Pore Pressure Observations and Efficiency of Cut Off Walls at Obra Dam

by

Hari Krishna*

M.C. Goel**

Introduction

Obra, a 29.25 m high and 480 m long earth and rockfill dam was constructed on river Rihand in 1969, about 35 km, downstream of Rihand dam in district Mirzapur (Uttar Pradesh). The dam is basically a pick up dam for levelling of tail race fluctuations from Rihand power house and the storage thus available is being utilised for the generation of the power by installing three units of 33 MW turbines each. The site plan and the section of the dam are shown in Figures 1 and 2.

The sub-soil investigations in the river bed portion indicated that the foundation of the dam consisted of 25 to 30 m deep alluvium underlain by rock comprising alternate bands of shale and limestone dipping upstream at an angle of 14°. The riverbed alluvium consists of medium to coarse sand mixed with occasional gravel, the coarseness increasing with the depth. In

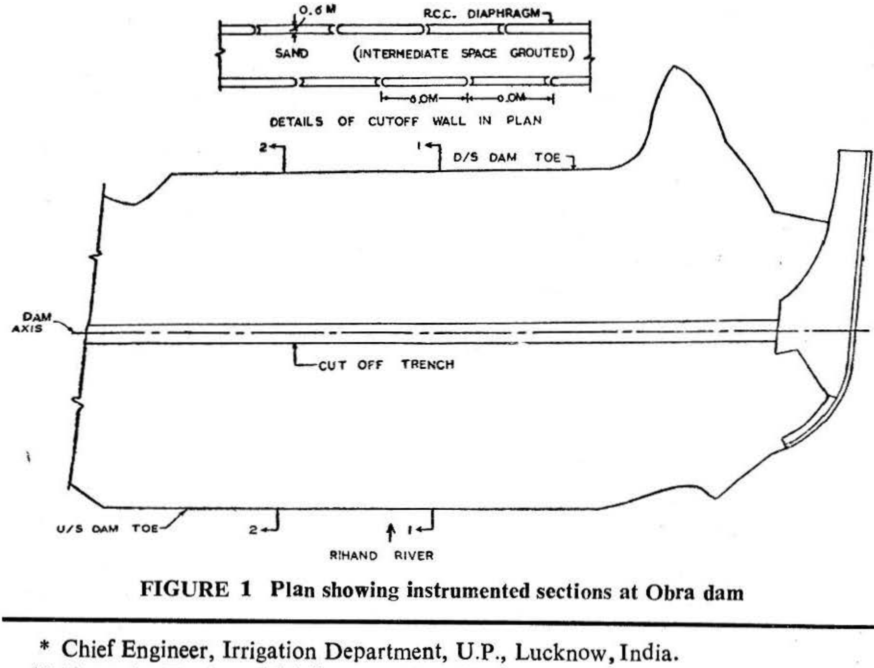

FIGURE 1 Plan showing instrumented sections at Obra dam

* Chief Engineer, Irrigation Department, U.P., Lucknow, India.

** Executive Engineer, Tehri Dam Design Circle, Roorkee.

This paper was received in Feburary, 1978 and is open for discussion till the end of November, 1978.

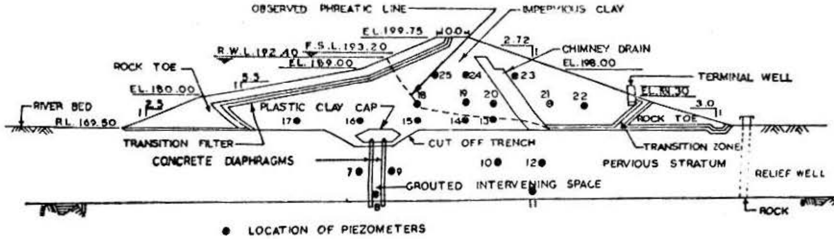

FIGURE 2*a* Location of piezometers at section 1-1

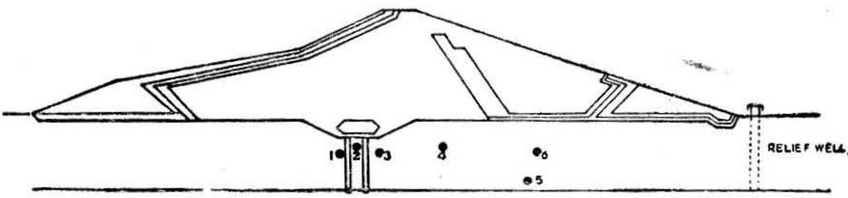

FIGURE 2*b* Location of piezometers at section 2-2

about 50 m length of the right flank adjacent to spillway abutment, the foundation sand overlies an intrusion of compressible clayey material. The foundation sand is poorly graded with mean size varying from 0.5 mm to 0.6 mm and uniformity coefficient from 2.5 to 8.0 (average 5.45). Dynamic and static cone penetration tests on foundation material indicated relative density varying from 30 to 70 per cent. Permeability tests carried out in the river bed by pump out method yielded a permeability value ranging from 1.5 to 0.3 cm/sec. Because of such high premeability, very high seepage through the foundation of the dam was inevitable. In order to reduce this, a complete cut off was designed and provided at site (Harkauli and Sharma, 1972). The cut off consists of two reinforced concrete diaphragms spaced 3 m apart with intermediate space grouted by means of cement, bentonite and chemical grout. Each diaphragm is 0.6 m thick and extends 1 m into the foundation rock. The two diaphragms were laid in 6 m panel length with joints staggered in plan. The top of diaphragm is embedded in a zone of plastic clay having liquid limit greater than 35 per cent, moisture content 5 per cent above O.M.C. so that the diaphragms may penetrate into the plastic mass, in case of excessive foundation settlement. The details are shown in Figures 1 and 2.

Instrumentation

To judge the efficacy of cut off, the standard U.S.B.R. foundation type piezometer tips (Earth Manual, 1965) were installed in two sections 1-1 and 2-2 at chainage 240 m and 330 m respectively in the foundation. Cell Nos. 7-12 were installed at section 1-1 while cell Nos. 1-6 at section 2-2. The cell nos 7 and 1 were placed just upstream of the first diaphragm, 8 and 2 in between the two diaphragms and the rest on the downstream of the second diaphragm. On the downstream of dam toe, relief wells of 150 mm diameter (shrouded to 450 mm diameter) have been provided at every 20.0 m spacing. The outlet of the relief well is at El. 172.00 which is above the highest tail water level. The location of the cells and relief well in the section is shown in Figure 2. The observations of these cells have been utilized for studying the efficiency of cut off at these sections.

In addition to the above foundation type piezometers, 13 Nos. standard U.S.B.R. embankment type piezometer tips were embedded in the dam at chainage 240 m (Section 1-1) for observing pore pressures developing during construction and post construction periods. The location of these embankment type piezometer cells is shown in Figure 2*a*.

Observations

The observations of pore pressure of foundation type piezometer cells of both the sections with respect to time from September, 1969 to August, 1975 (in terms of RL's) are plotted in Figures 3*a* and 3*b* and are also tabulated in Table Nos. 1 and 2. The observations of the embankment type piezometer cells are plotted in Figures 4*a* and 4*b*.

Discussion

Foundation Pore Pressures at Section 1-1

The foundation of Obra dam, in general comprises of coarse sand mixed with gravel. The observations at section 1-1 plotted in Figure 3*a* and tabulated in Table 1, indicated that the pressure indicated by cell No. 7 embedded just upstream of the grout curtain is maximum and has decreased in cells No. 8 and 9. The observations of cells No. 10-12 are almost equal and have indicated approximately equal rise of pore pressure. The pressure in cell No. 7 is approximately equal to the reservoir head and this trend is being followed almost during the entire period of observations. Cell No. 8 indicates a pressure lower than that of cell No. 7. Pressures observed by cell Nos. 9-12 indicated overlapping and erratic trend during

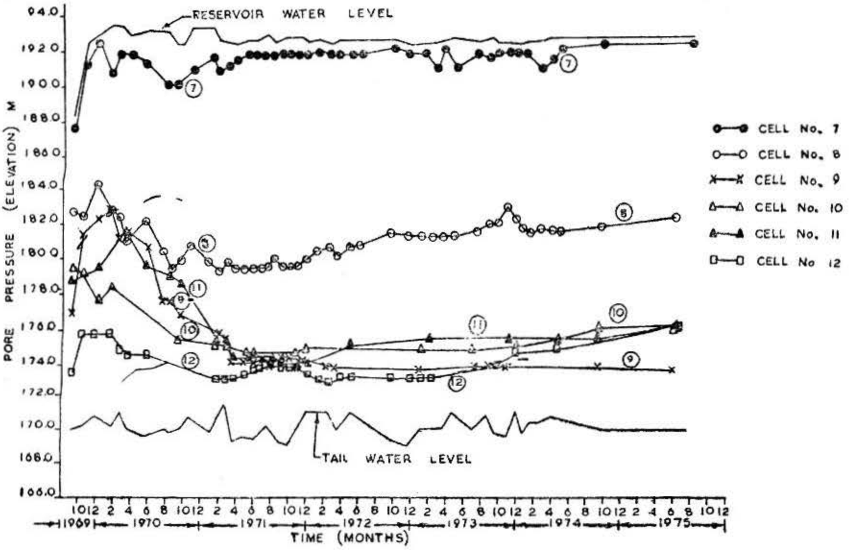

FIGURE 3*a* Pore pressure observations for piezometers in foundation at section 1-1

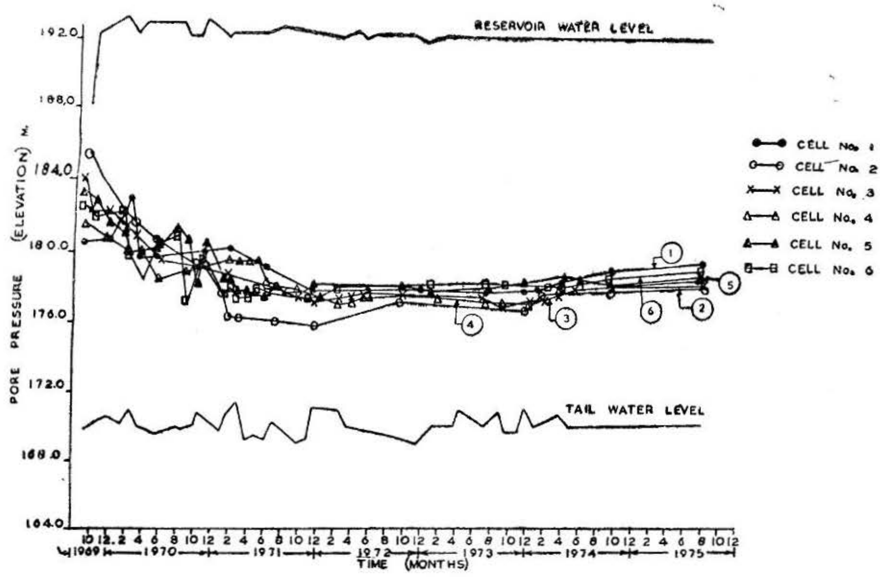

FIGURE 3b Pore pressure observations for piezometers in foundation at section 2-2

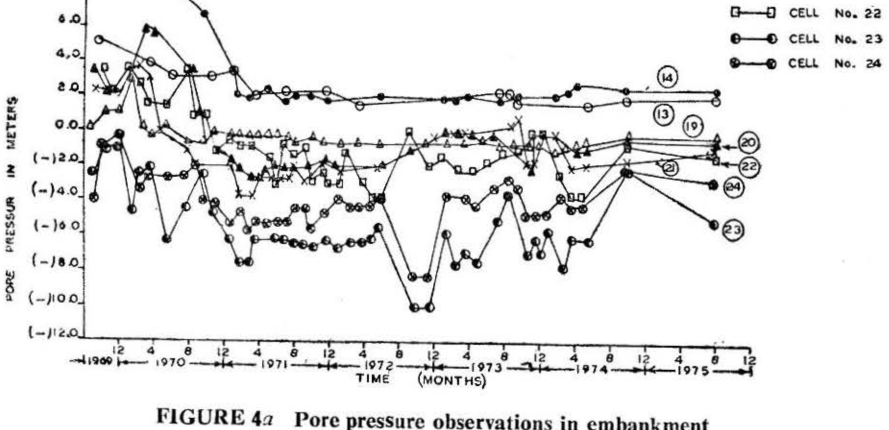

FIGURE 4a Pore pressure observations in embankment (Cell No. 13, 14, 19, 20, 21, 22, 23, 24)

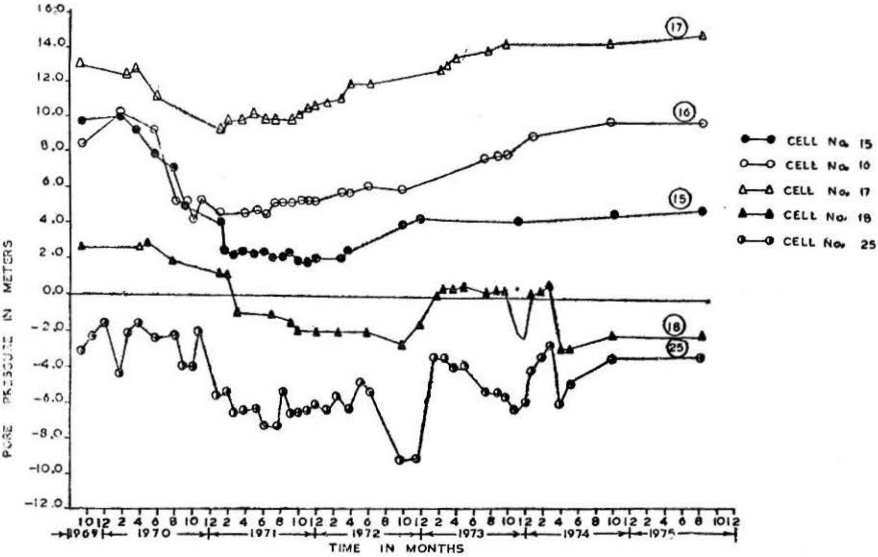

FIGURE 4*b* **Pore pressure observatoins (Cell No. 15, 16, 17, 18, 25)**

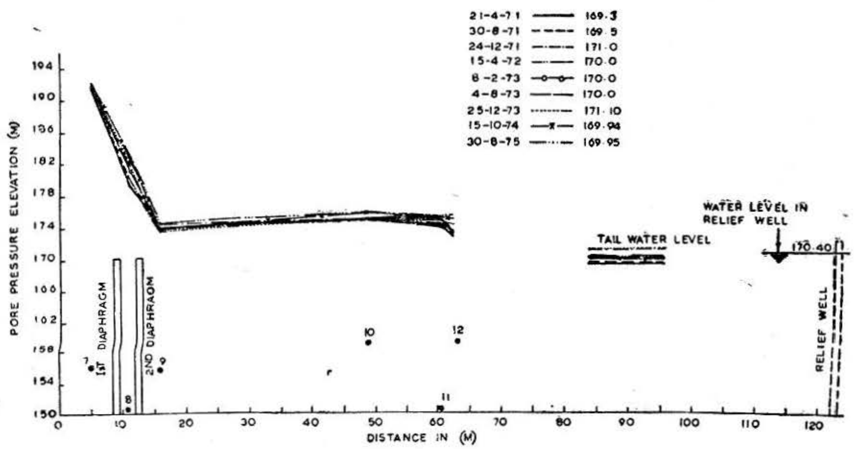

FIGURE 5*a* **Pore pressure variation with respect to position of grout curtain and *piezometers at section 1-1***

initial stage of filling but after the year 1971 they have indicated stabilizing trend.

The pore pressures in different cells with respect to the position of the cut off have again been replotted in Figure 5*a* for few selected dates in six year period alongwith tail water level and water level in the relief well.

These plots indicate :

(*i*) There is very little variation in pressures of the same cell on different dates.

(*ii*) There is marked fall in pressures in cell No. 7 to 8 and 8 to 9.

(*iii*) There is rising trend of pressures in cell No. 9 to 12 and the pressures recorded by these cells are higher than tail water elevation.

(*iv*) Water level in the relief well corresponds almost to tail water level.

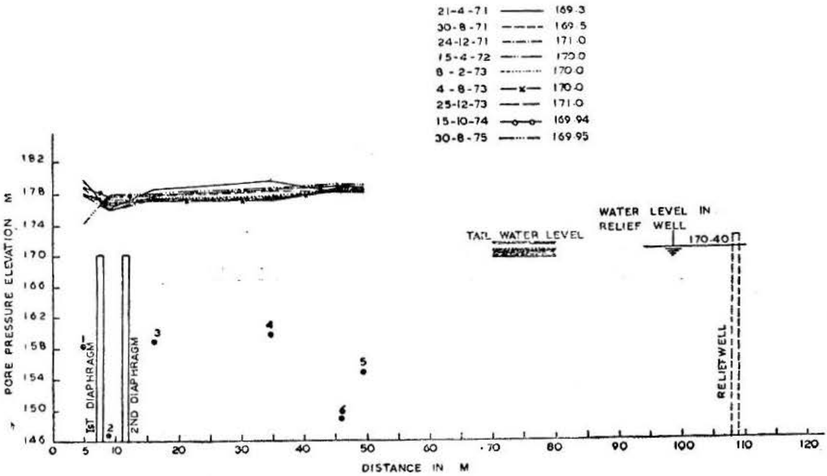

FIGURE 5*b* **Pore pressure variation with respect to position of grout curtain piezometers section 2-2**

The very little variation in the pore pressures in various cells on different dates indicates that the pressures have stabilised in all these cells. The dam being a pickup dam, there is no marked fluctuations in the upstream water level, as a result of which the pore pressures are almost the same in the same cells in different dates. The decrease in pore pressures from cell Nos. 7 to 8 and 9 is due to the fact that the cell No. 7 is situated on the upstream of the cut off, cell No. 8 in between the two diaphgrams while cell No. 9 is on the downstream. The pore pressure observations in cells No. 10, 11 and 12 are little higher as compared to that in cell No. 9. The pressures recorded by cell No. 9 are also higher than the tail water level. The increase in pressure in cells No. 9 to 12 may either be attributed to three dimensional flow from some buried channels underneath deep in the foundation and/or due to malfunctioning of the cells. It may, however, be pointed out that the water head given by the relief wells installed at 65 m downstream from cell No. 12, is almost equal to the tail water elevation. Also, pressure tip No. 12 is almost vertically under the downstream chimney filter and as such, there is hardly any chance of residual pressures at tip No. 12. During six years period of observation, water coming out of relief well has never been noticed. It may, therefore, be reasonable to assume that pore pressure tips No. 9 to 12 may not be recording pressures accurately.

TABLE 1

Efficiency of diaphragm walls from piezometer observations at Section 1-1

Date	*Pore pressure (elevation) in tip No.*						*Relie well*	*RWL m*	*Tail water level m*	*Difference H m*	*Decrease in pore pressure*		*8—Relief well*	*Efficiency*				
														1st diaphragm wall per cent	*II Diaphragm wall per cent*		*Combined per cent*	
	7	*8*	*9*	*10*	*11*	*12*					*7—8*	*8—9*			*From tip observation*	*From relief well obsevation*	*From tip observation*	*From relief well observation*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*
21.4.71	191.31	179.49	173.99	174.8	174.5	173.1	—	192.3	169.3	23.0	11.82	5.50	—	51.0	24.0	—	75.0	—
30.8.71	191.60	180.10	173.99	174.7	174.5	173.9	—	192.5	169.5	23.0	11.50	6.11	—	50.0	26.0	—	76.0	—
24.12.71	191.61	179.50	174.38	174.9	174.1	173.35	—	192.40	171.0	21.40	12.11	5.12	—	57.0	23.0	—	80.0	—
15.4.72	191.60	180.10	173.77	174.9	174.7	173.1	—	192.50	170.0	22.50	11.50	6.23	—	51.0	27.0	—	78.0	—
8.2.73	191.61	181.32	173.62	174.7	175.35	173.3	—	192.25	170.0	22.25	10.29	7.70	—	46.0	35.0	—	81.0	—
4.8.73	191.61	181.47	173.77	174.8	175.3	173.8	—	192.3	170.0	22.3	10.14	7.70	—	45.0	35.0	—	80.0	—
25.12.73	191.70	182.23	173.38	175.0	175.2	174.5	—	192.20	171.10	21.20	9.57	8.85	—	45.0	41.0	—	86.0	—
15.10.74	192.07	181.62	173.47	175.8	175.4	175.4	—	192.40	169.94	22.46	10.45	8.15	—	46.0	36.0	—	82.0	—
30.8.75	192.07	182.23	174.38	175.9	175.5	175.9	170.40	192.40	169.95	22.45	9.84	7.85	11.83	44.1	35.0	51.1	79.0	95.2

TABLE 2

Efficiency of diaphragm walls from piezometer observation at Section 2-2

Date	*Pore pressure (elevation) in tip No.*										*Decrease in pore pressure*			*Efficiency*				
	1	*2*	*3*	*4*	*5*	*6*	*Relief well*	*Reservoir water level m*	*Tail water level m*	*Difference H m*	*1-2*	*2-3*	*Relief well*	*Ist diaphragm wall*	*IInd diaphragm wall percent*	*Relief well*	*Combined per cent*	*Relief well*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*
21.4.71	179.65	176.15	178.30	179.4	177.7	177.6	—	192.30	169.30	23.0	3.40	—2.15	—	14.0	—9.0	—	5.0	—
30.8.71	178.65	175.95	177.60	177.9	177.75	177.70	—	192.50	169.50	23.0	2.70	—1.65	—	12.0	—7.0	—	5.0	—
24.12.71	177.80	175.90	177.15	177.55	177.85	177.7	—	192.40	171.00	21.40	1.90	—1.25	—	9.0	—6.0	—	3.0	—
15.4.72	177.85	176.45	177.40	177.20	177.95	178.0	—	192.50	170.00	22.50	1.40	—0.95	—	6.0	—4.0	—	2.0	—
8.2.73	177.85	177.20	177.55	177.40	177.90	178.0	—	192.25	170.00	22.25	0.65	—0.65	—	3.0	—3.0	—	0.0	—
4.8.73	177.90	176.90	177.15	177.00	177.90	178.0	—	192.30	170.0	22.30	1.0	—0.25	—	5.0	—1.0	—	4.0	—
25.12.73	177.90	176.70	177.50	177.20	178.20	178.1	—	192.20	171.0	21.20	1.20	—0.60	—	6.0	—4.0	—	2.0	—
15.10.74	178.80	177.55	177.70	177.90	178.40	178.30	—	192.40	169.94	22.46	1.25	—0.20	—	5.0	—1.0	—	4.0	—
30.8.75	179.20	177.70	178.00	178.10	178.60	178.60	170.40	192.40	169.95	22.45	1.50	—0.30	7.3	7.0	—1.0	32.0	6.0	39.0

TABLE 3

Efficiency of diaphragm walls assuming malfunctioning of cells at Section 2-2

Date	*Pore pressure (Elevation) in tip No.*			*R.W.L.*	*T.W.L.*	*H m*	*Decrease in pore pressures*		*Efficiency*		
	7	*2*	*Relief well*				*Tip No. 7 —Tip No. 2*	*Tip No. 2 —Relief well*	*Ist Diaphragm wall per cent*	*IInd Diaphragm wall*	*Combined per cent*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
21.4.71	191.31	176.15	—	192.30	169.30	23.0	15.16	—	70.0	—	—
30.8.71	191.30	175.95	—	192.50	169.50	23.0	15.35	—	71.0	—	—
24.12.71	191.60	175.90	—	192.40	171.00	21.40	15.70	—	73.0	—	—
15.4.72	191.6	176.45	—	192.50	170.00	22.50	15.15	—	70.0	—	—
8.2.73	191.61	177.20	—	192.25	170.00	22.25	14.41	—	64.0	—	—
4.8.73	191.61	176.90	—	192.30	170.00	22.30	14.71	—	66.0	—	—
25.12.73	191.70	176.70	—	192.00	171.00	21.20	15.00	—	70.0	—	—
15.10.74	192.07	177.55	—	192.40	169.94	22.46	14.52	—	64.0	—	—
30.8.75	192.07	177.70	170.40	192.40	169.95	22.45	14.37	7.3	64.0	32.0	96.0

The effectiveness or efficiency of a grout curtain has been defined (Casagrande, 1961) as the ratio $(q-q_c)/q$ where q is the seepage through the foundation without the grout curtain and q_c with the grout curtain. In the absence of any data with regard to the seepage with grout curtain, the efficiency of the cut off was determined from the decrease in pressure heads using the formula $(p_1-p_2)/p$ where p_1 and p_2 are the pressure heads upstream and downstream of the cut off respectively and p is the effective reservoir head. The same has been computed for both the diaphgrams and have been tabulated in Table 1, by taking pressure observations of cells No. 7, 8 and 9 and also water level in the relief well. It is seen that at section 1-1, the efficiency of first diaphragm wall is of the order of 45 to 50 per cent and that of second wall is 25 to 35 per cent, when pressure observations of tip No. 9 are taken into account. The efficiency of second wall, however, increases to 50 per cent when water level in relief well is considered and pressure observation of tip No. 9 is neglected. The overall efficiency of cut off is of the order of 75 to 80 per cent when considering tip observations and 95 per cent when considering water level in the relief well.

Foundation Pore Pressures at Section 2-2

The pressure observations at Section 2-2 plotted in Figure 3*b*, indicate almost similar trend as in section 1-1 with the difference that the pressure head indicated by cell No. 1 just upstream of the grout curtain is only 45 per cent as compared to 93 per cent indicated by cell No. 7 embedded in almost similar position. This may be either due to the malfunctioning of cell No. 1 or due to its embedment in some local pocket of the impervious material resulting into the indicated amount of head loss.

The pore pressure observations in different cells with respect to their position of cut off for this section for few selected dates in six years along with the water head in relief well have been replotted as before in Figure 5*b*. It is seen that the pore pressures indicated by cell No. 1 are the maximum for all the dates. These pore pressures have decreased in cell No. 2 due to its location being between the two diaphragms. The pressures indicated by cell No. 3 have, however, shown an increase in pore pressure whose trend is again different than that shown by cell No. 9 located in the similar position in section 1-1. The observations of cells 4 to 6 have shown further rise in pore pressures. But as in section 1-1, the water head indicated by the relief well is almost equal to the tail water elevation. The rising trend of observation indicated by cells No. 3 to 6 seems therefore erratic and for computation of efficiency the pressure on the downstream of grout curtain may be taken as that given by relief wells.

The efficiency of the cut off was computed for the pressures recorded by the tips and is tabulated in Table 2. The same was also computed by assuming that (*i*) cell No. 1 is malfunctioning and the trend upstream in the section, is the same as indicated by cell No. 7 in section 1-1, (*ii*) Cell No. 2 is working satisfactorily and (*iii*) water level in relief well is accounted for whereas observations of tip No. 3 to 6 are neglected. The efficiency, thus computed is tabulated in Table 3. It is seen that for the first case, the efficiency of the first diaphragm wall is of the order of 5 to 15 per cent and that of second wall of 1 to 9 per cent whereas for the second case, the efficiency is of the order of 60 to 70 per cent and 30 per cent for first and second diaphragms respectively. From this it is apperant that if it is taken for granted that cell No. 1 is functioning properly then the cut-off is not effective at all and a lot of seepage should have been observed in the section of the dam. But as this is not the case as per visual examination in the field, the second approach seems to be correct and in this way the grout curtain is effective by 96 per cent at this section.

The observations of pore pressures made on the upstream and downstream of the diaphragm walls in the two sections thus indicate that a single diaphragm wall is effective only to the extent of 45 to 60 per cent and therefore a double diaphragm with intervening space grouted must be provided to get an effective cut off for control of seepage.

As regards the performance of grouted space between the two diaphragms, specifications required that the 50 mm diameter holes drilled 25 m centre to centre along the centre line of grouted space, should not indicate permeability more than 10^{-3} cm/sec. Tests conducted in 20 holes, indicated that the permeability of grouted sand varied from 5 to 200 $\times$ 10^{-6} cm/sec as found out by falling head method.

The efficiency of grout curtain depends upon (*i*) the ratio of impervious bed width of dam (B) to the total depth of pervious strata (D), (*ii*) ratio of cut off width (l) to the pervious starta depth (D), (*iii*) open space ratio-W/D which is ratio of total length of leakage in the cut off depth (W) to the total depth of cut off (D) and (*iv*) the number of open spaces n. According to Ambrasseys (1961), for l/D=5 per cent for W/D=1 per cent, the efficiency of grout curtain cut off is 84 per cent and 35 per cent for B/D=1 and B/D=10 respectively, irrespective of the number of openings n varying between 10 to infinity. For B/D=4, the efficiency would be about 65 per cent. In the case of grout curtain of Obra dam, having B/D=4, width l=3 m, depth of pervious stratum D = 20 m, for the ratio l/D = 15 per cent the efficiency is likely to be more than 65 per cent which is the value for l/D = 5 per cent. Since the grouted space is confined in between the two concrete diaphragms, the chance of higher open ratio is remote.

Keeping in view the fact that wide cut off has been provided encased by concrete diaphragm, the efficiency of such type of cut off walls can be taken safely as 90 to 95 per cent.

Pore Pressures in Dam Section

The dam section had been constructed of clayey material (*CL*) with gravel ranging between 6 to 16 per cent, liquid limit 30 to 40 per cent and plasticity index 13 to 20 per cent. The coefficient of permeability of the embankment material was 5 $\times$ 10^{-6} cm/sec. The Proctor's maximum dry density at which the material was placed, was 1.8 gm/cc at O.M.C., 15.4 per cent. The fill placement was done at moisture content 2 per cent higher than O.M.C. The degree of saturation of the material computed by assuming specific gravity value of 2.7, worked out to 90 per cent at the time of placement.

The observations of piezometric cells embedded in the dam section are plotted in Figures 4*a* and 4*b*. It is seen that the pore pressure in the lower most tier are indicating positive pore pressure while in the upper two tiers negative pore pressures are recorded. This may be attributed to the fact that the line of saturation during the last six years has traveled through the first tier only and thus the zone above this line of saturation, is indicating negative pore pressure.

The time for complete saturation of the Obra dam was also computed by the method outlined by Cedergren (1967). Assuming the coefficient of permeability of 5×10^{-6} cm/sec of the embankment material and assuming 25 per cent porosity, the time for complete saturation worked out to 125 years. Since the reservoir has been filled during the past six years only, the line of saturation has moved only in the lower most tier. This time for complete saturation was also computed by assuming that the embankment has been constructed anisotropically compacted with horizontal permeability equal to four times the vertical permeability. The average permeability by this assumption works out to 10×10^{-6} cm/sec and the time for saturation for this value of permeability coefficient worked out to 75 years which is again very large as compared to the 6 years filling of the reservoir.

It may also be pointed out that the foundation strata is highly draining having permeability of the order 1 to 0.3 cm/sec as compared to the embankment material and its permeability may be of the same order or may be even more as that of the chimney drain material. It is just possible that the filter material in chimney drain might not be draining as effectively as envisaged in design due to comparatively lesser permeability of the material placed where as the foundation material might be acting as more effective draining material with the result that the phreatic line is deflected towards the foundation. If this is correct then further rise in phreatic line in times to come may not be possible. This is also important due to the fact that fill has been placed at 90 per cent saturation and time required for saturation, should not be too long. However, this has to be verified with the help of further observations.

Conclusions

The study indicates that diaphragm type cut off walls are satisfactory to reduce the hydrostatic pressures and seepage. However, single diaphragm is not likely to be dependable and two diaphragms with intervening space grouted, should be used. Inspite of the high degree of saturation of embankment material at which it was placed, the piezometric observations indicated that the phreatic line has traveled in the lower portion of the dam only during the past six years of the reservoir filling. This may perhaps be due to presence of very pervious foundation stratum.

Acknowledgement

The observational data for pressures was collected by the staff of U.P.I.R.I. Roorkee and the analysis thereof was carried out by staff and Assistant Research Officer of IV Sub-Division Soil Laboratory under the guidance of Shri M.C. Goel, Research Officer. The assistance rendered by Shri D.N. Bhargava, Assistant Research Officer and his staff is gratefully acknowledged.

References

HARKAULI, A.N., SHARMA, H.D., and BHARDWAJ, L.P., (1972), "Foundation Problems at Obra Dam", *Indian Geotechnical Journal*, Vol. 2 Number 1, pp. 21-40.

U.S.B.R. (1965), *Earth Manual*, E-27 Instructions for Installing and Reading piezometers in Earth Dams.

CASSAGRANDE, A., (1961), "Control of seepage Through Foundations and Abutments of Dams", First Rankine Lecture, *Geotechnique*, Vol. XI, No. 3, pp 161-181.

AMBRASEYS, N., (1961), Correspondence on Cassagrande's Lecture, *Geotechnique*, Vol. XI, No. 4 pp. 362-364.

CEDERGREN, H.R., (1967), *Seepage Drainage and Flow Nets*, John Willey & Sons, Inc. Publications, pp 253.