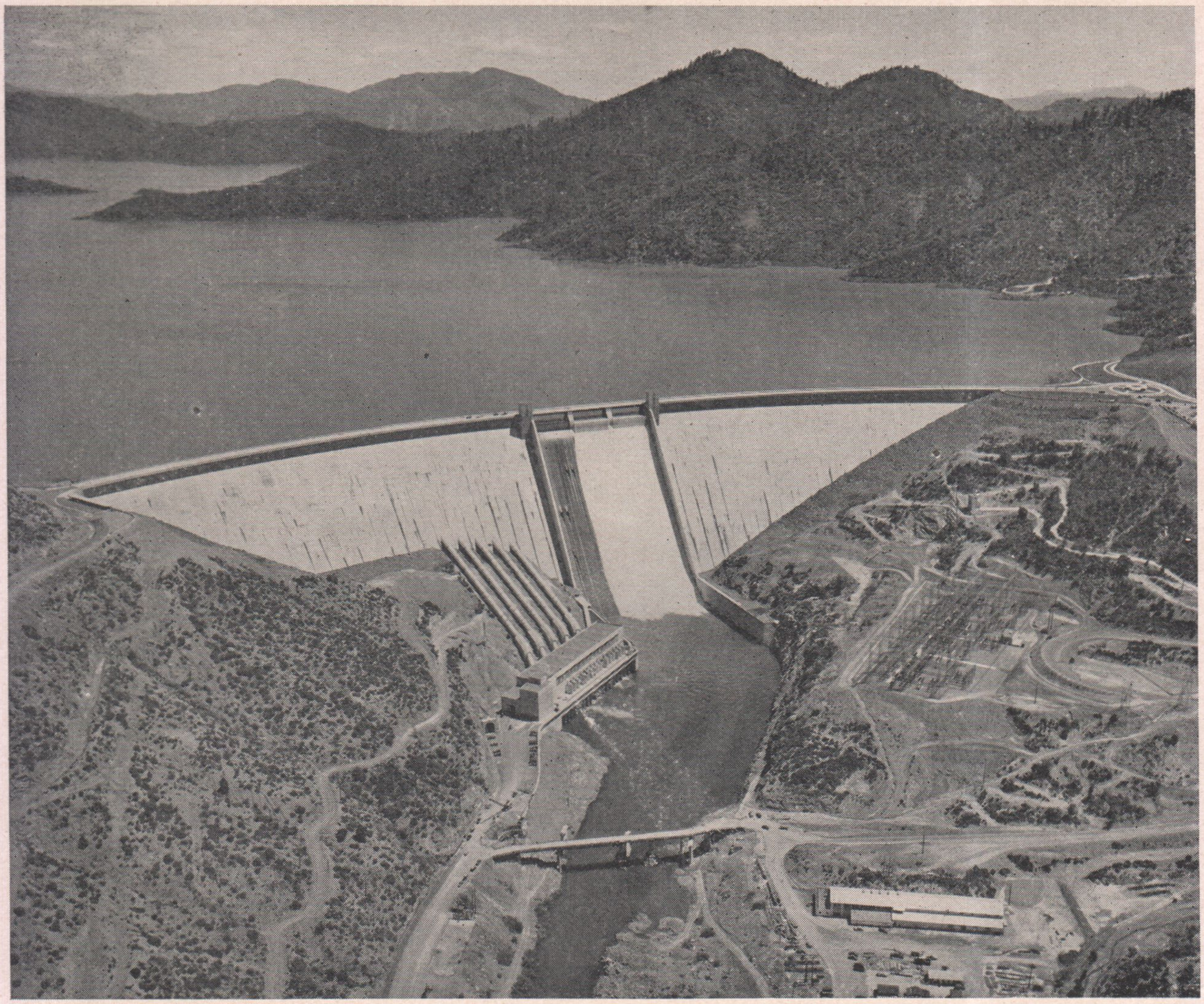

Fig. 1. Shasta Dam, the second highest in the world, and power station

The Central Valley Project—I

Stephen H. Poe, of the United States Bureau of Reclamation, gives an outline of this huge multiple-purpose project. The Central Valley embraces 18,000 square miles of the State of California and is nearly 500 miles long. The engineering works include the second highest dam (Shasta) and the second largest pumping plant (Tracy) in the world, one of the world's largest dams at Friant, and two immense canals (Delta-Mendota and Friant-Kern). A summary is given of work now in progress

IN August 1951, the first integrated operation of the Central Valley Project in California was begun, bringing to a climax 14 years of construction on the project by the United States Bureau of Reclamation. The event was of great significance because it marked the beginning of the unification of the water resources of the valley and the opening of a new era in the development of the rich Central Valley agricultural empire, bringing a new wealth to the district.

From an engineering standpoint, the Central Valley Project exemplifies the Bureau of Reclamation's progress in the design and construction of huge multiple-purpose developments. Features of the project are Shasta dam, world's second highest; Friant dam, one of the world's largest concrete barriers; Tracy pumping plant, second largest in the world; and the huge man-

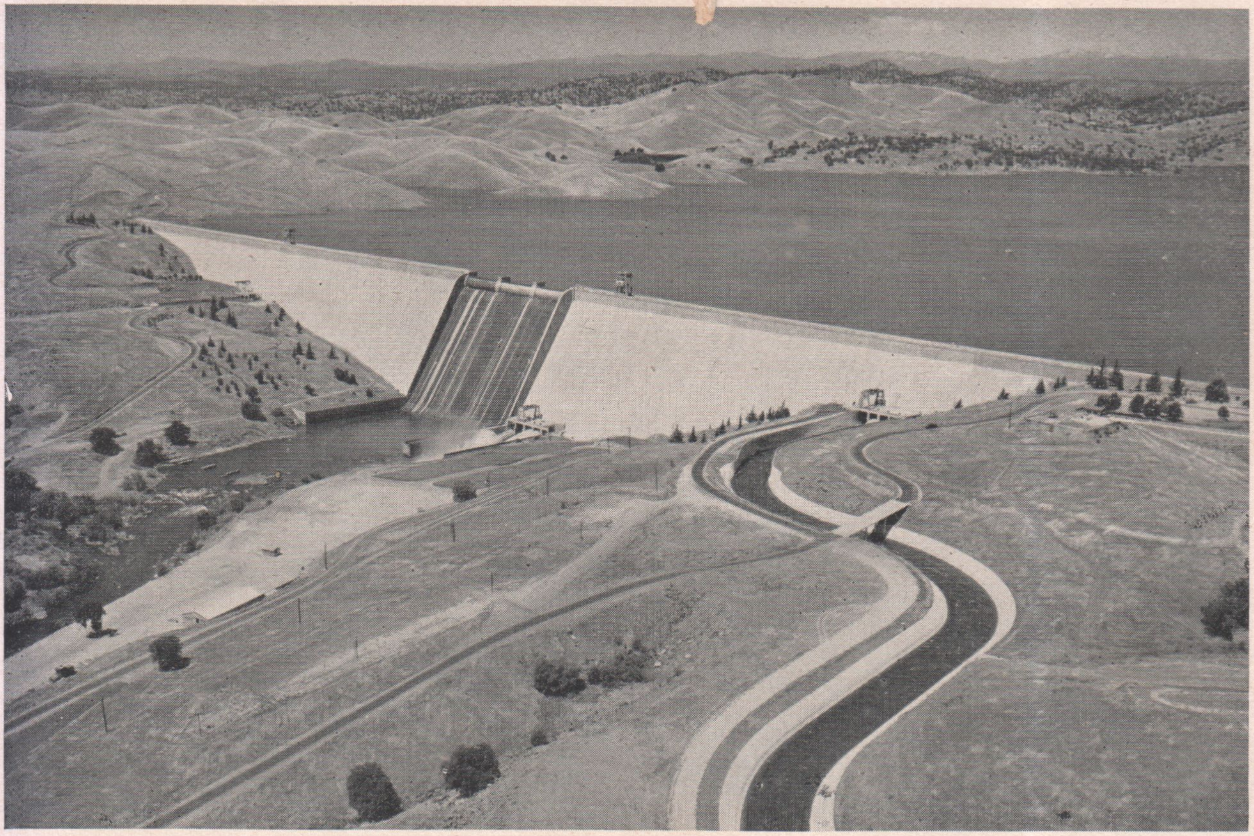

Fig. 2. Friant Dam, showing the commencement of the Friant-Kern canal on the right

made rivers, the Delta-Mendota and Friant-Kern canals. These and the assemblage of associated dams, canals, pumping plants, power plants, transmission lines, and irrigation distribution systems are integrated into a unified plan of service to bring new and supplemental water to vast reaches of the far-flung project.

The following series of notes describes the history of the Central Valley development, purpose of the project, and the project's major features.

History and Purpose of the Project

Interest in the water problems of the Central Valley began with the earliest history of California as a state, when in 1850 the first legislature passed a law requiring the preparation of plans for improving navigation, providing drainage, and furnishing irrigation water. During the succeeding 70 years many irrigation, flood-control, and hydro-electric projects were constructed. In 1919, the Chief Hydrographer of the United States Geological Survey submitted to the Governor of California a plan for the co-ordinated development of the water resources of the Central Valley. This created state-wide interest, and in 1921 the state legislature made the first of a series of appropriations for investigations of plans for the conservation, control, storage, distribution, and application of all the waters of the state. Intensive investigations by the state continued for 10 years until 1931 when the Division of Water Resources submitted to the legislature the State Water Plan, a comprehensive plan for utilising the water resources of the Central Valley.

In the meantime, serious water problems were developing particularly in the upper San Joaquin Valley, where the overdraft on ground water caused a continued lowering of the water table, and in the Sacramento—San Joaquin Delta where the encroachment of saline water endangered the industrial and agricultural development of the Delta region. In 1933, the state legislature approved the Central Valley Project Act which provided for the construction, operation, and maintenance of a system of works designated as the Central Valley Project, comprising essentially Shasta dam and reservoir, Contra-Costa canal, Delta cross channel, Delta-Mendota canal, Friant dam and reservoir, Madera canal, Friant-Kern canal, facilities for generation and transmission of electric energy, and such other units as may be added from time to time. This Act was also approved by a referendum of the people in 1933.

Efforts toward obtaining financial assistance on the initial units of the Central Valley Project, begun as early as 1929, were continued until 1935 when the project was authorised as an undertaking of the United States Bureau of Reclamation. Construction on the project began in 1937.

The Central Valley Project serves a large part of the central section of the State of California. The Central Valley itself, embracing 18,000 square miles, is nearly 500 miles long, extending from the foot of mount Shasta to the Tehachapi range, about 50 miles wide between the foothills of the Sierra Nevada and the coast range and varies in elevation from sea level to 400 ft. It is a huge platter-like valley, its high rim broken only at San Francisco bay through which its two principal rivers, the Sacramento and the San Joaquin, after joining in a common delta, flow out to the Pacific Ocean.

The Sacramento river has its source near mount

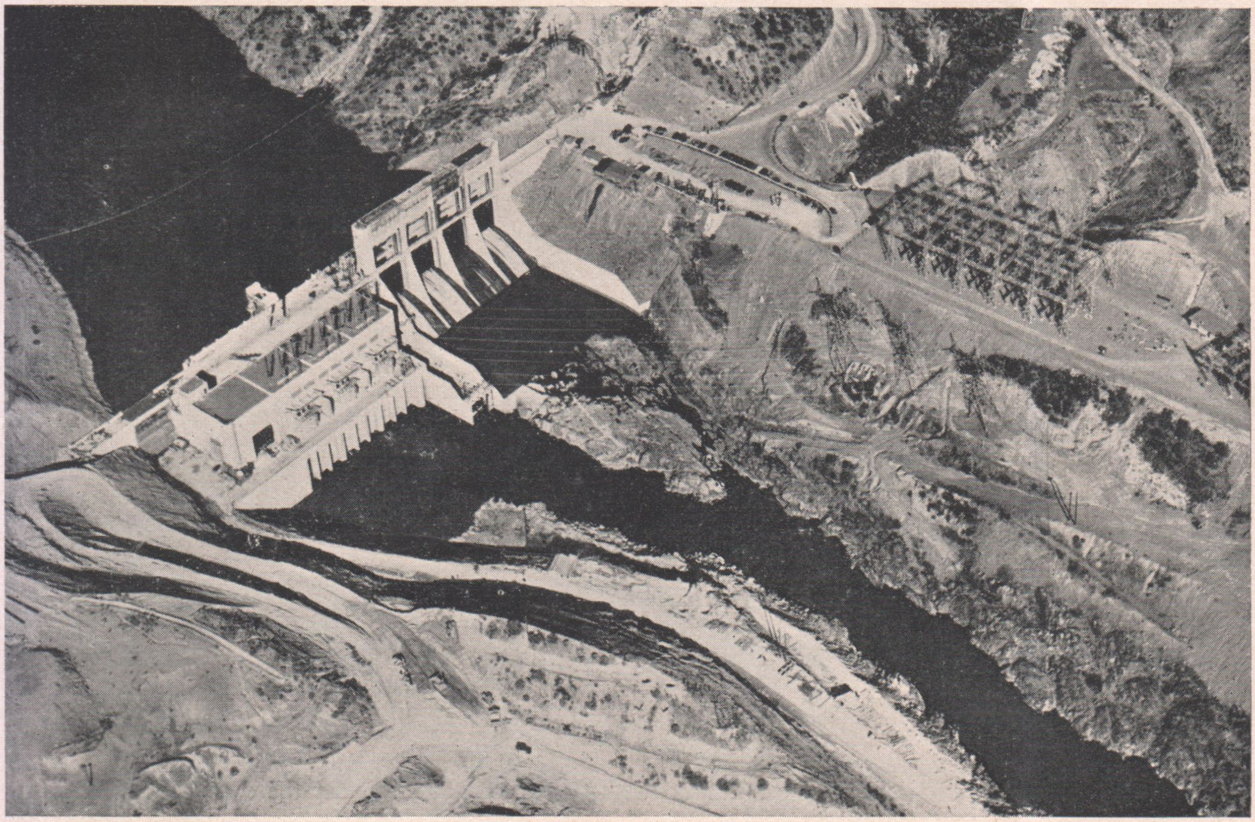

Fig. 3. Keswick Dam and power station, nine miles downstream from Shasta

Shasta at the northern end of the basin and flows southerly through the entire length of the Sacramento Valley. The San Joaquin river drains the northern half of the San Joaquin Valley. The river rises at the crest of the Sierra Nevada north-east of Fresno, flows down the western slope until it reaches the main valley, then turns north-westerly down the trough of the San Joaquin Valley.

The Central Valley includes 10 million acres of irrigable land surrounded by a mountain watershed of 40,000 square miles. The valley has been endowed with a rich soil and the elements of plant growth and temperature conducive to sub-tropical fruit culture all the year round. It is famous for its raisins, table grapes, and sweet wines. Major crops include peaches, figs, apricots, nuts, plums, olives, oranges, melons, alfalfa, cotton, grain, asparagus and potatoes.

The water problem of the Central Valley is mainly one of conservation. There is abundant water, but the agricultural development in the San Joaquin Valley in the last quarter century has far outstripped the natural limitations of the unregulated water supply; the water resources are out of balance with the irrigable land. Geographically, the Sacramento Valley in the north has tributary watersheds producing two-thirds of the water and has agricultural land with only one-third of the irrigation need, whereas the San Joaquin Valley in the south has one-third of the water and crop lands with two-thirds of the need. Seasonally, there are periodic floods and droughts—almost all the rain and snow falls in the few months of winter and early spring and two-thirds of the combined waters of the two rivers escape to the ocean during the non-irrigation season, leaving a shortage in the late summer and fall when water is most needed.

The Central Valley Project effects both the geographical and the seasonal redistribution of the water of this great valley to correct a series of maldistribution problems. By the conservation and regulation of the water resources of the valley about 1,000,000 acres of highly cultivated agricultural land is to be furnished with a supplemental supply of water; navigation is improved; salt-water intrusion in the Delta area is repelled; water is provided for domestic and industrial uses; fish and wildlife are conserved; recreational facilities are provided; and electric power is generated.

Shasta Dam and Power Plant

Shasta dam, the project's largest structure, is located on the Sacramento river 12 miles north of Redding, California, and five miles below what was formerly the confluence of the Pit and Sacramento rivers. Shasta dam now stores the spring run-off of the Sacramento river, releasing it as needed throughout the year for irrigation in the Sacramento Valley and for transfer as supplemental water to the San Joaquin Valley. In addition, Shasta dam develops power for use in the comprehensive Central Valley Project scheme.

Shasta dam is the third largest concrete dam in the world. The dam is a curved gravity structure 602 ft. from the lowest foundation to the crest and 3,500 ft. long at the crest.

In designing the dam its height was fixed within fairly close limits by the storage requirements of the project as a whole which established a gross reservoir storage capacity of $4\frac{1}{2}$ million acre-feet on the Sacramento river. Of this capacity, the top 500,000 acre-feet is used primarily for flood control, and a dead storage volume of 500,000 acre-feet is maintained to provide a minimum power head of 238 ft. At the left end of the dam, weathering affected the competency of the rock to great depth. To obviate removal of great quantities of material unsuited for foundation of a concrete dam, an earth- and rock-fill dam, 525 ft. long and 115 ft. high, was constructed in this area.

Shasta spillway, 375 ft. long, was designed for a maximum capacity of 185,000 cusecs at the full water reservoir surface elevation. Under maximum discharge conditions, the water drops 480 ft. on the downstream face of the dam, creating a dynamic energy of 7,200,000 h.p. A sloping apron at the base of the spillway provides for dissipation of this excessive energy.

The flow over the crest of the spillway and the water surface elevation of the reservoir above the elevation of the spillway crest are controlled by three floating-type drum gates. These gates are each 110 ft. long and have an effective operating height of 28 ft. They are automatically operated so that the discharge can be controlled closely within given limits.

When outflow from the reservoir is required in amounts greater than the discharge from the power-house turbines, the excess is discharged by the outlets, 18 conduits arranged in three tiers. All are 102 in. diameter welded steel pipe passing horizontally through the dam. Within a very few feet of the downstream face they turn downward abruptly until nearly parallel with the face so that the issuing jet will merge with minimum interference with the overflowing sheets from the spillway when it is in operation. The total combined capacity of the conduits is 65,000 cusecs.

Construction on Shasta dam began in September 1938. By the end of 1939, the greater part of the excavation had been completed. During the first 10 months of excavation, material was removed from the foundation of the dam at the average rate of nearly 230,000 cubic yards per month; the record month was 476,000 cubic yards. The first concrete was placed in the dam on July 8, 1940, and the first diversion of the river took place in August 1940.

By the end of 1940, 4,150,000 cubic yards of material had been excavated for the dam in the power plant, and 500,000 cubic yards of concrete had been placed. Concreting proceeded at an average rate of around 2,000,000 cubic yards a year until the six-millionth yard of concrete had been placed in December 1943. The last bucket of concrete was placed on the spillway bridge of the dam in December 1944, marking the production and placement of 6,535,000 cubic yards of concrete in the dam and appurtenant works.

The last of the work required under the major contracts for construction of Shasta dam was completed on June 20, 1945, on which date the United States accepted the Shasta dam and power plant. At the beginning of 1944, there was storage of only 18,000 acre-feet at Shasta reservoir. One year later, the reservoir contained a million and a half acre-feet. By December 1945, the storage elevation had increased to three and a quarter million acre-feet. The total capacity of Shasta reservoir is 4,493,000 acre-feet.

Shasta power plant, on the right bank of the river downstream of the dam, is a huge structure, although dwarfed by the immensity of the dam. In the power-house are five 103,000 h.p. turbines driving five 35,000 kVA generators, and two 4,250 h.p. turbines driving two 3,000 kW station-service generators. Five 15 ft. inside-diameter welded steel penstocks pass through the dam and convey water from the reservoir to the power plant. Water for each of the two station-service units is tapped from two of the main penstocks. The first power from the power plant was placed on the line on July 14, 1944. The last generator was placed in service on April 27, 1949.

Cooling pipes were installed throughout Shasta dam on top of each 5 ft. lift of concrete as it was placed, and at an average horizontal spacing of $5\frac{1}{2}$ ft. to provide a means of minimising the temperature rise associated with the heat of hydration of the cement in the concrete. River water for preliminary cooling was circulated through the pipes from pipe headers located on the downstream side of the dam or in galleries in the spillway section. Final cooling to specified temperatures was by water refrigerated in a special plant on the left abutment.

To control the development of cracks that would normally be associated with such temperature changes, a system of contraction joints at approximately 50 ft. intervals both parallel and perpendicular to the axis of the dam was incorporated in the dam. Thus, the dam was broken into a staggered series of columns roughly 50 ft. square. A system of piping and grout outlets was provided, and after completion of cooling and attainment of final volume of the dam, the contraction joints were filled with cement grout.

Grout pumped into a series of vertical holes drilled into the foundation near the upstream face of the dam forms a continuous curtain or barrier against the infiltration of water under the dam. Development of pressure from any slow seepage of water is inhibited by a system of vertical relief drains immediately downstream from the grout curtain. Another system of 5 in. porous-tile drains of the concrete near the upstream face of the dam serves to prevent the development of internal water pressure in the mass of concrete itself.

A feature of the construction of Shasta dam was the immense cableway head tower projecting 466 ft. above ground and anchored over 100 ft. deep into the rock of a small promontory immediately upstream from the dam on the right abutment. This single-cantilever structure was designed to take the surging loads from seven cableways radiating outward from the top of the tower. All cableways had movable tail towers, three of them being as much as half a mile away from the head tower. The carriages for all cableways ran on a 3 in. cable weighing about 22 lb. per running foot. This cable way system handled over 19,000,000 tons of material during the construction of the dam.

During the construction of Shasta dam, instruments were embedded and observational points were established from which to obtain data and measurements for checking the assumptions used in the design of the dam and also to record its structural behaviour. A seismograph station was set up about three miles from the dam to record normal seismic behaviour of the region and to detect any additional seismic activity due to the increased load upon the earth caused by the reservoir. (The weight of the reservoir is about $6\frac{1}{4}$ billion tons.)

Friant Dam

Friant dam is located on the upper San Joaquin river about 20 miles north of Fresno and 21 miles east of Madera, California. The dam is a straight gravity-type structure, 319 ft. high and 3,488 ft. long at the crest and contains 2,135,000 cubic yards of concrete. The dam serves the dual purpose of storage for irrigation

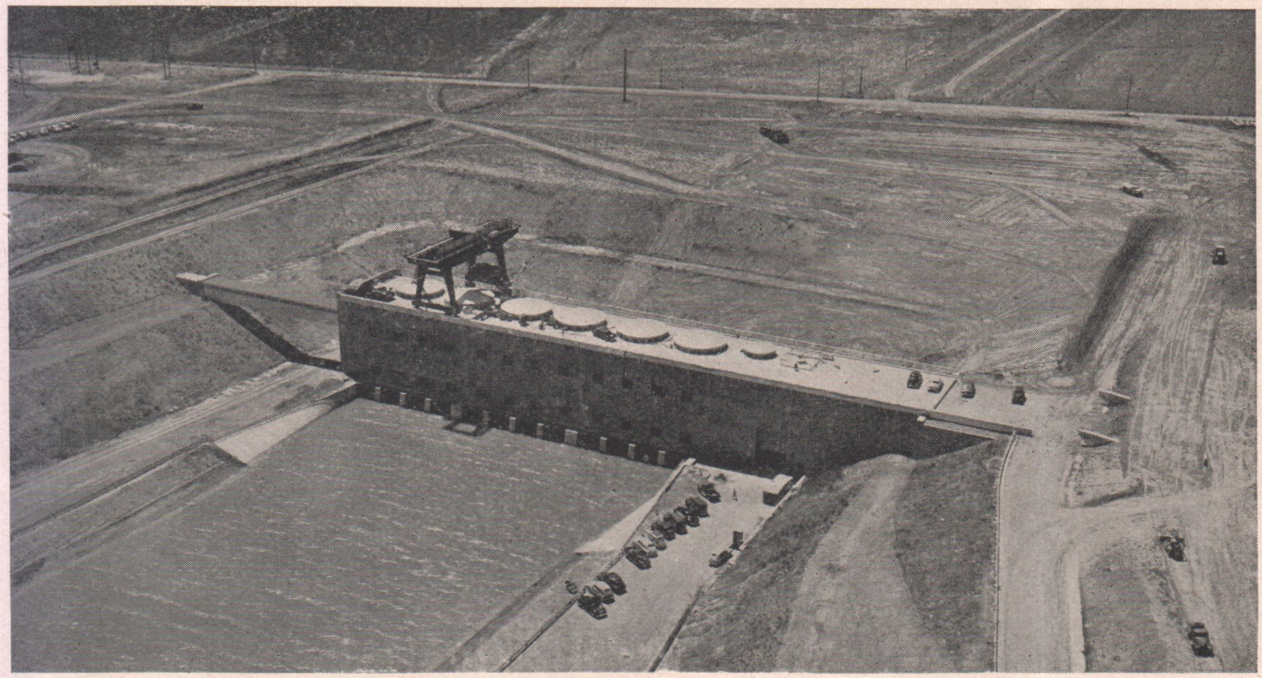

Fig. 4. Tracy pumping plant — the second largest in the world

and flood control. Water stored by the dam is distributed by a gravity system through two main arteries, Friant-Kern and Madera canals.

Millerton lake, the reservoir impounded by Friant dam, is 15 miles long and has a gross storage capacity of 521,000 acre-feet. The live storage above the canal headworks, exclusive of that reserved for flood control, is 360,000 acre-feet. The top 70,000 acre-feet in the reservoir is reserved for flood control. Actually the entire live-storage capacity of 430,000 acre-feet in conjunction with the canal diversion operates effectively for flood-control purposes. The dead storage of approximately 90,000 acre-feet forms a permanent lake about 10 miles long, providing excellent possibilities for boating, fishing, and other recreational uses.

Three 100 by 18 ft. drum gates control the overflow spillway which provides for a capacity of 92,000 cusecs. Four 110 in. conduit outlets located just adjacent to the spillway section are controlled by two 105 in. needle valves and two 102 in. tube valves hydraulically operated. In addition to these outlets, there are four 96 in. and two 78 in. valve-controlled outlets for the Friant-Kern and Madera canals. These outlets discharge into stilling basins and have a combined maximum capacity of 16,000 second-feet. On the upstream face of the dam, steel coaster gates operated by a travelling gantry crane on top of the structure provide for emergency closing of the canal outlets.

The contract for construction of Friant dam was awarded on October 9, 1939, and work at the site was begun by the contractor on November 3, 1939. The first bucket of concrete was placed in the dam on July 29, 1940; the millionth cubic yard was placed on May 31, 1941. The maximum concrete yardage placed in any one day amounted to 9,000 cubic yards and the maximum monthly total occurred in August 1941, when 228,000 cubic yards were placed. Friant dam was essentially completed on February 12, 1943. Further construction of the dam was halted by World War II. Installation of the drum gates and control equipment was completed in October 1947.

Most of the mass concrete in the dam and appurtenant structures was placed from a steel trestle, 2,200 ft. long, parallel to and 129 ft. downstream from the axis of the dam. From this trestle two hammerhead cranes and two whirley cranes placed the concrete. The trestle was embedded in the concrete as the structure rose.

Transverse contraction joints divide the dam into blocks 50 ft. wide in the abutment section and 56 ft. wide in the centre or storage section. As longitudinal joints were not provided, the individual blocks varied in length from about 30 ft. at the extreme abutment to a maximum of 270 ft. in the central section.

An interesting feature of Friant dam construction was the use of pumicite in the mass concrete for the dam. Specifications called for the substitution of pumicite by weight for 20 per cent. of the specified amount of cement. The large deposit of pumicite, a naturally occurring pozzolan, in the immediate vicinity of the dam site, led to consideration of its use as an ingredient in the concrete. It was found that the addition of an appropriate amount of pumicite made it possible to use mixes leaner than the usual fill of cement per cubic yard. At the same time, this practice was found to effect a considerable reduction in the heat of hydration or setting of the cement and made a more workable mixture and a denser, more nearly watertight concrete.

A supplemental contract permitted the contractor to recover the gold found in the gravel for the Friant dam concrete. Tests were made of several methods of recovering the gold, and it was finally determined that screen-lined chutes would be most efficient. At the end of the first month of construction more than $8,000 worth of gold was obtained.

Keswick Dam

Construction of Keswick dam began in October 1941, and was completed in October 1950, following the end of World War II. The dam, located about 10 miles downstream on the Sacramento river from Shasta dam, is designed to provide an afterbay regulating reservoir for Shasta dam. Keswick re-regulates releases from Shasta reservoir so that peak power production for short periods at the Shasta power plant will not create a hazard or interfere with other uses on lower reaches of the Sacramento river.

Keswick dam is a concrete gravity structure 159 ft. high above foundation, 1,046 ft. long at the crest, and has a volume of 197,000 cubic yards.

Keswick power plant, built as a part of the dam, contains three main generating units, each with a capacity of 25,000 kW driven by 34,600 h.p. hydraulic turbines. The output of these generators augments the power developed at Shasta and feeds directly into the service lines from Shasta's power-house.

The power-house structure measures 270 ft. along the axis of the dam. Water is admitted to each of the three turbines in the structure through three penstock passages, each 12 ft. 6 in. wide, leading to a scroll case formed in the power-house structure.

The spillway at Keswick dam is an ogee section controlled by four regulating gates each 50 by 50 ft. The maximum discharge capacity of the spillway is 250,000 cusecs. The outlet works consist of one outlet pipe 60 in. in diameter for the dam's fishtrap and three unlined penstocks controlled by three fixed-wheel gates each 12 ft. 7 in. by 23 ft. 5 in.

Keswick dam also protects the heavy fish run in the Sacramento river. The central section of the dam was designed as a fishtrap from which the salmon are removed and hauled approximately 40 miles in tank trucks to a hatchery on Battle Creek, a tributary of the Sacramento river. Here the eggs are removed, fertilised, and hatched, and released.

The fishtrap section is adjacent to the spillway and measures 64 ft. axially and 274 ft. along the direction of flow. It contains four holding pools, each 20 by 30 ft. 6 in.

Concrete was placed in Keswick dam in 5 ft. lifts, each surface being thoroughly cleaned by sandblasting before new concrete was applied. The excessive heat of the Sacramento Valley summer, which may reach 120°, brought special problems in the construction of the dam since specifications required that the concrete should be placed at a temperature not exceeding 85°. Spray nozzles discharging river water were used in the aggregate to precool the materials, and placed concrete was sheltered from the direct rays of the sun for three days and kept moist for 14 days while curing. Water from the river, without artificial cooling, was used for this purpose and also for circulation to the cooling pipes embedded in the concrete.

Tracy Pumping Plant

Tracy pumping plant is a major unit of the Central Valley Project. The plant has been referred to as the "heartbeat" of the project because it is the prime mover in the transfer of surplus water from the Sacramento river to the San Joaquin Valley. The plant discharges a maximum of 4,600 cusecs from an average elevation of 4 ft. above sea level to an average elevation of 201 ft. above sea level. The installation consists of six vertical pumping units each rated at 767 cusecs at a head of 197 ft. The Tracy pumping plant is the second largest pumping installation on any Bureau of Reclamation project, exceeded in size only by the Grand Coulee pumping plant of the Bureau's Columbia Basin project in the State of Washington.

The pumping plant, located about 10 miles east of Tracy, California, was constructed on the Delta-Mendota canal, approximately 13,400 ft. above its intake on the Old River—the old course of the San Joaquin river. Each pump discharges through a 108 in. diameter butterfly valve into a 10 ft. diameter steel discharge pipe. These pipes are paired into three 15 ft. diameter discharge pipes approximately one mile long. They discharge through a syphon structure into the Delta-Mendota canal.

It is anticipated that when the irrigation facilities are fully developed for the Central Valley Project and in operation, the maximum demand for water will occur in July and will be approximately 4,250 cusecs. Minimum demand is expected to occur in December and to be about 500 cusecs; the yearly average demand is estimated at about 2,060 cusecs. To meet this varying demand, it is expected that all six pumps will be operated in July and part of August.

The overall length of the plant is 362 ft. and its overall width is 96 ft. It is a reinforced-concrete structure of the semi-outdoor type. The plant is divided roughly into two parts, one consisting of a six-main pump bay having a length of 243 ft. and a service bay having a length of 119 ft. The roof deck supports a 100 ton gantry crane for lifting the plant's equipment.

The plant is supported on timber piles. The foundation is at an elevation of approximately 30 ft. below sea level. The centre line of the scroll-case of the pumps and of the butterfly valves in the discharge lines is at elevation 0 (sea level).

The Tracy pumps are of the vertical-shaft single-impeller single-suction centrifugal type. They are designated as 84 in. vertical volute pumps of the closed-type impeller design. The pumps are designed to have stable operation under all heads within a range of 174 ft. to 204 ft., the maximum input to the pumps not to exceed 22,500 h.p. over the entire operating range.

Each of the six main motors in the plant is rated at 22,500 h.p., 13,600 V, 0·95 leading power factor, three phase, 60 cycle, 180 r.p.m. The motors are of the synchronous vertical-shaft type with the thrust bearing and upper guide bearing located above the rotor and a lower guide bearing below the rotor. The motors are totally enclosed and are air cooled with forced surface-type coolers symmetrically spaced around the stator frame.

Power for the operation of the pump motors is supplied from the Tracy switchyard adjacent to the pumping plant, through circuit breakers connected to a 13·8 kV bus. Located in the switchyard and connected to the same bus is a 50,000 kVA synchronous condenser.

Construction of the Tracy pumping plant began in August 1947, and was completed in December 1949. Under a separate contract installation of the motors and pumps and electrical and mechanical equipment was started in September 1949 and completed in April 1951. Construction of Tracy switchyard was started in December 1949, and was completed in November 1951.

(To be continued)

Resistance Wires and Tapes. A booklet received from the Vactite Wire Co. Ltd., lists the various products they manufacture, giving dimensions, physical characteristics and spheres of application with a view to assisting the designer of apparatus in his work.