Chapter – 4
Design Aspects

4.0 General

Damanganga – Pinjal Link Project envisages construction of following components:

i A 851.50 m long composite embankment (concrete face rock fill) - cum - concrete dam across river Damanganga near village Bhugad with FRL 163.87 m and corresponding gross storage capacity of 427.070 Mm^3. The length of concrete face rockfill portion of the dam is 527.50 m and the length of concrete non overflow section and spill way is 324 m;

ii A Power house at the toe of Bhugad dam with 2 units of 1.0 MW Installed Capacity each;

iii A 618.20 m long composite embankment (concrete face rock fill) - cum - concrete dam at Khargihill across river Vagh (a tributary of Damanganga river) near village Behadpada with FRL 154.52 m and corresponding gross storage capacity of 460.896 Mm^3. The length of concrete face rockfill portion of the dam is 341.0 m and the length of concrete non overflow section and spill way is 277.20 m. A saddle dam of 400 m length and 25.92 m height with FRL 154.52 m is proposed on the left flank of the reservoir;

iv A Power house at the toe of Khargihill dam with 2 units each of 1.5 MW Installed Capacity;

v A 17.488 km long D shaped tunnel with 3.20 m diameter and bed slope of 1:1342 connecting Bhugad reservoir with Khargihill reservoir;

vi A 25.224 km long D shaped tunnel with 4.00 m diameter and bed slope of 1:1717 connecting Khargihill reservoir with Pinjal reservoir;

Index Map of Damanganga - Pinjal Link Project is at Plate - 1.1 in Volume –VII (A).

4.1 Engineering Assessment

Damanganga – Pinjal Link Project envisages diversion of surplus waters from Damanganga basin available at proposed Bhugad and Khargihill reservoirs to the Pinjal reservoir (proposed by Water Resources Department, Government of Maharashtra) across river Pinjal (Vaitarna basin) from where combined surplus waters of Damanganga and Pinjal rivers will be taken to Mumbai city for augmentation of its domestic water supply, as per the Plans of Mumbai Metropolitan Regional Development Authority (MMRDA). With a view to complete the Detailed Project Report of this project within scheduled time and also to utilize the vast experience of other Central / State Government Organisation in the relevant fields, the works related to design aspects of various components of the project have been carried out by the Design Directorates of Central Water Commission (CWC) and are briefly discussed in this chapter.

4.2 Bhugad Dam

Bhugad dam is proposed as composite concrete faced rockfill – cum concrete dam across river Damanganga near Bhugad village in Peint taluka of Nasik district of Maharashtra. The total length is 851.50 m, of which 527.50 m of the dam will be Concrete Faced Rock Fill Dam (CFRD) and the rest 324 m is concrete gravity dam. The catchment area of Damanganga basin upto proposed Bhugad dam site is about 708 Km^2. The top of dam, Full Reservoir Level (FRL), Minimum draw Down Level (MDDL), and River bed level of the Bhugad dam are 168.27 m, 163.87 m, 124.83 m, and 101.16 m respectively. These levels have been fixed based on the site conditions and functional requirements.

The gross and live storage capacities of the reservoir are 427.07 Mm^3 and 398.574 Mm^3 respectively. Based on the simulation analysis about 210 Mm^3

water at 100 % dependability is proposed to be diverted from Bhugad reservoir to Khargihill reservoir through a D shape tunnel of about 17.488 Km long and 3.2 m diameter.

4.2.1 Geology, Seismicity and Foundation

4.2.1.1 Geology

Geological Investigations of the various components of Damanganga – Pinjal link project were carried out by the project authority through Geological Survey of India (GSI) during preparation of Feasibility Report of the project. During preparation of DPR geological investigation could not be carried out at Bhugad and Khargihill dam sites due to resistance from local people, therefore, the geological investigations carried out at FR stage have been used for design of dam. The Length and RDs of dam axis indicated in GSI report are as per the dam alignment adopted at FR stage.

Aerial photographs pertaining to dam site and part reservoir area were scanned by GSI and based on the same two alternative dam alignment were marked. The dam axis-I is 250 m upstream of Bhugad village where as dam axis-II is located 300 m downstream of Bhugad village (Fig – 4.1). The dam site area covering both alignments has been mapped on 1: 2500 scale (0.85 km^2) and the finally selected dam axis-II has been geo-technically mapped on 1: 1000 scale. Based on this a geological section across dam axis A-II was prepared on 1: 1000 scale. The geotechnical aspects of Bhugad dam site are briefly discussed in the following paragraphs:

At Bhugad dam site, the Damanganga river flows through a 96 m wide well defined channel with boulder/river shingle bars here and there, with change in flow direction from NNW to SSW. The water channel remains close to the right bank at the dam axis-II in the lean season, with lateral erosion of the right bank. The river is flanked by steep slope (40^0) at the right bank rising from RL 102 to 245 m and forming a prominent rock scarp between RL 220 and 245 m. On the left bank the river is characterized by a narrow river terrace (RL 106 to 110 m) with a microscap (< 3 m) exposing cross stratified

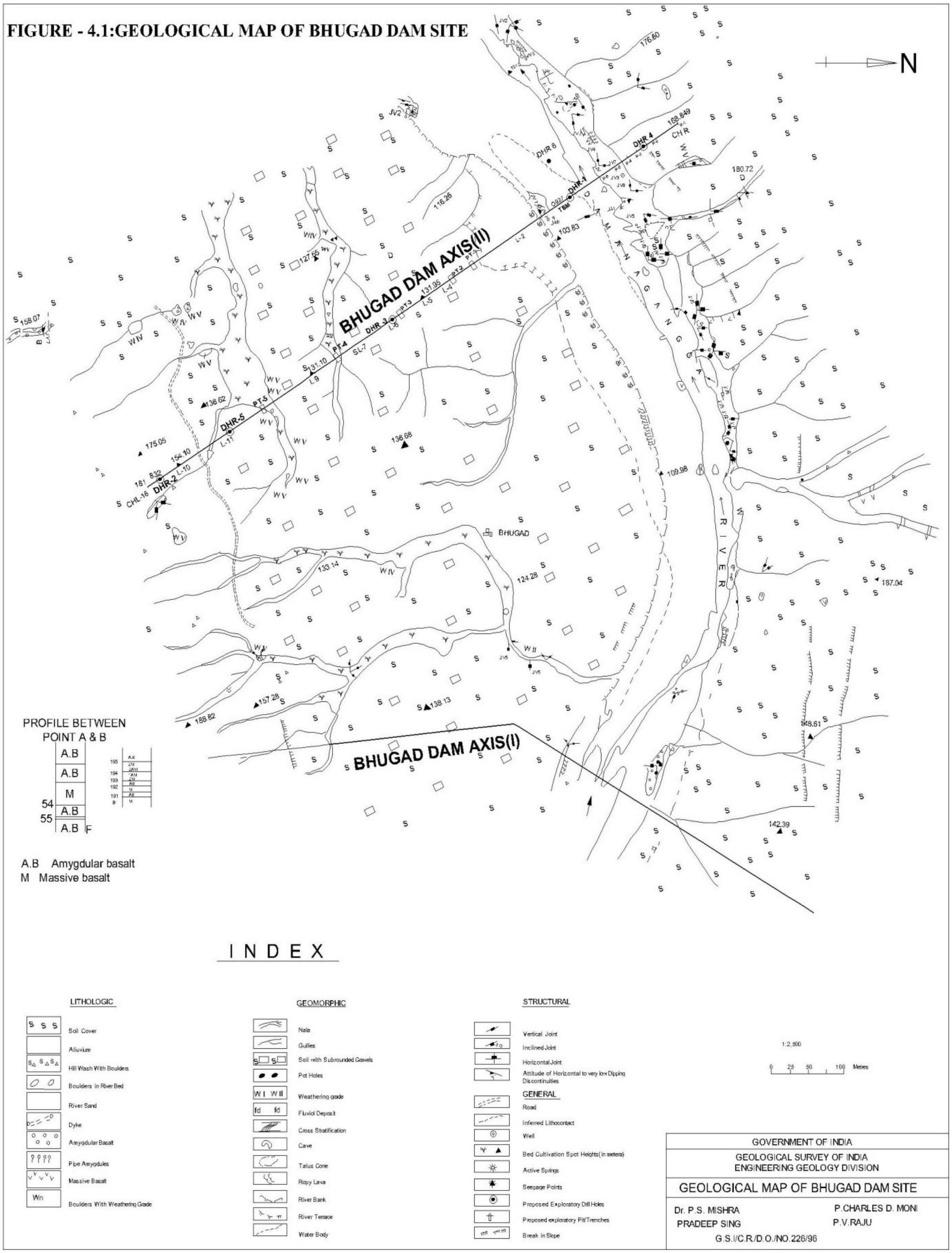


FIGURE - 4.1:GEOLOGICAL MAP OF BHUGAD DAM SITE sandy and bouldery river fill. Further beyond the terrace, the left bank is characterized by a wide spread area of highly gullied undulating and hummocks topography with hummocks rising to maximum height of RL 132 m. The left abutment rises at moderate slope (20^0) to a level of RL 190 m.

At the dam site, 9 units of sub–horizontally disposed compound pahoehoe flow are exposed. These flow units are characterized by alternating cyclic sequence of massive and amygdular basalts. The thickness of each flow unit varies from 4 to 20 m though the massive bands are laterally impersistant and lenticular in character and attain a maximum thickness of 16 m. Locally picrite nodules with medium sized (1 m dia max) volcanic blisters have been noted 1.5 km down-stream of final dam axis . Based on petrographic studies in the laboratory under microscope these are found to be divine rich porphyrite basalts with amygdales of zeolite, palagonite, chloropheate, seledonite, chlorite, calcite etc.

The pahoehoe lava sheet at dam site exhibit characteristic ropy structure imparting undulations and roughness to lava flow surfaces. At the basal zone, 3 m (approx) above river bed level, twin layers of pahoehoe flow with characteristic pipe amygdales (max 3-5 cm) are exposed. These are found to laterally continue for long distances (> 5 km) and hence can locally be used as marker beds. Tracing these, it is noted that in vicinity to dam site these are found to continue uninterrupted even across suspected fracture zones (based on aerial photo studies) and dykes ruling out presence of faults.

The lava flows have distinctive weathering characteristics. The massive bands stand out prominently with a marginal weathering (W –II, W-I) in contrast to this amygdular bands show intensive weathering ranging from W –II to W-V. The massive and amygdular lava flow units show distinctive discontinuity pattern. The prominent long traceable discontinuities are those imparted due to distressing along flow layers with accentuation forming prominent sheet joints. These indicate that the flow layers have a low gradient of 2^0-3^0 towards SW direction with a local steepening upto 5^0 - 6^0. Local water spring points along these discontinuities indicate that these are water conductive. Three sets of discontinuities in the foundation of dam site are mostly subvertical in nature.

4.2.1.2 Geotechnical Zonation of Bhugad Dam Site

A detailed geotechnical evaluation of alternative dam axis A-I and A-II was done. On comparative evaluation the dam alignment –II has been opted for development because of:

i. Shorter length of the dam (845 m) as compared to 945 m required at A-I axis;
ii. Shallow foundation in central river and on right bank; and
iii. Suitable conditions available to house spillway on the central river bed, with proper location for stilling basin and flood routing.

(The Length and RDs of dam axis indicated in GSI report are as per the dam alignment adopted at FR stage)

It was apprehended that with A-II axis alignment steep slope forming reservoir rim on the right bank would pose problem of reservoir rim stability inducing debry slide on rapid drawdown but after detailed geotechnical mapping it was found that the debry cover was < 5 m and discontinuities on lava flow units are not deeply penetrating type and hence large scale destabilization is not anticipated. Hence, the dam axis-II was finalized for further geotechnical evaluation.

Based on detailed geotechnical mapping of the area in vicinity to dam axis-II and evaluation of geotechnical parameters viz. nature of lithological assemblage, weathering characteristics, nature of discontinuities and joint volume, Geomorphic attributes and anticipated foundation grade level (FGL), the dam site area is divided into 5 geotechnical sub units:

(i) steep right abutment (RD 728 to 845 m);
(ii) river channel (RD 632 to 728 m);
(iii) left bank terrace segment (RD 529 to 632 m);

(iv) Undulating terrain with deep gulling and entrenched weathering (RD 110 to 529 m); and
(v) Moderately sloping left abutment (RD 0 to 110 m).

These sub units are briefly described in the following paragraphs.

a) The river channel with bed level RL 102 m (Unit-II, RD 632 to 728 m) exposes amygdular basalt with prominent sheet joints and twin layers of pipe amygdales. These show moderate weathering of the grade w-III and are characterized by low joint volume (JV average-5). The master discontinuities formed by these flow grade at low angle (2^0-3^0) towards downstream, these are found to be water conductive and a series of springs along these are noted at the right bank. One major (8 m wide sub vertical trending N–S) and a minor (NW–SE) dykelet emanating from the same traversed the area. In this segment suitable rock for foundation would be available at shallow depth.

b) The right abutment (Unit- I RD 728 to 845 m) rises steeply at 40^0 from RL 103 to 250 m with a scarp at its crown, has shallow debry cover < 3 m exposes different flow units of pahoehoe flow on the nala / gully beds. The contact between the basal compound pahoehoe and the upper porphyritic flow is exposed at RL 245 m i.e. 80 -100 m above TBL. The scarp at the crown is characterized by open discontinuities with tilted blocks at places. In this segment also, suitable foundation for masonry structure would be at shallow depth (< 5 m).

c) The river channel is flanked on the left bank by a narrow filled terrace (Unit-III RD 529 to 632 m) with RL 106 to 110 m consisting of fining upward cycle of channel lag and cross bedded sand and loamy soil. The terrace rises abruptly with a minor scarp (< 3 m). Underneath the alluvial fill shallow foundation grade (approx 100 m RL) is anticipated.

d) The segment (between RD 110 to 529 m) beyond river terrace is characterized by undulatory terrain with deep gullying (U –shaped) and weathered residual mounds. In this segment highly weathered (w-I) basalt is exposed locally on the Nala beds (<124 m RL). This segment is inferred to have deeply entrenched weathering and fresh rock for foundation for masonry is likely to be available at a depth (> 30 m). It is suspected that part of the Segment (between RD 529 & 295 m) is likely to contain a palaeo channel with deep alluvial fill. Hence it would be advisable to consider earth fill section.

e) The left abutment rises moderately at 20^0 from RL 130 to 194 m. It contains four units of lava flow covered under slope wash material. In view of the exposures in the vicinity it is anticipated that the foundation grade would lie at shallow level.

4.2.1.3 Seismicity

A site specific Seismic study of the project area has been carried by CWPRS (Report No. 4847, June 2011) for determining the seismic design parameters for dams and other components of the project. The seismic coefficient adopted by CWC for design of Bhugad dam are; α_h as 0.042g and α_v as 0.028g for Bhugad embankment dam and α_h as 0.16g and α_v as 0.11g for Bhugad concrete gravity dam.

4.2.1.4 Foundation treatment

The foundation treatment has been decided based on the geological interpretation carried out from the data of drill holes and other investigations. To control the under seepage, grout curtain in three rows staggered at 3m centre to centre up to a depth half the hydraulic head measured from bottom of plinth to FRL have been provided. The minimum depth of curtain grouting shall be 10 m. The post-grouting permeability should be less than 5 lugeons. Consolidation grouting to a depth of 10 m @ 3 m C/C staggered both ways below the full width of plinth have been provided.

The foundation treatment details are presented in Drawing No. DGPL – 5800 – P- 1213 and 1214 (Plate – 4.1 and 4.2 in Volume – VII(A)).

4.2.2 Free board

The basic requirement of free board is that the dam should not be overtopped under design wind conditions. The procedure adopted is based on recommendations of IS 10635-1993 (Reaffirmed 1998) "Guidelines for free board requirements in Embankment dams". For normal freeboard the wind velocity at the dam site over land has been taken as 44 m/s. The computed free board comes out to be 4.07 m and accordingly the top of dam calculated is 167.94 m. The top of the dam level has been fixed as 168.27 m against FRL of 163.87m. The maximum height of dam will be to 68.63 m and its length is 851.5 m (of which 527.5 m is CFRD).

The design computations of freeboard have been presented in Drawing No. DGPL- 5800-P-1201 (Plate – 4.3 in Volume – VII(A)).

4.2.3 River Diversion Arrangements

No formal diversion arrangement has been provided. The diversion arrangement during project construction will be evolved depending upon the requirement. As sufficient width is available, the flow only needs to be channelized through formed channels which can be decided at construction stage. Also the sluices proposed can be used for diversion during construction stage.

4.2.4 Details of Model Studies for Important Structures

No model studies are carried out at this stage. However, the same may be taken up at pre-construction stage of the project, if necessary.

4.2.5 Concrete Faced Rock Fill Dam (Bhugad Dam)

4.2.5.1 General Layout

The Bhugad dam is a composite dam comprising of Concrete faced Rockfill Dam (CFRD) and Concrete Gravity Dam. The maximum height of the CFRD portion of Bhugad dam is 68.63 m and its total length 851.50 m. Out of this, the length of CFRD is 527.50 m and the rest is power dam block NOF and OF blocks. The interface Key wall provided has a top width of 5 m and side slope 0.55 H: 1V towards dam side and slope of 0.25H: 1V towards spillway side. The power block provided has a width of 20 m and the spillway blocks have a length of 149.5 m and the length of NOF blocks is 154.5 m.

The layout of the dam and appurtenant structures are shown in Drawing No. DGPL - 5800 -P- 1205 to 1208 (Plate – 4.4 to 4.7 in Volume – VII (A)).

4.2.5.2 Reasons for selecting CFRD

At the selected Site, CFRD has been proposed for the following reasons:

- Non-availability of suitable earth fill material for earth dam.
- Non-availability of core material for rock fill dam.

4.2.5.3 Advantages of Concrete Faced Rock fill Dams

Concrete Faced Rock Fill Dam (CFRD) is suited to dam sites with a rock foundation and a source of suitable rock fill. In many cases CFRD will be a lower cost alternative than a Earth and Rock fill dam. Factors, which may lead to CFRD being the most economical alternative, include:

- The non-availability of suitable earth fill;
- Climate: CFRD are suited to wet climates, which may give short periods in which earth fill can be placed. This can result in significant overall savings in schedule;
- Grouting for CFRD can be carried out independently of embankment construction, which may result in saving in overall time for construction;
- Total embankment fill quantities are likely to be smaller and side slopes steeper for CFRD than for earth and rock fill dams leading to reductions in the cost of fill and diversion tunnels.

4.2.5.4 CFRD Section

The CFRD dam section consists of the following compounds:

Plinth: Reinforced concrete slab cast on sound, low permeability rock to join the face slab to the foundation.

Face slab: Reinforced concrete, preferably between 25 cm and 60 cm thick, with vertical, some horizontal and perimetric joints to accommodate deformation which occurs during construction and when the water load is applied.

Zone 2B: Transition rock fill, processed rock fill or alluvium, grading from silt to cobble or in more recent dams, from silt to coarse gravel size. The transition provides uniform support for the face slab and acts as semi-impervious layer restrict flow through the dam in the event that cracking of the faceplate or opening of joints occurs.

Zone 3A: Fine rock fill, selected fine rock which acts as a filter transition between Zone 2B and 3B in the event of leakage through the dam.

Zone 3B: Rock fill, quarry run, free draining rock fill placed in layers about 1 m thick. This zone provides the main support for the face slab and is compacted to a high modulus to limit settlement of the face slab.

Zone 3C: Coarse rock fill, quarry run, free draining rock fill placed in layers about 1.5 to 2 m. thick. Larger rock may be pushed to the downstream face. This zone is less affected by the water load than Zone 3B, so a lower modulus is acceptable. The thicker layers allow placement of larger rock.

Besides, two additional zones 1A & 1B are also normally provided to protect the plinth and it's joined the face slabs.

The details of the different zones and their gradation are given in CWC Drawing No. DGPL-5800-P-1202 (Plate – 4.8 in Volume – VII (A)).

4.2.5.5 Dam Slope Stability

When the CFRD is constructed of hard, free draining rock fill, the upstream and downstream slopes are fixed at 1.3H to 1V or 1.4H to 1V, which corresponds roughly to the angle of repose of loose dumped rock fill, and prevents raveling of the faces.

When gravel is used for the dam “rock fill “ zones, flatter slopes are needed to prevent raveling of the face. Usually 1.5H: 1V has been adopted in these cases although 1.6H: 1V has been used.

Haul roads may be needed on downstream slopes, or defined berms may be incorporated in the face. In these cases steeper slopes between the “berm” located by the haul road may be used, e.g. 1.25H: 1V.

The stability of the slopes in the dam is not usually analysed. This is of recognition of the fact that CFRDs have no pore pressures in the rock fill and will remain stable under static loads.

In the Bhugad CFRD 1.5H to 1V has been adopted for upstream and downstream slopes with two berms of 6 m width in downstream face as shown in Drawing No. DGPL – 5800 – P- 1202 (Plate – 4.8 in Volume – VII(A)). No berms have provided in the upstream face because of the requirement of concrete face slab.

4.2.5.6 Plinth

The principal purpose of the plinth (or “toe-slab) is to provide a “watertight” connection between the face slab and the dam foundation. The plinth is usually founded on strong, non erodible rock which is groutable, and which has been carefully excavated and cleaned up with a water jet to facilitate a low permeability cutoff. For those conditions the plinth width is of the order of 1/20 to 1/25 of the water depth. Up to the dam abutment, the width is changed according to the water head. The minimum width has generally been 3 m.

The minimum plinth thickness is usually 30 cm to 40 cm, but may be up to 0.6 m for the lower plinths of high dams. The plinth is anchored to the rock with grouted dowels, which are generally 25 mm to 35 mm diameter, reinforcing steel bars, 3m to 5 m long and are installed at 1 m to 1.5 m spacing. The anchors are provided nominally to prevent uplift during grouting, although it's reported that uplift will not develop in most cases.

In Bhugad CFRD dam, Reinforced Concrete Plinth having width of 5 m and thickness of 60 cm has been anchored to foundation rock by 32 mm dia bars @ 2 m c/c drilled 3 m into the rock. A nominal reinforcement of 20 mm dia bars @ 200 mm c/c in both direction and on both faces provided in the plinth slab as shown in Drawing No. DGPL – 5800 – P- 1203 (Plate - 4.9 in Volume – VII(A)).

4.2.5.7 Face Slab

4.2.5.7.1 Face Slab Thickness

The face slab thickness is generally determined from past experience. ICOLD (1989a), Cooke and Sherard (1987) and Cooke (2000) recommend that:

- For dams of low and moderate height (up to 100 m): Use constant thickness = 0.25 m or 0.30 m.
- For high and/or very important dams: Use thickness = 0.30 m + 0.002H where H = water head in meters.

In Bhugad CFRD dam, RCC Face slab thickness of 30 cm at top to 50 cm at bottom have been provided. Refer Drawing no. DGPL – 5800 – P- 1203 (Plate - 4.9 in Volume – VII(A)).

4.2.5.7.2 Reinforcement

In the face slab, steel reinforcement is provided to control cracking due to the temperature and shrinkage. In general the face slab is under compression.

ICOLD (1989a) and Cooke and Sherard (1987) recommend the use of 0.4 % reinforcing steel in each direction, with possible reduction to 0.3 % or 0.35 % in areas of the slab which will definitely be in compression, while retaining 0.4% within about 15 m of the perimeter.

The reinforcing steel is placed as a single mat at or just above the centerline. The reinforcing has generally been structural grade reinforcing steel (preferably consider resistant).

In Bhugad CFRD dam, Face Slab has been provided with the Reinforcement of 12 mm dia bars @ 300 mm c/c both ways. Refer Drawing No. DGPL – 5800 – P- 1203 (Plate - 4.9 in Volume – VII(A)).

4.2.5.7.3 Vertical and Horizontal joints

Most CFRDs have been constructed with each of the vertical joints being a construction joint. Vertical joints are generally provided at 12, 15, 16 or 18 m spacing depending on construction factors. For smaller dams, narrower spacing is desirable, e.g. 6 m.

ICOLD (1989a) indicates that design practice at that time did not include horizontal joints, except construction joints in which the reinforcing steel is carried through the joint without water stops. This is still current practice. The Hydro – Electric Commission retained a horizontal construction joint to reduce thermal shrinkage and face cracking.

In the case of Bhugad CFRD, vertical Joints at a spacing of 15m have been provided. However, near the abutments the spacing has been gloved to 7.5 m to take care of stress change from compression at the center to tension near the abutments.

4.2.5.7.4 Perimetric Joint

(i) General requirements: Instrumentation of CFRDs has indicated that compressive strains develop in more than 90% of the face due to settlement of the rock fill.

When the reservoir is filled there is further displacement of the slab, which leads to closing of vertical joints over most of the slab and opening of the perimetric joint and those joints near the abutments. The face slab also pulls away from the plinth, and offsets normal to the face slab, and parallel to the joint due to shear movement of the face. The joint is a common cause of leakage if not well designed, constructed and inspected.

To accommodate these movements, joints with multiple water stops are provided. The joints included two water stops:

- Primary – Copper or Stainless Steel "W" or "F" shaped.
- Secondary- Central "Bulb" water stop made of Rubber, Hypalon or PVC.

More recently, particularly for higher dams, a third water stop has been included in the form of Mastic or Fly ash filler covered with a PVC or Hypalon sheet.

(ii) Water stop details

Primary Copper or Stainless Steel Water Stop: These are either "W" or "F" shaped, with a high central rib to permit shear movement between adjacent slabs. To prevent external water pressure from squeezing the rib flat, it is filled with a neoprene insert, 12 mm diameter, held in place with a strip of closed cell polythene foam 16 x 12 mm. The water stop is supported on a cement mortar or asphalt impregnated sand pad.

Whether Copper or Stainless Steel is used depends on the aggressive nature of the reservoir water, but also seems to be matter of individual designer preference, with copper being more common. Fitzatrick et al. (1985) indicate that for the Reece Dam the HEC departed from its earlier practice of using copper water stop and used 0.9 mm thick grade 321 stainless steel. This was done because it was considered that the stainless steel would be “more robust” during construction, and there was not a significant cost differential, and the stainless steel would be less affected by the acid reservoir water.

ICOLD (1989a) indicate that it is advisable to form the copper or steel water stops in continuous strips to minimize the need for field splices. They recommend use of an electrode of high fluidity (silver content greater than 50%) for welding copper water stops to ensure full penetration into the two copper plates, then checking with a spark tester to ensure a good joint has been achieved. Fitzpatrick et al (1985) indicate that for stainless steel, jointing consists of a lap joint fixed by spot welding, then sealing by tungsten –insert gas welding, so that only one metal is involved.

Centre Bulb Water Stop: These are constructed of PVC, Natural Rubber or Hypalon.

Fitzpatrick et al. (1985) indicate that they prefer hypalon rubber instead of natural rubber or PVC because natural rubber in the atmosphere must be protected from oxidation and ozonation by the addition of antioxidants and antiozonants which could leach out. These materials will last indefinitely below minimum operating level where permanently submerged , but there may be problem between minimum operating level and flood level as PVC contains plasticizers , some of which are known to leach out.

Mastic Filler Water Stop: The concept of the mastic filler is that, as the perimetric joint opens, it will be forced into the opening by the water pressure. The mastic is covered with a PVC or hypalon membrane held in place by steel angles anchored to the concrete.

ICOLD (1989a) indicate that a chicken wire mesh was embedded in the mastic to prevent its flow downwards along the inclined joints. The covering membrane is convex upwards to provide for enough mastic volume. It is important that the membrane be sealed effectively so that the water pressure does not leak past the membrane, relieving the differential pressure needed to force the mastic into the crack. Adhesion is improved by painting the joints with mastic.

The mastic which has been used is IGAS which is a bitumen compound. It retains its flow characteristics provided it is not exposed to sunlight for extended periods.

The details of perimetric joint provided as given in Drawing No. DGPL-5800-P-1203 to 1204 (Plate – 4.9 and 4.10 in Volume – VII(A)).

4.2.5.8 Crest details

It is common to provide a reinforced concrete retaining wall ("Wave Wall", "Crest Wall" or "Parapet Wall") at the crest of the dam to reduce the volume of rock fill. Wave walls up to 3 m to 5 m have been used.

The base of the wall is usually above the full supply level and the wall is joined to the face slab with a flexible joint. The joint should be vertical, not normal to the plane of slab, so that differential settlement can be accommodated.

The crest width depends on the operational requirements but may be as narrow as 4.9 m. The Crest wall is constructed after the face slab, giving a relatively wide platform on which to work while the face slab is under construction.

The details of crest wall provided are given in CWC Drawing No. DGPL-5800-P-1203 (Plate - 4.9 in Volume – VII(A)).

4.2.5.9 Interface Wall

An interface wall has been provided between the CRFD and Concrete Gravity dam. The interface wall provide support to CFRD dam and act like an abutment. The interface wall has been designed as concrete gravity dam structure in accordance with provision of IS: 6512-1984. The gallery: grouting (curtain and consolidation) provision has been made as applicable for concrete gravity dams. The interface wall details are given in Drawing No. DGPL-5800-P-1209 to 1212 (Plate - 4.11 to 4.14 in Volume – VII(A)).

4.2.6 Bhugad Concrete Dam

4.2.6.1 Layout of Bhugad Concrete Dam

The Bhugad dam has been proposed across Damanganga river as composite embankment (CFRD) cum concrete dam. The total length of Bhugad dam is 851.50 m of which 324.0 m is concrete dam and remaining 527.5 m is CFRD. The Bhugad concrete dam is 69.42 m high and 324 m long (non over flow portion 154.5 m, power block of 20 m, and over flow portion 149.5 m). The non over flow portion consists of two non over flow (NOF) portions; Left NOF - 11.00 m, and Right NOF: 143.50 m, one power block of 20.00 m width on left side. The over flow portion consists of 9 bays of 13.50 m length and 8 piers of 3.50m width, to pass a peak flood of 8992 cumecs (PMF). Plan and upstream elevation of Bhugad concrete dam is at Drawing No. DGPL-5800-P-1108 (Plate – 4.15 in Volume – VII (A)).

The CFRD to be provided on the left side of the concrete dam will be suitably joined to the interface wall to prevent any seepage through the junction. The curtain grouting has also been suitably aligned and joined on similar considerations. For dissipating energy, stilling basin type of arrangement has been provided.

4.2.6.2 Free Board

The free board requirement of the concrete dam is less as compared to a CFRD. As such, the free board as worked out in the case of CFRD (Para – 4.2.2) has been provided for the concrete dam.

4.2.6.3 Zoning

Concrete having different strength has been proposed for different areas of the concrete gravity section based on the stress pattern. In each zone, the concrete satisfies the strength requirement defined by the state of stress. In the peripheral zones, the concrete is also subjected to the influence of external factors-variation in the temperature of air, seepage of water, alternate drying and wetting, erosion of overflow surfaces due to abrasion and cavitations. As such the concrete, depending upon its exposure to the external influences, should satisfy other requirements too. Based on the above considerations, the following zoning of the dam section in terms of concrete strength has been proposed (Table – 4.1 for non over flow section and Table – 4.2 for over flow section):

Table – 4.1
Classification of Concrete in Non Over Flow Section

S. No.	Location	Classification of Concrete	Max. size of Aggregate (mm)	Compressive strength of 150 mm cubes in N/mm^2 (28 days)
1	Concrete in Non overflow section (Except 1500 mm exterior thickness on u/s face)	C1	150	15.00
2	Concrete in foundation for filling up crevices etc.	C2	40	12.50
3	Concrete in U/S face (1500 mm thick).	C3	75	16.50
4	Fillets concrete.	C4	40	25.00
5	Concrete in parapet	C5	20	20.00
6	Concrete around foundation gallery, sump well, pump chamber, stair / lift well and other openings.	C6	40	20.00

Table – 4.2
Classification of Concrete in Over Flow Section

S. No.	Location	Classification of Concrete	Max. size of Aggregate (mm)	Compressive strength of 150 mm cubes in N/mm^2 (28 days)
1	(i) Concrete in spillway section (except 1500 mm exterior thickness on U/S face and D/S glacis).	C1	75	15.00
	(ii) Left and right training wall gravity section (except 1000 mm thickness on water side).			
2	Concrete in foundation for filling up crevices etc.	C2	40	20.00
3	(i) Concrete in exterior 1500 mm thickness on U/S face of spillway	C3	75	20.00
	(ii) Concrete in exterior 1000 mm thickness of the training wall (gravity section) on water side			
4	Fillets concrete.	C4	40	25.00
5	(i) Concrete in spillway bridge, deck slab, beams and parapet etc.	C5	20	20.00
	(ii) Concrete around foundation gallery, sump well, pump chamber, stair case/lift well and other openings.			

6.	(i) Concrete in spillway crest, pier, glacis, training wall (RCC section) and anchorage length of pier. (ii) Concrete in stilling basin, apron (Excluding top 1000 mm).	C6	75	20.00
7	Concrete in exterior 1000 mm thickness of stilling basin and apron.	C7	75	25.00
8	Concrete in stilling basin chute block, basin block and end sill.	C8	20	30.00

4.2.6.4 Design of Bhugad Concrete Dam

4.2.6.4.1 Design of Non Overflow Section

The stability analysis for non overflow section has been done at the deepest foundation level i.e. 98.85 m as per IS-6512-1984 for all the seven load combinations:

i	A (construction condition);
ii	B (Normal Operating Condition);
iii	C (Flood Discharge Condition);
iv	D (Combination A with earthquake);
v	E (Combination B with earthquake but no ice);
vi	F (Combination C but with extreme uplift drains inoperative);
vii	G (combination E but with extreme uplift drains inoperative).

The stresses obtained are within the prescribed limits in all the above mentioned conditions and the factor of safety against sliding is more than 1 as per IS.6512-1984. Following data have been adopted for the design of Non Overflow (NOF) sections:

Maximum water Level (MWL)	164.249m
Full Reservoir Level (FRL)	163.870m
Maximum Tail Water Level (Max. TWL)	115.000m
Minimum Tail water Level (Min. TWL)	98.850m
Silt Level in	110.030m
Top width of dam	8.0 m
U/S slope (H: 1)	0.100
Horizontal seismic coefficient	0.16g
Vertical seismic coefficient	0.11g
D/S slope	0.85
Cohesion of Dam & rock interface	70.0 T/m^2
Angle of internal friction of dam & rock interface	38^0
Width and height of foundation gallery	2.0 m x 2.5 m
Width and height of inspection gallery	1.5 m x 2.25 m
Deepest foundation level	98.850 m

The details of NOF section of Bhugad concrete dam are at Drawing No. DGPL-5800-P- 1101 t0 1103 (Plate – 4.16 to 4.18 in Volume – VII (A)).

The cohesion and angle of internal friction of the concrete rock interface has been assumed as 70 t/m^2 and 38^0 respectively.

Results of stability analysis and various load conditions of Bhugad concrete non over flow section are in Table – 4.3 and 4.4:

Table – 4.3
Results of stability analysis of
Bhugad concrete non over flow section

Load Combination	Vertical Stress (t/sq m)		FOS
	U/S	D/S	
A	155.43	17.02	
B	73.50	67.51	1.8
C	66.53	63.39	1.8
D	189.81	-5.28	8.3
E	27.39	103.69	1.6
F	38.94	61.43	3.2
G	-4.73	101.40	2.1

Table – 4.4
Bhugad concrete non over flow section
Various Load Conditions

Load Combination - A	
Vertical load	5832.350 t
Horizontal force	0.000 t
Moment about heel	144484.406 t-m
Vertical stress at heel	155.426 t/m^2
Vertical stress at toe	17.020 t/ m^2
FOS against sliding	Infinity
Load Combination - B	
Vertical load	4769.062 t
Horizontal force	2106.654 t
Moment about heel	159012.453 t-m
Vertical stress at heel	73.498 t/ m^2
Vertical stress at toe	67.510 t/ m^2
FOS against sliding	1.8
Load Combination - C	
Vertical load	4394.223 t
Horizontal force	2030.602 t
Moment about heel	147422.484 t-m
Vertical stress at heel	66.530 t/ m^2
Vertical stress at toe	63.395 t/ m^2
FOS against sliding	1.8
Load Combination - D	
Vertical load	5496.328 t
Horizontal force	672.045 t
Moment about heel	155555.859 t-m
Vertical stress at heel	189.815 t/ m^2
Vertical stress at toe	-5.285 t/ m^2
FOS against sliding	8.3
Load Combination - E	
Vertical load	4433.039 t

Horizontal force	3112.533 t
Moment about heel	179023.406 t-m
Vertical stress at heel	27.386 t/ m^2
Vertical stress at toe	103.686 t/ m^2
FOS against sliding	1.6
Load Combination - F	
Vertical load	3394.591 t
Horizontal force	2030.602 t
Moment about heel	123383.844 t-m
Vertical stress at heel	38.940 t/ m^2
Vertical stress at toe	61.428 t/ m^2
FOS against sliding	3.2
Load Combination - G	
Vertical load	3269.586 t
Horizontal force	3112.533 t
Moment about heel	151045.281 t-m
Vertical stress at heel	-4.725 t/ m^2
Vertical stress at toe	101.398 t/ m^2
FOS against sliding	2.1

4.2.6.4.2 Design of Overflow Section (Bhugad Dam)

The overflow section has been sized to pass peak flood of 8992 cumecs (PMF) keeping crest level at El. 153.00 m and maximum water level at 164.249 m. A vertical upstream face is provided from Elevation 151.55 m to 145.00 m and from Elevation 145.00 m up to foundation level a slope of 1H: 10V has been provided. The crest shape, discharge coefficients and d/s water surface and water nappe profiles have been worked out as per relevant I.S. Codes. Physical parameters of Bhugad concrete overflow section are in Table – 4.5. The details of over flow section of Bhugad dam are in Drawing Nos. DGPL-5800-P-1104 to 1106 (Plate – 4.19 to 4.21 in Volume – VII (A)).

Table 4.5
Physical parameter of Bhugad concrete overflow section

Maximum water level	164.249m
Full Reservoir Level	163.870m
Maximum T.W.L	115.000m
Minimum T.W.L	106.550m
Silt level	110.030m
Physical Parameters of dam	
Vertical Parameters:	
Foundation Level	98.850 m
U/S Kink Elevation	145.000 m
U/S T.P Elevation	151.550 m
Top of Crest	153.000 m
D/S T.P Elevation	144.170 m
Dam/Pier D/s intersection Level	137.680 m
Slope of U/S Batter	0.100:1
Slope of D/S Batter	0.850:1
Horizontal Parameters	
Width of u/s Batter	4.615 m
Width of d/s Batter	38.522 m
Width of u/s Crest quadrant	2.500 m
Width of d/s Crest quadrant	13.881 m
Distance of Drain from Heel	6.115 m
Distance of Drain from Toe	53.403 m
Distance of Gate Lip from Crest	2.750 m
Width of Block	17.000 m
Other parameters	
Density of Dam Material	2.400 t/m^3
Equation of d/s Crest quadrant	Y= 0.06800000x** 1.850
Pier width	3.500m

Density of Pier	2.400m
Physical parameters of Pier	
EL(4) EL(5)	EL(6) EL(7)
166.000 168.270	170.000 166.000
EL(8) EL(9)	
154.500 154.500m	
X(2) X(3)	X(4) X(5)
8.000 6.000	1.200 6.700 m
Physical Parameters of Bridge	
Road Level	168.270 m
Top width	8.000 m
Bridge-Dam Axis clearance	0.000 m
Bridge Weight	15.000 t/m run
<u>Seismic Parameters</u>	
Cm	0.630
Seismic Coefficient alpha-H	0.160
Max Ht. for Calculation of effect due to seismic forces	69.420 m
Other Parameters	
Radial gate Trunion Elevation	156.500 m
Tan-Phi	0.780
Coh	70.000 t/ m^2

The stability analysis for OF section has also been done at the deepest foundation level i.e. 98.85 m as per IS-6512-1984 for all the seven load combination as mentioned in Para 4.2.6.4.1.

The stresses obtained are within the prescribed limits in all seven loading conditions and the factor of safety against sliding is more than 1.0 as per IS.6512-1984. The results of stability analysis and various loading combinations of over flow section of Bhugad concrete dam are in Table – 4.5(A)

Table 4.5(A)
Over Flow Section of Bhugad Concrete Dam
- Various Load conditions

Load combination "a"	
Vertical load	4555.046 t
Horizontal force	0.000
Moment about heel	99847.406 t-m
Vertical stress at heel	137.010 t/m^2
Vertical stress at toe	16.056 t/m^2
Factor of safety against sliding	infinity
Shear friction factor	infinity
Load combination "b"	
Vertical load	3623.747 t
Horizontal force	2106.654 t
Moment about heel	121268.328 t-m
Vertical stress at heel	38.138 t/m^2
Vertical stress at toe	83.633 t/m^2
Factor of safety against sliding	1.444
Shear friction factor	3.319
Load combination "c"	
Vertical load	3266.685 t
Horizontal force	1980.358 t
Moment about heel	109801.102 t-m
Vertical stress at heel	33.564 t/m^2
Vertical stress at toe	76.209 t/m^2
Factor of safety against sliding	1.442
Shear friction factor	3.390
Load combination "d"	
Vertical load	4725.050 t
Horizontal force	340.008 t
Moment about heel	91745.461 t-m
Vertical stress at heel	162.159 t/m^2
Vertical stress at toe	-3.380 t/m^2
Factor of safety against sliding	14.139

Shear friction factor	23.093
Load combination "e"	
Vertical load	3453.743 t
Horizontal force	2756.040 t
Moment about heel	137636.281t-m
Vertical stress at heel	-1.012 t/m^2
Vertical stress at toe	117.070 t/m^2
Factor of safety against sliding	1.444
Shear friction factor	2.489
Load combination "f"	
Vertical load	2440.204 t
Horizontal force	1980.358 t
Moment about heel	91719.750 t-m
Vertical stress at heel	8.644 t/m^2
Vertical stress at toe	73.355 t/m^2
Factor of safety against sliding	2.714
Shear friction factor	3.065
Load combination "g"	
Vertical load	2491.818 t
Horizontal force	2756.040 t
Moment about heel	116591.734 t-m
Vertical stress at heel	-30.015 t/m^2
Vertical stress at toe	113.749 t/m^2
Factor of safety against sliding	1.965
Shear friction factor	2.217

4.2.6.4.3 Foundation Treatment and Seepage Control

The following provisions have been made for foundation treatment and seepage control:

(i) Consolidation grouting has been proposed throughout the base of the dam foundation. Ten metre deep holes at 3000 mm spacing, staggered both ways to be drilled and grouted under low pressure. The consolidation grouting is expected to increase the foundation properties.

(ii) Curtain grouting has been proposed through foundation gallery as a part of seepage control measure. Holes having a depth of (2/3H+8) m, where H is the height of reservoir at hole location. The holes will be drilled and grouted under pressure. The curtain grouting holes are proposed to be spaced at 3000 mm c/c.

(iii) Drainage holes have been proposed to trap seepage water and reduce uplift pressure. These holes will be drilled to a depth of 50 % of the hydrostatic head at a spacing of 3000 mm c/c.

The details of foundation treatment are in Drawing No. DGPL-5800-P-1109 (Plate – 4.22 in Volume – VII (A)).

4.2.6.4.4 Energy Dissipation Arrangement

Stilling basin has been provided for dissipation of the energy of the outflow. The proposed stilling basin with top at Elevation 96.0 m is 70 m long. Chute blocks, Basin blocks and End sill (dentated) have been provided in accordance with codal provisions. The performance of the proposed Energy Dissipation Arrangement has to be checked through model studies during pre-construction stage.

4.2.6.4.5 Sluices

Two sluices in the spillway portion have been provided for

- Diversion of water during construction;
- Meeting the water requirements of the downstream areas, if any;
- Emergency depletion of reservoir.

Each sluice has a size of 3.0 m (H) x 2.5 m (W). These sluices are proposed to be provided in spillway block numbers 9 & 10. The invert level of the sluices has been kept at EL 108.00 m. Vertical gates have been proposed for controlling the flow through these sluices. Details are in Drawing No. DGPL-5800-P- 1107 (Plate – 4.23 in Volume – VII (A)).

4.2.6.4.6 Additional Studies & Investigations

The present DPR has been prepared on limited geotechnical data/information and hence detailed geological investigations / tests need to be carried out at pre-construction stage.

4.2.7 Bhugad Dam Spillway Gates

Nine Spillway Radial Gates of size 13500mm X 11311mm will be provided to control the flow of spillway. These gates shall be operated by downstream twin cylinder Hydraulic Hoists.

The gate shall consist of curved skin plate stiffened by vertical stiffeners. The vertical stiffeners shall be supported by three (3 Nos.) horizontal girders. The load from horizontal girders shall be transmitted to trunnion by three radial arms on each side of gate. Independent anchor type of arrangement is proposed where the load from trunnion shall be further transferred to concrete pier through anchor girder. The Trunnion support structure of the gate would be above the water profile. Thrust block/Tie Beam shall be provided to transfer the lateral load of radial arms. Suitable bracings shall be provided for horizontal girder and radial arms.

The Radial gate shall be designed in accordance with the provision of IS: 4623 (latest revision) in general. The gate shall be designed for a total head of 11.31m corresponding to FRL of EL 163.87m. The radial gate shall be operated with the help of twin cylinder hydraulic hoist with minimum hoist capacity of 2x55t (approximate). The Hoist cylinders shall be pivoted on the Hoist support structure mounted on the pier. The power pack shall be installed on the top of the pier. Each gate shall have individual Power Pack. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210. However, provision shall be made to operate the adjacent hoists in case of emergency.

The sill level of gate shall be 152.559m and trunnion shall be installed at 156.50m. The radius of gate leaf shall be kept as 12.5m. Bottom seal of gate shall be provided as wedge type. The side seals shall be of Z type and will move on curved seal seat. Details are in Table – 4.6.

The general assembly of Radial gate has been shown in Drawing No. DGPL-5800-P-1501 & DGPL-5800-P-1502 (Plate – 4.24 and 4.25 in Volume – VII (A)).

Table – 4.6
Details of Spillway Radial Gates at Bhugad Dam

i	Clear Span	13.50 m
ii	Number of spans	10 Nos
iii	Full Reservoir level	163.87m
iv	Maximum water level	164.249m
v	EL of centre line of trunnion	156.50 m
vi	Sill level (for radial gate)	152.559m
vii	Crest level	153.0 m
viii	Inside radius of skin plate	12.5m
ix	Hoisting	By Twin Cylinder Hydraulic hoist with d/s suspension
x	Hoist Capacity	2 X 55 t
xi	Type of arms	Inclined arms
xii	Type of side seal	'Z' Type (Rubber)
xiii	Type of bottom seal	Wedge Type (Rubber)
xiv	Governing Indian Standard code	IS:4623, IS:800 (latest)

4.2.8 Bhugad Dam Spillway Stoplogs

One set of stoplogs for opening size of 13500mm X 11240mm shall be provided to carry out the maintenance of spillway Radial Gate. Each set of stoplogs shall consist of Nine units of 13500mm X 1290mm. Bottom Unit shall be non interchangeable type. All other units shall be interchangeable. The stoplogs shall be operated under balanced water head condition except top most unit which shall be lifted under unbalanced water head condition for one gate unit height water head.

Downstream skin plate and downstream sealing shall be provided. Wedge type bottom seal and solid bulb type side seals shall be provided to make the gate water tight. The Stoplogs shall be operated by gantry crane moving on the bridge. The Stoplogs shall be connected to gantry crane through Lifting Beam and Ramshorn Hook. The Details are in Table – 4.7.

The general assembly of Stoplog gate has been shown in Drawing No. DGPL-5800-P-1503 & DGPL-5800-P-1504 (Plate – 4.26 and 4.27 in Volume – VII (A)).

Table – 4.7
Details of Bhugad Dam Spillway Stoplogs

i	Width of opening	13500mm
ii	Size of Stoplogs	13500mmx1290mm (Each unit)
iii	Number of Stoplogs sets	One set Required
iv	Nos. of units per set	Nine units(All units are interchangeable except the bottom most)
v	Sill Elevation	152.63 m
vi	Top of Stoplogs unit	164.24m (When all units are installed)
vii	F R L	163.87m
viii	M W L	164.249m
ix	C/ C of side seals	13600mm
x	C/C of Tracks	14100mm
xi	Design Head	11.24m (corresponding to FRL condition)
xii	Sealing	Downstream sealing
xiii	Type of side seal	Plain rubber music note type
xiv	Type of bottom seal	Wedge type rubber seal
xv	Minimum thickness of skin plate	10 mm
xvi	Minimum thick of track plate	10 mm (after machining)
xvii	Minimum thickness of seal seat	10 mm (after machining)
xviii	Minimum thickness of guides	32 mm

4.2.9 Gantry Crane

The Bhugad dam Spillway Stoplogs shall be operated by moving Gantry Crane. The capacity of gantry crane shall be 25T (approx.). The Gantry Crane shall consist of hoist machinery mounted on trolley. The trolley shall be of moving type. The crane structure along with trolley shall be capable of moving in longitudinal direction with the help of LT travel mechanism. Suitable counter weight shall be provided to make the crane stable for different stability conditions. The crane shall be designed as per IS: 3177 and IS: 807. The Details are in Table – 4.8.

The general assembly of Gantry Crane has been shown in Drawing No. DGPL-5800-P-1505 & DGPL-5800-P-1506 (Plate – 4.28 and 4.29 in Volume – VII (A)).

Table – 4.8
Details of Gantry Crane

i	Capacity of Gantry Crane	25 t
ii	Class of Crane	Class II of IS-807-1976
iii	Gauge i.e. c/c of runway rails	5.5 m
iv	Wheel base of crane	7.5 m
v	Hoisting Speed	1.50 M/Min ± 5%
vi	Cross Travel speed (CT)	3.0 M/Min ± 5%
vii	Longitudinal Travel speed (LT)	6.0 M/Min ± 5%
viii	Type of hook	Ramshorn as shown on drawing
ix	Type of crane	Electrically operated outdoor traveling gantry

4.2.10 Bhugad Dam Sluice Gate (Service & Emergency Gate)

Two numbers sluice where opening size of 2500mm x 3000mm shall be provided in Dam. Provision of service and emergency gates shall be made to control the flow through sluice. Service and Emergency gates shall be of slide type. Gate shall be of U/S skin plate & D/S sealing. Gate shall be designed for static head of 55.87m corresponding to FRL 163.87m. These gates shall be operated under unbalance water head condition by Hydraulic Hoists. The hoist chamber shall be sealed by providing bonnet cover. Solid bulb rubber seals shall be provided on the d/s side to make the gate water tight. Suitable size of air vent shall be provided at the d/s of service gate and emergency gate. Model study for the gate is proposed to be carried out at the time of execution to assess hydro-dynamic forces and air requirement. Steel liners/HPC shall also be provided to avoid erosion of concrete in the vicinity of gates.

The service gate shall be operated by independent hydraulic hoist of 300 t (approximate) capacity. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210.

The emergency gate shall be provided on the U/S of the service gate for maintenance of the service gate. The emergency gate shall be operated by hydraulic hoist of 300 t. The details are in Table – 4.9.

Maintenance of these gates is proposed to be carried out at level EL 114.50m. The gate shall be designed in accordance with the provision of IS : 9349 (latest revision).

The general assembly of Dam Sluice Gate has been shown in Drawing No. DGPL-5800-P-1507 & DGPL-5800-P-1508 (Plate – 4.30 and 4.31 in Volume – VII (A)).

Table – 4.9

Details of Bhugad Dam Sluice Emergency Gate

i	Clear Span	2.5 m
ii	Number of openings	2 Nos.
iii	Full Reservoir level	163.87 m
iv	Maximum water level	164.249 m
v	Gate operation level	114.50 m
vi	Sill level	108.00 m
vii	Hoisting	By Hydraulic hoist
viii	Capacity of Hoist	Double acting 300 t (approx)
ix	Operation	The service gates shall be operated under unbalanced head condition
x	C/C of side seals	2650 mm
xi	C/C of tracks	2900 mm
xii	Design head	55.87 m (corresponding to FRL condition)
xiii	C/L of top Seal	111.05 m
xiv	Minimum thickness of skin plate	10 mm
xv	Minimum thickness of stainless steel track	10 mm (after machining)
xvi	Minimum thickness of seal seats of stainless steel	10 mm (after machining)
xvii	Type of side & top seal	Double stem, fluorocarbon cladded rubber seal for top. Music note type fluorocarbon cladded seal for side
xviii	Type of bottom seal	Wedge Type (Rubber) seal
xix	Governing Indian Standard code	IS: 9349, IS: 4622, IS: 800

4.3 Khargihill Dam

4.3.1 Concrete Faced Rockfill Dam (Khargihill Dam)

Khargihill dam is proposed as composite concrete faced rockfill – cum concrete dam across river Vagh (a tributary of Damanganga river) near village Behadpada in Jawhar taluka of Thane district of Maharashtra State. The maximum height of Khargihill dam is 72.92 m and its total length is 618.20 m, of which 341 m of the dam will be Concrete Faced Rock Fill Dam (CFRD) and the rest 277.20 m is concrete gravity dam. The catchment area of Vagh river upto Khargihill dam site is 646 km^2. The top of dam, Full Reservoir Level (FRL), Minimum draw Down Level (MDDL), and River bed level of the Khargihill dam are 158.92 m, 154.52 m, 109.75 m, and 84.79 m respectively. These levels have been fixed based on the site conditions and functional requirements.

The gross and live storage capacities of the reservoir have been fixed as 460.896 Mm^3 & 420.046 Mm^3 respectively. A 25.224 km long D shape tunnel with 4.0 m diameter connecting Khargihill and Pinjal reservoirs below their Minimum Draw Down Levels (MDDLs) has been proposed.

4.3.2 Geology, Seismicity and Foundation

4.3.2.1 Geology

Geological Investigations of the various components of Damanganga – Pinjal link project were carried out through Geological Survey of India (GSI) during preparation of Feasibility Report of the project. During preparation of DPR, geological investigation could not be carried out at Khargihill dam site due to resistance from local people. Therefore, the geological investigations carried out at FR stage have been used for the design of dam. The Length and RDs of dam axis indicated in GSI report are as per the dam alignment adopted at FR stage.

Based on aerial photo studies three alternative alignments: (i) Near village Behadpada; (ii) Near village Buruj upstream of village Behadpada; and (iii) Near village Butarshet downstream of village Behadpada, close to the tail end of Madhuban reservoir were suggested by GSI, Nagpur for study (Fig: 4.2). On further examination, especially on Engineering consideration with a view to optimize the reservoir capacity with a minimum submergence, dam site near village Behadpada is selected for further geotechnical evaluation. The detailed geotechnical investigation of dam site located near village Behadpada was taken up. Three alternative dam axis alignments (Fig: 4.3) were considered. The dam axis alignment A-I and A-II are beset with problems of (a) deep (20-30 m) earth fill foundation on left bank in Palaeo river fill section and (b) Unstable right abutment with impending problem of leakage/seepage outflanking and ensuring in deep cut nala . In case of dam axis A-I located almost close to the terminal or apex of triangular plateau, the right bank nala (bed level at RL 114.5) is located 225 m away from the distal end of dam. On the other hand in case of dam axis alignment II the nala lies at 237 m distance (distance corresponding to nala bed level of RL 126.0 m). As compared to these the upstream alignment A-III is found to be feasible on merit consideration of (a) shorter length, (b) Bowl shaped depression between two residual mounds of residual fill due to easterley flowing nala which offer shallow foundation(5-10 m) and suitable topographic condition to house the left embankment section, (c) The alignment is fairly upstream(160 m approx) of the downstream apex/nose of the triangular plateau on the right abutment and the nala (with raised bed level of 133m) lies at considerable distance from the distal end of the dam(>10D/H). Based on these consideration the dam alignment A-III has finally been found to be most feasible in order to gain advantage of the nala depression on left bank in minimizing the excavation and suitably seating of the dam

4.3.2.2 Geotechnical Zonation of Khargihill Dam Site

Based on physiographic & geomorphic attributes, slope gradient and breaks, erosional characteristics (gullying, lateral erosion etc) and geologic attributes (nature of exposed rock/fill, weathering grade), the dam site area is divisible into 6 sectors.(I). Left abutment terminating into a plateau at RL 170 in (RD 0 to RD 87 m), (II) Zone of Palaeo river fill (RD 87 m to 315 m), (III) Narrow belt of river terrace (RD 315 m to 345m), (IV) Active river channel (RD 345m to RD 460 m), (V) Right abutment with steep rock-cut slope (RD

FIGURE-4.2:ALTERNATE DAM AXIS OF PROPOSED KHARGIHILL DAM

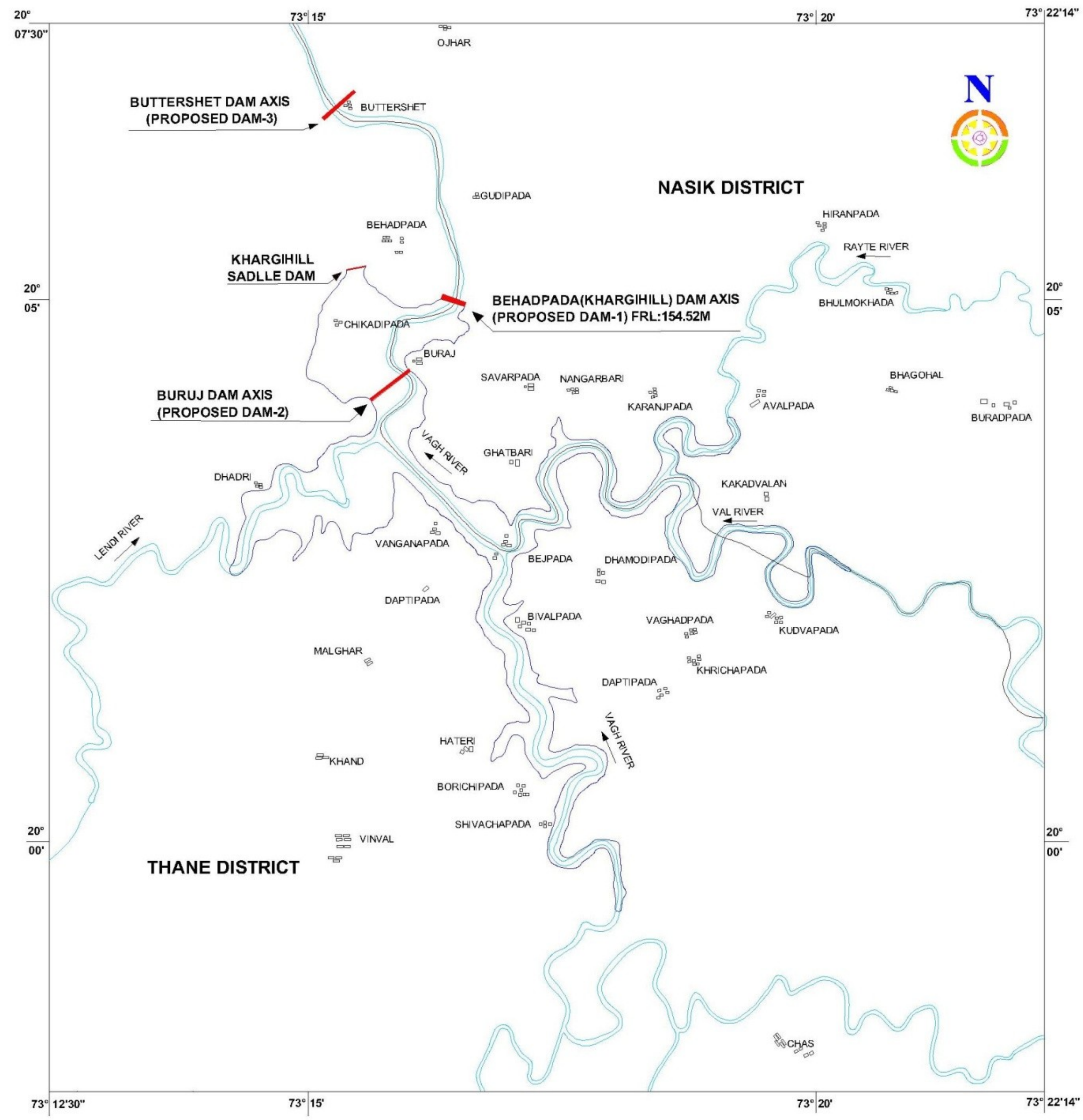
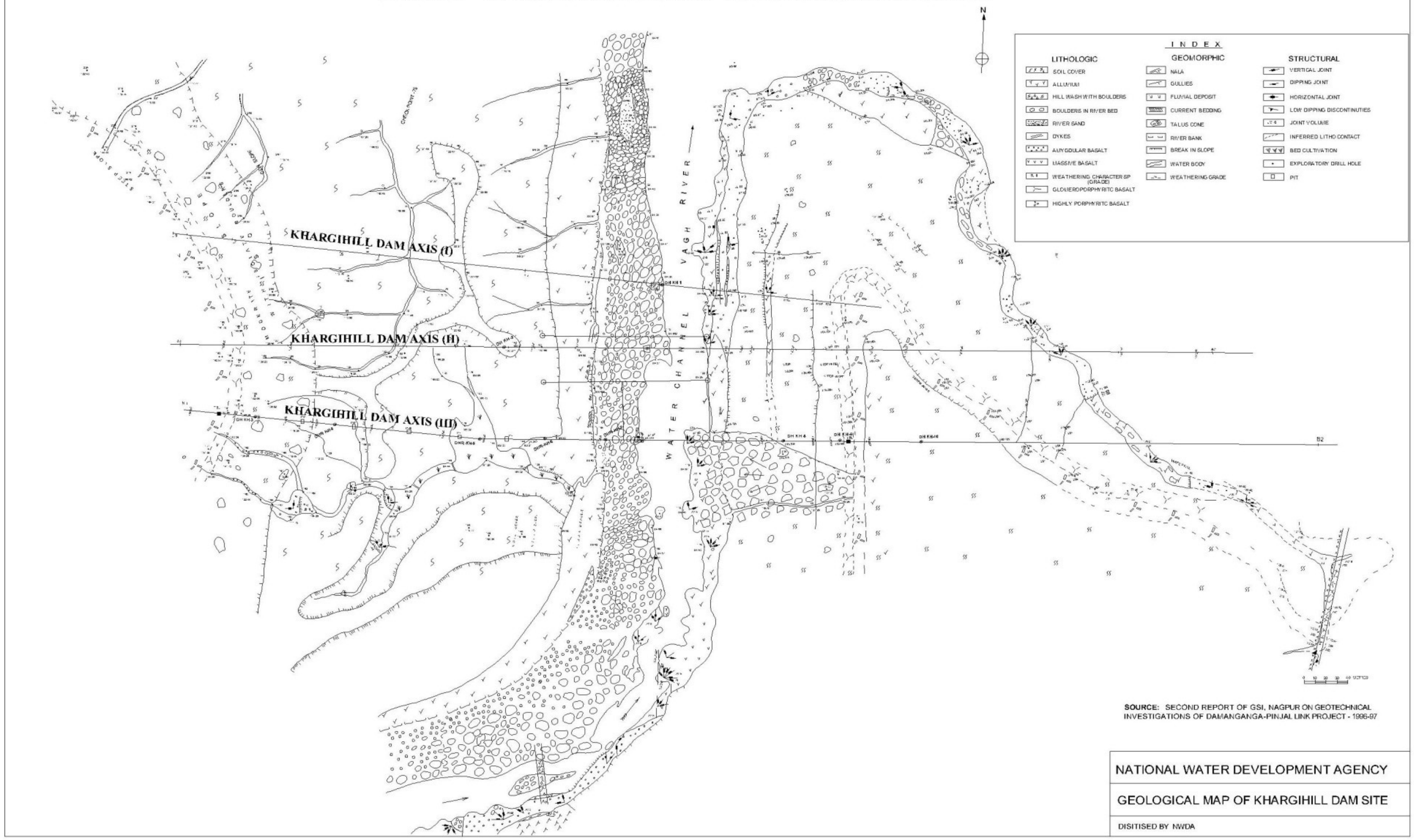


FIGURE - 4.3 :GEOLOGICAL MAP OF KHARGIHILL DAM SITE



450 m to 690m) (VI) High level plateau with deep nala on right (Beyond RD 690). The salient characteristics of these zones are as under.

Left Abutment: This segment is characterized by moderate slopes with debris consist of large transported rock blocks exposing highly poorphyrite open jointed massive basalt forming micro scarp between RL 150 m and RL 170 m. Further beyond, it forms a high level undulating plateau extending between RL 174m and RL 180 m.

Zone of Palaeo River Fill: A wide zone between RD 87 m and RD 315 m on the left bank is characterized by high undulatory terrain with deep gullying and residual mounds. The drill hole DHR-KH-2 taken on axis-II (A-II) reveals that this zone consists of 30-35 m thick pile of alluvial fill with upward fining sequences and a bouldery zone at the base. A nala trending in E-W on the zone upstream of water devide mound cuts a wide bowl shaped depression exposing highly weathered (W-IV) amygdular basalt at levels varying from RL 90 m to RL.95 m.

Belt of Terrace Deposit: The active river channel is flanked on the left bank by a narrow belt (RD 315 m to RD 345 m) of terrace with a gentle riverward slope lying between RL 91 m and RL 96 m. This is essentially a cut and fill terrace with a micro scarp towards river exposes boulder beds, ill stored cross bedded sand and occasional lenticular pockets of reddish brown mudstone. This is under active lateral erosion and reportedly has receded by 3 to 5 m in the last two years.

Active River Channel: As stated earlier the Vagh river at the dam site flows through 105 m wide, well defined channel. On the day of the mapping the river discharge has dewindled to less than 5 cusecs with visible rock stratum underneath the stagnant water column at the bed, is confined to 40 m wide zone close to right bank where as the remainder consists of bouldary soil. A drill hole DHR-KH-I on the river bed reveals that massive lava flow unit forming grade-I foundation with high RQD (>80%) is available at shallow depth of less than 4 m(RL 81-85 m.). The lava flow units (3 massive and 3 amygdular units) forming the substratum are essentially impervious excepting the zones with washout type percolation loss where permeability of the order of 14-21 Lugeon is reported.

Right Abutment: The right abutment rises abruptly at steep angle of 45^{o} from the river bed. At the bank level, adjoining the water channel hard, compact, massive basalt with moderate to high joint volume is exposed. This is overlain by highly amygdales basalt (30% amygdales) with prominent sheet joints formed due to accentuation of discontinuities along lava flow layers. Beyond these outcrops, at higher levels in the steep slope segment the bed rock is concealed underneath thin (<2 m) cover of slope wash material, excepting a zone of debris cone which descends along a nala located 130m upstream of dam axis A-I. This signifies active rock fall at the nala head in the vertical scarp at the crown. This segment is characterized by two break in slope at RL 115 m and at RL 136 m respectively. These denote presence of massive basalt bands thus revealing presence of three units of pahoehoc flows between river bed and the top contract of the flow.

High Level Plateau: The crown of the right bank is characterized by steep scarp face exposing highly open jointed porphyritic massive basalt with tilted blocks. This unit forms an extensive triangular plateau (RL 188-195m) margined towards east by a deeply incised nala exposing various How units. Luther margins of this triangular plateau are under active mass wastage and the sheet joint formed specially due to accentuation of flow layer are found to be water conductive showing dried up seepage marks.

4.3.2.3 Foundation Grade and Rock Characteristics

From the details inferred from drilling data, it is evident that the massive and amygdular basalt forming grade I/II is available at shallow depth in all geotechnical sectors excepting the one of palace river fill between RD 87 and RD 315 m where foundation grade level is anticipated at deep level (> 30 m at RD95 m ie. at RL 80m). The basaltic lava flows are mostly impervious excepting where washout and void filling type of losses had been noted during percolation test. These can be rendered impervious and monolithic by normal grouting. The lava flows in the dam site area are not intensively traversed by dykes, only two dykes are noted in vicinity to emulation area. The recent geological mapping has revealed that the right abutment, which was considered earlier stable is beset with proble of (a) recession of micro scarp and rock fall (b) seepage-leakage through discontinuities across the narrow right abutment into deeply incised nala forming eastern limit of the right abutment plateau.

4.3.2.4 Geotechnical Studies of Reservoir Area

The reservoir hill slopes are generally steep on both sides of the river and are thickly to moderately forested. On the basis of geotechnical studies, it is observed that the reservoir area is competent and likely to hold water. No fault or major shear zone was observed in the area and there is no problem of stability of hill slope.

4.3.2.5 Seismicity

A sit specific Seismic study of the project has been carried by CWPRS (Report No. 4847, June 2011) for determining the seismic design parameters for dam. The seismic coefficients adopted by CWC for designing the Khargihill dam are; α_h as 0.042g and α_v as 0.028g for embankment dams and α_h as 0.16g and α_v as 0.12g for concrete gravity dam.

4.3.2.6 Foundation treatment

The foundation treatment has been decided based on the geological interpretation carried out from the data of drill holes and other investigations. To control the under seepage, grout curtain in three rows staggered at 3m centre to centre up to a depth of (2/3H+8) where H is the head measured from bottom of plinth to FRL have been provided. The minimum depth of curtain grouting shall be 10 m. The post-grouting permeability should be less than 5 lugeons. Consolidation grouting to a depth of 10 m @ 3 m C/C staggered both ways below the full width of plinth have been provided.

The foundation treatment details are presented in Drawing No. DGPL – 5800 – P –1314 and 1315 (Plate – 4.32 and 4.33 in Volume – VII (A)).

4.3.3 Free board

The basic requirement of free board is that the dam should not be overtopped under design wind conditions. The procedure adopted is based on recommendations of IS 10635-1993 (Reaffirmed 1998) "Guidelines for free board requirements in Embankment dams". For normal freeboard the wind velocity at the dam site over land has been taken as 44 m/s. The computed free board comes out to be 5.04 m and accordingly the top of dam calculated is 159.56 m. The project authorities have fixed the dam top as 158.92 m against FRL of 154.52 m. The maximum height of dam will be to 72.92 m and its length is 618.20 m (of which 341.0 m is CFRD).

The design computations of freeboard have been presented in Drawing No. DGPL – 5800 – P –1301 (Plate – 4.34 in Volume – VII (A)).

4.3.4 Concrete Faced Rock Fill Dam (Khargihill Dam)

4.3.4.1 General Layout

The Khargihill dam is a composite Concrete Faced Rockfill cum Concrete Gravity Dam. The total length 618.20 m. Out of this, the length of CFRD is 341 m and the rest is power block, NOF & OF blocks. The interface Key wall provided has a top width of 5 m and side slope 0.55 H : 1V towards dam side and slope of 0.25H : 1V towards spillway side. The power block provided has a width of 20 m and the length of NOF blocks is 153 m and the length of spillway is 104 m.

The layout of the dam and appurtenant structures are shown in Drawing No. DGPL – 5800 – P –1305 to 1306 (Plate – 4.35 and 4.36 in Volume – VII (A)).

4.3.4.2 Reasons for selecting CFRD

At the selected Site, CFRD has been proposed for the following reasons:

- Non-availability of suitable earthfill material for earth dam.
- Non-availability of core material for rockfill dam.

4.3.4.3 Advantages of Concrete Faced Rock fill Dams

CFRD are suited to dam sites with a rock foundation and a source of suitable rock fill. In many cases CFRD will be a lower cost alternative than a Earth and Rock fill dam. Factors, which may lead to CFRD being the most economical alternative, include:

- The non-availability of suitable earth fill;
- Climate: CFRD are suited to wet climates, which may give short periods in which earth fill can be placed. This can result in significant overall savings in schedule;
- Grouting for CFRD can be carried out independently of embankment construction, which may result in saving in overall time for construction;
- Total embankment fill quantities are likely to be smaller and side slopes steeper for CFRD than for earth and rock fill dams leading to reductions in the cost of fill and diversion tunnels.

4.3.4.4 Dam Section

The CFRD dam section consists of the following compounds:

Plinth: Reinforced concrete slab cast on sound, low permeability rock to join the face slab to the foundation.

Face slab: Reinforced concrete, preferably between 25 cm and 60 cm thick, with vertical, some horizontal and perimetric joints to accommodate deformation which occurs during construction and when the water load is applied.

Zone 2B: Transition rock fill, processed rock fill or alluvium, grading from silt to cobble or in more recent dams, from silt to coarse gravel size. The transition provides uniform support for the face slab and acts as semi-impervious layer restrict flow through the dam in the event that cracking of the faceplate or opening of joints occurs.

Zone 3A: Fine rock fill, selected fine rock which acts as a filter transition between Zone 2B and 3B in the event of leakage through the dam.

Zone 3B: Rock fill, quarry run, free draining rock fill placed in layers about 1 m thick. This zone provides the main support for the face slab and is compacted to a high modulus to limit settlement of the face slab.

Zone 3C: Coarse rock fill, quarry run, free draining rock fill placed in layers about 1.5 to 2 m. thick. Larger rock may be pushed to the downstream face. This zone is less affected by the water load than Zone 3B, so a lower modulus is acceptable. The thicker layers allow placement of larger rock.

Besides, two additional zones 1A & 1B are also normally provided to protect the plinth and it's joined the face slabs. The details of the different zones and their gradation are given in Drawing No. DGPL – 5800 – P –1302 (Plate – 4.37in Volume – VII (A)).

4.3.4.5 Dam slope stability

When the CFRD is constructed of hard, free draining rock fill, the upstream and downstream slopes are fixed at 1.3H to 1V or 1.4H to 1V, which corresponds roughly to the angle of repose of loose dumped rock fill, and prevents raveling of the faces.

When gravel is used for the dam "rock fill " zones, flatter slopes are needed to prevent raveling of the face. Usually 1.5H: 1V has been adopted in these cases although 1.6H: 1V has been used.

Haul roads may be needed on downstream slopes, or defined berms may be incorporated in the face. In these cases steeper slopes between the "berm" located by the haul road may be used, e.g. 1.25H : 1V .

The stability of the slopes in the dam are not usually analysed. This is of recognition of the fact that CFRDs have no pore pressures in the rock fill and will remain stable under static loads.

In the Khargihill CFRD 1.5H to 1V has been adopted for upstream and downstream slopes with two berms of 6 m width in downstream face as shown in Drawing No. DGPL – 5800 – P –1302 (Plate – 4.37 in Volume – VII (A)). No berms have provided in the upstream face because of the requirement of concrete face slab. The Typical section of Khargihill saddle dam is at Drawing No. DGPL-5800-P-1313(Plate –4.38 in Volume – VII (A)).

4.3.4.6 Plinth

The principal purpose of the plinth (or "toe-slab) is to provide a "watertight" connection between the face slab and the dam foundation. The plinth is usually founded on strong, non erodible rock which is groutable, and which has been carefully excavated and cleaned up with a water jet to facilitate a low permeability cutoff. For those conditions the plinth width is of the order of 1/20 to 1/25 of the water depth. Up the dam abutment, the width is changed according to the water head. The minimum width has generally been 3 m.
The minimum plinth thickness is usually 30 cm to 40 cm, but may be up to 0.6 m for the lower plinths of high dams. The plinth is anchored to the rock with grouted dowels, which are generally 25 mm to 32 mm diameter, reinforcing steel bars, 3m to 5 m long and are installed at 1 m to 1.5 m spacing. The anchors are provided nominally to prevent uplift during grouting, although it's reported that uplift will not develop in most cases.

In Khargihill CFRD dam, Reinforced Concrete Plinth having width of 5 m and thickness of 60 cm has been anchored to foundation rock by 32 mm dia bars @ 2 m c/c (Staggered Both ways) drilled 3 m into the rock. A nominal reinforcement of 20 mm dia bars @ 200 mm c/c in both direction and on both faces provided in the plinth slab as shown in drawing no. DGPL – 5800 – P – 1303 (Plate – 4.39 in Volume – VII (A)).

4.3.4.7 Face Slab

4.3.4.7.1 Face Slab Thickness

The face slab thickness is generally determined from past experience. ICOLD (1989a), Cooke and Sherard (1987) and Cooke (2000) recommend that:

- For dams of low and moderate height (up to 100 m): Use constant thickness = 0.25 m or 0.30 m.
- For high and/or very important dams: Use thickness = 0.30 m + 0.002H where H = water head in meters.

In Khargihill CFRD dam, RCC Face slab thickness of 30 cm at top to 50 cm at bottom have been provided. Refer drawing no. DGPL – 5800 – P –1303 (Plate – 4.39 in Volume – VII (A)).

4.3.4.7.2 Reinforcement

In the face slab, steel reinforcement is provided to control cracking due to the temperature and shrinkage. In general the face slab is under compression.

ICOLD (1989a) and Cooke and Sherard (1987) recommend the use of 0.4 % reinforcing steel in each direction, with possible reduction to 0.3 % or 0.35 % in areas of the slab which will definitely be in compression, while retaining 0.4% within about 15 m of the perimeter.

The reinforcing steel is placed as a single mat at or just above the centerline. The reinforcing has generally been structural grade reinforcing steel (preferably consider resistant).

In Khargihill CFRD dam, Face Slab has been provided with the Reinforcement of 12 mm dia bars @ 300 mm c/c both ways. Refer drawing no. DGPL – 5800 – P –1303 (Plate – 4.39 in Volume – VII (A)).

4.3.4.7.3 Vertical and Horizontal joints

Most CFRDs have been constructed with each of the vertical joints being a construction joint. Vertical joints are generally provided at 12, 15, 16 or 18 m spacing depending on construction factors. For smaller dams, narrower spacing is desirable, e.g. 6 m.

ICOLD (1989a) indicates that design practice at that time did not include horizontal joints, except construction joints in which the reinforcing steel is carried through the joint without water stops. This is still current practice.
The Hydro – Electric Commission retained a horizontal construction joint to reduce thermal shrinkage and face cracking.

In the case of Khargihill CFRD, vertical Joints at a spacing of 15m have been provided. However, near the abutments the spacing has been reduced to 7.5 m to take care of stress change from compression at the center to tension near the abutments.

4.3.4.7.4 Perimetric Joint

(i) General requirements: Instrumentation of CFRDs has indicated that compressive strains develop in more than 90% of the face due to settlement of the rock fill.

When the reservoir is filled there is further displacement of the slab, which leads to closing of vertical joints over most of the slab and opening of the perimetric joint and those joints near the abutments. The face slab also pulls away from the plinth, and offsets normal to the face slab, and parallel to the joint due to shear movement of the face. The joint is a common cause of leakage if not well designed, constructed and inspected.

To accommodate these movements, joints with multiple water stops are provided. The joints included two water stops:

- Primary – Copper or Stainless Steel “W” or “F” shaped.

- Secondary- Central “Bulb” water stop made of Rubber, Hypalon or PVC.

More recently, particularly for higher dams, a third water stop has been included in the form of Mastic or Fly ash filler covered with a PVC or Hypalon sheet.

(ii) Water stop details

Primary Copper or Stainless Steel Water Stop: These are either “W” or “F” shaped, with a high central rib to permit shear movement between adjacent slabs. To prevent external water pressure from squeezing the rib flat, it is filled with a neoprene insert, 12 mm diameter, held in place with a strip of closed cell polythene foam 16 x 12 mm. The water stop is supported on a cement mortar or asphalt impregnated sand pad.

Whether Copper or Stainless Steel is used depends on the aggressive nature of the reservoir water, but also seems to be matter of individual designer preference, with copper being more common. Fitzatrick et al. (1985) indicate that for the Reece Dam the HEC departed from its earlier practice of using copper water stop and used 0.9 mm thick grade 321 stainless steel. This was done because it was considered that the stainless steel would be “more robust” during construction, and there was not a significant cost differential, and the stainless steel would be less affected by the acid reservoir water.

ICOLD (1989a) indicate that it is advisable to form the copper or steel water stops in continuous strips to minimize the need for field splices. They recommend use of an electrode of high fluidity (silver content greater than 50%) for welding copper water stops to ensure full penetration into the two copper plates, then checking with a spark tester to ensure a good joint has been achieved. Fitzpatrick et al (1985) indicate that for stainless steel, jointing consists of a lap joint fixed by spot welding, then sealing by tungsten –insert gas welding, so that only one metal is involved.

Centre Bulb Water Stop: These are constructed of PVC, Natural Rubber or Hypalon.

Fitzpatrick et al. (1985) indicate that they prefer hypalon rubber instead of natural rubber or PVC because natural rubber in the atmosphere must be protected from oxidation and ozonation by the addition of antioxidants and antiozonants which could leach out. These materials will last indefinitely below minimum operating level where permanently submerged , but there may be problem between minimum operating level and flood level as PVC contains plasticizers , some of which are known to leach out.

Mastic Filler Water Stop: The concept of the mastic filler is that, as the perimetric joint opens, it will be forced into the opening by the water pressure. The mastic is covered with a PVC or hypalon membrane held in place by steel angles anchored to the concrete.

ICOLD (1989a) indicate that a chicken wire mesh was embedded in the mastic to prevent its flow downwards along the inclined joints. The covering membrane is convex upwards to provide for enough mastic volume. It is important that the membrane be sealed effectively so that the water pressure does not leak past the membrane, relieving the differential pressure needed to force the mastic into the crack. Adhesion is improved by painting the joints with mastic.

The mastic which has been used is IGAS which is a bitumen compound. It retains its flow characteristics provided it is not exposed to sunlight for extended periods. The details of perimetric joint provided as given in Drawing No. DGPL – 5800 – P –1303 and 1304 (Plate – 4.39 and 4.40 in Volume – VII (A)).

4.3.4.8 Crest details

It is common to provide a reinforced concrete retaining wall ("Wave Wall", "Crest Wall" or "Parapet Wall") at the crest of the dam to reduce the volume of rock fill. Wave walls up to 3 m to 5 m have been used.

The base of the wall is usually above the full supply level and the wall is joined to the face slab with a flexible joint. The joint should be vertical, not normal to the plane of slab, so that differential settlement can be accommodated.

The crest width depends on the operational requirements but may be as narrow as 4.9 m. The Crest wall is constructed after the face slab, giving a relatively wide platform on which to work while the face slab is under construction.

The details of crest wall provided are given in Drawing No. DGPL – 5800 – P –1303(Plate – 4.39 in Volume – VII (A)).

4.3.4.9 Interface Wall

An interface wall has been provided between the CRFD and Concrete Gravity dam. The interface walls provide support to CFRD dam and act like an abutment. The interface wall has been designed as concrete gravity dam structure in accordance with provision of IS: 6512-1984. The gallery: grouting (curtain and consolidation) provision has been made as applicable for concrete gravity dams. The interface wall details are given in Drawing No. DGPL – 5800 – P –1307 to1312 (Plate – 4.41 to 4.46 In Volume – VII (A)).

4.3.5 Khargihill Concrete Dam

4.3.5.1 Project Layout:

The Khargihill dam is 618.20 m long and 83.92 m high, has been proposed as composite concrete – cum CFRD, comprising of 277.20 m long concrete dam and remaining 341.00 m as CFRD on economic considerations and also taking into account the availability of materials. The CFRD to be provided on the left side of the concrete dam will be suitably joined to the interface wall to prevent any seepage through the junction. The curtain grouting has also been suitably aligned and joined on similar considerations. For dissipating energy, stilling basin type of arrangement has been provided.

The Khargihill concrete dam consist of two Non over flow portions, (on the left side of spillway 11.00m, Right NOF: 142.20m), one power block of 20.00 m width on left side of spillway and over flow (spillway) portion of 104.00 m width. The over flow portion consists 6 bays of 14.0 m length each and 5 piers of 4.0 m width each to pass a peak flood of 10222 cumecs (PMF). Plan and upstream elevation of Khargihill concrete dam is at Drawing No. DGPL-5800-P-1158 (Plate – 4.47 in Volume – VII (A)).

4.3.5.2 Free Board

The free board requirement of the concrete dam is less as compared to a CFRD. As such, the free board as worked out in the case of CFRD has been provided for the concrete dam.

4.3.5.3 Zoning

Concrete having different strength has been proposed for different areas of the concrete gravity section based on the stress pattern. In each zone, the concrete satisfies the strength requirement defined by the state of stress. In the peripheral zones, the concrete is also subjected to the influence of external factors - variation in the temperature of air, seepage of water, alternate drying and wetting, erosion of overflow surfaces due to abrasion and cavitation. As such, the concrete depending upon its exposure to the external influences should satisfy other requirements too. Based on the above considerations, the following zoning of the dam section in terms of concrete strength has been proposed (Table – 4.10 for non over flow section and Table – 4.11 for over flow section):

Table – 4.10

Classification of Concrete in Non Over Flow Section

S.No	Location	Classification of Concrete	Max. size of Aggregate (mm)	Compressive Strength of 150 mm Cubes in N/mm^2 (28 days)
1.	Concrete in Non overflow section (Except 2000 mm exterior thickness on u/s face)	C1	150	15.00
2.	Concrete in foundation for filling up crevices etc.	C2	40	15.00
3.	(i) Concrete in portion above acceptable foundation grade, U/S face, D/S face (2000 mm thick) and fillet concrete.	C3	40	25.00
	(ii) Concrete around foundation gallery, sump well, pump chamber, stair / lift well and other openings			
4.	Concrete in parapet	C4	20	25.00

Table – 4.11
Classification of Concrete in Over Flow Section

S.No	Location	Classification of Concrete	Max. size of Aggregate (mm)	Compressive Strength of 150 mm Cubes in N/mm^2 (28 days)
1.	(i) Concrete in spillway section (except 2000 mm exterior thickness on U/S face and D/S glacis).	C1	75	15.00
	(ii) Left and right training wall gravity section (except 1000 mm thickness on water side).			
2.	Concrete in foundation for filling up crevices etc.	C2	20/40	15.00
3.	(i) Concrete in exterior 2000 mm thickness on U/S face of spillway	C3	40	25.00
	(ii) Concrete in exterior 1000 mm thickness of the training wall (gravity section) on water side			
	(iii) Fillets concrete.			
	(iv) Concrete in spillway pier, training wall (RCC section) and anchorage length of pier.			
	(v) Concrete in stilling basin, apron (Excluding top 300 mm).			

	(vi) Concrete in spillway crest and glacis (beyond 300mm and up to 2000mm from the exterior surface).			
	(vii) 2000 mm thick concrete above acceptable foundation level in dam body.			
4.	(i) Concrete in spillway bridge, deck slab, beams and parapet etc.	C4	20	25.00
	(ii) Concrete around foundation gallery, sump well, pump chamber, stair case/lift well and other openings.			
5.	Concrete in exterior 300 mm thickness of stilling basin, apron and spillway D/S glacis.	C5	20	50.00
8.	Concrete in stilling basin chute block, and end sill.	C6	20	30.00

4.3.5.4 Concrete Dam Design (Khargihill Dam)

4.3.5.4.1 Non Overflow Section

The Stability Analysis For Non Overflow section has been done at the deepest foundation level i.e. 81.00 m as per IS-6512-1984 for all the seven load combinations i.e.:

i	A (construction condition);
ii	B (Normal Operating Condition);
iii	C (Flood Discharge Condition);
iv	D (Combination A with earthquake);
v	E (Combination B with earthquake but no ice);
vi	F (Combination C but with extreme uplift drains inoperative);
vii	G (combination E but with extreme uplift drains inoperative).

The stresses obtained are within the prescribed limits in all the above mentioned conditions and the factor of safety against sliding is more than 1 as per IS.6512-1984.

Following data have been adopted for the design of Non Over Flow sections

i	Maximum water Level (MWL)	155.00 m
ii	Full Reservoir Level (FWL)	154.52 m
iii	Maximum Tail Water Level (Max. TWL)	96.00 m
iv	Minimum Tail water Level (Min. TWL)	81.00m
v	Silt Level in m	93.00m
vi	Top width of dam	8.0m
vii	U/S slope (H: 1)	0.25
viii	Horizontal seismic coefficient	0.18g
ix	Vertical seismic coefficient	0.12g
x	D/S slope	0.85
xi	Cohesion of Dam & rock interface	70.0 t/m^2
xii	Angle of internal friction of dam & rock interface	38^0
xiii	Width and height of foundation gallery	2.5m x 2.5m
xiv	Width and height of inspection gallery	2.5m x 2.5m
xv	Deepest foundation level	81.00m

The details of NOF section of Khargihill concrete dam are at Drawing No. DGPL-5800-P- 1151 to 1153 (Plate – 4.48 to 4.50 in Volume – VII (A)).

The cohesion and angle of internal friction of the concrete rock interface has been assumed as 70 t/m^2 and 38^0 respectively.

Results of stability analysis and various load conditions of Bhugad concrete non over flow section are in Table – 4.12 and 4.13:

Table 4.12
Results of Stability Analysis of
Khargihill Concrete Non Overflow Section

Load	Vertical Stress (t/ m^2)		FOS
	U/S	D/S	
A	144.74	40.48	
B	68.93	91.83	1.9
C	61.09	80.14	1.8
D	179.07	15.77	7.7
E	23.40	127.74	1.6
F	40.41	74.37	3.3
G	-2.37	120.55	2.1

Table 4.13
Khargihill Concrete Non Overflow Section
Various Load conditions

Load combination "A"	
Vertical load	7742.185 t
Horizontal force	0.000 t
Moment about heel	262900.875 t-m
Vertical stress at heel	144.740 t/m^2
Vertical stress at toe	40.480 t/ m^2
Factor of safety against sliding	Infinity
Load combination "B"	
Vertical load	6719.641 t
Horizontal force	2728.516 t
Moment about heel	294214.250 t-m
Vertical stress at heel	68.932 t/ m^2
Vertical stress at toe	91.825 t/ m^2
Factor of safety against sliding	1.9
Load combination "C"	
Vertical load	5903.393 t
Horizontal force	2651.420 t
Moment about heel	257858.453 t-m

Vertical stress at heel	61.088 t/ m^2
Vertical stress at toe	80.141 t/ m^2
Factor of safety against sliding	1.8
Load combination "D"	
Vertical load	7273.994 t
Horizontal force	936.381 t
Moment about heel	276791.750 t-m
Vertical stress at heel	179.067 t/ m^2
Vertical stress at toe	15.771 t/ m^2
Factor of safety against sliding	7.7
Load combination "E"	
Vertical load	6251.450 t
Horizontal force	4096.124 t
Moment about heel	321162.188 t-m
Vertical stress at heel	23.396 t/ m^2
Vertical stress at toe	127.743 t/ m^2
Factor of safety against sliding	1.6
Load combination "F"	
Vertical load	4797.635 t
Horizontal force	2651.420 t
Moment about heel	220317.969 t-m
Vertical stress at heel	40.410 t/ m^2
Vertical stress at toe	74.366 t/ m^2
Factor of safety against sliding	3.3
Load combination "G"	
Vertical load	4873.563 t
Horizontal force	4096.124 t
Moment about heel	274382.906 t-m
Vertical stress at heel	-2.372 t/ m^2
Vertical stress at toe	120.547 t/ m^2
Factor of safety against sliding	2.1

4.3.5.4.2 Overflow Section (Khargihill Dam)

The overflow section has been sized to pass peak flood of 10222 cumecs (PMF) keeping crest level at El. 138.52 m and maximum water level at 155.00 m. An upstream slope of 1H: 4V is provided from El. 136.704 m up to foundation level. The crest shape, discharge coefficients and d/s water surface and water nappe profiles have been worked out as per relevant I. S. Codes. Physical parameter of Khargihill Concrete Overflow Section are in Table – 4.14. The details of over flow section of Khargihill concrete dam are at Drawing No. DGPL-5800-P- 1154 to 1156 (Plate – 4.51 to 4.53 in Volume – VII (A)).

Table 4.14
Physical parameter of Khargihill Concrete Overflow Section

Maximum water level	155.000 m
Full Reservoir Level	154.520 m
Maximum T.W.L	96.000 m
Minimum T.W.L	75.000 m
Silt level	93.000 m
Physical Parameters of dam	
Vertical Parameters:	
Foundation Level	75.000 m
U/S Kink Elevation	136.704 m
U/S T.P Elevation	136.704 m
Top of Crest	138.520 m
D/S T.P Elevation	129.990 m
Dam/Pier D/s intersection Level	122.925 m
Slope of U/S Batter	0.200:1
Slope of D/S Batter	1.000:1
Horizontal Parameters	
Width of u/s Batter	12.341m
Width of d/s Batter	54.990 m
Width of u/s Crest quadrant	3.892 m

Width of d/s Crest quadrant	15.750 m
Distance of Drain from Heel	16.491 m
Distance of Drain from Toe	70.482 m
Distance of Gate Lip from Crest	2.500 m
Width of Block	18.000 m
Other parameters	
Density of Dam Material	2.400t/m^3
Equation of d/s Crest quadrant	Y= 0.05200000x** 1.850
Pier width	4.000 m
Density of Pier	2.400 m
Physical parameters of Pier	
EL(4) EL(5)	EL(6) EL(7)
157.060 158.920	160.810 158.310
EL(8) EL(9)	
146.750 142.750 m	
X(2) X(3)	X(4) X(5)
8.000 7.500	4.040 6.000 m
Physical Parameters of Bridge	
Road Level	158.920 m
Top width	8.000 m
Bridge-Dam Axis clearance	0.000 m
Bridge Weight	15.000 t/m run
Seismic Parameters	
Cm	0.630
Seismic Coefficient alpha-H	0.180
Max Ht. for Calculation of effect due to seismic forces	83.920 m
Other Parameters	
Radial gate Trunion Elevation	144.750 m
Tan-Phi	0.780
Coh	70.000 t/m^2

The stability analysis for OF section has also been done at the deepest foundation level i.e. 75.0 m as per IS-6512-1984 for all the seven load combination as mentioned in Para 4.3.5.4.1.

The stresses obtained are within the prescribed limits in all seven loading conditions and the factor of safety against sliding is more than 1.0 as per IS.6512-1984. The results of stability analysis and various loading combinations of over flow section of Khargihill concrete dam are in Table – 4.15:

Table 4.15
Khargihill Concrete Overflow Section
Various Load conditions

Load combination "a"	
Vertical load	7710.321t
Horizontal force	0.000
Moment about heel	260334.453 t-m
Vertical stress at heel	148.110 t/m^2
Vertical stress at toe	29.195 t/m^2
Factor of safety against sliding	infinity
Shear friction factor	infinity
Load combination "b"	
Vertical load	6613.922 t
Horizontal force	3220.036 t
Moment about heel	304951.781 t-m
Vertical stress at heel	62.294 t/m^2
Vertical stress at toe	89.799 t/m^2
Factor of safety against sliding	1.593
Shear friction factor	3.493
Load combination "c"	
Vertical load	5399.190 t
Horizontal force	2932.202 t
Moment about heel	246221.422 t-m
Vertical stress at heel	53.012 t/m^2
Vertical stress at toe	71.147 t/m^2

Factor of safety against sliding	1.534
Shear friction factor	3.513
<u>Load combination "d"</u>	
Vertical load	8021.943 t
Horizontal force	623.244 t
Moment about heel	245371.797 t-m
Vertical stress at heel	174.311 t/m^2
Vertical stress at toe	10.161 t/m^2
Factor of safety against sliding	12.436
Shear friction factor	19.808
<u>Load combination "e"</u>	
Vertical load	6302.300 t
Horizontal force	4363.877 t
Moment about heel	336947.438 t-m
Vertical stress at heel	22.583 t/m^2
Vertical stress at toe	122.344 t/m^2
Factor of safety against sliding	1.520
Shear friction factor	2.522
<u>Load combination "f"</u>	
Vertical load	4175.213t
Horizontal force	2932.202 t
Moment about heel	204009.234 t-m
Vertical stress at heel	30.202 t/m^2
Vertical stress at toe	65.810 t/m^2
Factor of safety against sliding	2.841
Shear friction factor	3.187
<u>Load combination "g"</u>	
Vertical load	4652.627 t
Horizontal force	4363.877 t
Moment about heel	280054.000 t-m
Vertical stress at heel	-8.160 t/m^2
Vertical stress at toe	115.151 t/m^2
Factor of safety against sliding	1.994
Shear friction factor	2.227

4.3.5.4.3 Foundation Treatment and Seepage Control

Following provisions have been made for foundation treatment and seepage control:

(a) Consolidation grouting has been proposed throughout the base of the dam foundation. Ten metre deep holes at 3000 mm spacing, staggered both ways to be drilled and grouted under low pressure. The consolidation grouting is expected to increase the foundation properties.
(b) Curtain grouting has been proposed through foundation gallery as a part of seepage control measure. Holes having a depth of (2/3H+8) m, where H is the height of reservoir at hole location. The holes will be drilled and grouted under pressure. The curtain grouting holes are proposed to be spaced at 3000 mm c/c.
(c) Drainage holes have been proposed to trap seepage water and reduce uplift pressure. These holes will be drilled to a depth of 50 % of the hydrostatic head at a spacing of 3000 mm c/c.

The details of foundation treatment are in Drawing No. DGPL-5800-P-1157 (Plate – 4.54 in Volume – VII (A)).

4.3.5.4.4 Energy Dissipation Arrangement

Stilling basin has been provided for dissipation of the energy of the outflow. The proposed stilling basin with top at EL. 75.0 m is 80 m long. Chute blocks and end sill (dentated) have been provided in accordance with codal provisions. The performance of the proposed Energy Dissipation Arrangement has to be checked through model studies during pre-construction stage.

4.3.5.4.5 Sluices

Three sluices in the spillway portion have been provided for:

- Diversion of water during construction;

- Meeting the water requirements of the downstream areas, if any;
- Emergency depletion of reservoir.

Each sluice has a size of 5.0 m (H) x 3.0 m (W). These sluices are proposed to be provided in spillway block numbers 9, 10 & 11. The invert level of the sluices has been kept at EL 108.00 m. Radial gates have been proposed for controlling the flow through these sluices.

4.3.5.4.6 Diversion Arrangement

No formal diversion arrangement has been provided. The diversion arrangement during project construction will be evolved depending upon the requirement. As sufficient width is available, the flow only needs to be channelized through formed channels which can be decided at construction stage. Also the sluices proposed can be used for diversion during construction stage.

4.3.5.4.7 Additional Studies and Investigations

a) The present DPR has been prepared on limited geotechnical data/information and hence detailed geological investigations / tests need to be carried out at pre-construction stage.
b) Model studies need to be undertaken to ascertain the discharging capacity of spillway, efficiency of energy dissipation arrangement and layout and profile of approach and spill channel at the pre-construction stage.

4.3.6 Khargihill Dam Spillway Radial Gates

Six Spillway Radial Gates of size 14000mm X 16280mm will be provided to control the flow of spillway. These gates shall be operated by downstream twin cylinder Hydraulic Hoists.

The gate shall consist of curved skin plate stiffened by vertical stiffeners. The vertical stiffeners shall be supported by four (4 Nos.) Horizontal girders. The load from horizontal girders shall be transmitted to trunnion by four radial arms on each side of gate. Independent anchor type of arrangement is proposed where the load from trunnion shall be further transferred to concrete through anchor girder. The Trunnion support structure of the gate would be above the water profile. Thrust block/Tie Beam shall be provided to transfer the lateral load of radial arms. Suitable bracings shall be provided for Horizontal girder and arms.

The Radial gate shall be designed in accordance with the provision of IS: 4623 (latest revision) in general. The gate shall be designed for a total head of 16.28m corresponding to FRL of EL 154.52m. The radial gate shall be operated with the help of Twin cylinder hydraulic hoist with minimum hoist capacity of 2x100T (approximate). The Hoist cylinders shall be pivoted on the Hoist Support structure mounted on the pier. The power pack shall be installed on the top of the pier. Each gate shall have individual Power Pack. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210. However, provision shall be made to operate the adjacent hoists in case of emergency.

The sill level of gate shall be 138.24m and trunnion shall be installed at 144.75m. The radius of gate leaf shall be kept as 18.5m. Bottom seal of gate shall be provided as wedge type. The side seals shall be of Z type and will move on curved seal seat. The details are in Table – 4.14

The general assembly of Radial gate has been shown in Drawing No. DGPL-5800-P-1509 & DGPL-5800-P-1510 (Plate – 4.55 and 4.56 in Volume – VII (A)).

Table – 4.14

Details of Spillway Radial Gates at Khargihill Dam

i	Clear Span	14.00 m
ii	Number of spans	6 Nos.
iii	Full Reservoir level	154.52 m
iv	Maximum water level	155.00 m
v	EL of centre line of trunnion	144.75 m
vi	Sill level (for radial gate)	138.238 m

vii	Crest level	138.52 m
viii	Inside radius of skin plate	18.5m
ix	Hoisting	By Twin Cylinder Hydraulic hoist with d/s suspension
x	Hoist Capacity	2 X 100 T (approximate)
xi	Type of arms	Inclined arms
xii	Type of side seal	'Z' Type (Rubber)
xiii	Type of bottom seal	Wedge Type (Rubber)
xiv	Governing Indian Standard code	IS:4623, IS:800 (latest)

4.3.7 Khargihill Dam Spillway Stoplogs

One set of stoplogs for opening size of 14000mm X 16770mm shall be provided to carry out the maintenance of spillway Radial Gate. Each set of stoplogs shall consist of Eleven units of 14000mm X 1570mm. Bottom Unit shall be non interchangeable type. All other units shall be interchangeable. The stoplogs shall be operated under balanced water head condition except top most unit which shall be lifted under unbalanced water head condition for one gate unit height water head.

Downstream skin plate and downstream sealing shall be provided. Wedge type bottom seal and solid bulb type side seals shall be provided to make the gate water tight. The Stoplogs shall be operated by gantry crane moving on the bridge. The Stoplogs shall be connected to gantry crane through Lifting Beam and Ramshorn Hook. The details are in Table – 4.15.

The general assembly of Stoplog gate has been shown in Drawing No. DGPL-5800-P-1511(Plate – 4.57 in Volume – VII (A)).

Table – 4.15

Details of Khargihill Dam Spillway Stoplogs

i	Width of opening	14000mm
ii	Size of Stoplogs	14000mmx1570mm (Each unit)
iii	Number of Stoplogs sets	One set Required
iv	Nos. of units per set	Eleven units(All units are interchangeable except the bottom most)
v	Sill Elevation	137.75 m
vi	Top of Stoplogs unit	154.52 m (When all units are installed)
vii	F R L	154.52 m
viii	M W L	155.00 m
ix	C/ C of side seals	14100 mm
x	C/C of Tracks	14600 mm
xi	Design Head	16.77m (corresponding to FRL condition)
xii	Sealing	Downstream sealing
xiii	Type of side seal	Plain rubber music note type
xiv	Type of bottom seal	Wedge type rubber seal
xv	Minimum thickness of skin plate	10 mm
xvi	Minimum thick of track plate	10 mm (after machining)
xvii	Minimum thickness of seal seat	10 mm (after machining)
xviii	Minimum thickness of guides	32 mm

4.3.8 Gantry Crane

The Spillway Stoplogs shall be operated by moving Gantry Crane. The capacity of gantry crane shall be 35t (approximate). The Gantry Crane shall consist of hoist machinery mounted on trolley. The trolley shall be of moving type. The crane structure along with trolley shall be capable of moving in longitudinal direction with the help of LT travel mechanism. Suitable counter weight shall be provided to make the crane stable for different stability conditions. The crane shall be designed as per IS: 3177 and IS: 807. The details are in Table – 4.16

Table – 4.16
Details of Gantry Crane

i	Capacity of Gantry Crane	35 T
ii	Class of Crane	Class II of IS-807-1976
iii	Gauge i.e. c/c of runway rails	5.5 m
iv	Wheel base of crane	7.5 m
v	Hoisting Speed	1.50 M/Min ± 5%
vi	Cross Travel speed (CT)	3.0 M/Min ± 5%
vii	Longitudinal Travel speed (LT)	6.0 M/Min ± 5%
viii	Type of hook	Ramshorn as shown on drawing
ix	Type of crane	Electrically operated outdoor traveling gantry

The general assembly of Gantry Crane has been shown in Drawing No. DGPL-5800-P-1511 (Plate – 4.57 in Volume – VII (A)).

4.3.9 Khargihill Dam Sluice Gate (Service & Emergency Gates)

Three numbers sluice with opening size of 3000mm x 5000mm shall be provided in the Khargihill Dam. Provision of service and emergency gates shall be made to control the flow through sluice. Service gate shall be of radial gate type and emergency gate shall be of fixed wheel gate.

The Service gate shall consist of curved skin plate stiffened by vertical stiffeners. The vertical stiffeners shall be supported by three (3 Nos.) horizontal girders. The load from horizontal girders shall be transmitted to trunnion by three parallel radial arms on each side of gate. Load shall be connected to concrete beam through trunnion bracket. The Trunnion support structure of the gate would be above the water profile. Suitable bracings shall be provided for horizontal girder and radial arms.

The Radial gate shall be designed in accordance with the provision of IS: 4623 (latest revision) in general. The gate shall be designed for a total head of 56.52m corresponding to FRL of EL 154.52m. The radial gate shall be operated with the help of twin cylinder double stroke hydraulic hoist with minimum hoist capacity of 2x60t (approximate). The power pack shall be installed on the top of the pier. Each gate shall have individual Power Pack. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210. However, provision shall be made to operate the adjacent hoists in case of emergency.

The sill level of gate shall be 98.00m and trunnion shall be installed at 103.75m. The radius of gate leaf shall be kept as 8.0m. Bottom seal of gate shall be provided as wedge type. The side seals shall be of Z type and will move on curved seal seat.

The emergency gate shall be provided on the U/S of the service gate for maintenance of the service gate. Emergency Gate shall be of D/S skin plate & D/S sealing. Gate shall be designed for static head of 56.52m corresponding to FRL 154.52m. These gates shall be operated under unbalance water head condition by Hydraulic Hoists. The emergency gate shall not be of regulating type. The hoist chamber shall be sealed by providing bonnet cover. Solid bulb rubber seals shall be provided on the d/s side to make the gate water tight. Suitable size of air vent shall be provided at the d/s of emergency gate. The gate shall be operated with the help of double acting hydraulic hoist with minimum hoist capacity of 150t (approximate). Model study for the gates are proposed to be carried out at the time of execution to assess hydro-dynamic forces and air requirement. Steel liners/HPC shall also be provided to avoid erosion of concrete in the vicinity of gates. The gate shall be designed in accordance with the provision of IS : 4622(latest revision). The details are in Table – 4.17 and 4.18. Maintenance of these gates are proposed to be carried out at level EL 109.30m.

The general assembly of Dam Sluice Gate has been shown in Drawing No. DGPL-5800-P-1512, DGPL-5800-P-1513 & DGPL-5800-P-1513(A) (Plate – 4.58 to 4.60 in Volume – VII (A)).

Table – 4.17

Details of Khargihill Dam Sluice Radial Gates

i	Clear Span	3.00 m
ii	Number of spans	3 Nos
iii	Full Reservoir level	154.52m
iv	Maximum water level	155.00m
v	EL of centre line of trunnion	103.75 m
vi	Sill level (for radial gate)	98.00m
vii	Crest level	98.0 m
	Inside radius of skin plate	8.0m
viii	Hoisting	By Twin Cylinder Hydraulic hoist with d/s suspension
ix	Hoist Capacity	2 X 60 T(approx.)
x	Type of arms	Straight arms
xi	Type of side seal	'Z' Type (Rubber)
xii	Type of bottom seal	Wedge Type (Rubber)
xiii	Governing Indian Standard code	IS:4623, IS:800

Table – 4.18

Details of Khargihill Dam Sluice Emergency Gate

i	Clear Span	3.0 m
ii	Number of openings	3 Nos.
iii	Full Reservoir level	154.52 m
iv	Maximum water level	155.00 m
v	Gate operation level	108.50 m
vi	Sill level	98.00 m
vii	Hoisting	By Hydraulic hoist
viii	Capacity of Hoist	Double acting 150 t (approx)
ix	Operation	The service gates shall be operated under unbalanced head condition
x	C/C of side seals	3150 mm
xi	C/C of tracks	3700 mm
xii	Design head	56.52 m (corresponding to FRL condition)
xiii	C/L of top Seal	103.05 m
xiv	Minimum thickness of skin plate	10 mm
xv	Minimum thickness of stainless steel track	10 mm (after machining)
xvi	Minimum thickness of seal seats of stainless steel	10 mm (after machining)
xvii	Type of side & top seal	Double stem, Teflon cladded rubber seal for top. Music note type Teflon cladded seal for side.
xviii	Type of bottom seal	Wedge Type (Rubber) seal
xix	Governing Indian Standard code	IS: 4623, IS: 800

4.4 Tunnels

4.4.1 Geology of the Tunnels Corridor

Deposited sediments/ river borne material, in-situ soil profile, scree material and bed rock comprising massive, amygdular and fragmentary porphyritic basalt are the lithounits exposed along the corridor covering the tunnel alignments. The plateau tops in general are occupied by in-situ soil with outcrops of bed rock along the drainage lines. The in-situ soil comprises ferricrete, ferruginous soil, lithomarge and saprolite. The vaxing and the middle part of the valleys and hills are covered by rock out crops with /without scree /thin soil cover. The beds of the major drainages are in general occupied by bed rock with/ without river borne material. Deposited sediments in the form of terrace/ point bar are observed along some stretches of the major river courses. The size of the deposited sediments varies from silt to boulders with graded bedding and cross bedding indicating that the deposited sediments could be fluvio-lacustrine origin. Both a'a and 'pahoehoe' type of basaltic flows were noticed, but the flow contacts cannot be established as it is gradational and devoid of bole beds.

Presence of bole bed is recorded only on the left bank of Damanganga River adjacent to Bhugad-Khargihill tunnel inlet area in the total area of the project. The bole bed is green in colour and the thickness varies from 30 cm to 50 cm. Projection of this bed indicated that it is extending to the sill area of the tunnel and will not pose any major problem.

During traverse geological mapping along tunnel corridor, at some locations (about 1km NW of Bejpada Village, Lat: 20˚03'19", Long: 73˚16'16"), secondary cavities of dimensions as large as 5m are reported. Such types of secondary cavities of larger dimensions are also anticipated during tunneling. These should be taken care of/ treated depending on dimensions of the cavities and composition of the filled cavities.

4.4.2 Hydraulic Design of Tunnel

The hydraulic designs of the tunnels have been carried out with the objective of supplying the water at average discharge of 210 Mm^3 over 365 days from Bhugad reservoir to Khargihill reservoir and average discharge of 579 Mm^3 over 365 days from Khargihill reservoir to Pinjal reservoir. An augmentation of 20% of the discharge has been considered in the hydraulic design of the tunnels. The sizes and the slopes of the tunnels have been worked out to supply the envisaged discharge under all possible prevailing head differences at connected reservoirs under pressurized flow conditions. The geometry of the link tunnels have been worked out under all possible head variations of the reservoirs taking the value of manning's coefficient varying from 0.012 to 0.016 for the concrete lined tunnel. Flow diagram of the Damanganga - Pinjal Link Project showing the design discharge is shown in Fig – 4.4. Following assumptions have been considered for the hydraulic designs of link tunnels:

(i) The minor losses occurring in the link tunnels e.g. entrance losses, trash rack loss, transition loss, exit loss; bend losses, gate groove losses, etc. are of negligible amount in comparison to the friction losses occurring in the tunnels and therefore not taken into consideration;

(ii) The flow through the tunnel is under pressure and driven by the head difference between the upper and lower reservoirs connected through tunnel; and

(iii) The gates installed at the intake and outfall of link tunnels are meant for regulating the discharge as well as for maintenance purpose.

The sizes of the link tunnels have been worked out in two steps:

Step- I: Different range of tunnel diameter are tried under maximum and minimum driving head between the linked reservoirs by adopting maximum and minimum value of manning's coefficient with envisaged value of diversion discharge. This step gives a range of tunnel sizes capable of carrying the design discharge which is found by equating the major friction losses occurring in the system with the driving head under all possible heads. This step was also attempted for different shapes of the tunnel.

Step - II: The tunnel diameter is then fixed on the basis of values obtained from Step- I. The adequacy of tunnel in terms of its conveying discharge is checked under all prevailing head conditions by adopting maximum and minimum value of manning's coefficient under all driving heads. The major friction losses are equated with the driving head to know the discharging capacity of tunnel under all possible variation of head.

The detail calculations for above two steps for tunnels from Bhugad to Khargihill and from Khargihill reservoir to Pinjal reservoir for D shaped tunnels are shown in Fig – 4.5.

Different alternatives of tunnels shapes, like D Shape, Circular & Modified horse shoe were attempted and arriving at final D shape, because of the following advantages:

(i) D Shaped section is suitable for tunnels located at massive hard rock;
(ii) As the internal and external pressures acting on the lining are not significant, therefore structural stability & rigidity can be ensured;
(iii) It gives added width of the invert for more working floor space during construction;
(iv) Suitable for small size tunnels ranging from 3 m to 5 m;
(v) A comparative analysis of the construction ease, concreting and excavation quantities involved for different shapes, favours adoption of D Shaped Section (Fig – 4.6).

Based upon the above detailed parametric studies, the link tunnel of D Shaped & size 3.2 m in diameter connecting Bhugad and Khargihill reservoirs is adopted. Similarly, the link tunnel of D Shaped & size 4.0 m in diameter connecting Khargihill and Pinjal reservoirs is adopted.

FIGURE 4.4 : FLOW CHART OF DAMANGANGA-PINJAL LINK

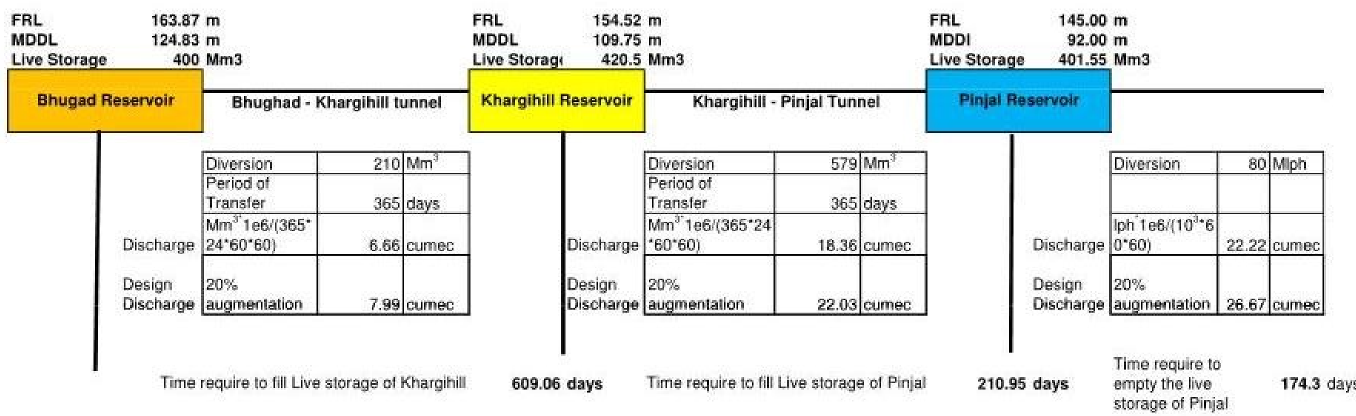


FIGURE 4.5 : DAMANGANGA- PINJAL LINK PROJECT

STEP - I

A range of different diameters is worked out to fix the size of tunnel capable of conveying the discharge under all prevailing driving head conditions

Tunnel 1, length =	17.488 km						
Length	17488	17488	17488	17488	17488	17488	m
Q	7.99	7.99	7.99	7.99	7.99	7.99	cumec
d	2.02	1.80	2.60	2.32	2.82	2.51	m
A	3.63	2.88	6.05	4.81	7.08	5.62	m²
P	7.20	6.42	9.30	8.29	10.06	8.96	m
R	0.50	0.45	0.65	0.58	0.70	0.63	
v	2.20	2.77	1.32	1.66	1.13	1.42	m/sec
	H = FRL-MDDL		H = MDDL-MDDL		H = FRL-FRL		
H	54.12	54.12	15.08	15.08	9.35	9.35	m
	nmax	nmin	nmax	nmin	nmax	nmin	
n	0.016	0.012	0.016	0.012	0.016	0.012	
f	0.03	0.01	0.03	0.01	0.02	0.01	
Head Loss	54.12	54.12	15.08	15.08	9.35	9.35	m
d max	2.82	m					
d min	1.80	m					

Tunnel 2, length =	25.224 km						
Length	25224	25224	25224	25224	25224	25224	m
Q	22.03	22.03	22.03	22.03	22.03	22.03	cumec
d	3.078	2.763	3.910	3.510	4.384	3.936	m
A	8.459	6.817	13.647	10.998	17.159	13.829	m²
P	10.99	9.87	13.96	12.53	15.66	14.05	m
R	0.77	0.69	0.98	0.88	1.10	0.98	
v	2.60	3.23	1.61	2.00	1.28	1.59	m/sec
	H = FRL-MDDL		H = MDDL-MDDL		H = FRL-FRL		
H	62.12	62.12	17.35	17.35	9.42	9.42	m
	nmax	nmin	nmax	nmin	nmax	nmin	
n	0.016	0.012	0.016	0.012	0.016	0.012	
f	0.02	0.01	0.02	0.01	0.02	0.01	
Head Loss	62.12	62.12	17.35	17.35	9.42	9.42	m
d max	4.38	m					
d min	2.76	m					

Bhugad Reservoir
FRL 163.87 m
MDDL 124.83 m
Live Storage 400 Mm3

Q= 210 Mm3 7.99 cumec
Q= 7.99 cumec
3.2m
Dia= 3.2 m
Velocity= 0.99358 m/sec

Khargihill Reservoir
FRL 154.52 m
MDDL 109.75 m
Live Storage 420.5 Mm3

4m
Q= 579 Mm3
Q= 22.03196 cumec

Pinjal Reservoir
FRL 145.1 m
MDDl 92.4 m
Live Stora 401.55 Mm3

STEP - II

Coveying capacity is checked under all prevaling head conditions for adopted size.

Tunnel 1, length =	17.488 Km						
Length	17488	17488	17488	17488	17488	17488	m
Q	27.39	36.52	14.46	19.28	11.38	15.18	cumec
d	3.2	3.2	3.2	3.2	3.2	3.2	m
A	9.14	9.14	9.14	9.14	9.14	9.14	m²
P	11.43	11.43	11.43	11.43	11.43	11.43	m
R	0.8	0.8	0.8	0.8	0.8	0.8	
v	2.996	3.995	1.582	2.109	1.245	1.661	m/sec
	H = FRL-MDDL		H = MDDL-MDDL		H = FRL-FRL		
H	54.12	54.12	15.08	15.08	9.35	9.35	m
	nmax	nmin	nmax	nmin	nmax	nmin	
n	0.016	0.012	0.016	0.012	0.016	0.012	
f	0.022	0.012	0.022	0.012	0.022	0.012	
Head Loss	54.12	54.12	15.08	15.08	9.35	9.35	
Q max	36.52	cumec					
Q min	11.38	cumec					

Taking Diam

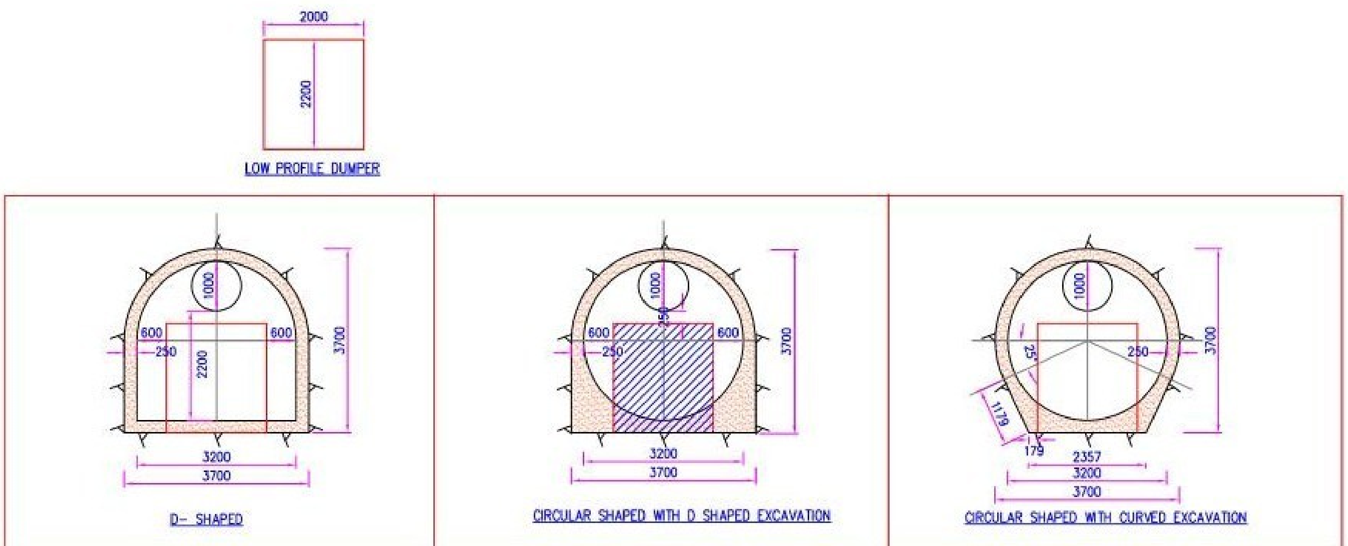
Tunnel 2, length = 25.224 km							
Length	25224	25224	25224	25224	25224	25224	m
Q	44.30	59.07	23.41	31.22	17.25	23.00	cumec
d	4	4	4	4	4	4	m
A	14.28	14.28	14.28	14.28	14.28	14.28	m²
P	14.28	14.28	14.28	14.28	14.28	14.28	m
R	1	1	1	1	1	1	
v	3.10	4.14	1.64	2.19	1.21	1.61	m/sec
	H = FRL-MDDL		H = MDDL-MDDL		H = FRL-FRL		
H	62.12	62.12	17.35	17.35	9.42	9.42	m
	nmax	nmin	nmax	nmax	nmax	nmax	
n	0.016	0.012	0.016	0.012	0.016	0.012	
f	0.020	0.011	0.020	0.011	0.020	0.011	
Head Loss	62.12	62.12	17.35	17.35	9.42	9.42	
Q max	59.07	cumec					
Qmin	17.25	cumec					

Time required to drain out this live storage in case of withdrawl from tunnel 1	**579.37**	**days**

Time required to fill this live storage in absence of any inflows & the inflow is only from tunnel 1 =	**60.91 days**
Time required to drain out this live storage in case of withdrawl from tunnel 2 and no inflow from tunnel 1	**220.90 days**
Time required to drain out this live storage in case of withdrawl from tunnel 2 and inflow from tunnel 1	**346.62 days**

Time required to fill this live storage in absence of any inflows & the inflow is only from tunnel 2 =		**5.78 days**
Time required to drain out this live storage in case of withdrawl from tunnel & no inflows from tunnel 2	**#DIV/0!**	**days**
Time required to drain out this live storage in case of withdrawl from tunnel 3 and inflow from tunnel 2	**infinite**	**days**

FIGURE 4.6 : VARIOUS TUNNEL SHAPE SECTIONS



	D- SHAPED	CIRCULAR SHAPED WITH D SHAPED EXCAVATION	CIRCULAR SHAPED WITH CURVED EXCAVATION
EXCAVATION VOLUME (cubic meter)	12.22	12.22	11.21
LINING VOLUME (cubic meter)	3.079	4.177	3.16

4.4.2.1 Bhugad - Khargihill Tunnel

4.4.2.1.1 Intake Structure at Bhugad Reservoir

The layout of the intake structure taking into consideration the geology and topography has been planned at RD 60.00 m along the alignment of Bhugad Khargihill Link Tunnel. The intake structure is designed, so as to produce an adequate acceleration of water from reservoir into the link tunnel. This is achieved by means of smooth entrance at the intake having elliptical bell mouth shape and also by placing intake inward below the minimum reservoir level so as to produce adequate submergence to avoid formation of vortices. Metallic trash racks are provided in front of intake structure to prevent entry of floating debris into the system. The water flows at a very low velocity through trash rack provided in the front of intake structure. The center to center spacing between the trash bars is provided as 100 mm. The total number of trash rack panels for the intake structure works out to eight in numbers.

Submergence of the intake centre line, below the minimum reservoir level (MDDL) has been checked as per the provisions of BIS-9761: 1995. The hydraulic design of the intake, its dimensioning and sizing has also been carried out as per the provisions of BIS-9761:1995. The centre line of the intake structure has been kept at elevation 117.80 m from above considerations.

The control structure of the intake is located at vertical shaft of diameter 7.5 m downstream of the intake structure. The vertical shaft consists of grooves for accommodating service and emergency gates of size 3.2m x 3.2m. The suitable transitions have also been provided for smooth transitions from rectangular intake opening into 'D' shape tunnel and 'D' shape tunnel into rectangular section at location of gates.

The service gate proposed will be regulating type to supply the required water demand. High velocities in the gate area and hydraulic jump formation are expected depending upon the extent of gate opening. To protect the concrete tunnel lining from abrasion, steel lining may also be provided downstream of service gate for an appropriate distance which is to be firmed up based on model studies. Hydraulic model studies are to be carried out at detailed design stage for firming up the hydraulic details of intake and its location in the reservoir.

The hoisting arrangements for operation of gates have been provided at elevation 168.880 m above FRL of 163.87m. The portion of tunnel in between the intake structure and control shaft is provided with RCC lining of M20 grade of concrete as per BIS-456:2000. Appropriate rock support system for control shaft structure has also been provided for its structure stability.

Reference Drawing Nos. DGPL-5800-P-1008 to 1010 (Plate – 4.61 to 4.63 in Volume – VII (B)).

4.4.2.1.2 Design of Bhugad - Khargihill Tunnel

The Prominent Elevations & RDs of Key points along the alignment of Bhugad - Khargihill tunnel are indicated in Table – 4.19:

Table – 4.19
Elevations & RDs at Prominent Points along Alignment of Bhugad - Khargihill Tunnel

Structure	Reduced Distance (RD)	Centre Line Elevation
Intake at Bhugad reservoir	60.0 m	117.80 m
Control shaft at Intake	205.00 m	117.80 m (C.L of Tunnel)
Adit 1	6498.00 m	113.111m (C.L of tunnel at junction with adit)
Adit2	12750.00 m	108.453 m (C.L of tunnel at junction with adit)
Control shaft at Outfall in Khargihill reservoir	17385.00 m	105.00 m
Outfall at Khargihill Reservoir	17548.00 m	105.00 m (C.L of Outfall)

The slope of the Bhugad – Khargihill tunnel works out to be 1 in 1342. Two construction adits of D shape and 6m diameter have been planned at RDs 6498.00 m and 12750.00 m for providing additional faces for excavation/ construction of tunnel. Layout Plan and Longitudinal section of Bhugad – Khargihill tunnel are at Drawing Nos. DGPL-5800-P-1001 to 1007 (Plate – 4.64to 4.70 in Volume – VII (B)).

The tunnel is provided with 250 mm thick PCC lining of M20 grade of concrete for ensuring smooth surface for conveyance of envisaged discharge. The lining shall be RCC at junctions with Adits and shafts, at bends and in very poor rock strata reach. The lining has been designed to resist the external and internal water pressure. The tunnel is proposed to be excavated by conventional drill and blast method and the design of rock support system is carried out using Barton's Q method. Different rock mass classes as per IS:13365 (part – II):

Group	**Q**	**Classification**
1	1000-400	Exceptionally Good
	400-100	Extremely Good
	100-40	Very Good
	40-10	Good
2	10-4	Fair
	4-1	Poor
	1-0.1	Very Poor
3	0.1-.0.01	Extremely poor
	0.01-0.001	Exceptionally poor

The rock support system for various category of rock mass is as per the Table – 4.20:

Table - 20:
Rock Support System for Various Category of Rock Mass

Rock Type	**Q**	**Support System**
Very Good Rock	100-40	SFRS 50mm (locally as required)+ 25 dia spot rock bolts 2500mm long
Good Rock	40-10	SFRS 50mm (wherever required) + 25 dia rock bolts 2500mm long wherever required
Fair Rock	10-4	SFRS 50mm + 25 dia rock bolts 2500mm long @ 1500mm c/c over arch portion
Poor Rock	4-1	ALT. 1: SFRS 75mm + 25 dia rock bolts 2500mm long @ 1500mm c/c over arch portion
		ALT. 2: SFRS 75mm + 25 dia rock bolts 2500mm long @ 1500mm c/c over sides and arch portion + steel rib 150 ISHB @ 1500mm c/c
Very Poor Rock	1-0.1	SFRS 100mm + 25 dia rock bolts 2500mm long @ 1500mm c/c over except bed + steel rib 150 ISHB @ 1500mm c/c arch portion+ steel rib 150 ISHB @ 1000mm c/c

The design of the rock support system is carried out by following empirical approach based upon the "Q" values of Rock mass and will need appropriate modifications depending upon the actual encountered rock mass. Also, the design of rock support system is not meant for shear zones, weak zones, cavities, very low cover zones, at junctions with adits/vertical shafts, etc. of the tunnel and the design in these zones require special attention. Further, the design of the tunnel is valid for full face excavation for tunneling being done with conventional drill & blast method. During excavation, 75 mm dia, 5000 mm long drainage holes are to be provided as required in seepage zones.

A typical scheme of contact and consolidation grouting has been proposed. The contact grouting in the tunnel is proposed to fully pack up the space between the concrete lining and the rock surface caused by shrinkage of concrete lining. Similarly, the consolidating grouting is also proposed to fill up the joints and discontinuity in the rock upto the desired depth. The contact grouting and consolidating grouting shall be carried out as per the provisions of BIS-5878(Part-VII). Reference Drawing Nos. DGPL-5800-P-1011 to 1013 (Plate – 4.71 to 4.73 in Volume – VII (B)).

Two construction adits have also been provided with appropriate rock support system to facilitate construction of tunnel by providing additional face for excavation. The adit - 1 is proposed to be plugged after construction of the link tunnel, whereas the adit - 2 will be provided with the gate to access tunnel for carrying out any maintenance of the tunnel required after being put into operation. The design of the concrete plug has been carried out as per the provision of BIS 456-2000. The portal locations for both of these adits have been firmed up based upon the geology likely to be encountered at these locations in consultation with NWDA and GSI. Typical portal details of the construction adits have been planned. The lengths and key elevations of the two construction adits are indicated in Table – 4.21. Reference Drawing Nos. DGPL-5800-P-1014 to 1021 (Plate – 4.74 to 4.81in Volume – VII (B)).

Table – 4.21
Details of Construction Adits of Bhugad – Khargihill Tunnel

Structure	Reduced Distance (RD)	Centre Line at Junction with Tunnel	Length of Adit	Slope
Adit 1	6498m	113.111m	205m	1 : 30 (Sloping upwards towards tunnel)
Adit 2	12750m	108.453m	154m	1 : 16 (Sloping downwards towards tunnel)

4.4.2.1.3 Outfall Structure at Khargihill Reservoir

Outfall structure of Bhugad – Khargihill tunnel for conveying the envisage discharge from Bhugad to Khargihill Reservoir is planned at RD - 17548 m keeping into consideration the topography and geology available at outfall location in Khargihill Reservoir. A control shaft at RD – 17385 m upstream of the outfall structure has been provided with provisions of two gates of size 3.2mx3.2m.

The vertical control shaft consists of grooves for accommodating service and emergency gates of size 3.2m x 3.2m. Suitable transitions have been provided for smooth transitions from rectangular intake opening into 'D' shape tunnel and 'D' shape tunnel into rectangular section at gates location. The centre line of the outfall is kept at EL.105.00 m. The outfall structure is provided with stoplog grooves. The hoisting arrangement for operation of gates has been provided at elevation 160.00 m above FRL of 154.52m. Reference Drawing Nos. DGPL-5800-P-1022 to 1023 (Plate – 4.82 to 4.83 in Volume – VII (B)).

4.4.2.1.3 Fixed Wheel Vertical Lift Gates at Intake of Bhugad – Khargihill Tunnel

The Intake of Bhugad – Khargihill Tunnel at Bhugad reservoir shall be provided with fixed wheel vertical lift gates (service & emergency gate each) of size 3200mm X 3200mm. Sill level of the gate shall be EL 116.20m. The gate shall be designed to FRL of EL 163.87 m.

The service gate shall be provided with D/S skin plate & D/S sealing and shall be operated under unbalanced head condition. For maintenance of service gate, emergency gate shall be provided on the U/S side. The emergency gate shall have upstream skin plate and upstream sealing. Emergency gate shall be operated under balanced head condition achieved by filling valve/crack opening. Wedge type seal shall be provided for bottom sealing and double stem solid bulb seals shall be provided for side & top sealing. The seal shall remain in contact with seal seats (stainless steel) to make the gate water tight

The gate structure shall consist of skin plate stiffened by vertical stiffeners and horizontal girders. The horizontal girders shall be supported by end vertical girders on each side. The water thrust will be transferred to concrete structures from the end vertical girder through wheels and wheel track. The wheels shall be mounted on spherical roller bearings. The BHN of wheel track shall be 50 BHN higher than the wheel material. 40 mm guide and two number guide shoes shall be provided on each side to guide the gate in grooves.

The service gate shall be operated by independent hydraulic hoist of 90 t (approximate) capacity. The power pack shall be installed on the top of the deck. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210.

The emergency gate shall be operated by Rope Drum Hoist of 35t (approximate). The Rope Drum Hoist shall consist of hoist machinery mounted on hoist support structure. The hoist machinery shall be equipped with two rope-drums, gears, pinions, couplings, shafts, worm reducer, motor and brakes. The hoist bridge shall be supported on trestles. The design of Rope Drum Hoist shall conform to IS: 6938 (latest revision). Details are in Table – 4.22 and 4.23.

The maintenance of these gates is proposed to be carried out at level EL 168.88 m. The gate shall be designed in accordance with the provision of IS: 4622 (latest revision).

The general assembly of Fixed Wheel gate has been shown in Drawing No. DGPL-5800-P-1514 & DGPL-5800-P-1515 (Plate – 4.84 and 4.85 in Volume – VII (B)).

Table – 4.22

Fixed Wheel Vertical Lift Gates (Service Gate) at Intake of Bhugad – Khargihill Tunnel

i	Clear Span	3.2 m
ii	Number of openings	1
iii	Full Reservoir level	163.87 m
iv	MDDL	124.83 m
v	Sill level	116.20 m
vi	Operation Platform Level	168.88m
vii	Hoisting	By Hydraulic hoist
viii	Operating condition	The service gates shall be operated under flowing water. Gates shall be regulating.
ix	Capacity of Hoist	90 t (approx)
x	C/C of side seals	3350 mm
xi	C/C of tracks	3800 mm
xii	Design head	47.67m (corresponding to FRL)
xiii	Minimum thickness of skin plate	10 mm
xiv	Minimum thickness of stainless steel track	10 mm (after machining)
xv	Type of side & top seal	Music note type seal for side
xvi	Type of bottom seal	Wedge Type (Rubber) seal
xvii	Minimum thickness of guides	40 mm
xviii	Governing Indian Standard code	IS: 4622, IS: 800

Table – 4.23
Fixed Wheel Vertical Lift Gates (Emergency Gate) at Intake of Bhugad – Khargihill Tunnel

i	Clear Span	3.2 m
ii	Number of openings	1
iii	Full Reservoir level	163.87 m
iv	MDDL	124.83 m
v	Sill level	116.20 m
vi	Operation Platform Level	168.88m
vii	Hoisting	By Rope drum Hoist
viii	Operating condition	The emergency gates shall be operated under balanced head condition.
ix	Capacity of Hoist	35 t (approx)
x	C/C of side seals	3350 mm
xi	C/C of tracks	3800 mm
xii	Design head	47.67m (corresponding to FRL)
xiii	Minimum thickness of skin plate	10 mm
xiv	Minimum thickness of stainless steel track	10 mm (after machining)
xv	Type of side & top seal	Music note type seal for side
xvi	Type of bottom seal	Wedge Type (Rubber) seal
xvii	Governing Indian Standard code	IS: 4622, IS: 800

4.4.2.1.4 Fixed Wheel Gates at Outfall of Bhugad - Khargihill Tunnel

The Outfall of Bhugad - Khargihill tunnel at Khargihill reservoir shall be provided with fixed wheel vertical lift gates (Outfall gate 1 & Outfall gate2) of size 3200mm X 3200mm. Sill level of the gate shall be EL 103.40m.

The Outfall gate 1 shall be designed for head of 54.12m (correspond to head between FRL at Bhugad & MDDL at Khargihill reservoir). Outfall gate 1 shall be provided with D/S skin plate & D/S sealing from Bhugad side. Outfall gate 1 shall be operated under unbalanced head condition. Wedge type seal shall be provided for bottom sealing and double stem solid bulb seals shall be provided for side & top sealing. The seal shall remain in contact with stainless steel seal seats to make the gate water tight

The Outfall gate 2 shall be designed for head of 51.12m (correspond to head between FRL & Sill at Khargihill reservoir). The Outfall gate 2 shall be provided on the D/S side of Outfall gate 1. The Outfall gate 2 shall be provided with D/S skin plate and D/S sealing from Khargihill side. Outfall gate 2 shall be operated under balanced head condition. Wedge type seal shall be provided for bottom sealing and double stem solid bulb seals shall be provided for side & top sealing. The seal shall remain in contact with stainless steel seal seats to make the gate water tight

The gate structure shall consist of skin plate stiffened by vertical stiffeners and horizontal girders. The horizontal girders shall be supported by end vertical girders on each side. The water thrust will be transferred to concrete structures from the end vertical girder through wheels and wheel track. The wheels shall be mounted on spherical roller bearings. The BHN of wheel track shall be 50 BHN higher than the wheel material. 40 mm guide and two number guide shoes shall be provided on each side to guide the gate in grooves.

The Outfall gate 1 shall be operated by independent hydraulic hoist of 110 t (approximate) capacity. The power pack shall be installed on the top of the deck. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210.

The Outfall gate 2 shall be operated by Rope Drum Hoist of 50t. The Rope Drum Hoist shall consist of hoist machinery mounted on hoist support structure. The hoist machinery shall be equipped with two rope-drums, gears, pinions, couplings, shafts, worm reducer, motor and brakes. The hoist bridge shall be supported on trestles. The design of Rope Drum Hoist shall conform to IS :6938 (latest revision). Details are in Table – 4.24.

Table – 4. 24
Fixed Wheel Gates at Outfall (Gate 1 and 2) of Bhugad - Khargihill Tunnel

		Outfall Gate - 1	Outfall Gate - 2
i	Clear Span	3.2 m	3.2 m
ii	Number of openings	1	1
iii	Full Reservoir level	163.87 m (at Bhugad)	154.52 m (at Khargihill)
iv	MDDL	124.83 m (at Bhugad)	109.75 m (at Khargihill)
v	Sill level at outfall	103.40 m	103.40 m
vi	Operation Platform Level	160.00m	160.00m
vii	Hoisting	By Hydraulic Hoist	By Rope Drum Hoist
viii	Operating condition	The Outfall gate 1 shall be operated under flowing water. Gates shall be open & close type	The Outfall gate 2 shall be operated under balanced head condition
ix	Capacity of Hoist	110 t (approx)	50 t (approx)
x	C/C of side seals	3350 mm	3350 mm
xi	C/C of tracks	3800 mm	3800 mm
xii	Design head	54.12m (corresponding to head between FRL at Bhugad and MDDL at Khargihill).	51.12m (corresponding to head between FRL at Khargihill & Sill at Outfall).
xiii	Minimum thickness of skin plate	10mm	10mm
xiv	Minimum thickness of stainless steel track	10mm (after machining)	10mm (after machining)

xv	Type of side & top seal	Double Stem	Double Stem
xvi	Type of bottom seal	Wedge Type (Rubber) seal	Wedge Type (Rubber) seal
xvii	Governing Indian Standard code	IS: 4622, IS: 800	IS: 4622, IS: 800

The maintenance of these gates is proposed to be carried out at level EL 160.00m. The gate shall be designed in accordance with the provision of IS :4 622(latest revision).

The general assembly of Fixed Wheel gate has been shown in Drawing No. DGPL-5800-P-1516 & DGPL-5800-P-1517 (Plate – 4.86 and 4.87 in Volume – VII (B)).

4.4.2.1.5 Adit Gate at Bhugad – Khargihill Tunnel

The gate of adit 2 shall be provided for inspection of the Tunnel in between Bhugad reservoir & Khargihill reservoir. The opening size of the hinge type adit gates are 2200mm x 2200mm. The gates are operated by hydraulic hoist of suitable capacity. Details are in Table – 4.25.

The general assembly of Adit gate has been shown in Drawing No. DGPL-5800-P-1522, DGPL-5800-P-1523, DGPL-5800-P-1524 & DGPL-5800-P-1525 (Plate – 4.88 to 4.91 in Volume – VII (B)).

Table – 4.25

Details of Adit Gate at Adit 2 of Bhugad - Khargihill Tunnel

i	Clear Span	2.2 m
ii	Clear Opening	2.2 m
iii	Number of opening	1
iv	Hoisting	By Hydraulic Hoist
v	Operating condition	The adit gate 2 shall be operated when HRT (in between Bhugad to

		Khargihill) is empty
vi	C/C of side seals	2350 mm
vii	C/C of tracks	2700 mm
viii	Design head	56.417 m
ix	Minimum thickness of skin plate	10mm
x	Minimum thickness of stainless steel track	10mm (after machining)
xi	Type of seal	Music note Type

4.4.2.2 Khargihill - Pinjal Tunnel

4.4.2.2.1 Intake Structure at Khargihill Reservoir

The layout of the intake structure taking into consideration the geology and topography has been planned at RD 630.0 m along the alignment of Khargihill- Pinjal Tunnel. The intake structure is designed, so as to produce an adequate acceleration of water from reservoir into the link tunnel. This is achieved by means of smooth entrance at the intake having elliptical bell mouth shape and also by placing intake inward below the minimum reservoir level so as to produce adequate submergence to avoid formation of vortices. Metallic trash racks are provided in front of intake structure to prevent entry of floating debris into the system. The water flows at a very low velocity through trash rack provided in front of intake structure. The center to center spacing between the trash bars is provided as 100 mm. The total number of trash rack panels for the intake structure works out to eight in numbers.

Submergence of the intake centre line, below the minimum reservoir level (MDDL) has been checked as per the provisions of BIS - 9761: 1995. The hydraulic design of the intake, its dimensioning and sizing has also been carried out as per the provisions of BIS-9761:1995. The centre line of the intake structure has been kept at elevation 102.00 m from above considerations.

The control structure of the intake is located at vertical shaft of diameter 7.5 m downstream of the intake structure. The vertical shaft consists of grooves for accommodating service and emergency gates of size 4 m x 4 m. The suitable transitions have also been provided for smooth transitions from rectangular intake opening into ‘D’ shape tunnel and ‘D’ shape tunnel into rectangular section at location of gates.

The service gate proposed will be regulating type to supply the required water demand. High velocities in the gate area and hydraulic jump formation are expected depending upon the extent of gate opening. To protect the concrete tunnel lining from abrasion, steel lining may also be provided downstream of service gate for an appropriate distance which is to be firmed up based on model studies. Hydraulic model studies are to be carried out at detailed design stage for firming up the hydraulic details of intake and its location in the reservoir.

The hoisting arrangements for operation of gates have been provided at elevation 158.000 m above FRL of 154.52m. The portion of tunnel in between the intake structure and control shaft is provided with RCC lining of M 20 grade of concrete as per BIS-456:2000. Appropriate rock support system for control shaft structure has also been provided for its structure stability. Reference Drawing Nos. DGPL-5800-P-1043to 1045 (Plate – 4.92 to 4.94 in Volume – VII (B)).

4.4.2.2.2 Design of Khargihill - Pinjal Tunnel

The Elevations & RDs at Prominent points along the alignment of Khargihill - Pinjal tunnel are indicated in Table – 4.26:

Table – 4.26
Elevations & RDs at Prominent Points along Alignment of Khargihill - Pinjal Tunnel

Structure	Reduced Distance (RD)	Centre Line Elevation (m)
Intake at Khargihill	630.00 m	102.00m
Control shaft d/s of Khargihill Intake	822.724 m	102m (C.L of tunnel)
Adit 1	5729.00 m	99.143 m (C.L of tunnel at junction with adit)
Adit2	11712.00 m	95.658 m (C.L of tunnel at junction with adit)
Adit 3	16082.00 m	93.113 m (C.L of tunnel at junction with adit)
Adit 4	21994.00 m	89.670m (C.L of tunnel at junction with adit)
Control shaft u/s of Pinjal Outfall	25720.00 m	87.50 m
Outfall at Pinjal Reservoir	25854.00 m	87.50 m (C.L of Outfall)

The slope of the Khargihill – Pinjal tunnel works out to be 1 in 1717. Four construction adits of D shape and size of 6 m diameter have been planned for providing additional faces for excavation/construction of tunnel. The layout and longitudinal Section of Khargihill _ Pinjal tunnel are at Drawing Nos. DGPL-5800-P-1028 to 1042 (Plate – 4.95 to 4.109in Volume – VII (B)).

The tunnel is provided with 250 mm thick PCC lining of M20 grade of concrete for ensuring smooth surface for conveyance of envisaged discharge. The lining shall be RCC at junctions with Adits and shafts, at bends and in very poor rock strata reach. The lining has been designed to resist the external and internal water pressure. The link tunnel is proposed is to be excavated by conventional drill and blast method and the design of rock support system is carried out using Barton's Q method. The rock mass classes as per IS:13365 (part- II):

Group	Q	Classification
1	1000-400	Exceptionally Good
	400-100	Extremely Good
	100-40	Very Good
	40-10	Good
2	10-4	Fair
	4-1	Poor
	1-0.1	Very Poor
3	0.1-.0.01	Extremely poor
	0.01-0.001	Exceptionally poor

The rock support system for various category of rock mass is indicated in Table – 4.27

Table – 4.27
Rock Support System for Various Category of Rock Mass

Rock Type	Q	Support System
Very Good Rock	100-40	SFRS 75 mm (locally as required)+ 25 dia spot rock bolts 3000 mm long
Good Rock	40-10	SFRS 75 mm (wherever required) + 25 dia rock bolts 3000 mm long wherever required.
Fair Rock	10-4	SFRS 75 mm + 25 dia rock bolts 3000mm long @ 1500 mm c/c over arch portion.
Poor Rock	4-1	ALT. 1: SFRS 100 mm + 25 dia rock bolts 3000 mm long @ 1500mm c/c over arch portion
		ALT. 2 : SFRS 100 mm + 25 dia rock bolts 3000 mm long @ 1500 mm c/c over sides and arch portion + steel rib 150 ISHB @ 1500mm c/c
Very Poor Rock	1-0.1	SFRS 100 mm + 25 dia rock bolts 3000 mm long @ 1500 mm c/c over except bed+ steel rib 150 ISHB @ 750 mm c/c arch portion+ steel rib 150 ISHB @ 500 mm c/c invert portion

The design of the rock support system is carried out by following empirical approach based upon the "Q" values of Rock mass and will need appropriate modifications depending upon the actual encountered rock mass. Also, the design of rock support system is not meant for shear zones, weak zones, cavities, very low cover zones, at junctions with adits/vertical shafts, etc. of the tunnel and the design in these zones require special attention. Further, the design of the tunnel is valid for full face excavation for tunneling being done with conventional drill & blast method. During excavation, 75 mm dia, 5000 mm long drainage holes is to be provided as required in seepage zones

A typical scheme of contact and consolidation grouting has been proposed. The contact grouting in the tunnel is proposed to fully pack up the space between the concrete lining and the rock surface caused by shrinkage of concrete lining. Similarly, the consolidating grouting is also proposed to fill up the joints and discontinuity in the rock upto the desired depth. The contact grouting and consolidating grouting shall be carried out as per the provisions of BIS-5878 (Part-VII). Reference Drawing Nos. DGPL-5800-P-1046 to 1048 (Plate – 4.110 to 4.112 in Volume – VII (B)).

The four construction adits have also been provided with appropriate rock support system to facilitate construction of link tunnel by providing additional face for excavation/construction. The adit 1, 2 & 4 are proposed to be plugged after construction of the link tunnel, whereas the adit 3 will be provided with the gate to access tunnel for carrying out any maintenance of the tunnel required after being put into operation. The design of the concrete plug has been carried out as per the provision of BIS 456-2000. The portal locations for all these adits have been firmed up based upon the geology likely to be encountered at these locations in consultation with NWDA and GSI. Typical portal details of the construction adits have been planned. The lengths and key elevations of the four construction adits are indicated in Table – 4.28. Reference Drawing Nos. DGPL-5800-P-1049 to 1054 (Plate – 4.113 to 4.118 in Volume – VII (B)).

Table – 4.28
Details of Construction Adits of Khargihill - Pinjal Tunnel

Structure	Reduced Distance (RD)	Centre Line at Junction with Link Tunnel	Length of Adit	Slope
Adit 1	5729 m	99.143 m	1700 m	1 : 16 (Sloping downwards towards tunnel)
Adit 2	11712 m	95.658 m	2283 m	1 : 17 (Sloping downwards towards tunnel)
Adit 3	16082 m	93.113 m	2050 m	1 : 18.5 (Sloping downwards towards tunnel)
Adit 4	21994 m	89.670 m	623 m	1 : 13.5 (Sloping downwards towards tunnel)

4.4.2.2.3 Outfall Structure at Pinjal Reservoir

Outfall structure of Khargihill – Pinjal tunnel for conveying the envisage discharge from Khargihill to Pinjal reservoir is planned at RD - 25854 m keeping into consideration the topography and geology available at outfall location in Pinjal Reservoir. A control shaft at RD - 25720 m upstream of the outfall structure has been provided with provisions of two gates of size 4mx4m.

The vertical control shaft consists of grooves for accommodating service and emergency gates of size 4m x 4m. Suitable transitions have been provided for smooth transitions from rectangular intake opening into 'D' shape tunnel and 'D' shape tunnel into rectangular section at gates location. The centre line of the outfall is kept at EL.87.50m. The outfall structure is provided with stoplog grooves. The hoisting arrangement for operation of gates has been provided at elevation 145.00m above FRL of 141.10m. Reference Drawing Nos. DGPL-5800-P-1055to 1056 (Plate – 4.119to 4.120 in Volume – VII (B)).

4.4.2.2.4 Fixed Wheel Gates at Intake of Khargihill – Pinjal Tunnel

The Intake of Khargihill – Pinjal Tunnel at Khargihill reservoir shall be provided with fixed wheel vertical lift gates (service & emergency gate each) of size 4000mm X 4000mm. Sill level of the gate shall be EL 100.00m. The gate shall be designed for the head of 54.52 m corresponding to FRL of EL 154.52 m.

The service gate shall be provided with D/S skin plate & D/S sealing. Service gate shall be operated under unbalanced head condition. For maintenance of service gate emergency gate is provided on the U/S side. The emergency gate shall be provided with upstream skin plate and upstream sealing. Emergency gate shall be operated under balanced head condition. Wedge type seal shall be provided for bottom sealing and double stem solid bulb seals shall be provided for side & top sealing. The seal shall remain in contact with stainless steel seal seats to make the gate water tight.

The gate structure shall consist of skin plate stiffened by vertical stiffeners and horizontal girders. The horizontal girders shall be supported by end vertical girders on each side. The water thrust will be transferred to concrete structures from the end vertical girder through wheels and wheel track. The wheels shall be mounted on spherical roller bearings. The BHN of wheel track shall be 50 BHN higher than the wheel material. 40 mm guide and two number guide shoes shall be provided on each side to guide the gate in grooves.

The service gate shall be operated by independent hydraulic hoist of 150 t (approximate) capacity. The power pack shall be installed on the top of the deck. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210.

The emergency gate shall be operated by Rope Drum Hoist of 70t (approximate). The Rope Drum Hoist shall consist of hoist machinery mounted on hoist support structure. The hoist machinery shall be equipped with two rope-drums, gears, pinions, couplings, shafts, worm reducer, motor and brakes. The hoist bridge shall be supported on trestles. The design of Rope Drum Hoist shall conform to IS: 6938 (latest revision). Details are in Table – 4.29 and 4.30.

Table – 4.29
Fixed Wheel Vertical Lift Gates (Service Gate) at Intake of Khargihill - Pinjal Tunnel

i	Clear Span	4.0 m
ii	Number of openings	1
iii	Full Reservoir level	154.52 m
iv	MDDL	109.75 m
v	Sill level	100.00 m
vi	Operation Platform Level	158.00 m
vii	Hoisting	By Hydraulic Hoist
viii	Operating condition	The service gates shall be operated under flowing water. Gates shall be regulating.
ix	Capacity of Hoist	150 t (approx)
x	C/C of side seals	4150 mm
xi	C/C of tracks	4600 mm
xii	Design head	54.52m (corresponding to FRL).
xiii	Minimum thickness of skin plate	10 mm
xiv	Minimum thickness of stainless steel track	10 mm (after machining)
xv	Type of side & top seal	Double stem solid bulb type seal
xvi	Type of bottom seal	Wedge Type (Rubber) seal
xvii	Governing Indian Standard code	IS: 4622, IS: 800

Table – 4.30
Fixed Wheel Vertical Lift Gates (Emergency Gate) at Intake of Khargihill – Pinjal Tunnel

i	Clear Span	4.0 m
ii	Number of openings	1
iii	Full Reservoir level	154.52 m
iv	MDDL	109.75 m
v	Sill level	100.00 m
vi	Operation Platform Level	158.00 m
vii	Hoisting	By Rope drum Hoist
viii	Operating condition	The emergency gates shall be operated under balanced head condition.
ix	Capacity of Hoist	70 t (approx)
x	C/C of side seals	4150 mm
xi	C/C of tracks	4600 mm
xii	Design head	54.52m (corresponding to FRL)
xiii	Minimum thickness of skin plate	10 mm
xiv	Minimum thickness of stainless steel track	10 mm (after machining)
xv	Type of side & top seal	Double stem solid bulb type seal
xvi	Type of bottom seal	Wedge Type (Rubber) seal
xvii	Governing Indian Standard code	IS: 4622, IS: 800

The maintenance of these gates is proposed to be carried out at level EL 158.00m. The gate shall be designed in accordance with the provision of IS: 4622 (latest revision).

The general assembly of Fixed Wheel gate has been shown in Drawing No. DGPL-5800-P-1518 and DGPL-5800-P-1519 (Plate – 4.121 to 4.122 in Volume – VII (B)).

4.4.2.2.5 Fixed Wheel Gates at Outfall of Khargihill – Pinjal Tunnel

The Outfall of Khargihill – Pinjal Tunnel at Pinjal reservoir shall be provided with fixed wheel vertical lift gates (Outfall gate 3 & Outfall gate 4) of size 4000mm X 4000mm. Sill level of the gate shall be EL 85.50m.

The Outfall gate 3 shall be designed for head of 61.92 m (correspond to head between FRL at Khargihill & MDDL at Pinjal reservoir). Outfall gate 3 shall be provided with D/S skin plate & D/S sealing from Khargihill side. Outfall gate 3 shall be operated under unbalanced head condition. Wedge type seal shall be provided for bottom sealing and double stem solid bulb seals shall be provided for side & top sealing. The seal shall remain in contact with stainless steel seal seats to make the gate water tight.

The Outfall gate 4 shall be designed for head of 55.5m (correspond to head between FRL & Sill level at Pinjal reservoir). The Outfall gate 4 shall be provided on the D/S side of Outfall gate 3. The Outfall gate 4 shall be provided with D/S skin plate and D/S sealing from Pinjal side. Outfall gate 4 shall be operated under balanced head condition. Wedge type seal shall be provided for bottom sealing and double stem solid bulb seals shall be provided for side & top sealing. The seal shall remain in contact with stainless steel seal seats to make the gate water tight

The gate structure shall consist of skin plate stiffened by vertical stiffeners and horizontal girders. The horizontal girders shall be supported by end vertical girders on each side. The water thrust will be transferred to concrete structures from the end vertical girder through wheels and wheel track. The wheels shall be mounted on spherical roller bearings. The BHN of wheel track shall be 50 BHN higher than the wheel material. 40 mm guide and two number guide shoes shall be provided on each side to guide the gate in grooves.

The Outfall gate 3 shall be operated by independent hydraulic hoist of 180 t (approximate) capacity. The power pack shall be installed on the top of the deck. Operating speed shall be approx. 0.65m/min. The design of Hydraulic Hoist components shall conform to IS: 10210.

The Outfall gate 4 shall be operated by Rope Drum Hoist of 80t (approximate). The Rope Drum Hoist shall consist of hoist machinery mounted on hoist support structure. The hoist machinery shall be equipped with two rope-drums, gears, pinions, couplings, shafts, worm reducer, motor and brakes. The hoist bridge shall be supported on trestles. The design of Rope Drum Hoist shall conform to IS: 6938 (latest revision). Details are in Table – 4.31.

The maintenance of these gates are proposed to be carried out at level EL 145.00m. The gate shall be designed in accordance with the provision of IS : 4622(latest revision).

The general assembly of Fixed Wheel gate has been shown in Drawing No. DGPL-5800-P-1520 & DGPL-5800-P-1521 (Plate – 4.123 to 4.124 in Volume – VII (B)).

Table – 4.31

Details of Fixed Wheel Gates at Outfall of Khargihill – Pinjal Tunnel

		Outfall Gate - 3	Outfall Gate - 4
i	Clear Span	4.0 m	4.0 m
ii	Number of openings	1	1
iii	Full Reservoir level	154.52 m (at Khargihill)	141.00 (at Pinjal)
iv	MDDL	92.60 m (at Pinjal)	92.60 m (at Khargihill)
v	Sill level at outfall	85.50 m	85.50 m
vi	Operation Platform Level	145.00m	145.00m
vii	Hoisting	By Hydraulic Hoist	By Rope Drum Hoist
viii	Operating condition	The Outfall gate 3 shall be operated under un- balanced head condition	The Outfall gate 4 shall be operated under balanced head condition
ix	Capacity of Hoist	180 t (approx)	80 t (approx)
x	C/C of side seals	4150 mm	4150 mm
xi	C/C of tracks	4600 mm	4600 mm
xii	Design head	61.92 m (corresponding to head b/t FRL at Khargihill and MDDL at Pinjal)	55.5m (corresponding to head b/t FRL at Pinjal and Sill at Outfall)
xiii	Minimum thickness of skin plate	10mm	10mm
xiv	Minimum thickness of stainless steel track	10mm (after machining)	10mm (after machining)
xv	Type of side & top seal	Double Stem	Double Stem
xvi	Type of bottom seal	Wedge Type (Rubber) seal	Wedge Type (Rubber) seal
xvii	Governing Indian Standard code	IS: 4622, IS: 800	IS: 4622, IS: 800

4.4.2.2.6 Adit Gates at Khargihill – Pinjal Tunnel

The gate of adit 3 shall be provided for inspection of the Tunnel in between Khargihill Reservoir and Pinjal Reservoir. The opening size of the hinge type adit gates are 2200mm x 2200mm. the gate is operated by hydraulic hoist of suitable capacity. Details are in Table – 4.32.

The general assembly of Adit gate has been shown in Drawing No. DGPL-5800-P-1522, DGPL-5800-P-1523, DGPL-5800-P-1524 & DGPL-5800-P-1525 (Plate – 4.88 to 4.91in Volume – VII (B)).

Table – 4.32

Details of Adit Gate at Adit 3 of Khargihill - Pinjal Tunnel

i	Clear Span	2.2 m
ii	Clear Opening	2.2 m
iii	Number of opening	1
iv	Hoisting	By Hydraulic Hoist
v	Operating condition	The Edit gate 3 shall be operated when tunnel (between Khargihill to Pinjal) is empty
vi	C/C of side seals	2350 mm
vii	C/C of tracks	2700 mm
viii	Design head	61.807 m
ix	Minimum thickness of skin plate	10mm
x	Minimum thickness of stainless steel track	10mm (after machining)
xi	Type of seal	Music note Type

4.5 Power House

4.5.1 Power House at Bhugad Dam

A Surface Power House is planned on the left bank of Damanganga River downstream of Bhugad Dam. The intake structure is provided adjacent to the main spillway also termed as "Power Block" of width 16 m. The power block monolith accommodates an intake structure and a steel penstock (main) of 1.5m diameter laid within the body of the dam. The penstock emanates horizontally from the intake structure at an elevation of 120.00 m and bends twice at an angle of 45^0 in vertical to attain centre line elevation of 108.00 m of machines installed in the power house. The main penstock of 1.5m diameter bifurcate near the power house into two units penstocks of 1m diameter each to lead the water to two generating units house in surface power house. The water from the draft tube is lead back to Damanganga River through an open tail race channel. Two draft tubes with separate gates have been provided

The power potential study has been carried out by THDC India Ltd. The rated discharge through each unit of the power house is 2.87 cumec and the maximum discharge through each unit is 3.13 cumec. The rated net head is 41.66m. The installed capacity proposed by THDC India Ltd. for this power house is 2000 KW comprising of 2 units each of 1000 KW of horizontal francis turbine.

The main components of the schemes comprise of:

i) Intake Structure
ii) Penstock
iii) Surface Power House
iv) Tail Race Channel

4.5.1.1 Intake Structure

The intake structure is designed to ensure smooth entry of water from the reservoir into the water conductor system. The required minimum submergence from MDDL has been checked as per the codal provisions of BIS-9761: 1995.

The centre line of intake has been kept at EL 120.00 m to avoid formation of vortices and the entry of air into the water conductor system. For minimizing the losses, the profile of the intake roof and sides have been streamlined and bell mouth entry has been provided. The size of the bell mouth opening is 4mx4m and intake structure are provided within the RCC Chamber of size 2mx1.5m inside the body of the dam. The two numbers of gate shall be incase in a shaft created at the downstream of dam axis and shall be operated from the dam top. The floor level of the intake approach is kept horizontal at EL 118.750m. The intake shall draw water from the vertical trash racks provided above the intake floor. A single trash rack bay of width 4m has been provided to arrest floating debris from entering into the penstocks.

4.5.1.2 Penstock

Rectangular intake duct, downstream of the gated structure is transition to 1.5m diameter steel penstock laid within the dam body. The penstock is bifurcated into two penstocks after a length of 176m for feeding water to individual turbine units. The diameter of the penstock has been kept 1m for generating flow velocity within permissible limits. The penstock is designed to withstand maximum internal pressure caused due to maximum water level in the reservoir and possible increase in pressure due to development of water hammer effect when arresting or releasing the flow of water. It is proposed to provide the Grade-I steel as per BIS-2000:2009 of thickness 12mm.

4.5.1.3 Surface Power House at Bhugad dam

The Power house of length 32.7m and cross section 8.28m (W) x 19m (H) has been provided to house two numbers of horizontal axis Frances turbines of 1000KW each at 9.3m centre to centre. The centre line of the machine has been kept at elevation 108.00 m and the main inlet valve (MIV) shall be housed inside the power house with power house floor at elevation 107.13m. The turbine and the generator floors are planned at an elevation of 107.13m and the service bay level has been provided at an elevation of 111.10m level.

The draft tube gates are planned to be hoisted at an elevation of EL 111.10 m. The downstream wall of the power house has been provided upto an elevation of EL 116.50m which is above the maximum tail water level of 115.0 m. The structure comprises of RCC columns and beams designed to bear the loads coming from various electro-mechanical equipments. The capacity of Electric Overhead Traveling Crane for power house is 10t. The crane beam has been designed accordingly. A steel truss forms the roof of the power house.

A transformer deck has been provided on the upstream side of the power house at an elevation of EL 111.10 m by raising of the back fill concrete above the penstock.

4.5.1.4 Tail Race Channel

The water is led back into the Damanganga River through an open tail race channel being provided by cutting the rocks along its profile. The bottom slope of the tail race channel has been provided with a gradient of 1(V): 6 (H) sloping upwards upto its meting point of the river. The tail race channel is proposed to meet tangentially the flow in Damanganga river.

Reference Drawing Nos. DGPL-5800-P-1024 to 1027 (Plate – 4.125 to 4.128 in Volume – VII (B)).

4.5.1.5 Intake Gates of Bhugad Power House

Fixed Wheel Vertical Lift Gate of size 1500mmx1500mm shall be provided at the intake of Dam Toe Power house at Bhugad. The gate shall have wedge type bottom seal and music note type side and top seals. The gate shall have D/S skin plate D/S sealing. These gates shall be operated by rope drum hoist mounted at top of the pier at EL 168.00 m. Sill level of gate shall be 119.25m and shall be designed to withstand a static head of 44.62m corresponding to FRL i.e. 163.87m. The gates shall be closed in unbalanced water head conditions and shall be lifted in balanced water head condition to be achieved by crack opening of gate. The gates shall be capable for fully open or fully closed positions. No regulation shall be provided. Details are in Table – 4.33 and 4.34.

Air vent shall be provided at the d/s of service gate to meet out the air requirement

The emergency gate shall be provided to carry out the maintenance of Service gate. The emergency shall have u/s skin plate and u/s sealings. The emergency gate shall be operated by rope drum hoist.

Table – 4.33

Details of Intake Gates (Service Gate) of Bhugad Dam Power House

i	Clear Span	1.5 m
ii	Number of opening	1
iii	FRL at Bhugad Dam	163.87 m
iv	Sill level	119.25 m
v	Operation Platform Level	168.00m
vi	Hoisting	By Rope Drum Hoist
vii	Operating condition	The service gates shall be closed under flowing water & open in balanced head condition. Gates shall not be of regulating type
viii	C/C of side seals	1600 mm
ix	C/C of tracks	2200 mm
x	Design head	44.62m (corresponding to FRL)
xi	Minimum thickness of skin plate	10mm
xii	Minimum thickness of stainless steel track	10mm (after machining)
xiii	Type of side & top seal	Music note type seal for side
xiv	Type of bottom seal	Wedge Type (Rubber) seal
xv	Governing Indian Standard code	IS: 4622, IS: 800
xvi	Hoist Capacity	10 t(approx.)

Table – 4.34

Details of Intake Gates (Emergency Gate) of Bhugad Dam Power House

i	Clear Span	1.5 m
ii	Number of opening	1
iii	FRL at Bhugad Dam	163.87 m
iv	Sill level	119.25 m
v	Operation Platform Level	168.00 m
vi	Hoisting	By Rope Drum Hoist
vii	Operating condition	The emergency gates shall be operated under balanced head condition
viii	C/C of side seals	1600 mm
ix	C/C of tracks	2200 mm
x	Design head	44.62 m (corresponding to FRL)
xi	Minimum thickness of skin plate	10 mm
xii	Minimum thickness of stainless steel track	10 mm (after machining)
xiii	Type of side & top seal	Music note type seal for side
xiv	Type of bottom seal	Wedge Type (Rubber) seal
xv	Governing Indian Standard code	IS: 4622, IS: 800
xvi	Hoist Capacity	10 t (approximate)

4.5.1.6 Draft Tube Gates

The draft tube gates shall be provided at the d/s of power unit. Each power unit of Power House shall have one draft tube gate of size 3400 mm X 2340 mm. The draft tube gate shall be lowered to isolate the power unit from d/s side and the maintenance of power unit will be carried out without affecting other units.

The skin plate of gate shall be stiffened by vertical stiffeners and horizontal girders. The load from horizontal girders shall be transferred to end vertical stiffeners provided on each side. Bronze pad shall be fitted to end vertical girders. The load will be transferred to concrete through bronze pad and stainless steel track.

The gate shall be closed in balanced water head condition. Lifting of gate shall be done in balanced water head condition which shall be achieved by filling valve. The filling valve shall be linked to lifting arrangement of gates. The initial movement of lifting arrangement shall open the filling valve. The gate shall be lifted after achieving the balance head on both sides of gate. The gate shall be linked to gantry crane through lifting beam.

Table – 4.35
Details of Draft Tube Gates of Bhugad Dam Power House

i	Width of opening	3400 mm
ii	Size of Gate	3400 mmx2340 mm
iii	Sill Elevation	103.49 m
iv	Maximum Water Level	115 m
v	C/ C of side seals	3500 mm
vi	C/C of Tracks	4000 mm
vii	Design Head	11.51 m (corresponding to Max TWL condition)
viii	Sealing	Downstream sealing
ix	Type of side seal	Plain rubber music note type
x	Type of bottom seal	Wedge type rubber seal
xi	Minimum thickness of skin plate	10 mm
xii	Minimum thick of track plate	10 mm (after machining)
xiii	Minimum thickness of seal seat	10 mm (after machining)
xiv	Hoist capacity	6 t (approximate)

4.5.2 Power House at Khargihill Dam

Another Surface Power House is planned on the left bank of Vagh river (a tributary of Damanganga River) downstream of Khargihill dam. The intake structure is provided adjacent to the main spillway also termed as “Power

Block" of width 20 m. The power block monolith accommodates an intake structure and a steel penstock (main) of 1.5m diameter laid within the body of the dam. The penstock emanates horizontally at an elevation of 105.75 m from the intake structure and bends twice at an angle of 45^0 in vertical to attain centre line elevation of 87.75 m of machines installed in the power house. The main penstock of 1.5 m diameter bifurcate near the power house into two units penstocks of 1m diameter each to lead the water to two generating units house in surface power house. The water from the draft tube is lead back to Vagh River through an open tail race channel. Two draft tubes with separate gates have been provided

The power potential study has been carried out by THDC India Ltd. The rated discharge through each unit of the power house is 3.59 cumec and the maximum discharge through each unit is 3.95 cumec. The rated net head is 49.40m. The installed capacity proposed by THDC India Ltd. for this power house is 3000 KW comprising of 2 units each of 1500 KW of horizontal francis turbine.

The main components of the schemes comprise of:

i) Intake Structure
ii) Penstock
iii) Surface Power House
iv) Tail Race Channel

4.5.2.1 Intake Structure

The intake structure is designed to ensure smooth entry of water from the reservoir into the water conductor system. The required minimum submergence from MDDL has been checked as per the codal provisions of BIS-9761: 1995. The centre line of intake has been kept at EL 105.75 m to avoid formation of vortices and the entry of air into the water conductor system. For minimizing the losses, the profile of the intake roof and sides have been streamlined and bell mouth entry has been provided. The size of the bell mouth opening is 4mx4m and intake structure are provided within the RCC Chamber of size

2mx1.5m inside the body of the dam. The two numbers of gates shall be incase in a shaft created at the downstream of dam axis and shall be operated from the dam top. The floor level of the intake approach is kept horizontal at EL 104.75 m. The intake shall draw water from the vertical trash racks provided above the intake floor. A single trash rack bay of width 4m has been provided to arrest floating debris from entering into the penstocks.

4.5.2.2 Penstock

Rectangular intake duct, downstream of the gated structure is transition to 1.5 m diameter steel penstock laid within the dam body. The penstock is bifurcated into two penstocks after a length of 215 m for feeding water to individual turbine units. The diameter of the penstock has been kept 1 m for generating flow velocity within permissible limits. The penstock is designed to withstand maximum internal pressure caused due to maximum water level in the reservoir and possible increase in pressure due to development of water hammer effect when arresting or releasing the flow of water. It is proposed to provide the Grade-I steel as per BIS-2000:2009 of thickness 12mm.

4.5.2.3 Power House at Khargihill dam

The Power house of length 32.7 m and cross section 8.28 m (W) x 19 m (H) has been provided to house two numbers of horizontal axis Frances turbines of 1500 KW each at 9.3 m centre to centre. The centre line of the machine has been kept at elevation 87.75 m and the main inlet valve (MIV) shall be housed inside the power house with power house floor at elevation 86.55 m. The turbine and the generator floors are planned at an elevation of 86.75 m and the service bay level has been provided at an elevation of 90.65m level.

The draft tube gates are planned to be hoisted at an elevation of EL 90.650 m. The downstream wall of the power house has been provided upto an elevation of EL 97.50 m which is above the maximum tail water level of 96.00 m. The structure comprises of RCC columns and beams designed to bear the loads coming from various electro-mechanical equipments. The capacity of

Electric Overhead Traveling Crane for power house is 12 t. The crane beam has been designed accordingly. A steel truss forms the roof of the power house.

A transformer deck has been provided on the upstream side of the power house at an elevation of EL 90.65 m by raising of the back fill concrete above the penstock.

4.5.2.4 Tail Race Channel

The water is led back into the Vagh River through an open tail race channel being provided by cutting the rocks along its profile. The bottom slope of the tail race channel has been provided with a gradient of 1(V): 6 (H) sloping upwards upto its meeting point of the river. The tail race channel is proposed to meet tangentially the flow in Damanganga river.

Reference Drawing Nos. DGPL-5800-P-1057to 1060 (Plate – 4.129 to 4.132 in Volume – VII (B)).

4.5.2.5 Intake Gates of Khargihill Power House

Fixed Wheel Vertical Lift Gate of size 1500mmx1500mm shall be provided at the intake of Dam Toe Power house at Khargihill Dam. The gate shall have wedge type bottom seal and music note type side and top seals. The gate shall have D/S skin plate D/S sealing. These gates shall be operated by rope drum hoist mounted at top of the pier at EL 158.92 m. Sill level of gate shall be 105.00 m and shall be designed to withstand a static head of 49.52 m corresponding to FRL i.e. 154.52 m. The gates shall be closed in unbalanced water head conditions and shall be lifted in balanced water head condition to be achieved by crack opening of gate. The gates shall be capable for fully open or fully closed positions. No regulation shall be provided. The details are in Table – 4.36 and 4.37.

Air vent shall be provided at the d/s of service gate to meet out the air requirement

The emergency gate shall be provided to carry out the maintenance of Service gate. The emergency shall have u/s skin plate and u/s sealings. The emergency gate shall be operated by rope drum hoist.

Table – 4.36

Details of Intake Gates (Service Gate) of Khargihill Dam Power House

i	Clear Span	1.5 m
ii	Number of opening	1
iii	FRL at Khargihill Dam	154.52 m
iv	Sill level	105.00 m
v	Operation Platform Level	158.92 m
vi	Hoisting	By Rope Drum Hoist
vii	Operating condition	The service gates shall be closed under flowing water & open in balanced head condition. Gates shall not be of regulating type
viii	C/C of side seals	1600 mm
ix	C/C of tracks	2200 mm
x	Design head	49.52 m (corresponding to FRL)
xi	Minimum thickness of skin plate	10 mm
xii	Minimum thickness of stainless steel track	10 mm (after machining)
xiii	Type of side & top seal	Music note type seal for side
xiv	Type of bottom seal	Wedge Type (Rubber) seal
xv	Governing Indian Standard code	IS: 4622, IS: 800
xvi	Hoist Capacity	10 t(approx.)

Table – 4.37

Details of Intake Gates (Emergency Gate) of Khargihill Dam Power House

i	Clear Span	1.5 m
ii	Number of opening	1
iii	FRL at Khargihill Dam	154.52 m
iv	Sill level	105.00 m
v	Operation Platform Level	158.92 m
vi	Hoisting	By Rope Drum Hoist
vii	Operating condition	The Emergency gates shall be operated under balanced head condition
viii	C/C of side seals	1600 mm
ix	C/C of tracks	2200 mm
x	Design head	49.52 m (corresponding to FRL)
xi	Minimum thickness of skin plate	10 mm
xii	Minimum thickness of stainless steel track	10 mm (after machining)
xiii	Type of side & top seal	Music note type seal for side
xiv	Type of bottom seal	Wedge Type (Rubber) seal
xv	Governing Indian Standard code	IS: 4622, IS: 800
xvi	Hoist Capacity	10 t(approx.)

4.5.2.6 Draft Tube Gates

The draft tube gates shall be provided at the d/s of power unit. Each power unit of Power House shall have one draft tube gate of size 3400 mm X 2000 mm. The draft tube gate shall be lowered to isolate the power unit from d/s side and the maintenance of power unit will be carried out without affecting other units.

The skin plate of gate shall be stiffened by vertical stiffeners and horizontal girders. The load from horizontal girders shall be transferred to end vertical stiffeners provided on each side. Bronze pad shall be fitted to end vertical girders. The load will be transferred to concrete through bronze pad and stainless steel track.

The gate shall be closed in balanced water head condition. Lifting of gate shall be done in balanced water head condition which shall be achieved by filling valve. The filling valve shall be linked to lifting arrangement of gates. The initial movement of lifting arrangement shall open the filling valve. The gate shall be lifted after achieving the balance head on both sides of gate. The gate shall be linked to gantry crane through lifting beam. The details are in Table – 4.38.

Table – 4.38

Details of Draft Tube Gates of Khargihill Dam Power House

i	Width of opening	3400 mm
ii	Size of Gate	3400 mmx2000 mm
iii	Sill Elevation	83.55 m
iv	Maximum Water Level	96.00 m
v	C/ C of side seals	3500 mm
vi	C/C of Tracks	4000 mm
vii	Design Head	12.45 m (corresponding to Max TWL condition)
viii	Sealing	Downstream sealing
ix	Type of side seal	Plain rubber music note type
x	Type of bottom seal	Wedge type rubber seal
xi	Minimum thickness of skin plate	10 mm
xii	Minimum thick of track plate	10 mm (after machining)
xiii	Minimum thickness of seal seat	10 mm (after machining)
xiv	Hoist capacity	7 t (approximate)

4.6 Infrastructure Studies

The entire project area is well connected with National Highway – 8 on western side) and National Highway – 3 on the eastern side. Similarly the Mumbai – Delhi Railway line of Western Railway is passing west side of the project area and Mumbai – Delhi railway line of Central Railway is passing east of the project area. The nearest rail heads for Bhugad dam are Valsad and Vapi and for Khargihill dam Bhilad/Sanjan on Western Railway. The project area is served by a wide network of State Highways/ major district roads/ other roads. For transportation of heavy machinery to the dam site some of the road bridges and culverts may have to be strengthen at the time construction of project.

4.7 Industrial and Urban Use

The project has been planned as domestic water supply project to augment the domestic water supply of Mumbai city. The water requirement of local people for various uses (including drinking, etc) has also been considered before affecting the transfer of water to Mumbai city.

4.8 Instrumentation

The requirement of special instruments for the construction of dam, tunnels and Power Houses are described in Chapter – 7 "Construction Program, Manpower and Plant Planning".

4.9 Navigation and Tourism Development

No Navigation is proposed in the project. The proposed Bhugad and Khargihill reservoirs can be developed as tourist spot. Provision for development of tourist spots has been made on the periphery of both reservoirs.

4.10 Operation and Maintenance

The operation and maintenance of Damanganga – Pinjal link will be looked after by one chief Engineer and two Superintending Engineers along with sufficient organizational set up. A suitable operation and maintenance programme will be developed keeping in view the various objectives of the project.

4.11 Other Studies

The studies required at DPR stage have been carried out and included in the report. The other studies which are not covered in the DPR will be carried out at preconstruction stage. However, if the Design (NW&S) organization of CWC suggests any studies the same may be carried out at pre-construction stage.