Paper No. 410

CONSTRUCTION OF TARBELA DAM PROJECT

By

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1. Synopsis

In 1972 the construction of Tarbela Dam Project is at its peak. The paper describes the construction works comprising a major storage and Hydro-electric Project on River Indus. Latest improved construction techniques are applied to construct this largest Project of Pakistan. Its Main Embankment Dam is the largest Earth and Rock Fill Dam in the world.

The paper describes the preliminary works, the tenders and the contract, the mobile and immobile construction plant and machinery in use, the river management, construction of temporary Coffer Dams, construction of the Main Dam, Auxiliary Dams, the Intakes, Tunnels, the Gate Shafts, the Outlet works and the Power Station. The paper describes the contractual arrangements, the programming of works with its networks mobilizing resources on a global scale. The staff and labour employed comes from 30 nations of the world. The size and complexity of the work is outstanding in the world of construction. The grandeur and greatness of Tarbela is unmatched.

2. Introduction

The multipurpose Tarbela Dam Project is being constructed on the Indus River about 70 miles north-west of Islamabad and 32 miles upstream of Attock Bridge on River Indus 800 miles from Karachi, the nearest seaport. Its location is shown in Figure 1.

The Tarbela reservoir would store water during the summer months when the mighty Indus swells with the waters of Himalayan melted snow and the monsoon rains. The Indus flow goes higher than 300,000 cfs. in mid summer and lower down to 14,000 cfs. in winter having an average of 64 MAF run-off at Tarbela site. A typical hydrograph of River Indus at Darband is shown in Figure 2. The reservoir will have a capacity of 11.1 maf. with a usable storage of 9.3 maf. Tarbela Power Station can produce up to 2.1 MKW of electricity when all the 12 sets of 175,000 each K.W. are installed.

River Indus brings in an estimated 440 million tons of sediment every year, reducing the life of the reservoir to about 65 years. Tarbela Dam has, however, a significant feature of off-channel storages. From Tarbela, Indus waters can be diverted and reserved up to 40 maf. in its off-channel storages in River Haro and River Soan basins. This is one solution for the short life of Tarbela Reservoir. Another solution may be found in installing upstream low head dams. Power generation, in any event, will continue even after siltation of the reservoir.

The construction work at site from early 1972 is in full swing. All operations are highly mechanized with latest construction equipment. The Contractor has installed computers in his Site Office and in his Installed Fixed Construction Plants for Earth/Rock Processing and Concrete Manufacture.

Beside the Main Contractor (TJV) there are three Sub-contractors and about twenty-one Supply Contractors from all parts of the world. There are men and women working at site from more than thirty nationalities. It is a global task, and WAPDA has mobilized resources of men and materials on a real global scale.

3. Scope of Project

The following data will give an idea of the scope of the Tarbela Dam Project :—

PROJECT VOLUMES	
Total Embankments and Fills	186,000,000 cu. yds.
Excavation, Required	96,000,000 cu. yds.
Excavation, Borrow	98,000,000 cu. yds.
Concrete	3,320,000 cu. yds.
RESERVOIR	
Length	50 miles
Maximum Depth	450 feet
Area	60,000 acres
Usable Capacity above El. 1,300 ft.	9.3 Million Acre ft.
Dead storage below El. 1,300 ft.	1.8 Million Acre ft.
Gross Capacity El. 1,550 ft.	11.1 Million Acre ft.
MAIN EMBANKMENT DAM	
Length at Crest El. 1565 ft.	9,000 feet.
Max. Height (from lowest foundation point)	470 feet.
Embankment Volume	138,000,000 cu. yds.
Blanket Volume	21,000,000 cu. yds.

AUXILIARY DAM No. 1

Length at Crest El. 1565	2,340 feet
Maximum Height	345 feet.
Volume including blanket	18,000,000 cu. yds.

AUXILIARY DAM No. 2

Length at Cres El. 1565	960 feet
Maximum Height	220 feet
Volume	2,000,000 cu. yds.

SERVICE SPILLWAY

7 Gates	50 ft. wide × 58′ ft. high
Discharge Capacity	650,000 cfs.
Concrete Volume	416,000 cu. yds.

AUXILIARY SPILLWAY

9 Gates	50 ft. wide × 58′ high
Discharge Capacity	840,000 cfs.
Concrete Volume	475,000 cu. yds.

TUNNELS AT RIGHT BANK

Four with lengths of concrete lined upstream of gate shafts	2,400 to 2,700 feet
diameter.	45 feet
Tunnels 1,2 and 3 diameter	43.5 feet
Tunnel 4 diameter	36 feet
Main Gates, two on each tunnel	13.5 × 45 feet each
Radial Irrigation Outlet Gates Tunnels 3 and 4 two on each tunnel.	16 × 24 feet each
Tunnel at Left Bank Stub portion 700 feet, dia	45 feet

POWER PLANT

Ultimate: 12 Units @ 175,000 Kw.	2,100,000 Kw.
Initial: Units 4 @ 175,000 Kw.	700,000 Kw.
Concrete Volume	400,000 cu. yds.

4. Pre-contract Site Investigations and Preliminary Works

Investigations for Tarbela Dam Project were originally started during 1953-54 by the Dams Investigation Circle of Government of Pakistan with the help of M/s. Tipton and Hill, Consulting Engineers. During 1959 the Project was accepted by the World Bank as a part of "Replacement Plan". WAPDA's Tarbela Dam Project Organization was set up. HARZA, the General Consultants, carried out preliminary studies for the Project. In February 1960 M/s. Tippetts Abbett McCarthy Stratton International Corporation (TAMS) of U.S.A. were appointed as Project Consultants.

Three sites, Kiara, Kirpalian and Bara were investigated. The Kiara Site had a storage capacity of 10 M.A.F., Kirpalian 4 M.A.F. and Bara 11.1 M.A.F. Of these Bara was selected for an earth and rock embankment dam. In January 1962 TAMS submitted their Project Planning Report. The site investigations and office studies continued and tender documents were prepared and submitted to World Bank in 1965. The World Bank Special Study Group agreed to the technical feasibility and economic viability of the Project, considering its contribution as a key to the Master Plan of Development of Water and Power Resources of West Pakistan.

The total cost of all the preliminary works totalled up to Rs. 134 million including a foreign exchange of Rs. 45 million.

Some $324 million were available from the Indus Basin Development Fund compared with the $900 million required for Tarbela Dam Project. Pakistan agreed in February 1966 to pay all the local currency required and also the foreign exchange required for the Power Station machinery. In May 1968 a Tarbela Development Fund Agreement was signed. It provided a total of $498 million in foreign exchange for the Project, as per details below :—

	Million Dollars
Balance of Indus Fund	324
Canada	5
U.K.	24
France	30
Italy	40
U.S.A.	50
World Bank	25
Total	498

The Tarbela Site was connected to the nearest Railway Station at Lawrencepur by a Railway line. The Grand Trunk Road was connected to the site by an all weather black top road from Lawrencepur to Ghazi and site. An Access Bridge across the River Indus was constructed. The existing Pehur Canal was relocated in the head reaches. A pumping plant of 250 cfs. capacity was constructed to pump water from Indus downstream of the Dam Site for Pehur supplies. Power facilities were provided to connect the site with the national grid with a 24 mile long double circuit 132 K.V. line from

WAH Grid Station to meet the power requirements of the Project construction. Residential colonies were constructed in four phases to accommodate the Employers' and Engineers' personnel for the construction of the Project. There are four colonies, three on the Left Bank and one on the Right Bank accommodating WAPDA and TAMS personnel. The existing Hattean-Ghazi road was also renovated to take up the construction road traffic. Immediate site area of 15,000 acres was acquired by March 1967. Pre-contract exploratory works and detailed engineering studies were completed.

5. Land Acquisition and Resettlement

In Fig. 3 the Tarbela Reservoir area is shown. An area of 100,000 acres in the districts of Hazara, Mardan, Campbellpur, State of Amb and Darband and tribal areas is to be acquired. About 150 villages will be submerged. WAPDA has established a Tarbela Dam Resettlement Organization to acquire the land and other property and also to resettle the affected population numbering 80,000 people. Hamlets at Ghazi, Pehur, Khalabat are constructed to settle the non-agriculturist population of the affected villages. The agriculturist class is being settled in the colony areas of the Punjab and Sind Provinces.

It is a great sacrifice of the affected people of the reservoir area to leave their ancestral homes and fields and go to far away areas and start a new life for Tarbela Dam Project. The nation will remain grateful to them for this great sacrifice.

6. Tenders and Awards of Main Civil Contracts (Contract-651)

Designs, specifications, contract drawings and tender documents were reviewed by HARZA, the World Bank (I.B.R.D.) and WAPDA. Finally, WAPDA issued tenders for the civil works contract to the following four carefully selected pre-qualified International Firms :—

1. Messrs Guy F. Atkinson, Sponsors of an American Consortium.
2. Messrs Morrison—Knudsen, Sponsoring a Joint American and British Consortium.
3. Messrs Hochtief, a German Swiss Consortium.
4. Messrs Impregilo, Sponsors of an Italian and French Consortium.

Tenders were opened on 30th November, 1967. Following were the bids :—

	Total Rs.	Foreign Exchange in Million Rs.
1. Hochtief (GSJV)	2,59,82,00,000.00	1,556
2. Impregilo (TJV)	2,96,88,42,633.00	1,718
3. Morrison Knudsen (IRC)	3,66,25,79,180.00	2,366
4. Guy F. Atkinson	3,84,43,71,887.00	2,107

The contract was awarded to the second lowest bidder TJV due to unacceptable qualifications imposed by the low bidder. A letter of intent was issued on 2nd April, 1968 and the contract was awarded on 14th May, 1968.

On May 14, 1968 the contract for the construction of the Civil Works of the Tarbela Dam Project at a price of Rs. 2,965,493,217 or $623 million was signed by WAPDA and the Tarbela Joint Venture, a group of three Italian and three French heavy construction contractors. Five German and two Swiss contractors have since joined the group. The Tarbela contract is the largest unit price construction contract ever to be let in history. TJV now includes the following Firms :—

> Impresit-Girola-Lodigiani (IMPREGILO) S.P.A., of Milan, sponsor; Construzioni Generali Farsura (Cogefar) of Milan; Impresa Astaldi Estero of Rome; Compagnie de Constructions Internationales (C.C.I.) of Paris; Compagnie Francaise d' Enterprises (C.F.E.) of Paris; Spie-Batignolles, of Paris; Hocktief A.G., of Essen; Philipp Holzmann, A.G., of Frankfurt; Strabagbau A.G., of Koeln-Deutz; Ed. Zublin A.G., of Duisburg; Conrad Zschokke, of Geneva; Losing and Co. A.G., of Bergne; and C. Baresel A.G., of Stuttgart.

7. Sub-Contractors

Tarbela Joint Venture has sublet the following specialized works to sub-contrators :—

Work	Sub-Contractor
1. Tunnel Liners and Penstocks (Nominated Sub-Contractor)	Chicago Bridge and Iron Co., Chicago, Illinois, U.S.A.
2. Erection of all Mech. and Electrical Plants	Hidromontaza, Maribor, Yugoslavia.
3. Drilling and Grouting Work.	Cementation Intrafor Limited, Croydon, England.

8. Electrical and Mechanical Supply Contracts

The Main Contract (No. 651) covers almost all activities of the Main Works. But to reduce the burden of a number of supply works for electrical and mechanical equipment, the Employers (WAPDA) decided to supply the E and M Equipment at the Manufacturer's plant to the Main Contractor (TJV) under separate supply contracts. Some thirty separate supply contracts worth about $32,000,000 of mechanical and electrical equipment will be awarded for installation by the Main Contractor. The supply contracts include the provision of staff to supervise erection by the Main Contractor. All designs, specifications, tenders and contract documents were prepared by TAMS, the Project Consultants and reviewed by Harza and Gibb.

The management and programming of supply contract is scheduled in such a way that the equipment is ready at site for installation when the Main Contractor is ready to instal it in his Civil Works. The job of inspection, testing of all equipment is done both at the manufacturers' plant and at site, as per the contract requirements.

Following is the list of supply contracts to be financed from Tarbela Fund :—

Contract No.	Description	Firm & Country	Price in Rs.
653	Gates and Hoists for Buttress Dam ..	Metalna, Yugoslavia	79,53,198
654	Stop log Cranes for Buttress Dam ..	Voest, Austria	3,08,000
655	Closure Gates and Hoists for Tunnels 1 and 2 ..	Metalna, Yugoslavia	57,27,639
656	Hemispherical Bulkhead and Hoists for Tunnels 1 and 2 ..	Hitachi, Japan	53,82,412
657	Service and Bulkhead Gates and Hoists for Tunnels 1,2,3 and 4 ..	Sorefame, Portugal	1,94,43,859
658	165-Ton Gantry Crane for Service and Bulkhead Gates..	Litostroj, Yugoslavia	10.72,789
659	Outlet Gates for Tunnels 3 and 4 ..	Voest, Austria	1,42,63,880
661	Crest Gates and Hoists for Spillways ..	Metalna, Yugoslavia	1,71,05,250

SUPPLY CONTRACTS NOT FINANCED BY TARBELA FUND

662	Turbines, Governors and Relief Valves ..	Hitachi, Japan
663	Cranes for Power House ..	Litostroj, Yugoslavia
664	Turbine Inlet Valves ..	Mitsubishi
666	Draft Tube Gates and Relief Valves ..	Karachi Shipyard and Engineering works Pakistan.
677	Main Electric Generators and Accessory Equipment ..	Hitachi, Japan.

679	220 K.V. Transformers and Appurtenances ..	Jeumont—Scheider, France

Contracts, 680, 683, 689, 693, 694 are in different stages of pre-contract activity.

9. Construction and Supervision Organization at Site

At site there are the following main Organizations for the execution and supervision of works :

1. Employer .. The General Manager and Project Director WAPDA.
2. Engineer .. M/s. TAMS Consulting Engineers for the Project Design, Contract Management and Supervision.
3. World Bank Representatives .. Administrators for Tarbela Development Fund —M/s. Sir Alexander Gibb and Partners.
4. General Consultants .. M/s. HARZA En ineering Co., Int.
5. Main Contractors .. M/s. Tarbela Joint Venture.

Besides the above Main Organizations there are other Organizations like the Government Auditors, Commercial Auditors, Sub-Contractors, Representatives of Suppliers etc.

To have a complete coordinated effort for the construction of this huge Project periodic meetings are held among various Organizations. The main meetings are as follows :—

1. Gibb Harza TAMS WAPDA site meeting are held every alternate Thursday at site in WAPDA or TAMS Offices. In these meetings a resume of construction progress is discussed. All problems connected with Suppliers, Contract Administration, Variations, Claims, Payments are discussed. A Representative of WAPDA Power Department is also present in these meetings.

2. Construction meetings are held every Friday either in TAMS Office or in TJV Office. These construction meetings are between TJV and their Sub-Contractors and TAMS. WAPDA and HARZA Representatives also attend these meetings. Construction problems are discussed and decisions taken for action.

Besides the above two meetings there are smaller meetings among various departments to solve the construction problems.

10. Labour

For the construction of Tarbela Dam Project an average of 14,000 to 15,000 labour is engaged in three shifts besides the Engineers and Supervisory and Managerial Staff. Skilled Pakistani personnel were available from Mangla and other recently completed Indus Basin Projects.

M/s. TJV have established a Training School for the technical training of all labour and technicians in all fields of Tarbela Dam construction activity. This training has been greatly beneficial for the execution of the Project.

Unskilled labour mostly is engaged from affected areas or nearby villages. TJV buses transport the labour from these villages to the work site and back. Skilled labour is drawn from all over Pakistan.

For the residence of labour from far off areas the contractor has constructed five Labour Camps with facilities of shopping, entertainment and food. For the Senior Supervisory Expatriate and Pakistani Staff the Contractor has constructed Sobra city with full facilities of a Modern Camp.

11. Construction Materials

The Employer, Engineer and Contractor have duly tapped resources on a global scale to obtain all construction materials other than earth, rock, air and water required for the construction of the Project.

The main material for the construction of the embankment is earth and rock which is available within the working area. All resources of earth and rock both from the required excavation and borrow have been utilized in a well calculated material utilization scheme with its excavation, processing, transportation and placement.

All concrete fine and coarse aggregates are available at site from river bed. The contractor has installed an aggregate Processing Plant (P-13) to process the locally available aggregate. [Please see Annexure I for detailed description of Plant P-13.]

Storage facilities for construction material include a large area at the Railway terminus of Lawrencepur Tarbela Railway line, a very large storage shed, a number of bins for cement.

An estimated 716,000 tons of cement is required for the construction of the Project, out of which about 170,000 tons is sulphate resistant cement to be used for concrete in contact with rocks which might be reactive. The contractor is getting his Portland cement requirements from Faruqia Cement Factory near Taxila. The sulphate resistant cement is coming from Associated Cement Company's Plant at WAH. The A.C.C. had to enlarge their Plant capacity to meet the cement requirements of Tarbela Dam Project.

An estimated 65,123 tons of reinforcing steel is required for the Project in various sizes up to size No. 18. The sources of reinforcing steel are from SCOP, BECO & GIS in Pakistan and Matsui Japan. G.I.S. installed a special Plant at Karachi for the rolling of sizes No. 14 and No. 18.

A substantial quantity of explosives for Tarbela Dam Project is being obtained from WAH Industries, Pakistan. Prilled Ammonium Nitrate is imported from Japan.

The Government of Pakistan has imposed a ban on import of certain items of construction material, locally available. The contractor makes every effort to obtain banned items locally. In case the required quality and quantity is not available, WAPDA obtains for the contractor an exemption from the Government for the import.

The contractor is purchasing from the World Market on competitive basis all his imported items of construction materials. Both the timing and cost of procurement are controlled with the full use of computer installed in the Contractors' site office. Forecasts of materials required are prepared much ahead of time to ensure that the material is there when the construction of that particular item of work is taken in hand. The contrator employs full-time experienced Engineers just to prepare these material requirement forecasts giving the kind, quality and quantity of materials required with the dates of requirement.

12. Construction Schedule and C.P.M. Network Analysis

To ensure completion of the Project on due date the following target, dates are fixed with a set daily bonus for early completion, and daily liquidated damages for late completion.

Work Completion	Target Date
1. Construction of Closure Section of Main Dam and Aux. Dams 1 and 2 in Stage III to EI, 1520 ..	September 15, 1974
2. Completion of Reservoir Works ..	March 1, 1975
3. Completion of Generating Units 1 and 2 ..	June 1, 1975
4. Completion of Generating Units 3 and 4 ..	April 1, 1976.

The Tender and contract documents of the main works contain construction Schedules in the forms of Bar Charts. A separate bar chart for each of the following activities was incorporated :—

1. Main Embankment Dam and Blanket
2. Auxiliary Dams
3. Spillways

4. River Diversion Work
5. Intake Area for Tunnels
6. Tunnels 1, 2, 3, 4.
7. Outlet Area for Tunnels
8. Power House and Switch-yard.

The Project is divided in three stages of construction considering the the River Management.

Each Bar Chart contains estimated quantities of work for the three stages of the Project Construction. An abridged Construction Schedule of the Project is shown in Figure 4.

The contractor has prepared detailed construction schedules in the shape of Bar Charts. These bar charts are submitted to TAMS periodically and kept up to date with all the required modifications and corrections.

It is a contractual requirement that TJV should prepare a Progress Chart consisting of Network Analysis Systems. The contractor employed a Consulting Firm of M/s. A. A. Mathews Inc. of U.S.A., for the preparation of the C.P.M. Network Analysis for the Project. The system selected delineates events, calendar days and activities on arrow diagram and provides various listings of the Computer Print out. The number of activities for the Project is 6500. The contractor prepared Network Analysis System for each of Stage I, Stage II and Stage III of the Project. The activities shown on the network not only consist of the actual construction operation with their inter-relations but also include the preparation and submitting of shop and other drawings, procurement of materials and equipment and installation and testing of major and critical items. Activities of the employer that affect the progress of work such as approval and delivery of employer furnished materials is also shown in the Network Programme. Related activities are grouped for simplification. The multiple critical paths are clearly shown on the network. One Critical Path runs through Tunnel No. 1 activities. The second through embankments.

The preliminary Network Analysis is first drawn by hand programs prepared and then fed into a computer. The Analysis lists all activities in the following groups with the use of the Computer :—

(*a*) A listing of all activities arranged by the event number.

(*b*) A listing of all activities arranged by the amount of float.

(*c*) A listing of all activities by their latest allowable completion dates.

(*d*) A listing of all activities grouped by responsibility (Employer, Contractor, Sub-Contractor, Engineer etc.).

The latest computer print out of the Network Analysis has two sheets of 7 ft. × 4 ft. size. All the Resident Engineers in the field follow the network in respect of their part of the activity.

For easy reference a Managerial Network is drawn showing all activities of the Project and Time Scaled Network of the size of a regular drawing sheet.

At Tarbela the Critical Path Network Analysis has proved to be a very useful tool for the time scheduling of the 6500 activities of Tarbela Dam Project Construction. It is the basis of planning tool of planning and programming that the contractor expects an early completion of the project to earn bonus.

13. Construction Plant and Equipment

As per the contract, there is an arrangement of purchase of Special Plant by the Contractor (TJV) up to a value of 15% of the Tender Amount for which the Employer has provided funds under set terms of repayment by the contractor from his pay estimate.

Almost the entire construction plant and equipment of the Main Contractors, TJV is at site. The Sub-Contractors, M/s. C. B. I. & M/s. Cementation, M/s. Hidromontaza have also brought on site their required plant and equipment. The value of equipment brought by TJV as per the latest Master Schedule is Rs. 50,88,14,508. It includes equipment of Cementation and Hidromontaza.

The total value of Plant of Equipment of Chicago Bridge and Iron Co. for steel lining work is Rs. 2,41,92,975. Chicago Bridge has established a welding, shaping, X-ray testing and heat stress releasing shop at site. They have their own Oxygen and Acetylene production Plants.

Up till January 1972 more than Rs. 52,90,00,000 ($110,000,000) worth of construction equipment had been purchased by the joint venture contractor including the following major items :—

29	Shovels draglines.
36	Wheel and track loaders (front end loaders).
63	Cranes.
222	Motor scrapers side, rear and bottom, dump trucks.
214	Crawlers and wheel tractors and dozers.
16	Motor graders.
36	Water and fuel trucks.
42	Rollers and compaction equipment.
30	Low loaders and trailers.
299	Lorries, buses and trucks.
673	Station wagons, pickups and sedans.
13	Locomotives.

141	Air Compressors, rock drills and breaking equipment.
12	Materials processing plants with a total capacity of over 63,000 tons per hour.
9	Belt conveyors over 13½ miles long with a combined feeding capacity of 40,000 tons per hour.
4	Concrete batching plants with a capacity of 660 cubic yards per hour.

Considering the great importance of construction equipment and plant for Tarbela construction, a complete list of all the equipment and Plants in use at site at Tarbela is given in Annexure I of this paper. A concise description of all the immobile plants is also given. Lists of equipment of TJV, CB & I, Cementation and Hidromontaza are given separately.

14. River Management and 3 Stages of Construction

River Indus has a seasonal flow pattern. June, July, August, September are months of high flow and the rest of year the river flow drops. A typical hydrograph of river Indus is shown in Figure 2. This flow pattern of river Indus determined the sequence of the main dam and tunnels. High flow periods are marked in dark shade in the construction schedule (Figure 4.).

At Tarbela site, the river has a braided pattern with three distinct channels. These had to be diverted into a side channel to proceed with the construction of the dam in the river bed. Considering the high flows of the mighty Indus, the River Diversion works were required to be positively strong and safe.

There are three distinct stages of construction. In the first stage (Figure 5) River flows in its natural channels. In the Right Bank a Diversion Channel was excavated, capable of taking the entire flow of Indus. Tunnel's excavation was started. A concrete buttress dam was constructed across the diversion channel. Earth Coffer Dams upstream and downstream were constructed to keep the river flows in its natural channels, but away from the Right Bank construction works including the First Stage Main Embankment Dam. Materials from the required excavation of diversion channel, the tunnels, the intake area and outlet area were utilized in building the first stage of Main Embankment Dam. The first stage of work ended when the river was diverted through the Diversion Channel in Ocrober, 1970. It was a major operation of River Diversion. Upstream an earth embankment coffer dam (c) was completed right across the river bed to hold the river away from the Main Embankment and the Blanket. Downstream a cellular coffer dam was constructed with steel sheet piles driven in circular shells and filled with sand to protect the outlet and power station works. The Cellular Coffer Dam will be removed when in Stage III river flows through the tunnels (Figures 7 and 8)

Stage II commenced in October 1970 when the river started flowing through the Diversion Channel which has a design discharge capacity of 750,000 cfs. Early, during this stage, a third earthen Coffer Dam was constructed downstream to permit the river flowing or ponding in the downstream river channels and damaging the Main Embankment Dam construction of Stage I and Stage II. The river flow condition in Stage II is shown in Figure 6. From March 1972 work on stage II is in full swing on the following jobs :—

1. Main Embankment Stage II and raising Stage I and installing instrumentation.
2. Completion of Tunnels and Gate Shafts.
3. Intake area works.
4. Outlet Control structures and Power House Works.
5. Construction of Auxiliary Dam-I.
6. Construction of Auxiliary Spillway and Service Spillway.
7. Auxiliary Dam II will also be constructed in this stage.

Stage III will start from September 1973 when the Buttress Dam Gates across Diversion Channel will be closed. The upstream plug of the approach to tunnels will be removed and the river will be diverted through the tunnels. The river flow condition in Stage III is shown in Figure 7. From September 1973 onwards the Dam construction closing the entire valley will be completed. River diversion in September 1973 is shown in Figure 8. The Right Bank portion of the Main Dam in the Diversion Channel and the Right Bank Contact area will be completed. With the Main Embankment finished, tunnels, 1 and 2 will be closed and the river will flow through tunnels 3 and 4 only. The Power Plant will then be completed and connected to Tunnel I for the initial installation of 700,000 K.W. generating capacity with 4 units of 175,000 K.W. each.

15. Earth and Rock Material Utilization

The earth and rock requirements for the construction of Main Embankment Dam, the Blanket Auxiliary Dam I, Auxiliary Dam II, the Coffer Dams, the road formations etc. works out to a total of about 196 million cubic yards. It is estimated about half of this requirement will come out of the required excavation and the other half will have to be borrowed. To handle the entire earth and rock material utilization scheme both from the required excavation and from borrow, the contractor has installed a unique and complex series of earth and rock processing plants in the right bank borrow areas inside Coffer Dam "C" Stage I Main Embankment, and on the Left Bank. Extensive use of conveyor belts has been made for conveying the materials up to 12″ size. Please see Figure 9 for the Earth and Rock Processing Plants and the Conveyor Belt system of the Project. A concise description of the Plants is given in Annexure I.

The main borrow area of the Project Baisak-Gandaf is a plain beyond a row of hills from the right bank of the river. The Baisak-Gandaf Area Yields Angular Boulder Gravel material and the Topi area yields silt. Plants P1A, P1B, P1C are receiving and conveying plants of ABG material. These plants prepare material by screening on 9″ grizzlies. A 12,000 tons per hour capacity conveyor belt, conveys the material from these three plants to the Central Processing Plant P-3. At Topi, Plant P-2 receives and conveys silty material to Plant P-3.

The conveyor belts handle 14,000 tons per hour—a load that can fill ten trains of 70 wagons of 20 tons capacity.

Plant P-3 is the Central Main Processing and Handling Plant for Topi Gandaf Borrow Materials. Photo 3 shows a view of the Plant P-3. A detailed description of Plant is given in Annexure I. From Plant P-3 earth and rock material, in the set gradations, is taken to Dam Fills by two conveyors, a distance of 3 miles. These conveyors cross the right bank hills through a one mile long conveyor tunnel constructed by the contractor at his own cost. One Conveyor is large, with a 12,000 tons per hour capacity. The other is small with a capacity of 2,400 tons per hour. There are a number of secondary conveyors on the Main Dam Embankment unloading in movable installed hoppers. One Secondary Conveyor crosses the entire width of the valley to unload in a hopper installed at left bank to convey material for Auxiliary Dam I, Blanket and impervious core.

All the materials that are received at the Gandaf Plants are analysed and their Gradation curves are prepared and the percentage of various grades of materials are examined in detail. Material is processed in three basic grades of 0 to ½″, ½″ to 6″, 6″ to 12″. By mixing these three grades of materials all other specified grades of materials are made. Before the materials are conveyed for placement in the Main Dam or the Blanket, the deficiency of any grade of material is determined and consequently made good by adding the required grade of material either direct from screening plants or from surge piles according to the need. Similarly if some material is found in excess after examination of the grading curve, the same is extracted by passing the material through screening plants and inter-mixed by adjustments of the belts to give resultant mixture of the required gradation limit. For instance, if B1 material is required and the material coming from P2 is found to contain more fines, then 0-6″ material is added either directly from the screening plant or ½″-6″ material from the surge pile is added to bring the load of main conveyor fall within the predetermined gradation limits of the B1.

The mixing is controlled by computer system and the various belts are regulated by the control centre to convey the pre-selected quantity of the material required for addition. For instance, if it is found that 60% of the quantity of

½″-6″ material is required to be mixed with the material passing on conveyor and the material received on the conveyor is 80%, then the computer is adjusted accordingly and the same in turn operates the feeder at the surge pile to convey 60% of the required material for mixing.

On the right bank the required excavation yielding materials consists of the diversion channel, the tunnels intake area, the tunnel's outlet area, the tunnels, the gate shafts. About 73 million tons of rock and earth materials are estimated from these excavations. To process this material the contractor installed Plants P4, P5, P6 for rock crushing and screening in the river bed upstream of stage I embankment. A stock pile and reclaiming Plant P7 was also installed. P4 and P5 are rock plants while Plant P6 is an Earth Plant. The Plants were fed by trucks and the processed material conveyed to the Fill or Spoil by Conveyor Belts. The rock supplied to plants P4 and P5 is categorized by the Geologists at site into five types. Type I is the best sound and durable rock and the quality of rock is lowered as the type number increases down to Type V which is classified as unsuitable for use and is spoiled. Plants P4, P5 manufactured materials for various zones except A1, A2, B1 and T. Please see Figure 10 for various zones of Main Embankment Dam. The alluvial rounded boulder gravel and sand and some angular boulder gravel was fed into Plant P6 to produce material for zones D, D1 and F.

On the left bank the required excavation consists of the foundation of Auxiliary Dams I and II, the Spillways and the Spillway channels. To process most of the excavated materials on the left bank the contractor has installed an Earth and Rock Processing Plant P8 and two rock processing Plants P10 and P11. For the location of the plants please see Figure 9. For a concise description of these plants please see Annexure I. Type III rock is sent direct to the fill of various zones when so classified by the Engineer's representatives at site on a round the clock operation. In the following table a description of the materials processed is given in all the three plants on Left Bank :—

Description	P-8	P-10	P-11
1. Material processed	ABG & ABGM Earth & Rock	Rock Type I	Rock Type II, III IV.
2. Capacity	3,000 Tons per hour	1,500 to 1,750 tons per hour	3,000 to 3,500 tons per hour
3. Processed Components of Rock/Earth	0-8″ 8″-24″ +24″	0-12″ 12″-40″/48″ +40″/48″	0-3″ 3″-24″ 24″-40″/48″ + 48″

Description	P-8	P-10	P-11
4. Grizzlys	0-8″ Vibrating 8″ fixed 24″ fixed grizzly.	Fixed Grizzlys	Combined vibrating screens and fixed grizzlys.
5. Transportation of material processed.	0-8″ with conveyor belt 8-24″ rear dumper+24″ rear dumpers.	0-12″ bottom dumpers 12-48″ rear dumpers + 48" loading by shovels and transportation by rear dumpers.	0-3″ bottom dumpers 3″-24″ -do- 24″-48″ rear dumpers +48″ -do-

On the left bank adjacent to the Spillway Channel there are the Borrow areas of Dal Darra and Dall Darra village. Material from these borrow areas either goes directly to the fill or passes through the left bank processing Plants P8, P10 or P11.

It is entirely the responsibility of the contractor to provide material according to the specifications. TAMS check up the material after placement at site. If the material is found to be out of specification, the same is removed from site and replaced.

Materials from left bank required excavation and left bank borrow are used for Auxiliary Dam I, Auxiliary Dam II and also for Main Embankment Dam. A Conveyor Belt from Plant P8 conveys materials to Main Dam.

For Rip Rap a quarry is being explored on the left bank hills. Large size rocks of good quality is being stockpiled for use as Rip Rap.

16. Drilling and Grouting

Foundation conditions at the Tarbela Dam Site and its allied principal structures are such that 122,000 feet drilling has been carried out up to March, 1972. Drilling is primarily required for additional and more detailed information for design and construction changes. Auxiliary Spillway may be quoted as a typical example where design changes were felt necessary due to presence of weak strata specially on the left side of the gate structure.

For bed rock instrumentation drilling is carried out and instruments placed.

Drilling is also carried out for the construction of drainage wells at the downstream of the Main Embankment.

Drilling is extensively used for grouting. Various types of grouting have been designed for different types of structures. Two types of drilling have been carried out on this Project.

1. Percussion Drilling.
2. Rotary Drilling.

Percussion drilling is generally carried out in thick overburden. Two types of rigs were used. One is called Cable Tool and the other Becker drill. Cable Tool has not been successful. Becker drilling is of two types. One type is for shallow drilling Becker 180 and the other for deep drilling Becker 240.

Rotary drilling is carried out in bedrock for coring and non-coring purposes. The names of the Rotary rigs as per their makes are: Haushee, Crelius, Winter Weiss, Failing 1500 and 2500, and Consolidated Pneumatic rigs.

Open work grouting in the river bed for Main Dam and Blanket was carried out to investigate the extent of open work gravel. It will be incorporated as part of permanent grouting if needed on the basis of results obtained. The grout lines are at 190 feet u/s., 650 feet u/s., 1120 u/s., of centre line M.E.D. and along the Coffer Dam C.

Consolidation grouting has been carried out practically at all the principal concrete structures of Intake, Gate Shafts Spillway foundations for the consolidation of the bedrock. Consolidating grouting was also carried out to consolidate weak rock for the tunnel excavation.

Contact Tunnel Grouting was carried out in the downstream tunnels for metal concrete contact and rock contact.

Curtain grouting was provided for cut offs at the upstream of Spillways and Auxiliary Dams. Curtain treatment was carried out on both the flanks of the Main Dam, especially at the blanket tie-in-area to avoid seepage of reservoir water. Special three row curtain grouting was done in the upstream cut off of Auxiliary Dam 1 due to the presence of large cavaties in cavernous limestone.

17. Construction of Main Embankment Dam and Blanket

The Main Dam above the foundation is composed of nine Major Zones. Each Zone is different from the other because of difference in gradation and classification of the material used in their construction. The gradation of the material controls the process of filling and the method of compaction of these zones. In Fig. 10 a section of the Main Dam and Blanket is shown.

The zones are named, starting from upstream A1, A2, A3, B1, T, D, C1, C2 and C3. The materials used in these zones are hauled from plants on the Right and Left Bank and also directly from Excavations of Diversion Channel, Tunnels, Inlet area of the Tunnels, Spillways, Auxiliary Dam and Spillway Channel. Fifty per cent fill material of the Main Dam comes directly from excavations and the remaining 50% comes from Borrow Areas on Left and Right Banks. The gradation of the material is tested and after the suitability of material is ascertained for various zones, the material is directed for placement in the appropriate zones in accordance with the specifications laid down for each zone. Good material shall have gradation with the limits specified and shall not vary from the low limit on one size of the sieve to high limit on the adjacent size sieve.

The classification and gradation of the material is checked by the contractor before sending to the site. It is checked by the Engineer at the time of placement in the Main Dam or Blanket. Any material found out of specification is removed from site.

Water is added to the impervious zones B1 and B2 at the hoppers at the ends of the conveyor belts and by means of tanker trucks. These are the only zones requiring addition of water.

Lift thickness has been fixed by the specifications for all the zones of the Main Dam and the Blanket.

The material is spread in different lift thickness in various zones. The surface of the spread lift is kept reasonably smooth before compaction, that is without significant undulation, low spots and high spots. Except B1, T and C1 all the rest of the zones of the Main Dam and Blanket have the lift thickness of 24″. Zones B1, T and C are spread in lifts of 12″. Lift thickness is checked by Supervisory Construction Staff and the Survey Party engaged for this purpose.

The next important point in construction operation is the process of compaction. In the contract specifications the required compaction is controlled by the number of passes of Specified Roller.

In impervious core zone B1, six (6) passes of one hundred Ton Rubber tired Roller is specified. In other zones four (4) passes of 10 Ton Vibratory Rollers is specified and followed at site. The speed of Rollers is 2½ miles per hour in both the cases. Since this is an important operation, the Engineer is taking due care. Besides number of passes being counted by the site Supervisory Staff, they also check the compaction by noting time of the roller use for measured area. When an area is ready for compaction, it is measured and time is noted from a graph prepared for this purpose. From the graph, time is noted according to the number of rollers towed by a dozer. A dozer may be towing one, two or three rollers. Time accordingly is noted and the dozer runs over the area for that much time. This checks the speed of the roller.

Moisture is controlled in Blanket and in the impervious core zone B1 of MED. It is generally 6.5% with 2% plus or minus. If the surface is dry, it is scarified and sprinkled with water to the required percentage.

If due to rain, the mositure content of B1 or blanket material becomes too high, the wet material is removed if the site is required for placement. Otherwise, it is scarified and allowed to dry before another lift is placed. This is usually done in Blanket Area where large area is available for placement elsewhere. Rock contact for Impervious Core and Impervious Blanket is carefully prepared by thorough cleaning, dental concreting or graniting as decided by the Engineer.

Photo 5 shows a view of Main Dam Construction.

Several Field Tests are carried out at site to ensure that the work is done in accordance with the specifications. Important tests are :—

1. *Field Density Test.*—This is done by what is called the water replacement method. The density of the fine material comes to about 145 lb. and that of coarse material ranges up to 150 lb.
2. *Compaction.*—This is done to see that the material placed is properly compacted.

   The compaction of fine material such as B1 & B2 etc. is done by AASHO Modified Compaction Method. The Compaction of coarse material is done by a method called Vibratory compaction. The percentage compaction should be more than 95%.
3. *Moisture Content.*—The Moisture Content is found by drying the samples and this method is called Hot-Plate Method.
4. *Gradation.*—This is done at site by Sieve-analysis and gradation curves prepared to check that they are within specified limits.

For B1-zones samples are collected for every 4000 cu. yds. of fill. For all other zones the samples are collected for every 6000 cu. yds. fill.

If any sample is out of gradation limits the same is ordered to be replaced. Gradation curves for Zone Fills of A3, D1, C1, C2, C3, T and B are given in Appendix II.

A total 5.2 million cubic yards was placed for the main embankment and blanket during March, 1972 bringing the total placed to 74.1 million cubic yards.

18. Construction of Auxiliary Dam I

Auxiliary Dam I is an earth and rock fill gravity dam, curved in plan. Fig. 11 shows a typical section of the Auxiliary Dam I. It has a peculiar type of double level and sloping impervious blanket laid on exposed rock after excavation. For an earth embankment, it is a complex structure, due to its geometric and site conditions. The gradation of different zones is the same as for Main Embankment Dam. Therefore, the construction procedures and field tests are the same as described for Main Embankment Dam Construction. All material except for the impervious zones is brought by trucks direct from left bank excavations or after processing in left bank Plants P-8, P-10 or P-11. The impervious material for Core and Blanket is brought from Right Bank Borrow (Gandaf) areas through a conveyor belt crossing the entire Indus River valley.

19. Construction of Auxiliary Dam II

In March 1972 the construction of Auxiliary Dam II has not yet started. In Fig. 12 typical cross sections of Auxiliary Dam II are shown. The construction method of Auxiliary Dam II will be same as for Auxiliary Dam I.

20. Construction of Intake Area Works

All works of excavation, with slopes stabilization, construction of power intakes for tunnels 1 and 2 and Irrigation Intakes for tunnels 3 & 4 are included in intake area works. With start of work on 1st stage construction, excavation for intake areas was started.

Excavation was done with blasting and removal of broken rock and overburden with 5, 10 and 15 cu. yds. shovels and transported with70 ton rear dumpers to Stage I fill or stockpile or spoil. Crawliers and Crawl Master drills were used for drilling operated by compressed air. The drill holes pattern was $10' \times 12'$, 18′ x 22′, $22' \times 26'$ depending on the nature and elevation of rock.

The cut slopes were constructed in different level berms as provided in the construction drawings. The wet slopes were stabilized with rock bolting, mesh reinforced shotcreting, or graniting. TAMS Geologists kept a complete record of geology of exposed rock and on that information TAMS Engineers decided on the slope treatment works. The Board of Special Consultants headed by Dr. Casagrande inspected the slopes during their yearly site visits and prescribed the protective works. Fig. 8 shows the intake area works. Photo No. 6 gives a view of intake area works in progress in March 1972.

With the excavation, the subsoil water level was touched. To dewater the intake area 34 tubewells were used. The pumped out water was measured for payment purposes.

To start the work of concreting of the Intake Structures, three Richier Cranes of 6.5 tons capacity at 163′ radius were erected. The foundation fill concrete was placed. Reinforced concreting was done in five feet lifts. At some places at foundation level $21\frac{1}{2}$ feet lifts were used.

Concrete was brought from Batching Plant P-15 located downstream of Intake Area. Concrete was brought from P-15 in Buckets of 2.6 cu. yds.

capacity placed on flat trucks to be lifted and unloaded for concrete placement. Astra rear dumper trucks of one bucket (2.6 cu. yds) capacity were also used for transportation. These were unloaded in buckets for lifting and final placement.

Curing of the concreting was done for 15 days. The normal tests for concrete as described in the specifications were carried out. Cylinders for testing were cast. Slump tests and air content tests were carried out.

21. Tunnel Excavation

Tunnel excavation was started both from upstream and downstream. For each tunnel, two Pilot Tunnels of about 8 feet diameter were excavated at the two ends of the arch. With these pilot tunnels excavated, concrete curbs inside pilot tunnels were made. Over these concrete curbs moved a mechanical shield for the upper heading of the tunnel. The shield was used for protection of drilling operators and equipment of the upper section of the tunnel. Tunnels 1 & 2 upstream and Tunnel 3 downstream were excavated without shield.

Excavation was done by drilling and blasting method. The muck was removed from tunnels with Front-end Loaders and End Dump trucks. The excavated material from tunnels was taken to Plants P-4 and P-5 or to spoil. It was also directly used for Main Dam Stage I fill.

To hold the exposed rock from collapsing steel ribs, lagging, and wooden blocks were installed for the upper section of the tunnel. The ribs are of four types. Ribs were taken into tunnels with cranes. These ribs were installed in two pieces for the upper half of the tunnel with the help of a Jambo fitted with Jacks. When the ribs were positioned, they were bolted and later joined with but strap welded joints at the crown.

In the area of poor rock, lagging was used over the ribs and in some places rock bolting and wire mesh shotcreting and graniting was used.

A complete dewatering arrangement was made to continuously dewater tunnels 1 and 2 upstream particularly in porous areas containing sugary limestone.

The Geologists and construction Engineers were constantly supervising the tunnel operations round the clock. A complete record of Geological Maps of the exposed rocks was kept.

After the upper section of the tunnel was excavated, first stage concreting on both sides up to 12′ height was placed. Excavation of the lower half was started which was comparatively an easy operation. When the excavation of the lower half was done, three other pieces of ribs were installed where required to make a complete ring of the ribs to support the tunnel invert. Blinding concrete was placed. The ribs will be finally embedded in concrete tunnel lining.

Proper arrangements for fresh air intake in the tunnel excavation was made. Arrangements for water, electricity and compressed air were made in the tunnel for excavation.

Fig. 14 shows typical profile and sections of the tunnels. Tunnels 1 to 4 are 45 feet diameter upstream of the Gate Shafts. The upstream portion of the tunnels will be concrete lined. The downstream portion of the tunnels 1, 2 and 3 has a diameter of 43'-6" and is steel lined. The downstream portion of tunnel 4 is 36 feet internal diameter and is steel lined.

Photo No. 7 shows a view of upper half excavation of tunnel. The shield is seen inside.

22. Tunnel Steel Lining Downstream

All the four tunnels downstream of transitions are steel lined. The Chicago Bridge Iron and Steel Co. are the nominated Sub-Contractors for Steel Lining Work.

Steel Plates of 2" to 2½" thickness are imported in flat condition. They are bent curved in the Site Welding Yard of CB&I. These curved plates are then welded into cans of 43'-6" or 36" diameter each 30' long. The cans are moved by means of a 250 ton derrick crane. After welding, these cans are stress-relieved by heating at 1200 degrees F. in specially made circular insulated furnaces. The welds are inspected and tested by Radiography, Ultrasonic, Magnetic particle and dye check penetration methods.

The cans are transported on specially made trolleys. Inside the tunnels they are taken or rails especially installed for this purpose. Work has started from transition and carried out to downstream end. In one operation CB & I place in position 3 cans, weld and check them and move out. Then TJV enters and place concrete around the steel liners. Thus alternatively CB & I and TJV work for tunnel steel liner work.

Concrete pouring around the steel liners is a complex job. Concrete from the batching plants P-14 and/or P-15 is brought in Rear Dumper Trucks of 35 ton capacity. Concrete is unloaded from a platform in two torkret concrete pump hoppers. These torkret pumps have a capacity of 100 cu. yds. per hour. Concrete placement is started from the bottom and continued up to crown area. Placement of concrete in crown area is done by Midec Air Pressure Pneumatic Concrete Pumps. The contract requirement of vibration is followed. Concrete is placed in a continuous operation for 90 ft. length of pour which goes nearly for 48 hours continuously night and day. As concrete is not exposed, no curing is required. The normal concrete tests as per contract requirements are carried out.

23. Tunnel Concrete Lining Upstream

Upstream of transitions, all the four tunnels are to be concrete lined. The thickness of lining is about 6 feet all-round. Designed reinforcement is placed.

Concreting of upstream tunnels has been planned to be in 3 stages. The 1st stage is of bottom invert lining up to 35 degrees each side. The 2nd stage is of the crown concreting.

In the crown of tunnels an I beam is welded to the ribs to work as a mono rail to run as overhead crane for all operations connected with the upstream concreting, like transport of reinforcing bars and concrete buckets etc. The concrete bucket used for upstream concreting of tunnels is of 4 cubic meter capacity which is the double size of other concrete buckets in use for all other jobs at Tarbela.

For invert concreting a special splitter machine is erected which runs on rails on both sides of the tunnel. This machine is used for vibration and splitting of the mortar and forming the required shape of finished surface of concrete lining. Pours in the invert concrete are placed in lengths of 60 feet. Photo No. 8 shows upstream tunnel lining invert work in progress.

For walls and crown concreting the contractor is modifying his concrete pump, plants used for downstream concrete placement.

24. **Gate Shafts Construction**

Gate Shafts 1 & 2 were excavated and supported with conventional methods with steel girders etc. Gate shafts 3 & 4 were excavated and supported by the New Austrian Tunnelling Method.

Excavation was carried out from top by drilling and controlled blasting. The muck was removed in about 3 cu. yds. buckets pulled up with overhead cranes. For tunnels 1 & 2 steel section supports were installed after each 5 feet excavation. The steel frames are at 4 feet vertical spacing. At places, graniting and shotcreting was applied as required by geology. First stage concreting was also placed.

Photo No. 9 shows Gate Shafts No. 1 in construction.

For gate shafts 3 and 4 excavation was done from top downwards. Drilling and controlled blasting was used. The muck was removed with buckets pulled up by the Atmo over head cranes. Excavation was done in depths of 7 to 10 ft. Soon after excavation shotcreting of 2″ thickness was applied on the entire surface of the gate shaft. Then wiremesh was fixed with the help of small size rock hooks and U clamps. Second cover of shotcreting up to a thickness of 4″ was applied. Drill holes for rock bolts for shortside 15 ft. vertical and 10 ft. horizontal distance as decided by the engineer at site. The diameter of the drilled holes was $2\frac{1}{2}'$. Rockbolts of No. 11 bar were placed. They used perfoshells 4 to 5 ft. long in two parts $\frac{1}{2}$ round each, with mortar and aluminium powder filled. The perfoshells were pushed in the hold with a rod up to the end of the hold and thus the rock bolt was anchored in the perfoshell. After 24 hours, the rock bolt was prestressed up to 10 tons stress. It was anchored with the rock with a $\frac{3}{4}''$ thick steel plate. The plate had a nipple for grouting. From the nipple it was grouted with cement and water. A plastic tube was initially attached with the rock bolt for grouting. Thus the support of excavation was completed.

For all the four gate shafts, concrete lining was done in 10 ft. lifts with the help of overhead crane.

25. Transition Construction

Excavation for transitions was done with the New Austrian Tunnelling Method as described in gate shafts construction above.

There are three sections of a transition. The upstream portion, the gates passages area, and the downstream portion. Concreting in all the 3 sections is being placed through Torkret Machines. Imbedded items are being installed by Sub-Contractor, Hidromontaza.

Before concrete in transition was started, dewatering arrangement was made. The rock around was treated with consolidation grouting.

Transition construction had a problem of approach. For transition 1 & 2 concrete was brought through access tunnel made earlier by the contractor for the purpose. The access tunnel runs across the main tunnels. For transition 3 & 4, concrete was brought from upstream of main tunnels. Tunnels 3 & 4 were interconnected by an adit near the transitions for easy approach.

26. Outlet Area Excavation and Slopes Stabilization

The elevation of the centre lines at outlet is 1106 for tunnels 1 & 2 and 1117 for tunnels 3 & 4. Rock and cover above them was very steep. Pilot tunnel had to start in July, 1969. This involved the opening of the rock and cover above the tunnel. A general excavation to the invert of the tunnel was not possible within the short time available as it involved large quantities to be excavated. The solution of partial excavation was adopted in the following stages:—

1. The western higher part at El. 1550 was opened.
2. Further excavation was carried in steps having benches at El. 1450, 1400, 1350, 1300 & 1250.
3. A trench was excavated from the river side at El. 1180 in the first instance and taken down to elevation 1120 and finally to elevation 1106 and 1117. At 1180 a berm 30′ wide was provided to give protection on the downstream side.

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4. After the excavation of trench, as mentioned in 3 above, general excavation first to elevation 1180, then to elevation 1120 and finally to elevation 1070 started. Besides this some additional local excavation was also done.

Ingersol rand Crawlairs for opening of excavation and for trimming and ingersol rand crawl master for heavy excavation were used. A pattern of $10' \times 12'$ and $26' \times 24'$ was generally adopted for crawlairs and crawl master respectively.

Consumption of explosive was kept to the minimum to produce proper fragmentation.

Extensive use of ANFO mixture requiring prilled ammonium nitrate and suitably primed with high strength explosive.

For loading earth and rock, 5, 10 & 15 cubic yard shovels were used depending upon the quantities to be excavated at each level. Rock was hauled by 70 ton rear dumpers, and earth by 110 ton bottom dumpers.

To stabilize the cut slope, guniting and wire meshing, rock bolt of various (15′-20′) length depending upon the nature of the rock were used.

Photo No. 10 shows a general view of outlet works in progress in March, 1972.

27. Power Station Construction

Initially 4 units are being installed. The Power Station Building has one Service Bay and 4 Unit Bays.

Photo No. 11 shows a view of Power Station construction in March 1972.

Foundation excavation for Power House was carried out for Service Bay Units 1 to 7. Excavation was made up to El. 1040. At places it went down to El. 1015 to reach a better rock.

Fill concrete was placed up to El. 1040 for service Bay Units 1-7 as required by design. Beyond this structural concrete was started for Service Bay Unit Bay 1-4. Under the present contracts only 4 units are to be installed. Foundation excavation and placing of fill concrete for Units 5-7 was done to facilitate future extension.

Four Richer cranes running on rails were erected for Power Station construction. Concrete was brought from Batching Plant P-14 and P-15. Concrete was bought in 2.6 cu. yds. buckets on flat bed trucks.

Installation of embedded parts for Power Station is being carried out by M/s. Hidromontaza.

28. Protective Slab Construction

This is 5′ thick reinforced concrete slab placed downstream of tunnels 1 & 2. To facilitate drainage of rock underneath, 24″ half round concrete pipes were placed on rock surface over porous concrete. The slab is anchored to the rock by means of grouted anchor bars.

29. **Stilling basings for tunnels 3 & 4**

(*a*) *Basin Slab.*—Structural excavation was carried to the required elevation. Afterward 30′ deep 3″ diameter percussion drill drains holes were made to 10′ C/C. Over these drain holes 24″ formed half round drain pipes over porous concrete were placed.

Concrete placing started after installation of Anchor bolts and other reinforcement. The thickness of the slab being kept as 10′ and surface finish as per specifications. The stilling basins slabs were divided into 24 panels for each tunnel. The lower 5′ concrete used was type V sulphate resistant cement having a strength of 5000 PSI and upper 5′ ordinary Portland cement of 4000 PSI. Rubber water stops were used between the panels for construction joints.

(*b*) *Stilling Basin Walls.*—Right and middle walls have each 12 monoliths having a length of 55′. Left wall has 17 monoliths of 55′ length. Concrete drain pipes have been provided within the walls. For concrete placing each monolith was divided into 5′ thick lifts. At lower height curing was done by sprinkling water manually, but at higher portion curing was by perforated plastic pipe secured on top elevation.

30. **Outlet control structures for tunnels 3 & 4**

The outlet control structures have the following parts :—

1. Upstream Block.
2. Bifurcation and Bend Block. Each tunnel is subdivided into two branches A and B.
3. Transition and Gate Chamber Block.
4. Actuator chamber.

Structural excavation for bifurcation and bend block up to elevation 1079 and for transition block up to El. 1082.00.

The work on the upstream block has not yet started. The space is used for tunnel works access.

Concrete placing first started in the bifurcation block and then progressed toward transition and gate chamber block. The steel liner installation started from the bifurcation block. Each branch has been provided with two drainage galleries with invert at El. 1085. All the galleries are interconnected and in turn they are connected with actuator chamber situated midway between the two tunnels.

The bifurcation blcok steel lining provided with a temporary pressure test head and tested successfully at 370 PSI. Later on, the pressure was decreased to 150 PSI and is being maintained till concrete placing in this block is completed to avoid any stressing of concrete placed.

The transition block was originally proposed to be ordinary reinforced concrete round the steel liner. However, it was feared that ordinary reinforced concrete will crack under the great pressure. As such, the design was later changed to make the section prestressed. Tendon sheaths both vertical and inclined, in both directions, are being installed in the concrete.

Concrete (for outlet works) was either brought in 2.6 cubic yds. buckets carried by means of lorry wagons or small rear dumpers and discharged into 2.6 cubic yds. buckets. The buckets were lifted by tower cranes of richier type and poured in position.

31. Construction of Auxiliary Spillway

Excavation work for Auxiliary Spillway was started in October, 1970 and about 85% is complete. Work on the excavation of the Flip Bucket area is in progress. Excavation was carried out in benches by drilling, blasting.

Prior to the concreting work, the structure portion of the spillway consolidation grouting of bedrock was carried out. This operation started in July, 1971 and was finished in December, 1971 and consisted of drilling of 3′ dia primary holes at 20′ C/C. Secondary holes at 10′ and 5′ C/C. were also drilled where required. Depth stages for drilling of the holes were 0 to 20' and 50′, 0′ to 20′ and 40′ and 0′ to 15′ and 31′. One PSI pressure per foot of hole depth was applied. The Grout Mix was one bag of cement to 30 gallons of water.

Concrete work of the spillway was started in October 1971 and by March 1972, 172,000 cu. yds. of concrete was placed in the structure portion of the spillway where gates are to be installed. For ease of concrete work the structure portion has been divided into 18 monoliths, each is further divided into vertical lifts of 2.5 to 5 feet height. Similarly chute portion has been divided into lifts of 33′ 4″ × 33′ - 4″ × 4 feet high.

Concrete is hauled by 2.6 cu. yds. 2 cu. meter capacity rear dumping Astra Trucks from the nearby Batching Plant P-16 having a capacity of producing 220 cu. yds. of concrete per hour. Different types of concrete mixes such as F-6, F-3, E-6, E-3, E-1½, D-3 D-1½ - D/3¾ M-534 etc. are used in the body of the spillway depending on the structure requirement. Annexure III gives a list of the concrete mixes in use at Tarbela.

An average of 1,500 cu. yds. of concrete is placed daily in Auxiliary Spillway and the total concrete that will be required to complete the spillway is about 475,000 cu. yds. A record monthly total of 60,045 cubic yards of concrete was placed during March 1972 in the headworks. Four Richier Tower Cranes of 10 ton capacity have been installed at the site for lifting and placing of concrete and other equipment and material where required.

Form work (shuttering) used is of CIFA type supplied in different sizes and shapes of the area where concrete is to be placed 2″ dia. soldier bolts with recess are provided in this type of steel forms which fix to the lower, already poured, concrete without any additional supports.

Two Nos. connecting galleries, two Nos. longitudinal galleries, one No. upper traverse gallery and one No. lower transverse gallery having a size of 5 feet wide by 7 feet high with a side ditch of 9″ × 8″ are provided in the body of the spillway for drainage of seepage from foundation and through the joints. Towards the upstream face of the spillway all along the section 6″ dia. vertical perforated pipes 8″ C/C rising from the bed rock have been provided for drainage of the up stream concrete work and the upper part of the foundation.

The Spillway when completed in October 1973 will be having 9 gates 50′ × 58′ high and will be able to discharge 840,000 cusecs of water and reservoir elevation 1552.00.

Photo No. 12 shows a view of Auxiliary spillway construction in March, 1972.

32. Construction of Service Spillway

Excavation for Service Spillway is being carried out in 50 ft. benches. No work on concreting has started yet.

General excavation at elevation benches 1530, 1485, 1450, 1400, 1350 is in progress. Where rock is encountered it is broken up by drilling and blasting. Ripping and dozing is also being done for removing rock.

Gravel master drill rigs are used for drilling 6″ dia. holes for primary blasts. The spacing of holes is 20′ on centres. The depth of the hole varies with the height of the excavation face. Average depth is 55′. The inclination of hole is generally 3 vertical on 1 horizontal.

For pre-shearing and lighter blasts 3″ dia. holes are drilled by crawl air drillings.

The main blasting explosives used are WABOX 80%, WABOFITE 70% and ANFO. For controlled blasting explosive used in GURIT cartridge with WABOX as a primary charge. Blasts are initiated by detonating fuse.

Loading of material is done by 3 numbers 10 cu. yds. Bucyrus 190-B electric shovels and one 8 cu. yds. capacity Marian 151-M electric shovel. Loading is also done occasionally with front end loader and one 88-B. Diesel Shovel. The material is hauled by R-70 End Dump Trucks-Haul Dak and Cat 769 trucks. Cat D-9 dozers assist the shovels at each bench in hauling the material.

Excavated material is taken to left bank plants or to fills or spoil depending on its quality.

Excavation of service spillway was complete in October 1972 and the spillway will be completed in August, 1974.

33. Construction of Left Bank Irrigation Tunnel Stub Portion

A length of 700 ft. of Irrigation Tunnel is being constructed on left bank with its intake structure by TJV. Excavation work has started on pilot tunnels and approach channel excavation. The slope stabilization for Intake structure is started.

34. Instrumentation

An extensive instrumentation system is being installed to provide knowledge of the behaviour of the foundations, embankments and concrete structures., as well as effects of earthquakes. Instruments will actually determine the following :—

1. Pore Water Pressures
2. Stresses in foundations, embankments and concrete structures.
3. Horizontal and vertical movements.
4. Water flow.
5. Temperature.
6. Acceleration and amplitude of earthquakes.

All instruments are installed by Engineer of TAMS and the contractor only provides labour and other assistance on day work order. All readings are taken by TAMS.

The following types of instruments are being installed :—

1. Pore Pressure Cell (PPC)	...	Geonor VibratingWire, Telemac Vibrating Wire, Hoke Pneumotic Glotzl Hydraulic Kyowa Resistivity Maihak Vibrating Wire
2. Rock Noise Counter (P.N.C.)	...	Walter Nold

3.	Multi-Point Borehole Extensometer (M.P.B.X.)	..	Telemac Interfels
4.	Torpedo Inclinometer	..	Telemac Vertical
5.	Linear Deformation Sensor (L.D.S.)	..	Terrametrics Mechanical Terrametrics Pneumatic Galileo Axial Movement
6.	Horizontal Linear Deformation Sensor (H.L.D.S.)	..	H1-Telemac Electrical
7.	Vertical Linear Deformation Sensor (V.L.D.S)	..	Telemac Electrical
8.	Mechanical Extensometer	..	Telemac
9.	Double Fluid Settlement Device (D.F.S.D)	..	Soils Instruments
10.	Strain Meter	..	Maihak Electrical Telemac Electrical Telemac Portable Interfels Portable.
11.	Inclinometer	..	Galileo Portable Telemac Fixed
12.	Water Level System U Tube	..	Galileo
13.	Temperature Gauge	..	Interfels Portable Maihak Embedded
14.	Stress Meter	..	Glotzl Interfels Hydraulic
15.	Convergency Measuring Device	..	Interfels

35. **Weather Conditions**

Weather conditions have been generally favourable for construction. Rainfall averages 30 inches per year with monthly averages varying between a low of 0.7 inches in June and 6.8 inches in August. Temperatures normally vary between 40° and 110°. Wind and heavy rain storms are usually of short duration. Approximately, 12 days during 1971 were lost on the embankment due to weather conditions.

36. Safety

The contractor has a full department of safety headed by an expatriate. Every month there is a safety meeting in which all aspects of safety are discussed for the Project. Each workman is instructed regarding safety measures to be taken on the Project. Up to March 1972 there were only 53 fatal accidents on the Project. The overall frequency rate from start is 17.6 and the severity was 2,885. The terms are defined as :—

$$\text{Injury-frequency rate} = \frac{\text{No disabling injuries} \times 1{,}000{,}000}{\text{No man hr. worked}}$$

$$\text{Injury-severity rate} = \frac{\text{No. of days lost} \times 1{,}000}{\text{No man hr. worked.}}$$

The safety record at Tarbela appears to be satisfactory for a Project of this size and complexity.

37. Progress

In March 1972 work on all phases of the Project is in progress. Overall Project is 55% complete. It is generally according to schedule. It is hoped that the Tarbela Dam Project will be completed on time with the international co operation and effort.

38. Acknowledgement

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Annexure 1

LIST OF CONSTRUCTIONAL PLANT AT TARBELA

S.No.	Plant Group	Type of Plant	No. in use
		(a) Mobile Plant	
1.	100	Marion 191-M 15 Cu. Yds. Shoevel	9
2.	101	Bucyrus-Erie 190B 10 Cu. Yds. Shoevel/Drag.	3
3.	101	Bucyrus-Erie 190B 10 Cu. Yds. Shoevel	1
4.	102	Bucyrus-Eire 88B 5 Cu. Yds. Shoevel	2
5.	102	Bucyrus-Eire 88B Shoevel/Drugline (5 Cu. Yds.)	2
6.	103	Bucyrus-Eire 61 B 3¼ Cu. Yds. Shoevel/Drag.	2
7.	104	Marion 93 M Crane/Dragline (21/2 Cu. Yds.)	3
8.	105	Marion 183 M Shoevel/Dragline (9 Cu. Yds.)	1
9.	106	Koehring 505 Hydraulic Skooper	2
10.	107	Supertalpa P-63 Hydraulic Excavator	2
11.	108	Marion 151 M 8 Cu. Yds. Shoevel	2
12.	109	Hydromac HYD. Hydraulic Crawler Excavator	1
13.	110	Hydromac HG 4 Hydraulic Tyred Excavator	1
14.	111	Caterpillar 561 Pipe Layer	1
15.	112	Poclain GC 120 Excavator	2
16.	113	Marion 111 M Excavator 5 Cu. Yds.	1
17.	120	Caterpillar 988 Loader	6
18.	121	Caterpillar 966 Loader	14
19.	123	Fiat FR 12 Loader	2
20.	141	Caterpillar 977H Loader	1
21.	150	Scoma MSC-250 Loader (Air)	9
22.	151	Caterpillar 955 Traxcavator	9
23.	158	Caterpillar D9 Tractor (Second Hand) W/Dozer)	2
24.	159	Caterpillar D9 Tractor W/Push Block	7
25.	160	Caterpillar D9 Bulldozer	19
26.	161	Caterpillar D8 Bulldozer	24
27.	163	Fiat BD 18 Bulldozer	6
28.	164	Caterpillar 834 Wheel Tractor W/Dozer	10
29.	165	Fiat 80R Wheel Tractor	4
30.	166	Fiat 750 Wheel Tractor	2
31.	167	Fiat AD 7/205 Bulldozer	1
32.	168	Caterpillar 78E Tractor	10
33.	169	Fiat AD4 Angle Dozer Tractor	2