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SYNOPSIS:distress has been observed in the above dam, on its right spillway immediately after its completion in 1957. The distress has been intensified in the eighties with development of thin horizontal cracks in the undersluice barrels, gate gallery and adjoining areas at a level 18m above bed. These have all been chiselled, opened up and epoxy grouted; besides with water proof cement. But parallel cracks opened up soon after. Studies in detail carried out by various government organisations point out that rapid placement of concrete in '55-'56 leading to thermal stress is the main cause. Though some attribute it to alkali aggregate reaction because of strained quartz in the aggregates. Further studies and remedial measures are under way.

INTRODUCTION

The Mahanadi River, rises in the uplands of Madhya Pradesh State of India; with a catchment area of 141, 600 sq.km. and a total length of 847 km. it debouches into the Bay of Bengal in Eastern India in the State of Orissa.

In the State of Orissa, the river flows in a general Northwest-Southeast direction, following the regional fracture and fault pattern, traversing through a suite of Pre-Cambrian rocks, consisting of schist, gneiss, granite, khondalite and charnokite. Just as it enters the deltaic plans, it cuts through upper Gondwana sandstones, with lattertic cover and thick deposits of recent deltaic alluvia in the coastal area. The Gondwana formations are found in faulted basins. It is significant to note that the course of the Mahanadi follows a faulted valley in Central Orissa. (Plate III).

Irrigation was taken up in the late nineteenth century in the deltaic regions of the river by construction of non gated barrages at Jobra and Birupa, and water is supplied to nearly 1,00,000 hectares by linking them with adjacent basins. In upper Mahanadi catchment two reservoirs constructed at Muram silli and Dudhawa irrigate nearly 91,000 hectares since independence. In 1945 multipurpose basinwise development of Mahanadi has been initiated by Dr.A.N.Khosla, the eminent irrigation Engineer commencing with the construction of a major composite dam at Hirakud, in Sambalpur Dt. Orissa. A number of reservoirs have been completed in upper Mahanadi basin as at Hasdeo-Bango, Upper Mahanadi Reservoir, at Gangrel, Sondur etc. since then.

GENERAL FEATURES OF THE DAM

At Hirakud located 10 km upstream of Sambalpur town in State of Orissa, the river Mahanadi, nearly four Km wide flows in three channels, separated by two islands, and flanked by steeply rising Chandli Dongri Hillocks on the right side and gently rising hillocks on the left side. (Soil covered alluvia are noted on the left flank between the hillocks and the channel). The channels are rocky, whereas the islands are made of soil and rivevine alluvial material. Two concerte spillways span two major channels, with a masonry dam and a powerhouse terminating into the right abutment hill anbd massive earth dams in the area between the channels and the left flanks. Five dyke sections nearly 21 km in total length cover the low areas on the right and left flanks of river, away from the main channels. The maximum height of the dam is 61m. One special featur]e is 64 no.of large openings for the under sluices in the concrete spillways. (Plate I & II).

GEOLOGICAL FORMATIONS

The geological succession at the dam area is as below:-

Recent and sub recent alluvia and sandy soil

Unconformity

Cudappahs - Shales, slates, mylonites

Quartzite and Arkose

Fault

Pre Cambrians - Granite, gneiss, schists, epidiorite and associated rocks

These rocks are emplaced by dykes of dolerite and quartz bands besides pegmatite. The Cudappahs occupy the right abutment hill feature, whereas the Pre-Cambrian granite, gneiss etc. are exposed in the two channels and the islands. (V.S.Krishnaswamy and M.C.Basu). On the base of right abutment hillock, the contact between the above two is faulted, with a 150m wide zone of crushing and fracturing, made up of whitish green slatyshales and grey mylonites towards the river side and clay gouge zone about 1.5 m wide zone of crushing and fracturing, made up of whitish green slatyshales and grey mylonites towards the river side and clay gouge zone about 1.5 m wide in the middle and extending parallel to the river, with steep dip towards it.

Some of the adverse foundation features were :-

a) Highly sheared and fractured shales and slaty rocks on the right bank in the power house and power dam, with clay gouge in the middle.

b) Deeply weathered gneissic and granitic rocks in the right channel, with a number of shears and minor faults, parallel to the flow and normal to it, with widths ranging from a few cm to a maximum of 1m.

c) A fractured and jointed epidiorite band 10m wide on the right channel, along a fault feature.

d) Very deep scouring of the rocks in the main channel with perennial springs at the bottom on account of a fault parallel to the flow.

e) Occurrence of very soft schisose pockets besides joints and minor faults within the granites on the left concrete dam.(GSM Rao, P.B.Srinivasan, N.R.N.Rao, A.Acharya & B.Ramachandran). (Plate III a)

Treatment was carried out for the above adverse foundations features by means of deep selective excavation, excavation on formula basis along joints, fractures and shears, provision of dowel bars on slopes, steel grilles over weatheered zones and extensive consolidation grouting after washing and cleaning of joints and fractures. On the right side additional rows of curtain grout holes were also provided. Nearly 101 tons of cement has been injected on the right side dam foundations. (R.C.Rao).

HISTORY OF DISTRESS FEATURES :

Immediately after the completion of the dam in 57-58 horizontal cracks appeared at the operation gallery of the right side spillway dam. The cracks were confined to the area adjoining the construction joints. Wet patches were seen in December 73 on the downstream wall of operation gallery, which was healed by grouting. In August 74, the lifting beams of gantry cranes in blocks were not moving freely, because of development of cracks nearby. The cracks are generally less than one cm wide, extending to lengthe of 1m to 3m, sometimes upto 10m. The deph of them are in the order of 1 to 2.2m inside. Sometimes they occur en echelon in pattern.

In July 83, the engineers of the Indian Institute of Technology, Delhi reported on horizontal cracks at block No.35 on both walls, in block 37, 38 and 39 on the side walls and on the downstream side wall in blocks 41, 44 and 45; besides extensive cracking on the side walls near the entrance adit, with the buckling of angles. Besides in almost all the sluice barrels, horizontal cracks had developed, 1 to 1.5m above the floor of the barrel. In blocks 46 and 47 vertical cracks have developed on the downstream face of the barrels walls, extending to a height of 3 to 4.5m. (Plate IV).

The Central Water and Power Research Station, (CWPRS), Khadakvasla, Pune, conducted static and dynamic analyses in October 78, by complete detailed stress distribution around the sluice openings. The stresses, becuase of normal gravity loads and water loads are not very high, though some tensile stresses are high on the downstream face of the dam. The internal pressure attributes to reduction of compression on the wall of the sluice. The compressive stress on the face of the large gate gallery is very small. These could very easily lead to cracking on account of thermal stresses, which may be in the order of 20 kg/sq.cm. Therefore, they conclude that thermal differential between the concrete and the air temperature has caused the cracking in the gate gallery and the sluice barrels. And also because of the rapid cooling of the interior concrete. (Plate V)

The Indian Institute of Technology, New Delhi in July '83 in their studies drew attention to the fact that there were large weakzones in blocks 45, 46 and 47 on the downstream side, which were not sufficiently treated. And also that there was very heavy scouring of the downstream area in the right side spillway, immediately after construction. But after detailed two dimensional and three dimensional analyses under noirmal loadings conditions, they have opined that the structural design of the dam is very satisfactory with the peak stresses in tension and compression within limits. Foundation settlement has also been ruled out by them, as also dynamic forces by CWPRS. They concluded that because of high heat of hydaration of high strength/high alkali cement, which was used, without precooling and post cooling besides non grading of aggregates, non use of pozzolanas and lack of construction control have resulted in higher temperatures, setting off thermal stresses. The horizontal direction of the cracks support this view.

Non destructive studies on the concrete spillway sections, by the Central Water and Power Research station, Pune in April 83 by ultrasonic pulse methods point out that wave velocities in the concrete generally range from 4.8 to 4.2 km.sec. at most places in blocks 35 and 46 on the right spillway, with lower values of 3.5 km/sec. at a few locations.

According to the report of the Cement Research Institute in June'83 the tests on concrete core samples from right side spillway indicate that modulus of elasticity are adequate, as also density and ultrasonic velocity pointing to proper compaction of concrete.

The hardened concrete had adequate cement content and PH value besides state of hydration (by XRD and DTA) and not attacked by sulphates, acid water, excessive leaching or carbonation. But some of the samples have been found to have undergone alkali silica reaction, according to them, manifest by the occurance of gel type of reaction products, dark reaction rims, alteration of borders of aggregates and presence of micro cracks in the mortar phase (as examined under the petrological and electron microscope).

The reaction products were termed by them as alkali-lime-silica-gel. The chemical composition was established by EDAX system with scanning electron microscope, chemical analyses and flame photometry, backed up by infra-red spectroscopy and petrographic studies including measurement of refractive index.

On the right concrete spillway, granites from Chiplima, dioritee from Lakshmi Dongri and possibly some river gravels from the Mahanadi were used. Earlier tests by the Hirakud Research Station in '51 point out that some of the river gravels containing chert, Chalcedony etc are reactive. In the granites and the diorites also, strained quartz with Undulose extinction occur, which may cause the reaction (Gogte)

In April 82, petrographic studies of the dioritic rocks used on the right side spillway from Lakshmi Dongri quary was carried out by Shri N. Mazumdar of Geological Survey of India. The aggregates were found to be free from any colloidal or amorphous silica; but the quartz grains plagiocase and microcline felspars all exhibit evidences of shearing and crushing, the quartz showing undulose extinction.

Fine aggregates used in the right side spillway dam, obtained from the right channel was tested in the petrological laboratories of Geological Survey of India, Central Region, Nagpur by Dr.S.S.Deshmukh and Dr.T.A.Selvan. The samples show feldspar (potassic) grains to the extent of more than 30% and quartz grains with undulose extinction. Impurities and weathered pieces form nearly 5 to 6% of the total weight, being within permissible limits.

Corepieces of concrete aggregate from block No.45 and block no.42 are made up of fine grained quartzite (slightly stained) with a few minor grains of shale, jasper etc and highly sheared granitic rock composed of quartz (with undulose extinction) and highly fractured felspars (microcline and plagioclase). respectively, as per the report of Dr.R.N. Pal.

The slightly higher percentage of felspars in the fine aggregates. may have caused some damage, in view of the fact that they have extremely low coefficients of thermal expansion in one crystallographic axis as compared with the other axis (Judd & Krynine-P330) According to F.G. Bell also, higher proportion of felspar in the fine aggregate could induce problems of distress in concrete. Legget in also support this view in his classic text book on engineering geology.

Recent studies by technical experts of the problem in 1989-90 have pointed out to the highly contaminated nature of the reservoir waters from the industries located at the North Eastern rim of the reservoir near New Brajrajnagar. Timber, and paper besides coalmines are some of the units functioning therein for the last several decades. Effluents from these industries has led the water becoming highly alkaline. The extra amount of alkalis from those effluents have set up reaction in the concrete, which has resulted in the development of cracks, it appears, according to the technical experts.

Possible causes for developments of cracks in the right spillway dam, as discussed in the above paragraphs, are listed as below, according to their order of importance.

a) Effect of themal stresses in the gate gallery and undersluice barrels, because of very rapid placement of concrete in those sections,w ithout precooling or postcooling, lack of pozzolanas and use of high alkali cement for obtainment of high strengths, as per studies conducted by the Central Water and Power Research Station Pune and Indian Institute of Technology, New Delhi.

b) Alkali-aggregate reaction, on account of possible use of river gravels as coarse aggregates, containing opal, chert and chalcedony, besides the strained quartz in the granites and diorite aggregate, as per the report of the Cement Research Institute, New Delhi after Petrographic, electron microscope, DTA & X-Ray studies of the aggregate from the concrete in the body of the dam.

c) Presence of large amount of feldspars (30 to 40%) in the fine aggregates from the river bed used in construction, according to the work of the Engg. Geology Division of the Geological Survey of India, besides the causes already mentioned in para b from their petrological studies and

d) Possible effects of industrial pollution of the reservoir water including attack on the concrete.

Remedial Measures : Ever since the development of cracks were observed, the project authorities have been opening them with chisels and jackhammers, and grouting them at pressures of 1 to 3 kg/sq.cm.with Cement and Epoxy resin. The grout appears to cover only 3 m from the crack surface. Guniting of some parts with waterproof cement has also been performed.

The latest measures consist of provision of steel sheets by international groups, the steel sheets, placed upstream of the dam extending from the river bed to the maximum water level in the non overflow and overflow sections. Steel sheets are expected to prevent further attack of the concrete and its deterioration subsequently.

It would be worthwhilke to carryout a seismic velocity survey of the foundations in a longtitudinal direction for determinations of any low areas of velocity in them which can be treated by means of vertical shafts on the downstream and adits leading to them and backfilling them with concrete.

Summing up, rapid placement of concrete without precooling and other construction control appears to be primary cause for the distress noticed; More so, because the cracks are horizontal and are confined to certain levels, where rapid placement has taken place. The theory of strained quartz causing alkali aggregate reaction is not universally accepted; Besides there are no evidences of extensive use of river gravels containing chert, chalcedony etc.

Acknowledgement:

Much of the data presented in this paper have been extracted from the report of the Committee of experts for study and advice of remedial measures of cracks in Hirakud Dam spillway constitauted by the Governmetn of Orissa in '83-84' (with Dr.Y.K.Murthy, World Bank Consultant as Chairman). I am thankful to the members of the Committee, who provided all the information presented. And thanks are expressed to my colleague in the Geological Survey of India, Shri P.B.Srinivasan, Retd. Director, who went thro the paper and discussed the various aspects.

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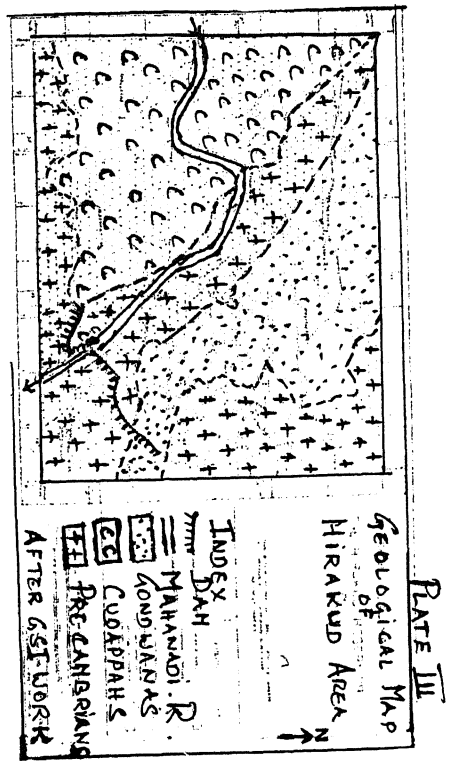


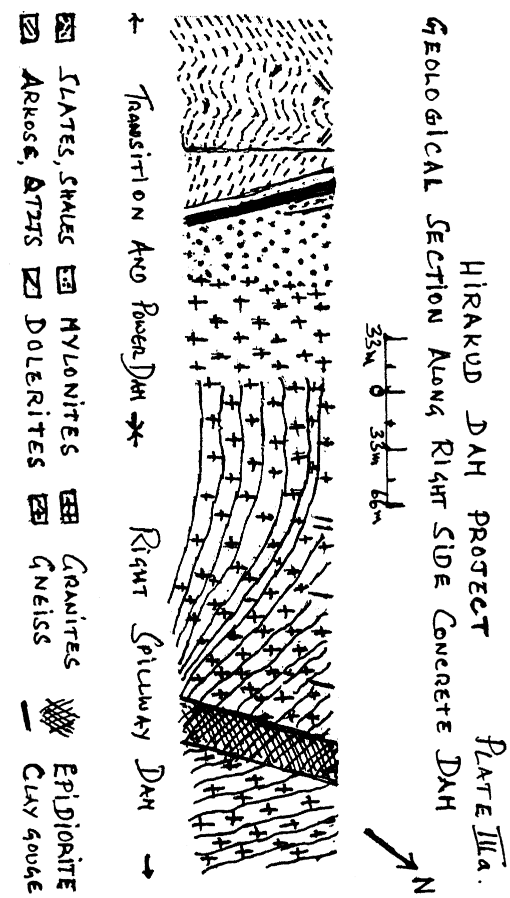
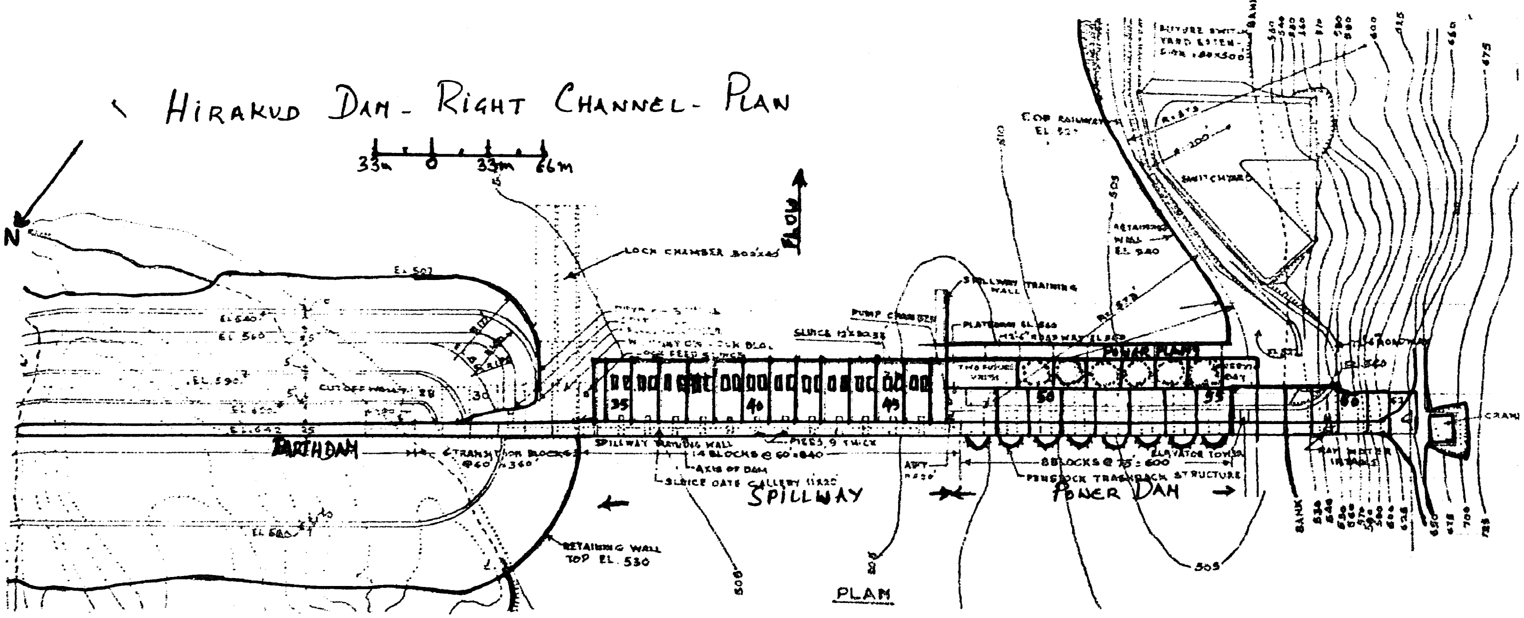
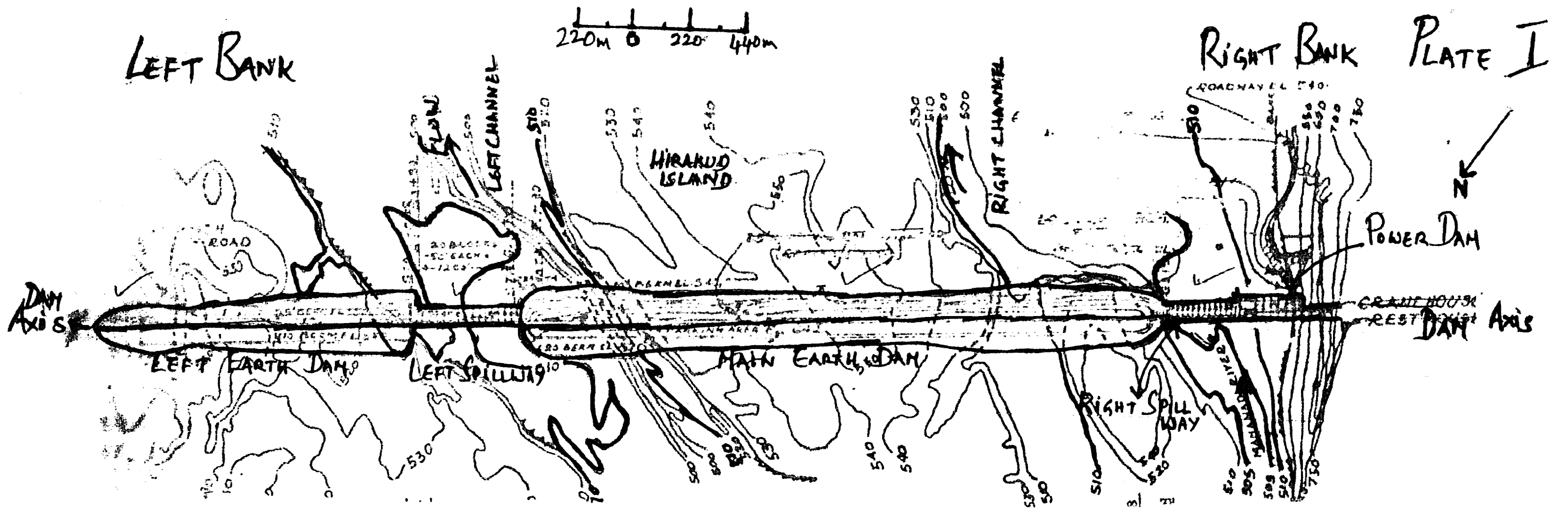


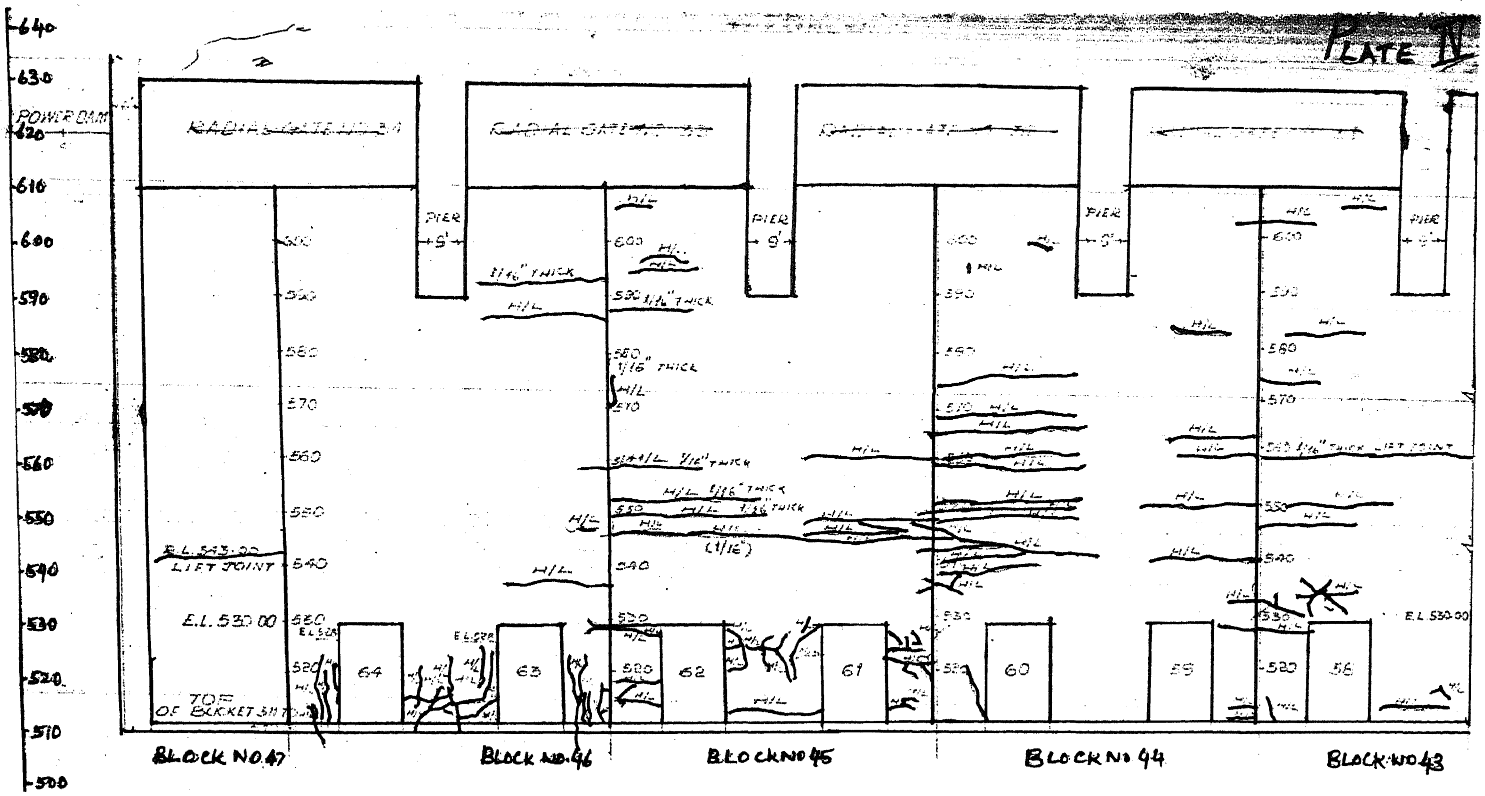
PLATE II



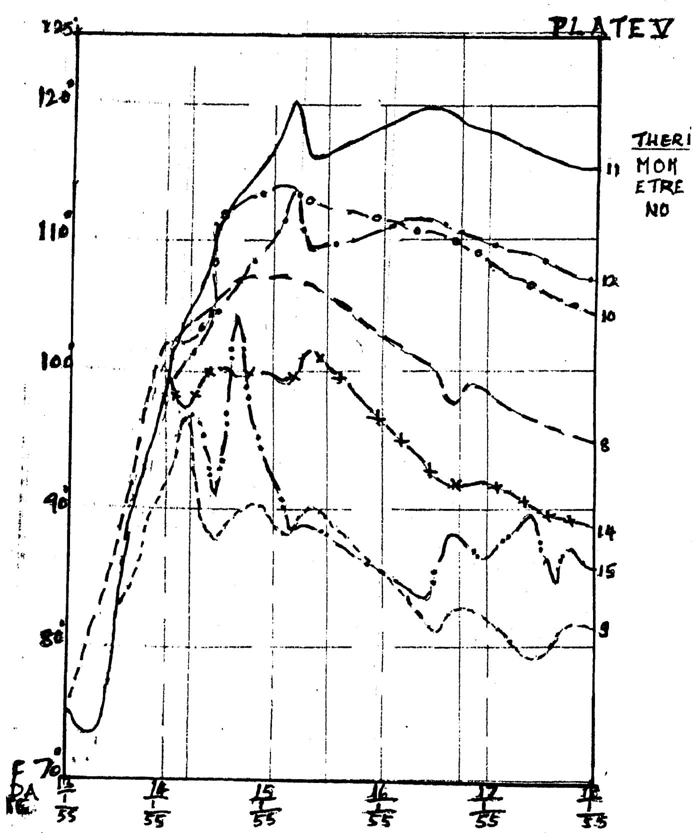
HIRAKUD DAM - RIGHT CHANNEL - PLAN

GENERAL PLAN OF HIRAKUD DAM.





CRACKS ON D/S FACE OF THE DAM- RIGHT BANK



EARLY TEMP. RISE FOR EL. 525-BLOCK 41 NO