HEIGHTENING OF DHANIKHARI DAM - HYDRAULIC DESIGN OF SPILLWAY AND ENERGY DISSIPATOR

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ABSTRACT

The demand for drinking water has been ever increasing across the world and dams serve as primary storages of water resources. To cope up with the increasing demands of water, either existing reservoir capacities are to be increased or new reservoirs are to be created. Heightening of existing dams is considered as a most effective and economic way of increasing the storage capacity of existing reservoir. Heightening of Dhanikhari dam was one of such projects of augmentation of existing reservoirs. Dhanikhari storage dam, in Port Blair city, in Andaman and Nicobar Island, India was built to cater for the drinking water needs of Port Blair city with storage capacity of 4.61 MCM. To augment for the increasing demand in water, it was proposed to raise its height by 5 m to create an additional storage of 3.23 MCM. This led to modification of spillway and appurtenant structures for safe disposal of increased flood. Hydraulic design of spillways and energy dissipators can be better carried out by hydraulic model studies and CWPRS, Pune carried out physical model studies on 1:25 scale spillway model of Dhanikhari dam. The heightening of dam was completed based on the recommendations of CWPRS in 2013. This paper describes the performance of modified design of spillway and energy dissipator of heightened Dhanikhari dam including various recommendations based on hydraulic model studies.

1. INTRODUCTION

Dams are heightened for various reasons and to mention a few are to provide domestic, industrial and irrigation water as per the increasing demands, to increase flood control capacity of dams, to protect the areas of downstream from submergence, etc. To increase the reservoir volume, dam heightening is one of the viable alternatives than building a new reservoir. Heightening minimizes additional submergence and also reduces environmental degradation. Hydraulic design of spillways and energy dissipators can be better carried out by hydraulic model studies. The purpose of hydraulic design of spillway is to ensure structures are of sufficient size that natural flooding is not worsened and to ensure that the structure can withstand the design flood and remain traversable. This is required in order to protect the property and residents upstream and downstream of structure. Hydraulic design also accounts for protection of river banks downstream of dam from scouring action of flowing floodwaters. Dhanikhari dam in Port Blair in Andaman and Nicobar, India is built on Dhanikhari river in 1973 as a drinking water supply project. To meet the demand for drinking water for future, it was proposed to increase the height of the dam by 5 m. Accordingly the spillway needed to be modified to pass the increased design flood. Various components of spillway and energy dissipator of Dhanikhari dam were modified and tested in CWPRS on a 1:25 scale physical model to improve/ economise the design.

2. ORIGINAL LAYOUT

The original design of dam was of 132 m long and about 32.25 m high with a storage capacity of 4.61 Mm^3 at FRL El. 61 m. The original overflow spillway comprised of 2 spans of 7.9 m (W) and 2.2 m (H) with crest at El. 58.5 m to pass the design of discharge of 141.5 m^3/s at FRL El. 61 m. The energy dissipator was in the form of stilling basin with invert El. at 31.2 m and dentated endsill. The top eleation of dividewalls was at El. 38.5 m to contain the flood releases and pass to downstream.

3. NECESSITY OF HEIGHTENING

Dam heightening was required to augment the reservoir storage capacity from existing 4.61 MCM to 7.84 MCM, i.e. an increase in storage of about 70%. This increase in storage intended to meet the requirements of city of Port Blair for about two decades or so.

4. MODIFIED DESIGN

Modifications to the design of M/s. NHPC Ltd wee suggested by CWPRS and were accepted for conducting physical model studies at CWPRS, Pune, India. The original design of dam was of 132 m long and about 32.25 m high with a storage capacity of 4.61 Mm^3 at FRL El. 61 m. To augment for the increasing demand in water, the dam was heightened by 5 m to create an additional storage of 3.23 Mm^3. The existing overflow spillway with 2 spans of 7.9 m (W) and 2.2 m (H) with crest at El. 58.5 m was modified to 3 spans of 3.6 m (W) x 3.6 m (H) with crest at El. 59.0 m by accommodating breast walls. The existing was made as per the existing BIS codal provisions as per the safety of the dam which provides 10% in operation gates. Hence, an extra gate was imparted to the existing two gates for safety in case of any extreme flood event and consecutive in operation of gates. New spillway is required to pass the modified design of discharge of 225 m^3/s against original design discharge of 141.5 m^3/s at raised FRL El. 66 m instead of existing FRL El. 61 m. The existing energy dissipator in the form of stilling basin with invert El. at 31.2 m and dentated endsill is partly modified by making solid endsill with top at El. 35.2 m. The modifications made to various components of spillway and energy dissipator are explained in detail below.

4.1 Spillway

Spillway and energy dissipator of Dhanikhari dam was modified for the following reasons:

(a) The augmentation of water storage in the reservoir was needed to cope up with the demands of the city of Port Blair and hence the dam was heightened

(b) The storage levels enhanced due to increase in storage, Full Reservoir Level (FRL) from El. 61 m to El. 66 m.

(c) The revised flood increased from 141.5 m^3/s to 225 m^3/s, which is to be passed through the spillway

The modifications done to design of spillway are as mentioned under. The plan of modified spillway of Dhanikhari dam is shown in Fig.1.

4.1.1 *Breastwall spillway*

Overflow spillway was modified as breastwall spillway as shown in Fig 2 to increase the regulating storage of flood discharge, reducing the height of gate, minimizing the cost of gate operating mechanism etc (IS: 6934, 1998). It also improves the discharging capacity of spillway. Breastwalls are useful in increasing the head of water above the crest and thereby improve the discharging capacity of spillway. The breastwall profile conforms to parabolic equation $x = 1.3\, y^{2.4}$

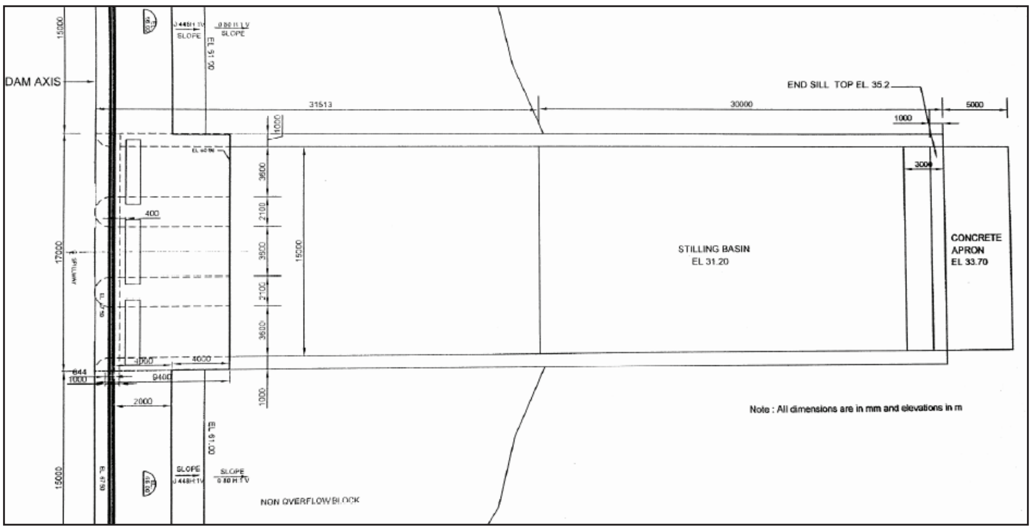

Fig. 1 : Modified plan of Dhanikhari dam spillway

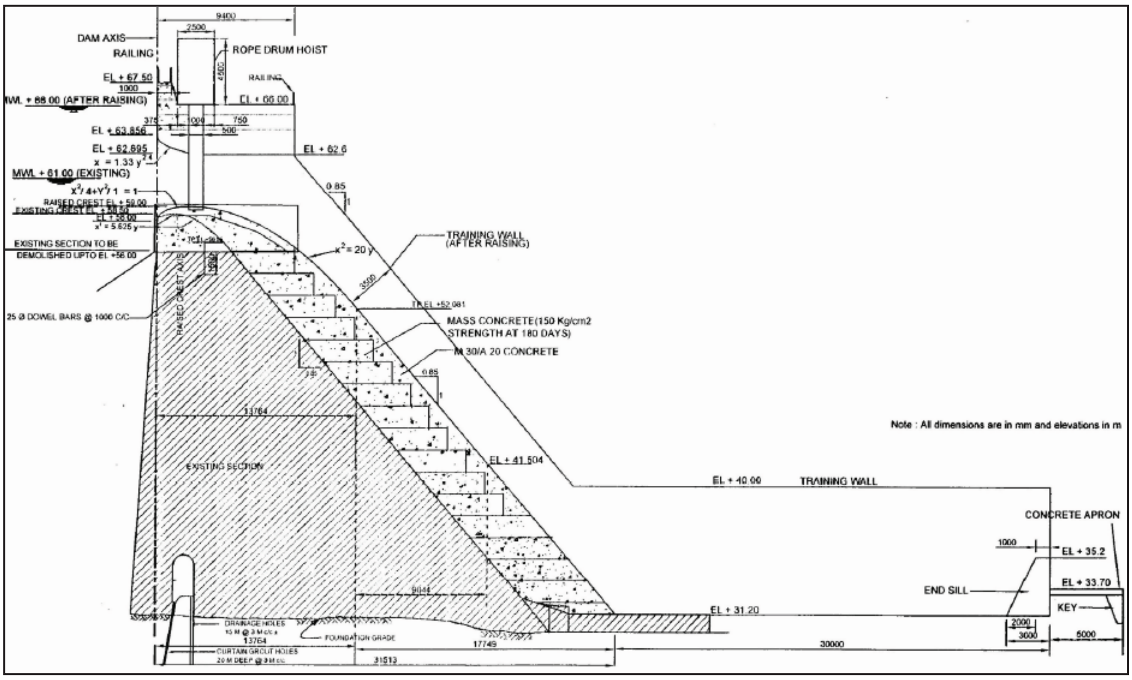

Fig. 2 : Original and modified cross sections of Dhanikhari dam spillway

4.1.2 *Upstream and downstream quadrants of profile modified*

The spillway upstream quadrant was modified to $\frac{x^2}{4} + \frac{y^2}{1} = 1$. The downstream profile made flatter from existing $x^2 = 5.625y$ to $x^2 = 20\ y$ (IS 6934).

4.1.3 *Crest level*

The original spillway had the crest at El. 58.5 m, which was raised to El. 59 m.

4.1.4 *Number and size of Spans and gates*

Spillway spans are increased by one, by introducing one more span without increasing the width of spillway. Adding one more span allows the incorporation of codal provision (IS: 11223- 1985) of 10% gate inoperative condition thus ensuring the dam safety. The overall area of spillway spans increased from 33 sq.m to 38.88 sq.m, increasing by about 37.8%. Construction of additional span enhanced discharging capacity.

4.2 Energy Dissipator

The function of energy dissipator is to absorb high energy of spillway flows and discharge these flows to the downstream water course, without causing serious scour or erosion of the toe of the dam/ spillway or damage to adjacent structures (IS 4997-1968). Normally hydraulic jump type stilling basins and bucket type energy dissipators are used depending upon conditions of downstream tail water. Although in case of projects where fall is greater than 15 m or discharge intensity is more than 30 m^3/ s/ m or for possible asymmetry of flow, it is recommended that performance of energy dissipation arrangement shall be tested on model.

4.2.1 *Stilling basin with Endsill*

The energy dissipator for the Dhanikhari dam was originally in the form of stilling basin with invert at El. 31.2 m and slotted endsill. This was slightly modified by converting dentated endsill into solid endsill to reduce the scour downstream of toe. The height of the endsill is kept at 4 m above the invert of the stilling basin at El. 35.2 m. A concrete apron of 5 m long was provided downstream of endsill to absorb the hydrodynamic loads from discharges released from stilling basin

4.2.2 *Training walls*

Training wall top elevation increased from existing elevation of about El. 38.5 m to El. 40 m, considering the increased bulk of flow due to increased flood and free board to avoid spilling of flow on the right and left banks, causing erosion. A Free board of about 3 m is provided for stilling basin training walls (IS: 5186, 1969). Curved training walls provided downstream of stilling basin to guide the river smoothly and safely to downstream.

5. HYDRAULIC MODEL STUDIES FOR MODIFIED DESIGN

Physical models are usually employed for atypical designs involving unusual topography, geometry and / or discharges or velocities that exceed experience levels. Spillway designs are efficiently made by conducting hydraulic model studies on physical models. For Dhanikhari dam heightening, the overall performance of spillway was assessed by carrying out hydraulic model studies on a 1: 25 scale geometrically similar Froudian scale model in CWPRS, Pune, India. Photos 1 and 2 show the upstream and downstream views of model showing modified spillway of Dhanikhari dam. The accepted equations for similitude based on Froudian criteria were used to express the mathematical relationship between the dimensions and hydraulic parameters of the model and prototype as shown in Table 1.

Table 1 : General Relationships in Terms of Model Scale

Dimension	Scale Relation
Length	1:25
Area	1:625
Velocity	1:5
Discharge	1:3125
Time	1:5
Pressure in m of water head	1:25
Manning's 'n'	1:1.71

Hydraulic model studies were carryout on the physical model of Dhanikhari dam to assess the modified spillway section alongwith energy dissipator for flood releasing capacity, suitability of spillway surface against cavitation erosion, adequacy of number of gates considering dam safety, efficiency of energy dissipation arrangement inclusion length of stilling basin and endsill arrangement and downstream flow conditions (CWPRS Technical Report No. 4717(2010)).

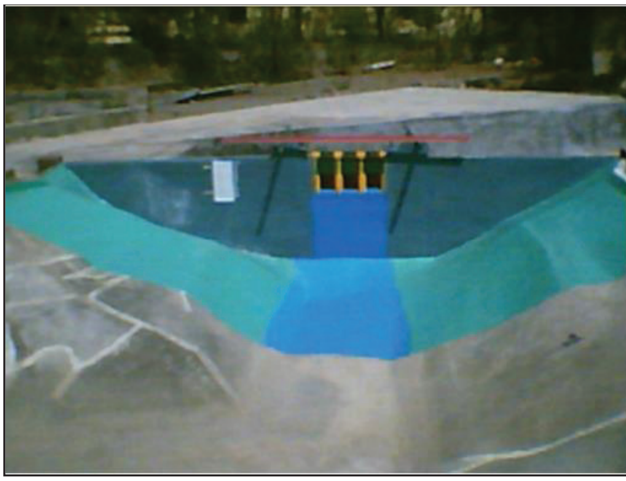

Photo 1 : Upstream view of spillway model

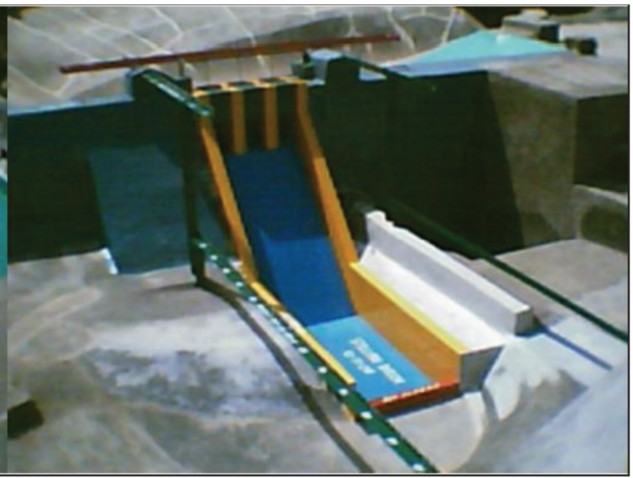

Photo 2 : Downstream view of spillway model

5.1 Hydraulic model studies of Spillway and stilling basin

Hydraulic model studies were conducted in CWPRS, Pune on 1: 25 scale Froudian comprehensive physical model. The studies carried out to assess the performance of modified spillway and stilling basin in respect of dam safety. The studies for assessment of discharging capacity of spillway, pressures upon spillway glacis, on stilling basin and over endsill and flow conditions downstream of spillway were done for various discharges for ungated and gated operating conditions of spillway.

5.1.1 *Performance of spillway*

By observing piezometric pressures over the modified spillway ogee profile, the profile was found acceptable in respect of pressures. Since the value of cavitation index (Falvey, 1990) at the locations of observed pressures was above the critical cavitation index, the profile was considered safe and not susceptible against cavitation. Figures 3 and 4 show the observed pressures over the spillway, stilling basin and endsill, while passing discharge of 150 m^3/s for gated and ungated operating conditions of spillway. Regarding the flood releasing capacity of spillway, the design discharge of 225 m^3/s could be passed at reservoir water level (RWL) El. 63.7 m, 150 m/s at RWL El. 62.8 m, and 75 m^3/s at RWL El. 61.3 m and a maximum discharge of 331 m^3/s could be passed at FRL El. 66 m with all the three gates fully open. Also, with one gate inoperative and FRL El. 66.0 m, the discharge of 225 m^3/s could be passed from the two gates fully open.

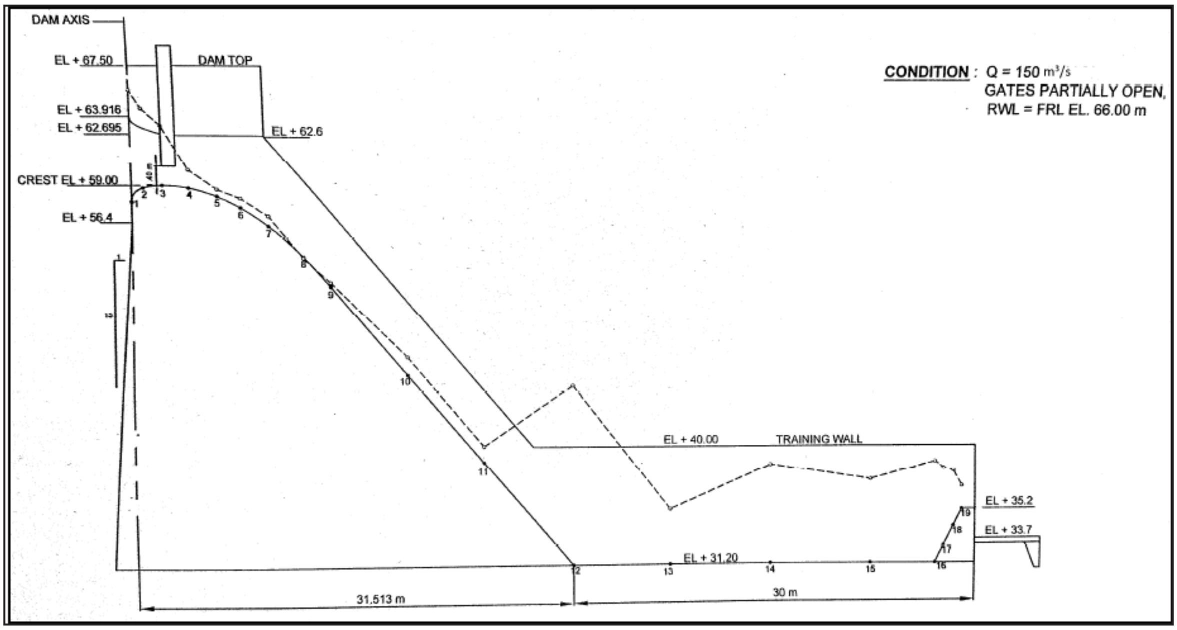

Fig 3 : Pressure profiles on spillway and stilling basin (discharge 150 m^3/s at FRL El. 66 m)

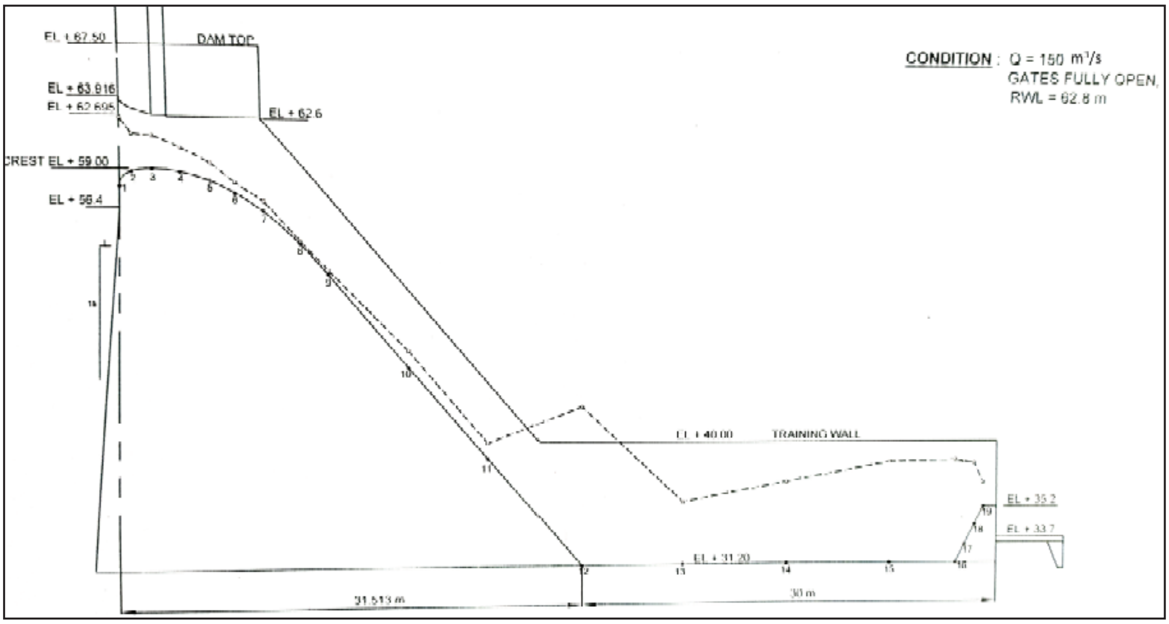

Fig 4 : Pressure profiles on spillway and stilling basin (discharge 150 m^3/s at RWL El. 62.8 m)

5.1.2 *Performance of stilling basin*

Studies on stilling basin with solid endsill showed that hydraulic jump was forming and contained in the stilling basin for various operating conditions of gated and ungated operation. The solid endsill was effective in containing jump. Due to hydraulic jump action, the incoming velocities of the order of 19- 23 m/s were reduced to 3-4 m/s at the end of stilling basin. Thus energy dissipation was satisfactory due to formation of strong hydraulic jump with Froude number 8- 14 and reduction in velocities by about 82%.

The stilling basin of 30 m long seems sufficient for containing hydraulic jump in it. Using empirical formula for the calculation of length of stilling basin with endsill only $L_b = K\, d_1\, F_1^{\,1.5}$, where d_1 is initial depth of jump, F_1 is the corresponding Froude number and K is the stilling basin coefficient which is 1.7 (USACE, 1990), the length of basin works out to be about 30 m. Figures 5 and 6 show the water levels in the stilling basin, while passing discharge of 150 m^3/s for gated and ungated operating conditions of spillway. Photo 3 shows flow conditions in stilling basin while passing discharge of 150 m^3/s at FRL. The length of stilling basin comes to 4- 5 times difference of initial depth (d_1) and sequent depth (d_2).

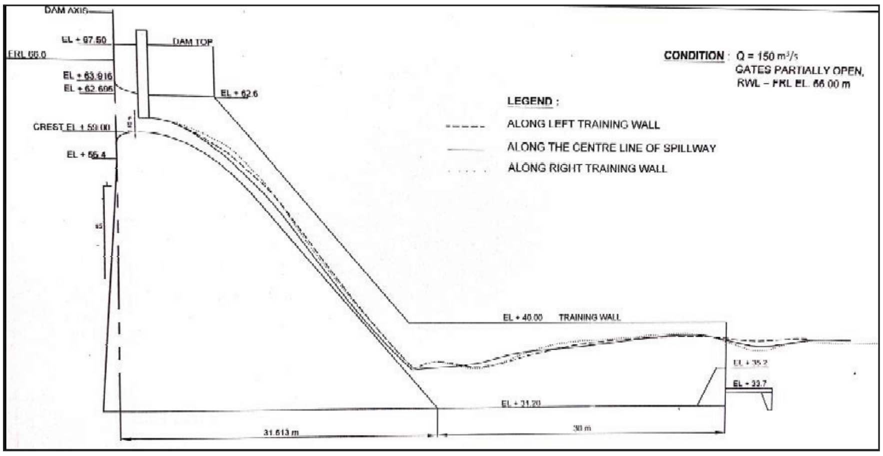

Fig. 5 : Water surface profiles on spillway and stilling basin ((discharge 150 m^3/s at FRL El. 66 m)

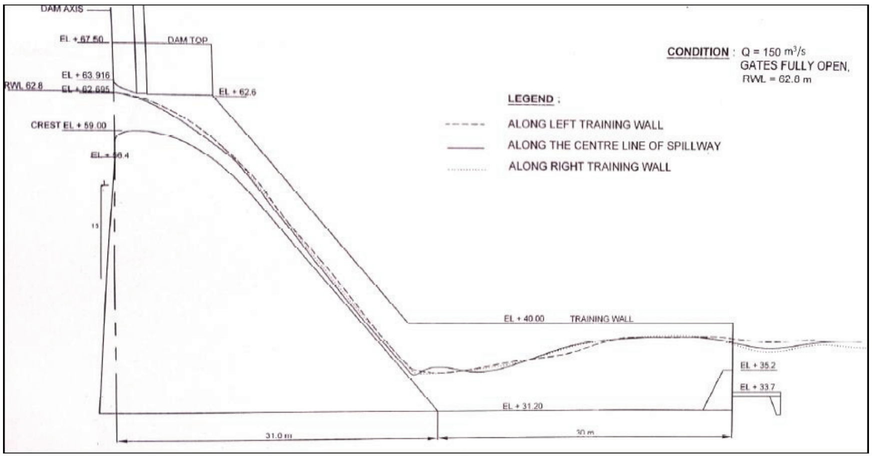

Fig 6 : Water surface profiles on spillway and stilling basin (discharge 150 m^3/s at RWL El. 62.8 m)

5.1.3 *Flow conditions in the river downstream*

Purpose of energy dissipator is mainly to dissipate the kinetic energy of flood entering it and safely dispose off to downstream of spillway. The velocities observed downstream river at various locations as shown in Fig 7 indicated maximum velocities were occurred of the order of 3 -5 m/s along the left bank of the river. This is mainly due to the 90 degree bend the river traverses just downstream of stilling basin. These studies are useful in designing protection arrangements/ structures along the banks of the river.

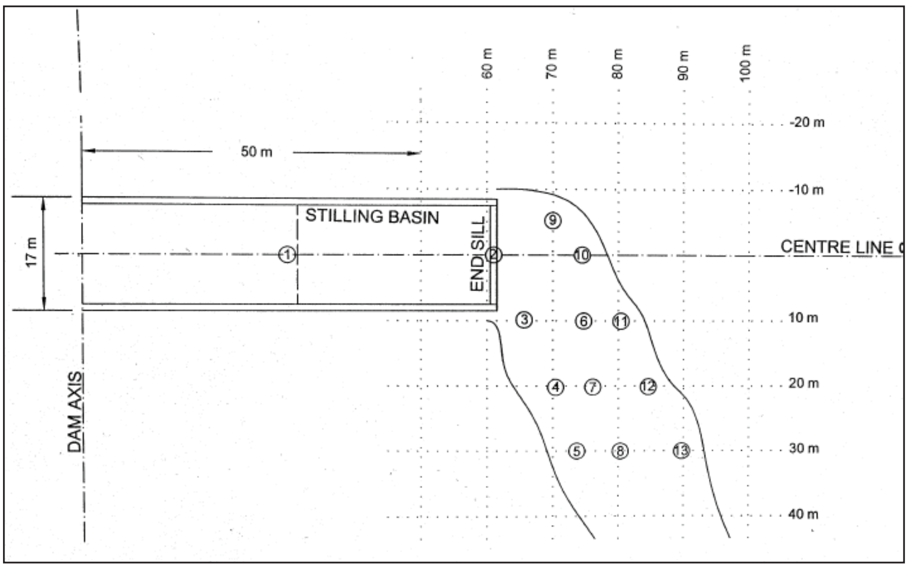

Fig 7 : Locations of velocity observations downstream of stilling basin

Photo 3 : Flow conditions in model of stilling basin (discharge 150 m³/s at FRL)

Photo 4 : Modified Dhanikhari dam (prototype)

6. CONCLUSIONS

To augment the storage capacity of spillway, dam heightening would be the most widely accepted choice to be considered. When the dam is to be heightened, the spillway and appurtenant structures need modification to have more consideration for dam safety. The dam safety issues are related to safe inflow and disposal of flood water. Hydraulic model studies play a crucial role in hydraulic design of spillway and energy dissipators. Dhanikhari dam in Andaman and Nicobar was heightened by 5 m to augment the storage capacity. Due to dam heightening, various components of spillway and energy dissipator needed modification and the efficiency of the design of modified spillway and energy dissipator was tested by conducting hydraulic model studies on a 1:25 scale comprehensive 3-D physical Froudian model in CWPRS, Pune, India. The dam was heightened in 2013 based on the design recommendations of CWPRS and the spillway as shown in Photo 4. The spillway has been performing satisfactorily during subsequent floods, as per feedback received form project authorities.

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