Discussion on Papers

Laboratory Studies on Filter Materials Placed at Ramganga Main Dam*

by

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1·0 Design Criteria

1.1 For gradation of filter material, Terzaghi's criteria is as below :

(*i*) $\frac{D_{15} \text{ size of filter material}}{D_{15} \text{ size of base material}} > 5$ (from drainability considerations).

(*ii*) $\frac{D_{15} \text{ size of filter material}}{D_{85} \text{ size of base material}} \not> 4$ (from migration of particles considerations).

(*iii*) The gradation curve of filter should have roughly the same shape as the gradation curve of the protected soil.

(*iv*) Filters should not contain more than about 5 percent of fines passing A.S.T.M. sieve 200 and the fines should be cohesionless.

1.2 These rules are conservative and should be adequate for any soil type. Since, it is very difficult and costly affair to follow this criteria, U.S.B.R. vide E.M. 425 (Karpoff, K.P.), has recommended, the following criteria for gradation of filters :

(*i*) $\frac{D_{15} \text{ size of filter material}}{D_{15} \text{ size of base material}} = 12 \text{ to } 40$

(*ii*) $\frac{D_{50} \text{ size of filter material}}{D_{50} \text{ size of base material}} = 12 \text{ to } 58$

1.3 Sherard et al mention that it is generally accepted as good practice to require that the relative gradation of adjacent soil zones meet 'established filter criteria' to prevent any possibility of appreciable migration of soil particles. He has further mentioned that at a site where extensive quantities of filters are necessary and where the easily available materials do not meet the 'established filter criteria', laboratory filter tests may demonstrate that the materials are adequate.

2.0 Filter Manufactured

2.1 As is stated in the paper, at Ramganga Project, fine filter is on

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finer side and coarse filter is on coarser side. The various ratios as observed during various years of construction are tabulated in Table I.

TABLE I

Various ratios of filter manufactured at project-site F.F for fine filter. C.F. for coarse filter.

	Average of year			Worst case of year			Average for full construction period	Ever worst combination
	1969-70	70-71	71-72	69-70	70-71	71-72		
1	2	3	4	5	6	7	8	9
$\frac{D_{15} \text{ C.F}}{D_{15} \text{ F.F.}}$	76.7	68·0	74·0	81·0	107·0	200	73·0	200
$\frac{D_{15} \text{ C.F.}}{D_{85} \text{ F.F.}}$	1·66	1·2	1.22	9.2	1·75	6·0	1·36	159
$\frac{D_{50} \text{ C.F.}}{D_{50} \text{ F.F.}}$	74·0	55·0	56·0	120.0	91·0	114·0	62·0	22·5

2.2 Table I indicates that the filter material produced at Ramganga Project does not fulfil the U.S.B.R. design criteria. It, however, fulfils three conditions of Terzaghi criteria. The condition that the gradation curve of filter should have roughly the same shape as the gradation curve of base material is not fulfilled as fine filter is deficient of + 4·76 mm to −20 mm material whereas coarse filter is deficient of + 10·0 mm to —38·0 mm.

The gradation curves for fine filter and coarse filter for quarterly averages for years 1969 to 1972 are given in Figure 1.

3.0 Discussion on Test Results

3.1 FIRST SERIES

3.1.1 In the first series of testing when fine filter was placed on I.S. sieve 480 (4·76 mm opening), the following gradations of fine filter *are reported to be tested:*

(*i*) Finest Filter designated as A

(*ii*) 80 percent Filter ,, ,, 1

(*iii*) Average Fine Filter ,, ,, 2

(*iv*) 80 percent coarsest of Fine Filter designated as 3

(*v*) Coarsest Fine Filter ,, ,, B

3.1.2 From Figure 1, it could be seen that for Ramganga Project, only first three cases are of importance as most of the filter material manufactured conforms to these three cases. Average filter however gives approximately correct average of the fine filter manufactured at site in the last three working seasons.

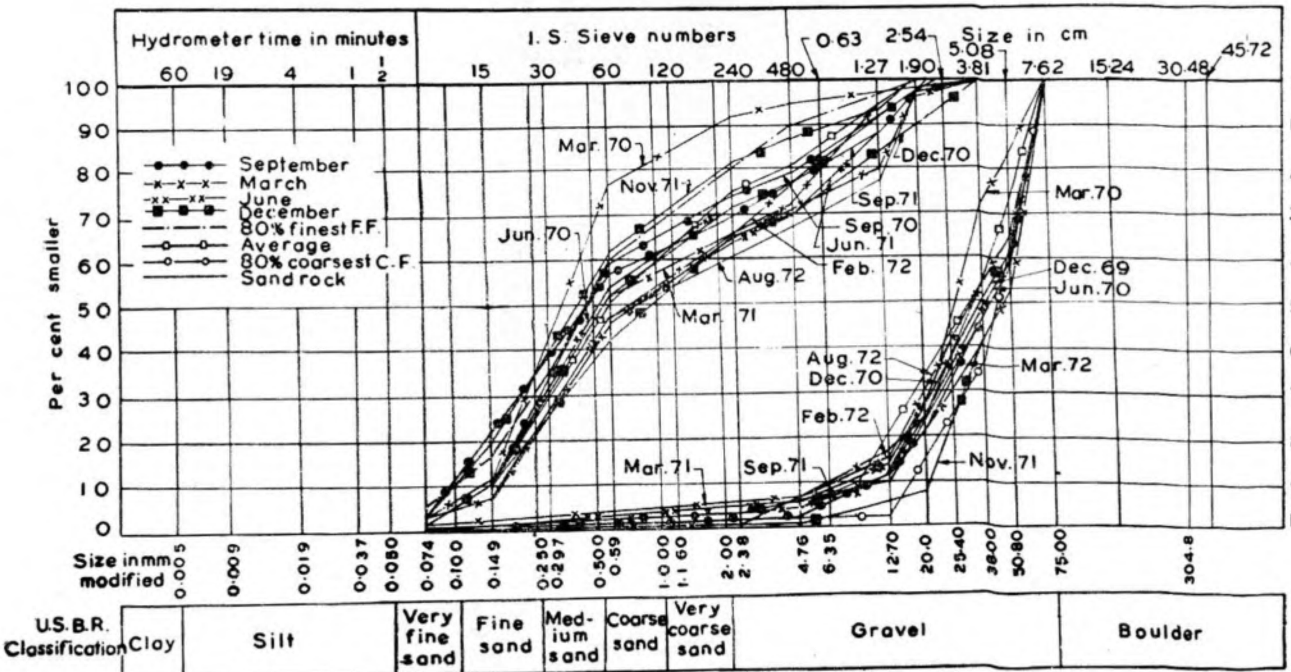


FIGURE 1: Gradation curves of filters laid at Ramganga Dam.

3.1.3 In the paper, material retained on sieve or passed through sieve, is only given. The percentage material of various gradations passed through sieve is given in Table II which would give comparative idea about migration of particles.

TABLE II

Statement showing percentage migration of particles of fine filter.

Size of screen	Percentage of each particle before test			Percentage migrated of its grade / Percentage migrated of total fine filter		
Set No.	A	1	2	A	1	2
1	2	3	4	5	6	7
76.2-38.1 mm	—	—	—	—	—	—
38.1-19.1 mm	—	—	1·0	—	—	—
19.1- 9.52 mm	2·5	5·0	12 0	—	—	—
9.52 mm-4 No.	2·5	7·0	8·0	—	—	—
4-8 No. A.S.T.M.	3·0	9·0	4·0	10·0/0·3	4·15/0·4	9·3/0·4
8-16 No. ,,	8·0	10·0	12·0	14.5/1.15	6.1/0.6	13.6/1.6
16-30 No. ,,	8·0	10·0	14·0	12·0/1·0	8.8/0.9	18.4/2·6
30-50 No. ,,	33·0	26·0	19·0	21.0/6.85	15.1/3.9	24.6/4.7
50-100 No. ,,	32·0	19·0	20·0	28·2/9.0	17.25/3,3	22.6/4.5
100-200 No. ,,	8·0	11·0	9·0	24.4/1.95	24.5/2.7	30.4/2·7
—200 No. ,,	3·0	3·0	1·0	31.0/0.95	33.4/1.0	23.5/0.2
Total	100·0	100·0	100·0	21.2	12.8	16.7

3.1.4 From Table II, it could be seen that total migration of particles finer than I.S. sieve 480, has been 21·2 percent, 12·8 percent and 16·7 percent for finest fine filter, 80 percent finest fine filter and average fine filter. The trend indicates that near about 20 to 30 percent material of each grade (finer than A.S.T.M. sieve No. 30) has washed out. In Table I of the paper, it has been shown that in the bottom half layer of average filter, only 18·32 kg material was retained after test against original weight of 25·5 kg which means that 28·3 percent material has passed from lower layer. Though these percentages of migration of particles are higher side, yet the following conclusions are significant :

(*i*) No migration of particles after 3 to 6 hours of testing and attainment of stable filter thereafter.

(*ii*) Migration of particles from fine filter took place mainly from the bottom half layer and there was almost no migration of particles from top layer.

(*iii*) There was no wash out of any particular particle size predominantly.

3.2 SECOND SERIES

3.2.1 In the second phase of testing, fine filter was placed over coarse filter. Figure 1 indicates that the following combinations of grades of fine and coarse filters are of interest :

(1) Average fine filter placed over average coarse filter designated (2-5).

(2) Average fine filter placed over 80 percent coarsest coarse filter *designated (2-6).*

(3) 80 percent fine filter placed over average coarse filter designated (1-5).

(4) 80 percent finest fine filter placed over 80 percent coarsest coarse filter designated (1-6)

In Table III, the total percentage of migration of various grades of fine filter, percentage of fine filter retained into coarse filter and percentage of fine filter migrated into the drain, have been shown for comparative study.

From this table, it would be observed that for combination Nos. 1, 2, 3 and 4, viz., average F.F. over average C.F., average F.F. over 80 percent coarsest C.F., 80 percent finest F.F. over average C.F. and 80 percent finest F.F. over 80 percent coarsest C.F., the total migration of fine particles is 9·9 percent, 14·09 percent, 23·6 percent and 38·8 percent respectively from lower layer out of which 8·35 percent, 7·6 percent, 9·1 percent and 25·7 percent respectively was retained by coarse filter and the balance drained off out side the coarse filter. There was no migration of fine filter particles from upper layer except in case of combination No. 1. The magnitude of migration is so small that it may be within permissible limits of experimental limitations and the entire migration in this case can also be presumed from lower layer. For combination Nos. 1, 2, 3 and 4 the total percentage of fine filter material drained off is 4·85 percent, 6·49 percent, 17·11 percent and 13·1 percent from the lower layer.

3.2.2 The test was done at 9·0 m head. Some head was noticed in coarse filter. This head steadily increased from zero but became constant after three hours. The final head developed (in percentage) for various combinations is given below :

(1) Average F.F. over average C.F.	20 percent
(2) Average F.F. over 80 percent coarsest C.F.	13·3 percent
(3) 80 percent Finest F.F. over average C.F.	23·4 percent
(4) 80 percent Finest F.F. over 80 percent coarsest C.F.	40·0 percent

These pressures were observed in coarse filter very near to fine filter and the pressures developed due to migration of fine particles. The check test indicates that pressures are developed in coarse filter only in the upper layer and no pressures are developed in middle and lower layer. The check test also indicates that out of total 18·3 percent migration of fine filter material from lower layer, 8·35 percent was retained in top layer of coarse

Table III

Statement showing total percentage fine filter migrated percentage fine filter-retained in coarse filter and percentage fine filter migrated in to drain

Size of screen	Percentage weight of particles in each layer before test				Per cent weight of particles migrated after test / Per cent of particles migrated of that grade							Per cent weight of fine filter retained in coarse filter / Per cent weight of fine filter retained of that grade				Per cent weight of fine particles drained out after test / Per cent weight of particles of that grade drained out			
Combination	1 (2-5)	2 (2-6)	3 (1-5)	4 (1-6)	1 (2-5) Upper layer	1 (2-5) Lower layer	2 (2-6)	3 (1-5) Upper layer	3 (1-5) Lower layer	4 (1-6) Upper layer	4 (1-6) Lower layer	1 (2-5)	2 (2-6)	3 (1-5)	4 (1-6)	1 (2-5)	2 (2-6)	3 (1-5)	4 (1-6)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
76·2-38·1mm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
38·1-19·1mm	1·0	1·0	–	–	0/0	0/0	0/0	–	–	–	–	–	–	–	–	–	–	–	–
19·1-9·52mm	12·0	12·0	5·0	5·0	0/0	0/0	0/0	0/0	0·32/6·30	–	–	–	–	–	–	–	–	0·32/6·30	–
9·52mm-4No.	8·0	8·0	7·0	7·0	0·16/2·10	0/0	0·46/5·80	0/0	1·84/26·50	0/0	1·85/26·50	0·06/0·70	0·64/8·0	1·40/20·0	1·71/24·40	0·10/1·40	-0·18/-2·20	0·40/6·50	0·14/2·10
4-8 No.	4·0	4·0	9·0	9·0	0·25/2·86	0·56/13·90	0·37/9·40	0/0	2·10/23·20	0/0	2·83/31·40	0·56/13·90	0·28/7·0	0·72/7·95	2·75/30·50	0·25/2·86	0·09/2·40	1·38/15·25	0·08/0·90
8-16 No.	12·0	12·0	10·0	10·0	0·06/0·50	1·44/12·0	1·95/16·20	0/0	1·54/15·40	0/0	4·17/41·70	1·39/11·60	1·39/11·60	0·40/4·0	3·22/32·20	0·11/0·90	0·56/4·60	1·14/11·40	0·95/9·50
16-30 No.	14·0	14·0	10·0	10·0	0·11/0·80	2·0/14·30	3·28/23·50	0/0	1·54/15·40	0/0	6·0/60·0	1·44/10·30	1·75/12·50	0·63/6·30	4·18/41·80	0·67/4·80	1·53/11·0	0·91/9·10	1·02/18·20
30-50 No.	19·0	19·0	26·0	26·0	0·76/4·10	1·20/6·40	2·27/11·40	0/0	8·50/32·60	0/0	10·40/40·0	0·78/4·10	1·00/5·25	3·41/13·20	6·56/25·30	1·18/6·40	1·27/6·15	5·09/19·40	3·84/14·70
50-100 No.	20·0	20·0	19·0	19·0	1·10/5·50	2·78/13·90	3·75/18·75	0/0	4·50/23·60	0/0	8·52/44·80	2·38/11·90	1·64/8·20	1·71/9·0	4·90/25·80	1·50/7·50	2·12/10·55	2·79/14·60	3·62/19·0
100-200 No.	9·0	9·0	11·0	11·0	0·66/7·40	1·62/17·90	1·68/17·60	0/0	2·66/24·20	0/0	3·52/32·50	1·44/16·10	0·74/8·30	0·57/5·20	2·25/20·20	0·84/9·20	0·95/8·30	2·09/19·0	1·27/12·50
-200 No.	1·0	1·0	3·0	3·0	0·20/27·80	0·30/33·30	0·33/33·30	0/0	0·60/20·0	0/0	1·51/50·50	0·30/27·60	0·18/18·0	0·26/7·60	0·14/3·80	0·20/33·50	0·15/15·30	0·34/12·40	1·38/46·70
Total–	100·0	100·0	100·0	100·0	3·30	9·90	14·09	0	23·60	0	38·80	8·35	7·6	9·10	25·70	4·85	6·49	17·11	13·10

Total–13·20 (columns 6 and 7)

filter, 1·87 percent was retained in middle layer, 1·0 percent in lower layer and the balance, viz., 7·08 percent washed out into drain. The material used in check test was 80 percent finest fine filter over 80 percent coarsest coarse filter and fine filter layer was 250 mm thick whereas coarse filter layer was 600 mm thick. The thickness of coarse and fine filter layer in second series test was only 250 mm for each. This indicates that as the thickness of coarse filter increases:

(1) Percentage migration of particles from fine filter decreases, and

(2) Pressures developed are also lesser.

3.3 This indicates that if thickness of filter layer is more, deviation from established filter design criteria can be permitted. According to Sherard et al, theoretically individual protective layer of properly graded filter material can be very thin. From tne practical stand point, however, the minimum thickness of a layer is that which can be constructed without danger of gaps or of areas of segregated material being in corporated in it. Because they are easy to place, horizontal layers can safely be made thinner than steeply inclined or vertical filters. Minimum thickness for horizontal layers are about 150 mm for sand and 300 mm for gravel. 2·5 m to 3·0 m horizontal width is recommended for chimney drains from ease in construction considerations. At a number of dams where the filter material is very scarce and expensive, vertical filter bands 1·0 to 1·5 m wide have been constructed, usually by means of wooden forms. At Sasume Dam (Kenya), 1·5 m wide vertical chimney drain was composed of three vertical bands of material with these gradations :

Band	Width	Gradation
Upstream	0·6 m	—25 mm to —200 No.
Middle	0·6 m	+25 mm to —75 mm.
Downstream	0·3 m	—25 mm ιo —200 No.

4.0 Filter Criteria for Ramganga Main Dam

The typical section showing thickness of filters and various zones of embankment is shown in Figure 2. The downstream chimney filter has been laid in three bands consisting of fine filter, coarse filter and again fine filter. The band thicknesses are 2·0 m, 3·5 m and 2·0 m respectively. The upstream chimney filter has been laid in two bands consisting of 2·0 m fine filter and 2·5 m wide coarse filter. The thicknesses provided at Ramganga Main Dam are considered adequate as the same are in accordance with the prescribed filter width. Since the thicknesses of filters are ample, the filter manufactured at site is considered adequate though the gradation of filter does not fulfil the established filter design criteria. Figure 3 indicates the gradation curve for base material as actually laid at site, gradation curves for permissible limits of filters and the allowable ranges from Terzaghi and U.S.B.R. criteria.

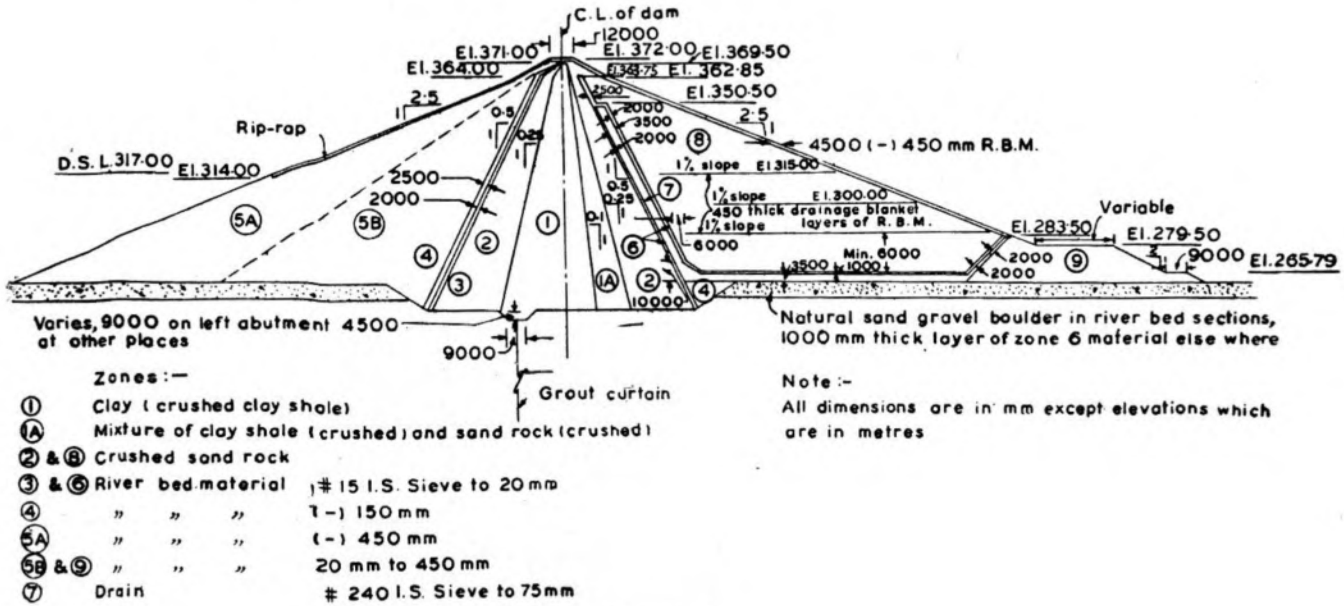
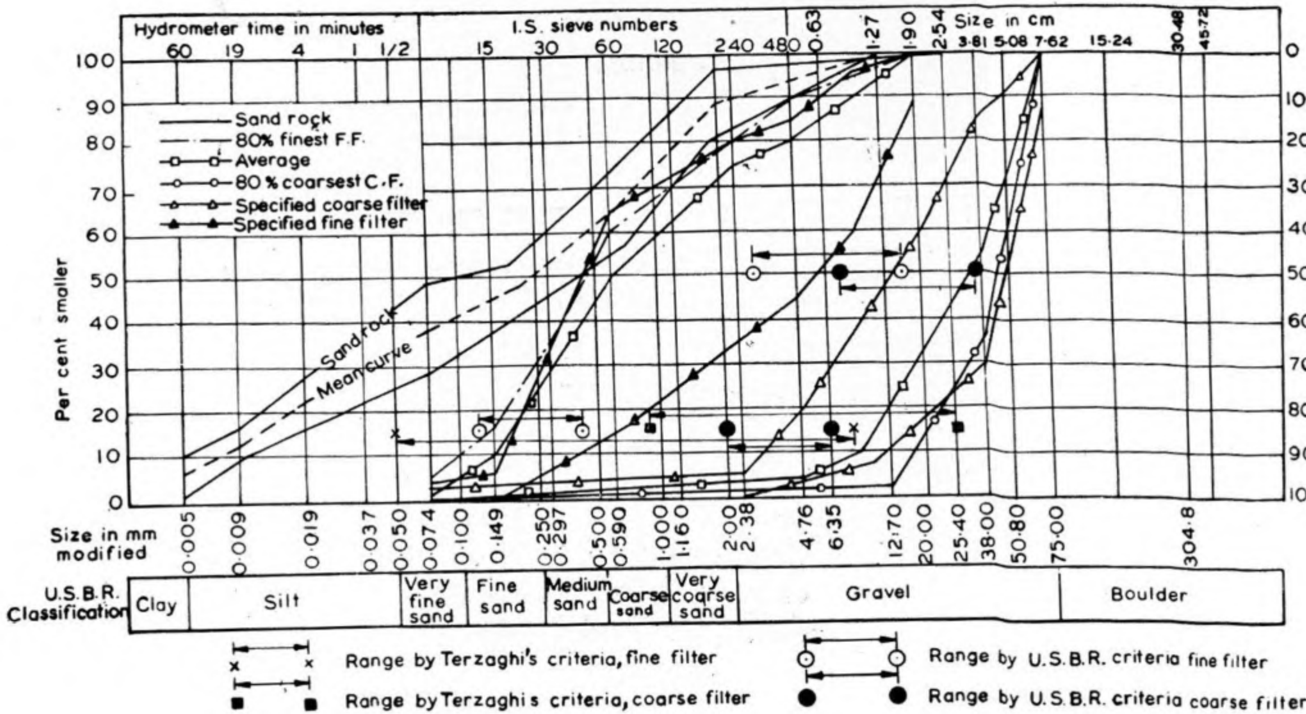

C.L. of dam
12000
El. 371·00
El. 372·00
El. 369·50
El. 364·00
El. 362·85
El. 350·50
2·5
1
Rip-rap
D.S.L. 317·00
El. 314·00
0·5
0·25
2500
2000
3500
4500 (-) 450 mm R.B.M.
1% slope El. 315·00
1% slope El. 300·00
450 thick drainage blanket layers of R.B.M.
1% slope
6000
Min. 6000
3500
1000
10000
Variable
El. 283·50
El. 279·50
9000
El. 265·79
Varies, 9000 on left abutment 4500 at other places
9000
Grout curtain
Natural sand gravel boulder in river bed sections, 1000 mm thick layer of zone 6 material else where
Zones :—
① Clay (crushed clay shale)
①A Mixture of clay shale (crushed) and sand rock (crushed)
② & ⑧ Crushed sand rock
③ & ⑥ River bed material (# 15 I.S. Sieve to 20 mm
④ " " " (-) 150 mm
5A " " " (-) 450 mm
5B & ⑨ " " " 20 mm to 450 mm
⑦ Drain # 240 I.S. Sieve to 75 mm
Note :-
All dimensions are in mm except elevations which are in metres

FIGURE 2.



Hydrometer time in minutes
60 19 4 1 1/2
I.S. sieve numbers
15 30 60 120 240 480
Size in cm
0.63 1.27 1.90 2.54 3.81 5.08 7.62 15.24 30.48 45.72
Sand rock
80% finest F.F.
Average
80 % coarsest C.F.
Specified coarse filter
Specified fine filter
Sand rock
Mean curve
Per cent smaller
Per cent larger
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
Size in mm modified
0.005 0.009 0.019 0.037 0.050 0.074 0.100 0.149 0.250 0.297 0.500 0.590 1.000 1.160 2.00 2.38 4.76 6.35 12.70 20.00 25.40 38.00 50.80 75.00 304.8
U.S.B.R. Classification
Clay
Silt
Very fine sand
Fine sand
Medium sand
Coarse sand
Very coarse sand
Gravel
Boulder
Range by Terzaghi's criteria, fine filter
Range by Terzaghis criteria, coarse filter
Range by U.S.B.R. criteria fine filter
Range by U.S.B.R. criteria coarse filter

FIGURE 3.

5.0 Conclusion

On the basis of test results conducted for horizontal filter layers, it has been presumed that the same results would be for vertical filters. However, it would be interesting to know the results for vertical or inclined filters. This will give valuable information regarding cracking of core which may happen due to migration of fine filter material laid adjacent to it.

6.0 Acknowledgements

The discussor is indebted to Shri V.K. Tyagi, Assistant Engineer for giving assistance in compiling th's discussion.

7.0 References

KARPOFF, K.P. : "The Use of Laboratory Tests to Develop Design Criteria for protective Filters, Earth Laboratory Report No. EM.425." *United States, Department of the Interior, Bureau of Reclamation.*

SHERARD, JAMES L. ; WOODWARD, R.J. ; GIZIENSKI, S. F. and CLEVENGER, W.A. : "*Earth and Earth Rock Dams.*" John Wiley and Sons, Inc.

AUTHORS' REPLY

The authors wish to thank Shri M.C. Goel, for showing his keen interest and agreement with the main conclusions of the authors in the paper. The points mentioned by him are briefly discussed below :

(*i*) The U.S.B.R. criterion for design of protective filters is more conservative and difficult than the Terzaghi's criterion as it puts greater restrictions than proposed in the latter. The filter grade which would meet the coarse limit of the Terzaghi's criterion with respect to a given base soil, shall not be able to fulfil the requirements of the U.S.B.R. criterion. The writer's view therefore on this point is incorrect.

(*ii*) Only one gradation analysis is conducted every day at processing plant of Ramganga Project for each days production. The filter grade shown by A in the paper is based on a single days production in year 1969-70. In the opinion of the authors, the filter grades designated by 1 and 2 are of importance and filter grade designated by A needs no consideration.

(*iii*) The condition that the gradation curve of the filter should have roughly the same shape as the gradation curve of base material is quite vague in the sense that it can be read with different degree of rigidness. In the opinion of the authors, a filter material should meet the Terzaghi's criterion except the condition No. 3 (as stated by the writer), should be well graded and should have a good distribution of all particle sizes in the size range of the filter for it to function satisfactorily as a filter. Test results as reported in the paper, shall confirm this conclusion.

(*iv*) In the first series of testing programme, fine filter was placed on I.S.S. size No. 480 to check its internal stability. It is natural that particles finer than 4·80 mm shall pass from the layer adjacent to sieve, till large particle clog over the openings, creating in turn smaller openings smaller than the particles of the soil (Figure 1). For this process to develop, the filter should have a good distribution of all particle sizes. Therefore, there shall be initially some amount of migration of particles, however, when this migration has taken place only from the lower layers of filter

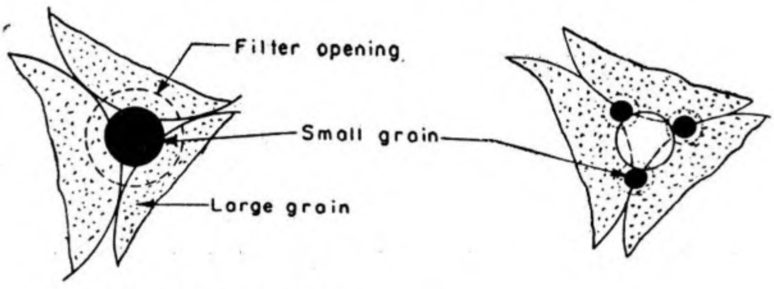


FIGURE 1.

adjacent to the sieve, it can be said that though the lower layers have become deficient in its fine sizes, yet it retained the capacity of holding the finest particles of the upper layers of fine filter. Such filter shall be termed as stable. The percentage of material migrated from a small layer (say of 150 mm thickness), adjacent to the sieve, in above circumstances shall be of no consequence, particularly in case of filters of large thickness.

There was some variation in the percentage of migration of each particle size out of its own grade, yet the gradation curve before and after test remained practically the same (being very close and parallel), indicating clearly that there was no substantial migration of any particle sizes.

(*v*) Due to penetration of fine filter particles (which are itself pervious in nature) into coarse filter, the affected width of coarse filter behaved like the extended width of fine filter. Hydraulic pressures after tests therefore dropped at the end of affected width of coarse filter instead at the previous contact of fine filter with coarse filter.

(*vi*) The criteria for design of protective filters by Terzaghi and U.S.B.R. were developed by passing water through layers of base soil and filter (keeping least thickness of filter layers as could be permissible) under different heads in vertical downwards direction, so also by authors in similar conditions but keeping the layers of filter sufficiently thick, i.e., thicker than permissible. It may here be stated that maximum amount of migration from base soil shall be achieved when water is passed in vertically downward direction and that may therefore be the probable reason why the researchers have selected this direction of flow for determining the adequacy of filter.

The authors had tried to test the filter by passing the water in horizontal direction for which the containers were placed horizontally, but it was seen that a clean slit between fine filter and top underside of the container was formed only after small migration from fine filter and through this slit all discharge of water started passing. This, therefore, rendered the present test set up unsuitable for such type of testing.

A new experimental set-up as shown in Figure 2 has been devised so as to afford proper testing by passing flow in horizontal direction. This set up shall also afford testing of filters under various confining pressures exactly in the way the filters are subjected in a dam embankment. The