ E02	
A02c	+ A03	+ A04b		B02	+ C	+ E02	
A02a	+ A03		+ A06c	B01	+ C		+ D
A02b	+ A03		+ A06c	B02	+ C		+ D
A02c	+ A03		+ A06c	B02	+ C		+ D

Note:

* In case there is no accessibility for total station survey, DTM (i.e., B02) may be used even for smaller heights (A02 $\leq$ 60m).

Table 3 (Continued). Investigation Matrices

(B) For Debris / Soil Slopes (Code A01b)

Site Description Based on Inspection					Detailed Field Investigations To Be Undertaken			
Slope Height	Slope Angle	Water Flow Source	Geological Data	Other Instability Issues	Topographical Mapping*	Geological Investigation	Geophysical Investigation	Any Other Investigation
A02a	+ A03				B01	+ C		
A02b	+ A03				B02	+ C		
A02c	+ A03				B02	+ C		
A02a	+ A03		+ C04e		B01	+ C	+ E01	
A02b	+ A03		+ C04e		B02	+ C	+ E01	
A02c	+ A03		+ C04e		B02	+ C	+ E01	
A02a	+ A03	+ A04b			B01	+ C	+ E02	
A02b	+ A03	+ A04b			B02	+ C	+ E02	
A02c	+ A03	+ A04b			B02	+ C	+ E02	
A02a	+ A03			+ A06a	B01	+ C		+ F01
A02b	+ A03			+ A06a	B02	+ C		+ F01
A02c	+ A03			+ A06a	B02	+ C		+ F01
A02a	+ A03			+ A06b	B01	+ C		
A02b	+ A03			+ A06b	B02	+ C		
A02c	+ A03			+ A06b	B02	+ C		
A02a	+ A03			+ A06c	B01	+ C		+ D
A02b	+ A03			+ A06c	B02	+ C		+ D
A02c	+ A03			+ A06c	B02	+ C		+ D

Note:

*In case there is no accessibility for total station survey, DTM (i.e., B02) may be used even for smaller heights (≤60m).

Table 3 (Continued). Investigation Matrices

(C) For Talus Slopes (Code A01c)

Site Description Based on Inspection					Detailed Field Investigations To Be Undertaken			
Slope Height	Slope Angle	Water Flow Source	Geological Data	Other Instability Issues	Topographical Mapping*	Geological Investigation	Geophysical Investigation	Any Other Investigation
A02a	+ A03				B01	+ C		
A02b	+ A03				B02	+ C		
A02c	+ A03				B02	+ C		
A02a	+ A03	+ A04b			B01	+ C	+ E02	
A02b	+ A03	+ A04b			B02	+ C	+ E02	
A02c	+ A03	+ A04b			B02	+ C	+ E02	
A02a	+ A03			+ A06c	B01	+ C		+ D
A02b	+ A03			+ A06c	B02	+ C		+ D
A02c	+ A03			+ A06c	B02	+ C		+ D

Note:

*In case there is no accessibility for total station survey, DTM (i.e., B02) may be used even for smaller heights (≤60m).

Table 4. List of Mitigation Measures

Broad Category	Code		Mitigation Measure	Reference*
Complete/ Partial Removal of Unstable Material	G01	a	Rock Scaling	IRC SP 48, Clause No. 4.3.2 E, Page No 78
		b	Offloading	IRC SP 48, Clause No. 4.3.2 D, Page No 78
		c	Terrace & Benching	IRC SP 48, Clause No. 4.3.2 D & E, Page No 78
		d	Bally Benching (Benching by Bamboo or Suitable Material)	IRC SP 48, Clause No. 4.3.2 G6, Page No 85
		e	Hill Cutting	IRC SP 48, Clause No. 4.3.2 D, Page No 78
Sub Surface Water/High Pore Pressure	G02	a	Semi Perforated PVC Pipe Wrapped with Non-Woven Geotextile	IRC SP 48, Clause No. 4.3.2 C1, Page No 73
		b	Grout Curtain	IS 11293
		c	Deep Trench Drain	IRC SP 48, Clause No. 4.3.2 C2, Page No 73
Erosion Control of Hill Slope	G03	a	Seeding & Mulching	IRC 56, Clause 5.3 Page No. 12
		b	Hydromulching	IRC SP 48, Clause No. 4.3.2 F4, Page No 83 IRC SP 106, Clause No. 8.3.8.1 & Table 8.7, Page No. 84 & 85 IRC 56, Clause 5.5 Page No. 14
		c	Vetiver Grass / Lemon Grass Plantation / Suitable local deep rooted grass	IRC 56, Clause 5.4 Page No. 12
		d	Jute Geotextile	IRC SP 106, Clause No. 8.3.7.2, Page No. 83

Broad Category	Code		Mitigation Measure	Reference*
		e	Geosynthetic mats/- Erosion Control Blanket (3D mats)	IRC SP 106, Clause No. 8.3.6.1, Page No. 81 & 82; IRC SP 48, Clause No. 4.3.2, F3, Page No 83 IRC 56, Clause 5.9 Page No. 19
		f	Geocell	IRC SP 48, Clause No. 4.3.2 F5, Page No 83 & 84 IRC 56, Clause 5.10 Page No. 22
		g	Coir geotextile	IRC SP 106, Clause No 8.3.7.1, Page No. 82
		h	Geotextile	IRC SP 59, Clause No 2.2, Page No. 16
Retaining Walls/ Structures	G04	a	Gabion Wall	IRC SP 48, Clause No. 4.3.3.2.1 B1 Page No. 96 IRC SP 106, Clause No. 8.3.2 Page No. 79 IRC SP 116
		b	Anchored Gabion Wall	
		c	CC Gravity Wall	IRC SP 48, Clause No. 4.3.3.2.1 A4 Page No. 94 IRC SP 106, Table 8.1 & Page No. 74, Clause No. 8.3.1 & Page No. 78
		d	Anchored CC Gravity Wall (Anchoring is to secure the wall)	
		e	CC Gravity Wall over Raft with Bundled Anchors	
		f	CC Gravity Wall over Raft with Micropile	
		g	RCC Stepped Wall	
		h	Anchored RCC Stepped Wall	
		i	CC Cladding (at Toe)	

Broad Category	Code		Mitigation Measure	Reference*
		j	Anchored CC Cladding (at Toe)	
		k	CC Cladding (over Slope)	
		l	Anchored CC Cladding (over Slope)	
		m	CC Cladding (at Crown)	
		n	Anchored CC Cladding (at Crown)	
		o	Gabion Wall for Supporting Carriageway (Valley Side)	IRC SP 48, Clause No. 4.3.3.2.1 B1 Page No. 96 IRC SP 106, Clause No. 8.3.2 Page No. 79 IRC SP 116
Reinforced Soil Structures	G05	a	Mechanically Stabilised Earth Wall/Reinforced soil wall or slopes	IRC SP 48, Clause No. 4.3.3.2.1 B2 Page No. 97 & 98 IRC SP 106, Table 8.1, Page No. 74 IS 18591 (Section 4 & 5)
		b	Shored Mechanically Stabilised Earth Wall (shored Reinforced soil wall or slopes)	IRC SP 48, Clause No. 4.3.3.2.1 B3 Page No. 98 & 99 IS 18591 (Section 7)
Surficial Treatment	G06	a	Rolled Cable Net** (steel wire ring net panels, steel wire rope net panels) with Secondary Mesh (drapery systems)	IRC SP 48, Clause No. 4.3.3.2.1 B7, Page No 106 to 108 IRC SP 106, Clause No. 8.2.2.1 Page No 76 & Table 8.3, Page No. 77 IS/ISO 17745 & IS/ISO 17746 IS 16014
		b	Wire Mesh** (drapery systems)	
		c	Double Twisted Mesh	
		d	Welded Wire mesh	IS 4948 ASTM A 974 - 97

Broad Category	Code		Mitigation Measure	Reference*
		e	Shotcrete	IRC SP 48, Clause No. 4.3.3.2.1 B7 (iii), Page No 108 & 109
		f	Geosynthetic Cementitious Composite Mat	ASTM D8364
		g	Concrete Crib Work with/ without Nails / Anchors (Japanese Crib wall)	IRC SP 48, Clause No. 4.3.3.2.1 A3 Page No. 93 IRC SP 106, Table 8.1 & Page No. 74
		h	Rolled Cable Net** (steel wire ring net panels, steel wire rope net panels) with Secondary Mesh - drapery system (at Crown)	IRC SP 48, Clause No. 4.3.3.2.1 B7, Page No 106 to 108 IRC SP 106, Clause No. 8.2.2.1 Page No 76 & Table 8.3, Page No. 77 IS/ISO 17745 & IS/ISO 17746 IS 16014
Slope Reinforcement	G07	a	Fully Grouted Solid Anchors (Passive)	IRC SP 48, Clause No. 4.3.3.2.1 B6, Page No 105 & 106 IRC SP 106, Clause No. 8.3.3, Page No. 79 & 80
		b	Self-Drilling Anchors (Passive)	
		c	Soil Nail (Grouted) / Rock Bolt (fully Grouted) (Both Passive)	
		d	Soil Nail Driven Type (Passive)	
		e	Prestressed Cable Anchors / Ground Anchors / Driven Anchors (Active)	IRC SP 48, Clause No. 4.3.3.2.1 B8 (iii), Page No 109 & 110 IRC SP 106, Clause No. 8.3.4, Page No. 80 & 81
River Training Structures	G08	a	Articulating Grouted Concrete Mattress/ Fabric Form Mattress	IRC SP 48, Clause No. 4.3.3.2.1 B5, Page No 103 to 105
		b	Gabion Revetment Mattress	IRC SP 48, Clause No. 4.3.2 F6, Page No 84 IRC SP 48, Clause No. 4.3.3.2.1 B5, Page No

Broad Category	Code		Mitigation Measure	Reference*
				101 to 103 IRC SP 116 (Section 3, 4, 5, 6 &7)
		c	Gabion Spurs	IRC 89, Clause 6
		d	Concrete Spurs	
		e	Tie Back Retaining Walls	IS 14458-1
Rockfall Protection Measures	G09	a	Rockfall Embankment/ Bunds	IRC SP 48, Clause No. 4.3.4.1 d) Page No 114
		b	Flexible / Dynamic Rockfall Barrier	IRC SP 48, Clause No. 4.3.4.1 f) Page No 115 to 117 IRC SP 106, Clause No. 8.2.2.2 Page No 77 & Table 8.4, Page No. 77 & 78 IS/ISO 17745 & IS/ISO 17746
		c	Cut and Cover Tunnel /Rock Shed	IRC SP 48, Clause No. 4.3.4.1 e) Page No 114
		d	Rock Buttress	IRC SP 48, Clause No. 4.3.4.1 a) Page No 112
		e	Attenuators / Attestors	IRC SP 106, Page No. 78 Clause 8.2.2.2
Debris Flow	G10	a	Debris Flow Barrier	IRC SP 48, Clause No. 4.3.4.2 (iv) Page No. 117 & 120 IRC SP 106, Clause No. 8.4.1, Page No. 85
		b	Anchored Gabion Block (short Check Dams made of Gabions placed across debris flow channels)	
		c	Drum Retaining Wall/Drum Anchored Diaphragm Wall	IRC SP 106, Clause No. 8.3.5, Page No. 81

Broad Category	Code		Mitigation Measure	Reference*
		d	Check Dam/Debris Flow Basin	IRC SP 106, Clause No. 8.4.2, Page No. 86
		c	Cut and Cover Tunnel	IRC SP 48, Page No 71
Pavement$	G11	a	RCC Pavement over Self Drilling Rock Anchors	
		b	RCC Pavement over Micropile	IRC SP 48, Clause No. 4.3.3.2.1 B9, Page No 110 & 111 IRC SP 106, Table No. 8.1, Page No. 7
Channelisation of Nala	G12	a	CC Channel	IRC SP 48, Clause No. 4.3.2 (B) Page No. 72 IRC SP 42
		b	Anchored CC Channel	
		c	Gabion Channel / Gabion Revetment Mattress Channel	
		d	Gabion Channel with Anchored Gabion Block	
		e	Contour Drains (to prevent water from entering the treated area, given around periphery of treated area, of lean CC)	IRC SP 48, Chapter 2 Page No. 16 to 39 IRC SP 106, Clause No. 8.5, Page No. 86
Emergency Works, Avalanche Protection & Other Instabilities	G13	a	Umbrella type Slope Consolidation Structure for Road Support	IRC SP 48, Clause No. 4.3.4.2 (v) Page 117& No. 120
		b	Umbrella type slope consolidation Structure for Avalanche Protection	IRC SP 48, Clause No.6.5 Page No. 166 & 168
		c	Articulation Form Mattress with cables for protection for toe erosion by water	IRC SP 48, Clause No.4.3.3.2.1 B5, (b) Page No. 104

Note:

* For the above mentioned codes, the latest update should be referred.

** The tensile strength of the meshes shall be as per codal provisions / design requirements.

1. The above suggested measures have been divided into thirteen broad categories; however, some measures given under one category may also belong to some other categories.
2. Mitigations measures other than above mentioned measures but having similar purpose may also be used.
3. Drainage system shall be provided as per site requirement and additional measures may also be provided in accordance with the guidelines of IRC SP 42.

Table 5. Mitigation Matrices

(A) For Rock Slopes (Code A01a)

Site Assessment Based on Investigations					Elements of Mitigation Measures to be Chosen					
A02	A03	C			G01	G04	G06	G07	G09	G12
		Geology[&]								
Slope Height	Slope Angle	SMR	Failure Mode	Weathering	Removal of Material	Retaining wall	Surface treatment	Slope Reinforcement	Rock fall Protection	Drainage
A02a/b	A03b/c/d	C06a (ii)			G01a					
A02a	A03b	C06a (iii)	C06a (α)	C06a (III)	G01a	G04j		G07a		G12e
A02a	A03b	C06a (iii)	C06a (α)	C06a (IV)	G01a	G04j	G06f	G07a		G12e
A02a	A03c	C06a (iii)	C06a (α)	C06a (III)	G01a	G04j	G06e	G07a		G12e
A02a	A03c	C06a (iii)	C06a (α)	C06a (IV)	G01a	G04j	G06e	G07a		G12e
A02a	A03d/e	C06a (iii)	C06a (α)	C06a (III)	G01a	G04j	G06a	G07a		
A02a	A03d/e	C06a (iii)	C06a (α)	C06a (IV)	G01a	G04j	G06a	G07a		
A02a	A03b	C06a (iii)	C06a (β)		G01a		G06g			
A02a	A03c	C06a (iii)	C06a (β)		G01a	G04c	G06a	G07b		G12e
A02a	A03d/e	C06a (iii)	C06a (β)		G01a	G04d	G06a	G07b		
A02a	A03c	C06a (iii)	C06a (γ)	C06a (III)	G01a	G04m	G06e	G07a		G12e
A02a	A03c	C06a (iii)	C06a (γ)	C06a (IV)	G01a	G04n	G06e	G07b		G12e
A02a	A03d	C06a (iii)	C06a (γ)	C06a (III)	G01a	G04m	G06e	G07a		
A02a	A03d	C06a (iii)	C06a (γ)	C06a (IV)	G01a	G04n	G06a	G07b		
A02a	A03e	C06a (iii)	C06a (γ)	C06a (III) / (IV)	G01a	G04n	G06a	G07b		
A02a	A03c/d/e	C06a (iv)	C06a (α)		G01a	G04j	G06a	G07a		G12e

Site Assessment Based on Investigations									Elements of Mitigation Measures to be Chosen										
A02	+	**A03**	+	**C**					**G01**	+	**G04**	+	**G06**	+	**G07**	+	**G09**	+	**G12**
Slope Height		Slope Angle		Geology[&] SMR		Geology[&] Failure Mode		Geology[&] Weathering	Removal of Material		Retaining wall		Surface treatment		Slope Reinforcement		Rock fall Protection		Drainage
A02a	+	A03c/d/e	+	C06a (iv)	+	C06a (β)			G01a	+	G04d	+	G06a	+	G07b			+	G12e
A02a	+	A03c/d/e	+	C06a (iv)	+	C06a (γ)			G01a	+	G04l								
A02a	+	A03c	+	C06a (v)	+	C06a (α)			G01a	+	G04d	+	G06a	+	G07a			+	G12e
A02a	+	A03c	+	C06a (v)	+	C06a (β)			G01a	+	G04h	+	G06a	+	G07b			+	G12e
A02b	+	A03b	+	C06a (iii)	+	C06a (α)	+	C06a (III)	G01a	+	G04i	+	G06e	+	G07a			+	G12e
A02b	+	A03b	+	C06a (iii)	+	C06a (α)	+	C06a (IV)	G01a	+	G04i	+	G06f	+	G07b			+	G12e
A02b	+	A03c	+	C06a (iii)	+	C06a (α)	+	C06a (III)	G01a	+	G04i	+	G06e	+	G07a			+	G12e
A02b	+	A03c	+	C06a (iii)	+	C06a (α)	+	C06a (IV)	G01a	+	G04j	+	G06a	+	G07b			+	G12e
A02b	+	A03d/e	+	C06a (iii)	+	C06a (α)	+	C06a (III)	G01a	+	G04j	+	G06a	+	G07a				
A02b	+	A03d/e	+	C06a (iii)	+	C06a (α)	+	C06a (IV)	G01a	+	G04j	+	G06a	+	G07b				
A02b	+	A03b/c	+	C06a (iii)	+	C06a (β)			G01a	+	G04d/j*	+	G06a	+	G07b			+	G12e
A02b	+	A03d/e	+	C06a (iii)	+	C06a (β)			G01a	+	G04d/j	+	G06a	+	G07b				
A02b	+	A03c	+	C06a (iii)	+	C06a (γ)	+	C06a (III)/(IV)	G01a	+	G04m	+	G06e	+	G07a			+	G12e
A02b	+	A03d/e	+	C06a (iii)	+	C06a (γ)	+	C06a (III)/(IV)	G01a	+	G04n	+	G06a	+	G07b		G09c/f		
A02b	+	A03c/d/e	+	C06a (iv)	+	C06a (α)			G01a	+	G04j	+	G06a	+	G07a		G09c/f		
A02b	+	A03c/d/e	+	C06a (iv)	+	C06a (β)			G01a	+	G04d	+	G06a	+	G07b				
A02b	+	A03c/d/e	+	C06a (iv)	+	C06a (γ)			G01a	+	G04l								
A02a/b	+	A03c/d/e	+	C06a (v)	+	C06a (α)/(β)/(γ)	+	C06a (V)	G01c	+	G04d/j	+	G06a	+	G07b	+	G09b/e		

Site Assessment Based on Investigations						Elements of Mitigation Measures to be Chosen					
A02 +	**A03** +	**C**				**G01** +	**G04** +	**G06** +	**G07** +	**G09** +	**G12**
Slope Height	Slope Angle	Geology[&] SMR	Geology[&] Failure Mode	Geology[&] Weathering		Removal of Material	Retaining wall	Surface treatment	Slope Reinforcement	Rock fall Protection	Drainage
A02c +	A03 +	C06a (iii) +	C06a (α)/(β)			G01a +	G04d +	G06h +	G07a +	G09a/b/e/f	
A02c +	A03 c/d/e +	C06a (iii) +	C06a (γ) +	C06a (III)/(IV)		G01a +	G04d+ G04n[#]			+ G09b/e	
A02c +	A03c/d/e +	C06a (iv) +	C06a (α)/(β)/(γ)			G01a +	G04d/j +	G06a +	G07b +	G09b/e	
A02c +	A03c/d/e +	C06a (v) +	C06a (α)/(β)/(γ)			G01a +	G04d/j +	G06h +	G07b +	G09b/e	

Additional Measures to Curb the Adverse Effect of Subsurface Water/Flowing Water over Slope						
A02 +	**A03** +	**A04** +	**C**	**G01** +	**G02** +	**G12**
Slope Height	Slope Angle	Seepage Source		Removal of Material	Perforated pipes	Channelisation of Nala
A02 +	A03a	A04a			+	G12a
A02 +	A03b	A04a			+	G12a
A02 +	A03c	A04a			+	G12b
A02 +	A03d	A04a			+	G12b
A02 +	A03	A04b		+	G02a	

Additional Measures for Shooting Stone Condition^									
A02	+	**A03**	+	**A04**	+	**A06**	+	**C**	**G09**
Slope Height		Slope Angle		Seepage Source		Shooting Stone		Geology	Rockfall Protection Measures
A02	+	A03				A06b			G09a**/G09b/G09c/G09e

Note:

[&]In cases where a site assessment factor is not written, it indicates that the particular factor is not a deciding factor for choosing mitigation measures.

* / sign inside cell indicates that one of the two measures are to be chosen. For e.g., G04d/j indicates that either G04d or G04j is to be chosen.

[#]plus inside cell indicates both mitigation measures are to be chosen. For e.g., G04d+G04n indicates that both G04d and G04n are to be chosen.

**G09a – Rockfall Embankment shall only be chosen for the locations having sufficient Road Width

^For the case - Slope height greater than 100m and Shooting Stone, ceasing of instability at crown and provision of rockfall barrier system is suggested as Cost Effective Solution. Ceasing of instability at crown can be done by provision of Anchored CC Cladding at Crown or provision of rolled cable net + self-drilling anchors.

Table 5. Mitigation Matrices

(B) For Debris / Soil Slopes (Code A01b)

Site Assessment Based on Investigations							Elements of Mitigation Measures to be Chosen												
A02	**+**	**A03**	**+**	**A07**		**C06**	**G01**	**+**	**G03**	**+**	**G04**	**+**	**G05**	**+**	**G06**	**+**	**G07**	**+**	**G12**
Slope Height		Slope Angle		RoW		Slope Composition	Removal of Material		Erosion Control		Retaining Wall*		Reinforced Structures*		Surface Treatment		Slope Reinforcement		Drainage
A02	+	A03a			+	C06b (I)			G03a/c	+	G04a								
A02a	+	A03b			+	C06b (I)	G01d**	+	G03a/c									+	G12e
A02a	+	A03b			+	C06b (I)	G01b	+	G03	+	G04a					+	G07d	+	G12e
A02a	+	A03c			+	C06b (I)	G01c	+	G03a+G06g/d	+	G04a			+	G06c	+	G07d	+	G12e
A02a	+	A03d			+	C06b (I)	G01c	+	G03b+G06e	+	G04e/f			+	G06b	+	G07d	+	G12e
A02b/c	+	A03b			+	C06b (I)	G01b	+	G03	+	G04a*		G05a/b*	+	G06b/d	+	G07d	+	G12e
A02b/c	+	A03c			+	C06b (I)	G01c	+	G03a+G03g/d	+	G04a*		G05a/b*	+	G06b/d	+	G07d	+	G12e
A02b/c	+	A03d			+	C06b (I)	G01c	+	G03b+G03e	+	G04e/f*		G05b*	+	G06b/d	+	G07b	+	G12e
A02	+	A03b	+	A07	+	C06b (I)	G01b	+	G03a/c	+	G04a*		G05b*	+	G06b/d	+	G07d	+	G12e
A02	+	A03c	+	A07	+	C06b (I)	G01b	+	G03b	+	G04e/f*		G05b*	+	G06b/d	+	G07d	+	G12e
A02	+	A03d	+	A07	+	C06b (I)	G01b	+	G03b+G03e	+	G04e/f*		G05b*	+	G06b/d	+	G07b	+	G12e
A02	+	A03b			+	C06b (II)	G01b	+	G03a+G03d	+	G04d*		G05b*	+	G06b/d	+	G07b	+	G12e
A02	+	A03c			+	C06b (II)	G01b	+	G03b+G03e	+	G04d*		G05b*	+	G06b/d	+	G07b	+	G12e
A02	+	A03d			+	C06b (II)	G01c	+	G03a+G03d	+	G04e/f*		G05b*	+	G06b/d	+	G07b	+	G12e
A02	+	A03e			+	C06b (II)	G01c	+	G03b+G03e	+	G04e/f			+	G06a	+	G07b	+	
A02	+	A03b/c	+	A07	+	C06b (II)	G01b	+	G03a+G03d	+	G04d*		G05b*	+	G06b/d	+	G07b	+	G12e
A02	+	A03d/e	+	A07	+	C06b (II)	G01b	+	G03b+G03e	+	G04d*		G05b*	+	G06b/d	+	G07b	+	G12e

Site Assessment Based on Investigations							Elements of Mitigation Measures to be Chosen												
A02	**+**	**A03**	**+**	**A07**		**C06**	**G01**	**+**	**G03**	**+**	**G04**	**+**	**G05**	**+**	**G06**	**+**	**G07**	**+**	**G12**
Slope Height		Slope Angle		RoW		Slope Composition	Removal of Material		Erosion Control		Retaining Wall*		Reinforced Structures*		Surface Treatment		Slope Reinforcement		Drainage
A02a	+	A03b/c			+	C06b (III)	G01b			+	G04e/f			+	G06a	+	G07b	+	G12e
A02a	+	A03d			+	C06b (III)	G01b			+	G04e/f			+	G06a	+	G07b	+	G12e
A02a	+	A03e			+	C06b (III)	G01b			+	G04e/f			+	G06a	+	G07b	+	G12e
A02b/c	+	A03b/c			+	C06b (III)	G01b			+	G04e/f/g*		G05a/b*	+	G06a	+	G07b	+	G12e
A02b/c	+	A03d			+	C06b (III)	G01b			+	G04e/f/g*		G05a/b*	+	G06a	+	G07b/G07e	+	G12e
A02b/c	+	A03e			+	C06b (III)	G01b			+	G04e/f/g			+	G06a	+	G07b/G07e	+	G12e

Additional Measures to Curb the Adverse Effect of Subsurface Water / Flowing Water Over Slope											
A02	**+**	**A03**	**+**	**A04**	**+**	**C06**	**G02**	**+**	**G10**	**+**	**G12**
Slope Height		Slope Angle		Seepage Source		Slope Composition	Perforated pipes		Debris Flow Barrier		Channelisation of Nala
A02	+	A03b/c	+	A04a	+	C06b				+	G12c
A02	+	A03d/e	+	A04a	+	C06b				+	G12d
A02	+	A03	+	A04b	+	C06b	G02a	+	G10a	+	

Additional Measures to Curb the Adverse Effect of Surface Flowing Water along with Debris Over Slope											
A02	**+**	**A03**	**+**	**A04**	**+**	**C**	**G02**	**+**	**G10**	**+**	**G12**
Slope Height		Slope Angle		Seepage Source		Slope Composition	Perforated pipes		Debris Flow Barrier		Channelisation of Nala
A02	+	A03b/c	+	A04a	+	C06b			G10b		G12c
A02	+	A03d/e	+	A04a	+	C06b			G10a		G12d

Note:

* While Retaining Walls (Code G04) are useful for hill side stabilisation, Reinforced soil structures (Code G05) are recommended for valley side construction. Mechanically Stabilised Earth Walls (Code G05a) are useful for locations where formation has breached and there is limitation on hill side cutting due to RoW or vulnerable slope on hill side. Reinforced wall shoring (Code G05b) is suitable at

places with excessive settlement and where sufficient foundation width is not available. In case of valley side being a water front structure, either of the two (i.e., retaining wall or reinforced soil structure) may be used depending upon the site conditions. In such cases, however, reinforced soil structure shall be designed as a submerged structure (IS 18591) and it may need to be combined with River Training Works (Code G08).

** The provision of bally benching should be recommended for locations where indigenous reinforcing materials are readily available and where there is no presence of moderate to heavy subsoil seepage water pressure or water springs.

1. If affected slope mass comprises of combination of exposed debris and rock surface, in those cases, investigation and design shall be combination of each slope type.
2. Provision of Off-loading shall be suggested as the per site requirement.
3. For site having high seepage water and installation of semi perforated pipe seems to be ineffective and there is no RoW restriction, in those cases, grout curtain (G02b) on uphill side may be suggested.

Table 5. Mitigation Matrices

(C) For Talus Slopes (Code A01c)

Site Assessment Based on Investigations					Elements of Mitigation Measures to be Chosen					
A02	+ **A03**	+ **A07**	+ **C04**	+ **C06**	**G01**	+ **G03**	+ **G04**	+ **G06**	+ **G07**	**G12**
Slope Height	Slope Angle	RoW	Rock Debris Contact Depth	Slope Assess ment	Removal of Material	Erosion Control	Retaining Wall	Surface Treat ment	Slope Reinforce ment	Drainage
A02	+ A03a		+ C04	+ C06c	G01b	+ G03c				
A02	+ A03b		+ C04	+ C06c	G01b	+ G03a/d	+ G04c	+ G06a	+ G07b	+ G12e
A02	+ A03c		+ C04	+ C06c	G01b	+ G03a/g	+ G04d	+ G06a	+ G07b	+ G12e
A02	+ A03d/e		+ C04	+ C06c	G01b	+ G03b/e	+ G04e	+ G06a	+ G07b	+ G12e
A02	+ A03d/e	+ A07	+ C04	+ C06c	G01b	+ G03b/e	+ G04e	+ G06a	+ G07b	+ G12e

Additional Measures to Curb the Adverse Effect of Subsurface Water / Surface Flowing Water Over Slope						
A02	+ **A03**	+ **A04**	+ **C**	**G02**	+ **G10**	+ **G12**
Slope Height	Slope Angle	Seepage Source	Slope Composition	Perforated pipes	Debris Flow Barrier	Channelisation of Nala
A02	+ A03a/b	+ A04a	+ C06c			G12c
A02	+ A03c/d/e	+ A04a	+ C06c			G12d
A02	+ A03	+ A04b	+ C06c	G02a		

Additional Measures to Curb the Adverse Effect of Surface Flowing Water along with Debris Over Slope						
A02	+ **A03**	+ **A04**	+ **C**	**G02**	+ **G10**	+ **G12**
Slope Height	Slope Angle	Seepage Source	Slope Composition	Perforated pipes	Debris Flow Barrier	Channelisation of Nala
A02	+ A03a/b	+ A04a	+ C06c		G10b	G12c
A02	+ A03c/d/e	+ A04a	+ C06c		G10a	G12d

Note:

If affected Slope Mass comprises of combination of exposed Debris and Rock surface, in those cases, Investigation and Design shall be a combination of each Slope type.

Table 5. Mitigation Matrices

(D) For Additional Measures to Curb Instability Issues (Code A06)

(i) Sinking

ADDITIONAL MEASURES TO BE SUGGESTED TO CURB THE EFFECTS SINKING												
A02	+	**A03**	+	**A06**	**G01**	+	**G02**	+	**G04**	+	**G11**
Slope Height		Slope Angle		Instability issue	Removal of Material		Erosion Control		Retaining Wall		Pavement
A02	+	A03	+	A06a			G02a	+	G04e+G04o	+	G11a/ G11b*

Note:

1. Consolidation grouting* is also recommended in the sinking zone to reclaim finer particle loss.

*Refer MoRTH DPR (2024) and NHAI DPR (2024) for application of 'RCC pavement over micropile plus consolidation grouting' measures.

(ii) River Action at Valley Toe

ADDITIONAL MEASURES TO BE SUGGESTED TO CURB THE EFFECT OF RIVER ACTION AT VALLEY TOE											
A02	+	**A03**	+	**A06**	+	**C**	**G01**	+	**G04 / G05**	+	**G08**
Slope Height		Slope Angle		Instability issue		Slope Assessment	Removal of Material		Retaining Wall / Reinforced Structures		River Training Structures
A02	+	A03	+	A06c	+	C06a			G04j	+	G08a+G08d
A02	+	A03	+	A06c	+	C06b			G04e / G05a / G05b	+	G08a+G08b+G08c

(iii) Road Widening towards Hill Side

ADDITIONAL MEASURES TO BE SUGGESTED FOR ROAD WIDENING – HILL SIDE																
A02	+	**A03**	+	**A06**	+	**A07**	+	**C**	**G01**	+	**G04**	+	**G06**	+	**G07**
Slope		Slope		Instability		RoW		Slope	Removal of		Retaining		Surface		Slope

Height	Angle	Issue				Assessment	Material	Wall	Treatment		Reinforcement
A02	A03	A06d	+	A07	+	C06a	G01e	G04j	G06a	+	G07b
A02	A03	A06d	+	A07	+	C06b	G01e	G04b	G06a	+	G07b
A02	A03	A06d	+	A07	+	C06c	G01e	G04d	G06a	+	G07b

(iv) Road Widening towards Valley Side

ADDITIONAL MEASURES TO BE SUGGESTED FOR ROAD WIDENING – VALLEY SIDE											
A02	+	**A03**	+	**A06**	+	**A07**	+	**C**	**G01**	+	**G05**
Slope Height		Slope Angle		Instability Issue		RoW		Geology	Removal of Material		Reinforced Structure
				A06d						+	G05a/b

(v) Emergency Road Support

ADDITIONAL MEASURES TO BE SUGGESTED FOR EMERGENCY ROAD SUPPORT							
A02	+	**A03**	+	**A06**	**G01**	+	**G13**
Slope Height		Slope Angle		Instability Issue	Removal of Material		Emergency Works
				A06f			G13a

Note:

1. Suggested measure is temporary solution and shall be suggested in case of emergency works

(vi) Avalanche

ADDITIONAL MEASURES TO BE SUGGESTED FOR AVALANCHE							
A02	+	**A03**	+	**A06**	**G01**	+	**G13**
Slope Height		Slope Angle		Instability Issue	Removal of Material		Emergency Works
				A06g			G13b

Bibiliography***

1. AASHTO manual. "LRFD Bridge Design Specifications", *American Association of State Highway and Transportation Officials.*
2. ASTM A974-97. "Standard Specification for Welded Wire Fabric Gabions and Gabion Mattress", *American Society for Testing and Materials.*
3. ASTM D5338. "The Aerobic Biodegradability under Controlled Composting Condition", *American Society for Testing and Materials.*
4. ASTM D7332. "Standard Test Method for Determination of Erosion Control Product (ECP) Ability to Encourage Seed Germination and Plant Growth Under Bench-Scale Conditions", *American Society for Testing and Materials.*
5. ASTM D7367. "Standard Test Method for Determining Water Holding Capacity of Fiber Mulches for Hydraulic Planting", *American Society for Testing and Materials.*
6. BS 8006-1. "Code of Practice for Strengthened / Reinforced Soils and other Fills", *British Standard.*
7. BS 8006-2. "Code of Practice for Strengthened / Reinforced Soils Walls - Soil Nail Design", *British Standard.*
8. BS 8081. "Code of Practice for Ground Anchorages", *British Standard.*
9. BS EN 1537. "Execution of Special Geotechnical Works – Ground Anchors", *British Standard.*
10. BS EN 14199. "Execution of Special Geotechnical Works - Micropiles", *British Standard.*
11. CIRIA C637. "Soil Nailing-Best Practice Guide", *CIRIA, UK.*
12. EAD 230005-00-0106. "Wire Rope Net Panels", *European Organisation for Technical Approvals, Brussels.*
13. EAD-340020-00-0106. "Guideline for European Technical Approval of Falling Rock Protection Kits", *European Organisation for Technical Approvals, Brussels.*
14. EAD-340059-00-0106. "Falling Rock Protection Kits", *European Organisation for Technical Approvals, Brussels.*
15. EN ISO 1461. "Hot Dip Galvanized Coatings on Fabricated Iron and Steel Articles-Specifications and Test Methods", *European Committee for Standardization, Brussels.*
16. EN ISO 14475. "Execution of Special Geotechnical Works-Reinforced fill", *European Committee for Standardization, Brussels.*
17. FHWA-CFL/TD-06-001. "Shored Mechanically Stabilized Earth (SMSE) Wall Systems Design Guidelines", *Federal Highway Administration, Lakewood, CO.*
18. FHWA-CFL/TD-11-002. "Context Sensitive Rock Slope Design Solutions", *Federal Highway Administration, Lakewood, CO.*
19. FHWA-IF-02-034. "Geotechnical Engineering - Evaluation of Soil and Rock Properties", *Federal Highway Administration, Washington, D.C.*
20. FHWA-IF-99-015. "Geotechnical Engineering - Ground Anchors and Anchored Systems", Federal *Highway Administration, Washington, D.C.*

21. FHWA NHI-05-039. "Micropile Design and Construction", *National Highway Institute, Federal Highway Administration, Washington, D.C.*

22. FHWA-NHI-10-024 GEC 011-Vol I. "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes", Volume 1, *National Highway Institute,* Federal *Highway Administration, Washington, D.C.*

23. FHWA-NHI-10-025 GEC 011 – Vol II. "Design and Construction of Mechanically Stabilized Earth walls and Reinforced Soil Slopes", *Volume 2, National Highway Institute, Federal Highway Administration, Washington, D.C.*

24. FHWA-NHI-14-007 GEC 007. "Soil Nail Walls-Reference Manual", *National Highway Institute, Federal Highway Administration, Washington, D.C.*

25. FHWA-NHI-HEC-23. "Bridge Scour and Stream Instability Countermeasures, Experience, Selection and Design Guidance", Volumes 1 and 2, *National Highway Institute, Federal Highway Administration, Washington, D.C.*

26. IRC 34. "Guidelines on Recommendations for Road Construction in Areas Affected by Water Logging, Flooding and/or Salts Infection", *Indian Road Congress, New Delhi.*

27. IRC 56. "Guidelines on Recommended Practices for Treatment of Embankment and Roadside Slopes for Erosion Control", *Indian Road Congress, New Delhi.*

28. IRC 75. "Guidelines for the Design of High Embankments", Indian *Road Congress, New Delhi.*

29. IRC 78. "Specifications and Code of Practice for Road Bridges-Section –VII-Foundations and Substructures", *Indian Road Congress, New Delhi.*

30. IRC 89. "Guidelines for Design and Construction of River Training and Control Works for Road Bridges", *Indian Road Congress, New Delhi.*

31. IRC 123. "Guidelines on Geophysical Investigation for Bridges", *Indian Road Congress, New Delhi.*

32. IRC HRB 15. "State of the Art: Landslide correction Techniques", *Indian Road Congress, New Delhi.*

33. IRC HRB 23. "State of Art: Design and Construction of Rockfall Mitigation Systems", *IRC Highway Research Board, New Delhi.*

34. IRC SP 19. "Manual for Survey, Investigation and Preparation of Road Projects", *Indian Road Congress, New Delhi.*

35. IRC SP 42. "Guidelines on Road Drainage", *Indian Road Congress, New Delhi.*

36. IRC SP 48. "Hill Road Manual", *Indian Road Congress, New Delhi.*

37. IRC SP 59. "Guidelines for Use of Geosynthetics in Road Pavements and other Associated Works", *Indian Road Congress, New Delhi.*

38. IRC SP 73. "Manual of Standards and Specifications for Two Laning of State Highways on B.O.T. Basis", *Indian Road Congress, New Delhi.*

39. IRC SP 80. "Corrosion Prevention", *Indian Road Congress, New Delhi.*

40. IRC SP 102. "Guidelines for the Design and Construction of Reinforced Soil Walls", *Indian Road Congress, New Delhi.*

41. IRC SP 106. "Engineering Guidelines on Landslide Mitigation Measures for Indian Roads", *Indian Road Congress, New Delhi.*

42. IRC SP 109. "Guidelines for Design and Construction of Small Diameter Piles for Road Bridges", *Indian Road Congress, New Delhi.*

43. IRC SP 113. "Guidelines on Flood Disaster Mitigation for Highway Engineers", *Indian Road Congress, New Delhi.*

44. IRC SP 116. "Guidelines for Design and Installation of Gabion Structures", *Indian Road Congress, New Delhi.*

45. IS 2131. "Method for Standard Penetration Test for Soils", *Bureau of Indian Standards, New Delhi.*

46. IS 4948. "Welded Steel Wire Fabric for General Use — Specification", *Bureau of Indian Standards, New Delhi.*

47. IS 10270. "Guidelines for Design and Construction of Prestressed Rock Anchors", *Bureau of Indian Standards, New Delhi.*

48. IS 11293. "Design of Grout Curtains for Earth and Rockfill Dams, Masonry Dams and Concrete Gravity Dams", *Bureau of Indian Standards, New Delhi.*

49. IS 11309. "Method of conducting pull-out test on anchor bars and rock bolts", *Bureau of Indian Standards, New Delhi.*

50. IS 12070. "Design and Construction of Shallow Foundations on Rocks", *Bureau of Indian Standards, New Delhi.*

51. IS 14458 Part 1. "Retaining wall for Hill Area-Guideline-Selection of type of Wall", *Bureau of Indian Standards, New Delhi.*

52. IS 14458 Part 2. "Retaining wall for Hill Area-Guideline-Design of Retaining/Breast Walls", *Bureau of Indian Standards, New Delhi.*

53. IS 14458 Part 3. "Retaining wall for Hill Area-Guideline-Construction of Dry-Stone Walls", *Bureau of Indian Standards, New Delhi.*

54. IS 14458 Part 4. "Retaining wall for Hill Area-Guideline-Construction of Banded Dry-Stone Walls", *Bureau of Indian Standards, New Delhi.*

55. IS 14458 Part 5. "Retaining wall for Hill Area-Guideline-Construction of Cement Stone Walls", *Bureau of Indian Standards, New Delhi.*

56. IS 14458 Part 6. "Retaining wall for Hill Area-Guideline-Construction of Gabion Walls", *Bureau of Indian Standards, New Delhi.*

57. IS 14680. "Landslide Control Guidelines", *Bureau of Indian Standards, New Delhi.*

58. IS 15681. "Geological Exploration by Geophysical Method (Seismic Refraction)", *Bureau of Indian Standards, New Delhi.*

59. IS 15736. "Geological Exploration by Geophysical Method (Electrical Resistivity)", *Bureau of Indian Standards, New Delhi.*

60. IS 15872. "Application of Coir Geotextiles (Coir Woven bhoovastra) for Rainwater Erosion Control in Roads, Railway Embankments and Hill Slopes – Guidelines", *Bureau of Indian Standards, New Delhi.*

61. IS 16014. "Mechanically Woven, Double-Twisted, Hexagonal Wire Mesh Gabions, Revet Mattresses, Rock Fall Netting and Other Products for Civil Engineering Purposes (Galvanized Steel Wire or Galvanized Steel Wire with Polymer Coating)", *Bureau of Indian Standards, New Delhi.*
62. IS 16098 Part 2. "Structured-Wall Plastics Piping Systems for Non-Pressure Drainage and Sewarage - Specification, Pipes and Fittings with Non-Smooth External Surface", *Bureau of Indian Standards, New Delhi.*
63. IS 18591. "Geosynthetic Reinforced Soil Structures — Code of Practice", *Bureau of Indian Standards, New Delhi.*
64. IS / ISO 17745. "Steel Wire Ring Net Panels Definitions and Specifications", *International Organisation for Standard, UK.*
65. IS / ISO 17746. "Steel Wire Rope Net Panels and Rolls-Definitions and Specifications", *International Organisation for Standard, UK.*
66. MoRTH DPR (2024). "Detailed Project Report for location at Ch. 20.415 to 20.615 km along Pasighat-Pangin (NH-13), Arunachal Pradesh", *Ministry of Road, Transport and Highways,* February 2024.
67. MORTH manual. "Specifications for Road and Bridge Works", *Indian Road Congress, New Delhi.*
68. NHAI DPR (2024). "Detailed Project Report for Slope Protection measures at Ch. 105.00 to 105.10 km along Jowai-Ratacherra Road (NH-06), East Khasi Hills District, Meghalaya", *National Highway Authority of India,* June 2024.
69. ONR 24810. "A Comprehensive Guideline for Building Better Rockfall Protection Structures", *Austrian Standards Institute.*
70. UNI 11167. "Structures for Rockfall Protection - Rockfall Embankments, Procedure Impact Test and Its Realization", *Ente Nazionale Italiano di Unificazione.*
71. UNI 11211 Part-4. "Rockfall Protective Measures - Part 4: Definitive and Executive Design", *Ente Nazionale Italiano di Unificazione.*
72. WSDOT M 46-03.16, "Geotechnical Design Manual", *WSDOT, Department of Transportation, Washington State.*
73. WSDOT WA-RD 612.2, "Design Guidelines for Wire Mesh/Cable Net Slope Protection", *WSDOT, Department of Transportation, Washington State.*

***In the codes mentioned above, the year of publication is not given; the latest update of the code shall be referred.

Annexure-A1

Steps to Use the Matrices

Steps to use the matrices are given under two broad categories, namely, Investigation stage and Mitigation measure stage, as given below.

(A) INVESTIGATION STAGE

The following step-by-step procedure should be followed.

a) Site Inspection or Reconnaissance Survey (Table 2A)

Reconnaissance survey is mandatory for designing the mitigations measures for the landslide prone area.

In hilly regions, there are many chronic landslide zones along road stretches, and many have developed in recent years which have disrupted the traffic. On receiving the report of any such event, the site engineer must visit the site for the reconnaissance survey.

During the Reconnaissance Survey, the following parameters shall be noted by visual inspection for planning and investigation purposes:

A01 - Slope Mass Type
A02 - Slope Height
A03 - Slope Angle
A04 - Source of Seepage
A05 - Area of Affected Slope
A06 - Other Instability Issues, if any
A07 - RoW Restriction.

These parameters may be ticked by the site engineer in a Site Assessment Check-list Sheet similar to the one given in Annexure A6.

b) Topographical Mapping (Table 2B)

The output of topographic survey is a topographical contour plan along with the corresponding cross sections of the affected site. The topographic survey is done either by total station or Lidar survey (Digital or Infrared videography may also be sufficient for small heights). For the sites, where the slope height is more than 60 m or there is no accessibility for total station survey, the topographic survey shall be carried out by Drone (UAV) with or without Lidar. The topographic survey shall be done on the scale of 1:500 to 1:2000. For larger areas, the scale of 1:500 might not be practical.

The information on slope geometry parameters, such as slope height and slope angle, gathered during the site inspection or reconnaissance survey is also verified from this survey.

c) Geological Investigation (Table 2C)

A geological investigation is the backbone of the investigation stage and shall be conducted by an experienced geologist. In this investigation, geological mapping of slope surface is done. The following parameters comprise the geological Investigation (Table 2C).

C01 - Assessment of Slope by Analyzing the Google Earth Imagery
C02 - Study of Physiography and Geomorphology
C03 - Study of Regional Geology
C04 - Site Specific Geology
C05 - Determining the Causative Factors
C06 - Slope Assessment (C06a/ C06b/ C06c)

- Determination of strength parameters of affected slope mass
- Determination of weathering characteristics of slope
- Type of slope composition (i.e., Rock slope, Debris slope, Talus slope)
- Type of Failure

C07 - Geological Mapping Incorporated with Joint Data

For Rock Slope, SMR class will be determined (refer Annexure A2). For weathering characteristics of slope, Annexure A3 may be referred. For Debris and Talus slopes, the determination of strength parameters of affected slope mass shall be done by back analysis (refer Annexure A4). These parameters will be used in the design of mitigation measures of the slope and evaluating its post mitigation stability. For the design of retaining structures, safe bearing capacity shall be evaluated as per codal provisions (refer Annexure A5).

d) Hydrological / Meteorological Investigation (Table 2D)

A hydrological / meteorological investigation shall be carried out for the slopes where the instability is due to toe erosion by river action (i.e., Code A06c). This Investigation shall be conducted for the determination of the following parameters.

D01 - Determination of Catchment Area
D02 - Determination of Peak Discharge
D03 - Determination of HFL, LWL, NWL, RBL
D04 - Analysis of Rainfall Data

Note that the rainfall data shall be analysed for the states having Average annual rainfall greater than 1800 mm as well as for local areas in other states that are susceptible to cloudburst (i.e., getting more than 100 mm rainfall per hour).

e) Geophysical Investigation (Table 2E)

A geophysical investigation (IRC 123) majorly involves the following two types of tests.

E01 - Seismic Refraction Tomography (IS 15681) / MASW
E02 - Electrical Resistivity Tomography (IS 15736)

The seismic refraction tomography (IS 15681) or Multichannel Analysis of Surface Waves (MASW) shall be conducted when no rock exposure is observed during geological investigation (i.e., case C04e) and on the recommendation of geologist. For the slopes, where seepage is observed during dry season, electrical resistivity tomography (IS 15736) shall be conducted.

f) Geotechnical Investigation (Table 2F)

Geotechnical investigation involves field work (borehole drilling, trial pits, etc.), in situ tests and laboratory tests. Standard Penetration Test (IS 2131) shall be conducted on site. For laboratory tests, both disturbed and undisturbed samples shall be obtained from borehole / trial pits. Various laboratory tests shall be conducted for determination of index and engineering properties.

Borehole drilling shall be performed at locations where geological investigations reveal that the depth of rock debris contact is more than 10 m. Borehole drilling shall also be conducted at sites where instability due to sinking is observed.

g) Investigation Matrix

The parameters related to site investigation (points b to f above) may be ticked by the site engineer in a Investigation Check-list sheet similar to the one given in Annexure-A6.

Based on a combination of site parameters observed during reconnaissance survey, site investigations to be performed at the site are given in the investigation matrix. Three investigation matrices are given, one each for rock slope, debris/soil slope and talus slope (Tables 3A, 3B and 3C).

(B) MITIGATION MEASURE STAGE

This stage involves listing of site assessment parameters and determination of mitigation measures.

a) Site Assessment Parameters

Once the site investigation is completed as per the investigation matrix, the following parameters are listed that constitute site assessment.

A01 - Slope Mass Type – It may be Debris, Rock and Talus Slope
A02 - Slope Height
A03 - Slope Angle
A04 - Source of Seepage
A06 - Other Instability Issues, if any
A07 - RoW Restriction
C - Geology

In case the slope mass type (Code A01) is rock, Geology (Code C) will be described by the following sub-parameters.

C06a(i-v) – SMR class
CO6a(I-V) – Weathering grade
C06a(α-γ) – Type of failure

In case the slope mass type (Code A01) is Debris/Soil, Geology (Code C) will be described by the following sub-parameter.

C06b(I-III) – Type of Slope composition

In case the slope mass type (Code A01) is Debris/Soil, Geology (Code C) will be described by the following sub-parameter.

C04a-e – Rock Debris contact depth

b) Determination of Mitigation Measures

Four mitigation matrices are given, one each for rock slope, debris slope and talus slope and one for additional measures to curb instability issues (Tables 5A, 5B, 5C and 5D). For determination of mitigation measures, a relevant table (Tables 5A, 5B, 5C and 5D) shall be referred and based on the combination of site assessment parameters, required elements of mitigation measures shall be chosen. Snapshots of some mitigation measures taken from Hill Road Manual are given in Annexure A7.

Annexure-A2

Slope Mass Rating (SMR)

To determine Slope Mass Rating (SMR) values, first Rock Mass Rating (RMR) is determined. Using RMR values, SMR values are then obtained.

a) Rock Mass Rating (RMR) Values

In Rock Mass Rating, the following six parameters are used to classify the rock mass.

1. Uni-axial Compressive Strength of Rock material
2. Rock Quality Designation
3. Spacing of discontinuities
4. Condition of discontinuities
5. Ground water condition
6. Orientation of discontinuities

The values of above parameters can be worked out based on Annexure B of IS 13365 (Part I).

b) Slope Mass Rating (SMR) Values

Slope Rock Mass Rating (SMR) is a method to assess the stability of natural and cut slopes. Slope mass rating (SMR) can be obtained based on IS 13365, Part 3 as follows:

$$SMR = RMR_{basic} + (F_1 \times F_2 \times F_3) + F_4$$

$$RMR_{basic} = \Sigma \text{ Parameters } (I + II + III + IV + V)$$

$$RMR = RMR_{basic} + \text{adjustment for joint orientation}$$

Factors F1, F2, F3 and F4 are determined as given in Tables A1 and A2. Slope Stability Classes as per SMR values are given in Table A3.

Slope mass rating is being used successfully for landslide zonation in rocky and hilly areas. Detailed studies should be carried out where SMR is less than 40 and life and property are in danger; and slopes should be stabilized accordingly. Otherwise, a safe cut slope angle should be determined to raise SMR to 60.

Table A1. Slope Mass Rating Factors F_1, F_2 and F_3 (IS 13365, Part 3)

Case of Slope Failure		Very Favourable	Favourable	Fair	Unfavour-able	Very Unfavourable
P T W	$\lvert\alpha_j - \alpha_s\rvert$ $\lvert\alpha_j - \alpha_s - 180°\rvert$ $\lvert\alpha_i - \alpha_s\rvert$	>30°	30 - 20°	20 - 10°	10 - 5°	<5°
P/W/ T	**F_1**	0.15	0.40	0.70	0.85	1.00
P W	$\lvert\beta_j\rvert$ $\lvert\beta_i\rvert$	<20°	20 - 30°	30 - 35°	35 - 45°	>45°
P/W	**F_2**	0.15	0.40	0.70	0.85	1.00
T	**F_2**	1.0	1.0	1.0	1.0	1.0
P W	$\lvert\beta_j - \beta_s\rvert$ $\lvert\beta_i - \beta_s\rvert$	>10°	10 - 0°	0°	0 - (-10°)	< -10°
T	$\lvert\beta_j + \beta_s\rvert$	<110°	110 - 120°	>120°	--	--
P/W/T	**F_3**	0	-6	-25	-50	-60

NOTATIONS: P - planar failure; T- toppling failure; W - wedge failure; α_s - slope strike; α_j - joint strike; α_i - plunge direction of line of intersection; β_s - slope dip and β_j - joint dip (see Figure 17.1); β_i - plunge of line of intersection

Table A2. Slope Mass Rating Factor F_4 (IS 13365, Part 3)

Method	Natural Slope	Pre-splitting	Smooth Blasting	Blasting or Mechanical	Deficient Blasting
F4	+15	+10	+8	0	-8

Table A3. Slope Stability Classes as per SMR Values

Class No.	V	IV	III	II	I
SMR Value	0 - 20	21 - 40	41 - 60	61 - 80	81 - 100
Rock Mass Description	Very bad	Bad	Normal	Good	Very good
Stability	Completely unstable	Unstable	Partially stable	Stable	Completely stable
Failures	Big planar or soil like or circular	Planar or big wedges	Planar along some joint and many wedges	Some block failure	No failure
Probability of Failure	0.9	0.6	0.4	0.2	0

Annexure-A3

Weathering Grades and Their Meaning

Rock mass classification in terms of weathering, state of fractures and strength is carried out as per IS 4464 as given in Table A4.

Table A4. Rock Mass Classification in Terms of Weathering

Terms	Description	Grade
Fresh	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces.	I
Slightly Weathered	Discoloration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering.	II
Moderately Weathered	Less than half of the rock material is decomposed or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as corestones.	III
Highly Weathered	More than half of the rock material is decomposed or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as corestones	IV
Completely Weathered	All rock material is decomposed and / or disintegrated to soil. The original mass structure is still largely intact.	V
Residual Soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported.	VI

Note: As weathering grade VI is similar to soil, it is not dealt in the rock slope matrix (Table 5A). Separate matrix (Table 5B) is given for Debris/soil Slopes.

Annexure-A4

Back Analysis to Determine Strength Parameters

Back analysis can be carried out for both rock and soil slopes including debris slopes. It gives the most realistic estimate of shear strength parameters for slope. First of all, based on ground observation, such as tilted trees, open ground cracks, break in slope profile at the upper part and other such features, a particular slope is judiciously selected. The philosophy of this approach is to back calculate the shear strength parameters of the rock mass / overburden slope under this near failure condition. In back analysis, one needs to appropriately model the slope geometry, failure mechanism and ground water conditions based on experience and engineering judgement.

For slopes made up of fairly homogeneous rock material or soil material including debris, back analysis can be carried out assuming a linear failure criteria (i.e., Mohr-Coulomb failure criterion). Initially the mode of failure is identified. The factor of safety of the slope is considered to be unity, i.e., the slope is on the verge of failure. Generally, a series of values of angle of internal friction (ϕ) is obtained assuming various types of slope materials from standard tables. The corresponding values of cohesion (c) are obtained from the back analysis. Based on engineering judgement, a suitable combination of c and ϕ is chosen (Anbalagan et al. 2007).

Alternatively, an iterative procedure may be adopted wherein first some reasonable soil / rock parameters are assumed as per engineering judgement and experience from the known site geometry and stratigraphy. The soil / rock parameters are then reduced until the failure is obtained (Factor of Safety = 1). Refer IRC SP 48, Page 56 and WSDOT M46-03.16 (2022).

References:

i. Anbalagan, R, Singh, B., Chakraborty, D, and Kohli A. (2007). “A Field Manual for Landslide Investigations”, *DST, India.*

ii. IRC SP 48. “Hill Road Manual”, *Indian Road Congress, New Delhi.*

iii. WSDOT M 46-03.16 (2022). Geotechnical Design Manual. *WSDOT, Department of Transportation, Washington State.*

Annexure-A5

Estimation of Safe Bearing Pressures

For preliminary design, safe bearing pressure of rock mass may be computed on the basis of the classification as per IS 12070 (refer Table A5). Such values should be checked or treated with caution for final design.

Table A5. Safe Bearing Pressure of Rock Mass Based on Classification (IS 12070-1987)

MATERIAL	q_{ns} (t/m^2)
Massive crystalline bedrock including granite, diorite, gneiss, trap rock	1 000
Foliated rocks such as schist or slate in sound condition	400
Bedded limestone in sound condition	400
Sedimentary rock, including hard shales and sandstones	250
Soft or broken bedrock (excluding shale), and soft limestone	100
Soft shale	40

Rock Mass Rating (RMR) may also be used to obtain net allowable bearing pressure as given below in Table A6. This bearing pressure will ensure settlement of raft foundation to be less than 12 mm. RMR to be used should be the average value within a depth below foundation level equal to width of foundation (refer IS 12070).

Table A6. Net Allowable Bearing Pressure of Rock Mass Based on RMR (IS 12070-1987)

CLASSIFICATION No.	I	II	III	IV	V
Description of rock	Very good	good	Fair	Poor	Very Poor
R M R	100-81	80-61	60-41	40-21	20-0
q_{ns} (t/m^2)	600-448	440-288	280-151	145-90-58	55-45-40

In the absence of soil test data, for preliminary design, the safe bearing capacity values for different soils given in Table A7 may be adopted (refer IS 14458 – Part 2).

Table A7. Safe Bearing Capacity Values for Different Soils (IS 14458 Part 2: 1997)

Type of Bearing Material	Symbol	Consistency of Place	Recommended Value of Safe Bearing Capacity (t/m^2)
(1)	(2)	(3)	(4)
Well graded mixture of fine and coarse-grained soil, glacial till, hard pan, boulder clay	GW-GC, GC, SC	Very compact	100
Gravel, gravel-sand mixtures, boulder-gravel mixtures	GW, GP SW, SP	Very compact Medium to compact Loose	80 60 40
Coarse to medium sand, sand with little gravel	SW, SP	Very compact Medium to compact Loose	40 30 30
Fine to medium sand, silty or clayey medium to coarse sand	SW, SM, SC	Very compact Medium to compact Loose	30 25 15
Fine sand, silty or clayey medium to fine sand	SP, SM, SC	Very compact Medium to compact Loose	30 20 15
Homogeneous inorganic clay, sandy or silty clay	CL, CH	Very stiff to hard Medium to stiff Soft	40 20 5
Inorganic silt, sandy or clayey silt, varied silt-clay-fine sand	ML, MH	Very stiff to hard Medium to stiff Soft	30 15 5

The shear strength parameters, cohesion and angle of internal friction, should be determined by experiments. However, for preliminary design, the values given in Table A8 can be used (refer IS 14458 Part 2).

Table A8. Typical Shear Strength Characteristics of Soil (IS 14458 Part 2: 1997)

Group Symbol	c (Cohesion of Soil) (t/m^2)		Φ' (Effective Stress Envelope) (degrees)
(1)	(2)	(3)	(4)
GW	0	0	> 38
GP	0	0	> 37
GM	—	—	> 34
GC	—	—	> 31
SW	0	0	38
SP	0	0	37
SM	0.5	0.2	34
SM-SC	0.5	0.15	33
SC	0.75	0.1	31
ML	0.7	0.1	32
ML-CL	0.65	0.2	32
CL	0.9	0.15	28
MH	0.75	0.21	25
CH	1.0	0.1	19

Annexure-A6

Check-Lists for Use in the Field During Mitigation and Design Stages

A Site Assessment check-list prepared for use in the field by site engineer and later during Site Investigation stage is given in Table A9.

Table A9. Site Assessment Checklist for Field Use

A01 SLOPE MASS TYPE	A01a - ROCK SLOPE	☒	A01b - DEBRIS/SOIL SLOPE	☐	A01c - TALUS SLOPE	☐

A02 SLOPE HEIGHT	A02a < 60 M	☒	A02b 60 M TO 100 M	☐	A02c > 100 M	☐

A0 3 SLOPE ANGLE	A03a < 30^0	☐	A03b 30^0 - 45^0	☒	A03c 45^0 - 60^0	☒	A03d 60^0 - 75^0	☐	A03e >75^0	☐

A04 SOURCE OF WATER FLOW	A04a NATURAL NALA	☐	A04b SEEPAGE THROUGH SLOPE (DRY SEASON)	☐

A06 OTHER INSTABILITY ISSUES A06a SINKING ☐	A06b SHOOTING STONE ☐	A06c TOE EROSION DUE TO RIVER ACTION ☐	A06d ROAD WIDENING ☐	A06e UNPLANNED MUCK DISPOSAL ☐	A06f WASHED OUT ROAD (EMERGENCY	A06g AVALANCHE ☐

					WORKS) ☐	

A07 ROW RESTRICTION (IF ANY)	A07a ROW RESTRICTION DUE TO VILLAGE ON HILL SIDE VICINITY	☐	A07b ROW RESTRICTION DUE TO FOREST LAND ON HILL SIDE VICINITY	☐

SLOPE MASS RATING (SMR)*	C06a (i) CLASS - I	☐	C06a (ii) CLASS – II	☐	C06a (iii) CLASS – III	☒	C06a (iv) CLASS - IV	☐	C06a (v) CLASS - V	☐

WEATHERING GRADE*	GRADE - W1	☐	GRADE – W2	☐	GRADE – W3	☐	GRADE – W4	☒	GRADE – W5	☐

TYPE OF FAILURE*	C06a (α) PLANAR FAILURE	☒	C06a (β) WEDGE FAILURE	☐	C06a (γ) TOPPLING FAILURE	☐	C06b (α) CIRCULAR FAILURE	☐	C06c (α) TRANSLATIONAL FAILURE	☐

TYPE OF SLOPE COMPOSITION*	DEBRIS STRATA	☐	RBM STRATA	☐	GLACIOFLUVIAL STRATA	☐

Annexure-A7

Snapshots of different mitigation systems from Hill Road Manual (IRC SP 48)

A few snapshots of different mitigation systems taken from Hill road manual (IRC SP 48) are given in Figs. A1 to A13.

Secured Drapery System (Passive system):

(i) Drapery systems will be a significant component of most of the protection, retention and prevention systems. Many times, their function will be to act as facia systems where prevention or retention is mainly done through long nails/anchors/bolts or surfaced nails/anchors/bolts. A typical example showing different types of products and their specification standards are given in **Fig. 4.26**

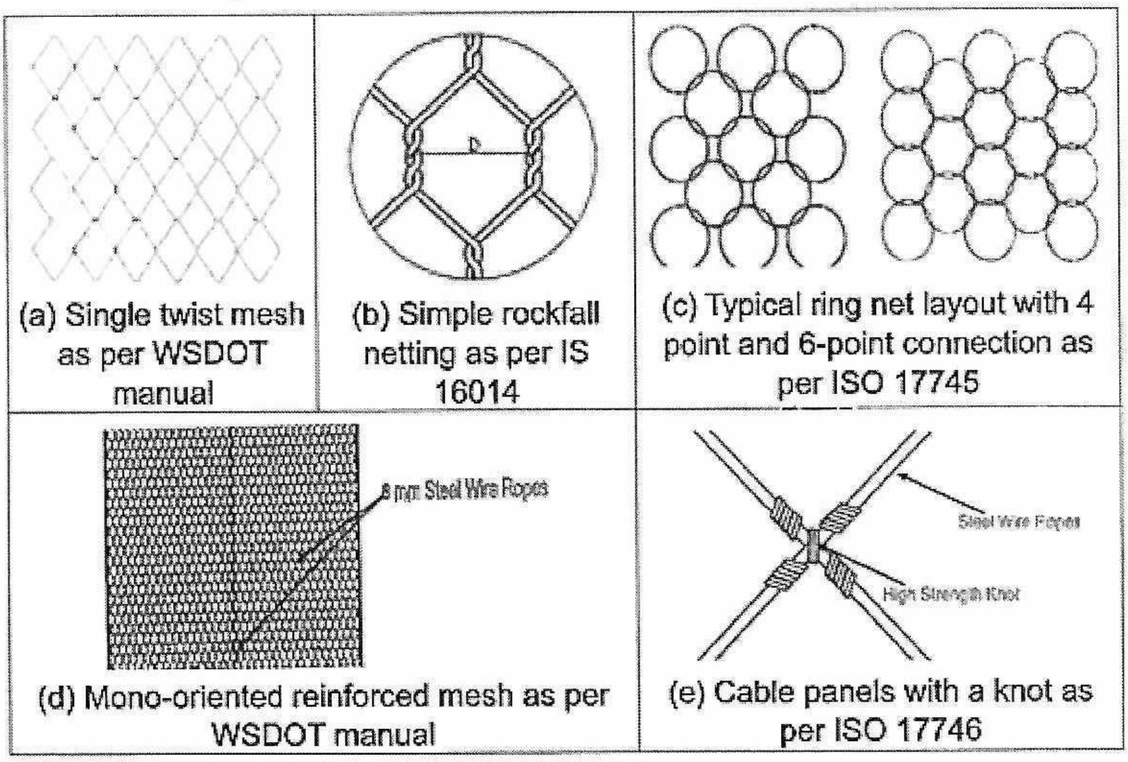


Figure A1. Examples of Types of Drapery Systems used for Rock fall Mitigation measures

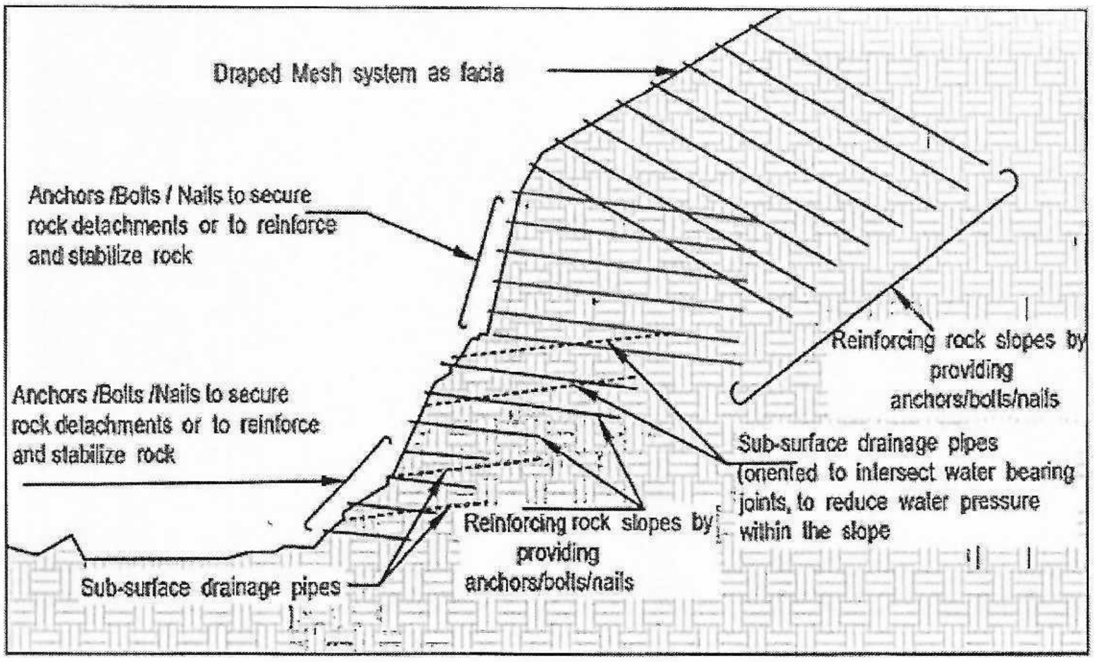


Figure A2. Typical Cross-section of Reinforcing Rock slope by Anchos/Bolts/Nails

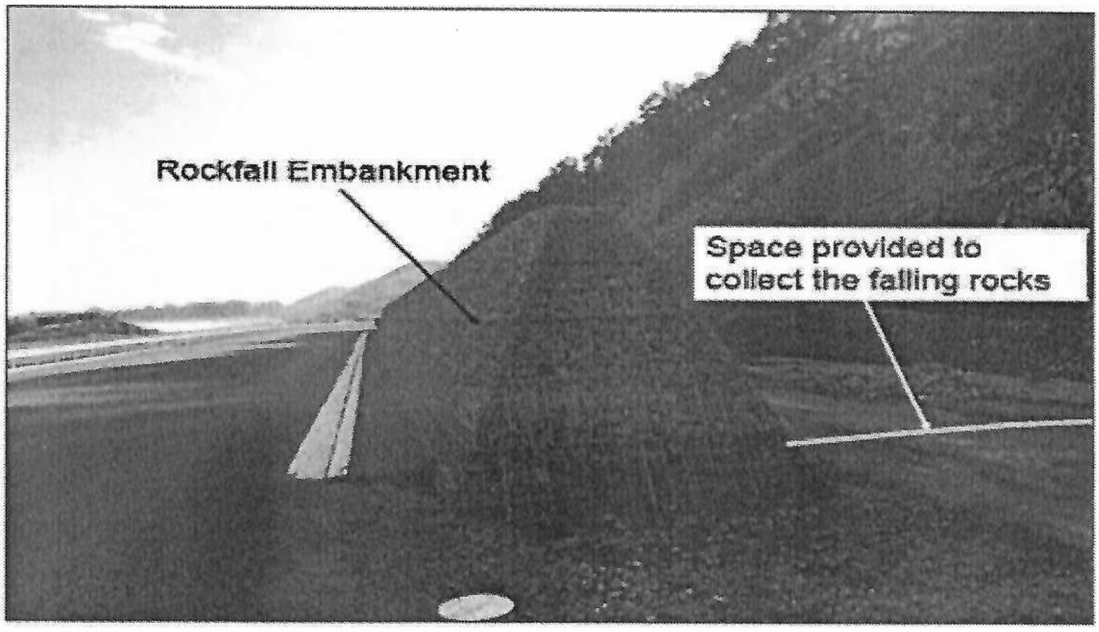


Figure A3. Rockfall Embankment to protect infrastructure and roads at the foot of cliff

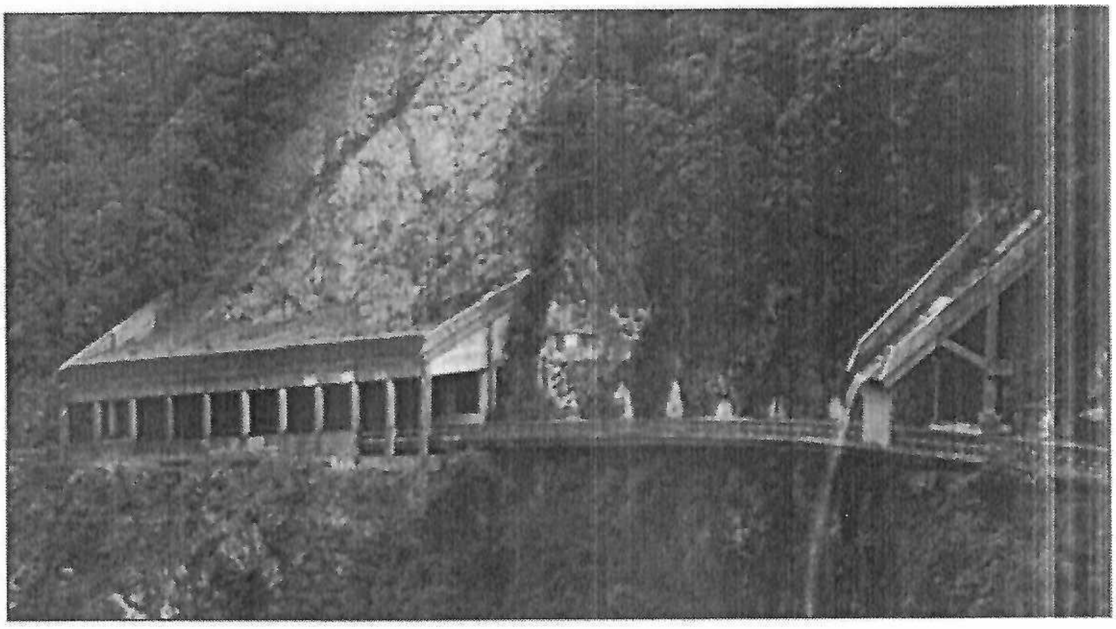


Figure A4. Site Photograph of Rock Shed

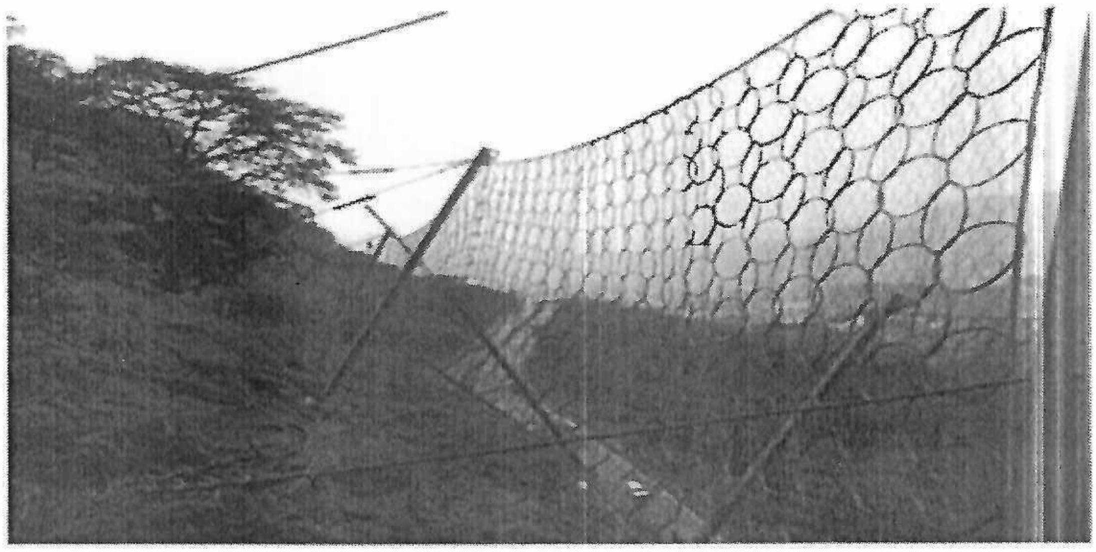


Figure A5. Flexible Rockfall Barriers

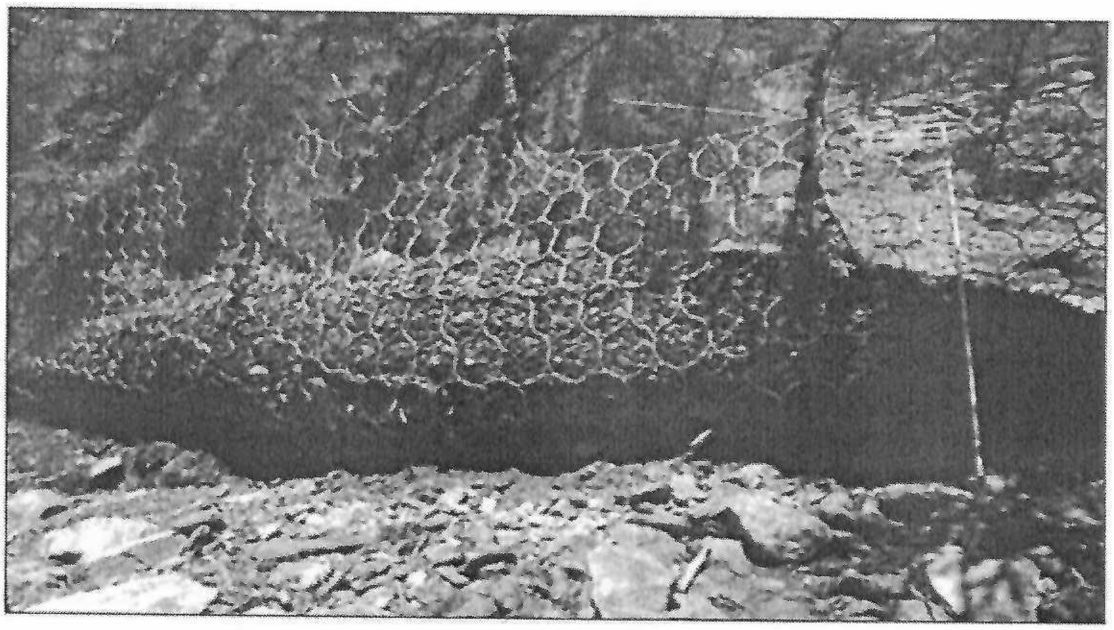


Figure A6. Debris Flow Barrier

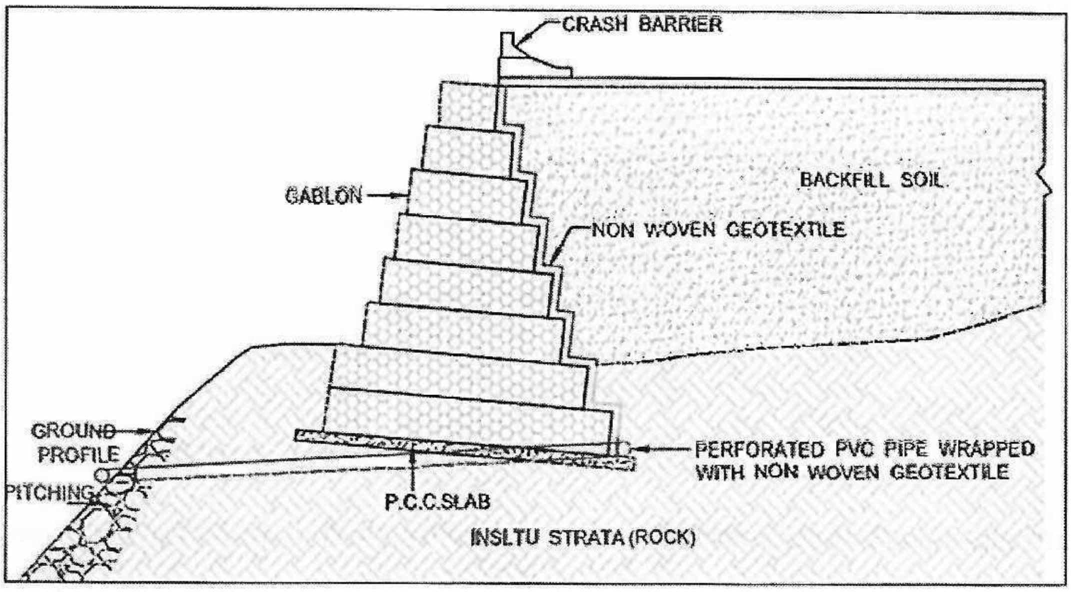


Figure A7. Indicative Cross-section of Gabion Retaining Wall

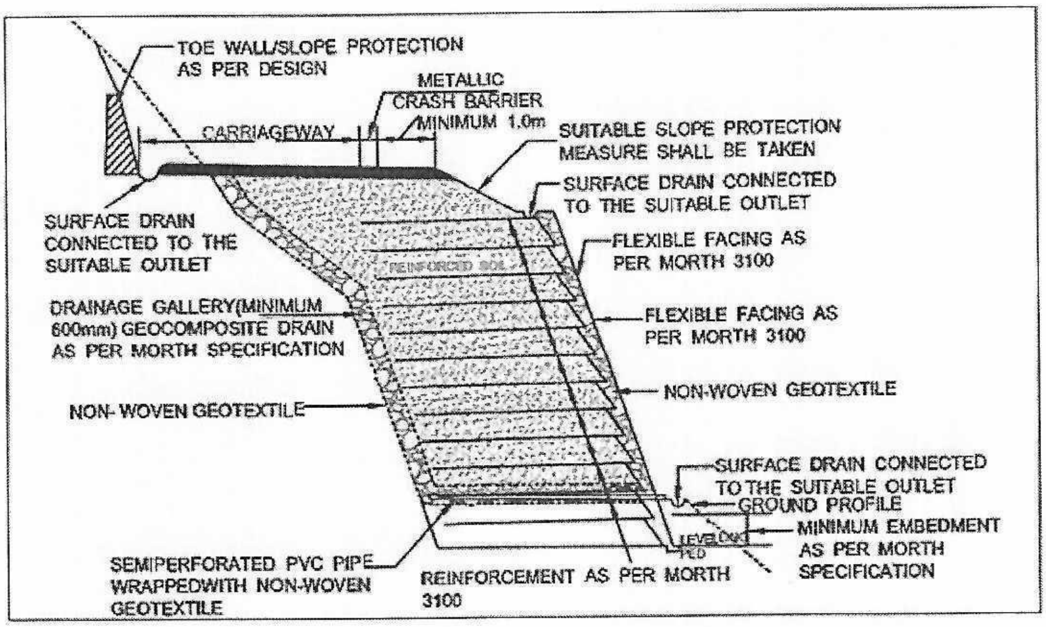


Figure A8. Cross-section of Reinforced Soil Slope with Flexible Facing

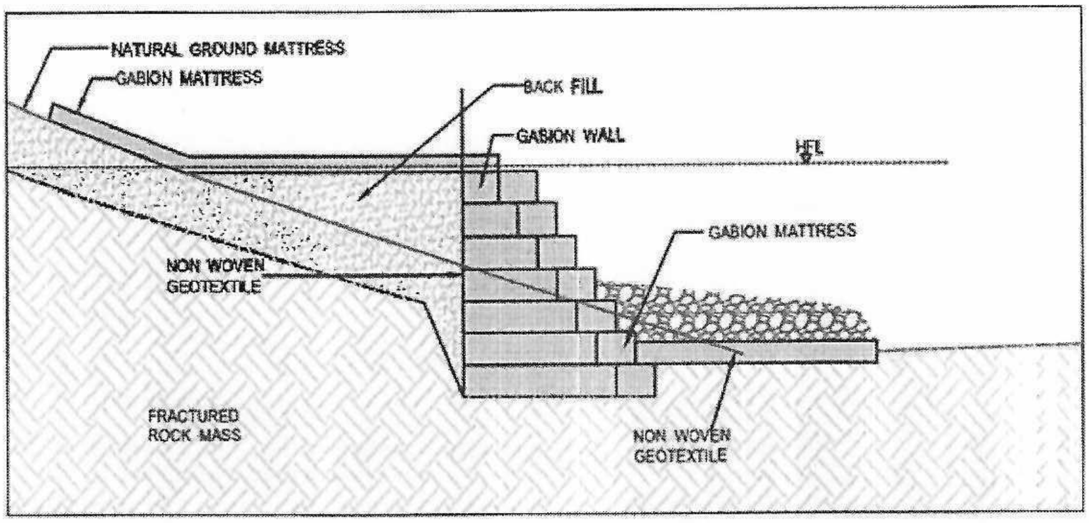


Figure A9. Cross-section of Gabion Retaining Wall with Launching Apron on River Bed

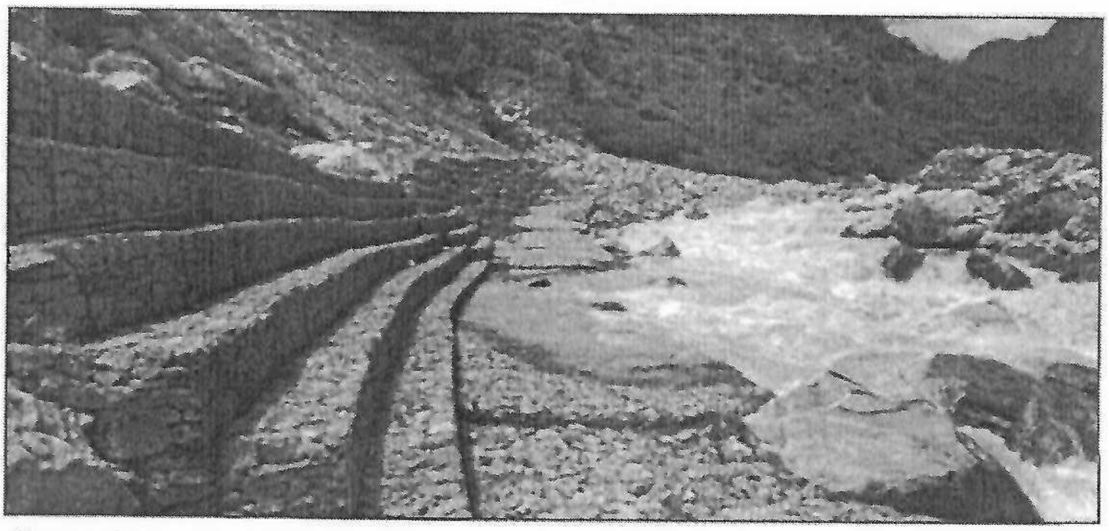


Figure A10. Photograph of Gabion Retaining Wall with Launching Apron on River Bed

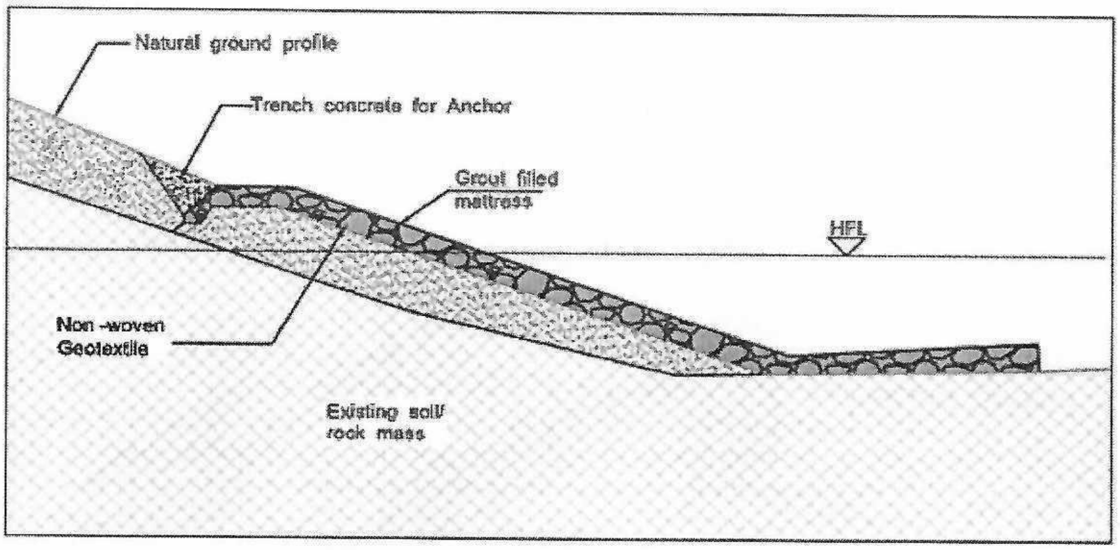


Figure A11. Cross-Section of Fabric Form Mattress with Launching Apron on River Bed

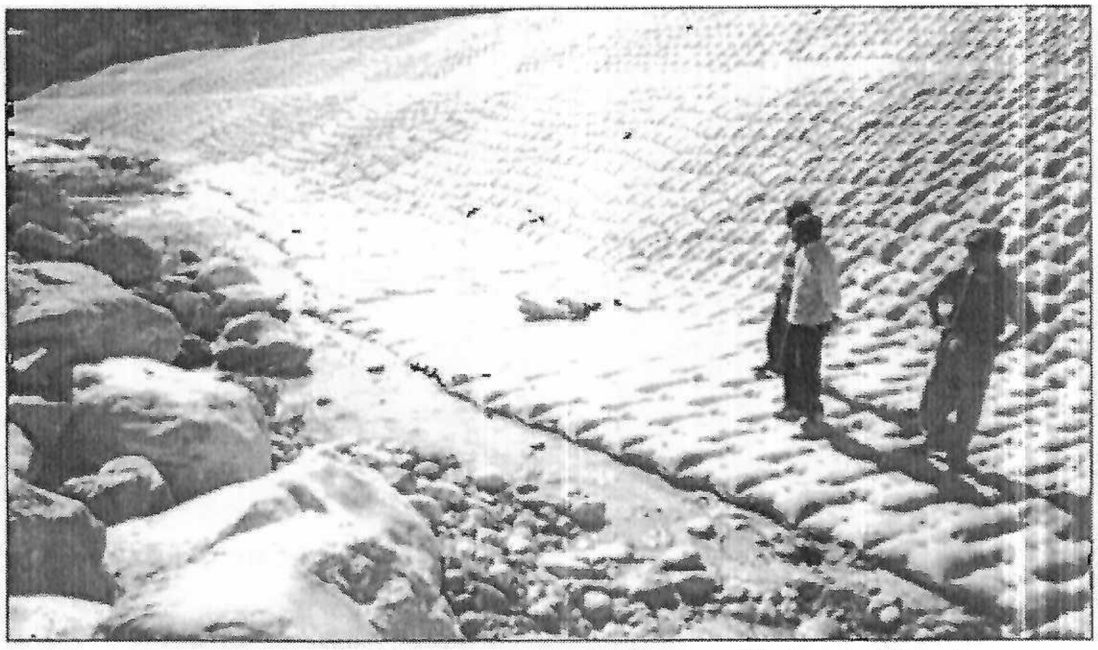


Figure A12. Photograph of Fabric Form Mattress with Launching Apron on River Bed

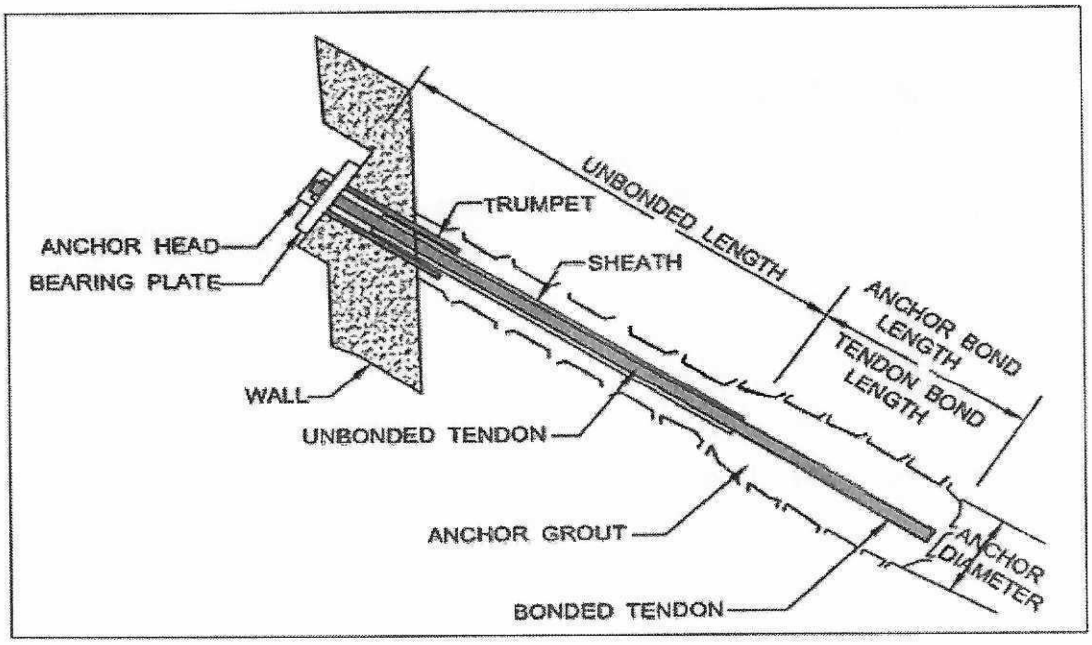


Figure A13. Typical Components of a Ground Anchor

Annexure-A8

Approval of All Committee Members

Approvals of all committee members received through WhatsApp are given below.

Cri Prasad
Dear sir the said report is ok and approved from my side. Thank you very much 🙏 23:26

TODAY

Colonel Soumendra Banerjee Vice President Terre Armee Reinforced Earth Wall

> Colonel Soumendra Banerjee Vice President Terre Armee Reinforced Earth Wall
> 01 v2 JTS final report - colored-SB.docx

Sir Document is approved from my end regards. 08:54

NM Niraj Kumar Agrawal Thdc Morth Committee

> Colonel Soumendra Banerjee Vice President Terre Armee Reinforced Earth Wall
> Sir Document is approved from my end regards.

Sir, Document is also approved by my side. 09:44

Dr. Sanjay Wakchure MORTH
Sir Document is approved ... 10:05

Sachin Joshi Mumbai Morth Committee Member

> You
> 01 v2 JTS final report - colored.docx

01 v2 JTS final report - colored 070724.docx
DOCX • 9 MB

Dear Sir,
👉 Draft report has nicely drafted & made in right flow and user friendly generic matrices. I am sharing minor comments on page no 6, 10, 28.
Request you to kindly review it, and can be incorporated if feel appropriate.
Also, suggest that, we should add a note on vote of thanks to MoRTH for opportunity given to committee after Acknowledgement.

Otherwise report is ok from my side and convey herewith my consent & approval on this draft report.
Regards, ...Sachin Joshi 16:48