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Strategies and Learnings in Execution of Filter works with Manufacture-sand in an Earth and Rock-fill Dam

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Abstract. The Main dam of Koldam is an 167m high earth and rock-fill dam with impervious central clay core having crest about 500 m long and 14 m wide with base width of 730m. The project area lies in zone-V as per the seismic zonation map of India. The upstream cofferdam is 60m high rock-fill dam and is integrated with main dam. The dam has been constructed using about 126 lacs m^3 of ten types of different earth materials viz, impervious clay, filter and other fill materials. The required quantity of filter material in dam construction was about 8.5 lacs m^3. To achieve economy and constructional advantage, the quartzite material available in the project vicinity was explored for use as filter material. During exploration as well as execution of filter works in dam, it posed various challenges which were overcome with proper strategies as described in detail in this paper without compromising on the specification requirements.

Keywords: Koldam, Main dam, Quartzite quarry, Filter material.

1 Introduction

The Koldam is an earth and rock-fill dam with a clay core flanked by filters on both upstream and downstream sides, followed by shell and riprap material. This is constructed across river Satluj in district Bilaspur (Himachal Pradesh) and provides a live pondage of 9000 Ha-m (90 Million m^3) between Full Reservoir Level (FRL) at El.642.00m and Minimum Draw Down Level (MDDL) at El.636.00m. The pondage reduces to 500 Ha-m after 30 years of operation due to silting. The height of dam above the deepest foundation level is 167 m. The project area lies in zone-V as per the seismic zonation map of India.

2 Earth & Rock-fill Dam

The Main dam of Koldam is an earth and rock-fill dam with impervious central clay core having crest about 500 m long and 14 m wide with base width of 730m. The upstream cofferdam is 60m high rock-fill dam and is integrated with main dam. The dam has been constructed using about 126 lacs m3 of ten types of different earth materials viz, impervious clay, filter and other fill materials. The general layout of the

Koldam project is shown following Fig.1 and the typical cross-section of the dam is shown in following Fig.2.

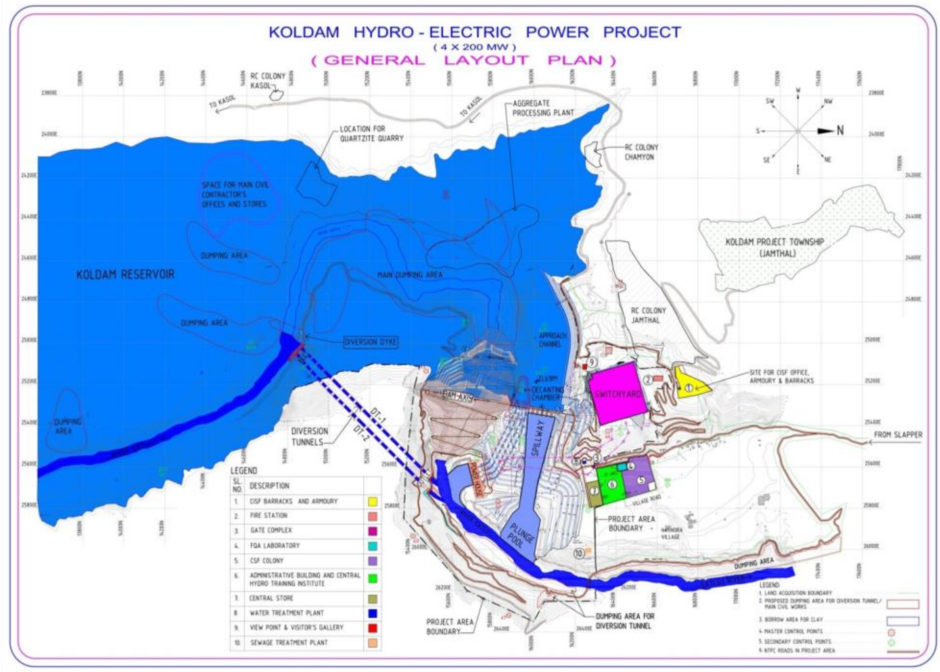


Fig. 1. General layout of the Koldam project.

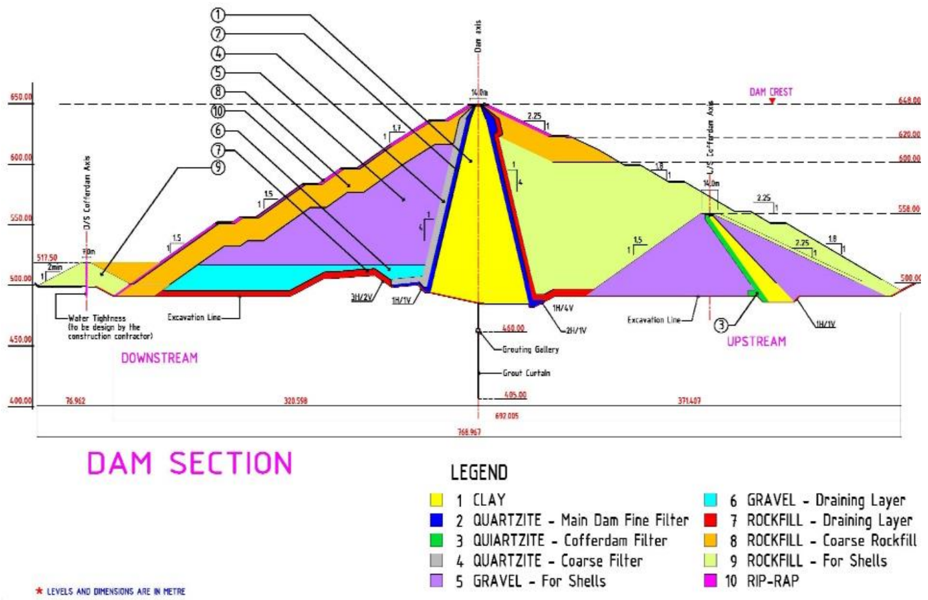


Fig. 2. Typical cross-section of main dam.

3 Manufacture sand (M-sand) as a filter material

The required quantity of filter material in dam construction was about 8.5 lac m^3. The quartzite material available in the project vicinity was explored for use as filter material based on the following requirements:

1. The role of the filters in a multi-zone earth-fill dam is (i) to ensure the transition between materials with different gradation and (ii) to prevent the internal erosion in case a water path occurs through the clay core.
2. Filters are selected to be cohesion free, in order to avoid the development of cracks through the filters which could lead to major leakage and piping

3.1 Identification of quartzite quarry

Based on the geological information and results of few basic tests conducted on loose rock samples collected from the quartzite quarry which was on the left bank, upstream of the dam, it was decided to make selected number of drill holes at the quartzite quarry so as to collect rock core samples and prepare logs of boreholes. These rock core samples were subjected to various laboratory tests. This information was to be used in exploiting the quartzite quarry. The preliminary laboratory tests conducted on rock core samples were as follows:

- Unconfined compressive strengths
- Specific gravity
- Water absorption
- Petrographic examination
- Slake durability index
- Soundness
- Los Angeles

Based on the above test results and after fulfilling the required criteria, the locations and depths of quartzite quarry was decided and earmarked for further investigation.

3.2 Investigation programme

The investigation programme was formulated to assess the suitability of the quarry for further exploration of filter material. Minimum 5 drillings were carried out as part of investigation requirement in the suitable excavation area. The depth of the drilling was fixed as to be at least the expected thickness of the excavated zone. The drilling pattern was programmed considering the geometry of the quarry area. For every core sample, unconfined compression strength, water absorption and specific gravity was to be measured. Amongst all the samples, some shall be selected for carrying out further tests as follows:

Table 1. Details of tests to carried out on core samples.

Test	Minimum number
Petrographic examination	5
Slake durability Index	5
Resistance to freezing and thawing	5
Soundness	3
Sonic monitoring	10
Los Angeles	10

3.3 Assessment of suitability of quarry material

The filter material shall be processed from the suitable quarry and shall include particles coming from the un-weathered, sound, durable and strong rock. Particles shall have a shape factor (maximum dimension to minimum dimension) higher than 2. They shall remain free draining at all times and have permeability not less than 10^{-2} m/s (for coarse filter) and $5x10^{-6}$ m/s (for fine filter). Further, the following required criteria to be met by the selected filter material.

Table 2. Criterias for selection of filter material.

Test	Criteria	Value
Unconfined compressive strength	UCS or RCS	> 100 MPa
Specific gravity	Gs/Gw	> 2.56
Water absorption	w	< 4.5%
Petrographic examination	-	No clay
Slake durability Index	-	>90 %
Resistance to freezing and thawing	-	insensitive
Soundness	-	< 12 %
Sonic monitoring	Ic	> 80
Los Angeles	-	< 30 %

Filter criteria

The base soils used in earth dam construction contains more portion of silt and clay compared to sandy soils found in riverbeds and some base soils in earth dams are also broadly graded or gap graded. For allowing smooth passage of seepage without buildup of excessive pore water pressures and preventing erosion of base soils following filter criterias were used in respect of base and filter materials and only after fulfilling the mentioned filter criteria, the filter materials of different zones were finally placed on the dam for spreading and compacting.

- $\frac{D_{15} \text{ of filter material}}{D_{85} \text{ of base material}} < 4 \; or \; 5 \; (to \; prevent \; piping)$

- $\frac{D_{15} \text{ of filter material}}{D_{15} \text{ of base material}} > 4 \text{ } or \text{ } 5 \text{ } (to \text{ } ensure \text{ } adequate \text{ } permeability)$
- $\frac{D_{50} \text{ of filter material}}{D_{50} \text{ of base material}} < 25 \text{ } (paralled \text{ } gradation)$

Further, the filters must remain cohesionless so that no tendency to crack exists even though an adjacent core zone may have been damaged by cracking. To ensure this, filters are to have a maximum particle of 75mm and a maximum of 5% passing the 0.075mm sieve with the plasticity index (PI) of the fines equal to zero. PI is determined on the material passing the 0.425mm sieve."

Grain size distribution

The grading of the materials either stocked and un-compacted or compacted in place shall be checked such that they are within the following range:

Table 3. Gradation range of different filter materials.

Sieve Size	Material 2 Main dam fine filter		Material 3 Cofferdam filter		Material 4 Main dam coarse filter	
	Grading 0/8 mm		Grading 0/30		Grading 0/60	
	Upper	lower	upper	lower	upper	lower
80 mm			100	-	100	-
20 mm	100		60	90	74	100
4.75 mm	90	-	15	45	18	54
2 mm	60	100	5	25	0	20
0.425 mm	20	50	2	10		5
0.075 mm	0	5	0	2		2

4 Execution methodology

4.1 Temporary storage

The temporary storage at stockpile shall be protected from any kind of contamination (clay, mixing with other material, sediment from flood, dust etc).

4.2 Placement during filling

The filters are to be placed by dumpers, spread by back-hoes parallel to the clay core, and compacted by roller compacters. The filters are placed with moisture content close to the water content of saturation. A procedure to be evolved to avoid segregation during filling process. This procedure shall describe the manner in which material is handled from the processing plant. Filter to be placed with such a thickness that the compacted thickness is similar to the thickness of the core. The following sequence of placement was adopted at the interface of clay core and filter to minimize contamination in the filter material:

- For trimming the compacted clay core the backhoe (EC-210) fitted with appropriate blade shall be operated from filter zone.
- For levelling the filter material and pushing the same towards the compacted clay core slope the backhoe has to be operated from filter material and on any account no vehicular movement on filter material shall be allowed so as to control the relative density of filter material within the specification requirements.
- After levelling, the recommended compactor alone be allowed for achieving the required compacity.

4.3 Compaction

The compactor used was a vibratory roller with following specifications.

- Linear weight of drum between 30 and 45 kg/cm
- Drum diameter higher than 1.2m
- Frequency lower than 25Hz
- Vibration amplitude higher than 1.4 mm
- Centrifuge force higher than 220 kN
- Speed less than 3 km/h

The test section shall check that the filters be compacted by adequate passes of roller with a target lift thickness similar to the lift thickness of the core. However, the maximum lift thickness shall be limited to the thickness of 2 layers of clay. The layers to be compacted to achieve the specification requirements.

4.4 Protection

During placing and filling operations, any kind of contamination of the filter shall be prevented. Any contaminated material shall be removed from filling. Additional attention is required to the protection of the filter crossed by the tracks to prevent contamination. The removable steel bridges for crossing the filter may be used for protection of filter material. The geotextile/ plastic sheet shall be laid underneath steel bridges.

Further, protection nets are to be installed above the left and right bank of the filter in order to prevent pollution by the abutment treatment works and cleaning above the executed layers.

5 Challenges during execution of filter works with Manufacture – sand (M-sand)

Results of various laboratory tests viz. grain size distribution (wet as well as dry sieving), sand equivalent and permeability tests conducted on filter material needs to be continuously checked. In case fines are present, possibility of migration of those fines within the fine filter zone may not be ruled out. Migration of fines within the filter zone is bound to create an impervious and cohesive zone (within the filter zone). This necessitates that representative material from the freshly manufactured sand is checked at regular interval for gradation by wet sieving and not by dry sieving. Further, based on the gradation, if the material passing the 75-micron sieve is found within limit, the material is accepted for transportation to the dam site for placement. If the percent of fines is found more than specified limit, the material is reprocessed in the washing arrangement in the crushing plant.

5.1 Challenges during quarry exploitation

While exploiting the quartzite quarry, off and on clay seams and silty materials were encountered and as such the blasted materials were containing fine materials well beyond the allowable limit. Due to this, while loading the blasted material, the power shovel operator has to avoid the loading of fine material and the operator has to load only the solid rock material for transportation to the crushing plant. The observed geological features in the two quartzite quarry is as follows.

Challenges at first quartzite quarry

The main geological features close to first quartzite quarry area consist in a smaller fault inside the quartzite and a large fault between quartzite and dolomite where an important thickness of breccia and mylonite is observed at the contact between the two formations. The same is indicated in following fig.3. Both of these faults seem to have the same orientation (approximately N-S) and seem to dip nearly vertically. Between these two faults, quartzite appears to be highly jointed and sheared, but the core boreholes have shown an improvement of the rock quality below 15 m depth. Considering the height of dam and use of filter material at varying levels, the compressive load on filter material will vary. However, it was felt necessary to ascertain the Unconfined Compressive Strength (UCS) values as per requirement and availability. Accordingly, UCS more than 100MPa was adopted for filling below El.600m and UCS less than 70MPa was allowed for filling above El.600m of dam.

To finalize the volume of quartzite compliant with the filter quality requirements, the geological mapping and geological cross sections of the area, including the location of the faults (with their dipping), the contours of the various geological formations, location of the boreholes etc was analyzed in detail.

Fig. 3. Geological features at first quarry.

Challenges at second quartzite quarry

A second quarry for the extraction of quartzite was also explored in adjoining project area for required filter material. The site consists in a rock ledge which is located between the quartzite rockslide area and the place where quartzite is surrounded by an old consolidated alluvial terrace having slope stability problems.

The rock ledge is strongly affected by slope effects (toppling, distressing, weathering) and it is possible to perform the extraction with a shovel only (without blasting). Thus, the quality of the quartzite seems to be lower compared to the previous quarry (where sound quartzite was extracted with blasting).

5.2 Challenges during crushing and screening

While crushing the quartzite which is very hard and tough material, the jacks used for initial crushing got damaged very frequently and as such the jacks were replaced resulting in non-achievement of the required quantities of filter materials for placement at the dam site. Further in the absence of sufficient quantities of these filter materials, placement of clay core materials also got affected. This necessitated for additional crushing plant to increase the production of filter material to meet the overall progress in the construction of the dam.

5.3 Challenges in controlling fines during crushing

In the quarry, it was difficult to completely remove overburden material consisting of vegetation, soil and weathered material. So, just after the jaw-crusher a screening machine was necessitated to remove contaminated and other unwanted material, in order to produce filter materials, which shall meet the specification.

To satisfy the grain size distribution of the filter materials with the base material (impervious clay) so as to achieve the required filter criteria, the aperture openings of various sieves provided in the crushing plant were adjusted during the initial stages of crushing.

Even though adequate control was maintained while collecting the solid quartzite material, excessive fine materials were produced during crushing. This necessitated additional spraying of water so as to achieve that the presence of fines well within the allowable limit of specification.

5.4 Challenges in controlling the clay fines

The results of grain size distribution and Atterberg limits tests of 17 samples collected from different layers of filter material, out of these 17 samples, in as many as 14 layer samples, PI values are found to vary from 5% to as high as 11% even though the percentage of fines (passing 75 micron sieve) are reported to be around 5%.

With the above PI values, it was concluded that the filter material selected for the dam contains plastic fines which, despite complying with the specifications in terms of gradation, are bound to affect the safety of the dam because of their plasticity particularly during reservoir operations.

As a consequence, considering the entire stockpiled material is contaminated with plastic fines resulting in high PI values, it was not desirable to accept the filter material only based on grain size distribution and permeability tests results. It necessitated that the selected filter material requires Atterberg limits test also. Based on the observed PI values, it required additional efforts to achieve the filter materials are free from plastic fines. To ensure that the washing of filter material was advised and it was suggested that the grain size distribution test has to be carried out on representative layer material by wet sieving and not by dry sieving. The stock pile material required through washing under strict supervision so as to achieve that filter material is free from plastic fines.

Finally, it was concluded that the placement of only non-plastic filter material is to be ensured. However, in case of emergent situation, filter materials with low plastic fines was allowed, subject to the condition that the PI of the material placed is not more than 4%. In case the PI of the layer material placed is found to be more than 4%, the entire material of the layer under reference shall be replaced with fresh filter material with PI between 0% and 4%. Further, to overcome problems due to contamination in the stockpiled material, following measures were adopted.

- To increase the water pressure/number of outlets in the form of jet and also deployment of additional JCB excavators for meeting the day-to-day filter material requirements with zero plastic fines.

5.5 Challenges in controlling the heterogeneity in the material

In the existing stockpile, it was necessitated to homogenize the material using the backhoe bucket to cut and rotate the material from top to bottom. The homogenized material shall then be checked for gradation before the material is transported to the dam site for placement.

5.6 Challenges in foundation preparation

Some continuous open joints were observed along the left/right bank abutments of dam. All these open joints and shears have to be caulked and filled properly with mortar / concrete, in order to avoid any potential migration of fine filter material inside these joints.

5.7 Challenges in using alternative material (limestone) above phreatic line

Due to the rockslide in the quartzite quarry, about 1 lakh cubic meters of quartzite was short for making the filters of the dam. The other sound materials found in the project vicinity were limestone and dolomite, which was suggested to be used as alternative material above phreatic line. However, the design consultant suggested not to use these materials for filter stating that international dam organizations recommend avoiding the use of crushed limestone or crushed dolomite for dam filters.

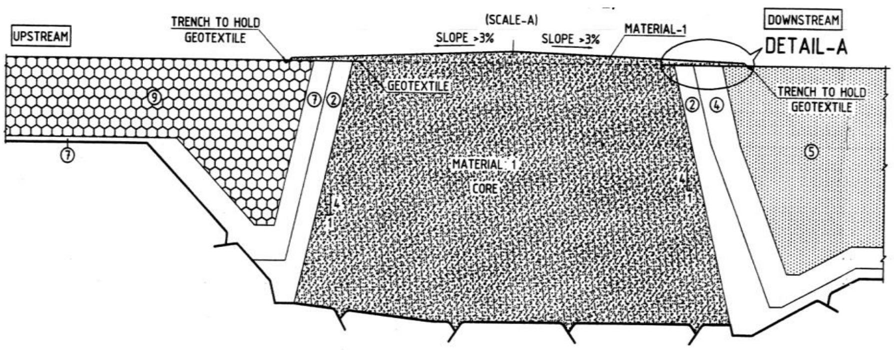
The main concern with the use of limestone is the risk of formation of calcareous concretions due to water passing through the filter and evaporating. Such concretions are likely to create cohesion between the rock grains, which is not desirable in a filter. In the downstream filters, localized water paths can occur and can create localized calcareous concretions, leading to cohesive zones where cracking can occur. Rainfall is also a source of humidity and water flowing across the filter.

The phreatic line in the downstream filter can be defined in normal operation conditions but cracks in the clay core can occur at any elevation. In particular, transversal cracks often occur at the dam crest due to the differential settlement of the clay core between the abutment and the dam centerline. Cracks might also occur in case of seism (amplification effect). Such cracks create direct water paths from the reservoir. At these locations, internal erosion initiating from the dam crest can be avoided only if the downstream filters are efficient, i.e. if they are not cohesive. This is the reason why the downstream filters shall be made with quartzite up to the crest, and not only up to the level of the phreatic line.

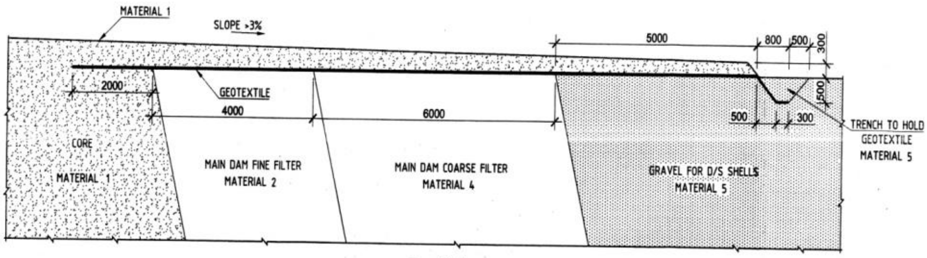
Due to above, the big boulders obtained from terrace material was crushed as an alternate option (because the boulders were mainly composed with quartzite) and screened in order to meet with the gradation specifications for filter material.

5.8 Challenges during monsoon

Just before the onset of monsoon, the compacted filter has to be protected from runoff and rainfalls to prevent filters contamination with other materials and choking. The entire surface of the filter was protected from contamination during monsoon by covering the same with large size geotextile just to allow the rain water coming from the core to flow into the shell without contaminating the filters. The typical arrangement of surface protection is shown in following fig.4 and fig.5.



Typical Section of Main Dam indicating Geotextile



Detail-'A'

Fig. 4 and Fig. 5. Typical arrangement of protection of filter layers using Geotextile

At the same time, proper drainage systems along each abutment and fill surface of the shells were provided in such a way that runoff water is discharged toward the exterior zones with the highest drainage capacity.

Additionally, during monsoon period it was practiced that even with occurrence of clear weather conditions for several days, the protected filter materials shall not be opened up for placement of new layers because it would be extremely difficult to protect the filter materials in case of sudden downpour. After the end of monsoon season and before resuming the filling, the material laid on slope is removed, geotextile is taken out and material layer is tested at suitable locations to see that the material has the properties as per technical specification. Even with protection measures, the filter material gets contaminated during the rainy season. As a consequence, at least 20cm to 30cm of material from the existing level should be removed and treated as waste material. Further, the stockpiled materials are also properly homogenized by making vertical cuts from top to bottom and rotating the same using heavy duty backhoe shovel and then the homogenized materials be checked for specification requirements.

5.9 Challenges in protection of filter from crossing road over the filters

Stock piles of various materials as well as filter/ material processing plant were located in reservoir area upstream of dam and clay from borrow area was being transported to dam site from downstream of dam. This necessitated crossing of filter by dumpers. For crossing the filter initially, a temporary movable steel bridge was provided as road crossing. In addition, the geo-textile was placed for the protection of the filters below the steel bridge. The movement of heavy dumpers / dozers over the filter was restricted to avoid uneven as well as over consolidation of already compacted layers.

Further, for crossing road over the core and filters, 14m wide and 1.8m fill (1.0m thick clay core material covered with 0.8m thick rockfill material) was placed over geotextile. After removal of road, the filter material was tested and if found unsuitable, the material was removed. The crossing road over the filter is shown in following fig.6.

Fig. 6. The crossing road over the filter zone

6 Conclusion

Results of various laboratory tests viz. grain size distribution (wet as well as dry sieving), sand equivalent and permeability tests etc conducted on filter material needs to be continuously checked at all stages. During execution of filter works, it posed various challenges which were overcome as described in detail without compromising on the quality of filter material as specified in the technical specification.

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