Geological and geotechnical investigations for preparations of bankable DPR on hydroelectric Project

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Abstract

The paper describes methodology for preparation of bankable DPR for water resource projects. Various stages of investigation and the processes involved are given which will facilitate in preparation of dependable DPR. The main requirement of DPR being bankable is the assurance of the project being constructed in the estimated cost and time schedule.
DPR stage Investigations can be broadly grouped under:

1. Topographic survey.
2. Hydro-metrological investigations.
3. Geological and geotechnical investigations.

The detailed investigations for various structures are also discussed. Investigations related to reservoir, construction material are also debated. The comprehensive paper includes discussion on rock mechanic tests also.

The water resources development projects like Hydroelectric, Irrigation, Water-Supply and Multi-purpose projects play an important role in economic development of a nation providing important inputs viz. power for industrialization, irrigation for sustainable agricultural production, public health, pisciculture, tourism, etc. Every project evolves through many stages before it becomes operational and serves the purpose for which it is constructed. The stages are:

1. Conceptual stage
2. Reconnaissance stage
3. Preliminary Investigations stage
4. Detailed Exploration stage
5. Pre-construction stage
6. Construction stage and
7. Post construction or O & M stage

Out of the above, Detail Project Report (DPR) of a proposed hydro project incorporates the stages from the Conceptual to Detailed Exploration stages.

1. Need of Geological & Geotechnical Investigations to produce a 'Bankable DPR':

For every water resources project, preparation of a DPR is a statutory requirement. It provides a road map of the project so that various governmental agencies, can examine its different aspects including the viability and techno-economic justification of the project.

Unfortunately, a majority of projects in the past could only be completed with enormous cost and time overruns, doubting the credibility of DPR. This has seriously undermined the credibility of civil engineers and geologists involved in investigation, planning, designing and execution of these projects. The concept of 'Bankable **DPR**' has evolved because of such past experiences.

2. A Bankable DPR:

A bankable DPR is a document which can give enough confidence to the lending agencies that each component of the proposed project has been adequately explored in such a way that there will be very limited scope of deviation and nature of work would not undergo major changes during construction stage. The constraints and uncertainties are well understood and suitable provisions are made in design so that these are not met as surprises. The main requirement of a DPR being bankable is the assurance of the project being constructed within the estimated cost and time schedule.

3. DPR Stage Investigations:

The DPR stage investigations can broadly be grouped under Topographical survey, Hydro-meteorological investigation and Geological and geotechnical investigation:

3.1 Topographical Survey:

This includes establishment of BMs with the help of SOI followed by detailed topographical survey of reservoir and different component of the project. Every project is allocated a pair of elevations along the river viz. the Full Reservoir Level (FRL) and the Tail Water Level (TWL) for development. This is to avoid interference with the immediate upstream and downstream projects and for optimum utilization of the water resources of the basin.

3.2 Hydro-meteorological Investigation:

The hydrological data such as discharge, rainfall, catchment area and characteristics, snow fed area etc. are vital to work out the power potential and maximum flood discharge.

3.3 Geological and geotechnical investigation:

The authors on behalf of Geological Survey of India had prepared a guideline on geological and geotechnical investigations at DPR stage for hydroelectric projects in Himalayan terrain. Though this is for Himalayan terrain, but can be useful for preparing the DPR in other areas also. The salient features from this guideline are provided below.

In the Detailed Project Report, a separate volume on geology and geotechnical aspects containing different chapters like i) salient features of the project, ii) introduction, iii) regional geology, iv) geomorphology and geology of the project area, v) geology of project components, vi) surface and subsurface investigation/exploration, vii) detailed geological and geotechnical evaluation of all the project components, viii) seismicity, ix) construction material with x) conclusions and recommendations are to be incorporated. The detailed geology including the explorations/investigations carried out for each project component along with geotechnical assessment, remedial measures, seismic design parameters and construction material are to be discussed with relevant maps, sections at appropriate scale and photographs.

Regional Geomorphology and Geology:

A chapter on Physiography/geomorphology, geology, structure, tectonics, seismicity on regional scale (1:50,000/2,50,000/available larger scale map) for an area of about 50km radius or more to show the major tectonic units is to be incorporated in the DPR.

Catchment area study:

Regional geology of the catchment including major thrusts/ faults/ lineaments are to be discussed and the relevant map to be incorporated. The terrain evaluation should include basin morphometry like drainage (pattern, density etc.), slope, relative relief and also distribution of snow fed & rain fed areas, glaciers, presence of glacial lakes and possibilities of breaking of such lakes to produce Glacial Lake Outburst Flood (GLOF), possibility of formation of landslide dams. The impact of lake burst viz., surge of water discharge and accompanying sediments, bed load should be studied and incorporated in the design.

Geomorphology and Geology of Project site:

This should briefly discuss the geomorphology, geology, seismology, neotctonic activity (if any), status of explorations/investigations, geotechnical appraisal, requirement and availability of suitable construction material for the proposed project.

Remote sensing and Photogeological studies:

A photogeological/landsat imagery study of the project area may be included in the DPR. Lineament map, preferably, on 1: 50,000 scale, showing the major and minor lineaments and the project location should be incorporated. If these lineaments are affecting or influencing the project components, they may be studied and discussed in detail and plotted on the large scale maps and sections.

Seismicity:

Both regional and local seismicity is to be discussed with relevant plates. Site specific seismic parameters are to be determined. MEQ studies and active fault studies are to be conducted, if required. This study may be carried out for all large dams located in Seismic Zones –IV & V.

Studies for Alternative Project Layout:

The DPR should contain various alternative studies of project layouts on the basis of regional and local geology, topography, types and locations of dam and powerhouse, alignments of HRT, etc. The alternative locations are to be studied based on geological mapping, geophysical explorations and drilling, if required. From these alternatives, the final site may be selected with the suitable type of diversion structure like a barrage/ weir or dam (concrete, rock fill, CFRD, arch dam, earth dam etc), Desilting Chamber (surface/ underground), HRT alignment and surface or underground powerhouse. Advantages and disadvantages of all these alternative locations are to be discussed on techno-economic consideration.

Detailed geology and geotechnical investigations of project structures:

Diversion Structure

Geomorphology, geology in and around proposed dam area, including both banks/abutments, river bed to accommodate all the project components of diversion structure complex are to be described. Detailed geological mapping of project area, about 200m upstream (u/s) and 300m downstream (d/s) of dam axis, accommodating u/s and d/s cofferdams, intake, Diversion tunnel etc are to be carried out on 1: 1000 or 1:2000 scale. The map should also be extended at least 50m above the dam height or more depending on the site geology. An outcrop geological map and an interpreted geological map may be provided.

Boreholes should be drilled in river bed, each abutments/bank along dam axis, toe of the dam, spillway bucket/ stilling basin area/ plunge pool to know the bedrock configuration and rock mass condition of the foundation media. If required, boreholes between dam axis and bucket area may also be drilled. In all these boreholes, drilling should be done at least 20m within bedrock as presence of huge boulder/rock blocks as fluvio-glacial deposit/ landslide debris etc cannot be ruled out. Among the above holes, at least two holes to be extended down to 2/3rd 'H' along the axis, (preferably in the river section) and one hole at the bucket portion down to 'H' depth at the river section, where 'H' is height of FRL from foundation level of that point. These drill holes will help to assess the rock mass condition, depth of grout curtain and detect any adverse features like fault/shears etc below the dam body that may endanger the stability. From the results of all the drill holes and depending upon the site geology, additional holes can be planned as required.

Permeability tests are to be carried out in all the drill holes. Test grouting of the foundation media should be carried out to know the efficacy of grouting as well as to determine spacing, orientation of grout holes for consolidation and curtain grouting.
In order to work out the stripping limits, drift on both abutments should be excavated along dam axis. A few downstream (d/s) and upstream (u/s) cross cuts are to be done to know the lateral rock mass variation/condition. The number of drifts are to be determined depending upon the dam height for which the BIS guideline may be adopted. The drift may be at about 50m interval of dam height, where the height may be calculated from the

deepest foundation level. The minimum length of the drift should be at least 30m, or more if required, as per geology of the site/space required for seating the dam and/or spillway. The length of cross cuts may be equal to the width of the proposed dam body at that location. Insitu tests within drifts like shear test (rock to rock and concrete to rock), deformability test, etc are to be conducted. Laboratory test to determine the engineering properties, required in the design is to be carried out. For rock and earth fill dam, exploration of the abutments through drifting may also be required, depending upon the geological considerations.

If barrage and weirs are to be founded in rock, then the investigation required for that of concrete dam should be followed. If the diversion structure is to be founded on pervious foundation/riverine material**,** holes should be drilled down to the hard rock level or to a minimum depth of 30m below the deepest river bed level, to determine characteristics of foundation material. One or two deep boreholes may be drilled to know the nature of riverine material, identify liquefiable zones (if any) present below the foundation. Liquefiable zones, if present, should also be delineated through SPT and/or geophysical investigations. Exploration through drifting may also be done, if required to know and detect the continuity of shear zones/faults, etc or any other adverse geological features/conditions. The required insitu and laboratory tests (as per the BIS guideline) should also be carried out for design purposes.

Structural analysis of discontinuities through stereographs, rose diagrams and wedge analysis are to be carried out to work out the support system along the cut slope for the dam foundation on both the banks.
In all the above cases, geophysical methods may also be employed to obtain additional geological information, preferably in the gap areas. It is to be ensured through adequate investigation that no major geological surprises /uncertainties should be present at the diversion complex.

River Diversion Arrangement

Cofferdam

Geological mapping of u/s and d/s cofferdam sites are to be done in the same scale as that of dam area. Drill holes to know the details on bedrock configuration, rockmass condition and depth of overburden/ cut-off along axes etc. of both u/s and d/s cofferdam is required to be done.

Diversion Tunnel

Geological mapping preferably in the same scale as that of the dam area, tentative distribution of different classes of rock mass anticipated at the tunnel grade such as stretch wise Rock Mass Quality (Q) and Rock Mass Rating (RMR), rock category, with approximate percentage likely to be encountered along tunnel alignment etc. has to be carried out. Geology of the portal sites should be discussed elaborately along with their slope stability measures.

Boreholes are to be drilled (if required) to assess the overburden depth and rockmass condition at the portals and along the tunnel alignment. If any deeply incised nalas, weak/shear zones are cutting across the alignment then holes should be drilled to know the rock cover as well as rock mass condition. Stretch wise structural analysis of discontinuities through stereographs, rose diagrams and wedge analysis may be carried out along the tunnel alignment to work out the support system.

Water Conducting System

Intake

Geological mapping of the intake tunnel on 1:1000 or larger scale should be carried out. Geology of the intake portal, depth of weathering, i.e. fresh rock profile/stripping limit is to be reflected and discussed. Back slope stability of the portal is to be studied, measures envisaged and discussed in the DPR. A hole may be drilled to assess bedrock depth, nature of bedrock. Cut slopes of the portals may be designed as per the structural data and shear parameters. Geology along intake tunnel, rock cover, tentative rock mass condition /class should be incorporated. Drilling may be undertaken to ensure sufficient rock cover, confirm anticipated shear, fault, weak zones etc. depending upon site condition.
Structural analysis of discontinuities through stereographs, rose diagrams and wedge analysis are to be carried out stretch wise, along the intake tunnel to work out the support system.

Desilting Chamber

Geological mapping of all chambers along with appurtenant structures are to be done on 1:1000/2000 scale. Geological sections along and across the desilting chambers, adit(s) to DC and SFT (Silt Flushing Tunnel) are also to be prepared.

In case of *Underground* structure, the orientation of the chambers should be worked out on the basis of geological data (rock type and structural data). Drift should be excavated for the entire length of the chamber with cross cuts; rock mass condition and discontinuity planes assessed. Structural analysis of discontinuities through stereographs, rose diagrams and wedge analysis are to be carried out along the chambers and accordingly treatment measures planned and discussed. Holes are required to be drilled to know the rock mass condition above the cavern. Hydrofracture test, to assess in situ stress field of the rock mass should be conducted and orientation of chambers optimised. Other tests like deformation modulus, shear parameters of the rock mass, etc may also be carried out to meet the design criteria. Geology of the portals and their stability as well as alignments of the construction adits, adit to gate chamber, silt flushing tunnel etc. are to be discussed. If required, holes may be drilled to assess the bedrock depth and rock mass condition at portal locations of the adits and to know the rock cover along the alignment.

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In case of S*urface Desilting basin*, assessment of foundation media, slope stability studies including engineering properties (through both insitu and laboratory tests) of the rock and overburden material is required.

Head Race Tunnel (HRT):

Geological map and sections of the tunnel alignment on 1:5,000 / 10,000 scale have to be prepared based on surface geological observations and sufficient drill hole information. Salient features like orientation of the tunnel with respect to regional strike and weak zones of the rock formation, maximum and minimum cover over tunnel alignment, joint sets, low cover and high cover zones, weak/shear/fault zones likely to be encountered, vertical and lateral rock covers at all nala crossings etc are to be discussed. In case tunnel is situated within a folded sequence, or other discontinuity planes like, thrust or fault, lineament, then the orientation of the tunnel with respect to those structural features along with other discontinuities (foliation, joint) is to be discussed.

Tentative distribution of anticipated rock mass at the tunnel grade (stretch wise Q and RMR value, rock category, with approximate percentage likely to be encountered along tunnel alignment), groundwater table, presence of hot springs, etc are to be reflected. Possibilities of squeezing, slabbing, rock burst due to stress field, presence of deleterious gases, for e.g. methane, to be studied and indicated. Discontinuity analysis should be done stretch wise. Structural analysis of discontinuities through stereographs, rose diagrams and wedge analysis are to be carried out along the tunnel alignment to work out the support system. The HRT alignment should be explored through drill holes and drifts (if required) at locations of anticipated zones of low cover, shear/fractured rock mass, nala crossings, etc. The holes should be drilled down to the invert level of the tunnel.

Geology including geological maps of adit portals and their alignments on 1:500/1000 scale should be incorporated. Rockmass condition, rock cover etc. along the adits should be determined along the adits through drill hole, if required. Geology of the portal of the adits and their stability is to be discussed. If required, drill holes may be drilled at portal location to assess the bedrock depth and rock mass condition.

Power House Complex

Comprehensive study for the alternative locations is to be conducted on the basis of geological mapping and subsurface exploration through few drill holes, if required. Merits and demerits pertaining to each location are to be discussed.

Detailed geological mapping of each component of the selected powerhouse complex is to be carried out at 1: 1000/2000 scale showing the explorations/investigations.

It is to be ensured through adequate investigation that no major geological surprises/ uncertainties should be present at the Power House complex.

Surge Shaft

For *open to sky surge shaft*, an exploratory hole down to at least five metres below the bottom level of surge shaft/invert of HRT is to be drilled. Water Percolation Test (WPT) may be conducted. The adequacy of lateral rock cover is to be ensured.

For *underground surge shaft,* drifts at bottom and top levels of surge shaft are required to obtain information on slump limit and know the rock mass condition. Drill holes from the drifts along the surge shaft are required to know the rock mass condition, if not feasible from the surface. Information regarding rock mass condition at the actual site along with detailed profile section of surge shaft is required to be developed. Analysis of discontinuity data may be carried out.

Detailed geological section of surge shaft is to be developed and incorporated in DPR.

Pressure shaft

Geology, presence of any shear/weak zone, rock cover, overburden thickness, orientation of discontinuities w.r.t tunnel alignment, tentative distribution of different rock types and classes (Q value, RMR), stretch wise along the tunnel grade based on surface geology and subsurface exploration are to be discussed. If required, depending upon the geology, drill holes may be drilled. If the scheme has surface penstock proposal, geology has to be discussed along the proposed alignment along with the proposed locations of anchor blocks. In addition, slope stability along the penstock alignment, may also be addressed.

Power House Structure

In case of *Surface Power house***,** whether powerhouse is to be founded in rock or overburden is to be mentioned. Depth of bedrock and foundation grade rock is to be determined through drill holes. Minimum five boreholes (at corners and centre) are required to delineate the bedrock depth and rock mass condition, depending on geology. Stabilization of the back slope/cut slope is to be discussed and if required, boreholes may also be drilled to know the depth of bedrock/rock mass condition. Geophysical survey may be undertaken to fill up the gap area. Engineering / physical properties of the overburden material/rock mass and structural analysis of the rock mass may be carried out for the cut slopes and foundation media. If the foundation is proposed on overburden then nature of overburden, liquefaction potentiality below the foundation, bearing capacity of the foundation material etc. are to be assessed.

In case of *underground powerhouse*, orientation of the cavern may be decided on the basis of prominent structural data and rock types. A drift should be excavated along the entire length of powerhouse, preferably a few metres below the crown of the cavern to explore the rock mass condition. Once the drift reaches the actual location of the proposed structure, few cross cuts should also be excavated to assess the overall variation in rock mass condition of the cavern. 3D geological log of drift, insitu and laboratory rock mechanic tests may be carried out to work out the design support system. Hydro fracture test should also be carried out to determine the principal horizontal stress for optimization of the orientation of the powerhouse cavern. The rock mass condition above the crown may be accessed through drill holes from the top or from the drift. Wedge analysis of the cavern to plan the support system may also be carried out.

Tail Race Tunnel (TRT)/Channel(TRC)

Geological mapping along tunnel alignment has to be done. Salient features like orientation of the tunnel with respect to discontinuity surfaces, maximum and minimum cover over tunnel alignment, joint sets, low cover and high cover zones, weak/shear zones likely to be encountered, vertical and lateral rock covers in all nala crossings etc are to be discussed.

Drill holes may be required to fix the TRT portal and to assess the rock mass condition so as to provide stability measures. Also, holes may be done along TRT alignment to pick up any adverse features (weak/shear zones), assessment of rock mass condition, rock cover etc. Boreholes may also be drilled to assess vertical and lateral rock covers if the tunnel is crossing any deeply incised nala. These boreholes may also be taken down to the invert level of the tunnel to assess rock mass condition.

In case of TRC, slope stability studies including determination of geomechanical properties of the overburden material is required.

Reservoir

Geology and geomorphology of the reservoir area needs to be discussed in details. Competency of reservoir, reservoir rim stability, seismic characteristics and its effects due to construction of dam, possibilities of Reservoir Induced/triggered Seismicity, occurrence of landslide dams etc may be discussed in DPR. If required, detailed explorations in the form of pits, trenches, drill holes, seismic surveys and drifts may also be undertaken.

Geological mapping of the reservoir, up to 50 metres above the FRL (or as required on geological consideration) may be done in 1: 5000/10,000 scale based on remote sensing data and Land sat imageries with field checks incorporating details like; geological units, critical zones, potential reservoir leakage zones, structural discontinuities etc. In the geological map of the reservoir area, FRL & MDDL should also be marked and labelled to demarcate the fluctuation zone. Also, land use, land cover and any vulnerable/unstable slopes within the fluctuation zone (if present) should be highlighted.

Any mineral of economic importance, civil structures of archaeological importance, human settlement etc, present within the reservoir area which is likely to be vulnerable after impounding of reservoir is to be reported. Potential sliding zones are to be studied and explored to decipher the effective remedial measures to contain them. Monitoring system to record any sudden slope movement during reservoir filling and afterwards may also be envisaged, if required.

Construction Material

Suitability tests for both coarse and fine aggregates for wearing and non-wearing surface concrete for concrete dam, to be conducted. Availability of suitable construction material in adequate quantity for the project is to be quantified and incorporated in the DPR. For this purpose, geological mapping of the selected quarry areas in 1: 1000 or less should be carried out and if required, pitting, trenching or drill holes/small drifts may be got done to establish the lateral and vertical continuity of the source materials , vis-à-vis reserve estimation. Borrow areas for impervious material, filter material, rock blocks for rockfill/earthen dams are to be identified and necessary suitability tests, reserve estimates etc, assessed. Geological map of Quarry areas, showing the sample location, project site, etc should also be incorporated.

Laboratory Tests

Laboratory rock mechanic tests should be conducted on selective core samples of different rock types present in the project site and from all components of the project. Petrography and physical parameters like bulk density, specific gravity, grain density, water content at saturation, apparent porosity, density and engineering parameters like Uniaxial compressive strength, modulus of deformation, triaxial compressive strength (c and phi) and compression and shear test, etc are to be carried out.

The required physico-mechanical and chemical test for assessing suitability of the construction material has to be carried out and their availability in adequate quantity has to be ensured and included in the DPR.

To assess the corroding / abrading potential of the suspended material carried by the water to the turbines, composition and angularity of the suspended materials collected systematically from different G&D sites need to be assessed periodically (monsoon and non-monsoon).

Geological Maps, Plates and sections of all the aspects of the project components discussed above along with reports of all tests (laboratory, insitu), site specific seismic studies, suitability of construction materials etc should be incorporated in the DPR. Also, photographs of locations of different project components, all the investigations, drill cores, drifts, important geological features, etc may be included.