26 YEARS OPERATION OF MANGLA DAM

26 ANS DE FONCTIONNEMENT DE MANGLA BARRAGE

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SYNOPSIS: Mangla Dam is ranked among the largest earth fill dams in the world. Uptill 1992, 26 cycles of reservoir operation have been completed since first impoundment during 1967. The seepage measured downstream of Mangla Dam showed a stable and satisfactory trend. Some boils which appeared in sandstone beds and in downstream nallahs of Sukian Dyke were treated with inverted filters and are kept under close watch. Uptill now 1.5m maximum settlement has been recorded at the crest of Main Dam. There have been no cracks or signs of distress on the dam. High construction pore-pressures recorded in the interior of Clay Core during initial years of reservoir operation are dissipating gradually. Flood peak of about 28320 cumecs (1 million cfs.) equal to the designed capacity of Main Spillway has been passed through Mangla Spillway during Sept,1992. Mangla Dam Project is well maintained. Benefits from the project upto date are over 16 times the investment.

INTRODUCTION

Multi-purpose Mangla Dam is one of the highest earth-fill structures in the world. It is located about 60 miles South East of Islamabad, on river Jhelum at a point where the river passes through the Swalik foothills and enters the Punjab plain. The drainage area at the site is about 30,000 square km.. The Project is designed to conserve 7155 million cu.m (5.8 MAF) of water for irrigation. Mangla Power House generates 1000 MW electricity through its ten units each of 100 MW capacity. Earth work structures include Main Dam 116 m (382 Ft.) Intake Embankment 71.3m (234 Ft.), Sukian Dyke 46m (150 Ft.) and Jari Dam 71.3m (234 Ft.) high. The concrete structures comprise Main Spillway, Emergency Spillway, Power House, Tunnels, New Bong Escape and Jari Outlet Works. Fig-1 shows layout plan of the project. The construction of Mangla Dam Project started in 1962 and was completed in 1967. During past twenty five years the project structures have undergone four periodic and twelve annual inspections. These safety inspections testify that the project is problem free and properly operated and maintained.

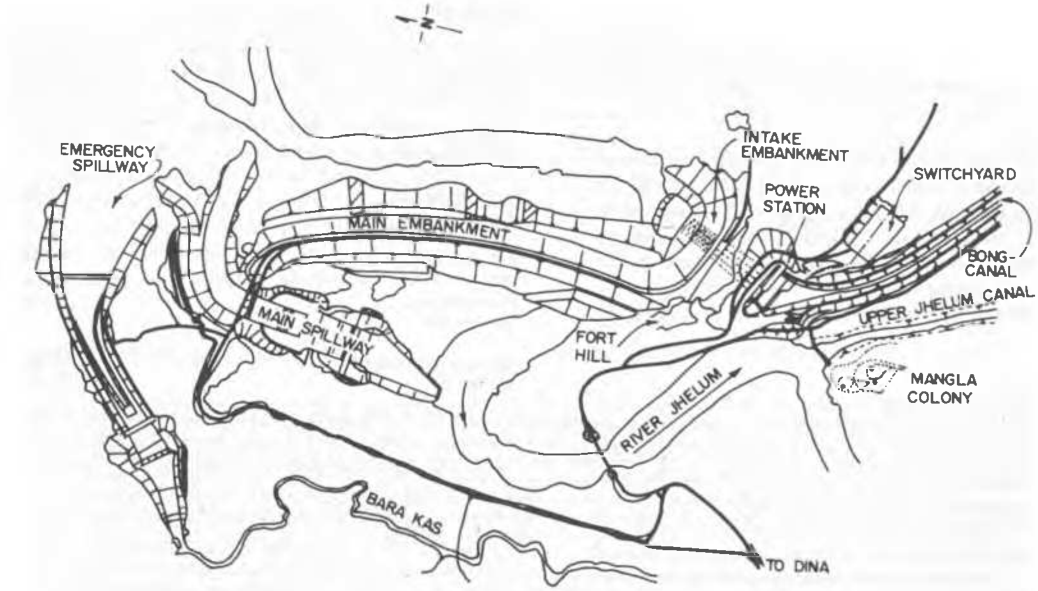

Fig.1 Lay out plan Mangla Dam Project.

GEOLOGY AND SEISMICITY

The Mangla Dam is situated at the foot hills of Himalayas. The bed rocks belong to Siwalik System of Miocene age. The Siwaliks are fresh water sediments deposited by streams rejuvenated by a major uplift of the Himalayas. The area is seismically active. The Siwaliks consists of alternating beds of sandstone, siltstone and claystone. During construction the design was changed to account for the residual shear strength of the clay beds along sheared zones found during excavation. The design earthquake was derived by assuming that an earthquake of magnitude of Kangra 8.6 on Richter Scale could reoccur on the Main Boundary Fault closest to Mangla 45 Km. The design "g" value was 0.15g used in pseudo static stability analysis. No earthquake was recorded during the first filling of the reservoir. Although many earthquakes of magnitude less than 0.1g have been recorded but no major earthquake has been felt at site. During one of the lowering of the reservoir, a land slide in clay bed along a very shallow angle occurred into the reservoir. Although it had no bearing on the project but it proved the decision to use residual shear strength was justified.

RESERVOIR OPERATION

The primary objective of Mangla Dam and reservoir was to store and regulate the seasonal floods of Jhelum River in order to divert western river supplies to Eastern river canal system. The power generation, flood control, fish culture and recreation are secondary benefits of this project. First impounding of Mangla reservoir commenced in 1967. Uptill 1992, 26 cycles of reservoir operation have since been successfully completed. During this period it was not possible to fill the reservoir, upto normal conservation level, only four times due to low inflows. The reservoir is normally operated according to maximum and minimum rule curve envelope developed on the experience of historic river inflows and irrigation demand.

The designed minimum reservoir level is 317m (1040 ft.) Survey of Pakistan datum (SPD). During the history of reservoir operation, there were only two occasions, when the reservoir was drawn down to this minimum threshold level. Fig.2 shows reservoir operation during the last 8 years. Uptill now valuable experience, covering 26 years of actual prototype operation, has been gained based on which the reservoir operation has been optimized to give more benefits in the form of water storage, electricity generation and environmental impact. Conjunctive use of the two reservoirs Mangla & Tarbela has yielded better results.

Mangla Spillway with two stage stilling basin has a discharge capacity of 24638 cumecs (870000 cusecs) at conservation level 366m (1202 ft.) SPD. Main Spillway was never used to full capacity until recently when a historic flood over 25488 cumecs (900000 cusecs) was released through the Main Spillway on 10.9.1992. The performance of the structure was satisfactory during this historic flood and no adverse effect/damage was observed. This has given confidence in routing the probable max. flood.

Live storage of Mangla reservoir at present is 5946 million cu mecs (4.82 MAF) against 6587 million Cu.m. (5.34 MAF) original capacity showing reduction of 0.52 MAF. The average annual rate of sedimentation in the reservoir is about 39.8 million Cu.m. (32,300 AF) as compared to the estimated 49.3 million Cu.m. (40,000 AF). The reduction can be attributed to the water shed management. From the very start of the project, extensive watershed management was carried out in the catchment area of the reservoir in Pakistan. Thousands of check dams and millions of trees were planted to check erosion of the soft sedimentary rocks in the catchment. Life of the reservoir which was estimated to be 100 years is expected to be more than 125 years.

RAISING OF CONSERVATION LEVEL

The raising of reservoir conservation level has been under consideration since 1967. At the time of design, one of the major consideration to fix 366m (1202 ft.) SPD as the maximum conservation level was routing of flood of record through emergency spillway alone and sedimentation above conservation level.

Now we have 26 years experience of actual reservoir operation in addition to about 30 years of hydro-met data. Fig. 3 shows hydrographs of major historic floods at Mangla. During this period no sedimentation has taken place in the flood storage zone above conservation level. Based on this Harza Engineering Company, Chicago, USA in their report of February, 1992 has recommended the new flood routing scenario for flood of record by including releases through irrigation outlets, 30% main spillway capacity in addition to Emergency spillway discharge. No sedimentation allowance in the flood storage zone has been kept in this study. Recommendation was then made to raise the conservation level from 1202 to 1204 ft. SPD.

SURVEILLANCE

For project monitoring and surveillance, a comprehensive instrumentation net work was designed and installed on the dam structures to verify the design parameters and to monitor the performance of the structures during construction and reservoir impounding/operation. A list of Instruments is given below:

Instrument	Total Installed	Working	% Failed	Parameter to be Monitored
Hydraulic Piezometers	548	534	4	Pore Water Pressure
Electrical Piezometers	138	109	21	Pore Water Pressure
Slope Indicator Movement	34	33	3	Horizontal
Settlement Gauges	44	44	-	Vertical Movement
Plumblines Movement	11	11	-	Horizontal
Surface Movement Markers	374	374	-	Horizontal and Vertical Movement

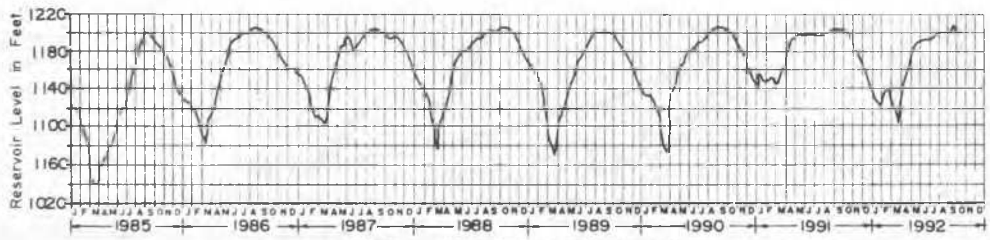

Fig.2 Mangla Reservoir Operation.

In addition to the above instruments, 34 seepage measuring points in the form of V notches and gauges and more than 20 boiling points are observed at regular intervals. The old seismic network which comprised of 3 micro seismic stations and one strong motion accelerograph SMA, is now being improved by the addition of 12 micro seismic stations and six strong motion accelerographs SM3.

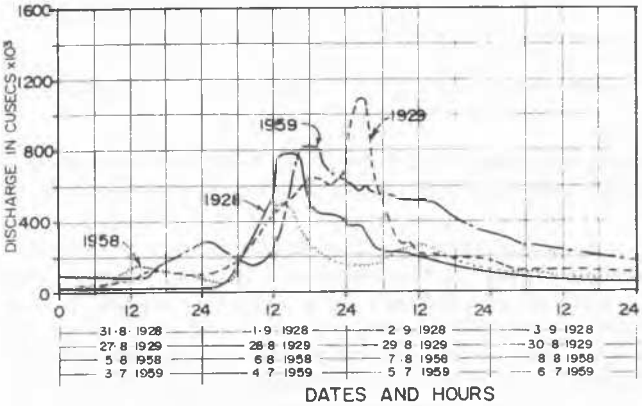

Fig.3 Hydrographs of major historic floods at Mangla.

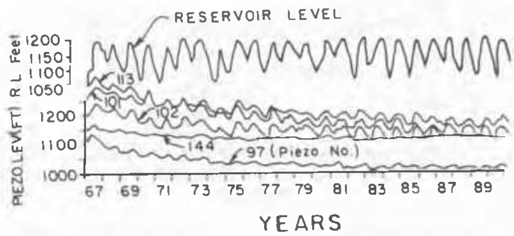

Fig.4 Dissipation of Pore Pressure in Mangla Core.

MONITORING OF CLAY CORE

Mangla Dam has two instrumented sections at which closed circuit Bishop type hydraulic Piezometers have been installed in the Core. Fig 4 shows pore pressures of the Piezometers in the core. The pore-pressures are dissipating gradually and reducing every year. High construction pore-pressures upto 0.7 ru (Pore Pressure ratio) developed in the core. The piezometric level fluctuates with reservoir level. The peaks and troughs in the pore-pressure record coincide exactly with high and low reservoir level with no time lag. This suggests that the pore pressure changes are a result of change in static load on filling of reservoir and release of this load during draw down.

Fig 5 shows the contours of equal pore pressure in the core. The shape of the contours follows the shape of the clay core. The maximum pore pressures are at the centre and in the lower part of the core which has the maximum fill. The upper part has lesser weight and lesser pore pressures. The exterior parts in contact with the upstream and downstream shells and the chimney drain have the facility of easy drainage and show lower pressures than that of the heart of the core. The lack of flownet development is also supported by analysis of the return water from the hydraulic Piezometers in the core which show large percentage of carbonates as against the return from the Piezometers with sandstone fill through which phreatic line has developed.

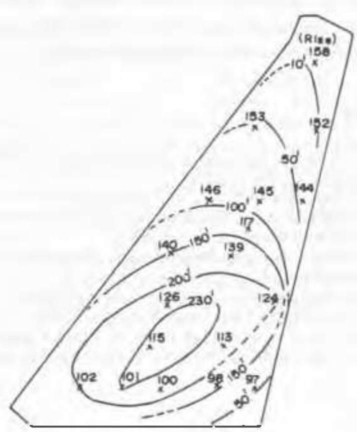

Fig.5 Equipotential Contours of Mangla Core.

SEEPAGE - SAND BOILING IN SANDSTONE BEDS

There was practically no seepage downstream of Mangla Main Dam during initial years of reservoir impounding. The seepage recorded during later years showed a stable and satisfactory trend. Some boiling points downstream of Main Dam in the river bed section were observed. These were filter treated and are kept under close watch. Boils which appeared in the sandstone beds and nallahs downstream of Sukian Dyke from where construction material was borrowed had comparatively more discharge as compared to Main Dam river boils. These were treated with inverted filters. These boils have stabilized and are kept under close watch.

SETTLEMENT MAIN DAM

Total settlement of 1m was envisaged in the design and an allowance was made for this in construction of the dam. Until now 1.5m of max. settlement has been recorded at the crest of dam. Fig 6 shows the settlement of main dam with the passage of time. The settlement was more in the initial years. Thereafter it is reducing progressively. The max. settlement has been where the core height was maximum. However there have been no cracks or signs of distress on the dam. Maximum horizontal displacement of 1m occurred mostly on the first filling of the reservoir. This coincided with the point of maximum settlement.

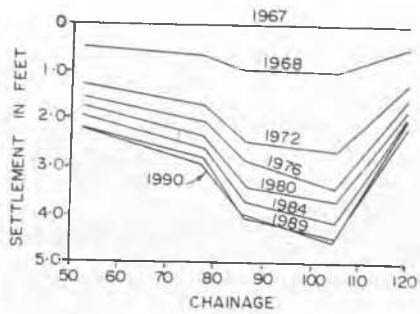

Fig.6 Settlement at Crest of Mangla Dam.

COST AND BENEFITS

Mangla dam was completed in 1967 at a total cost of Rs. 3.2 billion. During 25 years of operation it has generated over 100 billion KWTHS of energy. It has also provided 116 MAF of irrigation supplies. Mangla dam has repaid its cost over 16 times through its water and power benefits since its commissioning. Flood control,fish culture, recreation and environmental impacts are additional benefits.

CONCLUSIONS

- Mangla Dam has played a pivotal role in the Socio-economic development of the country.
- Mangla Dam is a well maintained project.
- Use of residual shear strength parameters for over consolidated sheared clays proved to be justified.
- The spillway has passed the design flood safely and proved the model studies and design to be correct.
- The construction pore pressures in the centre of the clay core are still continuing and dissipating gradually.
- Because of the plastic clay core no cracks have been observed inspite of recorded settlement above the designed value.

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