सत्यमेव जयते

भारत सरकार

Government of India

विद्युत मंत्रालय

Ministry of Power

केंद्रीय विद्युत प्राधिकरण

Central Electricity Authority

जल विद्युत परियोजना प्रबोधन प्रभाग

Hydro Project Monitoring Division

Date: 05.10.2023

Subject: Guidelines for Slope Stability in Hydro Power Projects – reg.

In the MoP OM dated 11.01.2023 forwarding therewith Minutes of the meeting chaired by Hon'ble Minster for Power and New & Renewable Energy for discussion on the study report on Landslides in commissioned/under-construction hydropower projects utilizing remote sensing and GIS technology by IIRS Dehradun, the following was stated:

9. Hon'ble Minister further directed to develop a comprehensive technical manual/ guidelines by CEA about aspects to be kept in view before and during construction of hydro project including the mandatory aspects like building retaining wall wherever slope is interfered, reinforcement/ strengthening of any identified geological fault etc. For projects above certain threshold level say 400 MW, the project proponent may be made responsible to examine upper reaches including reservoir area, dam site and identify faults/ slides and take remedial measures for stabilization.

10. The Hon'ble Minister also directed CEA to constitute an Expert Committee for developing the manual/ guidelines, within a period of one month.

2. In compliance to HMoP's direction, an Expert Committee was constituted consisting of Members from CEA, CWC, GSI and Hydro CPSUs for drafting the *Guidelines for Slope Stability in Hydro Power Projects*. A copy of the said *Guidelines for Slope Stability in Hydro Power Projects* is enclosed herewith for kind information and necessary compliance by all Hydro Developers.

3. This issues with the approval of Chairperson, CEA.

Signed by Faraz
Date: 05-10-2023 14:37:54
Reason: Approved

(Faraz)
Deputy Director
Email: faraz@nic.in

To (Via email) -
1. Chairman, CWC
2. Principal Secretary (Energy) of all States/ UTs
3. Chairman (BBMB/ DVC)

4. Director General, GSI
5. CMDs of all Hydro CPSUs (NHPC/ NTPC/ THDC/ SJVN/ CVPPL/ NEEPCO/ NHDC)
6. All Private Sector Hydro Developers

Copy to (Via email):
1. JS (H), MoP
2. Chief Engineer (HPPI/HPA/HETD/CD), CEA
3. SA to Chairperson, CEA
4. SA to Member (Hydro), CEA
5. IT Division, CEA – With a kind request to upload the Guidelines on CEA website under **Live Streaming** and **What's New** for giving wide publicity to the same.

Guidelines for Slope Stability in Hydro Power Projects

1. Introduction

The design, construction and maintenance of the slopes is one of the major challenges during planning, construction and operation of Hydropower projects. Generally slope instabilities in hydropower projects are encountered during execution as well as operation. Slope instabilities are generally caused when the force/ load equilibrium of the stable slope is disturbed due to change in geometry of the natural slope, hydrogeological regime, deforestation, and/or weathering effect.

Slope stability is quantified by a factor of safety (FoS) - the ratio of the rock/soil's in situ shear strength to the shear strength required for equilibrium along a given potential failure surface. To stabilize an unstable slope, the factor of safety must be increased, either by introducing stabilizing forces (increasing capacity) or limiting destabilizing forces (decreasing demand). Slopes can be stabilized by adding a surface cover to the slope, excavating and changing (or regrading) the slope geometry, adding support structures to reinforce the slope or using drainage to control the groundwater seepage in the slope material.

Hydro Power Projects usually involve heavy surface excavation for placing the Dam, Power Intakes, Surface Power House and other structures that lead to the formation of excavated rock/soil slope. It is essential to maintain the stability of these slopes for unhindered and successful delivery of the project. A careful and thorough investigation of project area prior to excavation, utilizing advance techniques covering all the aspects of slope stability can mitigate the possibility of slope failure and effective measures for slope stabilization may be planned in advance reducing the cost of stabilization.

The site selection for critical components of Hydro Power Projects should be such that the orientation of joint/ bedding planes is favorable (preferably dips away from the excavation plane) for a stable excavation. However, it is not always possible to have desirable geological formations for placing the structures due to certain technical requirements leading to instability of slopes. In those cases, slope stabilization techniques should be used to increase the stability of slopes. The conditions for selection of the stabilization technique are dependent on Geotechnical requirement (geology, rock/soil properties, groundwater, and stability analysis), Construction requirement (types of construction equipment, access to the construction site, construction expenses), Ecological requirement, etc.

2. Objective and Scope

These guidelines are applicable to Hydro Power Projects Developers in hilly terrains guiding them to take cognizance of past slope failures and existence of unstable slopes in the project area covering the affected zones and recommend necessary remedial measures for slope stabilization of hydro power projects prior to construction, during construction, and post commissioning of the project.

3. Stages of Slope Stabilization/Monitoring

Slope stabilization/monitoring may be divided in three stages:

A. **Practices to be followed prior to commencement of construction**- This step includes survey and investigation (S&I) at regional geological level, project geological level, mapping &satellite imaging, collection of field data and testing, etc. followed by design & engineering of slope.

B. **Slope Stabilization Methods** including restoration of failed slope, if required, during construction which includes structural as well as non-structural measures.

C. **Practices to be followed post commissioning of the Project** like monitoring of movement of vulnerable slopes especially in reservoir rim area and energy dissipation area.

3.A. Practices to be followed prior to commencement of construction

"Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects" issued by Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti (erstwhile Ministry of Water Resources), "Guidelines for Formulation of Detailed Project Reports for Hydro Electric Schemes" issued by Central Electricity Authority, and "Guidelines for Investigations and Explorations required at Detailed Project Report (DPR) stage of proposed Hydroelectric Project in Himalayan Terrains" issued by Geological Survey of India (GSI) may be referred for S&I and preparation of DPRs of hydro power projects. With regard to slope stability measures, the following Survey, Investigation and mappings may also be carried out at DPR stage:

3.A.1. Survey and Investigation (S&I) of the Project

a) After the allocation of the site for the project development, the area needs to be studied on a regional scale (1:50,000/1:25,000) for depicting regional geological features such as geological setup/ stratigraphy of the area, major and minor thrust/ faults, folds, and other discontinuities/deformation in the rock mass, analysis of their impact to the proposed project, and delineation of vulnerable zones/ landslides/ subsidence and also land use/ land cover. Subsequently, a project component-specific large/ detailed scale study (1:1000/ 1:2000) needs to be carried out as per extant IS code /requirement based on the assessment of the regional study. The regional scale study would be based on the available data, Toposheet map of Survey of India (SoI), a regional geological map of GSI, and other relevant maps/data being provided by the Government agencies or available data for use. The study may be supplemented by the limited field survey.

b) Before starting the project excavation works, detailed geological and geophysical investigations/ explorations of the slopes of the project area should be carried out to delineate various slope parameters viz. soil/ rock-mass characteristics/ class, hydrological/ hydrogeological details, and other governing parameters for slope stability as per extant IS codes. The area of the project for this work shall be the affected zone above Full Reservoir Level (FRL) till Tail Race Tunnel (TRT)/ Tail Race Channel (TRC) Outfall i.e., within the acquired project land.

c) The detailed study should encompass detailed geological mapping and evaluation of geotechnical parameters to minimize or mitigate the probable failures in slopes during the construction stage in and around the project structures areas. The study shall identify potential slope stability issues and consequently, sufficient provisions need to be kept for treating and stabilizing the slopes in order to minimize the occurrence of failures in the area. The project proponent shall keep a record of changes occurring in the topography/ status of landslides from 500 m upstream from the Dam axis till, if necessitated by the data available and studies conducted, 500 m downstream from the TRT/TRC before the start of construction, monitoring the same with suitable instruments and on-time application of remedial measures (if any) to limit the extent of the damage. Required steps for data collection, mapping and mitigations are mentioned below.

3.A.2. Data Collection and Mapping & Analysis

Physical access to the glaciated/ permafrost/ major landslide zones/ avalanche prone areas in the mountains is always difficult. Vulnerable zones in these areas can be identified using Remote Sensing and Geographic Information System (GIS) techniques with limited field work. The dimension (length, width and depth), angle and altitude of slope, volume, etc. of the potential slide zones may be measured precisely and quickly by using technologies such as drone and Light Detection and Ranging (LiDAR) technology. With orthomosaic images of vulnerable zones taken at different times having Post-Processing Kinematics (PPK) capability, it may be possible to detect the changes in earth movement and to measure its velocity. These techniques will be helpful to understand/ estimate the impact of the slide on the downhill side and to plan effective prevention measures. Indian Space Research Organisation (ISRO) satellite data are helpful for this purpose and the feasibility for improvement in spatial and temporal resolution may be considered.

Before starting the project excavation works, following may be carried out to map the vulnerable zones and potential slope failures.

i. Collection of reports/ records of all existing major slope failures including satellite imageries in and around the project area. Review of available/ collected data and reports including satellite imageries of past more than 20 years shall be carried out.
ii. Periodic satellite imageries shall be kept in record. The period of such images may be defined as 3-6 months and one such image shall be taken before construction and just before first filling of the reservoir. Suitable photography and videography of the reservoir rim area and households shall also be carried out.
iii. Study of topographical sections and assessment of break in the slope profiles along the chosen section in order to delineate potential sections for stability analysis.
iv. Preparation of geological maps, geo-morphological maps, rock out-crops, overburden maps and slope classification maps.
v. Use of modern techniques such as Remote Sensing & GIS technology, drone, LiDAR technology, etc. to measure and monitor vulnerable zones such as Glacial Lakes, Landslide, and Avalanche prone areas.
vi. Landslide Hazard Zonation mapping of the project area including the catchment area on 1:25000 or 1:50000 scales. Related available reports/ maps may be obtained from GSI.
vii. Quantification of Landslide Hazard Evaluation Factors (LHEF) such as lithology, slope morphometry, relative relief, proximity to fault/Shear/weak zones, land use/ land cover, drainage density and hydrogeological conditions. Related available reports/ maps may be obtained from GSI.
viii. Preparation of Detailed geotechnical mapping of the unstable slopes on 1:1000 or 1:2000 scales.

ix. Kinematic analysis of discontinuities in the case of rock slopes and then the estimation of FoS. In the case of soil and weak/weathered rock (assumed as soil), estimation of FoS for critical slip surface by following the standard methods. In this regard, computer-based softwares may be used for expediting the analysis.
x. Preparation of Slope vulnerability map and Landslide risk mitigation plan to meet the functional requirements by possible solutions and provision of the detailed design of optimum solution based on economy, functionality and availability in the DPR stage.

Note: Geological map, geomorphological map, and National landslide Susceptibility Map (NLSM) on 1:50,000 scale are freely available on GSI Bhukosh Portal (https://bhukosh.gsi.gov.in/Bhukosh/Public), which can be used for regional study. Further, GSI can also facilitate the Hydro Developers in carrying out the detailed geological mapping on requirement basis. The need for detailed maps/ detailed study shall depend on the extent of vulnerable zones and their risk to the proposed structures.

3.A.3. Reservoir Rim Stability

The competency of the reservoir, reservoir rim stability, and its effects due to the construction of the dam may be discussed in DPR. The following may be carried out:

i. Geological map of the proposed reservoir area, up to 50 metres above FRL or up to affected zone above FRL (whichever distance is farther) on 1:15,000 or 1:10,000 scale, may be prepared based on either existing geological maps or by way of study of recent remote sensing data with limited field checks.
ii. The reservoir map having details like FRL and Minimum Draw Down Level (MDDL), should also incorporate geological units, critical zones, structural discontinuities, land use, and land cover.
iii. Developer shall identify events of slope stability aspects in the reservoir area i.e., Old/ Dormant/ Active Landslides and also keep a record of changes occurring in the topography of the reservoir rim area. In addition, Developer shall also study and evaluate landslide susceptibility and hazard zonation and proposed mitigation measures.
iv. Geological sections need to be prepared for identified vulnerable zones/ slides.
v. Reservoir rim slopes that are prone to instability due to water level fluctuations should be analysed for their global and local stability. The categorization of slopes prone to failure shall be done based on damages it may cause to human habitats/ economic losses and to be treated accordingly with suitable long term measures.
vi. Stability analysis of critical stretches of reservoir rim area slopes shall also be done under seismic conditions by taking the proper damping effect of the slope material to indicate the behaviour of the slope.

Project authorities should carry out Numerical Model Studies of vulnerable slopes using latest Limit Equilibrium Method (LEM)/ Finite Element Method (FEM)/ Finite Difference Method (FDM) software based on in-situ and laboratory test results as input parameters of excavated/ natural slopes.

3.A.4.1. Formulation of slope design

The slope design process at any level of a project essentially involves the following steps:

i. Formulation of a geotechnical model for the slope area;
ii. Populating the model with relevant data;
iii. Division of the model into geotechnical domains;
iv. Subdivision of the domains into design sectors;
v. Design of the slope elements in the respective sectors of the domains;
vi. Assessment of the stability of the resulting slopes in terms of the project acceptance criteria;
vii. Definition of implementation and monitoring requirements for the designs.

3.A.4.2. Slope design methods

The process of slope design starts with dividing the geotechnical model for the proposed slope into geotechnical domains with similar geological, structural and material property characteristics. For each domain, potential failure modes are assessed and designs at the respective scales (bench, inter-bench, overall) are based on the required acceptance levels (FOS) against instability.

Once domains have been defined, their characteristics can be used to formulate the basic design approach. This involves evaluating the critical factors that will determine the potential instability mode(s) against which the slope elements will be designed. A fundamental division relates to the rock properties in that, for stronger rocks, structure is likely to be the primary control, whereas for weaker rocks strength can be the controlling factor, even down to the bench scale.

Where structure is expected to be a controlling factor, the slope orientation may exert an influence on the design criteria. In this case, a subdivision of a domain into design sectors is normally required, based upon kinematic considerations related to the potential for undercutting structures (planar) or combinations (wedges), or toppling on controlling features.

In weak rocks, where the rock mass strength is expected to be the controlling factor in slope designs, the design process commences with analysis to establish the overall and inter-bench slope angle ranges that meet the acceptance criteria for stability. The type of stability analysis performed to support the slope design depends on several factors, including:

i. available data;
ii. the scale of slope under consideration;
iii. the properties of the materials that will form the slopes.

The main analysis types used for design include:

i. Kinematic analysis for bench designs in strong rock;
ii. Slope mass rating method as per IS-13365 Part-3;
iii. Limit equilibrium analysis applied to:
    - structurally controlled failures in bench and inter-bench design,
    - inter-bench and overall slopes where stability is controlled by rock mass strength, with or without structural anisotropy;
iv. Numerical analysis for assessing failure modes and potential deformation levels in inter-ramp and overall slopes.

It should be stressed that stability analysis are tools that help formulate slope designs. The results must be evaluated in terms of other factors before they are finalised. These other factors include the excavation methods and equipment that will be used to excavate the slopes, as well as the operators' capability to consistently implement such aspects as controlled blasting, surface water control, etc.

3.B. Slope Stabilization Techniques/ Methods

3.B.1. The design and construction of stable slopes depend on various factors. Single technique or method may or may not be adequate for stabilizing the slopes. It will therefore be prudent to execute the optimum solution based on detailed design considering the economy, functionality, and availability. Some of the techniques or methods for slope stabilization are described below.

a. **Geometric techniques**: The application of geometric techniques brings about a change in the geometry of the slope. Planning must be made for construction of the slopes and the plan should be stuck to without any deviation from it. Stand-up time for the cut slope may also be established in consultation with the site geologist & Engineer-in-Charge (EIC) and immediate support may be ensured to the cut slope before moving to further excavation down the slope. Slope stabilization using geometrical techniques can, inter-alia, be achieved by:

i. Flattening the slope;
ii. Eliminating part of the soil/rock;
iii. Eliminating load from the top of the slope and therefore reducing the shear stresses on critical planes;
iv. Constructing loading berms at the toe of the slope and thereby providing extra safety against toppling failure; and
v. By re-compaction of slip debris to provide more resistance against loading.

b. **Hydrological techniques**: The adoption of hydrological techniques reduces the water content of soil/rock material. Slope stabilization using hydrological techniques can, inter-alia, be achieved by:

i. Construction of peripheral, catch and step drains along the slope may be planned to reduce the possibilities of slope failures from overflow of water;
ii. Installing surface and subsurface drain pipes and therefore reducing pore water pressure;
iii. Use of inverted filters;
iv. Replacement of slipped material by free-draining materials and therefore reducing the build-up of pore water pressure;
v. Use of thermal techniques, such as ground freezing and heating methods;
vi. Use of Drainage Tunnels, Adits, Galleries and Drainage Wells; and
vii. Use of Geotextile Filters.

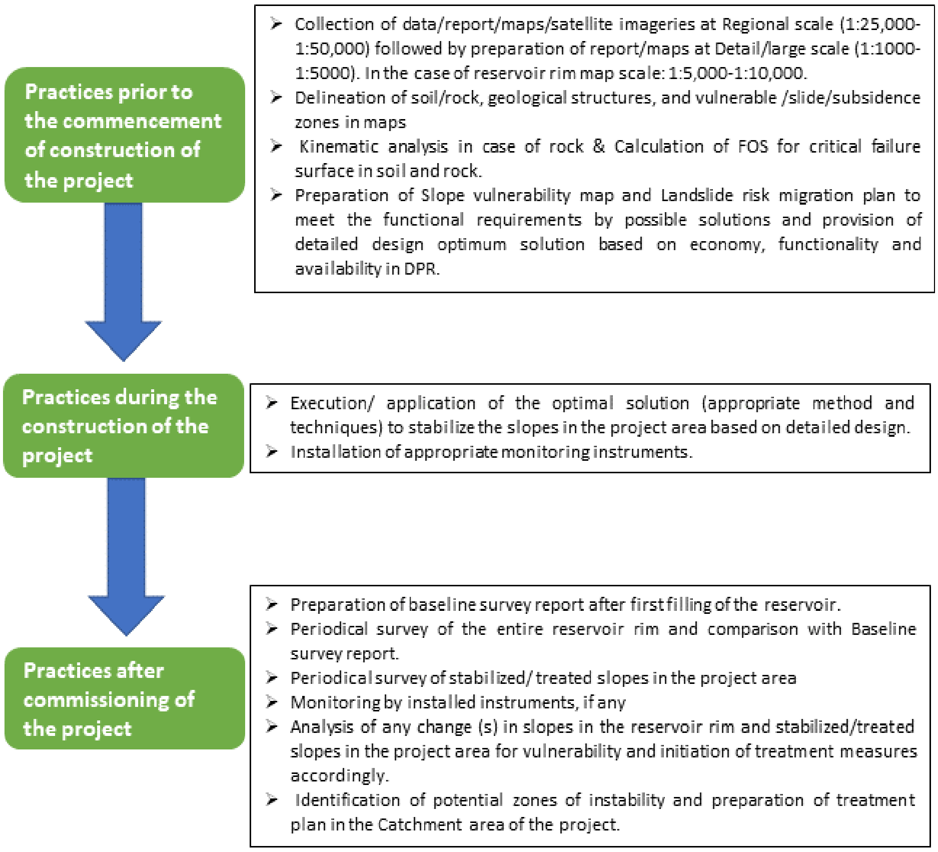
c. **Chemical and mechanical techniques**: Chemical and mechanical stabilization techniques increase the shear strength of the critical plane of soil/rock mass by external means. In addition, the shear strength of the slope can also be increased by minimizing the external forces triggering the slope failure. Slope stabilization using chemical and mechanical techniques can, inter-alia, be achieved by:

i. Using grouting to increase the shear resistance of the slope;
ii. Constructing restraining structures, such as concrete gravity, cantilever walls, reinforced earth walls;
iii. Construction of gabion structures, baby crib walls, and embankment piles in order to provide resistance against toppling;
iv. Constructing lime and cement columns;
v. Installing ground anchors, rock bolts, nails, cable anchors, piles, micro-piles, etc. to provide effective tension to rock blocks;
vi. Application of plain/ fiber reinforced soil erosion;
vii. By planting shrubs and grasses to reduce soil erosion; and
viii. Non-Frame Method of Slope Stabilization.

3.C. Practices to be followed for Slope Stabilization post commissioning of the Project

i. A baseline survey of entire reservoir rim area after initial filling shall be carried out through physical visits or through drones or satellite imagery and a baseline survey report shall be prepared.
ii. Periodical survey of entire reservoir rim area shall be carried out through physical visits or through drones or satellite imagery and comparison with the baseline survey report shall be made to identify any changes.
iii. Changes shall be analyzed for vulnerabilities and treatment measures be initiated accordingly.
iv. Treated slopes shall also be monitored for their behavior during reservoir operation.
v. Developer shall carry out Catchment Area Treatment Plan and identify potential zones of instability as well as improvement of slopes in the catchment area with concerned state authorities.

A generalized diagram depicting broadly the measures/ practices to be adopted prior to commencement of construction, during construction and post commissioning is given below:



4. Examination of Upper Reaches in Critical Hydro Power Projects

For vulnerable Hydro Power Projects, the Project Authority shall be responsible to examine the upper reaches including reservoir area, dam site and identify faults/ slides and take remedial measures for stabilization. The vulnerable projects for the purpose of this Clause shall include 400MW and above capacity Hydro Power projects located uppermost in a river or its tributary at an elevation above 1500 m in cases where the gross reservoir storage is at least 50 MCM (Million Cubic Meter). The examination of upper reaches may include study of hazards due to avalanche, GLOF (Glacier Lake Outburst Flood), landslide hazard analysis of slopes above the reservoir rim area, etc.

5. Monitoring Mechanism for Critical Slopes

The critical slopes for the components of the Project can be monitored using the combination of the following methods depending on the criticality of the slope/ component:

i. Surface target with Total station;
ii. Inclinometer;
iii. Piezometer for measuring pore pressure and water table;
iv. Single/ Multi-point borehole extensometer;
v. Load cell;
vi. Ground based radar.