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Behaviour of Ramganga Dams

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SYNOPSIS Two earth and boulder fill dams of height 127.6m and 72.2m are major structures of Ramganga River Project. Their foundation rocks are alternations of clayshale and sandrock of Middle Siwaliks. Both have thick core consisting of central zone of crushed clayshale encased by crushed sandrock zones. The clayshale and sandrock available from spillway excavations, just adjacent to these dams, were utilized as dam fill. No major problem except that of seepage control in cut off trench excavation and compaction near abutments, was encountered during construction. Both the dams are well instrumented. Their construction was completed in 1974-75 and the reservoir has nine fillings since then. Observations reveal that phreatic line has not yet been fully established. The stressmeters installed in clay zone of the core of main dam show effective stresses less than half of the overburden effective stresses, thereby indicating arching due to interaction between clay and sand zones of core.

INTRODUCTION

Ramganga River is a tributary of River Ganga. Its discharge varies from minimum 2.2 cumecs during winters to 6430 cumecs during monsoons. In order to utilize the flood waters of the river, the multipurpose scheme was formulated primarily for irrigation, power generation and flood protection. It was decided to construct an earth dam (main dam) across the river in the Sub-Himalayan region of Siwalik ranges at the site which is 3 kms upstream from the place where the river enters the plains.

The layout of the main works of the project is shown in figs. 1 and 2. The project comprises of the following major structural components: (1) Two circular diversion tunnels of 9.45m dia on the right flank of the dam. The tunnels have been designed to carry a discharge of 1 in 1000 year frequency flood. One of the tunnels has been later used as power tunnel and the other has been provided with irrigation outlets, (2) Main dam across river Ramganga is an earth and boulder fill structure, the deepest foundation being at EL. 244.4m and the height of the dam above it is 127.6m. The height has been provided so that the flood waters of 26 out of 100 years shall be fully stored, (3) Saddle dam, required to plug saddle on left flank of the reservoir, is an earth and boulder fill structure. The deepest foundation being at EL 299.8m and the height of the dam 72.2m, (4) Chute spillway and its control structure, with crest at EL 352.0m, is located on the right abutment of the main dam. The spillway, having a designed discharge capacity of 7600 cumecs, has been provided with 5 bays of 142.0m each. A slope of 1 in 3 has been provided in the chute with a deep stilling basin for energy dissipation by formation of hydraulic jump, (5) Auxiliary spillway (chute type) is located on the right flank of the saddle dam. It would come in operation when the flood exceeds the 1 in 750 year frequency flood. It has 3 bays of 142.0m each. A flip bucket has been provided at the end of the outfall, (6) Irrigation outlets to give a discharge of 142 cumecs have been embedded in one tunnel under the chute spillway. The discharge is controlled by means of Butterfly and Inwell Bungers valves. Water from the reservoir shall normally be released through turbines, but, in the inevitability of any breakdown in the power plant, these outlets shall be made use of, (7) Power Intake struct-

Fig. 1. Layout of Main Works of the Project
ure to get controlled quantity of water from reservoir and pass to the penstocks to run the turbines. (6) Power House, located on the main dam toe and founded on sandrock band. It has been provided with three Francis Turbines of 66 M.W. each. (7) Drainage Tunnels on left and right abutments of main dam and the left abutment of saddle dam have been provided in 1500m length for release of seepage water expected through joints of sandrock and clayshale bands. In addition to the above, two galleries in the chute spillway have been provided: one in the control structure under the crest and another along the centre line of the chute. The drainage tunnels, 2.1m high and of 1.5m width, are D shaped having vertical sides and semicircular top.

This paper describes about the Main Dam and Saddle Dam, the design and construction problems encountered and the behaviour of the dams during construction period and the nine years' period after the construction.

GEOLOGY OF THE AREA

(i) Main Dam

The Middle Siwalik rocks were clearly exposed at the dam site. These continue for a distance of 7 km upstream of the dam site. These comprise of alternation of sandrock and clayshale, the latter constituting about 25% of the total rock sequence in the dam area.

The general strike of the rock was observed N 40° W/S 40° E to N 80° W/S 80° E with dip varying between 35° to 45° towards upstream direction. Since the axis of the dam is aligned in N 80° 58' 45" W/S 80° 56' 45" E direction, it is oblique to the general trend of the rock sequence by about 30°. The foundation rocks of the dam, consist of a sequence of Sandrock and clayshale bands which were locally numbered as 4 to 20 as indicated in Table 1. Amongst these rock bands, the odd and even numbers indicate sandrock and clayshale bands respectively. Due to the bands of sandrock which were less erodable than interbedded clays, a typical topography of ridges and saddles of the Siwalik country had been formed.

TABLE I Thickness of Clayshale and Sandrock bands at Main Dam Site.

<table>
<thead>
<tr>
<th>Band Number</th>
<th>Thickness of band (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>17.7</td>
</tr>
<tr>
<td>2</td>
<td>9.4</td>
</tr>
<tr>
<td>6</td>
<td>25.6</td>
</tr>
<tr>
<td>7</td>
<td>23.9</td>
</tr>
<tr>
<td>8</td>
<td>43.9</td>
</tr>
<tr>
<td>9</td>
<td>16.7</td>
</tr>
<tr>
<td>10</td>
<td>20.7</td>
</tr>
<tr>
<td>11</td>
<td>25.3</td>
</tr>
<tr>
<td>12</td>
<td>25.3</td>
</tr>
<tr>
<td>13</td>
<td>15.8</td>
</tr>
<tr>
<td>14</td>
<td>5.8</td>
</tr>
<tr>
<td>15</td>
<td>12.8</td>
</tr>
<tr>
<td>16</td>
<td>1.5</td>
</tr>
<tr>
<td>17</td>
<td>4.5</td>
</tr>
<tr>
<td>18</td>
<td>10.6</td>
</tr>
<tr>
<td>19</td>
<td>15.8</td>
</tr>
<tr>
<td>20</td>
<td>42.6</td>
</tr>
</tbody>
</table>

Regarding lithological character of the rocks, the terraces comprised principally of boulders of quartzite and sandstones inter mixed with micaceous sand, fragments of slates, quartzites and clayshales. The sandrocks were most poorly consolidated and cemented where not calcified and hence were easily crushable and friable; some of the bands disintegrated when soaked in water. Hard calcified layers and lenses were occasionally met within the generally soft sandrock sequences. Two varieties of clayshales were present in the dam area, one chocolate coloured and other green coloured, the former being more common. But the varieties were nodular, largely unconsolidated, mostly compact in appearance, some time thinly bedded. These were variable in thickness and included sandy and silty layers, a few being highly plastic and sticky, but with thin layers of clay. All the clayshales showed air-slackening. The clayshale contained harder bands which were principally siltstones or contained a larger admixture of silty and sandy materials. The insite clay was practically impervious.

(ii) Saddle Dam

At the saddle dam site, the Middle Siwalik rocks consisted of alternation of sandrock and clayshales, the latter being thinner and constituting only 11% of the sequence; number of pebble beds were also associated with sandrock bands at the site.

The sandrock bands at the site were much more poorly consolidated and cemented compared to those at the main dam site due to their younger age and higher position in the Siwalik sequence. They varied in texture from fine to coarse grained. All of them were markedly friable under slight pressure and easily disintegrated when soaked in water.

A much more marked lateral variation in the thickness of the sandrock and clayshale bands
had been recorded at this site as compared to the members at the main dam site. Some of the clayshale bands had been completely pinched out and some contained a number of sandrock lenses and thus minimised the effective thickness of the band for control of seepage through the foundations of the dam.

The strike of the rock beds at the site was recorded between N 70° - 80°W - S 70° - 80°E and the dip varied between 23° - 32° in NNE, or upstream direction.

**DESIGN OF DAMS**

(i) **Main Dam**

The dam consists of three zones of impervious material (fig. 3), the central inner core is of crushed clayshale (zone-1) surrounded by crushed sandrock (zone-2) on both sides, mainly borrowed from chute spillway excavation. The outer upstream shell consists of previous zone of river bed material (zone-5) with transition filter (zone-4) between pervious and impervious zones. A filter drain (zone-5 and 7) underneath the downstream outer shell has been provided to keep outer shell (downstream sandrock zone-3) free from saturation.

**TABLE II Design Values for Embankment Materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Shear Values</th>
<th>Unit Weights, T/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>φ deg.</td>
<td>C, kg/cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moist</td>
</tr>
<tr>
<td>Sandrock</td>
<td>33</td>
<td>0.344</td>
</tr>
<tr>
<td>Clayshale</td>
<td>22</td>
<td>0.97</td>
</tr>
<tr>
<td>Pervious (unscreened)</td>
<td>38</td>
<td>-</td>
</tr>
<tr>
<td>Pervious (screened)</td>
<td>38</td>
<td>-</td>
</tr>
</tbody>
</table>

Seismic coefficient of 0.12 was adopted for carrying out pseudo static slope stability analysis for steady seepage condition. Half of this value (0.06) was adopted for temporary conditions of end of construction and sudden drawdown. The analyses were carried out (Chaturvedi and Lavania 1970) on electronic digital computer. Construction pore pressures in Clayshale and sandrock, worked out from one dimensional consolidation curves of the two materials, were adopted to be half and one-fourth of the total stress above the point considered. The steady state and drawdown pore pressures were assumed equivalent to a water column of height equal to the vertical distance between the point under consideration and the phreatic line or the free water surface.

The in situ permeability tests indicated the average coefficient of permeabilities of clayshale and sandrock in foundation of the order of 2.4 x 10⁻⁵ cm/sec and 3.0 x 10⁻⁵ cm/sec. The permeability decreased with depth. The remoulded sample permeability values were much less. The cut off trench, varying in depth from 4.5m to 9.1m depending on the depth of overburden, was provided below the impervious core and was connected to foundation clayshale band. A single line grout curtain below the cut off trench was recommended. For proper contact and to reduce differential settlements, abutment slopes in transverse and longitudinal direction were specified. Abutment drainage tunnels were provided to reduce uplift. It was decided to provide a number of piezometers, settlement measuring devices, pressure cells and surface monuments for ascertaining the behaviour of the dam during and after construction.
As for the main dam, the design of saddle dam was based on maximum utilisation of the most readily available materials. The core is made up of a central zone of clay flanked by sand-rock on either side (Fig. 4). The upstream shell consists of river bed material and an impervious blanket of crushed sandrock under it with a minimum thickness of 5.0m on flanks, increasing to about 10.0m towards the deepest section. The downstream shell is made up of crushed sandrock separated from the core by a filter drain.

**CONSTRUCTION OF DAMS**

(1) **Main Dam**

The first operation in foundation and abutment preparation was to strip the rock of all materials like overburden, loose and weathered rock, top soil and vegetation including roots and other organic matter unsuitable for use in permanent embankment construction. The rock slopes in different reaches were specified as follows:

1. **Core-trench :**
   - (a) Side slope 1H:1V.
   - (b) Longitudinal slope 1/4H:1V.

2. **Rest of the core base :**
   - (a) Slope in the upstream direction not steeper than 2H:1V.
   - (b) Slope in the downstream direction not steeper than 4H:1V.

3. **Outer shells :**
   - (a) Transverse slope 3/4H:1V.
   - (b) Longitudinal slope 1/4H:1V.

The lowest level of core trench in river bed was at EL 244.4m. After reaching EL 262.1m, seepage problem, in both abutments, in core trench was encountered. The problem was more acute on the left abutment. At the place of the seepage, the trench was intercepted with sandrock band (No. 12) at an oblique angle of 20°. The seepage was found to increase with lapse of time and becoming 5 litres/min on April 16, 1969. It was considered to indicate connection of the core trench with the upstream water pool through joints in rock. Two sumps were created by blasting the rock and water was pumped out. However, the problem continued in the first two years of construction making the conditions slushy and rendering compaction almost impossible. The depth of trench was increased locally and perforated horizontal pipes covered with filter were laid hugging the abutments. Seepage was collected in a 450 mm dia vertical pipe and bailed out. The perforated pipes were connected with blind pipes through which grouting with cement slurr was subsequently done.

The sand rock band (No. 12) was given additional grouting treatment up to the adjacent clay band (No. 13). Two rows of holes on either side of the grout curtain, were grouted. The inclination of holes with the horizontal varied from 50° to 80°. Similarly five line grouting was done in other areas of trouble (Fig. 5).

**Fig. 4. Typical Section of Saddle Dam**

Design of saddle dam was done similar to the design of main dam and most of the design features are identical.

**Fig. 5. Foundation Grouting At Main Dam**

A grout curtain extending to depth equal to half height of dam above it, subject to a minimum of 22.5 m was established under the core trench. The holes at 6m were extended to the full depth, those at middle to the half of the maximum and at quarter points to the quarter depth (Fig. 5). However, in places where grout intake was high, grouting was done in a five row pattern. Also at places where high grout intake was found at any depth in primary holes, secondary holes, in between primary holes, were extend to the depth of primary holes. In areas with conspicuous open jointing, blanket grouting was done extending from 6m upstream of the start of core section to 6m downstream of the end of core section.

For construction of dam, Clay shale obtained from spillway excavation was very tough and difficult to break to specified gradation. Therefore, the material was processed outside the embankment. For this purpose, the material brought by dumper or scrapers was spread in the area by dozers and impactor was run to break the clods. The process of harrowing and breaking was repeated till proper gradation (maximum clod size 100 mm) was obtained. After this moisture conditioning of the material was done. The processed clay was spread in core area of the dam in 150mm layers. The desired density of 1.90 t/m³ was achieved by about 14 passes of Hyster compactor. Near the abutments, the fill was...
placed in 100 mm layers and compaction was done by pneumatic compactors.

Processing of sandrock was not required as it crushed to powder under the tractor chain. However, in core area, it was laid in 100 mm thick layers to avoid clods of over 100 mm and to have better moisture conditioning. Moreover, layers were done for proper mixing and bonding. Three such layers (300 mm thick) was then compacted with Hyster Compactor. Seventeen to twenty passes gave the required density of 2.00 ton/m³. In the downstream shell, sand rock was laid in 150 mm thick layers. Two such layers were compacted together to achieve the desired density.

Pervious material of upstream shell consisting of sand, gravel and boulder (river bed material, R.B.M.) was placed in 600 mm thick layers and compacted by vibratory rollers. Four passes of a 10 tonne roller gave a density of 2.24 ton/m³ to 2.52 ton/m³. In the transition filters, the material was placed in 300 mm thick layers and compacted with 10 ton vibratory rollers. There was considerable difficulty in laying the material in required small widths by machines, especially in the vicinity of the abutments. Manual labour was also used for this purpose. During rainy season, near abutments the coarse filter was protected against choking by muddy water by covering it with polythene sheets over laid by 500 mm thick fine filter material and 300 mm thick sandrock layer respectively.

(ii) Saddle Dam

The construction procedure for saddle dam was the same as for main dam. However, no grout curtain has been provided under this dam due to upheaval of the ground and negligible grout intake during test grouting.

INSTRUMENTATION AND OBSERVATIONS

The 56 piezometers, 6 vertical movement devices, 36 surface settlement points, 5 slope indicators and, 12 soil stress meters have been installed at main dam. At saddle dam, 30 piezometers, 2 vertical movement devices, 25 surface settlement points and, 1 slope indicator has been installed. Ramganga Dam reservoir got its maiden filling in the year 1974-75 and has had nine fillings since then. During this period the minimum and maximum reservoir elevations observed are 294.1m and 364.1m respectively. The Synopsis of observations on various instruments installed is given as under:

(i) Main Dam

The 9 foundation piezometers installed indicate that the grout curtain is quite effective. One piezometer installed in clayshale band near upstream of core trench has of late started showing development of pore water pressure nearing the static head of reservoir. This indicates the possibility of direct connection of the tip with reservoir. The 17 Nos. twin-tube hydraulic type embankment piezometers have been installed in the clay core zone at different tier elevations. The development of pore water pressures during the last nine fillings of the dam indicate that saturation in the clay region adjacent to the upstream sandrock zone has started and the phreatic line has not yet completely developed through the zone. The development of pore pressures in the clay zones is consistent with the following design assumptions:

(1) The pore water pressures dissipate slowly as compared to fall in the reservoir level. (This behaviour strengthens the assumption for no dissipation under sudden drawdown conditions). (2) Under steady reservoir conditions, the pore pressures are equal to height of phreatic line above the point. (3) There is time lag between the development of pore water pressures and rise in reservoir level indicating that there is no easy seepage through the core.

Out of the 12 Nos. twin tube hydraulic type piezometers installed in sandrock, 7 are in upstream zone 2A and 5 in downstream zone 2B. Seepage has not yet travelled to Zone 2B. The pore water pressure variations during the operation indicate that the sand rock of the zone is fairly imperious.

Two piezometer tips have been installed in the upstream R.B.M. zone. The pore pressures in this zone correspond to more or less rise and fall in the reservoir level indicating that this zone has been allowing full dissipation of pore pressures under drawdown conditions.

Vertical settlement during construction ranges from 1.39% to 2.16% of the dam fill. The post construction settlements, measured for a period of four to six years only due to checking of the devices with measuring torpedo, were not significant.

Out of 12 Nos. stress meters installed in main dam at different sections and elevations in positions ; (1) flat, to measure vertical pressure, (2) parallel to dam axis, (3) perpendicular to dam axis and, (4) 45° to dam axis, at present only 7 Nos. are functioning. The effective stresses have been worked out at these locations on the basis of observed values of pore water pressures in near-by piezometers. In general the effective stresses are less than the effective overburden pressures and at one location, where the stress meter is at about mid-height and mid-width of clay core, the effective stress is only about 43.3% of the stress due to overburden. This shows that the clay portion of the core is behaving as a thin core in itself.

(ii) Saddle Dam

Instrument observations on saddle dam show its behaviour similar to main dam. Phreatic line has been developed only upto upstream mid-width portion of the clay zone of the core. No stress meter has been installed in this dam.

CONCLUSIONS

The construction of the two dams in south of Himalayan foot hills demonstrates the use of weak rocks in shell as well as in core of the dams. These fill materials were available as a result of excavations of chute spillway just adjacent to the dams. The seepage through
foundation of main dam has been effectively controlled by provision of cut off trench and a single line grout curtain with additional rows in some specific areas. In saddle dam only cut off trench with upstream sandrock blanket is adequate for the purpose. The instruments installed in general indicate normal behaviour of the two dams. However, the stress meters installed in main dam core show pressures less than half of the overburden pressures. From this it can be inferred that in case of such composit core the interaction between the zones should be considered in design.

REFERENCES


Design Memoranda (No. 3 and Supplements), (1963-1976), Design of Main Dam. Ramganga River Project, Irrigation Department U.P. State, India.

Design Memoranda (No. 7 and Supplements), (1963-1976), Design of Saddle Dam. Ramganga River Project, Irrigation Department U.P. State, India.

Design Memoranda No. 3U (1980) and No. 3V (1982), Main Dam and Saddle Dam Instrumentation, Ramganga River Project, Irrigation Department U.P. State, India.