Compaction of filter on power channel slopes of Ghazi-Barotha hydropower project

Compactage du filtre (sableux) des paroies inclinees canal d'ameneé du projet hydroélectrique de Gazi-Barotha

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ABSTRACT: Ghazi-Barotha Hydropower Project situated near Attock, Pakistan includes a 52 km long, 1,600 cumecs capacity concrete lined power channel. Underdrainage system under the channel lining has been provided in most of the reaches to ensure that the lining is not subjected to uplift pressures. This drainage system comprises laying of sand filter blankets on channel slopes and bed.

The compaction of sand filter layer on 1V:2H side slope of the channel posed practical problems. Initially concrete lining machine was used to place and compact filter on channel slope, the attempt was unsuccessful as vibratory pokers, good for compaction of concrete, would not compact the filter to the specified relative density of at least 70 percent. Subsequently, heavy vibrating roller being used for compaction of the same filter in the channel bed was tried. The roller was used up and down the slope and in different directions but again the required compaction could not be achieved as the 15 cm thick layer of sand filter compacted during one pass would get disturbed during the next pass. After trying various techniques, required compaction was finally achieved using light weight rollers working through Yo-Yo system.

INTRODUCTION

Ghazi-Barotha Hydropower Project is a run of the river project being built on river Indus in Pakistan. It is presently under construction and is scheduled to be completed in year 2002. It has a peak generating capacity of 1,450 MW and will produce an average annual energy of 6,600 GWh.

The project consists of three main components:

- a barrage located about 7 km downstream of Tarbela dam to regulate the daily discharges from Tarbela and divert water into,
- a 52 km long power channel to convey up to 1,600 cumecs of water to,
- a power complex, comprising a forebay, two headponds, spillway, a 1,450 MW capacity powerhouse and a tail race channel to return water to river Indus.

The layout of the project is shown in Figure-1.

The power channel is concrete lined and runs along left bank of Indus river at a uniform gradient of 1:9600. It has a water depth of 9 m, a base width of 58.4 m and side slope of 1V:2H. Channel is mostly in cut with a maximum cut of about 40 m. Figure-2 shows a typical section of the power channel.

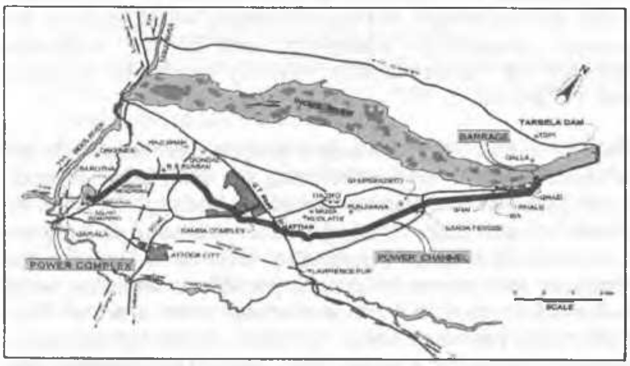

Figure -1 Project layout plan

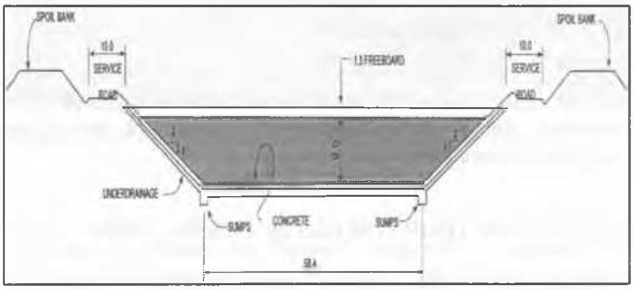

Figure - 2 Typical cross section of power channel

In reaches where ground water is above the invert level of channel, the thin (135 mm thick) concrete lining is susceptible to rupture due to external hydrostatic pressure. In these reaches and where ground water can rise above invert in future, underdrainage system has been provided under the lining to ensure that it is not subjected to uplift pressure. Underdrainage has been provided for a length of about 38 km out of the total length of 52 km.

The drainage system includes sand filter blanket on channel slopes as well as on bed. Compaction of sand filter on slopes proved to be problematic and could not be achieved by the method proposed by the contractor in his method statement or by the compaction methods generally used for various fills, and the available compaction equipment. Extensive trials were then conducted using different techniques to find the best method to achieve the required density. Search for precedents on compacting filters on slopes for other projects throughout the world was also conducted. Alternatives such as cement stabilised filter were also investigated.

DETAILS OF THE UNDERDRAINAGE SYSTEM

Power channel underdrainage arrangements consist of drainage blanket on slopes and bed with slotted uPVC pipes within the bed filter. Seepage collected in filters is communicated by side collector drains under gravity to sumps, where water is pumped back into the channel.

Drainage blanket consists of a single layer filter, thickness of which is 150 mm on slopes and 300 mm on bed.

FILTER GRADATION AND COMPACTION REQUIREMENTS

Two types of filters have been specified, i.e., fine filter designated as F1 for silty and clayey base soils and coarse filter F2 for sandy and gravelly base soils. Gradation of the two types of filters is shown in Figure-3. Discussion in this paper is confined to fine filter F1 used in majority of the reaches.

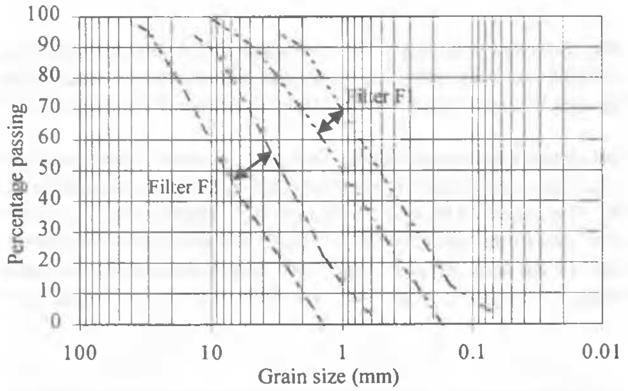

Figure -3 Filter gradation limits

Specification required filter material to be compacted to a minimum relative density of 70 % with two third density test results to be more than 80 %.

SPECIFIED METHOD FOR FILTER COMPACTION

Vibratory roller with minimum static weight of 12 tons was specified for all project fills. For compaction of filters on slopes, concrete lining machine, was allowed provided contractor could demonstrate that required compaction is achieved. Contractor was also at liberty to propose any other compaction device for approval of the engineer.

Moisture content appropriate to the compaction equipment was to be used.

In his method statement submitted with the tender, the contractor opted for use of concrete lining machine for placement and compaction of filters on slope with extra rolling on bed.

INITIAL TRIALS

Contractor's concrete lining machine was equipped with internal tube type vibrators. This machine was used to place and compact the filters. Trials were started with saturated filter on the basis that this will make the material like wet concrete and, therefore, would be compacted by internal vibrators. The trials showed that this amount of water was quite excessive and that water content close to the optimum yielded better results. However, at low moisture content the immersed vibrator motor on filter placing machine would heat up and burn out quickly. Relative density achieved with the lining machine generally ranged from 35 to 50%, i.e, much below the minimum required relative density of 70%. Various modifications to the lining machine were attempted to improve the compaction of the filter such as re-orienting and placing the vibrators at closer spacing. This resulted in only slight improvement to the compaction.

It was concluded that internal vibrators are only good for compaction of wet concrete which gets plasticised and liquefied due to high frequency. Compaction being achieved in case of filter was merely the result of drop of the material from the feeding belt and self imposed load of the weight of the material in the lining machine concrete bin. The lining machine itself adds very little reduction in volume if any as it passes over the filter layer.

Required compaction of filter on level portion of channel invert could also not be achieved using lining machine alone. However, after placing filter by lining machine on the bed, required compaction was achievable by 2 to 4 passes of 12 tons vibratory roller.

The 12 ton vibratory roller was also tried on side slopes with the aid of a dozer and a winch located at the top of the slope, but specified compaction could not be achieved. The roller would compact satisfactorily when moving up the slope but displaced the soil when travelling downwards.

OTHER OPTIONS

After the failure of envisaged compaction methods, i.e, by lining machine and the 12 ton vibratory roller moving up and down, some other options for satisfactorily placing the filter on slope were also tried as described below:

Longitudinal movement of the roller: Since downward movement of roller would disturb the already compacted material it was decided to use the roller longitudinally on slopes parallel to the axis of the canal. The 12 ton vibratory roller was suspended over the slope by a dozer mounted with winch at the top of the slope. This resulted in improved compaction, however, co-ordination between the dozer and the roller was problematic and roller would be pulled off the course damaging the previously compacted material.

Use of Vibrating Plate: Contractor also tried using vibrating plate. Filter was placed on the slope with lining machine and compacted with a vibratory plate trailing the machine. Plate was 1.2 m x 2 m size and 25 mm thick. Two counter weights with two 4 kN external vibrators were used. Total weight was 87 kg. Some improvement in compaction level was achieved with an average relative density of 60 % still less than the required minimum density of 70 %.

Cement Stablised Filter: In view of failure to achieve the specified compaction of filter on slopes, the contractor proposed a cement-stabilised filter with 1-2 % cement. The stablised filter would be mixed in pug mill or other suitable plant and then placed by lining machine at low relative density, i.e, around 15-20 % as compared to specified 70-80. It was argued that addition of cement makes continuous placement feasible and facilitates the placement of waterstops and reinforcement. The cement would provide strength and the low density would facilitate the required permeability. Laboratory tests by the contractor indicated that the permeability would be acceptable, i.e, more than 10^{-2} cm/sec.

The low relative density of sand requires cement to provide the inherent strength to support the lining and water in the channel. It was feared if cement losses strength by leaching, there will be a risk of settlement of lining due to the collapse of grain structure of the filter. Permeability tests carried out by the contractor showed that leaching is possible as inflowing water had a pH of about 8.2 and outflowing water a pH of 12.4. Further, no precedent could be found demonstrating use of cemented filter for a canal filter layer. The proposal was, therefore, dropped.

SEARCH FOR PRECEDENTS

After failure to achieve the required compaction of filter on channel slopes with the available compaction equipment worldwide search for precedent on compaction of filters on slopes was made. The following information was collected:

- There are several canals in United States of America (USA) where filter blanket had been compacted on slopes even steeper than 1V:2H, to a relative density of above 70 %. Table-1 gives summary of the available data for these canals.
- 12 ton vibrating roller is rather heavy for the job of compacting only 15 cm of filter material.
- Relatively small, light weight, smooth drum vibratory roller is more appropriate for compaction of filter on slopes. Vibration should be only upslope.
- Two small vibratory rollers working up and down in a Yo-Yo system is the most successful method of compacting filter on slopes.

Table - 1 Summary of filter compaction on slopes for various projects in USA

Project Title	Slope Gradient	D_{15} of Filter (mm)	Thickness	Relative Density	Compaction Method
Grand Coulee feeder canal	1.5H: 1V	0.60 to 0.12	3inch	>70%	Small vibratory rollers working in Yo-Yo system
Central Arizona project	1.5H: 1V	0.60 to 0.12	5inch	>70%	Winching smooth roller up and down
California aqueduct		0.60 to 0.12	5inch		Lining machine
Several canals in state of California (main aqueduct)	1.5H: 1V	Concrete Sand		>70%	Small vibratory rollers working in Yo-Yo system

ADOPTED COMPACTION METHOD

Based on the precedents of successful compaction of filters on slopes, it was decided to use small vibratory rollers in Yo-Yo technique. Step by step procedure adopted for placement and compaction of filters on slopes for the Ghazi-Barotha Power Channel is given below:

1. Filter material was obtained from natural sand sources.
2. The material was processed as a mixture of $1/3^{rd}$ washed and $2/3^{rd}$ unwashed sand before stockpiling.
3. The slope surface was trimmed with trimming machine to filter laying level and sprayed with water immediately before placing filter material.
4. Filter material was laid with lining machine continuously loaded by means of blow-knox which was fed by trucks. The machine laid 15 cm layer of filter on slope and 10 cm on bed. The remaining 10 cm thickness of layer on bed was later laid by means of trucks and spreaded by graders.
5. Compaction of filter placed on slopes was done by means of two 2.7 ton vibratory rollers working simultaneously with the Yo-Yo technique. The two rollers were tied together on front part with two steel wires and driven up and down (Yo-Yo) by means of a side beam attached to a dozer as shown on Figure-4. Figure-5 is a photograph showing compaction of filter being carried out on power channel slope by 2.7 ton vibratory rollers working in Yo-Yo system.

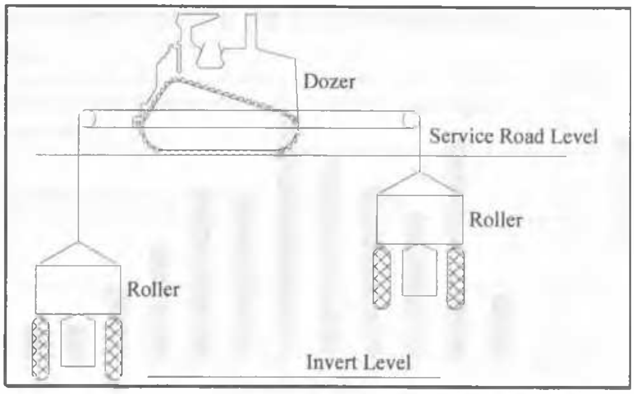

Figure - 4 Schematic diagram of rollers in yo-yo system

Figure - 5 Compaction of filter on power channel slope by rollers working in yo-yo system

6. Generally the required compaction was achieved with 6 number of passes. Vibration was used once, i.e., only on 2^{nd} upslope pass with no vibration on the downward passes.
7. On invert the first layer of 10 cm was compacted by 12 tons vibratory roller. Generally 2 vibratory passes were enough to achieve the required density. The compaction of second layer of 20 cm was done by 2.7 ton roller by applying two vibratory passes.

SOME OBSERVATIONS ON THE ADOPTED METHOD OF COMPACTION

1. The successful use of the Yo-Yo technique is dependent on the careful and controlled operation of the rollers. Smooth travel, no jerks and consistent speed are key to success.
2. Difference in compactibility was observed between material from different sources although the grading was the same and there was little difference in particle shape and mineralogy.
3. Increase in percentage of silt content (variation within the specified range of 0-5 %) improves the compactability.
4. Moisture content has significant influence on compaction and optimum value was found to be around 6 %.
5. The maximum particle size of the material does not appear to significantly affect its compactablity.
6. Histogram of relative density test results for a section of power channel is shown in Figure-6.

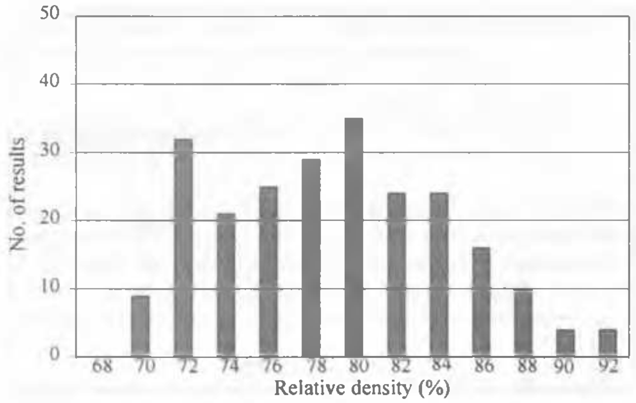

Figure - 6 Histogram of relative density test results

SOME OTHER RELATED ISSUES

Relative density control of compaction: Relative density control of compaction is very sensitive and careful field and laboratory testing is required. Slight variation in density value can make significant changes in relative density value. Table 2 shows relative density values corresponding to two sets of maximum/minimum density test values carried out on material of similar gradation from the same stock pile. Table shows that for a given set of laboratory maximum and minimum density values increase in density of only 2 % increases the relative density by about 10 %. Results also show a difference in relative density up to 8.4 % for the same field density for the two sets of maximum/minimum density.

Field density in uniformly graded smooth surfaced material: Field density testing by replacement method in uniformly graded filter consisting of smooth rounded material needed great care. Density test hole would get disturbed easily and collapse. Nuclear densometer was, therefore, used routinely giving quick

Table - 2 Comparison of relative densities

Field Density γ_d (g/cc)	Relative Density (%) Set 1 $\gamma_{max} = 1.956$ g/cc $\gamma_{min} = 1.640$ g/cc	Relative Density (%) Set 2 $\gamma_{max} = 1.934$ g/cc $\gamma_{min} = 1.574$ g/cc
1.88	79.02	87.44
1.90	84.70	92.18
1.92	86.98	96.81
1.94	95.72	101.35
1.96	101.06	105.80

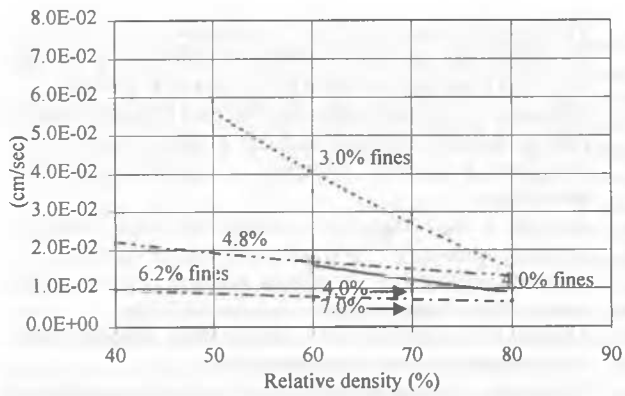

Figure - 7 Filter F1, permeability vs relative density

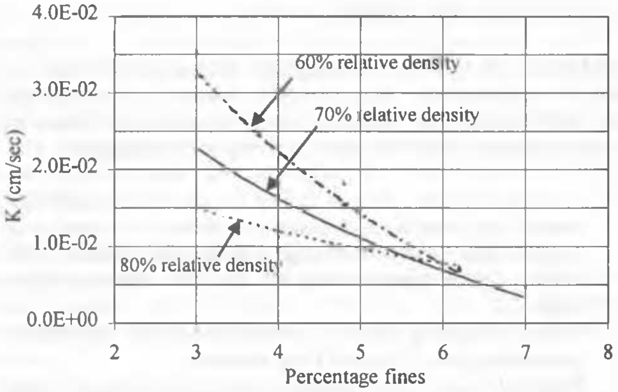

Figure - 8 Filter F1, permeability vs percentage fines

results which were verified randomly by carefully carried out tests by sand replacement method.

Effect of fines and compaction on permeability: A lot of laboratory testing was carried out in the process of resolving the issue of filter placing on side slopes. Permeability tests carried out in this respect indicated that;

1. Increase in compaction reduces the permeability of the filter material but the effect is not very significant. Effect of compaction on permeability is shown in Figure - 7.
2. Amount of fines in filter material has significant effect on its permeability. Effects of fines in filter on its permeability are shown in Figure - 8.

CONCLUSIONS AND RECOMMENDATIONS

1. Internal tube type vibrators good for compaction of cement concrete cannot compact sand filers.
2. 12 ton vibratory roller is too heavy for compacting thin (15 cm) filter on slopes. Light weight rollers in the range of 2 to 4 tons are more appropriate.
3. Satisfactory compaction of filter on channel side slopes was achieved by light weight rollers of 2.7 tons working in a Yo-Yo system with upslope vibration only. The Yo-Yo operation eliminates the disturbance and loosening effect on down trip.
4. Relative density control of compaction requires very accurate measurement of field density as well as laboratory maximum/minimum densities. Procedure based on compaction control may be more convenient with occasional verification through careful field and laboratory testing.