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Construction Pore Pressures — Case Study of Ramganga Dam

Pressions Interstitielles durant l'Exécution: Barrage de Ramganga

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SYNOPSIS The observational data of pore pressures during construction period for 128 m high Ramganga zoned section is collected and analysed. The paper discusses the comparison of the analytical results found by different methods with the observational data. It is seen that assumed design values of construction pore pressures were higher than those actually developed or those determined by various analytical methods. The nature of pore pressure curve obtained by Gibson's method, is different from that of the actually observed curve.

INTRODUCTION

The correct prediction of construction pore pressure for a fill at the design stage is difficult in view of uncertainities involved. Some of the important factors that affect the development of construction pore pressures are the soil type and its compressibility, placement moisture content, permeability, drainage conditions, rate of construction and shutdown periods, degree of compaction, embankment section etc. Hilf's method (1948) for estimation of construction pore pressures does not take into account the drainage effect whereas Bishop's method (1957) takes into account the shutdown during construction. Li (1959) extended Bishop's method for accounting the rate of construction. These three methods depend on the results of laboratory tests and should be supplemented by field observations. Gibson (1958) has given a partial differential equation based on the theoretical analysis of consolidation of a clay layer increasing in thickness with time using assumptions similar to Terzaghi's one-dimensional consolidation theory. The method takes into account the rate of construction and shutdown periods also and thus can be used for prediction of pore water pressures during construction. Gray (1972) has solved this equation by finite difference approach for Trinity Dam.

The basic partial differential equation governing the pore pressures set up in an earth dam during construction is

$$c_v . \frac{\partial^2 u}{\partial x^2} = \frac{\partial u}{\partial t} - \gamma . \bar{B} . \frac{dh}{dt} \qquad \ldots (1)$$

where

c_v = coefficient of consolidation

u = pore pressure at any height x from base at any time t.

γ = density of fill material

$\bar{B}$ = Skempton's pore pressure coefficient $= \Delta u / \Delta \sigma$

$\frac{dh}{dt}$ = rate of construction

$\Delta \sigma$ = change in major principal stress

The finite difference form of the Eq.1 after rearranging the terms is,

$$u_{i,j} = u_{i-1,j} + B_o (u_{i-1,j+1} - 2u_{i-1,j} + u_{i-1,j-1}) + m \qquad \ldots (2)$$

where

$$B_o = \frac{c_v . \Delta t}{(\Delta x)^2} \qquad \ldots (3)$$

$$m = \gamma \bar{B} . \Delta h \qquad \ldots (4)$$

i, j are prefixes for node of F.D. grid in space and time direction respectively.

x, t are increments in space and time respectively.

A case study of construction pore pressures of Ramganga dam is presented in the following paragraphs.

RAMGANGA DAM

Geology & Dam Section

Ramganga Dam is a 128 m high earth and boulder fill dam constructed across the river Ramganga in U.P. State of India in 1974. The length of dam at river bed is 91 m increasing to about 608 m at the crest. The dam rests on alternate bands of sand-rock and clay shale of middle Siwalik age, the prevalent strike being N 60° W-S 60°E, the dip being 35° - 45° NNE. Sand rocks are poorly consolidated and cemented and are easily crushable. Sand rocks constitute the major rock formation. The clay shales are also largely uncemented, mostly compact in appearance, but sometimes thickly bedded. The clay shales comprise of about 22 percent of the formation at the dam site. The valley is located in high seismic zone. The dam comprises of a zoned section with a clay shale core flanked by zones of crushed sand rock with shells of river bed material. A general section of the dam with the piezometer installation has been shown in Fig. 1.

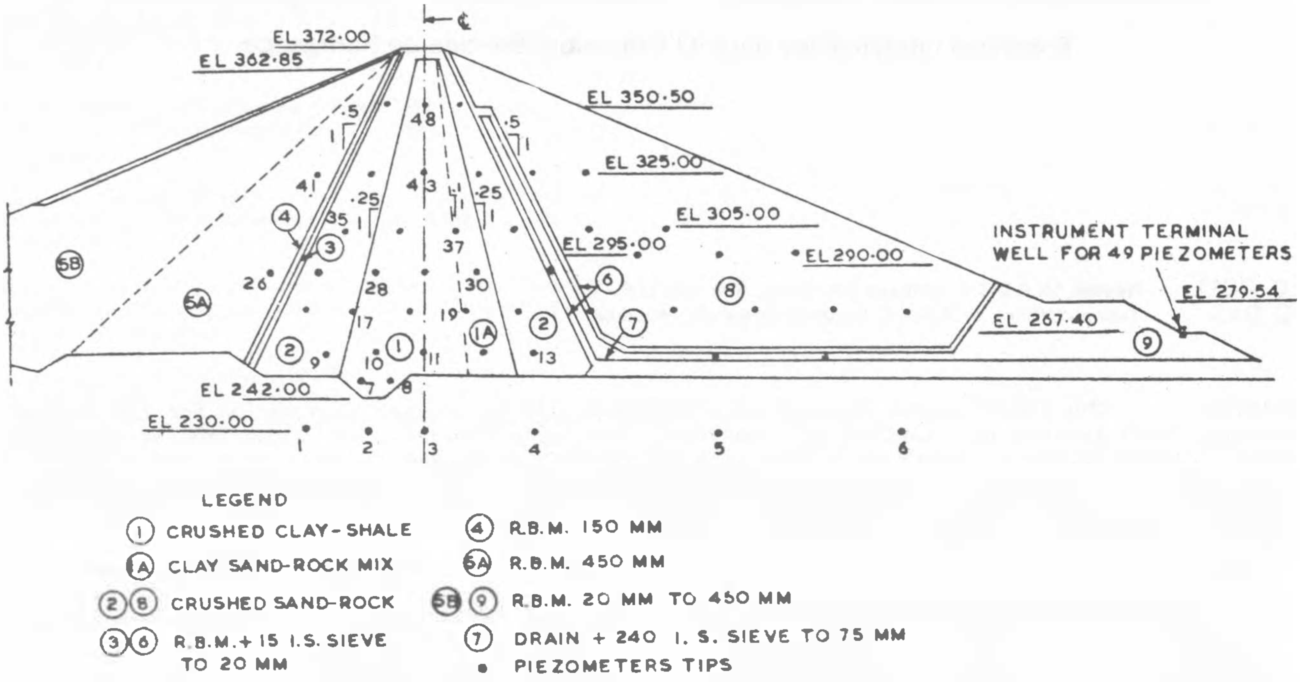

FIG. 1 CROSS SECTION OF RAMGANGA DAM SHOWING PIEZOMETER TIPS.

The material properties of fill material are indicated in Fig. 1 and Table - 1.

Table 1 -Properties of Construction Material

Properties	Clay shale	Sand rock
Coefficient of permeability	0.01×10^{-6} cm/sec	0.8 to 20×10^{-6} cm/sec
Cohesion 'c'	1.0 kg/cm^2	0.35 kg/cm^2
Ange of internal friction 'Ø'	22^o	35^o
Plasticity Index (P.I.)	6% to 14%	Nil
Specific gravity 'G'	2.7 to 2.73	2.66 to 2.69

The entire foundation under the core, after removing weathered rock, was excavated 1.5 m inside sound rock, and a 9 m wide cut off trench was provided under the clay core located at the upstream edge. The trench was backfilled with clay. The grout curtain upto 0.5 H is provided approximately in the centre of cutoff trench because of the erodable nature of otherwise impermeable foundations.

Instrumentation

To know the pore pressures during and after construction, U.S.B.R. twin-tube hydraulic piezometers, both embankment and foundation type, were installed in Ramganga Main Dam at the section 393.5 m from the end point B on the left abutment of the dam (Goel and Tyagi, 1974). Pore pressures were recorded from the date of installation at regular intervals of

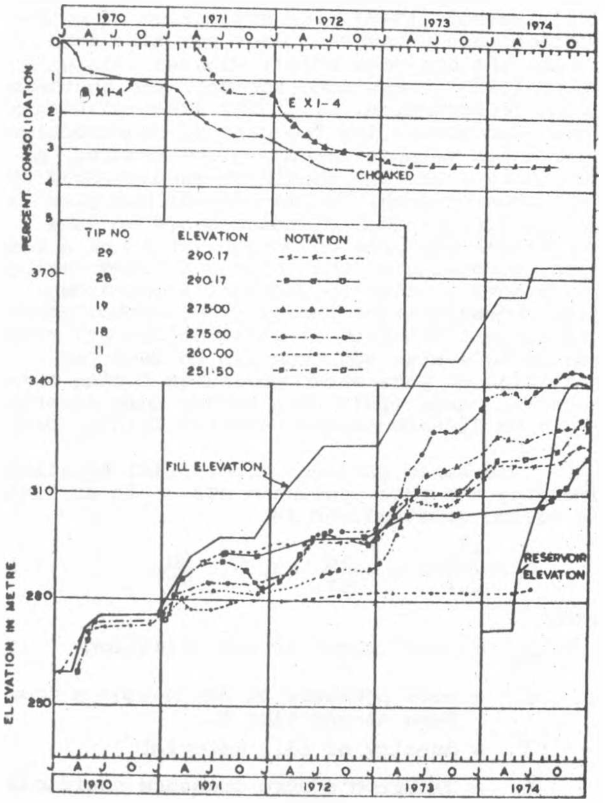

FIG. 2 OBSERVED PORE PRESSURE AND SETTLEMENT OF RAMGANGA DAM (CLAY CORE)

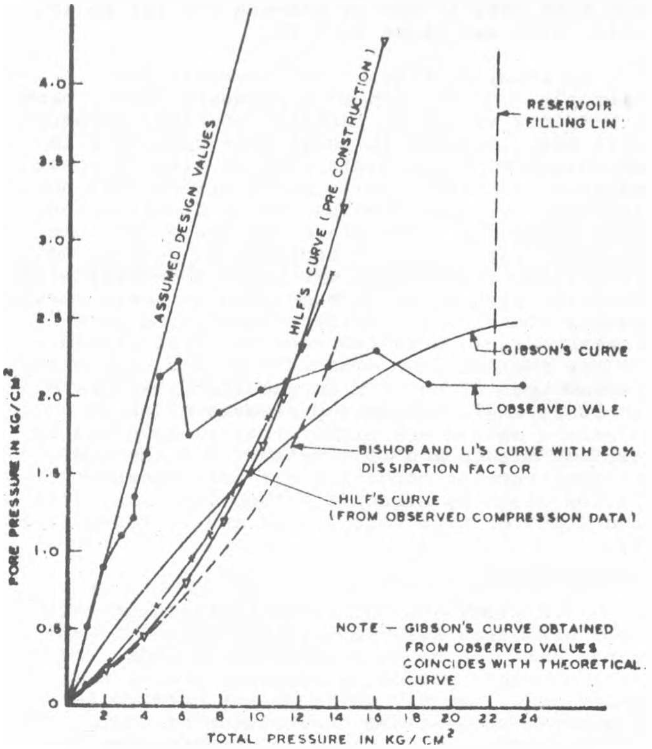

FIG. 3 CONSTRUCTION PORE PRESSURE FOR TIP NO 11 IN CLAY CORE

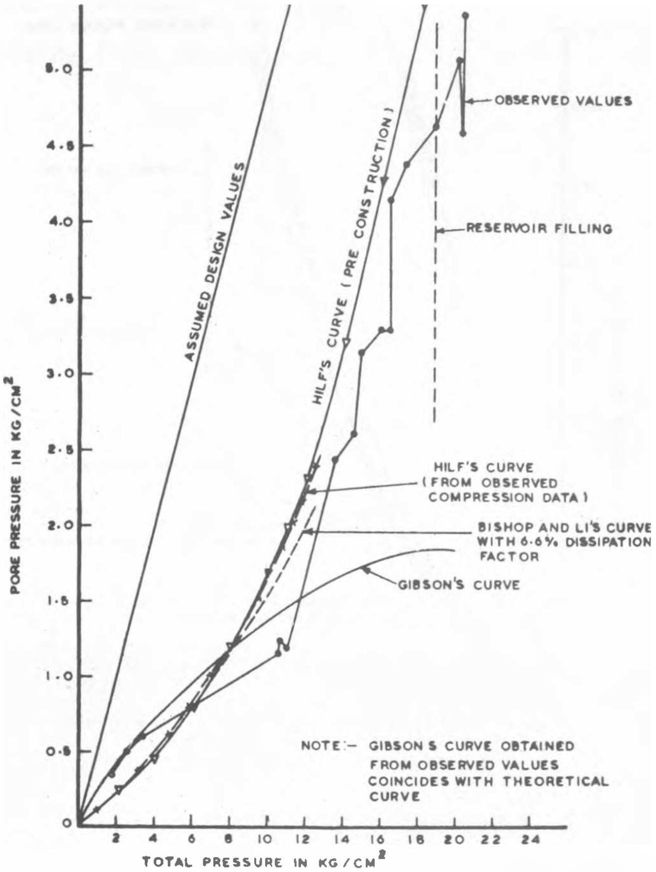

FIG. 4 CONSTRUCTION PORE PRESSURE FOR TIP NO 19 IN CLAY CORE

15 days in the terminal well by means of Bourdon gauges.

To know the settlements during and after construction of the dam, six U.S.B.R. combined vertical settlement and horizontal movement devices were installed. Three were installed in the deepest corss-section out of which, device, 'A' is in upstream pervious shell of R.B.M., device 'B' in central clay core and device 'C' in downstream outer shell of crused sand rock. The vertical devices D, E and F are all provided in clay core, device 'D' being near steep left abutment and E and F near steep right abutment. The settlement data was measured periodically by measuring the distance between two cross arms which were fitted at about 3 m interval.

OBSERVATIONAL DATA AND ANALYSIS

Presentation of Results

The total pore pressure at a tip is obtained from the measured value in metres of water head by adjustment for the tip elevation. For the clay core, the plots of pore pressure against time are shown in Fig.2. In the same figure cumulative settlement with time is also shown. Construction pore pressures estimated by Hilf's method using effective stress-volume strain relationship obtained from laboratory tests prior to start of construction without accounting for drainage at the design stage along with the assumed design and observed values for different total stress values are shown in Fig.3 to 5 for tips no.11, 19 and 29 respectively, embedded in the clay core. Using actually observed effective stress-volume strain relationships on prototype, Hilf's construction pore pressures for these tips have also been plotted in these figures for comparison . Goel and Basa (1979) have shown that dissipation factor for tips no.11, 19 and 29 was found to be 1/5, 1/16 and 1/10 respectively using L_i's method. The construction pore pressures corresponding to these values, have also been plotted in these figures. Also construction pore pressures from Gibson's method have been found and plotted in these figures. The value of consolidation coefficient c_v was determined from tests performed on undisturbed samples collected after construction. Similarly for values of B, actual field compression has been taken into account. For analysis purposes, the observed settlement data of device B should have been used because of its proximity to the tips under consideration. As construction of the dam was started after the monsoon of 1969 and continued upto June 1974, the data of settlement should have been available for this entire period. However, in October, 1972, the vertical device B became choked and the fill elevation attained at this data was 323 m giving a total stress of 16 kg/m^2 whereas the fill elevation for entire height

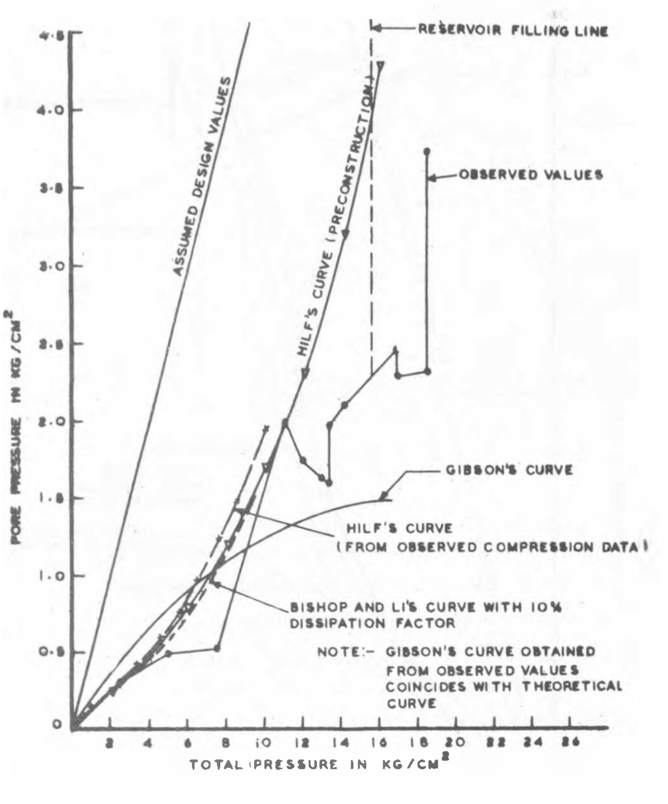

FIG. 5 CONSTRUCTION PORE PRESSURE FOR TIP NO 29 IN CLAY CORE

of dam was 372 m giving a total stress of 25 kg/m^2. Hence for the entire range of total stress, settlement data on device "B" is not available. In order to cover the complete range of total pressure in computing B, the vertical device "E" which is located at El. 282.61 in clay core and is fairly close to device B, has been considered. The pore pressures after taking into account the settlement as recorded by devices B and E were calculated and it was found that the trend of pore pressure development in both the cases was practically the same and as such the pore pressure development based on field compression of device E was used for determination of values of B. The entire construction work was completed in five working seasons and five work stoppages.

DISCUSSION

At design stage it was assumed that construction pore pressure would be 50% of the total stress. This was based on the enveloping of the various Hilf´s curves obtained from laboratory test results. Figs. 4 & 5 indicate that construction pore pressures developed in tip nos. 19 and 29 are much less as compared to assumed design value. However, for tip no.11 (Fig.3) the construction pore pressures are more or less coinciding with the design values at low heights but subsequently the pore pressure values have come down considerably indicating that for end of construction condition, the assumed design values were conservative. The pore pressure ratios at the end of construction have been of the order of 0.10 for tips nos. 11 and 29 whereas for tip no.19, this value was close to 0.22.

A study of Figs. 3 to 5 reveals that Gibson´s construction pore pressure curves have a tendency to become parallel to total pressure axis with increase in total pressure. This is explainable on the basis that as time of construction increases, while total stress does not increase, greater dissipation of construction pore pressures takes place and hence the pore pressure ratio goes on decreasing. This trend is different from that exhibited by curves given by Hilf, Bishop and Li´s methods as these curves have a tendency to indicate increasing pore pressure ratio with increase in total pressure. It has further been noticed that for dam constructed upto 40 to 50 m height (total stress 8 to 10 kg/cm^2), the pore pressures given by Gibson´s method are higher than those given by Hilf or Bishop and Li´s method. For the end of construction condition the pore pressure ratios given by Gibson´s method are 0.11, 0.19 and 0.09 for tips nos. 11, 19 and 29 respectively.

CONCLUSIONS

The study has indicated that construction pore pressures assumed for the design of Ramganga dam, are on the conservative side. The pore pressure ratios as observed are of the order of 0.1 to 0.2 which do not conform to predicted values. The correctness of the values predicted by Gibson´s method, depends upon the selection of values of c_v and B.

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