PAPER NO.579

PERFORMANCE OF TARBELA RESERVOIR

BY

Sardar Muhammad Tariq, M. Mushtaq Chaudhry

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Sardar Muhammad Tariq[1] M. Mushtaq Chaudhry[2]

INTRODUCTION

Tarbela Reservoir is located about 64 air km (40 Miles) northwest of capital Islamabad in Pakistan. The reservoir extends about 97 km (60 Miles) upstream in an area of 260 km^2(100 sq. miles). It stores about 15% of the Indus River flows annually which fluctuate from a minimum of 310 m^3/s (11,000 cfs) during winter to an average maximum of 14,100 m^3 /s (498,000 cfs) during summer months. The first filling (partial) of reservoir commenced in summer 1974 and has been in operation for the last twenty three (23) years. This paper describes the reservoir performance in the fields of reservoir slopes, sedimentation, impacts on ground water, water quality, downstream channel and reservoir induced sesimicity.

GENERAL

Tarbela Dam Project (Fig-1) built from 1968 to 1974 on the river Indus constitutes the following main features.

Reservoir

- ☐ Catchment area :169,600 Km^2 (65,500 Sq. miles)
- ☐ Reservoir area at maximum Pool Elevation :260 Km^2 (100 Sq. miles)
- ☐ Maximum depth of water :137 m (450 ft)
- ☐ Total storage capacity :14.3 Bm^3 (11.62 MAF)
- ☐ Live storage capacity :11.94 Bm^3 (9.69 MAF)

Main Embankment Dam

- ☐ Maximum Height :143 m (470 ft)
- ☐ Crest Length :2740 m (9000 ft)
- ☐ Crest Elevation :477m (1565 ft) (above mean sea level)
- ☐ Total volume of earth and rock used for the project :153 M m^3 (200 Mcyd)

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Project Outlets

- ☐ Combined irrigation release capacity through two low level tunnel outlets (Dia 10.97 m) :4900 m^3/s (173,000 CFS)
- ☐ Combined Discharge capacity of two gated spillways :42,000 m^3/s (1,500,000 CFS)

Power House

Installed generating capacity of power units on three tunnels.

Tunnel No. 1	: 4 x 175 MW
Tunnel No. 2	: 6 x 175 MW
Tunnel No. 3	: 4 x 432 MW

PERFORMANCE OF RESERVOIR DURING FIRST FILLING AND DEPLETION

The first impounding of Tarbela Reservoir (Fig-2) commenced in July 1974 in the summer season. When the reservoir was filled to about 80% of the total depth on August 21, 1974, an upstream section of one of the four tunnels (Tunnel No. 2) located at the right abutment collapsed for about 76.2 m (250 ft) length due to stucking problem of the central intake diversion gate. As a consequence, the reservoir had to be depleted for about 110 m (361 ft) depth in a period of 26 days by opening all the available low level outlets. The reservoir was kept empty till summer 1975 to complete remedial works of tunnel No. 2. During the quick drawdown of reservoir in 1974, the maximum being 7m (23 ft) during 24 hours, no instability at reservoir banks was observed.

In the subsequent years, the reservoir is being operated on a seasonal basis and annual reservoir water level fluctuation is generally about 76.2 m(250 ft). The lowest levels are often reached in May -June before the start of high flow season and the maximum pool level 472 m (1550 ft) is generally attained on August 20 each year.

RESERVOIR SLOPES

The reservoir slopes are steep with general slopes between 40°-80°. The geologic surveys in the reservoir area before the construction of dam showed only a few potentially unstable slopes. All these unstable slopes have been under observations particularly during reservoir impounding and quick drawdown periods. So far no large mass sliding have taken place. Only four small slides have been experienced in the reservoir rim between 10 to 15 km upstream of main embankment dam. These slides apparently were caused by progressive movement of thin layers of overburden and weathered rock outcrops. These slides did not have any effect on the performance of the reservoir and other Project features.

The reservoir rim slopes close to the project are monitored very closely by survey markers. No movements have so far been recorded. However certain areas susceptible to

erosion due to severe wave action at reservoir surface have been protected with dowelled stepped skin concrete which often gets undermined at the toe levels and needs periodic restoration.

RESERVOIR SEDIMENTATION

While evaluating the economic feasibility of Tarbela Project, it was considered that live storage would last for a period of about 50 years. During the time of design, it was not considered feasible to take measure that could decrease the production of sediments in the watershed.

The snow and glacier melts mainly constitute the base flow in the Indus River. The Tarbela reservoir impounds about 15% of the mean annual Indus River flow. In accordance with the reservoir operation rule curve for filling and emptying the reservoir (Fig-3) the summer inflows raise the pool from lowest operation level 396 m (1300 ft) to maximum reservoir level 472 m(1550 ft) in about 8 weeks. The top elevation is invariably reached on August 20 and is maintained for some time depending on the D/s irrigation requirements. The seasonal fluctuation in river flows and corresponding sediment load cause sediment accumulation and redistribution. Due to huge size of reservoir and therefore long detention time, nearly all the suspended sediments (97%) are trapped in reservoir.

During the months of May and June, the high temperatures accelerate the snow melt. The water at low reservoir level, upon surging through the exposed sediment deposits causes the river channel to widen and the banks to collapse in the upper reaches of reservoir resulting in considerable increase of sediments in the water flowing downstream. The sediments so eroded and the new sediments brought by the inflow are deposited in the main river and help the delta to develop and advance downstream towards the dam. Beyond the delta, the fine silt and clay particles are carried along the reservoir bottom and are deposited further downstream.

During reservoir filling stage from elevation 396 m (1300 ft) and above the reservoir increases in length and width causing the deltaic sediments to be deposited further and further upstream while the delta which was built during the low reservoir further downstream is overlaid by finer material. Within the dead storage section of reservoir, sediments go on accumulating throughout the year.

HYDROGRAPHIC SURVEY

Hydrographic surveys of reservoir were first started in 1979 and are being carried out annually throughout the entire length of 97 km (60 Miles) of reservoir. These surveys have revealed that during the last 22 years (upto September 1996) about 2.98 Bm^3 (2.417 MAF) of sediments have been deposited (Fig.4). The gross storage capacity of reservoir has reduced by 20.8% from 14.3 Bm^3 (11.62 MAF) to 11.36 Bm^3 (9.20 MAF) and the usable capacity by 16.2% from 11.94 Bm^3 (9.69 MAF) to 10.01 Bm^3 (8.11 MAF) (fig.5).

The reservoir operation has a significant effect on the sediment deposition and advancement of delta towards the dam. When the reservoir is not brought to lower levels, substantial amount of sediments are deposited in the upper reaches of the reservoir. On the other hand, heavy inflows during the flood period (June to September) bring large amounts of sediments. These inflows though heavy do not cause the delta to advance unless the reservoir is depleted close to minimum pool level 402m (1320 ft) and stays at this level for sufficient number of days. It has also been observed that freak flows and high inflows at high reservoir levels have insignificant effect on the advance of delta.

To preserve/enhance the storage life of Tarbela reservoir it has been considered advisable to initiate a well thought out plan of sediment management for which in depth studies by the international experts have already been initiated and would be completed by the end of 1997.

The reservoir delta sediments have been tested in laboratory under dynamic loading condition in the past. These tests indicate high potential of liquefaction under moderate earthquake shaking and may result in clogging of low level tunnels. In order to meet such an eventuality a manual for unclogging operation has been prepared.

During the occurrence of several earthquake having local intensity upto VII on mm scale no abnormality of forest slope has, however, been noticed from the sonar surveys.

IMPACTS ON GROUNDWATER

The Tarbela Dam reservoir setting can be broadly divided into five major areas of interest as regards ground water changes and its effect due to impoundment. In the north and along its 97 km (60 miles) length (Fig.2), the reservoir is bounded by high mountains. The area in which people did not opt to move out and instead constructed new dwellings above the reservoir level are virtually free from any ground water effect. The other four surrounding areas which experienced both prudent and imprudent ground water fluctuations are discussed hereunder:

The Western Area

This area lies on the west of the right bank mountain and was the main borrow area for silt and coarse material used in the construction of the Dam (Area-1). This area experienced major ground water fluctuations during construction state and post-construction era. During construction, when river was diverted through the diversion channel, this area faced substantial drop in the water table with the result that most of the village wells in the area went dry. To meet water requirements of the villagers, the project contractor was asked to provide water through Tankers. This process continued for almost 3 years till the reservoir was filled up in 1974. Immediately after the filling of reservoir this area got recharged and experienced rise in the water table with almost all wells refilled to substantial depth offering minimum efforts to water extraction. The rise in general ground water as confirmed through recent isotopic surveys has helped agriculture and the area once so barren is now lush green with vegetation and crops such as wheat, mustard, maize, etc., and is being extensively

cultivated for al sorts of vegetable and other cash crops. Part of this area has been earmarked for establishment of an Industrial estate. Over fifty medium sized units are already functioning. To meet the industrial and domestic water requirements tubewells have been installed which are working efficiently. In general the reservoir has benefited this area largely in meeting agriculture, domestic and Industrial water supplies.

Area Along Eastern Periphery of the Reservoir (Area-II)

This area is known as Haripur basin and lies over flatter grounds where reservoir depth is also shallow. Prior to the reservoir, the ground water was at a substantial depth and generally drained towards the present reservoir. The area was dry and limited agriculture was practiced. After the reservoir development, the water table started rising slowly and for the first 10 years extensive "Well Irrigated Agriculture" was followed which benefited the local populations tremendously. However, during the recent years and with further rise of the water table, the area more or less has become water-logged which not only effected adversely the agricultural production but damaged the built-up properly as well. Detailed investigations carried out by isotropic surveys indicated that reservoir water had not intruded in to the area but in fact the reservoir water had created hydrostatic pressures which obstructed the movement of ground water and natural drainage thus raising the water table.

However as we move further south of Haripur Basin and into area III, the soil generally consists of sand and gravel with self draining slopes. This area was the most barren area and water was a scarce commodity. The author's family owns somewhat over 3000 hectares of land in this area. The water levels in the village wells were generally about 120m (390 ft) to 130m (425 ft) below ground level. The vegetation was sparse the very little agriculture was practiced. After the impoundment of Tarbela reservoir, the water table rose to some 5 (16 ft) to 8 (26 ft) meters below ground level. At number of places natural springs with perennial flow of crystal clear water sprouted out. The whole area has turned in to a green belt and presently is under extensive irrigated agriculture. The price of land has appreciated between 120 to 170 times. The growth of vegetation in the barren areas has provided breeding grounds to the wild-life. The government has declared this area as game reserve.

Area South of Dam and Along River Banks (Area-IV)

The flows in river Indus in the area under reference fluctuates on the average between 310 cumecs (11,000 Cfs) to 14,000 cumecs (498,000 Cfs) annually. During low flow periods in winter months, the water table drops considerably which adversely affects the winter crops and vegetable yields in the area.

RESERVOIR WATER QUALITY

About 90% of the flow into Tarbela reservoir is from snow and glacier melt. The remaining 10% of the flow is from small rainfed cachment area. The drainage area upstream of Tarbela though substantially large, is very thinly populated with virtually no industry in existence.

With small storage capacity of the reservoir as compared to annual inflows, about 85% of the inflows do not get stored in the reservoir. This facilitates recharging of reservoir with fresh water annually. The reservoir submerged area was substantially cleared of forests and other organic matter prior to impoundment, thus having no organic matter to decay. The reservoir water therefore remains largely free of pollution and odour. Since 90% of the flow is also snow and glacier melt it also remains free of pathogenic germs known for diseases such as typhoid fever, dysentery and cholera. The slats such as sodium, calcium and magnesium largely control the quality of water for domestic and industrial uses. The total dissolved solids (TDS) is an indicator of slat concentration. Chemical analysis carried out on water samples collected from the reservoir soon after impoundment in 1976 indicated TDS as 99 PPM which gradually reduced to 82 PPM in 1992 that indicates improvement in the water quality. The pH value of reservoir as analyzed in 1976 was 6.5 which changed to 8.0 indicating the reservoir water slowly changed in nature from slightly acidic form to alkaline form.

DOWNSTREAM CHANNEL

Twenty two years of reservoir operations and sediment sampling carried out on all the hydraulic outlets indicates that most of the sediments remained trapped in the reservoir and only 2 to 3% of the sediments are flushed out. River waters downstream of Tarbela Dam virtually remained free of sediments. Under such operating conditions elsewhere, the river flows would have substantially degraded the downstream of Tarbela Dam. This effect has not been noticed anywhere downstream of Tarbela Dam. The main reason for such eventuality not taking place is the size of the bed material deposited by river Indus in the geologic time. The bed material generally consists of cobble size stones well armoured offering maximum resistance to scour.

RESERVOIR INDUCED SEISMICITY

An earthquake is a failure in the crust caused y an increase or a decrease in the strength beyond critical limits. Generally, a reservoir will cause a change in both stress and strength in its vacinity. The stress is affected by the reservoir load and strength by change in the pore pressure.

Seismotectonic Features at Tarbela

The Tarbela Project lies in seismotectonic belt (Fig.6) where several moderate earthquakes with magnitudes less than 7 have been recorded. Concentration of epicentre related to active seismic zone, has been noted. Around Tarbela, a lot of seismic activity has been recorded which could be mostly associated with Darband fault, Panjal Fault and Hazara Thrust System (HTS).

1. The Darband Fault is a steeply dipping strike slip fault which passes below the Main Dam and forms a 214 m (700 ft) nearly vertical escarpment in the dam foundation and continues about 100 km (62 miles) north of it.

2. The Panjal fault is the nearest one point approximately 12 km (7.5 miles) from the dam site and extends about 80 km (60 miles) southwest from the Western Himalayan Syntaxial Bend to Attock area. At both ends it appears to merge with major faults of Himalayan Thrust System.
3. The Indus Kohistan Seismic Zone (IKSZ) is considered to be a straight extension of Main Himalayan Thrust belt and is at a distance of about 80 km (60 miles) northwest or Tarbela.
4. Hazara Lower Seismic Zone (HLSZ) is another narrow seismic zone interpreted on seismological evidence and is present below the Detachment Fault. It is located about 60 km (38 miles) south of IKSZ. However, its motion is right lateral strike slip. At a depth of about 35km (22 miles) it branches out into a gently dipping fault that is considered to be exposed on the surface in the shape of Hazara Thrust System or Salt Range Fault and takes a sharp gradient south of Tarbela Region. This Hazara Thrust system passes at a distance of about 40 km (25 miles) south of Tarbela.
5. Hindukush seismic Zone is another very active zone located about 250 km (150 miles) northwest of Tarbela. More than 20 seismic events per day have their epicentres along this zone.

Seismic Events and Reservoir Levels

The effect of Tarbela Reservoir on seismicity has been studied both in time and space especially with respect to seismic energy released within 40km (25miles) radius of the dam against reservoir bench. The plot of energy release versus levels from the first impounding in 1974 upto 1996 is shown in (Fig.7). This plot indicates that the effect of Tarbela reservoir on seismicity is temporary quiescence due to negative effect of reservoir load on differential stress in a tectonic regime where the maximum compressive stress is subvertical i.e., a regime of thrusting.

A long term effect is superimposed on the yearly cycle of reservoir filling and seismicity. At the time of first reservoir filling to high levels in 1975, the seismic energy release in Tarbela region dropped drastically. Since then the yearly release of seismic energy started rising steadily and by 1983-84 reached the pre-impounding level. Beyond 1984 the cycles of high and low seismicity are observed. Presently the seismicity near the dam is of high level and this trend is expected to continue.

During the period Jan 1970 through May 1996, as many as 152 earthquakes have been felt at Tarbela Dam Project including 50 with epicentres along the Tarbela region (160 km radial distance). The distribution of these earthquakes along the seismotectonic features of Tarbela region is listed here.

TABLE 1

SEISMOTECTONIC FEATURES	EVENTS %	MAXIMUM		
		MAG.	INTENSITY	ACCEL (g)
Indus Darband Fault	38.3	5.3	VI-VII	0.27
Hazara Thrust System	20.2	5.0	VII	0.25
Tarnawi Panjal Fault	6.1	4.5	V	0.04
Main Mantle Thrust	4.2	4.7	II	0.01
Indus Kohistan Zone	2.0	5.1	V	0.14
Inferred Fault	20.2	4.9	IV	0.04
Other sources	9.1	6.1	V	0.08

The above table indicates that about 38.2 % earthquakes occurred due to the movement along Indus Darband fault. Three of these earthquakes, felt on 17.04.72, 25.03.92, 20.02.96, are very important regarding seismic hazard assessment for the Project. These earthquakes generated acceleration of 0.25%g, 0.21g and 0.27g respectively on rock. Out of these, the seismic event of February 20,1996 which took place at Res. E 1.432.9m (1420 ft) is discussed below:

Seismic Event of February 20,1996

The February 20, 1996 earthquake was located very close to the critical structures of Tarbela Dam Project and in the Darband Fault Zone (Fig.8) and had the following seismological data:

Origin Time	:	02 Hrs: 57.19 min GMT
Magnitude	:	5.3 Richter Scale
Local Intensity	:	VI-VII (MM Scale) (Fig.9)
Epicenter	:	34°03.5` N
		72°40.0`E
Focal Depth	:	5.0 km

The earthquake generated 0.27g acceleration on the free field rock an 0.25g on the rock at the toe of main dam. This event was followed by as many as ten (10) after shocks within two (2) days. (Fig.10). Immediately after the occurrence of earthquake on February 20, 1996, a 'Yellow Earthquake Drill was carried out to physically inspect the embankment dams, abutments, concrete structures and rock cut slopes.

No sign of rockfall or other major abnormality was noticed within the Project area. However, some significant changes were recorded prior to, on the day of event and during post event period which are discussed below:

Piezometers:

The monitoring of all the piezometers located in the upstream blanket, embankment dams (fill and foundation) and areas downstream of embankment dams revealed that:

- A piezometer (BB-105) located in the upstream blanket and four piezometers MA/P2-4, MB/P2-1, MX/P2-56 (located in the main dam fill and foundation) which were previously declared erratic started responding (Fig. 11&12).
- Three piezometers MC/P2-57, MC/P2-62 and ME/P2-2 at main dam showed a drop of 2.1m (7ft) 2.1m(9ft) and 1.2m(4ft) respectively (Fig. 13&14).
- Piezometers B-593 and B-664 located at downstream of grout curtains at Auxiliary Dam-1 (AD-1) and Auxiliary spillway showed maximum drops of 3.6m (12 ft) and 2.4m (8ft) respectively (Fig.12)
- Piezometers B-764 located in the area downstream of AD-1 dropped by 0.3m (1ft) (Fig.14).
- Piezometer B-730 located in the right abutment of main dam dropped by 2.1m (7 ft). (fig.13)

Seepage

The seepage was monitored in all the adit systems of the abutments and spillways. No effect was noticed in the overall seepage of any system. However the discharges from some of the drain holes in adits RAA-2 and RDA-20 increased by one to six g.p.m. and were higher than the discharges at maximum reservoir level 472m (1550 ft) (Fig.15).

Sediment Delta

Two Echo Sounder Profiles were run in the mid channel of the reservoir. The first profile was run immediately after the event and the second after a lapse period of two (2) weeks. No movement of major delta was noticed. However immediately after the event, Power Unit Nos. 11 and 13, installed on Tunnel-3, started discharging, turbid flows in the tailrace area. Water samples collected after the event indicated high concentration of sediments (2740 PPM) against normal value (15-20 PPM) Fig.16. The turbidity started decreasing after about five hours and became normal on February 21, 1996 at 0800 Hrs. No turbidity was noticed on Power units 1-10, (installed on Tunnels 1 & 2). Power units 12 & 14 (installed on Tunnel 3) were not operating at that time.

As Tunnel 3 has Intake Structures at lower than tunnel 2, it appears that due to seismic activity, the delta fine deposits in the close vacinity of Tunnel 3 Intake got agitated and resulted in passing of turbid flows through Power units 11 & 13.

Electrical and Mechanical Equipment

Five Power Units (1,3,7,9 & 10) in the Power House No. 1 were tripped and Relief Valves went into operation automatically.

Structural Damages to Buildings

The physical inspection of building after the event indicated that about 50 percent residential buildings had experienced structural damages. Some non-residential buildings also were severely affected.

Land sliding and rupturing, ranging between 10mm and 50mm in width and extending to about 20m, were also observed in the fields and flowing channels in areas about 3 to 5 km from the project.

The seismic event of February 20, 1996 is associated with the phenomena of Reservoir Induced Seismicity. This even has generated an acceleration of 0.27g on free field rock and 0.25g on rock at the toe of the dam. These values are high for the Project structures which were basically designed for acceleration values between 0.10g and 0.15g only.

SUMMARY

Tarbela Dam Project, the largest rock and earth fill dam with reservoir area of 260 km^2 has been in operation for the last 23 years with its mega reservoir having gross storage capacity of 14.3 billion cubic metre.

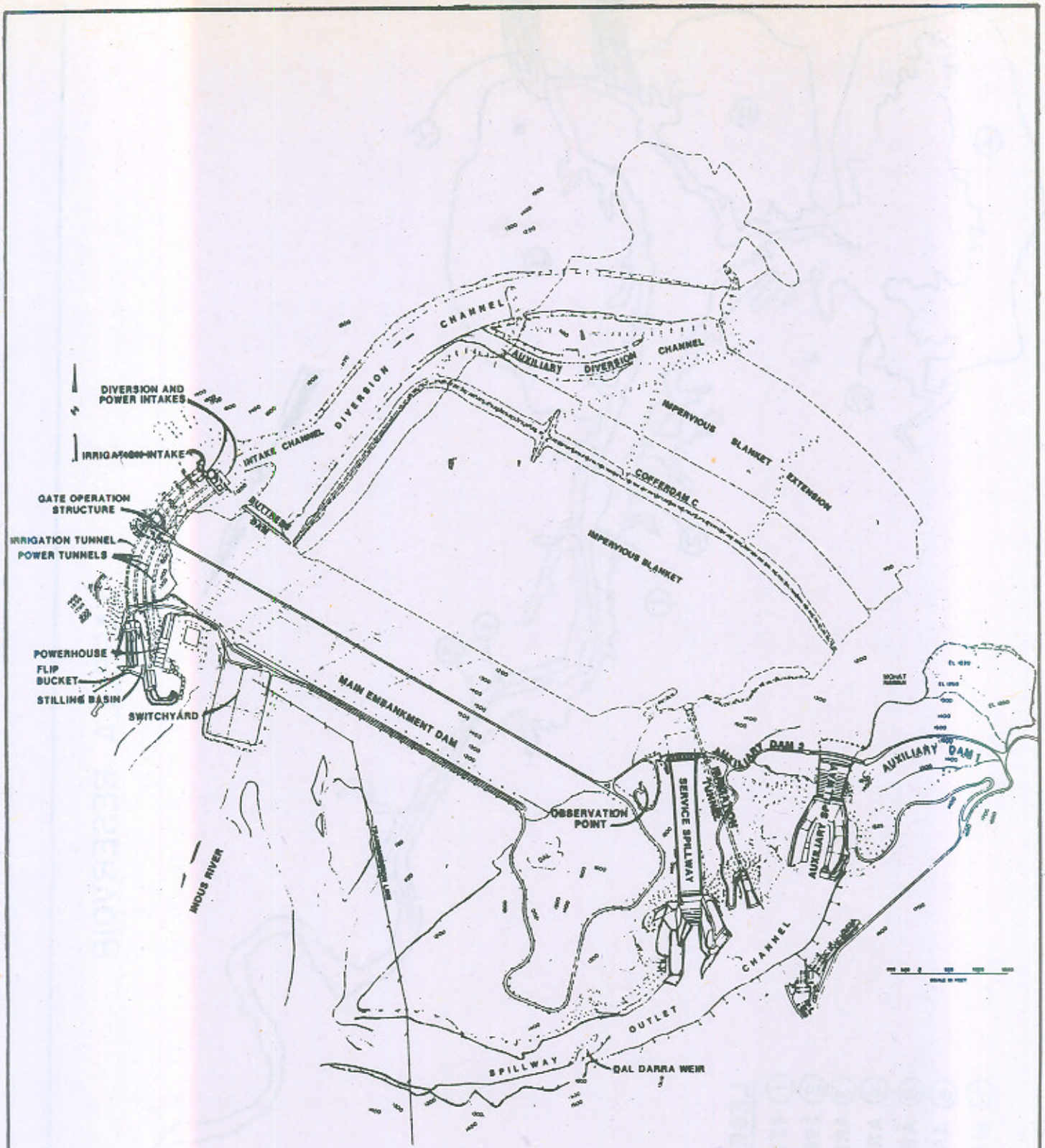
The reservoir banks in a length of 97 km though steep (40°-80°), have generally remained stable. However, four small slides have so far been experienced which have been caused by progressive movement of thin layers of overburden and weathered rock outcrops.

Sedimentation in the reservoir is fastly reducing the economic benefits of the project. The 1996 hydrographic surveys indicate that the gross storage capacity of the reservoir has reduced by about 21% and usable capacity by 16%. In order to prolong the life of the reservoir, sediment management studies have been started.

Before the creation of reservoir, the submerged area was cleared of forests and other organic matter. Therefore the water remains free of pollution and odour. Due to mostly glacier melt inflows in the reservoir, the water gets recharged with fresh water annually which helps arrest water degradation. River waters downstream of Tarbela reservoir have generally remained free of sediments.

Groundwater effects due to reservoir have been mostly positive along the periphery of reservoir except in a limited area where the rise in ground water has adverse effects.

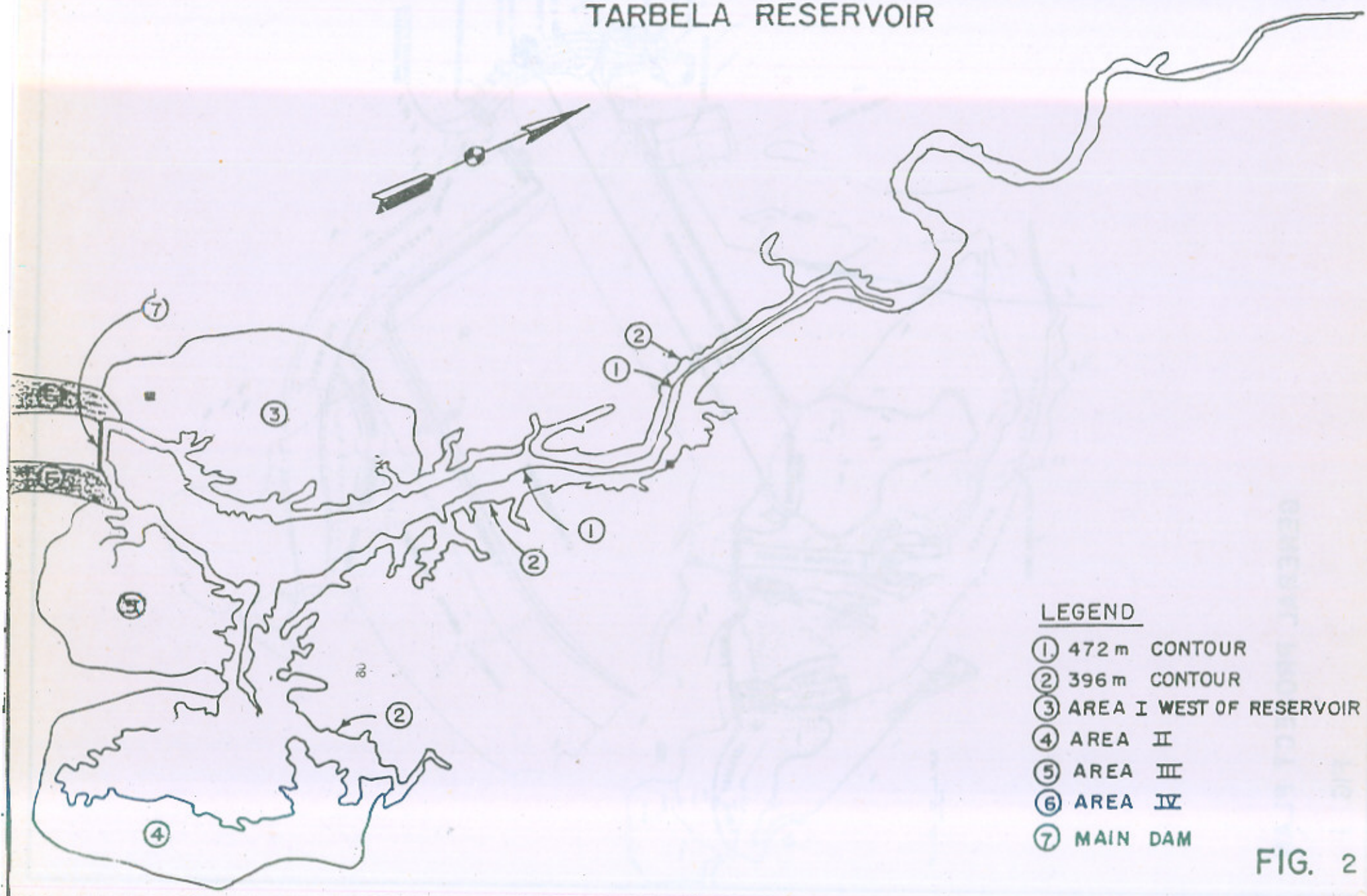
Reservoir Induced seismicity (RIS) remains one of the hazards at Tarbela. Most of the seismic events have occurred due to movements along the existing Indus Darband Fault under the main dam and have generated accelerations upto 0.27g. Very useful data, generated by Feb. 20, 1996 earthquake can benefit the planned projects in this region.



GENERAL PROJECT PLAN

FIG. 1

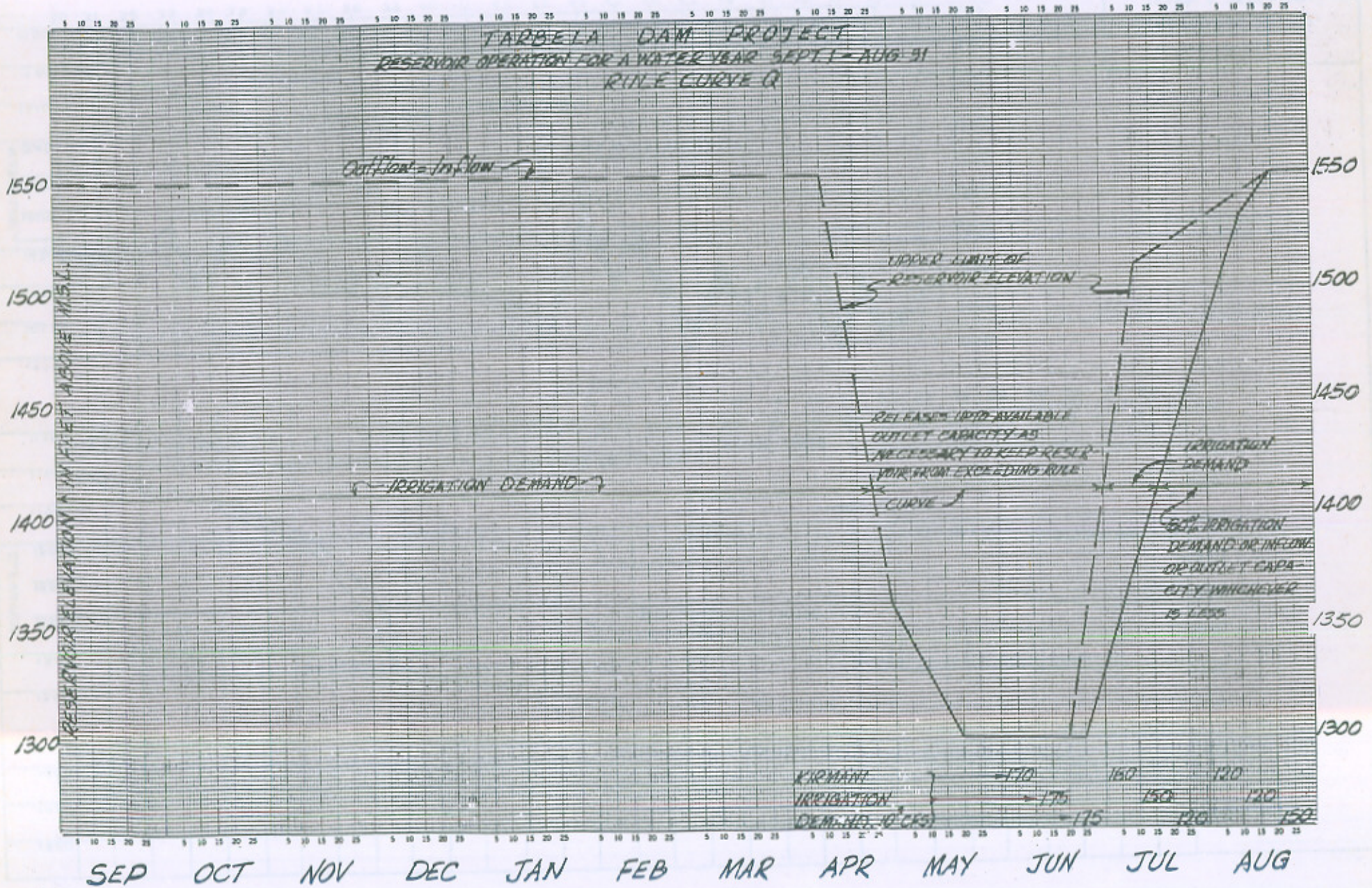
TARBELA RESERVOIR

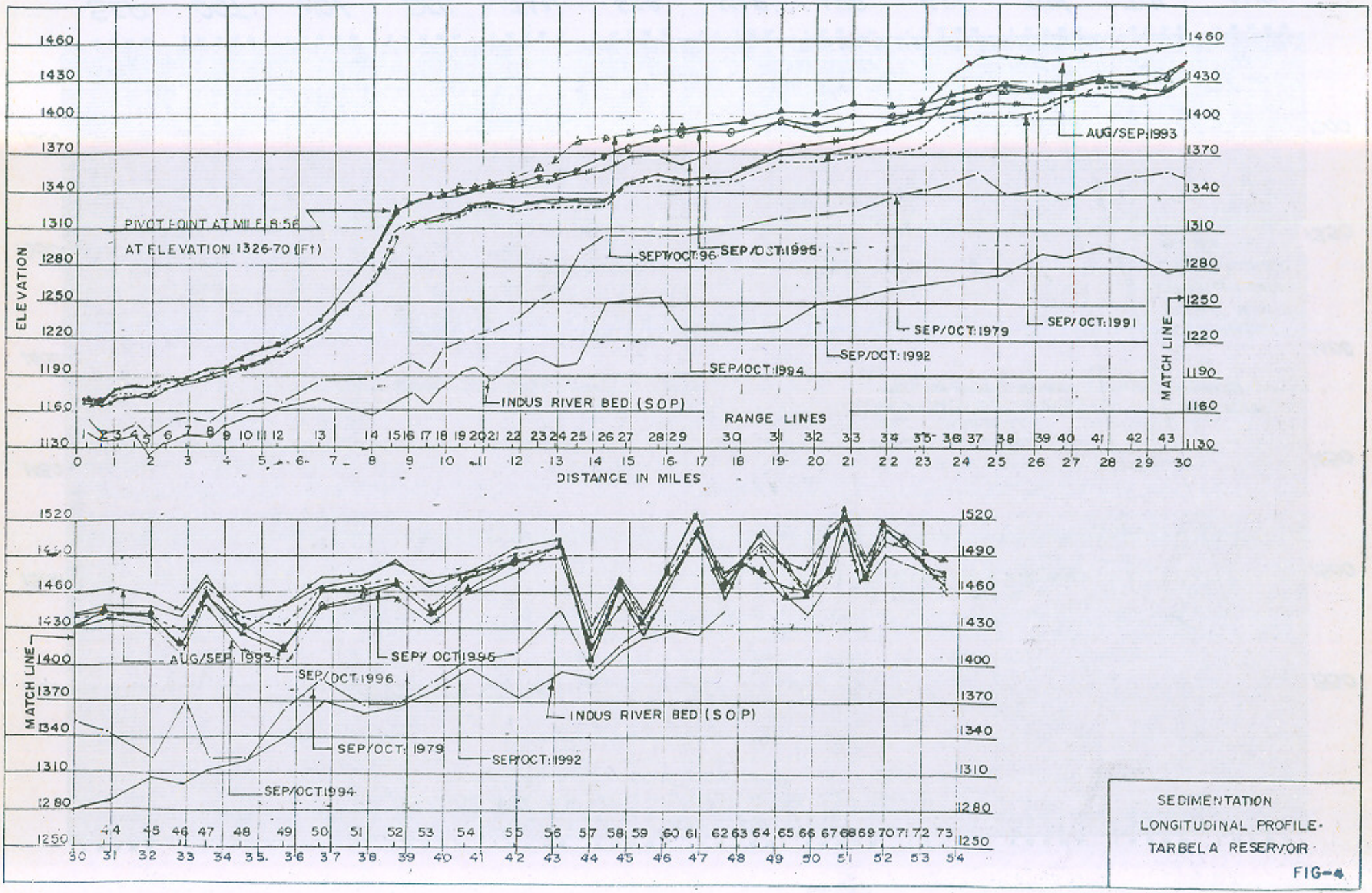


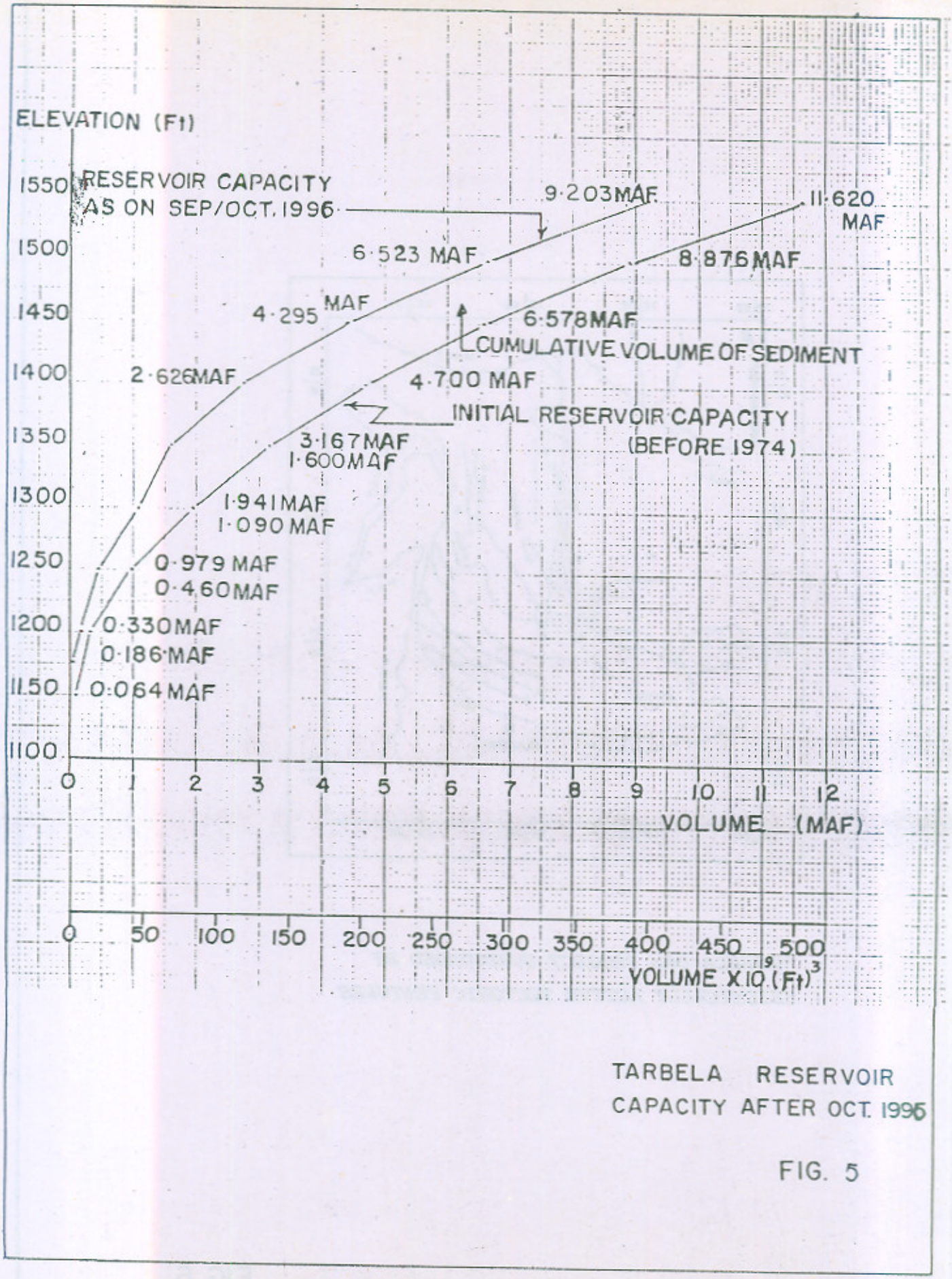
LEGEND

1. 472 m CONTOUR
2. 396 m CONTOUR
3. AREA I WEST OF RESERVOIR
4. AREA II
5. AREA III
6. AREA IV
7. MAIN DAM

FIG. 2

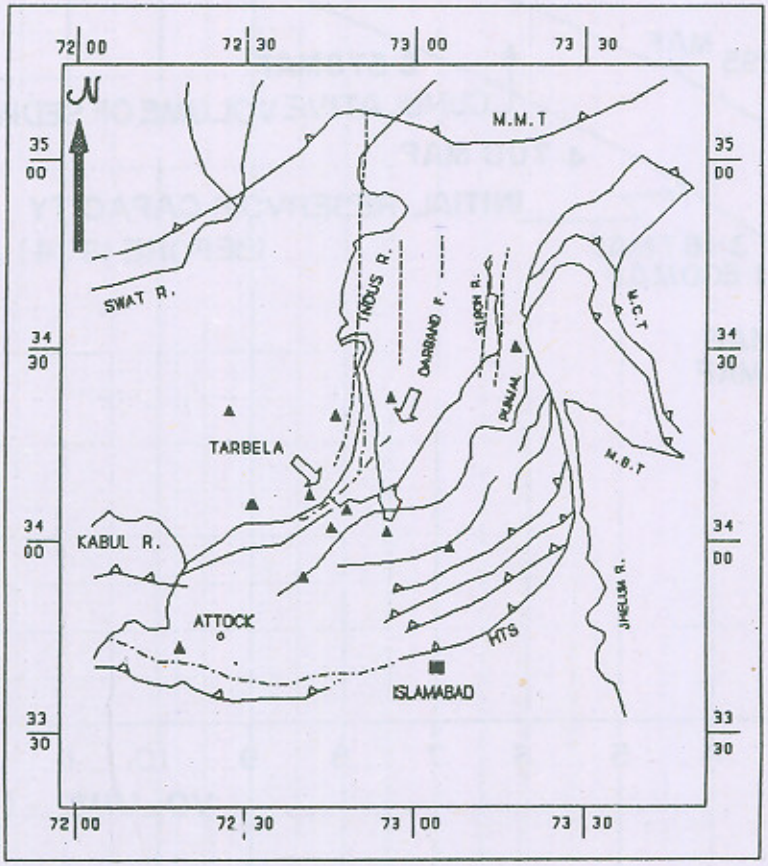

TARBELA DAM PROJECT
RESERVOIR OPERATION FOR A WATER YEAR SEPT 1 - AUG 31
RULE CURVE Q
OUTFLOW = INFLOW
IRRIGATION DEMAND
UPPER LIMIT OF RESERVOIR ELEVATION
RELEASES UPTO AVAILABLE OUTLET CAPACITY AS NECESSARY TO KEEP RESERVOIR FROM EXCEEDING RULE CURVE
IRRIGATION DEMAND
60% IRRIGATION DEMAND OR INFLOW OR OUTLET CAPACITY WHICHEVER IS LESS
KARMANG IRRIGATION DEMANDS (CFS)
1550
1500
1450
1400
1350
1300
RESERVOIR ELEVATION (IN FEET ABOVE M.S.L.)
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG


ELEVATION
DISTANCE IN MILES
RANGE LINES
MATCH LINE
PIVOT POINT AT MILE 8.56
AT ELEVATION 1326.70 (Ft)
AUG/SEP: 1993
SEP/OCT: 1996
SEP/OCT: 1995
SEP/OCT: 1979
SEP/OCT: 1991
SEP/OCT: 1992
SEP/OCT: 1994
INDUS RIVER BED (SOP)
SEDIMENTATION
LONGITUDINAL PROFILE
TARBELA RESERVOIR
FIG-4



TARBELA RESERVOIR CAPACITY AFTER OCT. 1996

FIG. 5



TARBELA DAM PROJECT SURROUNDED BY SEISMICALLY ACTIVE TECTONIC FEATURES

FIG. 6

TARBELA DAM SEISMICITY

AREA < 40 km redius. DEPTH < 10 km

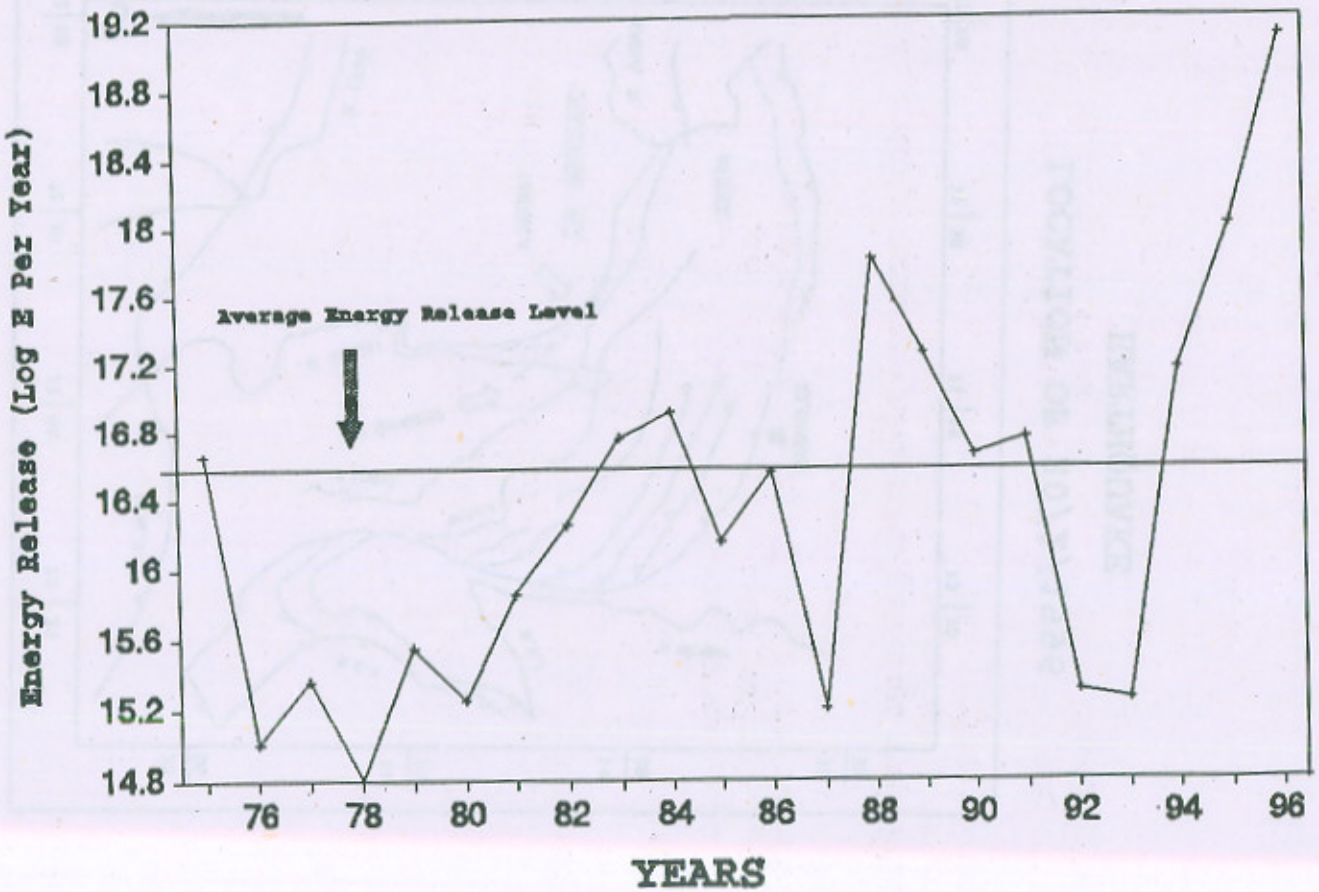
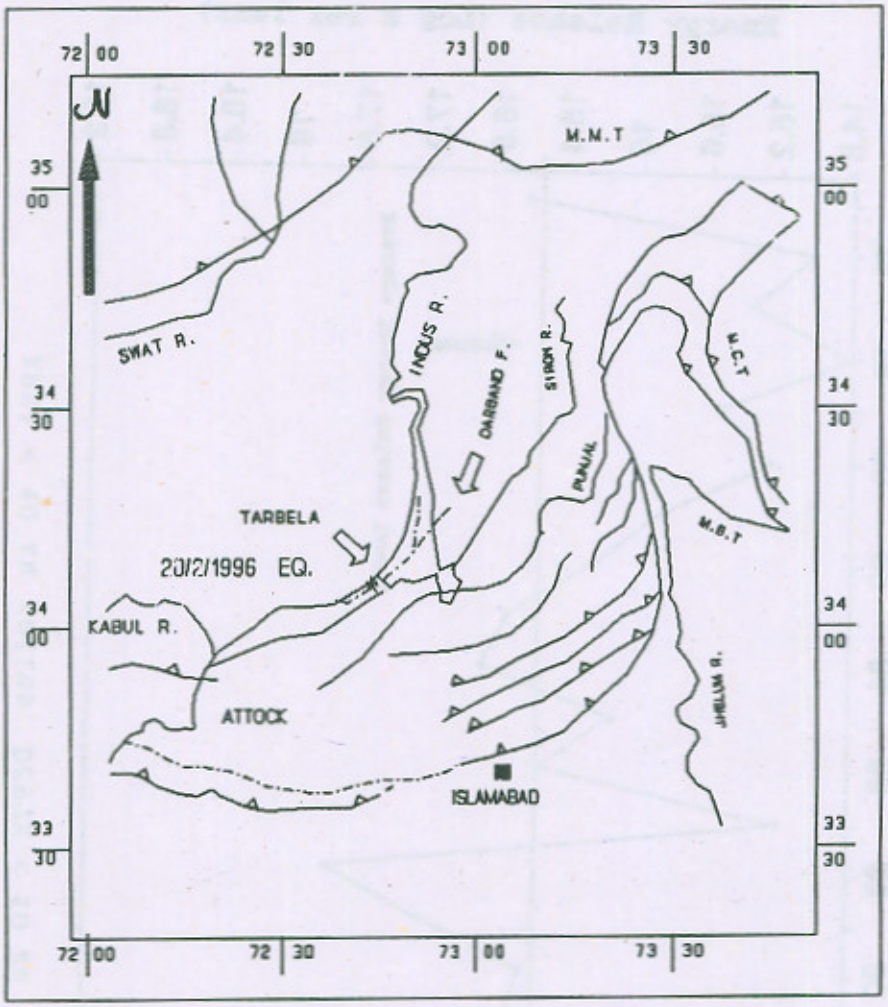


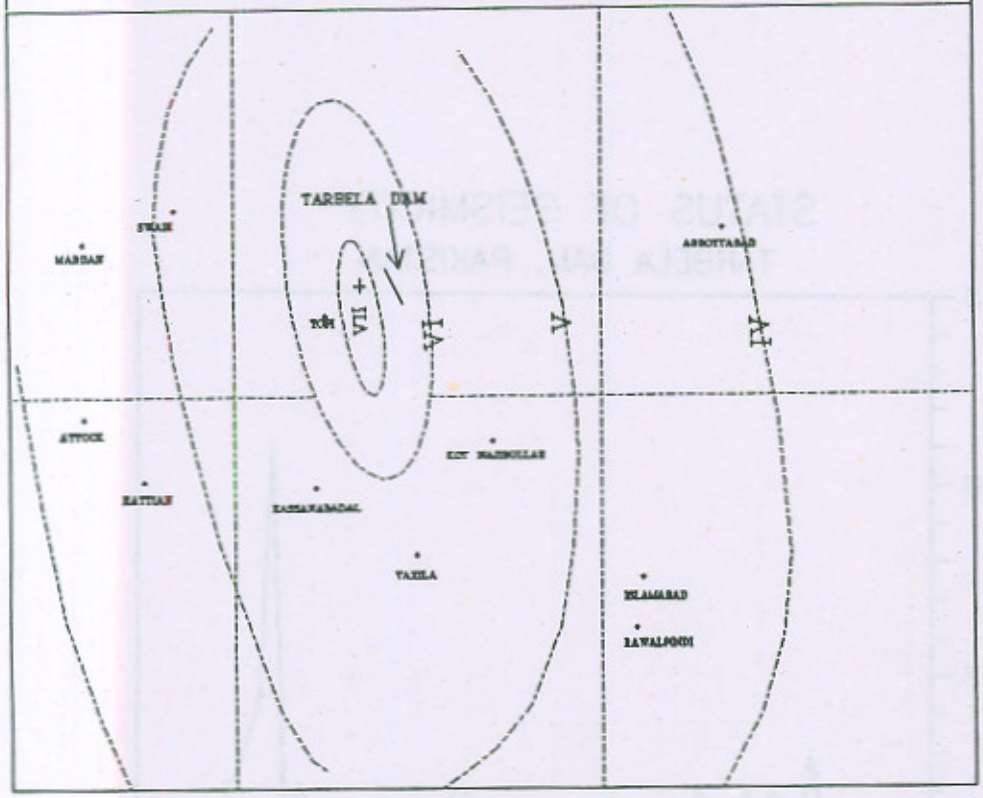
FIG.7



LOCATION OF 20/2/1996
EARTHQUAKE

FIG. 8

INTENSITY SURVEY



SEISMOLOGICAL DATA

DATE FEB:20, 1996.
ORIGIN TIME 0757.19 P.S.T.
MAGNITUDE 5.3 RICHTER SCALE
INTENSITY VI-VII AT TDP.
DEPTH 5.0 KM.
LOCATION { 34:03.5N / 72:40.0E
MAX ACCEL { 0.27g (ON ROCK) / 0.10g (ON ALLUVIUM)

\+ EPICENTER.
⊂ VII INTENSITY.

FIG. 9

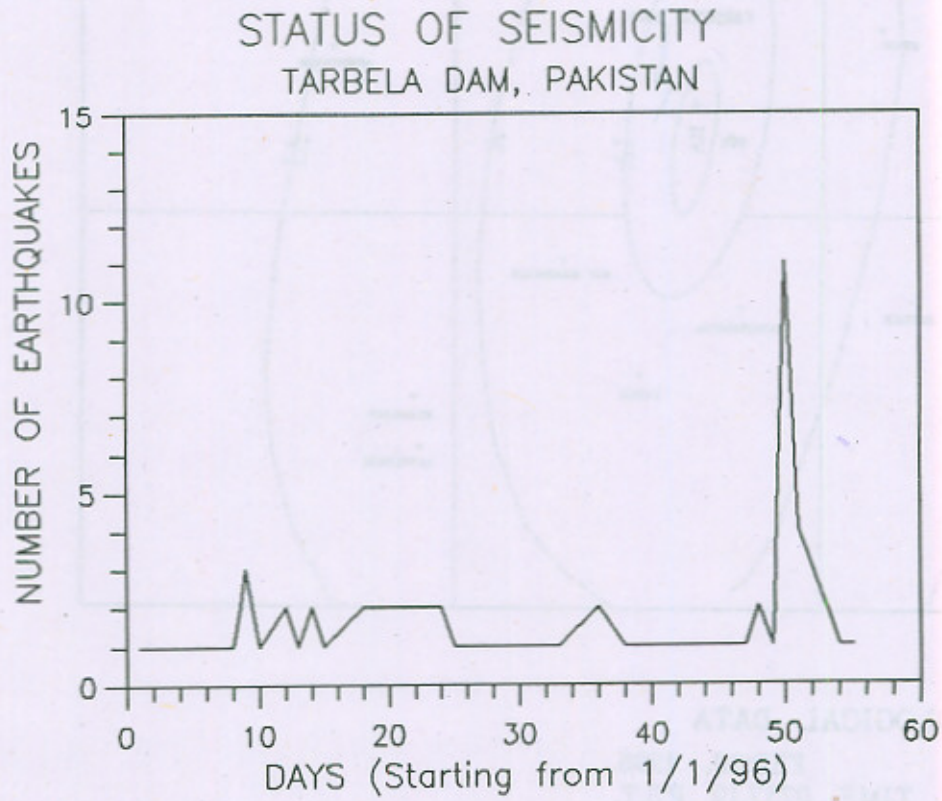
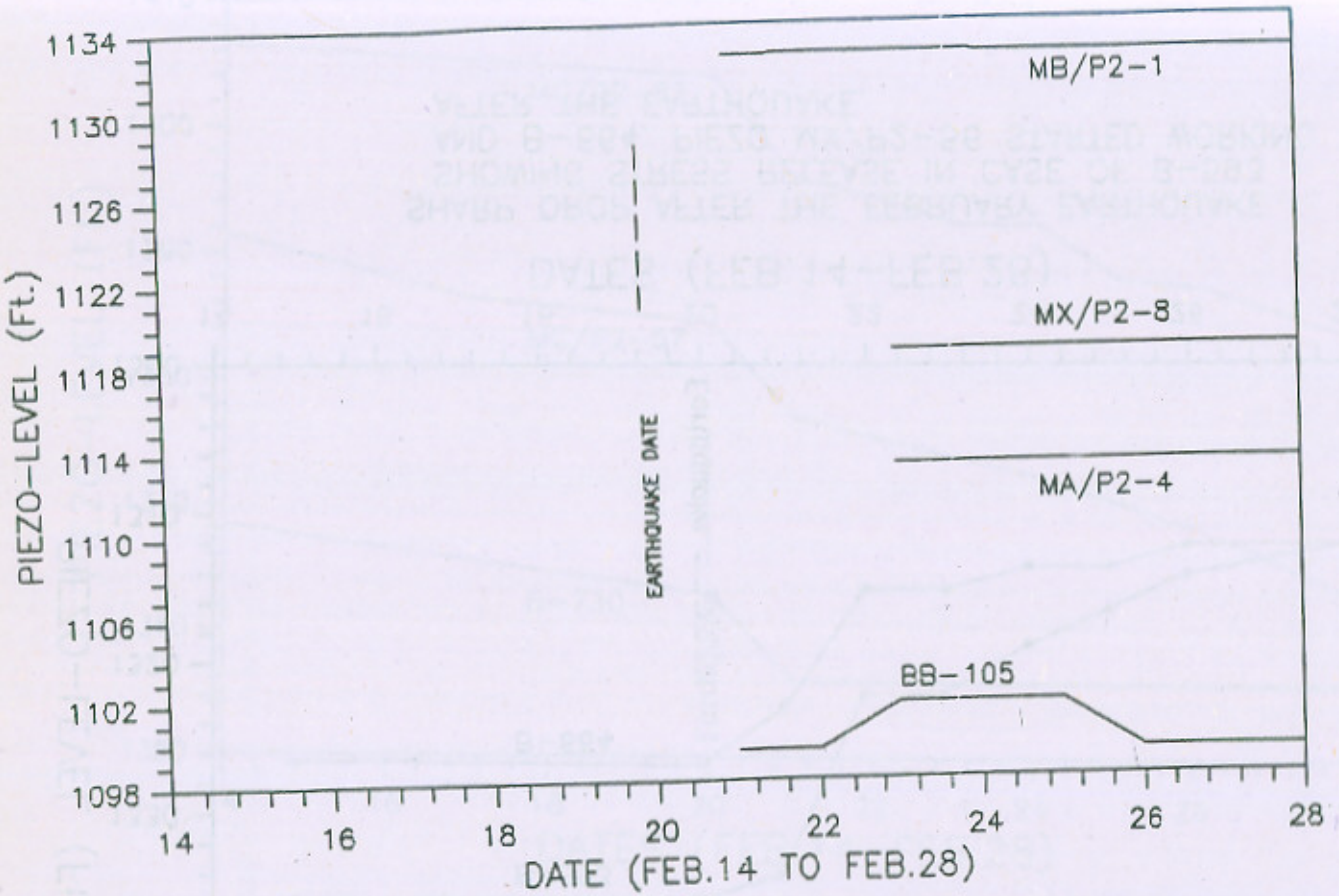

STATUS OF SEISMICITY
TARBELA DAM, PAKISTAN
NUMBER OF EARTHQUAKES
15
10
5
0
0
10
20
30
40
50
60
DAYS (Starting from 1/1/96)
EARTHQUAKES OCCURRED WITHIN 40 Km.
RADIUS AND 15 Km. FOCAL DEPTH

FIG. 10

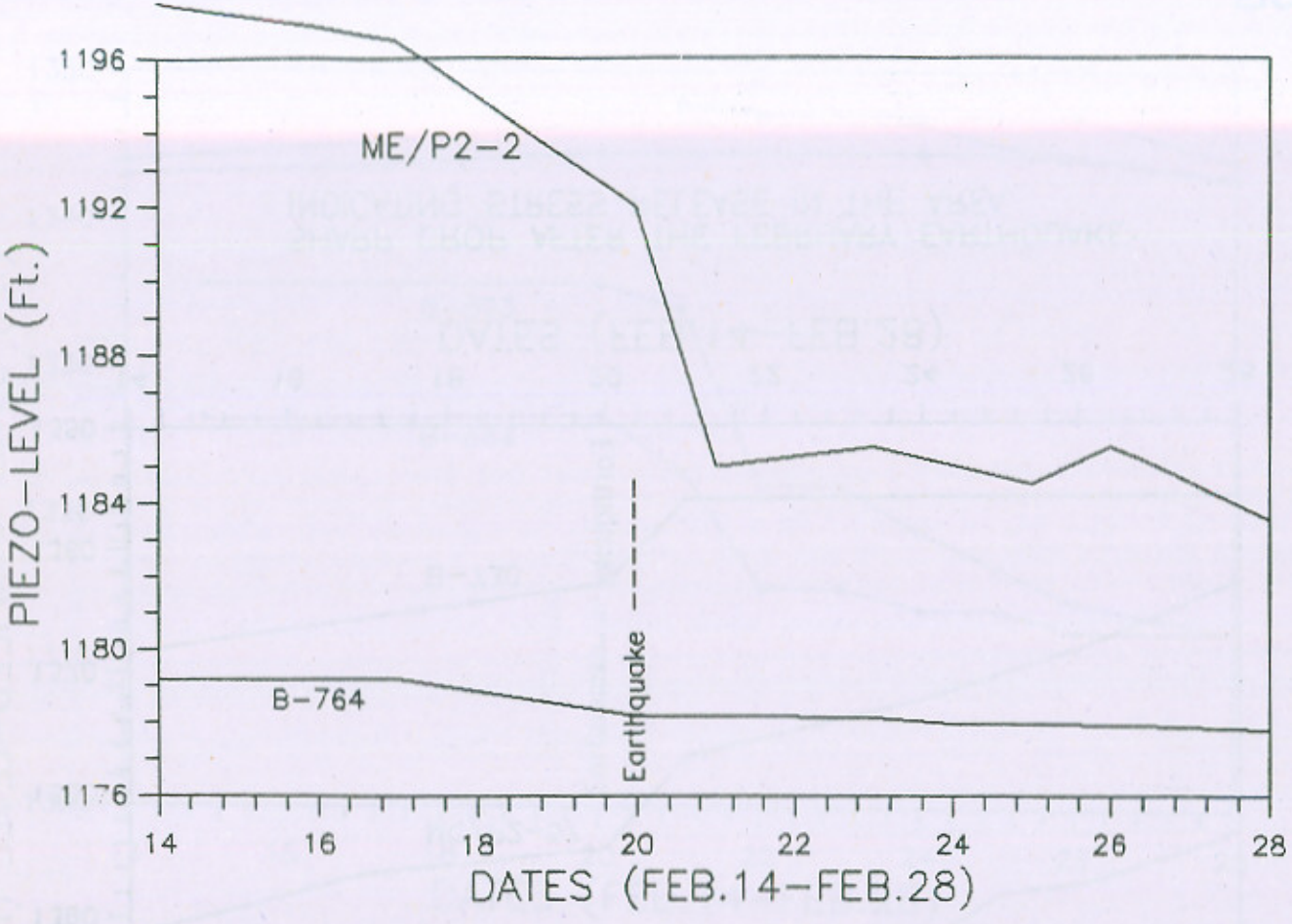
BEHAVIOR OF PIEZOMETERS



PIEZOMETERS THAT WERE NOT FUNCTIONING BEFORE 20th.FEB.1996, STARTED WORKING AFTER THE EARTHQUAKE.

FIG. II

BEHAVIOR OF PIEZOMETERS

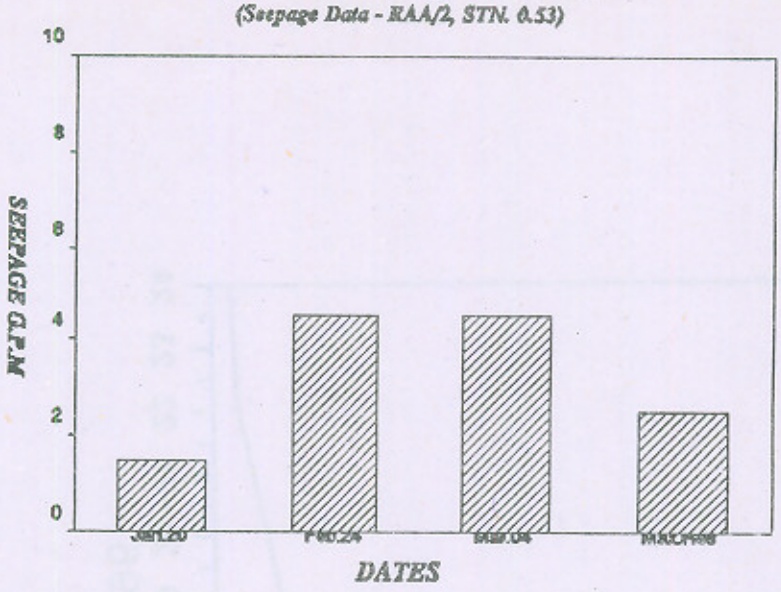


SHARP DROP AFTER THE FEBRUARY EARTHQUAKE
SHOWING STRESS RELEASE IN CASE OF B-764.
THE DECREASE STARTED FROM FEBRUARY 17,96

FIG. 14

Feb, 20 Earthquake 1996

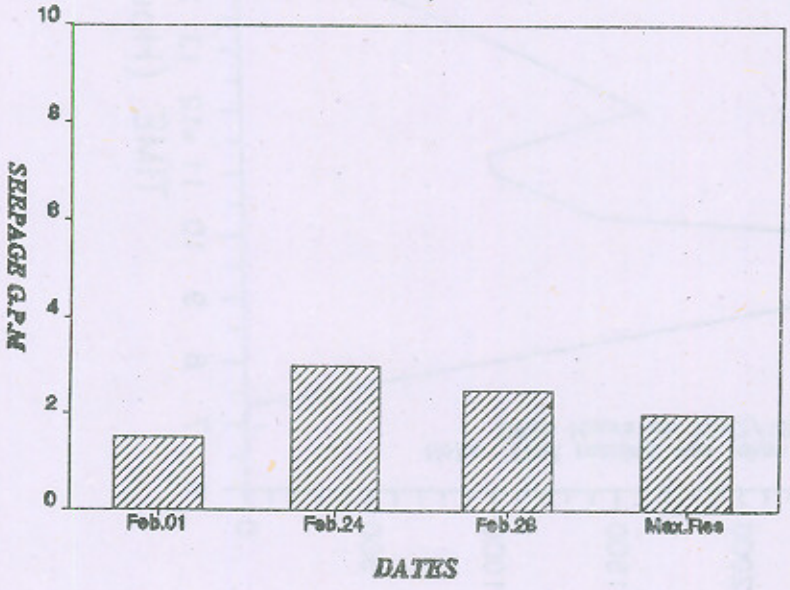
(Seepage Data - RAA/2, STN. 0.53)



SEEPAGE = INCREASED DUE TO FEB. EARTHQUAKE.
EVEN COMPARED TO THE MAXIMUM RESERVOIR LEVEL

Feb, 20 Earthquake 1996

(Seepage Data - RDA/20, STN. 0+45)



SEEPAGE = INCREASED DUE TO FEB. EARTHQUAKE.
EVEN COMPARED TO THE MAXIMUM RESERVOIR LEVEL

FIG. 15

RESULTS OF SEDIMENTATION SAMPLES
(COLLECTED FROM TAIL RACE (UNITS 11–14)
AFTER EARTHQUAKE ON 20/2/96

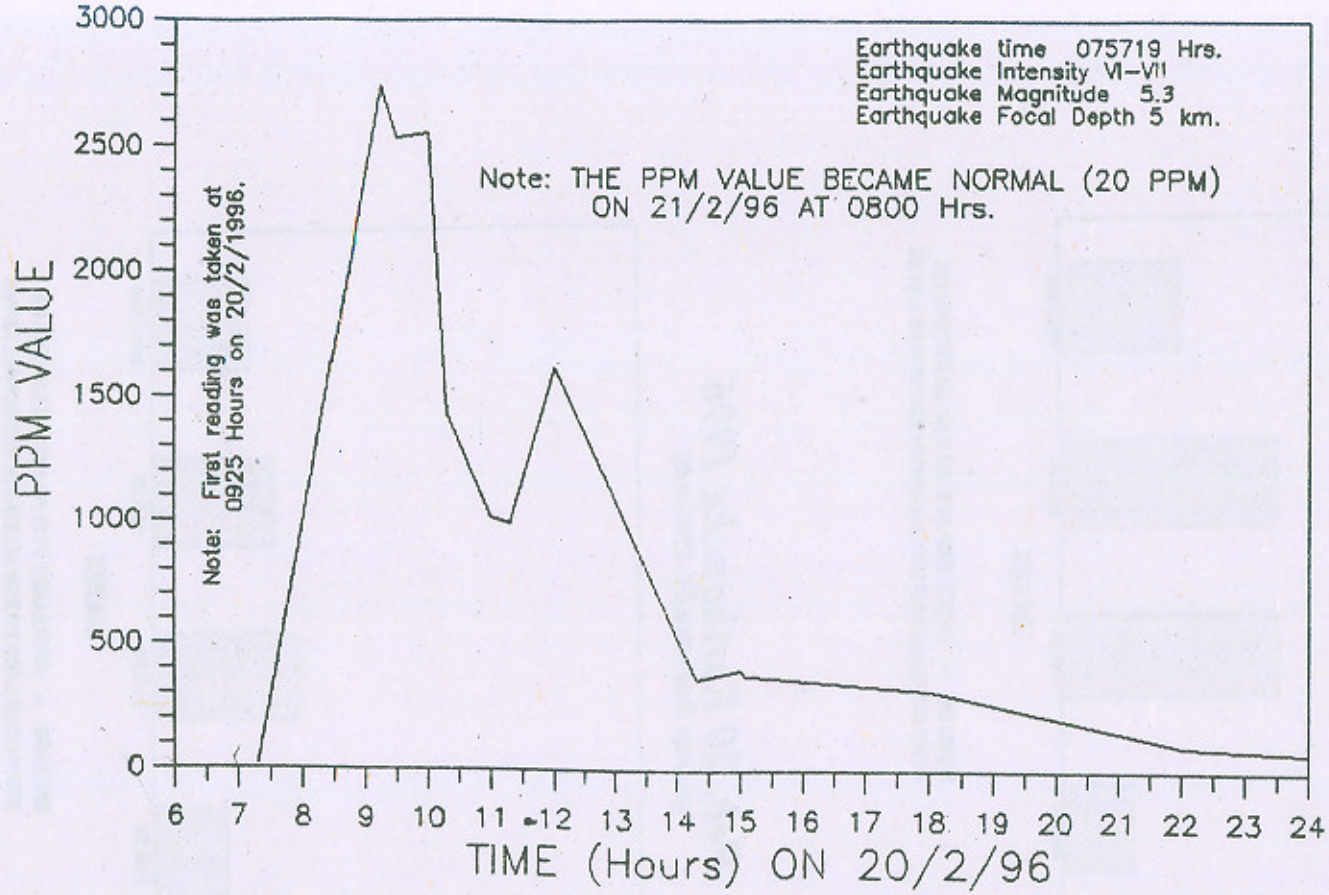


FIG. 16