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Mangla dam project – Behaviour of Siwalik clays/sandstones

Barrage de Mangla – Comportement des argiles/grès Siwalik

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SYNOPSIS Mangla Dam Project structures have foundations/abutments of Siwalik formation of Plio-Pliostocene era. Since the completion of the Project in 1967, the foundation/dam have gone through 18 cycles of impoundments & drawdown. Residual shear strength parameter for clays was used for the long term satisfactory performance of slopes & foundation. The slips in the reservoir/one in tailrace of emergency spillway confirm the wisdom of using residual values. Bedrock sandstone is weakly cemented fine to medium grained. Boiling has been rampant d/s of Sukian Dam, a low dyke along a ridge. It is possible to control the boiling by vigilant observation and treatment with inverted filters. Clays/sandstones have performed satisfactory as fill materials for core/shoulders.

INTRODUCTION

Mangla Dam Project on Jhelum River PAKISTAN completed in 1967 has variety of structures and embankments and offers an interesting variation of the performance of the four dams forming the rim of its reservoir. Main Dam has a maximum height of 138m above core trench, a rolled clay core and rolled sandstone/gravel shoulders, Intake Embankment 89m high with rolled sandstone core & gravel shoulders; Sukian is a homogeneous embankment of rolled sandstone mostly 23m high. Layout of structures is at Fig-1 & 2 and is well documented elsewhere (Binnie etal 1967)

Mangla Dam is in highly seismic zone & details of the seismic design of the dam has been presented (Eldridge etal 1967). Structures around Mangla are designed with 0.1g acceleration whereas for Jari Dam 0.15g was used. No major earthquake has so far occurred in the area. Also no seismic activity occurred due to impoundment. The bedrocks belonging to fresh water deposits called Siwaliks of Plio-Pliostocene age, forming the foundation of the embankment and the structures are weakly cemented sandstones and clays with shallow dips 10-12° upstream for Mangla, whereas for remote Jari dam dips are 45° upstream. Shear zones in clay bed rock were discovered during the excavation for foundation for project structures. Redesign of the structures was therefore carried out, using residual shear strength as below for critical slopes (Skempton etal 1967).

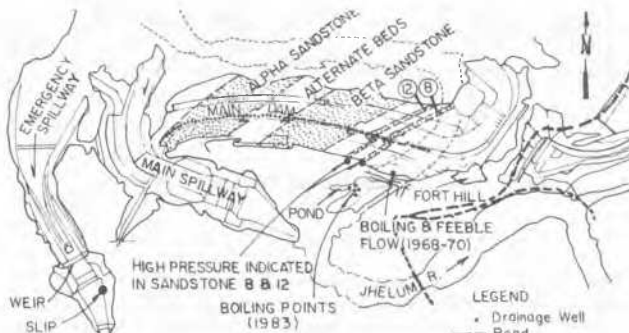


Fig.1 Layout Plan Mangla – Main Dam/Boiling Locations & Geology

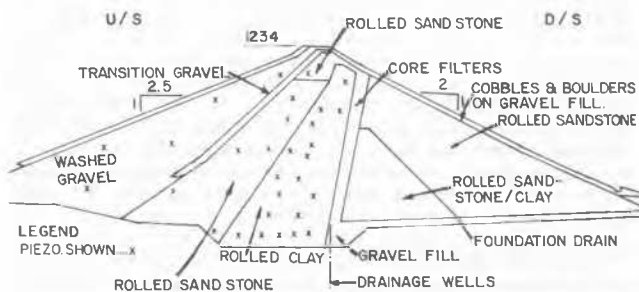


Fig.2 Mangla Main Dam

Final Design Bedrock Parameters

| POSITION | CLAY BEDROCK | | | | | | SANDSTONE BEDROCK Lb/Sq. IN. ϕ % |
|------------------------------|-------------------|--------|--------|-------------------|--------|--------|--|
| | ALONG BEDDING | | | ACROSS BEDDING | | | |
| | C Lb/Sq IN. | ϕ | R % | C Lb/Sq IN. | ϕ | R % | |
| Mangla Dam | 0 | 18° | 100 | 6 | 26° | 50 | |
| Intake Embankment | 0 | 18° | 100 | 0 | 24° | 100 | |
| Sukian Dam (Western Half) | 0 | 18° | 100 | 6 | 25° | 50 | 0 38% 100 |
| Sukian Dam (Eastern Half) | 0 | 16° | 100 | 6 | 25° | 50 | |
| Jari Dam | 0 | 13° | 100 | 5 | 20° | 50 | |
| Jari Rim Works | 0 | 13° | 100 | 0 | 16° | 100 | |

Clays in Foundation

Natural slopes, excavated slopes & slopes forming part of the structures have so far performed satisfactorily, however these have not been subjected to limiting condition viz tremors close to design value/saturation. However, there have been slides in the reservoir and one in the tailrace of emergency spillway which point out adequacy of the design and wisdom of designing the structures for long term residual shear strength.

Slopes in bedrock close to structures & forming part of structures are generally 1 in 1.75 (30°) but in some cases viz emergency spillway are 1 in 2.25 (24°) & 1 in 4.5 (12°) for intake pool.

Slide in tailrace of emergency spillway occurred along bedding plane shear zone at 12°, caused by rain water seeping along the shear zone & reducing the effective stress. Wedge type failure occurred upstream of emergency spillway, along reservoir helped by impounding & drawdown along dip at 12°. There has been no slip because of earthquake in recent times, however since the tectonic movement, Probably in the middle of Pleistocene epoch & consequent development of shear zones where strength are in most cases at residual values, erosion/weathering leading to removal of several thousand feet of deposits has occurred and may have been helped by slides due to earthquakes, but no such signs exist. The slips in reservoir are few, even with now 18 impounding & drawdown with slopes dipping into the reservoir & clays having sheared zones (Fig-3). This is probable, as only part of slopes are being subjected to saturation/drawdown. Also wedge type failures are helped by tension crack or free surface on upstream. It is apparent that dips of bedrock in reservoir area are substantially lower than average shear strength along a slip plane refer above table except for Jari where no slips have occurred (Fig-3) although the bedrock contain larger percentage of clays. This is probably due to silt blanketing providing a toe weight/flat topography.

Clays as Fill

Mangla Main Dam has a rolled clay core, constructed of excavated Siwalik clays which was watered, broken & stockpiled. It was then laid at OMC (Optimum Moisture Content) to OMC+2 % in 0.3m layers. High construction pore-pressures upto 0.7 ru (Pore-Pressure ratio) developed. Over the last 17 years, pore-pressures have dissipated but no flownet seems to have developed, is apparent and would take much greater time (Fig-2, Fig-4).

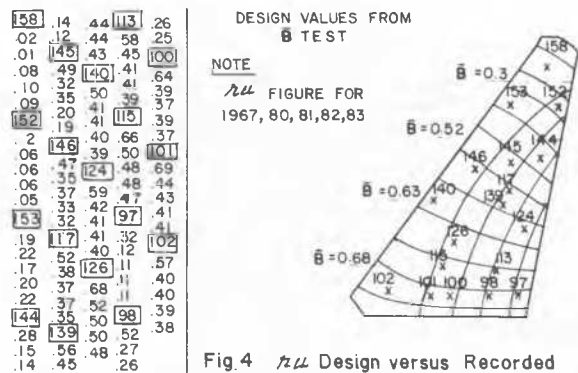


Fig. 4 μ Design versus Recorded

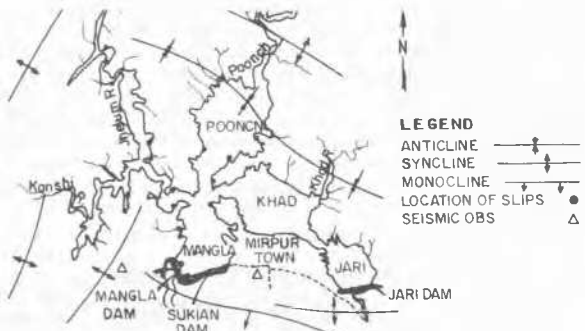


Fig. 3 Reservoir structural geology - locations of slips

Clay bedrocks in foundation on removal of load exhibited rebound of the order of 0.2 per 18.3m excavation. This was dealt during construction by frozen bench mark at the structures; having lower excavation levels to compensate for rebound likely and a system of closure pours so as not to stress the structure. The clays are dominantly montmorillonites and after few years of impounding swelling was recorded particularly at Sukian Dam where clay fraction ranges generally 40% to 60%, although the beds are gradational. The swelling caused by increase of moisture content was helped by rapid travel of seepages through the discontinuities viz sheared zones. No structural distress as a result of swelling has been noticed except at emergency spillway where spalling at the joint downstream of the weir had to be remedied for the entire length.

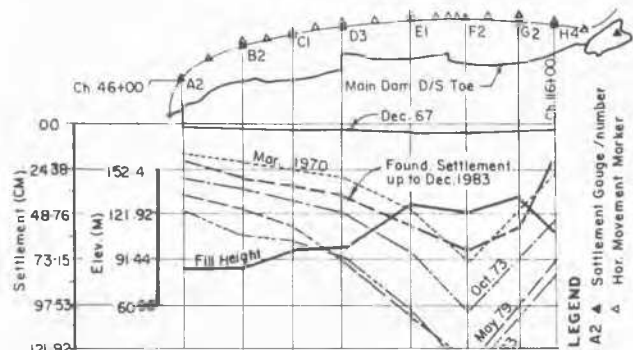


Fig. 5 Main Dam-Settlement Pattern

Settlements of the dam is continuing & post construction maximum is of the order of 1.3m & obviously at the location of maximum fill refer settlement pattern (Fig-5). Extension/compression over the full length of dam (+2741m) has been measured over the years (Fig-5) & reveals extension, near the left abutment (Fort hill) uptill now of 0.2m in a length of 273m. Looking at the maximum settlement/extension in the same reach of the dam, so far there has not been any transverse/longitudinal crack (Fig-1 & 2). However, it was noticed that a crack appeared at location of top edge of the core on the access road from spillway early (1969) & produced a marked depression on the downstream face of the dam in continuation.

Sandstone in Foundation

Sandstone of Mangla are weakly cemented, fine to medium grained, with carbonate binder upto 20%, hard lenses sometimes 10%, with general perme-

ability of 10^{-4} cm/sec, but at some places is 10^{-3} cm/sec. They also have discontinuities in the form of clay balls, concretions.

The design of Main Dam has a line of wells at 3.8m centres downstream of the core under the chimney filter (Fig-1). This is a good location for the line of wells, however, the experience of having minor boiling at toe, dictates that it would have facilitated if working of drainage curtain & individual performance of wells were known. The boiling apparently has not involved the components of the zoned dam. However, there are pressures higher than ground level at the toe, in 2 sandstone beds. Extensive drilling has been done to know pressure at the toe as well as confirming the lithology at toe. It is proposed to install relief wells in the sandstone with higher pressure. Sukian Dyke sited on a ridge (Fig-6), with deep cuts (nalas) on upstream & downstream, has experienced boiling/piping through the weakly cemented sandstone downstream of dam. Boiling is occurring sometimes at distances of more than a mile & continues long after reservoir depletion due to time lag. Sandstone strata close to dam exhibiting boiling has been treated with inverted filters. It is proposed to try blanketing upstream exposures.

apparently at higher gradient. Seepage downstream of Sukian with about 60% bedrocks as sandstone has doubled to about 453L/sec and is close to optimum since impounding whereas for main dam because of shorter paths, it developed to about 0.2 cms. Carbonate binder of sandstone is removed as bicarbonates, however, the rate of dissolution is slow and may have minor longterm effects. Carbonates also cause encrustation of drainage wells. A system of cleaning of well screens and inspection by CCTV Camera has been established for more than 400 wells, after the dramatic complete choking of one well of spillway drainage system within 3 months. Chemical cleaning by sulphamic acid was needed for few wells only.

Sandstone as Fill

Sandstone fill was easy although rippers had to be employed. Sandstone fill did not have construction pore-pressure of any significance. Most of the settlement took place during construction and post construction; settlement of fill is a fraction of meters ($0.06m \pm$ for/30.5m of fill). Main dam upstream shoulder piezometers in rolled sandstone follow reservoir closely except one at bottom close to core (Fig-2). This is because piezometer leads crossing from sandstone shoulder to free drainage gravel fill at same elevation have not been properly placed (Altaf-ur-Rahman, 1970). Seepage through sandstone fill of Core Intake (615m long, 82m high) and Sukian Dam (5,178m long, 23m high) is only ± 75 and 87 LPM/ Piezometer behaviours according to flow net. Sandstone fill will dilate during earthquake and it can be logically concluded that behaviour of sandstone fill is satisfactory.

Conclusion

The design of the foundation clays was done at residual shear strength. Although few slips have occurred but one in the emergency spillway and other along the reservoir point out the wisdom of design on residual value. The clays as fill developed high pressures during construction, which have slowly dissipated. Sandstone has experienced boiling at gradient of 1 in 10 to 1 in 20 and satisfactory performance has been assured by proper vigilance. Fine to medium grained sandstone can be used as the core of a dam/shoulder.

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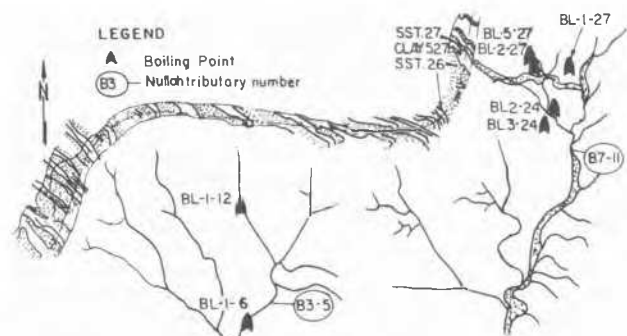


Fig.6 Sukian Dam - Boiling D/S Nullah

Boiling Points Sukian Dam And Intake Area

| NULLAH No. | G. PT. No. | ELEV. SPD. | STRTA | LENGTH (L) m. | HI AT | | L. AT | |
|------------|------------|------------|----------|---------------|--------|--------|--------|--------|
| | | | | | 366.1m | 338.3m | 366.1m | 338.3m |
| B3 | BL-1-6 | 296.5 | SUKIAN-6 | 1675 | 69.7 | 42.2 | 1/24 | 1/40 |
| B3 | BL-1-12 | 327.2 | -do-12 | 609 | 38.9 | 10.9 | 1/16 | 1/56 |
| B7 | BL-1-27 | 332.1 | -do-27 | 685 | 40.5 | 13.7 | 1/17 | 1/55 |
| B7 | BL-2-27 | 332.6 | -do- | 381 | 33.5 | 5.5 | 1/11 | 1/69 |
| B7 | BL-5-27 | 332.2 | -do- | 381 | 33.9 | 5.9 | 1/11 | 1/65 |
| B7 | BL-2-24 | 317.9 | -do-24 | 609 | 48.3 | 20.3 | 1/13 | 1/30 |
| B7 | BL-3-24 | 316.2 | -do- | 609 | 51.4 | 21.9 | 1/12 | 1/28 |

There has been an incident of piping (1968) in sandstone 27 (Fig-5 & 6). Sandstone 27 has the lower half virtually of uncemented sand regularly graded unlike other sandstones consisting of fine to medium sand. It appears that the piping was triggered by blockage of seepage leading to high pressures in the cliff face in nala. Removal of overburden of a meter lead to piping which was controlled immediately by putting filters. No piping has subsequently occurred in the nala bed close by at lower levels, and