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Repair of Spillway and Energy Dissipater Severely Damaged By Rolling Boulders during Floods in Himalaya

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ABSTRACT

Rehabilitation of a dam is the act of restoring the distressed dam not only to its original state but also to make improvement to meet added requirements caused by changes in the safety criteria from time to time. In this paper author has described special rehabilitation measures implemented on the 40 m high concrete gravity dam constructed across a river in Himalayan region, India. The dam is located in steep, young Himalayan 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. It was also observed that distress included severe damages on all four-bays of spillway glacis, destruction of the energy dissipater (slotted roller bucket) and severe damages on the training walls. As a rehabilitation measures, 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 spillway 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 fibre and one bay without steel fibre. Bonding agent was used between the M90 concrete and the old concrete along with key cutting in the existing concrete glacis and anchors. Additionally, the left and right training walls were re-aligned and re-constructed with M60 grade concrete facing on the water side backed with M15 concrete. Other rehabilitation measures planned include construction of a stilling basin with M90 concrete on top to replace the earlier slotted roller bucket. The repaired spillway had performed well after passing floods in the last five monsoon seasons.

KEYWORDS

Rehabilitation of dams, high strength concrete, spillway glacis, repair of spillway.

I. INTRODUCTION

This hydroelectric scheme was planned to harness the energy of waters flowing down in a Himalayan River. The project was commissioned in the early nineteen eighties. The annual generation of this project is approximately 455 MU.

This comprises of: -

a) A 40 m high and 125 m long Concrete Gravity Dam across Perennial River in Himalayas which houses the spillway. The spillway was designed to pass flood of approximately 5000 cumec. It consists of four numbers of radial gates of size 13 m width & 14.55 m height each, separated by 4 m thick piers. A slotted roller bucket was provided for energy dissipation. The downstream view of 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.
c) An 8 km long and 4.75 m diameter circular concrete lined Head Race Tunnel (HRT).

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Photograph 1: Downstream view of a dam in Himalaya

d) A 70 m high and 11 m diameter underground surge shaft of restricted orifice type along with 316 m long and 6 m diameter upper expansion chamber, 89.5 m long and 6 m 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.

DETAILS OF DAMAGES

Frequent floods in the rivers of Himalayas in past decades badly damaged some hydro-electric power projects mainly in Himalayan River valleys. The spillway of this dam was also severely damaged during these floods with heavy leakages downstream from the spillway gates.

The damages observed in spillway bays no. 1 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 to 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: 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 the stoplog 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.
c) The damages in the energy dissipation arrangement and the downstream areas were mainly as under:

- The slotted roller bucket was completely damaged and was washed out (See photograph 3).
- Deep scour holes/cavities were observed in the bucket area.
- The spillway training walls were badly damaged – the damage being much more in the right training wall (See photograph 4).

Photograph 3: Cavity in Slotted Roller Bucket

Photograph 4 Damaged Training wall

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PROBABLE CAUSES OF DAMAGES

A close examination of the flow conditions in this dam reveals that the following were the major reasons of damages.

a) 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 damage to the spillway glacis, bucket, and downstream training walls of 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 towards downstream. 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 damages to spillway structure and roller bucket.

REHABILITATION WORKS CARRIED OUT EARLIER IN SPILLWAY BAYS NO. 1 & 2

Initially to arrest leakages, temporary arrangements such as caulking of gates were undertaken. After a monsoon period, comprehensive rehabilitation/repair of dam was planned by project authorities. Prior to current 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 powerhouse for a period of around a month.
b) Repair work in entire spillway glacis from 2.00 m downstream of sill beam of radial gate in running powerhouse condition.

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 – 5.
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 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 between old and new concrete.
i) Laying of concrete (Dry Crete of M80 grade) in the cavity between sill beam of stop log gate and radial gate (see photograph – 6 & 7).
j) Fixing sill beams i.e., ISMB 300 (300 x 140) conforming to IS: 2062 (E250) with 20 mm SS plate for Stop Log gates and Radial gates.
k) Laying concrete (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.
m) Grouting between steel plate and concrete through holes cut in the steel plate.

Photograph 5: (Temporary Bund for channelization of stream water)

Photograph 6: (Laying concrete in spillway bay no 2)

Photograph 7: Laying and Grouting of MS Plate in Spillway Bay no 2

To complete the repair works of spillway bays no. 1 & 2 within stipulated period, all the pre-requisites such as manpower, material etc. were arranged before the start of work. The work was taken up in 3 shifts continuously and completed within one month and the Powerhouse was restarted thereafter.

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 powerhouse 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

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M60 concrete (used for repair of spillway bays 1&2) was carried out by project authorities. The 28-day target strength of trial mix proportions for M60 grade of concrete was achieved as 68.9 N/mm^2.

REHABILITATION/REPAIR WORKS CARRIED OUT

A. 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 flood as can be seen in photograph 4. 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.

B. REPAIRS OF SPILLWAY GLACIS IN SPILLWAY BAY NOS. 3 & 4

The spillway glacis of bay 3 was repaired with M90 grade concrete with steel fibres and that of bay no. 4 with M90 grade concrete without steel fibres. 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.
- 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.
- Anchors were provided at a spacing of about 2 m c/c at the interface.
- Bonding agent was used for bonding.
- Concreting was done using shutters of size 2.5 m width and 1.25 m height.

The concrete mix design for M90 grade concrete and construction supervision of high strength concrete work was carried out by one of the reputed organizations in the country.

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

C. 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 pits 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:

- First select the scour hole / pit with the least depth for repairs, out of the three.
- After dewatering, chipping of the entire concrete surface of the hole /pit to get a rough surface, is to be carried out.
- 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.
- 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.
- Consolidation grouting of the area in the bucket portion to close any inter connections of pits and damaged rock mass with open joints etc.

D. 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:

- To provide cladding with steel plate (20 mm thick say) 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. 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.
- 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.
- 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.

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E. PROPOSAL CONSTRUCTION OF 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 an appurtenant has been proposed instead.

The spillway was originally designed for 5000 cumec. After reviewing 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. 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 m^3/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: 4997 using the tail water rating curve obtained by HEC-RAS. 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. 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.

The primary author was involved in repair works on the spillway glacis of bay numbers 3 and 4, utilizing M90 concrete and dismantling the damaged training walls and reconstructing and realigning them with M60 concrete, backed by M15 concrete. The author was a part of the Central Project Management Unit (CPMU) responsible for monitoring the quality control of the ongoing works. Quality control included casting cubes for random testing and extracting and testing concrete cores from the finished surface of the spillway glacis. Additionally, the author contributed to the hydraulic and structural design of the proposed stilling basin, intended to replace the existing slotted roller bucket-type energy dissipation arrangement.

II. CONCLUSIONS

The various rehabilitation measures carried out were:

i. For repair works of spillway glacis in bays no. 1 and 2: This was carried out by using M60 grade concrete and fixing MS steel plate over prepared profile followed by cement grouting to fill the gap.
ii. For the repair of the glacis of spillway bays no 3 & 4: This was carried out und using M90 grade concrete for the first time in India both with and without steel fibres in bay no. 3 & 4 respectively.
iii. The left and right training walls were re-aligned and re-constructed with M60 grade concrete facing on the water side backed by M15 concrete.

The various rehabilitation measures carried out in the concrete gravity dam had improved the operational performance of spillway and structural safety of the dam. Dams are major components of the comprehensive strategy to address water resource challenges posed by drought, flooding, depleted aquifers, environmental needs, energy demands, increased consumption due to population increase in India. So, it is very much necessary to survey the old existing dams and to take rehabilitation measures properly to meet water and power requirement of the country. The spillway glacis repairs with M90 concrete have withstood five 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 also expected to provide sustainable rehabilitation solution for the spillway.

DISCLAIMER

The views expressed in this paper are strictly individual views of the authors and do not, in any

way, represent the views of the department/organization where they are presently working.

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