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Efficacy of Grout Curtain at Ramganga Dam

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SYNOPSIS The analysis of foundation piezometer records at main dam and saddle dam of Ramganga Project, has indicated that the single row grout curtain at main dam, is ineffective so far as the hydrostatic pressure reduction in foundation is concerned, whereas under similar conditions, upstream impervious blanket at saddle dam, is more effective in pressure reduction. Experimental test results by electrical analogy technique using graphite paper, has indicated that in case of Ramganga main dam, the total net pressure reduction for fully effective grout curtain would have been only 25%. The design curve for efficiency versus different openings in grout curtain is also given.

INTRODUCTION

Studies made by some eminent engineers in the past, cast doubt about efficacy of grout curtain in reducing hydrostatic pressures. A Cassagrande (1961) in his mathematical analysis of the efficiency of imperfect cutoffs, has demonstrated that a steel membrane having 1.52mm slits spaced every 1.52m with an open space ratio of 0.1%, would have a theoretical cut off efficiency of 29% i.e. 71% of the rate of flow without cutoff, would still be going through these thin slits. If the same 0.1% open area is divided into a large number of smaller slits, the cut off efficiency would drop to even lower values. Ambrasseys (1961) has shown that for $B/D=1$, where B is width of foundation and D is depth of cut-off, for very thin cut off with an open-space ratio of 1%, the efficiency is in between 4 and 21% as the number of slits varies from 60 to 10. However with a cut off whose thickness is 5% of depth of cutoff, the efficiency with the same open space ratio, is 84% for all values of slit numbers between ten and infinity. To attain this efficiency, the thickness of the cut off and depth of cut-off should be equal to the base width of foundation which implies that for homogeneous dam section, the depth of grouting should be near about five times the reservoir height against the conventional depth of 50% of reservoir height.

Based on actual field observations of piezometers for a 35m high typical zoned earth dam with a highly impervious clay core extending down to grouted bed rock and having 18m deep curtain grout, Cedergren (1967) has concluded that the grout curtain was of no use and could have been avoided. Cassagrande (1961) has also shown that grout curtain has been ineffective in case of concrete gravity Fontanna and Hiawasse dams. He has the same conclusion for a 30.5m high homogeneous earth dam resting on fractured gneiss foundation and having single row grout curtain. The piezometers extending into the fractured rock, had shown a practically straight line drop from reservoir level at location coinciding approximately with the upstream toe of

the dam without the slightest indication that there might be any obstacle to seepage at the location of the grout curtain.

RAMGANGA PROJECT

The multipurpose Ramganga project situated in Pauri-Garhwal district of Uttar Pradesh in India, consists of two earth and boulder fill dams - one 125.6m, high located on the main Ramganga river and the other 72.25m high saddle dam. The formation at the two dam sites consists of alternate bands of sand rock and clayshale. The sand rock is poorly cemented, mostly massive or coarsely jointed. The average insitu permeability value for clay shale and sand rock was of the order of 2×10^{-5} and 4×10^{-5} cms/sec. respectively but the large variations observed in the values of permeability during field tests, and complete loss of drilling water also observed in some holes at main dam, indicated the possibility of cavities, fissures and cracks. No upheaval was noticed at a pressure of 0.17 kg/cm²/m of rock cover at main dam site whereas upheaval was noticed at 0.11 kg/cm²/m of rock cover at saddle dam site. Moreover at saddle dam site, grout tests indicated low permeability and cement intake was little. Hence at main dam, the open joints and fissures were sealed by grouting whereas at saddle dam site, an upstream impervious blanket of crushed sand rock, 3m thick underneath the pervious upstream shell was provided. Depending upon the variation of the grout intake, the pattern of grouting adopted varied from reach to reach at main dam (Fig.1). Grouting was done with portland cement without any admixture. The pattern of grouting adopted was a single line grout curtain underneath the cut off trench with holes located 6m apart extended to half of the dam height with a minimum of 22.75m in the entire length of dam. Secondary holes in between primary holes upto the depth of primary holes were also provided in reaches of excessive grout intake. In reaches of very high grout intake, even five row grout curtain of varying depth was provided. In areas with conspicuous open jointing, blanket grouting

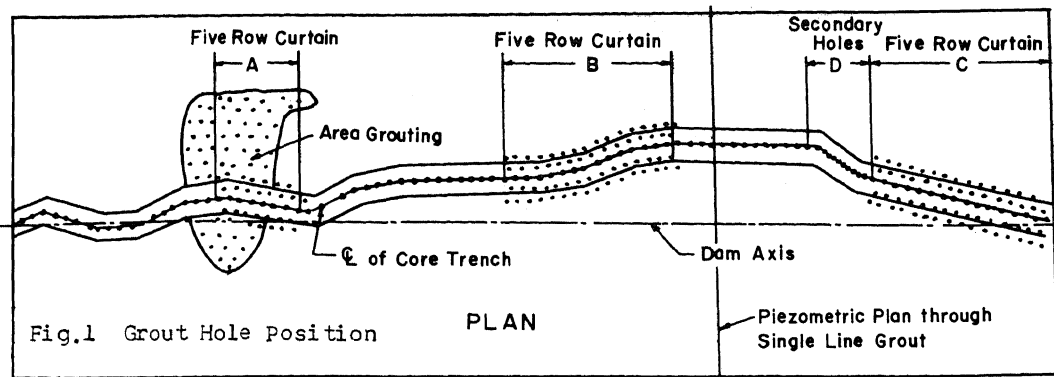


Fig.1 Grout Hole Position

PLAN

Piezometric Plan through Single Line Grout

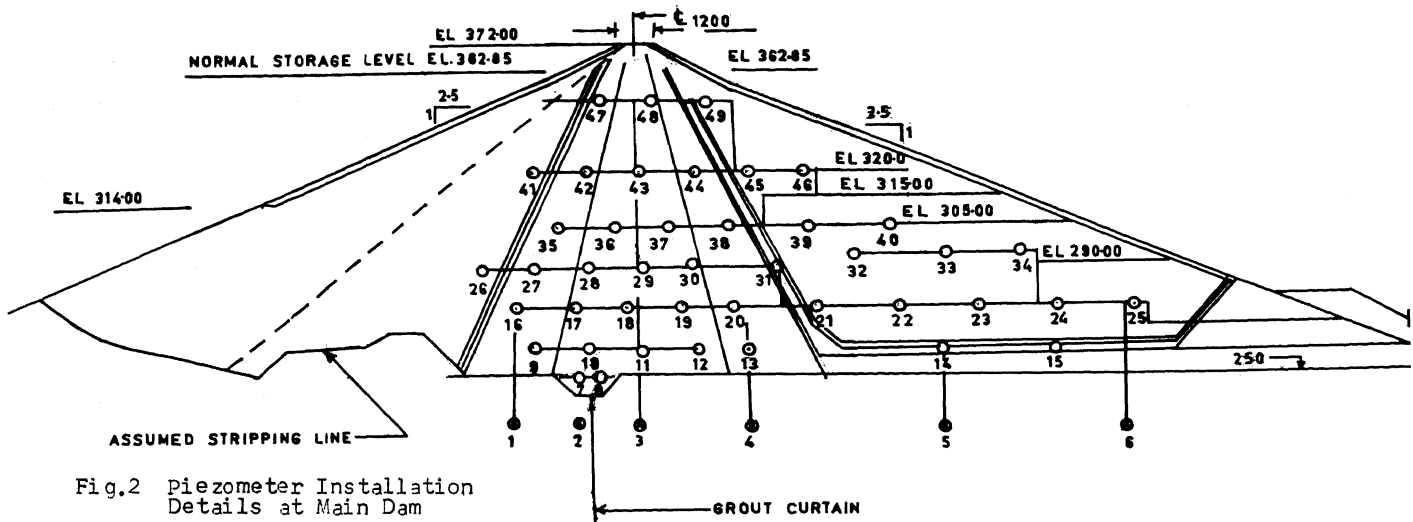


Fig.2 Piezometer Installation Details at Main Dam

was done extending 6m upstream of the start of core section to 6m downstream of core section.

Instrumentation

Twin tube U.S.B.R. type hydraulic piezometers were installed at both dams (Figs.2 and 3). From Fig.2, it could be seen that tips no.1&2 are upstream of grout curtain where as tips no.4,5 and 6 are downstream of grout curtain. Tip no.3 is not working. From Fig.1, it could be seen that the section under study having piezometer installation lies in single row grout curtain reach, indicating thereby that study could be made for the efficiency of single row grout curtain only.

Observational Data

Ramganga reservoir had its first filling in year 1974-1975. Piezometer readings for 8 years for both the dams from October 1975 to August 1982 alongwith reservoir fluctuations were available. Out of eight year data, four typical data representing reservoir levels at 362.8, 349.84, 342.31 and 324.15 have been chosen for presentation for main dam. For saddle dam, the analysis is done for three reservoir levels at 362.8, 355.85 and 342.10.

EXPERIMENTAL DETAILS

With a view to compare the observed foundation piezometer readings with that of the typical theoretical case, laboratory experiments were carried out by electrical analogy method using

graphite paper. In case of main dam, two cases viz.(i) dam core impervious but foundation of uniform permeability, and (ii) dam core and foundations equally permeable, were studied. To judge the efficacy of grout curtain, cases with (i) grout curtain fully effective (ii) grout curtain with 10%, 25%, 50% and 75% openings, uniformly distributed along the depth of grout curtain and (iii) no grout curtain, were studied. For drawing equipotential lines, the upstream heel of core was taken as entry point and the toe of core was taken as exit point.

For determining the point of entry in case of upstream of blanket of saddle dam, the effective length of blanket was worked out using procedure of finite blanket. A finite blanket is one where part of the flow enters the foundation at the upper limit of blanket. For such a finite blanket, the effective length was found out to be 47.5m upstream of core heel against total length of 75m of blanket. For calculating effective length, the permeability of blanket was assumed as 2.8×10^{-6} cm/sec and that of foundation as 4.2×10^{-5} cm/sec as actually observed at site. The depth of foundation was taken equal to width of core at contact. The core was assumed impervious and the downstream contact point core was considered as exit point.

ANALYSIS FOR MAIN DAM

Tips no.1&2 upstream of grout curtain and tip no.4, downstream of grout curtain, are situated

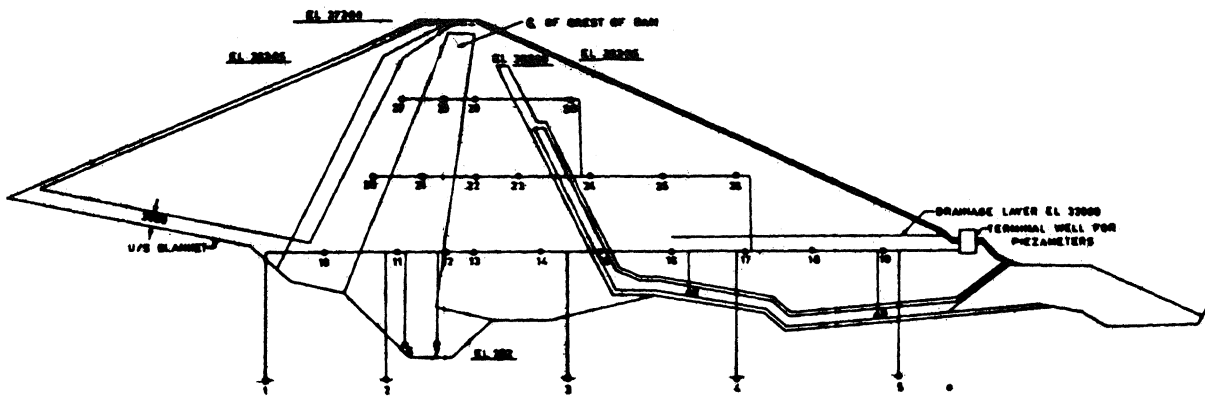


Fig.3 Saddle Dam section

below impervious core portion where as tips no. 5 and 6 are below pervious shell portion(Fig.2). Since no tip is located at the junction of downstream impervious core and shell, for drawing gradient line of observed pore pressure, the gradient line for tips no.5 and 6 was extended backward and from the intersection point of it with the vertical through downstream of impervious core, was connected to the piezometric level at tip no.4. The observed hydraulic gradient line was higher than the experimental gradient line obtained for (i) with curtain and (ii) without curtain grout. At the first instance for experimental studies, the tail water level was assumed 258.5 corresponding to tail water of power house located at toe of dam. However the recorded pore pressures in tips no.5 and 6 were of the order of 276.0+ indicating thereby residual pressures of the order of 18m. Almost the same order of residual pore pressures was also observed in tips no.14 and 15 located in the downstream drain of dam section. This confirmed that the emergence level was of the order of 276+ and not of 258+ i.e. tail water level. Hence for further experimental studies exit level was taken corresponding to piezometric readings for tip no.6.

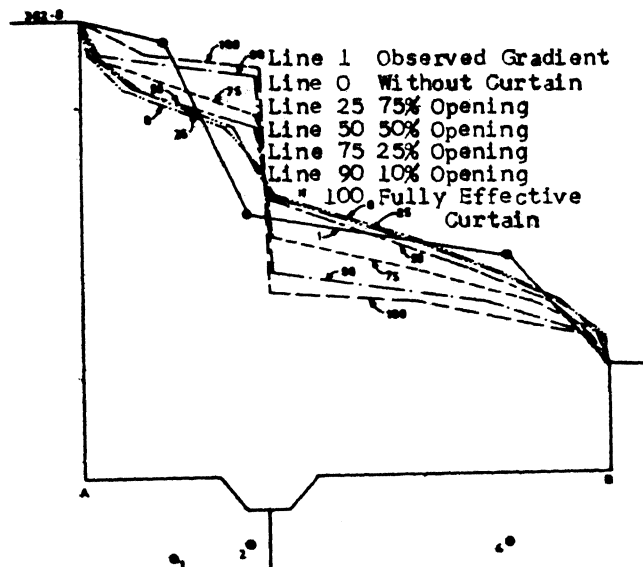


Fig.4 Observed & Theoretical Foundation Pressures at Main Dam (Core Impervious)

The experimental hydrostatic gradients for various conditions of grout curtain and observed piezometric gradients corresponding to four reservoir levels viz.362.8,349.84,342.31 and 324.15 were drawn. A typical curve corresponding to reservoir level of 362.8 is shown in Fig.4. For fully effective grout curtain (line 100), the experimental residual heads downstream of grout curtain are 20m, 15.5m, 14.5m and 10.0m corresponding to the four reservoir levels. This gives 77% efficiency in terms of head reduction. The effectiveness of grout curtain in reducing pore pressure at a point downstream of grout curtain for various percentages of openings, is tabulated in Table 1. From this table, it could be seen that the reduction in pore pressure downstream of grout curtain varies from 50.06% to 77.17% for no grout curtain to fully effective grout curtain. This means that had grout curtain been fully effective, the pore pressures would have not been reduced below a limit of 27.11%. If the grout curtain has openings which is usually a practical case, the reduction in pressures would be still lower. The percentage of opening in grout curtain is represented graphically in Fig.5. From this graph, it could be seen that

Table 1-Reduction of Pore Pressure on Downstream of Grout Curtain.Net Head H=87.6lm

% opening area	Head relative to without curtain (m)	%age re- duction	Head(h) (m)	% effectiveness (H-h)/H
100*	0	-	43.75	50.06
75	0.5	2.1	43.5	50.35
50	1.5	6.3	43.0	50.92
25	10.5	44.0	33.5	61.76
10	19.0	79.8	25.0	71.46
0**	24.0	100.0	20.0	77.17

* Without grout curtain,
** Fully effective grout curtain

for 50% opening, the percentage reduction in pore pressure, is only 6.3%.For the next 10% reduction in opening, the increase in reduction of pore pressure is 9% only. Further, it is seen that for 50% reduction in pore pressure, the opening should be limited to 20%. In the figure, the effectiveness of grout curtain with variable

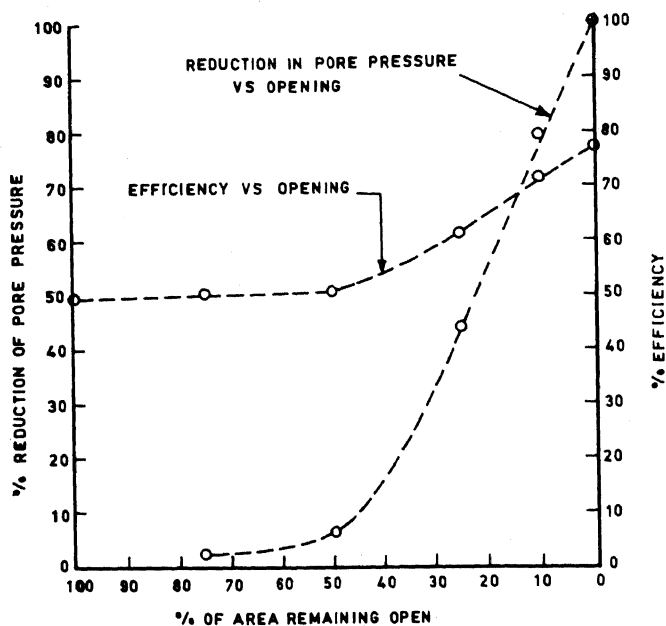


Fig.5 Efficiency versus Openings in Grout Curtain opening is also plotted in terms of percentage pressure reduction.

Table 2- Observed Residual Hydrostatic Head

Month of observation	Reservoir level	Net head (H) (m)	Head (h) d/s of grout curtain (m)	Efficiency in % $\frac{H-h}{H}$
Sept.1978	362.80	87.61	38.50	56.0
Oct.1981	349.84	69.54	29.0	58.29
Aug.1982	342.31	61.71	34.0	44.90
Apr.1980	324.15	43.54	25.50	41.40
			Mean	50.15

The observed residual hydrostatic pressure downstream of grout curtain for the four cases under study, is listed in Table 2. This shows that the pressure reduction is of the order of 41 to 58% with an average value of 50.15%. Interestingly, the theoretical pressure reduction without grout curtain was also found to be 50.06%. This indicates that the grout curtain at Ramganga dam is fully ineffective so far as the reduction of pressures in foundation is concerned.

Saddle Dam

The experimental hydrostatic gradients corresponding to three reservoir levels viz, 362.8, 355.85 and 342.10 and corresponding tail water levels of 315.41, 314.59 and 315.00 together with actually observed piezometric levels, were drawn. A typical representation for reservoir level of 362.8 is shown in Fig.6. It was seen that in all the three cases studied, the gradients for the experimental and the observed coincided within practical limits.

Relative Effectiveness of Grout Curtain and Impervious Blanket

To judge the relative efficacy of grout curtain vis-a-vis horizontal impervious blanket, the

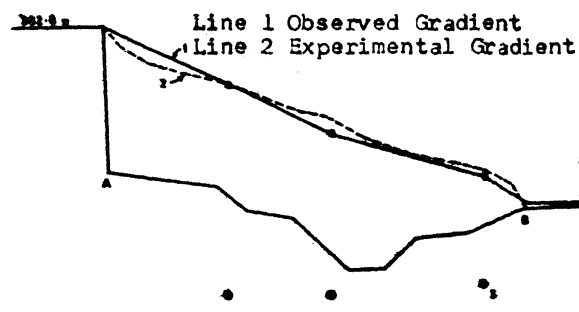


Fig.6 Observed & Theoretical Pressures at Saddle Dam

percent reduction in pore pressure at centre of cut off for saddle dam as well as for main dam for different reservoir levels, has been worked out in Table 3. From this table, it could be seen that with the presence of grout curtain in main dam the pressures could be reduced by 50% whereas in case of saddle dam with blanket, the pressures could be reduced by 60% at centre of cutoff trench. This shows that under similar conditions, horizontal blanket is more effective in reducing pressures as compared to grout curtain.

Table 3 - Comparison of Blanket and Grout Curtain in Reducing Hydrostatic Head

Reservoir level	Saddle dam			Main Dam
	Net head (H) (m)	Head(h) at mid point of cut-off(m)	Efficiency in % $\frac{H-h}{H}$	Efficiency in % (Table 2)
362.80	47.39	17.50	63.07	56.0
355.85	41.22	15.50	62.40	-
342.10	27.10	12.0	55.72	44.90
		Mean	60.39	50.45

CONCLUSIONS

The experimental test results have indicated that total net reduction in pore pressure just downstream of fully effective grout curtain would be of the order of 25%. Since it is impracticable to attain the fully effective grout curtain, the actual gain in pressure reduction would be still lower. The grout curtain at main dam is ineffective in reducing pressures, though it might have reduced seepage flow. For pressure reduction upstream impervious blanket is preferable as compared to grout curtain under similar conditions.

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