ICOLD Symposium on Sustainable Development of Dams and River Basins, 24th - 27th February, 2021, New Delhi

MANERI DAM - REPAIR OF SPILLWAY AND ITS ENERGY DISSIPATER SEVERELY DAMAGED BY ROLLING BOULDERS DURING FLOODS – CASE STUDY

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ABSTRACT

Special rehabilitation measures were implemented on the 39 m high Maneri concrete gravity dam constructed across river Bhagirathi near Uttarkashi in Uttarakhand, India. The dam is located at the foot of steep, young Himalaya hills and suffers damages due to rolling boulders during floods. The situation is compounded by the fact that the dam is constructed in a curvilinear reach with highly adverse flow conditions and silting of the dam up to the spillway crest. Observed distress included severe damages on all four-bays of spillway glacis, total destruction of the slotted roller bucket and severe damages on the training walls. For the first right two spillway bays, a 20 mm thick mild steel plate having yield strength of 450 MPa underlain by around 250 mm thick M60 grade concrete was used for repair of the glacis. A bonding agent was used to fix the M60 concrete to the old concrete along with dowels and the MS sheet was anchored to the concrete. Gaps between the MS sheet and the concrete were cement grouted. For the other two bays, a minimum 500 mm thick M90 grade concrete has been placed - one bay with steel fibres and one bay without. Bonding agent was used between the M90 concrete and the old concrete along with key cutting in the existing concrete glacis and anchors. The repaired spillway has performed well after passing floods in the last two monsoon seasons. Additionally, the left and right training walls were re-aligned and re-constructed with M60 grade concrete facing on the water side. Other rehabilitation measures planned include construction of a stilling basin with M90 concrete on top to replace the earlier slotted roller bucket. To get adequate water way d/s of the dam, the protruding left bank hill is proposed to be dressed /cut appropriately. All this will be based on the physical hydraulic model studies.

1. BRIEF DESCRIPTION OF THE PROJECT

Maneri Bhali Stage-I (90 MW) Hydroelectric scheme was planned to harness the energy of waters flowing down river Bhagirathi between Maneri and Uttarkashi. It was commissioned in October 1984. The annual generation of this project is approximately 455 MU.

This scheme comprises of: -

(a) A 39 m high and 127 m long Concrete Gravity Dam across river Bhagirathi near Maneri which houses the spillway. The spillway was designed to pass 5000 cumec. It consists of four numbers radial gates of size 13 m width & 14.55 m height each, separated by 4m thick piers. A slotted roller bucket was provided for energy dissipation. Downstream view of Maneri dam can be seen in Photograph – 1.

(b) An Intake structure which comprises of three bays 9.00 m. wide each with an all-weather channel on the left flank. A sedimentation tank with total of 08 hoppers of 15.00m width, 15.70 m length and 5.75 m depth in 2 rows (i.e. 4 in each row) is provided to remove silt particles which are flushed back to the river downstream of the dam through a silt flushing tunnel.

(c) An 8.631 km long and 4.75 m diameter circular concrete lined Head Race Tunnel.

(d) A 69 m high and 11 m diameter underground surge shaft of restricted orifice type along with 316 m long and 6m diameter upper expansion chamber, 89.5 m long and 6m diameter lower expansion chamber.

(e) About 456 m long steel lined penstock of 3.8 m diameter with three branches of 2.5 m diameter just upstream of the powerhouse.

(f) A surface power house near Uttarkashi, housing three Francis turbines of 30 MW capacity each, i.e. total installed capacity of 90 MW. The firm power is 38.23 MW. The design discharge of the power station is 71.4 m3/s. The difference in elevation between the dam and the power station provides for a design head of 147.5 metre and a gross head of 180 meters.

(g) An open tailrace channel about 120 m long joins river Bhagirathi at Uttarkashi.

Photograph 1 : Downstream view of Maneri Dam

2 DETAILS OF DAMAGES

Severe floods in the rivers of Uttarakhand in August 2012 and June 2013 badly damaged some hydro-electric power projects mainly in Bhagirathi and Alaknanda river valleys. The spillway of Maneri Bhali Stage –I dam was also severely damaged during these floods with heavy leakages downstream from the spillway gates.

The damages observed in Spillway bays no. 1 & 2 on the right bank (Photograph 2) were mainly as under: -

(a) The sill beam of stop log gate and radial gate was washed out in a length of approximately 6.00 m and 8.00 m respectively out of a total length of 13 m. The flange of the remaining sill beams was also completely damaged.

(b) As both the sill beams were washed out in some length, therefore a cavity of about 6 - 7 m in length along the piers having a depth up to 2.00 m was created in between the radial gate and stop log gate. The flood also damaged the spillway glacis on the right side and in the d/s of radial gate sill beam throughout its length & up to the slotted roller bucket in about 3.00 m width with varying depth with a maximum 13.00 m depth.

Photograph 2 : Shows the damages in Spillway bay no-1

The damages observed in Spillway bays no. 3 & 4 on the left bank were mainly as under: -

(a) The concrete in between stop log gate and the radial gate was eroded due to high flood. The depth of erosion was in the range of 0.25 m to 0.70 m.

(b) The spillway glacis was also damaged. The depth of erosion ranged from 0.25 m to 0.80 m.

The damages in the energy dissipation arrangement and the downstream areas were mainly as under:

(a) The slotted roller bucket was completely damaged and was washed out (See photograph 6).

(b) Deep scour holes/cavities were observed in the bucket area (See photograph 7).

(c) The spillway training walls were badly damaged – the damages being much more in the right training wall (See photograph 6 for the left training wall).

3 PROBABLE CAUSES OF DAMAGES

A close examination of the flow conditions in Maneri Bhali Stage-I dam reveals that the following were the major reasons of damages

(a) Maneri dam is silted up to the spillway crest. Because of this, big size boulders which come with the floods in monsoon period roll down the spillway and cause damages to the spillway glacis, bucket and downstream training walls of Maneri dam.

(b) In the upstream side, there is a turn in the river and shortest radius of the turn is towards the bay no.1 on the right bank. Because of this, rolling boulders in monsoon season pass more through bay no. 1 in comparison to other spillway bays resulting in more damages in the bay.

(c) The width of the river downstream of the slotted roller bucket is converging. The training walls obstruct the flows released downstream from the spillway resulting in adverse flow conditions d/s of bucket/return flows with eroded materials drawn into the bucket etc. and results in damages to spillway structure and roller bucket.

4 REHABILITATION WORKS CARRIED OUT BY UJVNL PRIOR TO DRIP IN SPILLWAY BAYS NO. 1 & 2

Initially to arrest leakages, temporary arrangements such as caulking of gates were undertaken. After the monsoon of 2014, comprehensive rehabilitation/repair of Maneri Dam was planned by UJVNL. First of all rehabilitation works for the spillway bays no. 1 & 2 on the right bank were undertaken. The repair works of these spillway bays were carried out on priority basis in two phases: -

(a) Repair work from the sill beam of stop log gates to 2.00 m downstream of sill beam of radial gates by taking shutdown of Power House for a period of 36 days from 02.12.2014 to 07.01.2015.

(b) Repair work in entire spillway glacis from 2.00 m downstream of sill beam of radial gate in running powerhouse condition.

4.1 Repair works from the sill beam of stop log gates to 2.00 m downstream of sill beam of radial gates in spillway bays 1&2.

Following activities were performed in sequential order during the closure period to complete the works:

(a) Creation of bund in front of spillway bay 1, 2 & 3 to divert water through spillway no. 4 (see photograph – 3).

(b) Dismantling damaged mild steel sheets previously placed over spillway concrete profile.

(c) Damaged & remaining sill beams of stop log gate and radial gate were removed.

(d) Dismantling of concrete so as to get a minimum thickness of 250 mm of new concrete and a cover of 200 mm over the reinforcement.

(e) Drilling hole of 600 mm depth and 32 mm diameter in a staggered manner in parent concrete for fixing anchors.

(f) Fixing 25 mm diameter Fe 500 TMT bars in drill hole with grouting material for anchorage of reinforcement as well as dowel bars for fixing of MS plates.

(g) The reinforcement was laid with 20 mm diameter bars @ 150 c/c keeping the top cover of 200 mm. Where the cavity was more than 80 cm deep, reinforcement was provided in intermediate layers also keeping the top cover & bottom cover of 200 mm.

(h) Applying bonding coat (BASF make) between old and new concrete.

(i) Laying of concrete (ACC make Dry Crete of M80 grade) in the cavity between sill beam of stop log gate and radial gate (see photograph – 4).

(j) Fixing sill beams i.e. ISMB 300 (300 x 140) conforming to IS: 2062 (E250) with 20mm SS plate for Stop Log gates and Radial gates.

(k) Laying concrete (ACC make Dry Crete of M80 grade) up to the final level as per the profile.

(l) Fixing MS sheet (20 mm thick with a yield strength of 450 MPa) over the prepared concrete surface (see photograph – 5).

(m) Grouting between steel plate and concrete through holes cut in the steel plate.

To complete the repair works of spillway bays no. 01 & 02 within stipulated period, all the pre-requisites such as manpower, material etc. were arranged before the start of work. The works were taken up in 3 shifts continuously and completed within 36 days and the Power House was restarted thereafter.

4.2 Repair Works in Spillway Glacis of Spillway bays 1&2

Repair works in spillway glacis was carried out from 2 m d/s of radial gates during power house running condition. All activities were same as stated above. Only instead of M80 Dry Crete, M60 grade concrete was used.

Based on IS: 10262-2009 and IS: 456-2000 a mix design for M60 concrete (used for repair of spillway bays 1&2) was carried out by UJVNL which is as under:

(a)	Cement	450 kg/m^3
(b)	Water	157 kg/m^3
(c)	Silica fume	25 kg/m^3
(d)	Fine Aggregate	598 kg/m^3
(e)	Coarse Aggregate	1269 kg/m^3
(f)	Chemical Admixture	7.125 kg/m^3

The 28-day target strength of trial mix proportions for M60 grade of concrete was achieved as 68.9 N/mm^2.

Photograph 3 : (Temporary Bund for channelization of stream water)

Photograph 4 : (Laying concrete in spillway bay no 2)

Photograph 5 : (Laying and Grouting of MS Plate in Spillway bay no 2)

Photograph 6 : (Damaged Left Training wall)

Photograph 7 : (Cavity in Slotted Roller Bucket)

5 REHABILITATION/REPAIR WORKS CARRIED OUT/PROPOSED UNDER DRIP

5.1 Re-alignment and Reconstruction of downstream training walls

The training walls were originally constructed with a converging alignment in plan. In addition to the slotted roller bucket which was totally damaged, the training walls were also badly damaged in the floods of August 2012 and June 2013 as can be seen in photograph 6. To improve the flow conditions and to mitigate the damages due to flowing boulders, these walls were dismantled and re-constructed with a straight alignment. A drawing showing their original spillway plan and cross-section is attached as Drawing no. 1.

5.2 Repairs of spillway glacis in Spillway bay nos. 3 & 4

The spillway glacis of bay 3 was repaired using M90 grade concrete with steel fibres and that of bay no. 4 with M90 grade concrete without steel fibers. The minimum thickness of M90 concrete was 500 mm.

For joining the high strength concrete with the original spillway glacis concrete the following procedure was adopted:

- Work was taken up from the elevation corresponding to the point of intersection of the spillway piers with the spillway glacis from bottom to top.
- Chipping of spillway glacis to achieve minimum 500 mm thickness for placing rich concrete etc.
- Shear keys of size 1.0 m x 0.3 m with a depth of 0.45 m were cut in alternate shutters at about 5 m c/c.
- Thorough washing of existing concrete was carried out using high pressure air-water jets.
- About 1.5 m long anchors were provided at a spacing of about 2 m c/c at the interface (approximately 1 m deep in existing concrete).
- Bonding agent of BASF was used for bonding.
- Concreting was done using shutters of size 2.5 m width and 1.25 m height from bottom to top.

The concrete mix design for M90 grade concrete and construction supervision of high strength concrete work was carried out by National Council for Cement and Building Materials (NCCBM), Ballabhgarh.

The high strength M90 grade concrete mix design details were as under:

Grade of Concrete:	**M90A20 with Chemical Admixture**	**Exposure Condition:**	**Severe**
Workability:	125-150 mm at 30 minutes	**Maximum W/C Ratio:**	As per IS: 456
Cement:	OPC 53 Grade (Ultratech)	**Minimum Cement Content:**	As per IS: 456

The recommendations for M90A20 grade of concrete for the target average 28 days compressive strength of 98.25 N/mm^2 are given below.

Sl. No.	**Mix Constituents**	**For One Cubic Meter of M90 Concrete with Steel Fibers (Kg)**	**For One Cubic Meter of M90 Concrete without Steel Fibers (Kg)**
1.	Cement (OPC 53 Grade)	527	490
2.	Fly Ash	145	135
3.	Silica Fume	55	50
4.	Water	160	152
5.	Fine Aggregate (Crushed)	655	424
6.	Coarse Aggregate 10-20 mm	329 (40 %)	589 (50 %)
7.	Coarse Aggregate < 10 mm	493 (60 %)	589 (50 %)
8.	Chemical Admixture BASF Glenium Sky 8866	12.7 (@ 1.75 % by wt. of cementitious material)	6 (@ 0.9 % by wt. of cementitious material)
9.	Water Cementitious ratio	0.22	0.225
10.	Steel Fibers (1.27 % by volume of concrete)	100	--

5.3 Repairs of deep cavities downstream of the spillway

Three deep scour holes /pits of big size had formed in the bucket area in front of bays 1, 2 & 3. One of the pit in front of bay-3 was the deepest. These pits were reported to be inter-connected. For filling these holes /pits, the following was recommended:

(a) First select the scour hole / pit with the minimum depth for repairs, out of the three for repairs.

(b) After dewatering, chipping of the entire concrete surface of the hole /pit to get a rough surface, is to be carried out.

(c) After cleaning and drying of the pit and provision of dowel bars, fill the pit with M20 concrete with non-shrink admixture by tremie concrete in lifts of 1 m height and giving a time gap of minimum 72 hours between each lift.

(d) Provide reinforcement mesh of 20 mm dia. Tor steel bars @ 150 mm c/c both ways in the top layer and flush it with the existing surface. This area is later to be covered with high strength concrete as required for the EDA.

(e) Consolidation grouting of the area in the bucket portion to close any inter connections of pits and damaged rock mass with open joints etc.

5.4 Proposed repair of spillway piers

The d/s vertical face of the piers had also been eroded badly and the reinforcement was exposed. The same was recommended to be repaired as under:

(a) To provide cladding with steel plate (20 mm thick) having width equal to the thickness of the spillway piers less about 15 cm on both sides to avoid possible damages to the plate on account of erosion of the pier faces later on. The height of this plate cladding could extend about 1 m higher than the highest damaged point on the pier. The lower elevation of this plate would be the elevation of the point of intersection of the pier with the spillway glacis.

(b) This cladding plate to be fixed using anchor bolts of 25 mm dia., 1.5 m long at 0.50 m spacing (Staggered) on to the existing concrete face of the pier.

(c) The space between the eroded d/s face of the pier and the cladding plate to be filled with cement grout / mortar / micro-concrete after tightening the anchor bolts. The end of the anchor bolts be also welded with the cladding plate.

5.5 Construction of proposed stilling basin in place of slotted roller bucket

In view of problems of rolling boulders and unsymmetrical flows from the spillway it was felt not to reconstruct the slotted roller bucket as it is prone to damages. A stilling basin without appurtenants has been proposed instead. The unsymmetrical flow from the upstream can be seen from Drawing 2.

The spillway was originally designed for 5000 cumec. After review the revised design flood to be adopted for safety of the dam has been determined as 8368 cumec (SPF). However the maximum flood observed by the project authorities has been 1457 m^3/s only on 16.06.2013. The dam is likely to get overtopped with the increased flood. This issue is to be looked seriously into by the project authorities.

As regards the energy dissipation arrangements it is considered adequate to design for the original design flood of 5000 m3/s only which is about 60 % of the revised flood. The Tail water rating curve was worked out by HEC-RAS model. Also it was co-related with the original tail water levels available with IRI, Bahadrabad. As there were some differences in the tail water levels the hydraulic model studies are planned to be carried out with both the curves. Also it is planned to consider the upstream reservoir as silted up to the spillway crest for assessing the discharging capacity of the spillway.

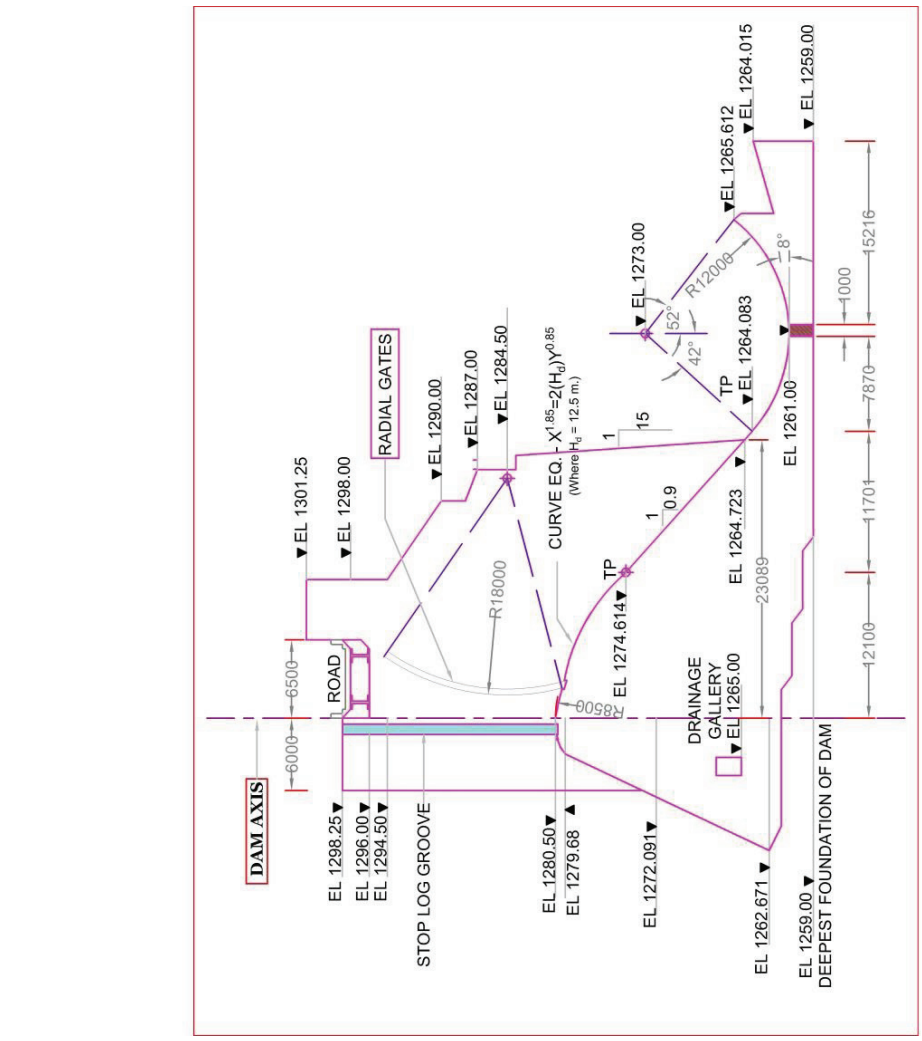
The stilling basin design was carried out as per IS 4997using the tail water rating curve obtained by HEC-RAS. A drawing showing the proposed stilling basin is attached as Drawing 6. A length of 100 m with invert at El. 1258 m has been arrived at. To avoid cutting below the spillway the d/s toe the spillway is proposed to be extended on the downstream with provision of a small sloping apron before the stilling basin.

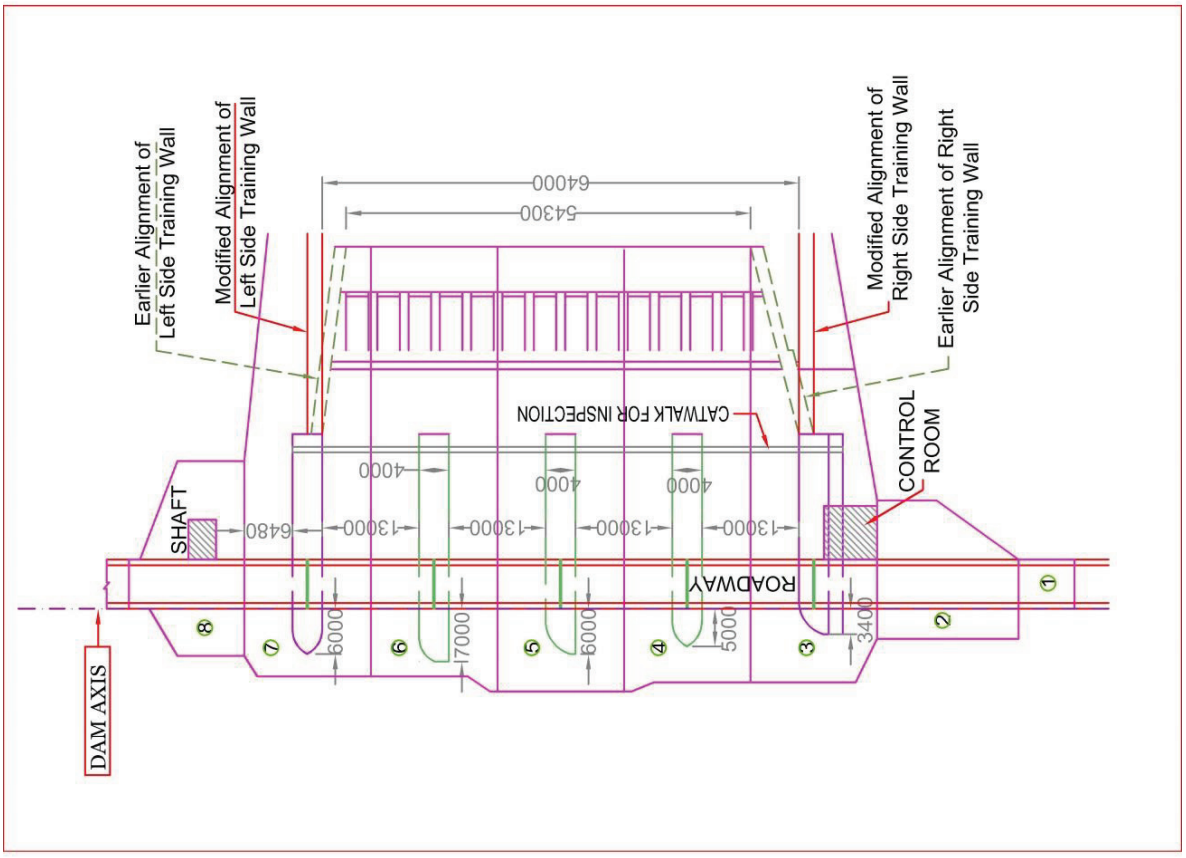
The top about 750 mm of the stilling basin is proposed to be constructed with M90.Presently the hydraulic model studies are under progress at IRI, Bahadrabad. A composite model has been prepared by IRI, Bahadrabad simulating the downstream topography. In order to get required width for the stilling basin in the lower d/s reach the proposal envisages hill cutting on the left bank for extension of training wall. Slope protection measures will also be required to be taken on the left bank. Drawings showing these aspects are attached as Drawings 3, 4, 5 & 6.

6. CONCLUSIONS

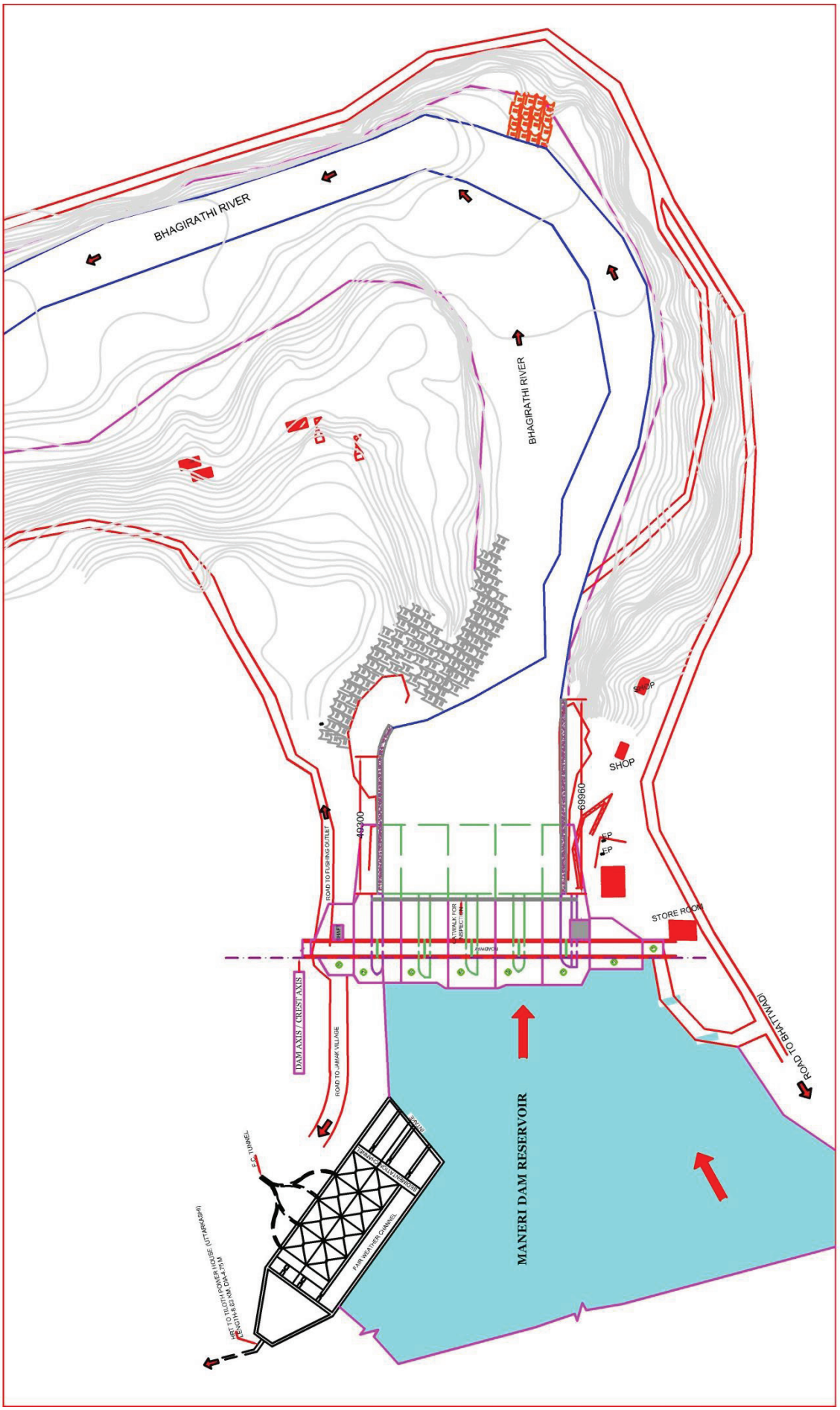
Repair works of spillway glacis in bays no. 1 and 2 were carried out by using M60 grade concrete and fixing MS steel plate over prepared profile followed by cement grouting. The repair works of the glacis of spillway bays no 3 & 4 have been carried out under the DRIP using M90 grade concrete for the first time in India both with and without steel fibers. The spillway glacis repairs with M90 concrete have withstood two monsoon seasons successfully. Long term monitoring of the spillway performance with these three diverse types of repair works is to be carried out and conclusions can thereafter be drawn as to which method is the most suitable for repairing of spillway glacis and energy dissipation arrangements for the severe conditions prevalent in this project.

The construction of stilling basin and improvement in d/s flow conditions is expected to provide sustainable rehabilitation solution for the Maneri dam spillway.

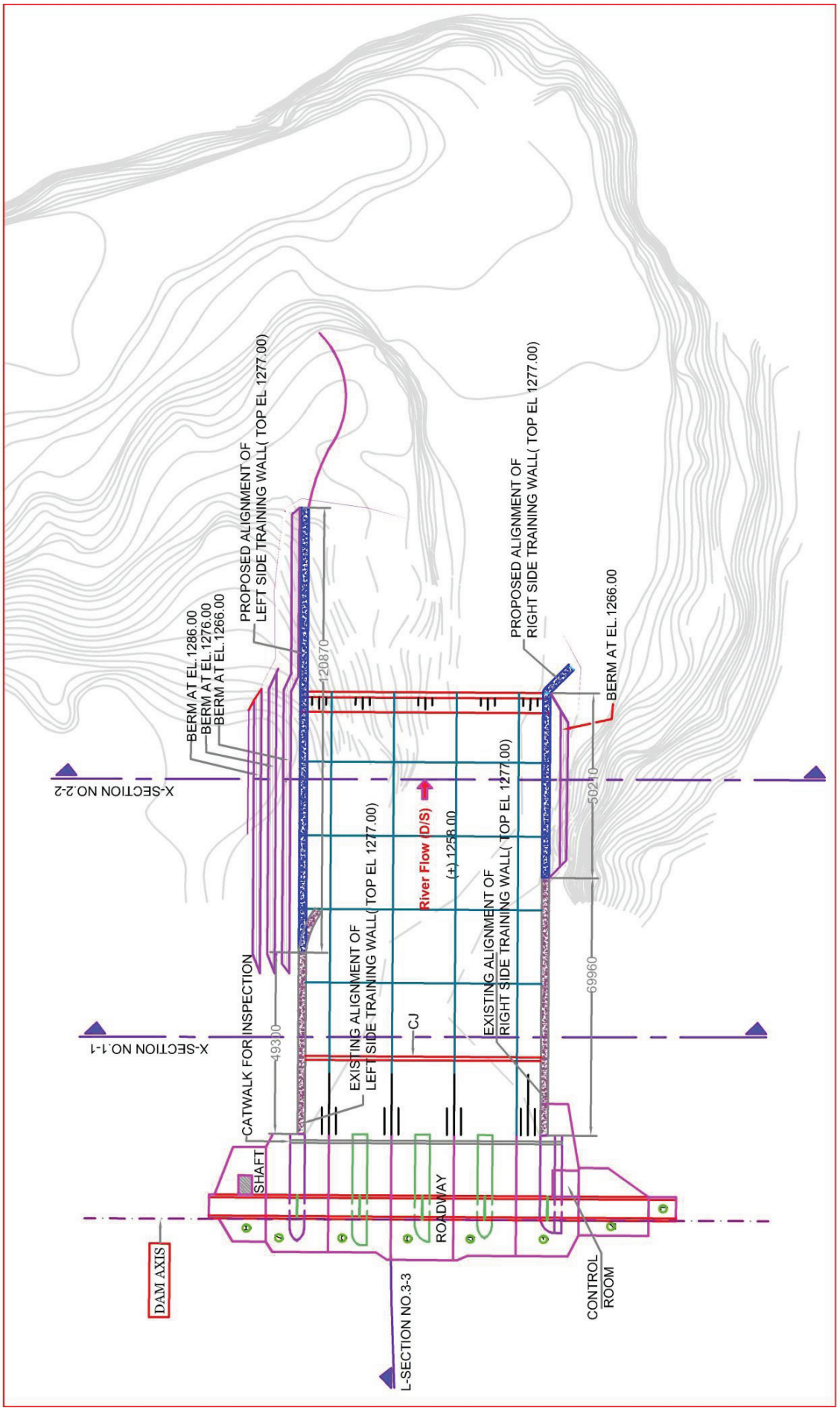




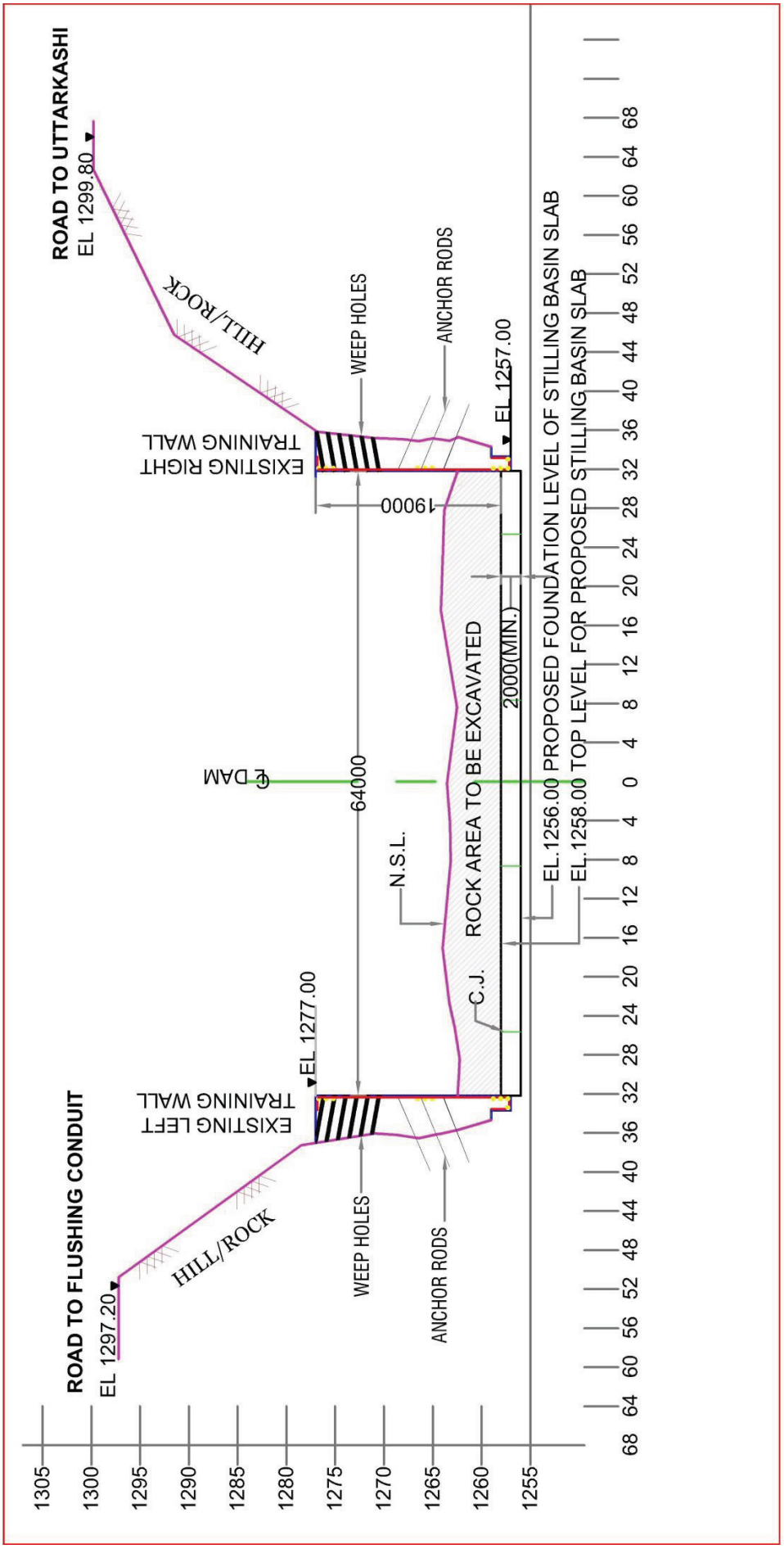
Drawing 1 Original Spillway Plan and Cross Section



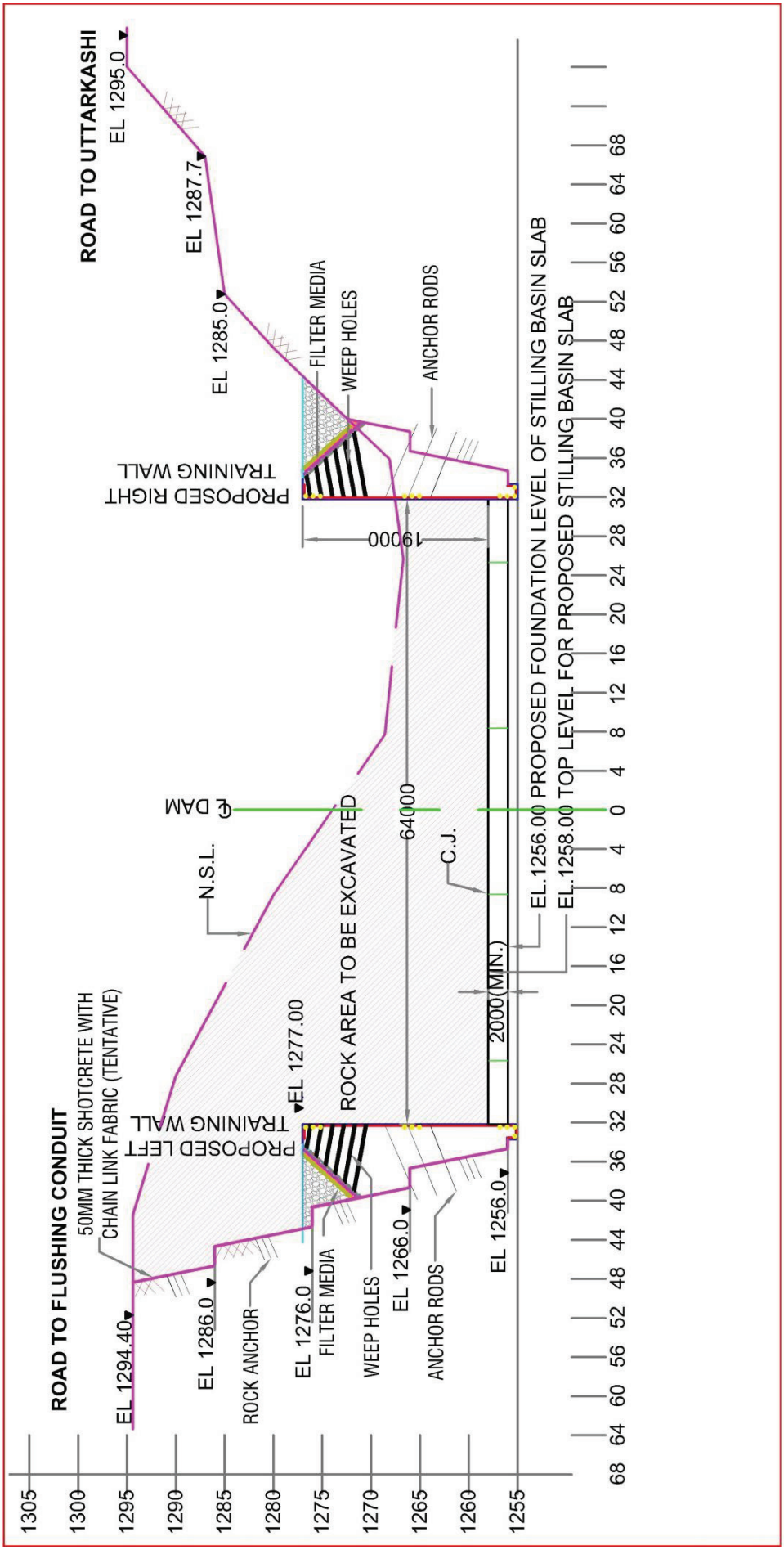
Drawing 2 Unsymmetrical flow from the upstream side



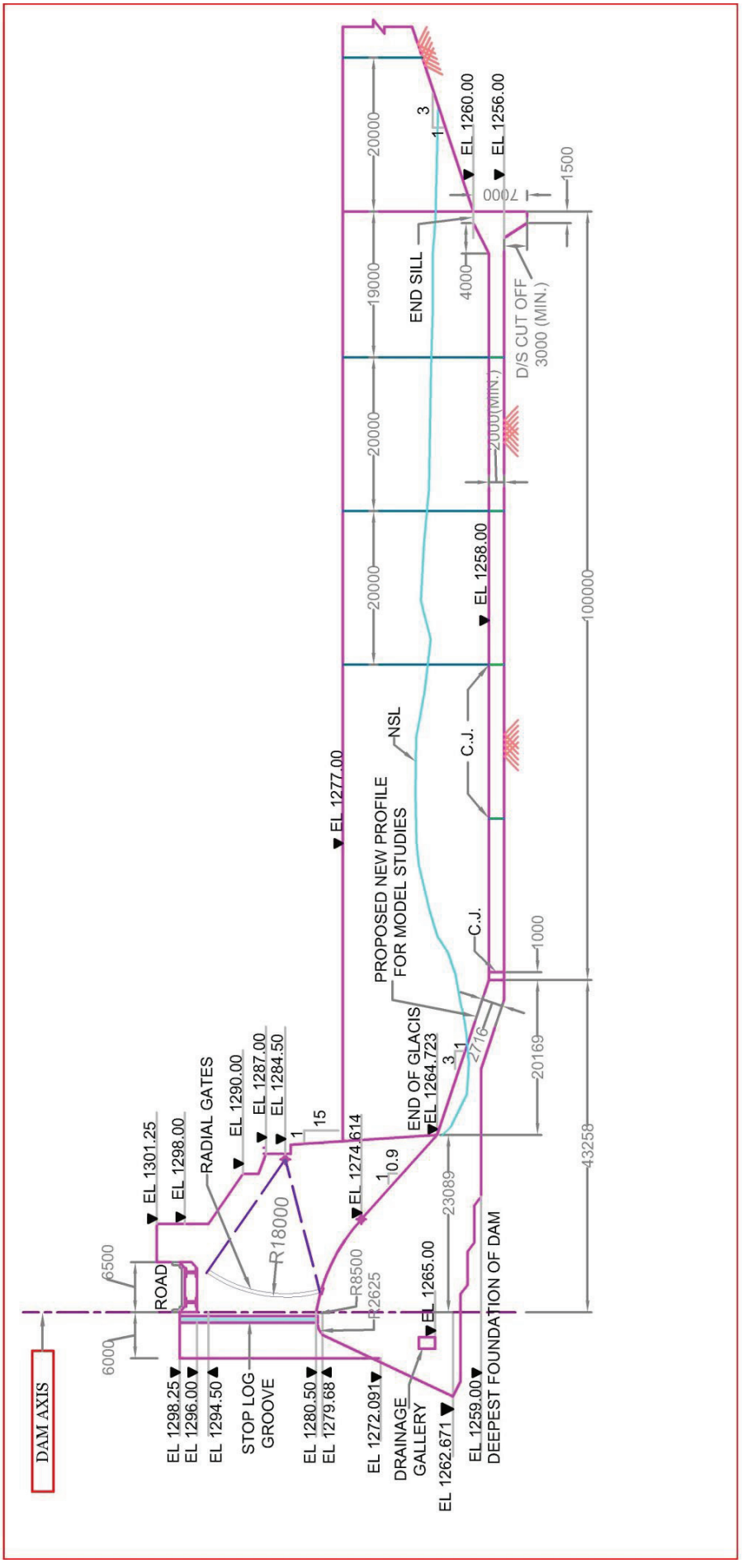
Drawing 3 Layout Plan of Proposed Stilling Basin & Extended Training Walls



Drawing 4: Cross Section 1-1 at RD 50.00 m from Dam Axis



Drawing 5: Cross Section 2-2 at RD 120.00 m from Dam Axis



Drawing 6: Longitudinal Section of Proposed Stilling Basin