2. Pumping. The capacity of pumps to be installed will depend on the expected infiltration and the area covered as this will determine the speed of unwatering after flooding. It is generally advisable to select a combination of pumps, for example high head pumps to remove the leakage and low head pumps to remove most of the water after flooding.

For coffer dams, it is desirable to have rugged and reliable pumps which can be easily shifted. The vertical type is most adaptable as it can be installed easily in places where the horizontal type will be difficult of installation. It also avoids priming the foot valves and prevents sand from blocking the rotating parts.

The capacity of pumps can be appreciably increased by putting in syphons extending over the coffer dams down to the outer water level so as to reduce the effective head on the pump. This has been successfully tried both on the reconditioning of Marala Headworks and the construction of the Kalabagh Barrage.

It is desirable to have either petrol or diesel driven pumps also available as these prove handy in the event of a failure of the electric supply, when electric pumps go out of action.

In the case of porous foundations, the water level can conveniently be lowered by adopting the well point pumping principle, in which a series of points spaced at intervals are connected by a header line to the pump.

3. River Diversion. One of the most critical operations in the construction of a dam is the river diversion. This has to be timed in such a way that unwatering of foundations for construction work is done when the water level in the river is at its minimum.

In narrow canyon projects, as in the case of Bhakra, the river has to be diverted through tunnels, after throwing in barriers both upstream and downstream of the dam site.

A closure against the head of 1 ft. to 2 ft. can be easily effected by using earth or a combination of earth and rock embankment, and rock-fill has to be used for heads from 2 ft. to 4 ft. More elaborate arrangements are required for greater heads. The closure can then be done by using sheet pile portal gates, gates on rollers, segmental arch rings or other similar devices. In the Shipshaw development in Canada, an obelisk 92 ft. high, 45 ft. wide and 40 ft. at its maximum depth was erected on the dry end and then tipped in the river by blasting away a portion of its supporting pedestal.

An extensive passageway is required in the case of wide rivers. Some of the methods employed are :—

(*i*) Putting in poles and bundles of brush in alternate layers between rows of piles which are driven in advance.

(*ii*) Carrying the low water discharge over the construction area in flumes.

Anderson Ranch Dam under Construction
(Courtesy of Morrison Knudsen Co.)

(*iii*) Diverting the water through notches in partly completed sections of the dam. These notches are subsequently closed by means of special diversion gates which permit a temporary sealing of the opening whereby concreting can be done behind the gates, finally transferring the river through permanent sluice ways located in the body of the dam.

It is generally worthwhile not to stint the initial expenditure involved so as to make the chances of successful diversion reasonably secure, as otherwise the start of construction may be delayed by a full year.

4. Excavating equipment and its performance. For planning excavation it is necessary to know beforehand where the excavated material has to be dumped and how it is to be transported. In working out the quantities of material to be transported, suitable provision for swell after excavation should also be made. For an economical working there should be a balanced running of the excavating and hauling equipment and the best possible advantage should be taken of the pit layout. In view of the large number of variables affecting the output of excavating equipment the monthly output is generally only 50 to 70 per cent of the optimum ability of the plant. (See photograph of Anderson Ranch Dam).

The important factors to be considered in selecting the equipment are :—

(*i*) The total quantity of excavation.
(*ii*) The time available.
(*iii*) The type of excavation and the nature of the area.
(*iv*) The designed rate of output of the equipment.

A table showing the variables which affect performance of some excavating equipment, (Dragline, shovels, tower excavators, bulldozers and graders) based on T. V. A. experience is given in Plate I.

A lot of modern excavation equipment has been developed which alone has made it possible for the execution of the collosal quantities involved in the construction of high dams. Most of the earth moving tools are drawn by tractors. Bulldozers are used for excavation and spreading of earth. With 4′ x 10′ blade, a bulldozer travelling at 120 ft. per minute loads in a distance of 30 ft. and carries from 2 to 3 cubic yards per load. With rapidly moving hauling equipment, bulldozers facilitate a proper shaping of an excavation job at the digging and dumping ends. Clam-shells, dippers and ditchers are adaptations of convertable shovels used for special jobs. The dragline is a more flexible excavating tool as it has a greater reach than a shovel but it cannot handle hard digging. Elevating graders are used for cutting earth and deflecting it on to a short section of belt conveyors which are operated by power units either mounted directly on the graders or driven from a power off-take from the tractor. Like the bulldozer, the power shovel is a most useful equipment for digging at close range. The popular makes have the capacity of two to three yards and can operate at 2 to 3 cycles per minute. The power shovel can be readily converted into a clam-shell, crane, ditcher, dragline or scoop.

For maximum efficiency these machines are generally equipped with a Ward-Leonard control system consisting of a direct current motor-generator driving separate motors connecting to each machine for the different functions of hoisting, swinging, etc.

The rooter is a tractor drawn auxiliary, used for ploughing up clay and soft rock foundation. The scraper is a combination of excavator and mower generally used for excavation and spreading earth for hauls up to 1,000 ft.

The walking dragline is used for travelling on soft bottom with a bearing pressure of only 4 to 6 lbs per square inch. This machine does not need any steering mechanism as it automatically travels in a direction opposite to which the boom points. It is operated by a diesel engine with remote control operating levers. electric or air powered. This can give an average of 8,000 to 10,000 cubic yard per day with a 8 yard bucket.

5. Transporting equipment and its performance. The transporting epuipment should be selected to suit the job in question so as to secure the most economical production rate. The main factors which have to be considered are :—

(*i*) The initial and operational cost of the loading and hauling equipment.

(*ii*) The out-turn of the equipment.

(*iii*) The round trip time cycle of the hauling unit.

(*iv*) The number of units that can be loaded per hour by the loading unit, which is generally the key equipment.

A statement compiled in the Tennessee Valley Authority office indicating the variables which effect the performance of transporting units is given in Plate II.

Another statement, similarly based on T. V. A. experience, is given in Plate III showing the advantages and limitations of the various types of transporting equipment along with the average costs obtained on various projects in the United States.

Before selecting any particular type of equipment, it is essential to carry out a detailed analysis of the cost per cubic yard by employing different types of loading and hauling equipment to determine the most economical combination.

6. Compressed air equipment. It is generally desirable to have smaller units instead of one big unit in spite of the extra cost involved in the foundations and superstructure, as this provides a desirable flexibility and allows the air-plant to be built up as the necessity arises. It is also more convenient in cases of breakdown.

Diesel driven compressor plant has the great advantage that it enables the starting of operations at a new dam construction much in advance of the installation of the electric construction power plant. It also does away with the necessity of transmission lines which are generally a matter of considerable difficulty, particularly if electrical stores are not readily available. It is also a matter of convenience if the various compressor units are purchased in identical dimensions so ensuring interchangeability of parts which facilitates replacements, etc.

Two stage compressors are preferable for pressure exceeding 70 lbs in view of their lower power requirements and reduced operating temperatures. Water cooled intercoolers are required between stages of such compressors to reduce the temperature and volume of the air. A similar function is performed by aftercoolers through which the air passes after the final stage of compression. An air receiver for equalizing compressor discharge pulsation is generally placed outside and near the compressor house.

It is most desirable to keep a constant check over any possible air-leakages as even a $\frac{3}{8}$ inch opening would amount to a loss of Rs. 3,000 per month.

7. Drilling equipment.

This is subdivided as follows :—

Drilling equipment.	Percussion drills.	Hammer drills	Jack hammers.	Used in drilling vertical holes.
			Drifters.	Used in drilling up, down, or side holes.
			Wagon drills	Can drill in any direction below horizontal, suitable for quarry and foundation work.
			Well drills.	Used for large blast holes 3" to 8" or more in diameter.
		Piston drillls.		An obsolete type.
	Abrasion drills.		Diamond drills.	Run up to 3" dia; can drill at any angle and go up to 1000'. Useful for exploration.
			Shot core drills.	Used for cores 3" to 48" in diameter. Can drill to a maximum angle of 45° downwards.

"The drilling speed attained depends on the size depth and spacing of hole, type of terrain, character of overburden, hardness of rock, prevalence of seems and cavities, amount of ground water, condition of equipment, efficiency of operation and type and quality of supervision."

Drill bits used with hammer type drills can be either detachable or forged and are generally made to suit the terrain. Chisel bits are adopted for very hard rocks, including trap, granite, quartz, chert, gray wacks and quartzite. Four point cross bits are used for medium rocks such as limestone and dolomite and fish tail bits are used for very soft rocks as shale and soft limestone. For brittle rocks whether very soft or extremely hard, a six point cross bit is generally used.

Detachable bits are now-a-days more popular than forged bits as these have a better metallurgical composition and temper. Proper heat treatment, using oil furnaces, is of primary importance in the sharpening shop at the site of the job equipped with forges, sharpeners, shank and bit punches, quenching outfit and grinder, etc.

8. **Aggregate Production.** A thorough analysis of the processes involved in the production of aggregate of the requisite composition and quality is of primary importance for high dam construction as it contributes materially to economy in the overall cost of the dam.

The first step is the selection of a quarry or a source with natural gravel deposits, if available, within an economical haul. A line diagram should then be prepared after taking into account the character of the rock, the quantity and rate of crushing, the economics of the quarry operation and the desired sizes and gradation of products.

A modern stone and sand crushing plant usually consists of a primary crusher, scapling screen, secondary crusher, belt conveyors, sizing screens, sand mills, sand screens, classifiers or washers, storage piles, reclaiming tunnels and means for the disposal of waste. The main considerations governing the arrangement of these parts are accessibility, ease of maintenance, flexibility and avoidance of duplication in the handling of materials.

The plant should always be designed with some excess capacity as it should be capable of catching up with consumption after any shut down. Another matter to be kept in view is that it is sometimes more economical to make up any shortage in sand by the installation of an additional sand mill rather than throw away any aggregate of other size which may occur in excess in the materials transported from the source.

Various types of equipments have been evolved for the manufacture of sand. Prominent among those are the high speed hammer mills, which have a rotating armature with suspended hammers which repeatedly strike the rock and throw it against breaker plates. In the ring crusher there are swinging annular rings instead of the hammers. Core or gyratory crusher has a heavy conical head suspended from an overhead spider and designed to rotate with an oscillating motion. Gyrosphere is similar to the gyratory crusher, but has a spherical head. The roll-crusher is an important piece of equipment for this purpose and has two steel cylinders rotating towards each other. The rod mill is a perpendicular revolving cylinder with a charge of steel rods constantly tumbling over each other and thus crushing the rock. This was used on the Fontana Dam. It should be borne in mind that the desired gradation of sand is very difficult to obtain directly from the machinery and a very flexible screening arrangement is, therefore, to be combined with the sand producing machinery.

It may also be remarked that the primary crushing of aggregate is generally done either in a jaw-crusher which can take large pieces or in a gyratory or cone type. The latter type is most commonly used for secondary crushers also. Another type used for secondary crushing is known as a newhouse—the main advantage in this is that it is suspended from the building frame thus saving the cost of concrete foundations.

The primary aim of processing is to produce first class concrete with a minimum of cement and all that is needed is that the specified sizes of aggregate should be of a composition consistent to attain this object on recombining. Two main groups of screen have to be used and these are, (*i*) shaker screen and (*ii*) positive throw eccentric vibrating screen.

They are provided with vibrating frames for the segregation of sand and small stone.

9. Concrete Manufacture.

(*i*) *General*. In the field of construction the most noteworthy advance has been the closer approach to uniformity of the concrete in place, so that the designer can now consider concrete more than ever before to be homogeneous as well as uniformly elastic in all parts of the structure. Deformations due to applied loads can thus be determined fairly closely by formulae derived on the basis of the theory of elasticity or may be estimated from laboratory measurements on models constructed of elastic materials.

According to I. L. Tyler, concrete suitable for use in dam construction must have the following characeristics :—

(*a*) Strength sufficient to carry the loads and provide a required factor of safety.

(*b*) Weight in the case of gravity dams to provide safety against sliding and overturning.

(*c*) Durability to ensure against weathering and erosion.

(*d*) Impermeability to prevent water percolation and solution of concreting materials.

(*e*) Continuity in order that the structure may act according to assumptions of design.

This can be attained by a judicious control of materials as well as the methods adopted for the manufacture, transportation placing, curing and temperature control of the concrete. The important points in this connection are briefly mentioned below :—

(*ii*) *Cement*. The cement used in large dams should have, in addition to its normal properties bearing on strength and durability, a low rate of heat evolution during hardening and a low total heat liberation.

(*iii*) *Aggregate.* This may be of two types, natural or manufactured, obtained by crushing suitable deposits of rock. Before selecting an aggregate for use on a dam, the following investigations are necessary :—

(*a*) Chemical analysis.
(*b*) Prototype analysis.
(*c*) Absorption.
(*d*) Specific gravity.
(*e*) Abrasion.
(*f*) Sodium sulphate or magnesium sulphate test for soundness.
(*g*) Strength of the aggregate in compression.
(*h*) Strength of mortar and concrete containing the aggregate.
(*i*) Freezing and thawing tests on aggregate and on concrete containing the aggregate.
(*j*) Expansion due to temperature change.
(*k*) Expansion due to moisture change.
(*l*) Thermal properties.

It is essential that processing plants and handling methods and equipment should be such that the combined aggregate at the mixing plant will be clean and of a uniform grading. The aggregate should also have a uniform moisture content when delivered in a mixer to permit an accurate control on the quantity of mixing water required.

According to present day practice, aggregate for mass concrete is separately classified into the following groups :—

(*a*) Under No.4 mesh ; sand.
(*b*) No. 4 mesh to 3/4 inch ; fine.
(*c*) 3/4 inch to 3 inches ; coarse.
(*d*) 3 to 6 inch ; cobbles.

Sizes over 6″ and up to 9″ have also been used with good results on the compressive strength, but these have the disadvantage of too excessive a wear on the belt conveyor system.

The grading formula generally used is

$p=\left(\frac{d}{D}\right)^n$ where p = proportion passing a given screen of sized,

D = Maximum size of aggregate,

and n = factor roughly measuring harshness of the mix.

The actual grading should however be done on the basis of actual tests of results of trial batches of concrete.

(*iv*) *Mixing water*. Mixing water should be tested for any impurities of harmful nature.

The quantity of mixing water has a very important bearing on the quality of concrete and must take into account the free-water carried by aggregate and sand. Consistency meters have been used in some cases as indicators of the mixing water contents.

(*v*) *Batching*. Automatic batching is now being used on all dam constructions on account of its greater uniformity and precision in operation and speed in batching. Weigh-batching is preferred to volumetric batching as this gives more accurate proportioning.

(*vi*) *Transportation*. The main aim in transportation is to transfer concrete to the point of deposit in the minimum time possible and without segregation of materials. The modern methods used in this connection have been described separately in greater detail.

Bottom dump concrete buckets loaded directly from the mixers or from intermediate transfer devices are necessary to reduce segregation.

For concrete containing smaller maximum size aggregate, pumping offers a satisfactory solution under suitable conditions, for the transportation of the concrete. This method is particularly handy in concreting in inaccessible places like tunnel linings, etc.

(*vii*) *Concrete Placing*. In large dam constructions this is generally done by using bottom dump buckets handled either by cranes on trestles or cableways. The details and comparative merits of these alternative methods have been discussed separately.

(*viii*) *Concrete Placing Buckets*. The large bucket is one of the many construction developments brought about by the ever increasing demand for greater speed and increased economy. According to R. F. Blanks of the Bureau of Reclamation, the economy resulting from the use of large buckets is counterbalanced by either one or both of the following factors :—

(*a*) Increased cement content to provide a higher slump for a given water cement ratio.

(*b*) Increased cost of vibration and other consolidating operations.

In this connection, it is to be noted that the costs of vibrating concrete in the United States are much higher than would be the case in the Punjab due to the very high rates of wages for manual labour, that prevail in the States.

If, however, the concrete could be properly distributed as it is discharged rather than being dumped in one pile, the objectionable features would be minimized.

Francis T. Crowe (with whom the authors had a discussion on the subject) has developed an eight cubic yard bucket which was used at Shasta Dam and shows promise of reducing the objections to the use of a large size bucket.

It will be of interest to mention that buckets of large capacity are of considerable benefit in hot arid localities where a rapid rate of concrete placing is necessary in order to maintain a live concrete working surface and thus avoid cold joints and unsatisfactory consolidation.

The preparation of surface for placing concrete and the desirability of using internal vibrators has been described in Punjab Engineering Congress Paper No. 251 by Mr. Mahbub.

The present day tendency is towards drier concrete which can now be placed with the use of vibrators as it is generally justified on grounds both of quality and of cost. As a result mainly of less water content, the strength of concrete after 28 days as indicated by tests, was as high as 7,500 to 8,500 lbs per square inch on the Ross Dam of Seattle City Light Company, which is at present being raised from a height of 350 ft. to 475 ft. and was visited by the authors during its construction.

(*ix*) *Curing and Surface Treatment.* The essential requirement of a concrete finished surface is that it should be able to withstand erosion and weathering for which a low water ratio and proper compaction are necessary. This can be attained by doing the minimum amount of work on the surface needed to produce the desired texture, by the use of absorption from lining, and by curing which ensures its protection from extreme temperatures and other possible damaging agents after the concrete has been placed in the forms. It is often difficult to remove forms early enough (say within 24 hours) to control surface and near surface temperatures properly and it is also not economical to leave forms in place long enough to be of any particular benefit. If forms could be designed so that these could be loosened after 24 hours to begin the spraying of concrete with water, the detrimental effect of high surface and near surface temperatures would be minimised and the surface cracks prevented. In very recent constructions, extended use is being made of vacumetric process, for sucking out moisture from the surface of film of concrete thus enabling it to acquire a compactness and hardness which is highly resistant to the abrasive action of water due to its high velocities as in the case of a spillway tunnel. This process utilizes specialized apparatus for which the patent rights are as yet the monoply of the manufacturer. The costs are high at present, although a claim is made that these are offset by the additional strength of the concrete and consequent possibility of economising in cement. At the Fontana Dam of the T.V.A. visited by the authors this method was being satisfactorily used.

(*x*) *Prevention of cracks.* Cracking in concrete may be due to temperature effects, moisture volume changes, foundation deflections, load deformation or a combination of these. High alkaline content of cement has also been regarded as a cause for disintegration or cracking of concrete as evidenced on the Parker Dam. This high alkilinity produces the worst results if the aggregate used contains opal (amorphous, hydrous silica) or fine grained igneous rock ranging from rhyolitic to andesitic composition.

Most of the cracking is, however, due to temperature stresses which are produced either by temperature changes in a block of concrete acting as an unrestrained unit or caused by the restraint of one section by another. The crack prevention measures adopted on the T.V.A. dams in the order of their estimated relative importance are :—

(*a*) The use of low heat cement.

(*b*) A slow pouring programme.

(*c*) A low proportion of cement in the concrete mix.

(*d*) Artificial cooling of concrete after deposition in the forms.

(*e*) The use of artificially cooled mixing water during summer.

On the Hiawassee Dam a basic pouring rate of one five feet lift every 5th day was adopted for the dam as a whole with the stipulation that for a distance of 10 ft. above level foundations the rate would be one 2·5 ft. lift every three days.

The extent to which artificial cooling in dams is economically justified would naturally depend upon the size of the project and the progress rate required by the construction schedule.

In spite of the above precautions, however, there is a tendency towards increased cracking in the concrete of masonry dams due to modern speed of construction.

To avoid such cracks which are considered objectionable both from considerations of safety and appearance, it is necessary to provide suitable construction joints. These joints can be either plain or keyed and are provided both in the transverse and longitudinal directions.

The spacing of these joints has to be decided after considering "the type and height of the dam, profile of the dam site, foundation materials and conditions, speed of construction, climate, architectural treatment, whether artificial cooling of the concrete or aggregate is resorted to, the heat flow characteristics of the aggregate themselves, water cement ratio of the concrete, height of lifts, time interval elapsing between lifts and the type of cement."

At present the most popular spacing for the vertical joints normal to the axis of the dam is 50 ft., each joint extending entirely through the structure.

From the stand point of structural sufficiency longitudinal cracks in a dam are far more objectional than transverse ones, since the latter principally effect the water-tightness qualities of the dam whereas the former may divide the dam into parts that would not be stable, especially if hydrostatic pressure builds up to reservoir head in the crack. Longitudinal joints have been used in the construction of some large dams as Boulder and Shasta but the intricacies of the construction procedure due to the necessity for grouting longitudinal joints have made the type relatively unpopular and one that should be avoided if practicable.

10. Concrete Mixing. Concrete mixing plants are generally designed for vertical flow of aggregate from storage bins at the top through aggregate batches and from there to the mixers. In view of the elaborate proportioning of the aggregate necessary to obtain a high quality concrete, different sizes of aggregate are batched almost simultaneously and a collecting hopper below the individual batches, which are generally of the C. S. Johnson type, feeds a revolving discharge chute, which directs the aggregate to each mixer in sequence. The mixers are set radially and discharge into a common central opening to the concrete transporting means below.

It is necessary to determine the size and number of mixers before a mixing plant can be designed. The desired output would be a function of the following factors :—

(*i*) The speed with which aggregate can be supplied economically.

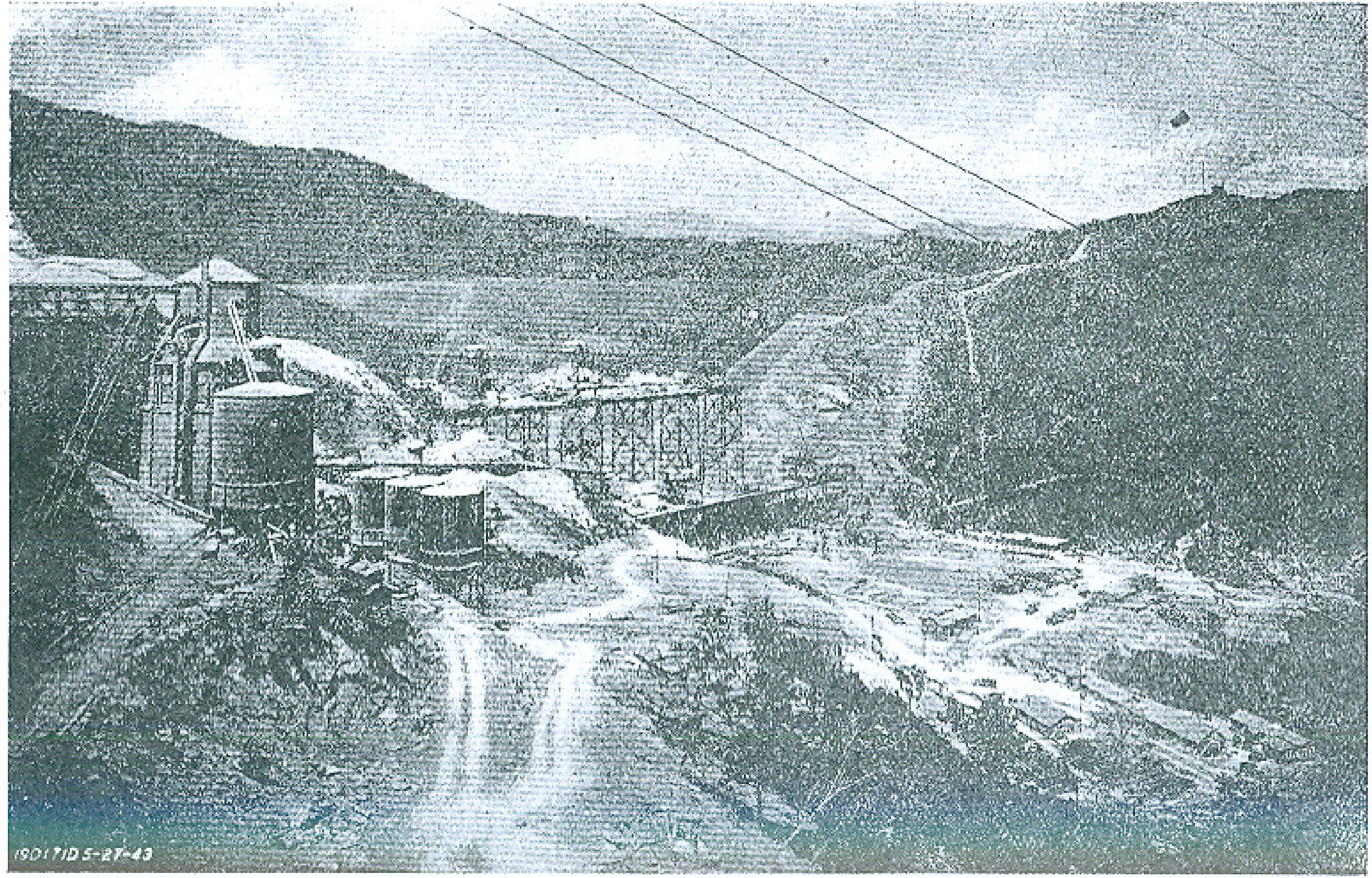
(*ii*) Type of concrete placing plant selected for the job and its capacity.

(*iii*) The period during which it is desired to complete the job.

To ensure maximum efficiency it is very desirable to frame a detailed operating chart indicating the functions of all parts of the plant and the duties of each portion.

It might be of interest to give details of a modern mixing plant as seen by the authors during their visit to Fontana Dam, on which the construction was in its final stage. This contained five, 4 cubic yard front charge tilting Smith mixers. A tilting type, it may be remarked, is more useful on large constructions as it enables aggregate of six to eight inches and larger size to be used without difficulty. The non-tilting mixers are satisfactory if the aggegate size is three inches or lower. These have the advantage of simpler charging and discharging spouts. The maximum monthly out-turn of concrete obtained on the above plant was 245,000 cubic yards or an average of about 9,000 cubic yards in 27 days of the month. The foundation platform for the mixers was a concrete structure built separately from the building frame itself. This was done to absorb the vibration from the mixture and prevent it from being transmitted to the steel frame of the bin structure. The cement bin had been welded at the joints to make the bin water tight. The approximate weight of the mixing plant complete without mixers was about 500,000 lbs. the mixers weighing about 145,000 lbs. The plant was about 110 ft. high and cost in all a sum of Rs.5 lacs. A photograph of the plant showing the mixers, the cement silos, cement conveyor system, conveyors for feeding the aggregate to the plant and for taking the concrete from the plant to the concrete pacing trestle, is attached, (see photograph).

The mixer plant was fully automatic and could be operated by one man. It was found desirable, however, to post one man on top of the bins to operate the turnhead and control the filling of the aggregate bins. Another man was needed to operate the concrete conveyor and discharge gate under the wet batch concrete hopper. A despatcher was also needed to control the distribution of concrete to the forms and determine the



Fontana Dam under Construction
Showing Mixer Plant in the Foreground (Courtesy of T. V. A.)

proper mix to be batched and delivered. An appreciable amount of maintenance is necessary to keep an automatic plant of this type tuned up and in operating condition all the time.

11. Cableways *versus* Trestles.

(*i*) *General.* Concrete placing is generally done either by cableways or tresles. A cableway consists of a track cable supported at each-end by either moving or fixed towers on which travels a carriage carrying a hook which can be raised and lowered. The head and tail towers can both be fixed or both movable on straight parallel runways, or one tower can be fixed and the other tower movable on a radial runway.

The following factors must be satisfied if a cableway installation is to be justified :—

(*a*) The length of the dam or structure must be short enough so that the span of the cableway can be within reasonable limits. A span of about 2,500 ft. is the longest used for concrete placing to date, and a shorter span is preferable.

(*b*) The topography at each end of the cableway must be such that fixed towers or runways for movable towers can be located and built economically.

(*c*) The amount of concrete to be placed and equipment to be handled must be sufficient to justify the capital outlay for the cableway installation.

(*d*) It should be possible to locate the cableway runways and towers so as not to interfere with actual construction on the dam.

(*e*) The construction schedule for placing concrete must be such that the number of cableways which can be physically and economically placed over the area can handle the volume in the time required.

(*f*) The estimated cost of placing concrete per yard by cableway should be less than the estimated cost by other schemes taking into account other practical advantages of this scheme.

When one cableway is used it is usually a simple matter to arrange it so that it can cover the entire area either by using parallel runways or by a tower at one end and a radial runway at the other. When two cableways are used on runways common to both, as at Norris Dam, they must operate about 50 ft. apart, up and downstream. If more than two cableways are used on the same parallel runways this limitation becomes very objectionable and cableways radiating from a central fixed tower or several towers may cover the area in a more effective manner. Shasta Dam was an example of such a layout. It is not always possible on a job where the concrete pouring schedule is exceptionally fast to arrange the cableways in sufficient number to meet the schedule. This was true at the Fontana Dam (T. V. A.) where the cableway scheme was discarded. The Fontana topography was such that a cableway scheme using three units could have been built, but this was too slow and a trestle and crane scheme was adopted.

(*ii*) *Advantages of cableways over trestles.* The advantages of a cableway over a trestle and crane installation, derrick set up, etc., are as follows :—

(*a*) Clear access to all parts of work without interference of trestles, derriks, guy wires, etc.

(*b*) The maximum hoisting capacity of the cableway is available over any portion of the job covered by it and a load can be transported from any point to any other point. Two cableways operating on one track can be used in tandem with proper lifting beams and double the lifting capacity to handle items like penstocks and other special loads.

(*c*) A single set up of the cableway can be made to handle the whole job. In many cases where a trestle is used it is necessary to do it in two stages with trestles at first on a lower and then on a higher elevation with consequent shutdown of work while the change is being made. With cableways the necessity for shifting is eliminated.

(*iii*) *Disadvantages of cableways over trestles.* The disadvantages of a cableway over a trestle and crane installation, derrick set up, etc., are as follows :—

(*a*) The concrete bucket if discharged quickly is suddenly "bounced" upward by the track cable when the load is released, causing segregation of the concrete. On some projects this is reduced by first settling the bucket down and then releasing the concrete after some of the rebound in the cable has been taken out. This is slower, however.

(*b*) The complete cycle from the time the concrete bucket is picked up till it is dumped and returned to its starting point is slower on a cableway than on a crane. This is partly offset by the use of a 6 c.y. or 8 c.y. bucket on a cableway insead of the usual 4 c.y. bucket by cranes.

(*iv*) *Typical cableway installations.* The first important installation of heavy-duty cableway was used in the construction of Owyhee Dam in 1929. This has a 25 ton capacity, and in this case the towers were mounted on heavy railroad trucks and the entire horizontal load was carried on the wheel flanges. This method proved to be impracticable for heavy loads, and on subsequent cableway installations the thrust was taken by other means.

Practically all cableways used in the last twelve years have been of the thrust wheel type or an adaptation of it. Madden Dam in Panama was the first and Norris Dam (T. V. A.) was second. The thrust wheel has as its principal feature a set of horizontal thrust wheels placed at the back of the movable cableway tower to transmit the horizontal pull of the track cable to the runway. This location of the thrust, at the back of the runway, is advantageous and in some cases necessary if the runway is perched on a precipitous cliff where a heavy thrust near the front edge would be dangerous. In the particular case of Norris Dam this design proved its effectiveness when a cave-in occurred under the head tower runway. It was conceivable at that time that one of the cableways might have been damaged or lost, had not the horizontal thrust been transmitted to the back of the runway where it was solidly anchored into the hill. This method of anchoring has been adopted at the Ross Dam construction now in progress and seen by the authors.

Sometimes the towers are built with the horizontal thrust wheels in the centre about halfway between the front and rear tracks, and sometimes the front tracks are placed at an angle with the horizontal and perpendicular to the resultant load to take care of the horizontal thrust. In the latter case the entire thrust is put on the front edge of the runway. This method should be used only when the runway can safely take this load.

(*v*) *Cableways for Bhakra Dam.* The total quantity of concrete at Bhakra Dam may be assumed at this stage to be 2.5 million yards as the upper limit for a dam 480 ft. high above bedrock. Assuming that concreting is done for 25 days in the month and the work of concreting is to be completed in 30 months, the average daily out-turn should be 3,333 cubic yards. Four-thousand cubic yards would thus be a suitable figure for the average when the work is in full progress.

If cableways were used on the Bhakra project an average out-turn of 4,000 cubic yards per day may be reasonably expected using a 6 yard concrete bucket. This would be correspondingly increased if an 8 yard bucket were used.

It would not thus be necessary to have 5 cableways. As against this, 3 cableways would not seem to be enough as provision has to be made for a certain amount of idle repair time. It may be pointed out that if all four cableways were placed parallel to each other and to the axis of the dam only one or two of these would be in a position to be used when the concreting gets close to the top of the dam. This would be partly taken care of by placing the cableways on a slight skew to the axis of the dam so that at least two of them would cross the axis and could both be used on topping off the dam.

If, however, cranes and trestles were to be used, an average of 4,000 cubic yards per day would be possible of attainment by using one revolving crane on the Power house trestles and two revolving cranes and one hammerhead crane on the main trestle. This quantity would be naturally increased if two hammerheads were used on the main trestle.

(*vi*) *Operating Costs.* It will be of interest to record the operating costs of cableways and cranes including operation, repairs, depreciation, power and maintenance, as obtained on some of the T. V. A. Projects.

Equipment.	*Dam.*	*Operating Cost.*
Cableway, 6 cubic yard bucket.	Norris	88.3 Rs. per hour.
Cabeways, 7½ cubic yard bucket.	Hiwassee	86.6 Rs. per hour.
40 ton revolving crane	Cherokee	34.1 Rs. per hour.
40 ton revolving crane	Fontana	41.0 Rs. per hour.
Hammerhead crane	Fontana	75.0 Rs. per hour.

The actual costs obtained in India would be different but the above may be considered a fairly good indication of the relative costs. It may be pointed out that with cableways it is possible to go as high as an 8 yard bucket whereas the cranes are built for a 4 cubic yard size. The somewhat slower speed of the cableway would therefore be offset to some extent with the larger size bucket.

12. **Elements contributing to success in construction industry.** The science of construction although dependent on materials, can never rise to its full efficiency unless the human element involved is also provided with the same scientific spirit and zeal as in the case of the machine. The following factors in this connection are worthy of note :—

(*i*) As in the case of machines, the operating organisation should function at the maximum efficiency and skill of the men engaged in the construction.

(*ii*) To achieve the above object, the best possible and safest working conditions for the men should be provided and expenditures in this connection should not be stinted.

(*iii*) The rate of wages should not be fixed with a view to exploit the labour. On the other hand it should be adequate to secure for the workers, a sustaining quality and quantity of food, clothing and shelter.

(*iv*) Full regard should be paid at the very start to the ample provision of hygienic essentials such as drinking water supply. Adequate arrangements for sanitation both in the residential and field area should also be made for human and animal labour.

(*v*) The workers should be given the opportunity of developing initiative, skill and ambition. As a reward for their loyal devotion to duty, continuity of employment should be provided as far as possible.

(*vi*) Everything should be done to secure the goodwill of the workers and not merely their service.

CHAPTER VIII

ALTERNATIVE CONSTRUCTION AGENCIES

1. **Force Account system.** It will be of interest at this stage to add a few remarks in regard to the alternative construction agencies employed for large construction works in the United States of America. One of the methods adopted is the "Force Account" in which Government selects, hires, trains and supervises the workmen and is responsible for the policies governing wages and conditions of work. This system was adopted on the construction of all T. V. A. dams as it was considered that the main objective was the welfare of the region rather than the mere construction of dams and it was thought by the T. V. A. that doing the work by "force account" would afford a better opportunity for the men of the region to learn new skill, skill that would be badly needed with the development of industry.

2. **Contract system.** Practically all the dams constructed by the Bureau of Reclamation since 1925, however, have been constructed under "contracts" giving fixed unit-price rate. The main arguments urged in favour of this system are :—

(*i*) It enables open competition between competent contractors, who are allowed to bid for the job and it is thus possible to obtain maximum economy.

(*ii*) The Bureau as a body do not maintain any construction organization of their own, although they have a large number of technical supervisory staff. Some of the U.S. contractors on the other hand, have huge construction forces with considerable skill and experience and can also provide and operate the specialized mechanical equipment required. Some of the points urged against this system are :—

(*a*) Any change in design or specification after the letting out of the contract involves an amendment of the original contract and affords the contractors an opportunity to make disproportionately high claims for such charges.

(*b*) The contractors' interest slackens towards the finishing stages of the job and the job does not have that final finish, which is possible under the "Force Account."

(*c*) The letting out of a contract requires detailed plans and specifications as a basis for competitive bids and this may delay the initiation of work in the field, if comprehensive and detailed plans have not been drawn out.

3. **"Cost-plus" contracts.** To obviate this difficulty and in view of the unstable prices of labour and materials due to war conditions, contracts for construction works are in some cases being let out by U. S. Government at present on the basis of "cost plus" contracts. These are either "cost plus a percentage" contracts or "cost plus a fixed fee" contracts. In the first class, the fee or profit of the contractor is made dependent on the

cost of the work and it is thus to the financial interest of the contractor to have the cost of work run high. This, however, is not the case under the second class as in this, the fee is not affected by variations in cost but is dependent only on changes, if any, in the scope of the work. In some cases where the location is isolated and the engineering data available is meagre, this method is considered to be the best, especially when the early completion of a project is important.

CHAPTER IX

PUNJAB PROJECTS

1. The Punjab Projects. The following major schemes are worthy of notice in the Punjab at the present time :—

(*i*) *The Bhakra Dam.* This comprises a dam about 500 ft. high across the river Sutlej at Bhakra, founded on Lower Siwalik sandstones (with occasional bands of clay) for a live storage of about 4 million acre-feet and for generation of about 200,000 K.W. (73 per cent load factor) of firm power and, if required, a considerable amount of secondary power. This scheme is capable of irrigating gross area of nearly 5 million acres. Water will be delivered through some 200 miles of lined main canals and an extensive net-work of distributaries, part of which may also be lined.

(*ii*) *The Kalsi Dam.* This comprises a dam about 200 ft. high across the Tons near Kalsi founded on Lower Siwalik sandstones, for the generation of about 30,000 K.W. of firm power. This in conjuction with tube wells along the Western Jumna Canal, can supply perennial irrigation to areas in the Rohtak district. This will have to be a joint undertaking between the Punjab and the U. P. Governments.

(*iii*) *The Kishau Dam.* The Kishau Dam Scheme on the Tons tributary of the Jumna River : This comprises a dam about 730 ft. high across the Tons at Kishau, founded on hard magnesian-limestone, for a live storage of about 1·25 million acre feet of water and for generation of 125,000 K.W. (73 per cent load factor) of firm power and a considerable amount of secondary power. This scheme will also have to be executed jointly by the Punjab and the United Provinces.

On the Punjab side the stored water can be utilised to extend irrigation to about 1 million acres (gross) of arid areas of Gurgaon, Rohtak and Hissar districts.

(*iv*) *The Dhiangarh Dam.* This comprises a dam about 750 ft. high across the River Chenab at Dhiangarh in Jammu State founded on hard dolomites, for a live storage of about 2·5 million acre feet and for generation of anything up to one-half million K.W. (73 per cent load factor) of firm power. The stored water can be used for supplementing supplies to the Sutlej Valley canals and other canals in the north Punjab, for improvement of existing irrigation and for its extension into new areas. This scheme if approved, will have to be constructed and operated jointly by the Punjab and Jammu and Kashmir Governments.

(*v*) *The Marhu Tunnel Scheme.* Linked with the above is a scheme for the construction of a tunnel at Marhu (Chamba State) across the Pir Panjal Range (elevation 14,000 to 15,000 ft.) about five miles long and 35 ft. internal diameter to divert about 20,000 cusecs from the river Chenab into the river Ravi. The hydro-electric prospects of this have not been investigated so far but promise to be substantial.

(*vi*) *The Larji Dam.* This comprises a dam about 730 ft. high across the Beas at Larji in the Kulu valley, founded on hard dolomitic limestones, for a live storage of two million acre feet and for generating 125,000 K.W. (73 per cent load factor) of firm power.

(*vii*) *The Rohtang Tunnel.* Linked with this is the scheme for the construction of a four mile length of tunnel about 22.5 ft. internal diameter across the Pir Panjal Range at the Rohtang Pass (R.L.13,000) to divert about 10,000 cusecs from the Chenab into the Beas to add to the scanty supply at Larji and improve its power development.

(*viii*) *The Rasul hydro-electric and tubewell scheme.* This scheme is now in hand and comprises a power station at Rasul utilising the 80 ft. fall from the Upper Jhelum Canal into the Lower Jhelum Canal and generating power for use in pumping water from a battery of 1,960 tubewells sunk alongside the canals, for the dual purpose of abstracting water from the sub-soil and extension of irrigation.

The location of the above dams is indicated in Plate V.

2. Suggested criterion for financing Irrigation projects. To promote irrigation, the Government in U.S.A. actually subsidise it by charging no interest on construction costs. The revenue from the irrigation works are in most cases supposed to repay in forty years, without interest, the total cost of such works. This means that at 3½ per cent interest, the State accepts a voluntary contribution of $ 46·61 for every $ 100 spent on Reclamation works which are made repayable in 40 uniform instalments of $ 2·5 per year, as a sum of $ 53·32 invested at 3½ per cent interest compounded annually, will amount to a sum of $ 100.

In general, the subsidising of irrigation is warranted so long as the total benefits to the nation exceed the total costs, and to the extent that the total benefits exceed those costs which the direct beneficiary can afford to assume.

In U.S.A., the loss of interest on irrigation construction cost has been more than balanced by increased tax income from the wealth created. It has been estimated that every dollar put in the irrigation works represents an addition of 3·80 dollars to the national wealth.

For obvious reasons, therefore, both the direct and indirect benefits must be taken into account while testing the productivity of a project. It would also seem fair to consider a particular irrigation project required to ensure a bare standard of living for a certain backward section of the country as a part of the overall irrigation system in the province and apply the test of productivity to this canal system as a whole instead of to the individual project.

With regard to the accounting of the indirect benefits, the President of the Central Board of Irrigation in its 16th Annual Meeting held in November 1945, remarked :—

"It has been accepted for a long time, that the benefits that accrue from irrigation and hydro-electric projects cannot be measured only in terms of direct addition to revenue; our works bring a large number of indirect benefits to the community and to local bodies, to Provincial Governments and to the Central Government. I trust that the Board will make a definite recommendation to the Government of India to set up machinery by which these additional benefits can be assessed and taken into account in determining the productivity of irrigation and hydro-electric works."

His Excellency the Viceroy, while addressing the same meeting said :—

"I am sure that you are right to insist on the indirect benefits provided by your schemes being taken into consideration when the financial implications are being worked out. I am convinced that irrigation is of such vital importance to India and of such lasting benefit that we must adopt a much bolder policy in the matter of finance than we have sometimes done in the past."

The importance of merging the capital cost of any new project which appears financially unproductive in the capital cost of projects already executed was also urged by R. B. L. Kanwar Sain, in his Paper No. 228 presented to this Congress in 1939.

The existing standard of productivity *viz.*, 4 per cent return on the capital cost, ten years after the completion of a project should not thus be a criterion for determining whether to go ahead with a particular scheme or not. All possible indirect benefits must be taken into account and if a particular project is likely to add to the national wealth of the Province, it should be pushed on as long as the Irrigation system as a whole remains productive.

3. Scope for increased electrification. The storage from the principal projects detailed in para 1 may aggegate about ten million acre feet and the power generation about one million K. W. of firm power. In addition, a much greater amount of secondary power can be developed at these sites. A number of other suitable sites are available on all the Punjab rivers both for storage and for power development. The possibilities of the great Indus river have not yet been explored. By interlinking the schemes mentioned above, it will be possible to increase the magnitude of available firm power on the entire system as the period of low supplies or low heads occur at different times on the different rivers.

Thus in the Punjab alone the water power development may aggregate to over one million H. P. of primary power and a still greater amount of secondary power. This comprises the first stage of development to be followed by further developments of equal or greater magnitude. Of the vast (possibly 30 million H. P.) available power potential of India only an insignificant fraction has been developed and utilised to date. Against that, U.S.A. with an estimated potential of 77 million H. P. has developed about 30 million. Europe (excluding Russia) with a potential of 74 million H. P. has developed about 30 million, and Canada with a population of barely 10 million has developed 9·5 million H. P. With an area less than ⅛th of Punjab, Switzerland has an installed capacity of well over 4 million H. P. Russia has developed over 30 million H. P. out of her 280 million K.W.H. or 50 per cent stream flow and 58 million K.W.H. or 95 per cent stream flow basis. Not much development has been done in China but her power potential may easily exceed the power potential of most other countries of the world. One single project in China is said to be capable of developing about 14 million H. P. of water power : the largest single installation in the world, at present, being the Grand Coulee in U.S.A. with 2·74 million H. P. China has many other projects for the generation of 1 to 3 million H. P. each.

If India is to count among the progressive nations of the world, she must develop her power potential. The development in Canada, U.S.A. and Russia should serve as a guide and incentive. The industrial background of India can be gauged amongst other factors by the quantity of electricity used per head. It works out to (pre-war figures) 980 K.W.H. in U.S.A., 976 K.W.H. in Belgium, 602 K. W. H. in United Kingdom, 560 K.W.H. in Australia, 520 K.W.H. in South Africa, 433 K.W.H. in France, 368 K.W.H. in Japan, 343 K.W.H. in Germany, 341 K.W.H. in Italy and only 5 K.W.H. in India. The average for the Punjab is also about the same and there are hardly any industries worth the name. Industrialisation is required to create conditions of full employment, which will relieve pressure on agriculture and absorb the unemployed and under-employed. It will absorb the raw material capacity of agriculture, fully utilise the mineral resources of the country and produce enough to meet the consumption requirements of the people. It should also aim at producing capital goods. Power is required for all this. In addition to industrial expansion and formation of electro-chemical and metallurgical industries, electricity is likely to be utilised in rural electrification including lift irrigation and de-watering, production of inorganic fertilizers and transportation. There is great scope for increase in the domestic use of electricity also. Thus there should be no difficulty in absorbing in due course the one million K.W.H. which the Punjab Projects at present under contemplation, are capable of producing, provided there is industrialisation and the people are educated in the use of electricity and there is a judicious scale of rates.

APPENDIX I

DETAILS OF PROPOSED BHAKRA DAM PROJECT.—(*Tentative*)

1. **Geology of Dam Site.** The rock strata in the gorge consists predominently of hard sandstones with beds of buff coloured clay or shale. The sandstones are massive and thick-bedded although jointed throughout. There are many zones in which the sandstones have been extremely sheered and shattered.
2. **Type of Dam.** Straight Gravity Type with cross section similar to that of Grand Coulee.

3.	**R. L. Winter Low water** ...	1,164
4.	**R. L. mean bed at Dam site** ...	1,143
5.	**R. L. assumed rock bed at site** ..	1,100
6.	**Maximum Reservoir Level** ...	1,580
7.	**Freeboard** ...	20′
8.	**R. L. Top of Dam** ...	1,600
9.	**Maximum height of Dam above assumed bedrock** ...	500′
10.	**Width of Dam at Top** ...	30′
11.	**Crest Length** ...	1,180′
12.	**Slope of dowstream face** ...	Vertical from R. L. 1,600 to 1,565 and .8 to 1 slope below this level with intersection with axis at R. L. 1,602.5.
13.	**Slope of the upstream face** ...	Vertical from R. L. 1600 to R. L. 1325 and ·15 to 1 below this level.
14.	**Maximum head** ...	1580—1169 (discharge 20,000 Cs) =411′
15.	**Maximum recorded flood at Bhakra** ...	2,50,000 cusecs.
	Maximum flood based on local enquiry ...	3,50,000 to 3,70,000 cusecs.
16.	**Spillways** (provisional) ...	2 Tunnels 50 ft. diameter. Length of left tunnel=2,838′ Length of right tunnel=2535′ 5373′ Thickness of lining (maximum). = 24″
17.	**Capacity of irrigation Outlets** ...	=37,000 cusecs at the dead storage level of 1,385.
18.	**Dimensions of Outlets** ...	Four 16′ diameter welded steel pipes in groups of 2 on either side of river; from each of these pipes 3,9′ diameter pipes branch off.

Discharge through each outlet would be controlled by 96″ size needle valve housed in R. C. structure. The 16′ diameter pipes are provided with Coaster gates on the up face of the dam for emergency closure and for simultaneous unwatering of both the valves and the penstocks.

19.	**Power Plant** ...	Location downstream toe of dam. Proposed capacity to be installed—3 main units of 80,000 K. V. A. each, plus two station service units of 3,000 K. V. A. each. Extra provision for future development—2 main units of 80,000 K. V. A. each.
20.	**Penstocks** ...	Diameter of penstocks =18 feet. Velocity through penstocks =15.5/Sec

APPENDIX II

STATEMENT SHOWING PROBABLE DETAILS AND COSTS IN U. S. A. OF MAJOR EQUIPMENT REQUIRED FOR THE BHAKRA PROJECT

Item No.	Item of Equipment.	Number required	Estimated cost each (in U.S.A.) Dollars	Estimate total cost (Equipment and material). Dollars.
1.	Diesel Power Plants—1,000 K. W. Units ..	5	1,00,000	5,00,000
2.	Portable Kohler Plants—5 K. W. Units ..	10	1,195	11,950
3.	Air Compressors—Portable—300 c.f.m. ...	5	5,680	28,400
4.	Air Compressors—Stationary—3,000 c.f.m. ...	5	22,000	110,000
5.	Shovel Dragline Combination—Diesel 2½ C. Y.	4	37,850	151,400
6.	Shovels, Diesel—3½ Cu. Yd. ...	2	48,000	96,000
7.	Shovels—Dragline Combination Diesel ...	2	24,500	49,000
8.	Cranes—15 Ton Crawler ...	1	19,000	19,000
9.	Cranes—5 Ton Crawler ...	2	11,000	22,000
10.	Cranes—5 Ton Truck Mounted ...	1	12,000	12,000
11.	Derick—10 Ton Guy (Incl. Motor) ...	1	8,000	8,000
12.	Drills—Wagon, Drifters, Core Churn ...	83	...	60,000
13.	Drills—Jackhammers ...	36	200	7,200
14.	Tractors (Including Dozers Power-Units) ...	22	9,340	205,418
15.	Trucks—12 Cu. Yd. Dump ...	24	11,500	276,000
16.	Trucks—5 Cu. Yd. Dump ...	10	6,000	60,000
17.	Trucks—Flatbeds 2½ Ton. ...	8	3,000	24,000
18.	Trucks—Panel Body (Pickups) ...	15	1,200	18,000
19.	Trucks—Buck Cement—(50 Bbl. Cap.) ...	15	4,100	61,500
20.	Carryall Scrapers—12 Cu. Yd. ...	4	4,875	19,500
21.	Automobiles ...	7	1,500	10,500
22.	Busses—Transportation ...	10	2,800	28,000
23.	Sheep's Foot Rollers ...	4	1,050	4,200
24.	Roller-10 Ton Butt Spring ...	2	4,250	8,500
25.	Power Graders—Diesel ...	2	7,400	14,800

26.	Tank Trucks	4	3,500	14,000
27.	Pumps—1000 G. P. M., 500′ Head (Including Motors)	5	11,000	55,000
28.	Pumps—6″ to 10″	8	..	15,000
29.	Aggregate Plant 150 Tons/HR	1	108,000	108,000
30.	Aggregate Plant 600 Tons/HR	1	300,000	300,000
31.	Concrete Plant Batch Mix 2-2 C. Y.	1	40,000	40,000
32.	Concrete Plant—Automatic 4-4 C. Y.	1	110,000	110,000
33.	Aggregate Conveyor System at Dam	3,300 L. F		132,000
34.	Locomotives—Diesel—120 Tons	2	85,000	170,000
35.	Rail Cars—Bottom Dump—40 Cu. Yd.	12	8,000	96,000
36.	Locomotive—8 Tons—Gasoline	3	5,000	15,000
37.	Transfer Cars—Special 2-4 C. Y. Dump Bodies	4	2,500	10,000
38.	Cableways—Complete	3	...	409,000
39.	Cement—Handling System	Complete	...	15,000
40.	Gunite Machine	1	1,800	1,800
41.	Concrete Mixers—Portable—14 S.	2	1,945	3,890
42.	Refrigeration Plant	Complete	...	150,000
43.	Concrete Buckets 4-8 C. Y., 2-4 C. Y., 4-2 C. Y.	10	..	8 800
44.	Vibrators	20	345	6,900
45.	Grout Pumps	2	600	1,200
46.	Mucking Machine—Conway 75	1	15,160	15,160
47.	Muck Cars	10	250	2,500
48.	Concrete Pump—2 Cu. Yd. Pneumatic	2	12,000	24,000
49.	Drill Jumbos—Track Mounted	2	8,000	16,000
50.	Drill Jumbo—Rail Mounted.	1	5,000	5,000
51.	Invert Forms and Gantry	1	25,000	25,000
52.	Sidewall Forms and Gantry	1	50,000	50,000
53.	Arch Forms and Gantry	1	30,000	30,000
54.	Collapsible Forms (set)	1	15,000	15,000
55.	Ventilating Systems 25,000 c. f. m.	4	10,000	40,000
56.	Machine shop Equipment (2-Shops)	Complete	...	30,000
57.	Drill Shop	"	...	3,040
58.	Carpenter Shop	"	...	8,000
59.	Rigger's Shop	"	...	3,000
60.	Electrical Shop	"	...	3,000
61.	Fuel, Oil and Grease Shop Equipment	"	...	5,000
62.	Electrical Distribution System	"	...	50,000
63.	Water Distribution System, (Not including Pumps)	"	...	20,000
64.	Warehouse Suppliers and Ports Portable	"	...	200,000
65.	Electric Arc Welders 24 K. W.	8	1,200	9,600
66.	Forms—Mass Concrete	Job	...	150,000
67.	Forms Hoists	20	250	5,000
	Total Estimated Major Equipment	...	...	4,176,000

(Move-in and plant erection cost not included)

Note.—This statement is just indicative of the equipment required for a dam of the size of Bhakra and is based on a tentative study of the construction plant layout. The construction plant layout finally adopted may however be radically different with a corresponding change in the equipment required.

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PLATE I.
VARIABLES AFFECTING THE OUTPUT OF EXCAVATI

Classification of Variables—Output Controll

Type of Excavator	Physical Conditions of the Job.	Materials to be Handled.	Limitations in
Dragline ...	1. Size of Excavation Area.	1. Type of Material: (1) Sand, (2) Gravel, (3) Rock, (4) Clay.	1. Size of Dipper
Shovels ... Tower Excavators	2. Type of Bottom: (1) Muddy, (2) Hard, (3) Smooth (4) Rough, (5) Sandy (6) Rocky.	2. Size of Pieces.	2. Angle of Swi
Bulldozers ...	3. Distance between loading and Dumping.	3. Moisture Content.	3. Necessary Re Loading to I
	4. Required Lift—Digging to Dumping.	4. Foreign Matter.	4. Height of Du
	5. Depth of Excavation.	5. Weight of Material as loaded.	5. Manoeuvrabi under Vario tions.
	6. Proximity to Supply of Fuel and parts.		6. Speed of Ma
	7. Weather.		7. Quality of Maintenanc
	8. Obstructions and Interference from other Structures.		8. Quality of F of Supply.
	9. Time Available.		
	10. Power Available.		
	11. Altitude.		
Dredges ...	1. Distance to Discharge Point.	1. Type of Material.	1. Size of Su Discharge I
	2. Presence of Trees, Roots, Vegetation, Obstructions, etc.	2. Size of Pieces.	2. Length of D
	3. Route to Discharge Point—by Water or Land.	3. Abrasiveness of Material.	3. Suction Vac
	4. Required Lift-Suction and Discharge.	4. Foreign Matter.	4. Discharge F
	5. Anchorage Available.		5. Action of C
	6. Proximity to Supply of Fue and Parts.		6. Quality o Maintenan
			7. Quality of of Supply.
			8. Alignment

PLATE II.

VARIABLES AFFECTING THE PERFORMANCE OF TRANSPORTING EQUIPMENT

	Classification of Variables—Performance Controlled by			
Type of Equipment	Physical Conditions of the Job	Materials to be Handled	Limitations in the Machine	Method of Operation
Scrapers ...	1. Length of Haul (Pit and Road).	1. Type of Material : (1) Sand, (2) Gravel, (3) Rock, (4) Clay.	1. Size of Load.	1. Number of Units in Operation.
Trucks ...	2. Type of Bottom : (1) Muddy, (2) Hard, (3) Smooth, (4) Rough, (5) Sandy, (6) Rocky.	2. Size of Pieces.	2. Speed of Movement.	2. Method of Loading.
Tractors and Wagons ...	3. Type and Location of "Out" and "Return" Ramps.	3. Moisture Content.	3. Manoeuvrability of Machine under Various Road and Weather Conditions.	3. Capacity of Loading Equipment.
	4. Type of Road or Route.	4. Specific Gravity.	4. Reliability and Performance of Power Unit.	4. Speed of Loading.
	5. Hauling Grade (Ramp and Road).	5. Swell of Material when loosened by loading.	5. Type of Wagon on Car Body.	5. Method of Deposition of Load. (Waste or Fill) (Spreading or Spot Dumping).
	6. Depth of Excavation.	6. Sticky or Readily Dumped	6. Type of Dumping Mechanism	6. Layout of Cuts, Ramps and Roads.
	7. Size and layout of Dumping Area.	7. Foreign Matter. (See 1, 2, 3, 4, 5, 6, 7 above)	7. Quality of Machine and Maintenance.	7. Skill and Experience of Operators and Supervisors.
	8. Weather.	8. Abrasive Qualities. (See also 1, 2, 3, 4, 5, 6, 7 above). (See 1, 2, 3, 4, 7, 8 above).	8. Quality of Fuel and Reliability of Supply.	8. Track and Switch Layout.
	9. Proximity to Supply of Fuel and parts.		9. Alignment of Track.	9. Disposal of Dumped Material from Track, (See also 1, 2, 3, 4, 5, 7 above).
Trains ...	10. Stability and Drainage of Subgrade.		10. No. of cars per train. (See also 1, 2, 3, 5, 6, 7, 8 above).	10. Layout of Conveying System.
	11. Curves (Vertical and Horizontal). (See also 1, 5, 7, 9 above).		11. Size of Load or Width of Belt.	11. Layout of Feeder System. (See also 1, 2, 3, 4, 5, 7 above).
Belt Conveyors ...	12. Supporting Structure Required (Trestle or Tower).		12. Type of Power and Power Control. (See 1, 2, 3, 4, 7, 8 above).	12. Alignment of Sluiceway.
Tramways ...	13. Layout and Location of Loading and Discharge Terminals, (See also 1, 6, 7, 8, 9, 11, above).		13. Size of Pipe.	13. Per Cent Solids Carried.
Sluicing Troughs	14. Slope of Sluiceway.		14. Discharge and Velocity of Sluicing Stream.	14. Number and Location of Booster Pumps in Pipe Line.

	Low mechanical maintenance			tive used. Average maximum 3%	Large	Locomotive 90-tons steamer or diesel 7-10-30 yd. cars	15 to 30	30,000	Depends on size of train		Boulder Dam (aggregate) 50 ton hopper cars (Hauling to Lomix Batcher)	30,00,000
LT CONVEYORS	Continuous uniform haulage at high efficiency Low labour and repairs requirement Can be supported on light-weight bridges, trestles or suspension cables to avoid rough ground and long detours	Unless covered, rain will decrease output seriously when handling earth or clay	Size of pieces is limited by width of belt and shape of rollers. Wet, sticky material is hard to handle. Requires a special feeder	Any route for which supports can be provided for the ends of the conveyor flights. Maximum grade up to 40% depending on material	Small	Belt Width 24"-300 c. yd. per hour.	4.5	20,000	Depends on length	The above costs on hauling equipment must be modified to suit local condition	Pickwick Dam Aggregate-24" Belt Concrete-30" Belt	8,00,000 6,00,000
					Medium	Belt Width 36"-850 c. yd. per hour.	5.7	20,000			Grand Coulee Dam Foundation Excavation-60" Belt Aggregate-48" Belt	1,40,00,000 35,00,000
					Large	Belt Width 60"-2800 c. yd. per hour	6.8	20,000			Atlantic-Gulf Ship Canal 2-36" Belt and crawler stacker	12,00,000
RIAL AMWAYS	Carries material over rough, rugged terrain and over long distances Avoids surface congestion of traffic Low labour requirements Can often carry load by gravity, requiring only a small amount of power to return the buckets	High winds hamper operation	In general, small buckets limit the material to small pieces such as crushed ore, sand, gravel and similar material	Long spans and angles in the line are not desirable. Maximum grade limited only by power available.	Small	Bucket size half yard	5.5	30,000	Depends on length	In the case of trains, conveyors, tramways, Dredge Lines and the like, costs depend entirely on individual installations and local conditions	Gilboa Dam, New York	4,50,000
					Medium	Bucket size one yard	5.5	40,000	One mile long, cost about Dollars 62,000 depends on length		Pardee Dam 200-30 cu. ft. buckets	6,00,000
					Large	Bucket size 4 yard	5.5	40,000			Madden Dam Panama 48-33 cu. ft. buckets	5,72,080
EDGE LINES	Sub-aqeous excavation High production from single digging Unit. Especially suitable for moving and placing core material in hydraulic fill dams as the discharge system permits the graded deposition of particle sizes	Storms, floods, and ice hamper operations on floating dredges Can operate and place fill, through ordinary rains and changes in water level	All types which can be broken by cutter-head. Size of piece is limited by size of discharge line and the clearance in the pump.	Any route on which the pipe can be supported. Straight line and constant grade layout is desirable	Small	(6") 15 to 45 cu. yd. per hour	8.2 (FPS)	*50,000 to 75,000	25,000		Fort Peck Dam 4-28" dredges, 5 pumps per dredge	10,00,00,000
					Medium	(16") 140 to 425 cu. yd. per hour	10.2 (15 FPS)	*50,000 to 75,000	1,00,000		Miami conservancy District 15" dredge	7,000,000
					Large	(30") 6,540 to 2,000 cu. yd. per hour	11.5 (17 FPS)	*50,000 to 75,000	10,00,000		Pickwick Dam 1-15" dredge, 2 pumps per dredge	26,00,000

*Depends on materials being handled

PLATE III.

RELATIVE PERFORMANCE OF VARIOUS TYPES OF TRANSPORTING EQUIPMENT

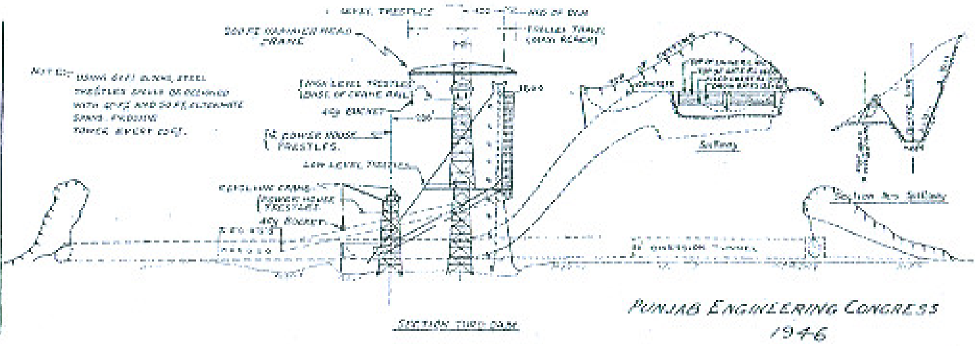
		LIMITATIONS				RATED CAPACITY PER LOAD				AVERAGE COSTS			
Type	Special Advantages	Weather	Material	Route Condition, type, maximum grade, etc.	Size	Water level	Heaping full	Rate of movement M. P. H.	Life of unit Economical hours of operation	Initial	Operating	Maintenance and Repairs	
						C. Yd.	C. Yd.			Dollars	Dollars per hour of operation		
TRACTOR DRAWN SCRAPERS	Combined loading and dumping unit Fast loading and dumping. No delay Can spread material at dump Can load, haul and dump with only one operator	Unsuited in rain or mud	Best suited to earth. Can handle sand to heavy clay and loosened shale and gravel. Low output in sticky clay. Scarifier may be read for solidly compacted material	Only general road maintenance required. Maximum grade 25% on firm roadbed	Small	6	7.5	3	10,000	8,400	1.10 to 1.50	1.15 to 1.45	2
					Medium	8	9.5	3	12,000	10,500	1.30 to 1.70	1.40 to 1.70	3
					Large	12	15	3	15,000	12,500	1.40 to 2.00	1.75 to 2.25	4
TRUCKS	High mobility Adaptable to various types of hauling Single unit for power and hauling High speed hauling and return Can back easily	Poor going in rain or mud	Able to handle all types depending on body design	Requires special road maintenance. Maximum grade 15% to 25%	Small	4	5	26	10,000	2,500	.90 to 1.30	.65 to .95	1
					Medium	8	10	11	12,000	5,000	1.20 to 1.70	1.40 to 1.80	3
					Large	12	15	8	12,000	8,000	1.40 to 2.00	1.80 to 2.20	2
RUBBER TYRED TRACTORS AND WAGONS	Fair mobility Can handle large loads Medium speed haulage and return Side rear or bottom dumping available. Can operate in tendom for long hauls. Sharp turning radii	Poor going in rain or mud	Able to handle all types depending on body design	Fair road Maintenance desirable but not essential Maximum grade 25%	Small	6	7	9	10,000	6,500	1.20 to 1.60	.95 to 1.25	2
					Medium	10	12	8	10,000	8,500	1.30 to 1.70	1.35 to 1.65	2
					Large	18	24	4	12,000	12,000	1.40 to 2.00	1.75 to 2.15	4
CRAWLER TRACTORS AND WAGONS	Fair mobility Can operate on soft and rough ground with large loads Side, rear or bottom dumping available Can operate in tendom for long hauls	Rain and mud reduce production	Able to handle all types depending on body design. Bottom dump for earth side or rear dump for heavy rock.	Only general road maintenance required. Maximum grade 25%	Small	6	7.5	3.5	10,000	7,000	1.10 to 1.50	1.20 to 1.50	3
					Medium	10	13	3.5	10,000	8,000	1.30 to 1.70	1.40 to 1.70	3
					Large	15	18	3.5	10,000	11,500	1.40 to 2.00	1.75 to 2.15	4
RAIL ROAD TRAINS	Effective high speed and long range haulage Economical haulage over a fixed	No limitations	Able to handle all types depending on body design	Requires expensive rail and roadbed instruction and	Small	Locomotive 8-ton gas. 2-6 yds. cars		4 to 5	20,000	8,000			

PLATE III.

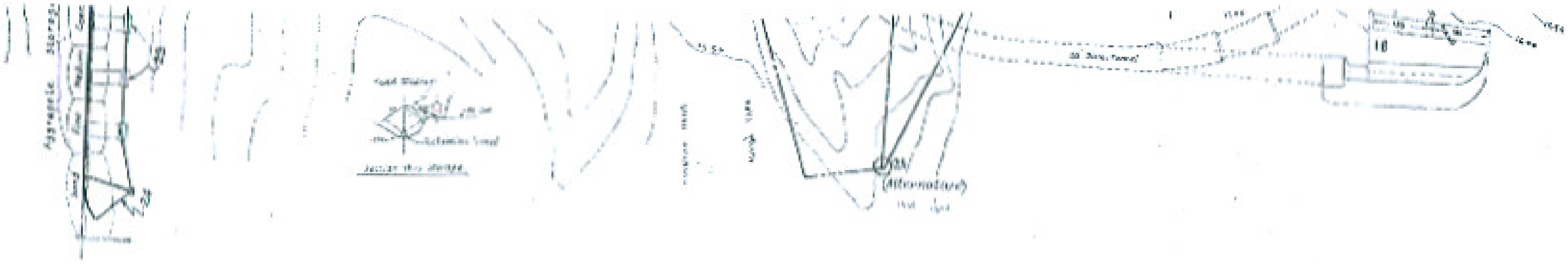
RELATIVE PERFORMANCE OF VARIOUS TYPES OF TRANSPORTING EQUIPMENT

	LIMITATIONS			RATED CAPACITY PER LOAD				AVERAGE COSTS				ACTUAL EXAMPLES			
	Material	Route Condition, type, maximum grade, etc.	Size	Water-level	Heaping full	Rate of movement M. P. H.	Life of unit Economical hours of operation	Initial	Operating	Maintenance and Repairs	Total for average life of equipment	Project	Job Yardage	Length of haul	
				C. Yd.	C. Yd.			Dollars	Dollars per hour of operation				C.U. Y.D.	Maximum feet	Minimum feet
ain or	Best suited to earth. Can handle sand to heavy clay and loosened shale and gravel. Low output in sticky clay. Scarifier may be read for solidly compacted material	Only general road maintenance required. Maximum grade 25% on firm roadbed	Small	6	7.5	3	10,000	8,400	1.10 to 1.50	1.15 to 1.45	3.10 to 3.80	Atlantic Gulf Ship Canal 6-12 yard and 1-6 yard	25,50,000	700	500
			Medium	8	9.5	3	12,000	10,500	1.30 to 1.70	1.40 to 1.70	3.60 to 4.30	Tricity Airport. Tenn. 1-8 yard and 3-12 yard	14,48,000	1,800	...
			Large	12	15	3	15,000	12,500	1.40 to 2.00	1.75 to 2.25	4.00 to 5.10	Highway—Crescent City, Calif 2-12 yard and 3-7 yard	6,70,000	1,000	500
rain	Able to handle all types depending on body design	Requires special road maintenance. Maximum grade 15% to 25%	Small	4	5	26	10,000	2,500	.90 to 1.30	.65 to .95	1.80 to 2.50	Boulder Dam Excavation 9-16 yard size	12,00,000	3,900	200
			Medium	8	10	11	12,000	5,000	1.20 to 1.70	1.40 to 4.80	3.00 to 3.90	Norris quarry 6 to 7 units. 12 yard capacity	21,[illegible]000	1,450	200
			Large	12	15	8	12,000	8,000	1.40 to 2.00	1.80 to 2.20	3.90 to 4.90	Fort Peck Excavation. Foundation. 230-6 yard size spillway, 96-6 yard size	41,00,000 1,05,50,000	9,000 8,000	7,500 5,000
rain	Able to handle all types depending on body design	Fair road Maintenance desirable but not essential Maximum grade 25%	Small	6	7	9	10,000	6,500	1.20 to 1.60	.95 to 1.25	2.70 to 3.41	Pickwick Dam 4 to 7-11 yard Trac-Tracs	5,03,000	800	200
			Medium	10	12	8	10,000	8,500	1.30 to 1.70	1.35 to 1.65	3.50 to 4.20	Cordelia-Carquinez Bay. Calif 1-24 yard buggy	11,66,000	...	1,500
			Large	18	24	4	12,000	12,000	1.40 to 2.00	1.75 to 2.15	4.35 to 5.30	San Francisco-Oakland Bay Bridge 4-24 yard buggies Piedmont Dam 2-30 yard buggies	3,00,000 6,15,000	... ...	2,400 1,900
mud tion	Able to handle all types depending on body design. Bottom dump for earth-side or rear dump for heavy rock.	Only general road maintenance required. Maximum grade 25%	Small	6	7.5	3.5	10,000	7,000	1.10 to 1.50	1.20 to 1.50	3.00 to 3.70	Atlantic-Gulf Ship Canal 8-10 yard and 1-6 yard	21,10,600	700	500
			Medium	10	13	3.5	10,000	8,000	1.30 to 1.70	1.40 to 1.70	3.50 to 4.20	Grand Coulee Dam Excavation 12 to 20 yard tractor wagons and trucks feeding conveyors	14,00,000	500	...
			Large	15	18	3.5	10,000	11,500	1.40 to 2.00	1.75 to 2.15	4.30 to 5.30	Madden Dam, Panama 10-8 yard, 5-10 yard and 6-12 yard	2,40,000	4,200	500
	Able to handle all types depending on body design	Requires expensive rail and roadbed construction and	Small	Locomotive gas. 2-6 yds.	8-ton cars	4 to 5	20,000	8,000				Fort Peck Dam Std. gauge-general supplies Boulder Dam (raw gravel) 4 trains, 90 ton	150,00,000 (tons) 45,00,000	12.2 miles 7 miles	... ...

3. Bridge.
4. Bridge over open cut diversion channel exit.
5. Bucket Elevators and shuttle conveyor for storing
6. Bypass conveyors.
7. Conveyors (other)
8. Cement lines to mixing plant for pumping by compressed air.
9. Cement unloading plant silos 6000 bbl. (ultimately)
10. Cement unloading plant silo
11. Compressor house.
12. Concrete hoppers.
13. Conveyors for reclaiming.
14. Crusher building
15. Fixed stackers
16. Grout plant for low & high level
17. Hammer head crane
18. Left Spillway.
21. Mixing plant (alternate location)
22. Power house.
23. Power house trestles.
24. Radial stacker.
25. Raw water pumps
26. Revolving crane
27. Right spillway
28. Rinsing screen
29. Sizing plant
30. Sub station.
31. Steam plant.



PUNJAB ENGINEERING CONGRESS
1946



3. Bridge.
4. Bridge over the open cut diversion channel exit.
5. Bucket Elevators and shuttle conveyor for storing
6. Bypass conveyors
7. Conveyors (others)
8. Cement lines to mixing plant for pumping by compressed air.
9. Cement unloading plant silos 6500 bbl.
10. Cement unloading plant [illegible] silos
11. Compressor house
12. Concrete [illegible]
13. Conveyors for reclaiming
14. Crusher building
15. Flood [illegible]
16. Grout plant for low & high level outlets
17. Hammer head crane
18. Left Stilling

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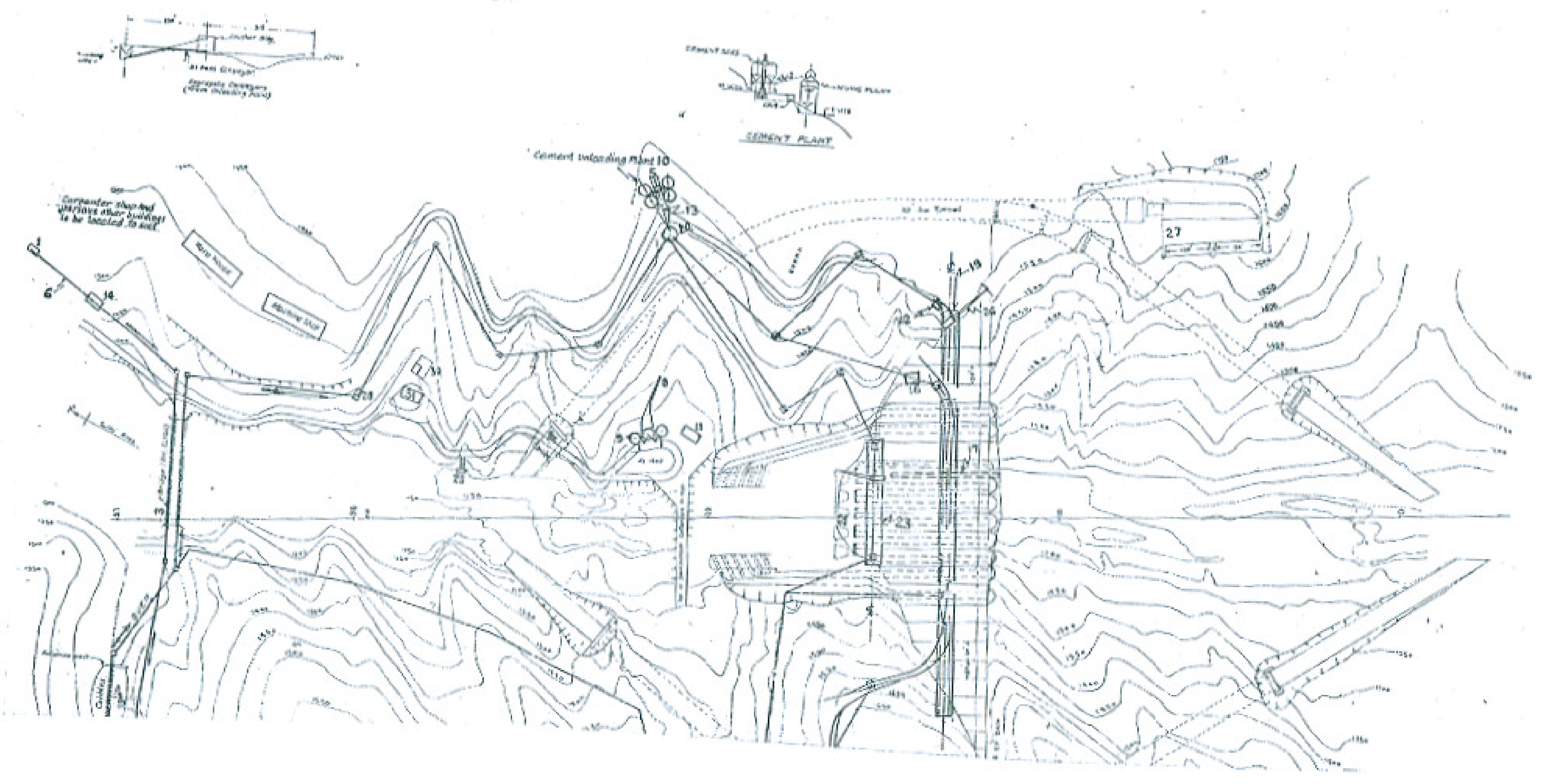
CEMENT PLANT
Cement unloading plant 10
Carpenter shop and various other buildings to be located to suit
Machine Shop
30' Dia Tunnel
27
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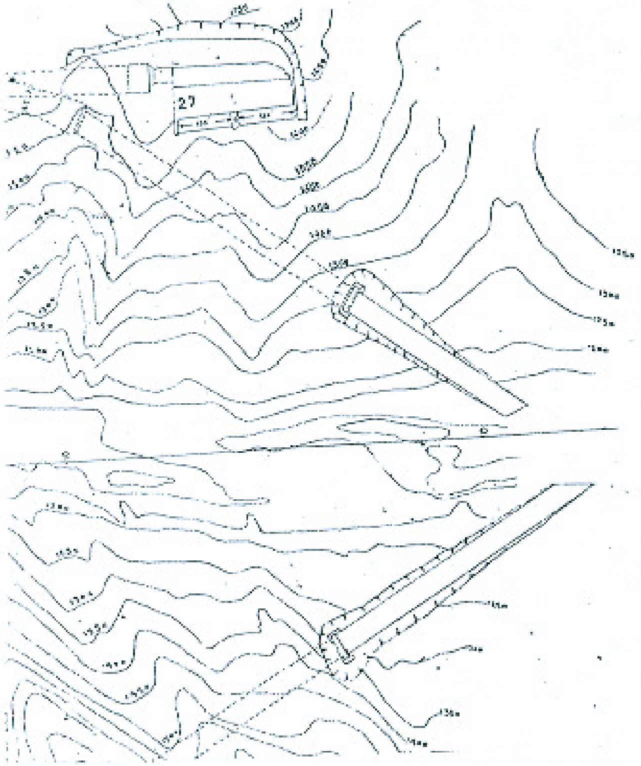
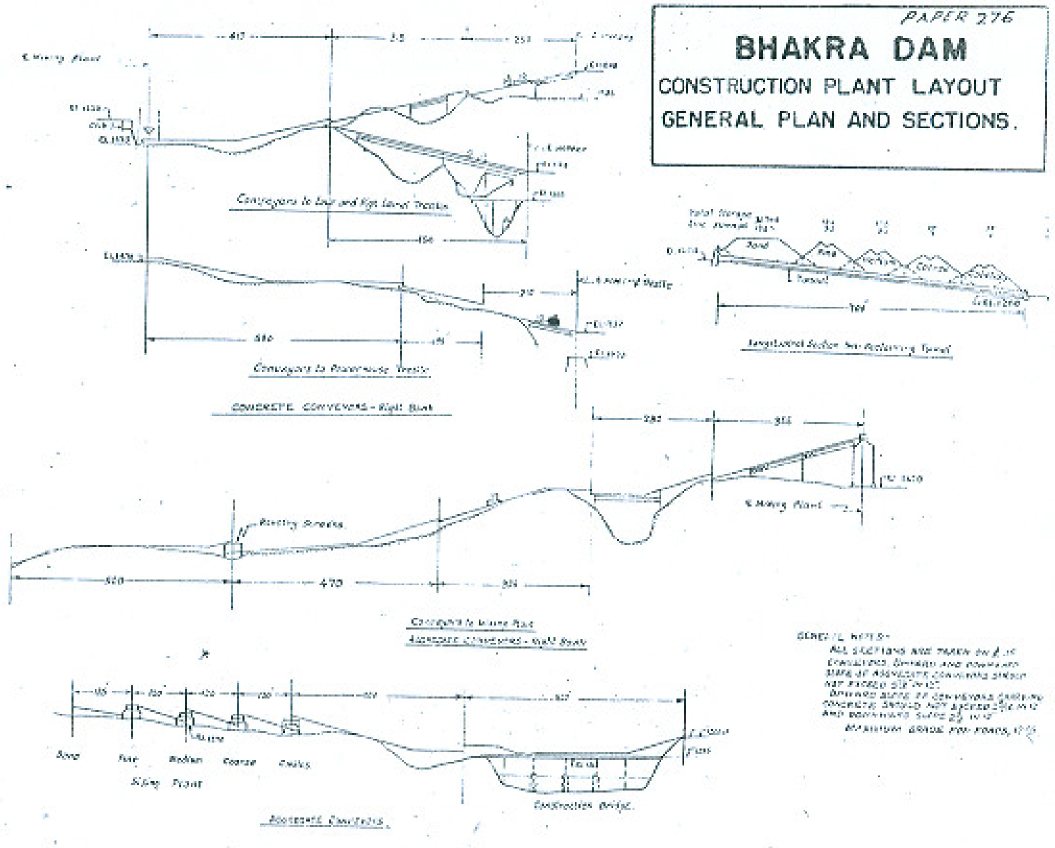
PLATE IV

PAPER 276

BHAKRA DAM

CONSTRUCTION PLANT LAYOUT GENERAL PLAN AND SECTIONS.





Conveyors to Low and High Level Trestles

Conveyors to Powerhouse Trestle

CONCRETE CONVEYORS – *Right Bank*

Longitudinal Section thru Reclaiming Tunnel

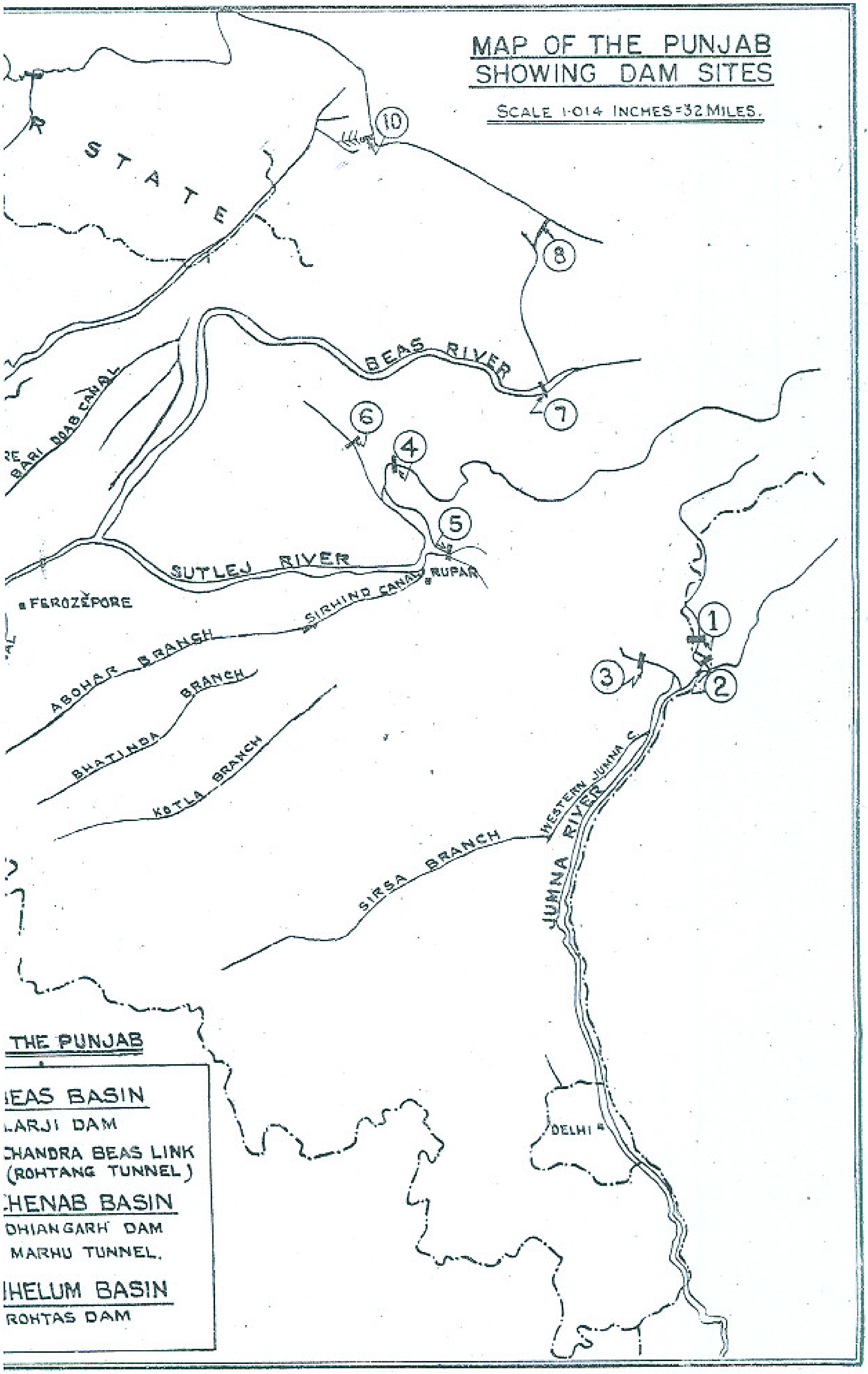
Conveyors to Mixing Plant

AGGREGATE CONVEYORS – Right Bank

AGGREGATE CONVEYORS.

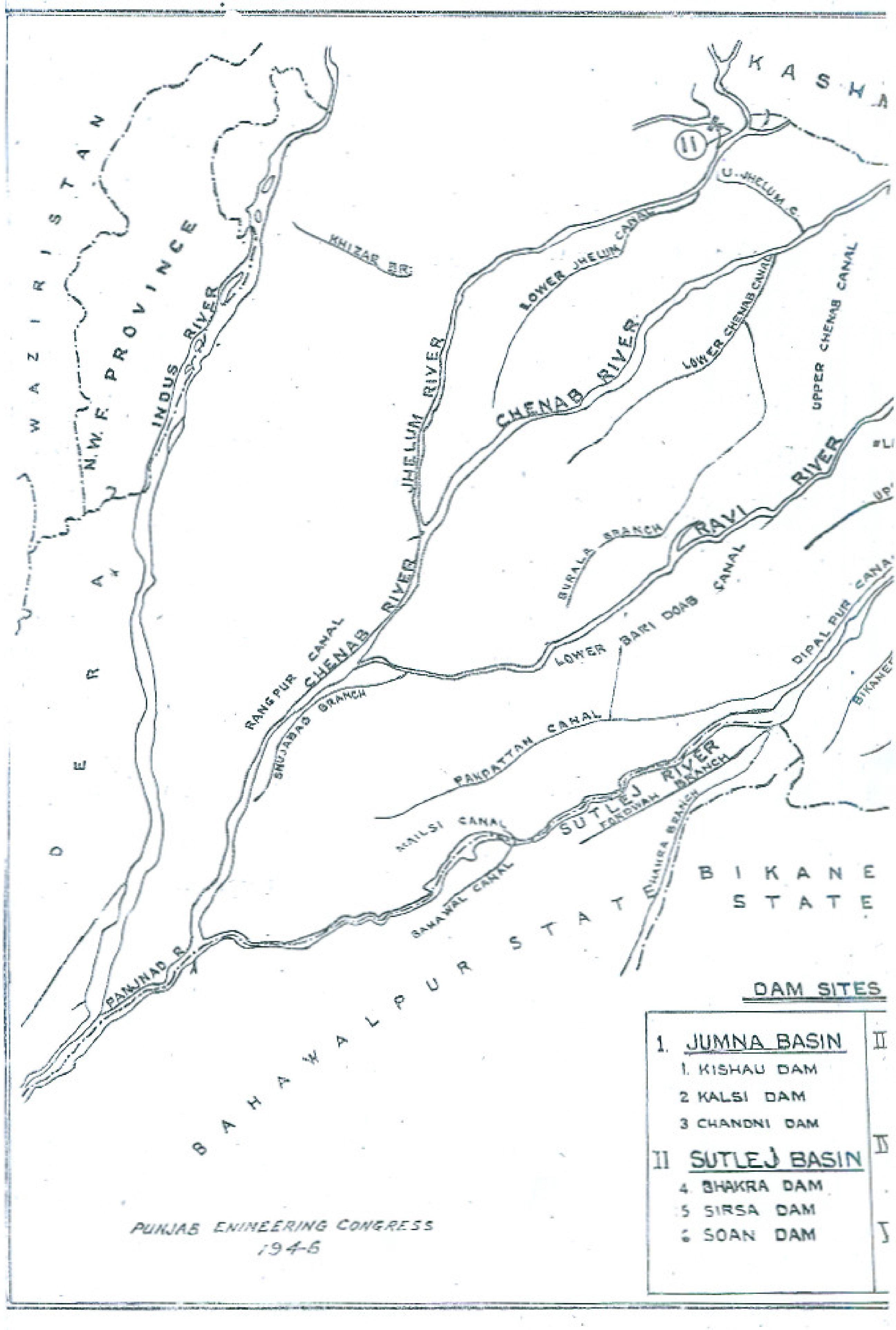
GENERAL NOTES:-
ALL SECTIONS ARE TAKEN ON ℄ OF
CONVEYORS. UPWARD AND DOWNWARD
SLOPE OF AGGREGATE CONVEYORS SHOULD
NOT EXCEED [illegible] IN 12".
UPWARD SLOPE OF CONVEYORS CARRYING
CONCRETE SHOULD NOT EXCEED [illegible] IN 12
AND DOWNWARD SLOPE [illegible] IN 12"
MAXIMUM GRADE FOR ROADS, [illegible]

PLATE V
PAPER 276.



MAP OF THE PUNJAB
SHOWING DAM SITES

SCALE 1·014 INCHES=32 MILES.



PUNJAB ENINEERING CONGRESS
1946

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Rio Grande
Colorado River
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$100,000,000 ANNUAL YIELD OF CROPS
$200,000,000 MARKET FOR INDUSTRY

3,000,000 IRRIGABLE ACRES
50,000 IRRIGATED FARMS
250 CITIES AND TOWNS
20,000 MILES OF CANALS
2,000,000 IRRIGATION STRUCTURES
23 POWER PLANTS.

CONSERVATION OF 60 MILLION ACRE-FEET
(20,000 BILLION GALLONS)
OF THE ARID WEST'S VALUABLE WATER FOR
IRRIGATION, FLOOD CONTROL, POWER, RECREATION

FEDERAL RECLAMATION PROJECTS

CONSTRUCTED BY BUREAU OF RECLAMATION

IN. U.S.A

Scale of Miles.

50 0 50 100 150

PUNJAB ENGINEERING CONGRESS 1946.

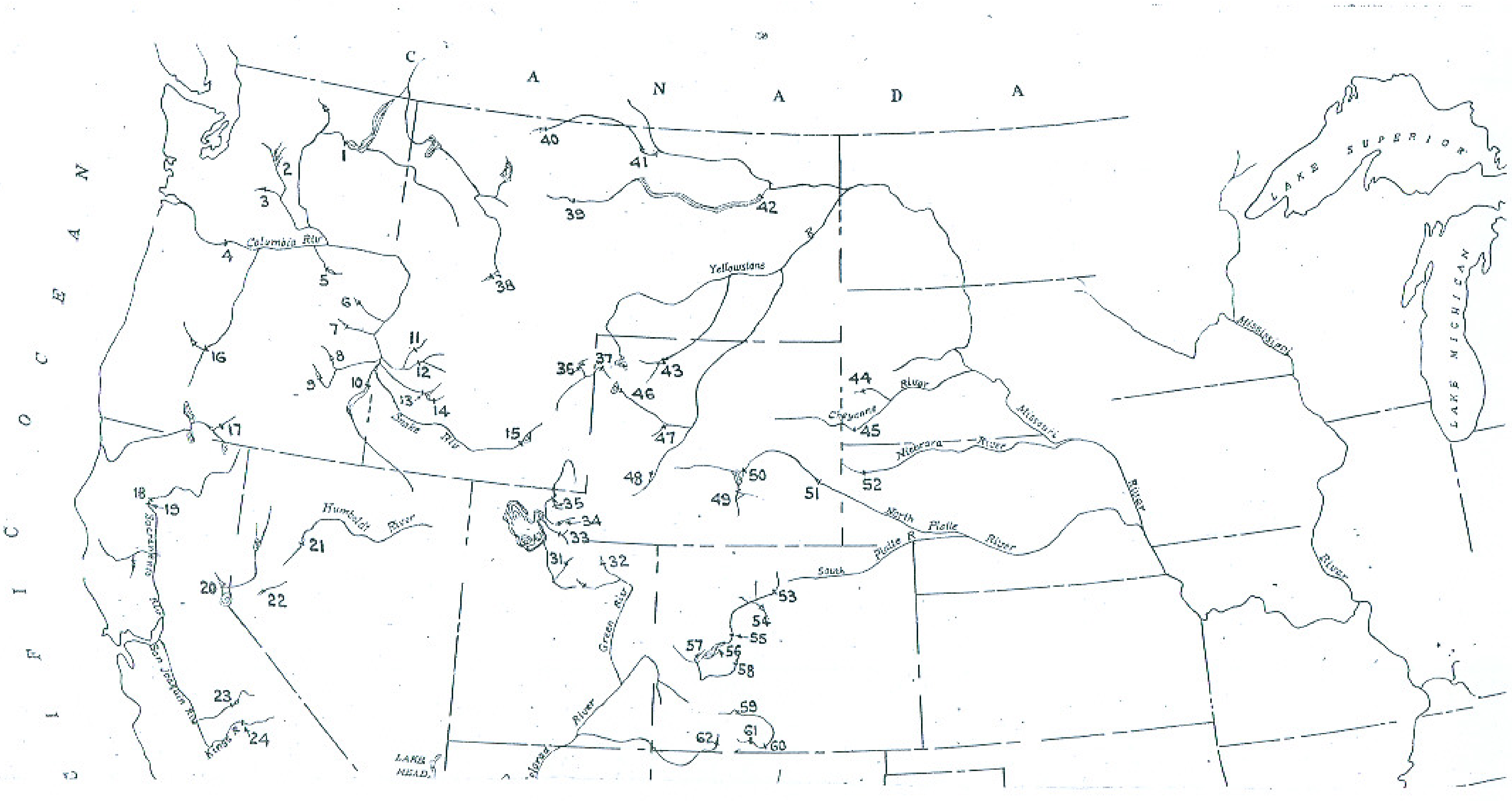
CIFIC OCEAN
CANADA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE MEAD
Columbia Riv
Snake Riv
Yellowstone R
Cheyenne River
Niobrara River
Missouri River
Mississippi
River
North Platte River
South Platte R
Humboldt River
Sacramento
San Joaquin Riv
Kings R
Green River
olorad River
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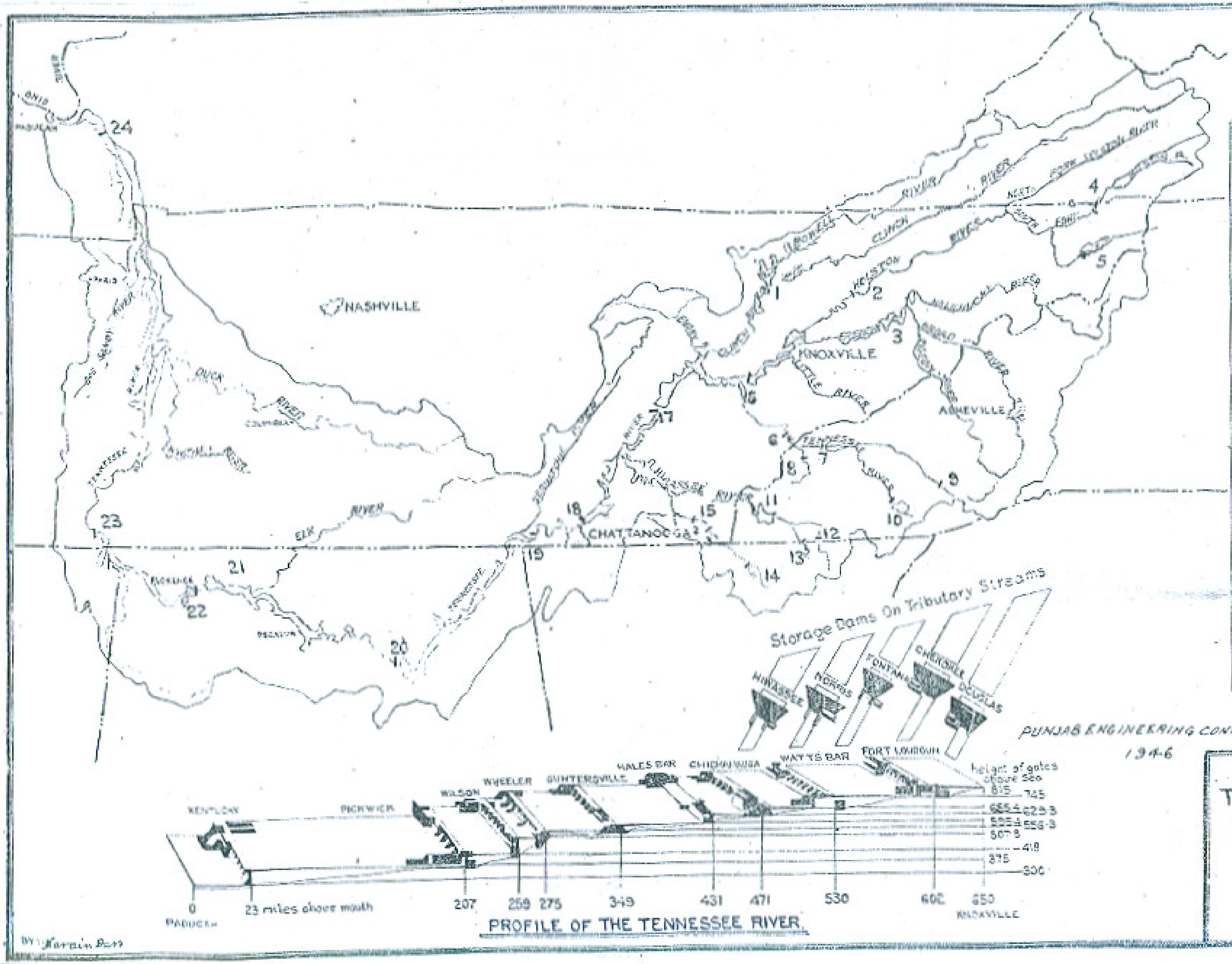
PLATE No. VI
PAPER No. 276.

1	GRAND COULEE DAM	27	DAVIS DAM	53	RANBY DAM
2	CLE ELUM RES.	28	BOULDER DAM	54	GREEN MTN DAM
3	TIETON RES.	29	BARTLETT DAM	55	SPRING CREEK DAM
4	BONNEVILLE DAM	30	ROOSEVELT RES.	56	BEAVER DAM
5	MC KAY RES.	31	DEER CR RES.	57	FRUIT GROWERS DAM
6	THIEF VALLEY RES	32	MOON LAKE RES.	58	TAYLOR PK RES.
7	UNITY RES	33	ECHO RES.	59	WAGON WHEEL GAP DAM
8	AGENCY VALLEY RES.	34	PINE VIEW RES.	60	MOGOTE DAM
9	WARM SPRINGS RES.	35	HYRUM RES.	61	PLATORA DAM
10	OWYHEE RES.	36	ISLANDPK DAM	62	VALLECITO DAM
11	CASCADE DAM	37	GRASSY LAKE DAM	63	CONCHAS DAM
12	DEADWOOD RES.	38	LAKE COMO RES.	64	ALAMOGORDO RES.
13	ARROWROCK RES.	39	GIBSON RES.	65	MC MILLAN RES.
14	ANDERSON RANCH DAM	40	SHERBURNE LAKE RES	66	AVALON RES.
15	AMERICAN FALLS RES.	41	FRESNO RES.	67	ELEPHANT BUTTE RES.
16	WICKIUP DAM	42	FT. PECK DAM	68	CABALLO RES.
17	GERBER DAM	43	SHOSHONE RES.	69	ALTUS RES.
18	SHASTA DAM	44	DEERFIELD DAM	70	MARSHALL FORD DAM
19	KESWICK DAM	45	RED CANYON DAM		
20	BOCA DAM	46	JACKSON LAKE DAM		
21	RYE PATCH DAM	47	BULLLAKE DAM		
22	LAHONTAN RES.	48	BIG SANDY DAM		
23	FRIANT DAM	49	SEMINOE RES.		
24	PINE FLAT DAM	50	PATHFINDER RES.		
25	IMPERIAL DAM	51	GUERNSEY RES.		
26	PARKER DAM	52	BUX BUTTE DAM		

PLATE VII
PAPER 276



1. NORRIS DAM
2. CHEROKEE DAM
3. DOUGLAS DAM
4. SO. HOLSTON DAM
5. WATAUGA DAM
6. CALDERWOOD DAM
7. CHEOAH DAM
8. SANTEENTLAH DAM
9. GLENVILLE DAM
10. NANTAHALA DAM
11. HIWASSEE DAM
12. CHATUGE DAM
13. NOTTELY DAM
14. BLUE RIDGE DAM
15. OCOEES DAM
16. COULTER SHOAL DAM
17. WATTS BAR DAM
18. CHICKAMAUGA DAM
19. HALES BAR DAM
20. GUNTERSVILLE DAM
21. WHEELER DAM
22. WILSON DAM
23. PICKWICK LANDING DAM
24. GILBERTSVILLE DAM

PUNJAB ENGINEERING CONGRESS
1946

MAP OF THE
TENNESSEE VALLEY
SHOWING DAM SITES

SCALE OF MILES