# A Massive Chute Spillway, Partly Resting on Terrace Material - a Case Study

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**Synopsis**

*The chute spillway of Koldam HEPP was originally designed to rest completely on rock foundation. However, during excavation, it was found that a paleo channel was passing through the spillway area, which was missed during the preconstruction investigation and as a result, the rock level was present at lower levels in a stretch of about 150 meter of the spillway chute. The Project Consultant suggested a conservative solution of removing the entire terrace material and replacing it with concrete, which would have resulted in considerable cost overrun as well as time overrun of about at least one working season. After detailed analysis, the owner NTPC found that the terrace material also is having adequate strength to withstand the forces expected from the spillway operation and hence overruled the advice of Consultant and founded the spillway chute partly on the terrace material, with some confidence building measures such as confinement with curtain grouting and consolidation by area grouting.*

## Introduction

Koldam Hydro Electric Project ( 4x200 MW) has been envisaged across Satluj River , upstream of the tail race outlet of Dehar Powerhouse of BBMB, in Mandi district of Himachal Pradesh and is being constructed by NTPC Ltd. The storage structure is planned as a 165 meter high Earth & Rock fill Dam with clay core and the flood water escape is a concrete chute spillway of about 55 meter height, located by the side of the dam. The Koldam Project was originally conceived by HPSEB and after fairly elaborate geotechnical investigations; a DPR was prepared by them. However, after taking over the Project, NTPC had also carried out additional investigations in association with the Project Design Consultant, M/s EDF ,France and the DPR was updated in association with M/s WAPCOS and EDF. The General Layout of Koldam Project is presented at Fig 1.

Salient Features of Spillway

Crest level - El. 625 M

Total width of crest - 132.60 M

No. of gate bays - 6 each of 17.10 M clear span

Length of Spillway chute - 420 M

Radial gates - 17.1 x 17.3 M

Design discharge- 16500 Cumec

## The original design concept of spillway system

As per the investigation details available up to the preconstruction stage, rock was present at fairly high level and excavation of the order of about 60 to 70 meter depth in hard rock was to be carried out to accommodate the spillway chute. The above concept was adopted in the DPR, tender design, and in the construction drawings developed by EDF. The hydraulic design of spillway was validated and optimized by EDF, after conducting model studies at a Hydraulic Institute in Belgium.

## Differed Site Condition

During excavation of the spillway, in about one-third of the chute length extending to about 150 meter, rock level was found to be present at much lower level than those anticipated in the design (about 100 meter

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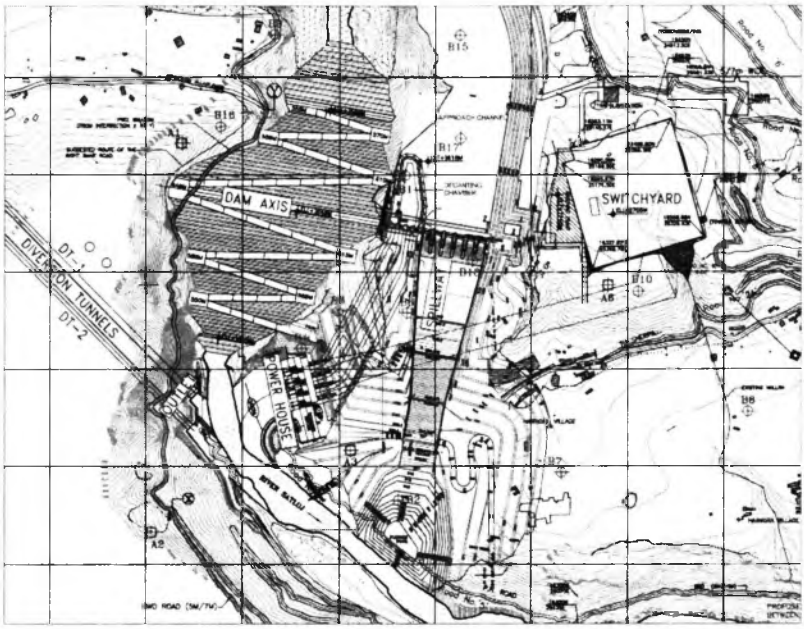


Fig. 1: General Layout of Koldam Project

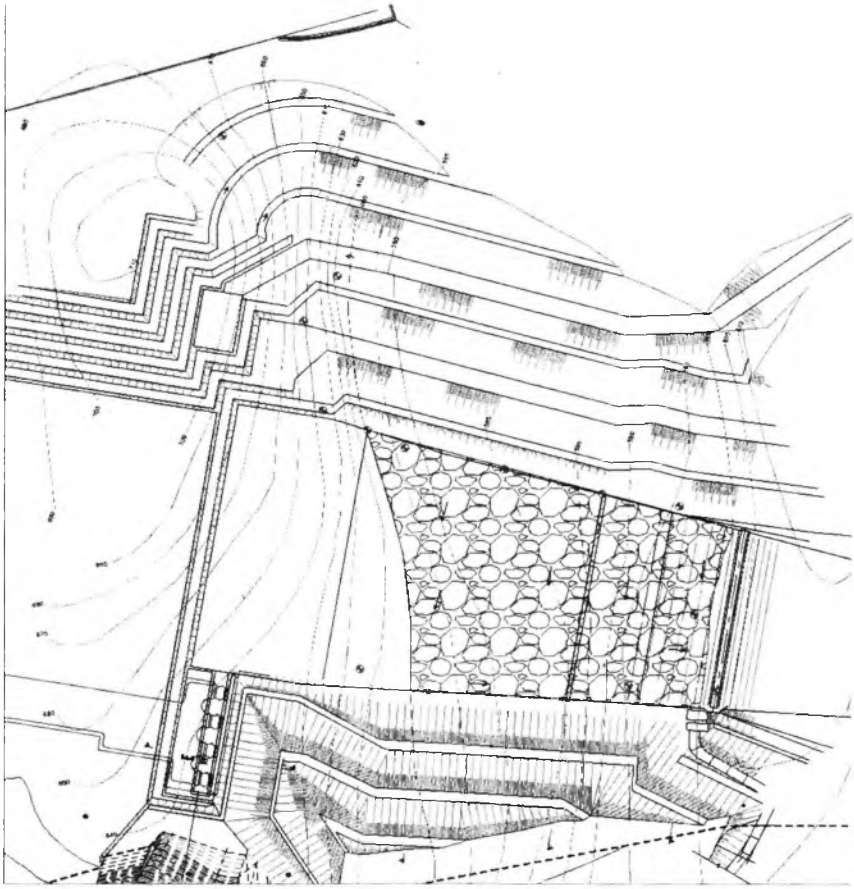

Fig. 2: Part Plan of spillway chute

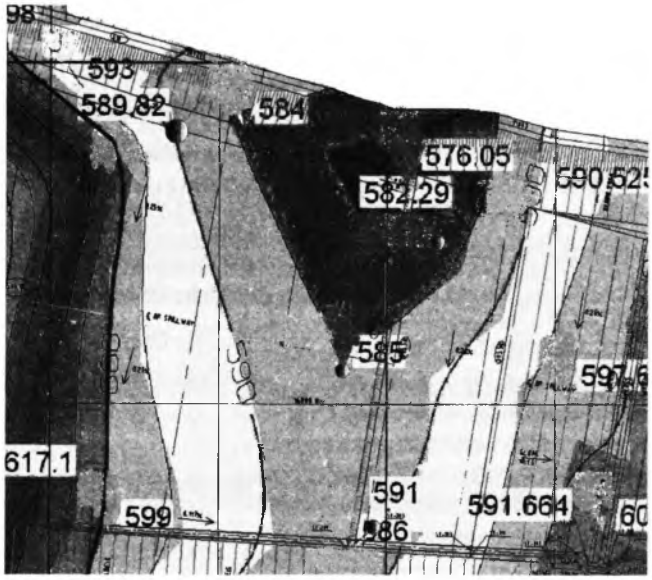


Fig. 3: Ground contours at the paleo channel portion of Spillwaycs

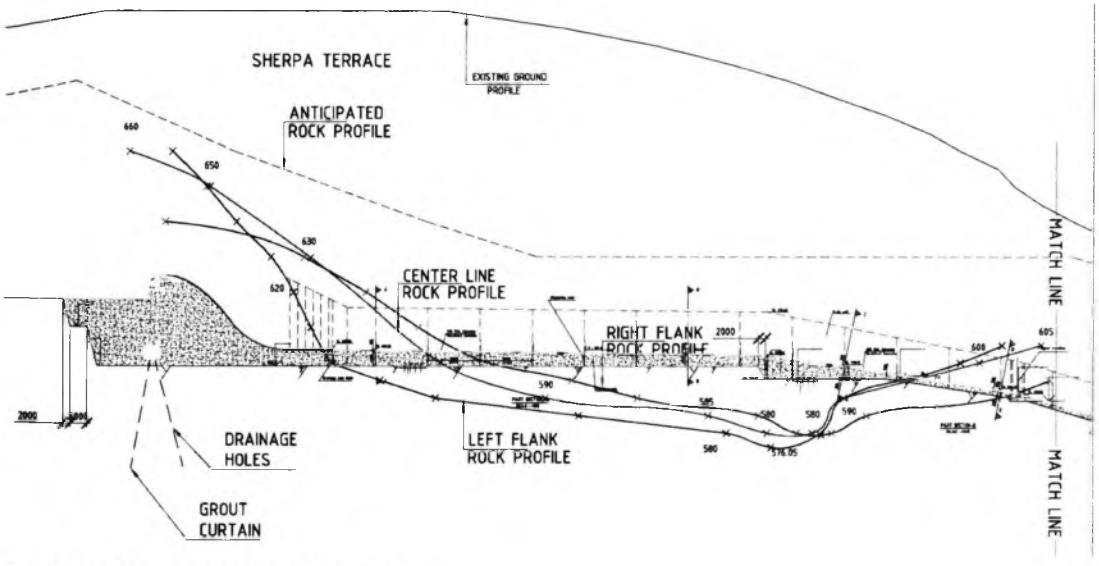


Fig. 4: Part Cross Section of Spillway

lower). On detailed examination, it was found that a paleo channel (probably the original Satluj river course) was passing through the spillway area. Additional Borings carried out in that area revealed that the rock level varied up to a maximum of about 20 meter below the spillway chute design foundation level. Figures 2, 3 & 4 indicate the plan, contour details and cross section of the Spillway at the paleo channel location. The Consultant EDF suggested excavating the terrace material right up to the rock level and to build up to the design foundation level with lean concrete. This alternative would have involved additional excavation of about 1.7 lacs cubic meter of terrace material and filling with concrete of about 1 lac cubic meter. NTPC was reluctant for such an alternative which would have involved substantially high cost overrun in addition to time overrun of at least one working season. Hence EDF was requested to suggest an alternative techno economic solution, but they kept on insisting that replacement of terrace material is the only safe solution.

## Geotechnical investigation resuits of the terrace material

Tests were conducted for determining bearing capacity, groutability, permeability of overburden material etc. and the results are summarized below:

- The overburden thickness varied from 9.50 m to 18 m.
- The permeability was in the range of 1 to $9\times10^{-3}$ cm/s.
- Density was 1.96-2.17 g/cc which denoted a relatively high degree of denseness for the overburden material.
- The Ultimate bearing capacity was more than 225 $t/m^2$.
- Fines in terrace material was about 23%
- The Gradation analysis of the particles indicated that the material resembled naturally occurring filter material and was self draining type.

From the test pad grouting, following was observed:

- Grout intake is very high.
- Grout flow under gravity only, indicating good groutability of terrace material.
- Grout intake reduces when grouting progressed from primary to secondary and to check hole.
- Reduction in permeability of terrace material subsequent to grouting.
- Traces of grout in the core recovery of check holes indicating good grout penetration

## Apprehensions raised by the Consultant

The main apprehension of EDF was the possibility of material erosion from the terrace material and consequent differential settlement of chute slab units leading to cavitation failure. They also apprehended differential settlement due to seismic action and also felt that the anchors in terrace material may not be fully effective as in rock foundation. EDF was only raising their apprehensions, but could not give any technical justification or explanation for their reservation. However, on detailed analysis, NTPC found that the properties of the terrace medium were adequate to satisfy all standard design requirements and also the design philosophy adopted by EDF for spillway design. Eminent Indian Experts also concurred with the opinion of NTPC Design Engineers, that the spillway chute slab can be founded on the terrace material without any additional treatment. However, to take care of the concern of EDF, some precautionary measures like confining the terrace material with a grout curtain and consolidating the terrace material with cement grouting were added, mainly from psychological point of view. The apprehensions rose by EDF and the analysis of those points by NTPC are briefly presented in Table 1.

Table-1 EDF apprehensions and NTPC views on them

| **Apprehension of EDF** | **NTPC views** |
|---|---|
| Differential settlement due to Seismic action | EDF has estimated P-wave velocities of 2100-2300 m/sec (for Hamora Terrace) and 2800-3200m/sec (for Sherpa Terrace). Considering a Poisson's Ratio as 0.3, the shear wave velocity works out to more than 1000m/sec for Hamora Terrace and 1400 m/sec for Sherpa Terrace deposits.<br>As per literature, Material with shear wave velocity in excess of 600 m/sec is typically classified as "rock". Therefore, the terrace foundation is expected to behave similar to rock in the case of any earthquake acceleration.<br>In view of the above, no differential settlement is anticipated due to seismic action. |
| Differential settlement due to material erosion from foundation medium due to seepage flow from reservoir. | For accommodating spillway chute, about 70-80m of terrace material has already been excavated, requiring blasting. Thus material encountered at spillway foundation level is much more consolidated.<br>Seepage may not reach the paleo channel because of the grout curtain barrier along dam axis continuing to spillway and then extending by about 200m in left abutment.<br>Even In the extreme case of any windows in the grout curtain, the seepage through windows will be detected by the piezometers located downstream of grout curtain and such leakages can be plugged by grouting from the drainage gallery.<br>RG, GSI during discussions with EDF (June '07) has opined that based on geological formations/data as encountered during spillway excavation (about 60 - 70m in depth) and other investigation data, probability of presence of any sand layer in paleo channel is remote. However, local sand pockets may be encountered which may not be detrimental from safety point of view of chute slab.<br>As the gradation of soil medium in the terrace material is satisfying the self filter criteria, no internal erosion within the terrace material is expected. |
| Differential settlement due to material erosion from foundation medium due to leakages through chute slab joints as a result of failure of water stops. | As an additional precaution, two layers of water stops have been provided in the terrace area against only one layer on rock foundation.<br>To avoid apprehension of differential settlement, keys have been provided below the chute slab, at joints as suggested in IS Code, for spillways resting on soil. |
| The anchor rods provided in terrace medium will be less effective, compared to anchors in rock/ concrete medium | As per the model studies carried out at Belgium by EDF, no uplift/ negative pressure have been observed under any flow condition.<br>An elaborate sub-surface drainage arrangement consisting of drain holes downstream of grout curtain, 200mm thick no fines concrete and a network of half pipes of 400 mm dia. has been provided which will prevent development of any uplift pressure. Also no uplift force has been considered in the design by EDF on account of drainage system. Even if some uplift develops, the thick chute slab of thickness varying from 3.3m to 4.0m, can withstand the same.<br>Anchors of 25mm dia 3m long at spacing of 1.5m c/c (Staggered) will also develop some strength due to frictional resistance. |

## Final arrangement adopted.

After very elaborate examination and deliberations within NTPC and also after many interactions with eminent experts , NTPC concluded that the terrace material is having adequate bearing strength, erosion resistance , denseness etc. to support the loads expected to be transmitted by the spillway chute and overruled the advice of

EDF, France to replace the terrace material with concrete and finally decided to found the spillway chute slab on the terrace material present at the original design foundation level.

As an abundant precaution (to take care of apprehension of movement of fines) terrace material was grouted, as under

- Two rows of curtain grouting extending up to rock level, along both left and right chute training/ retaining walls to provide confinement.
- Area grouting in the confined spillway zone.

  Based on the results of test pad grouting, the final procedure for grouting of terrace medium was formulated as follows:

- Curtain grouting to provide the confinement to terrace material below chute slab and area grouting to provide the binding effect between the soil grains, in addition to reduction of voids. As such, the grouting will take care of apprehension of movement / erosion of fines.
- Grouting to be performed backward i.e. from bottom to top in stages of 3m each.
- Each stage shall be grouted in various steps with grout mix having cement water ratio varying from 1:1 to 1.2:1, 4% bentonite, 3% sodium silicate and fine sand varying upto10% depending upon the grout intake.
- Max. Grout pressure of 0.018 MPa per m of overburden.

The construction of spillway chute slab in the terrace portion has been completed on the above lines.

## Acknowledgements

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