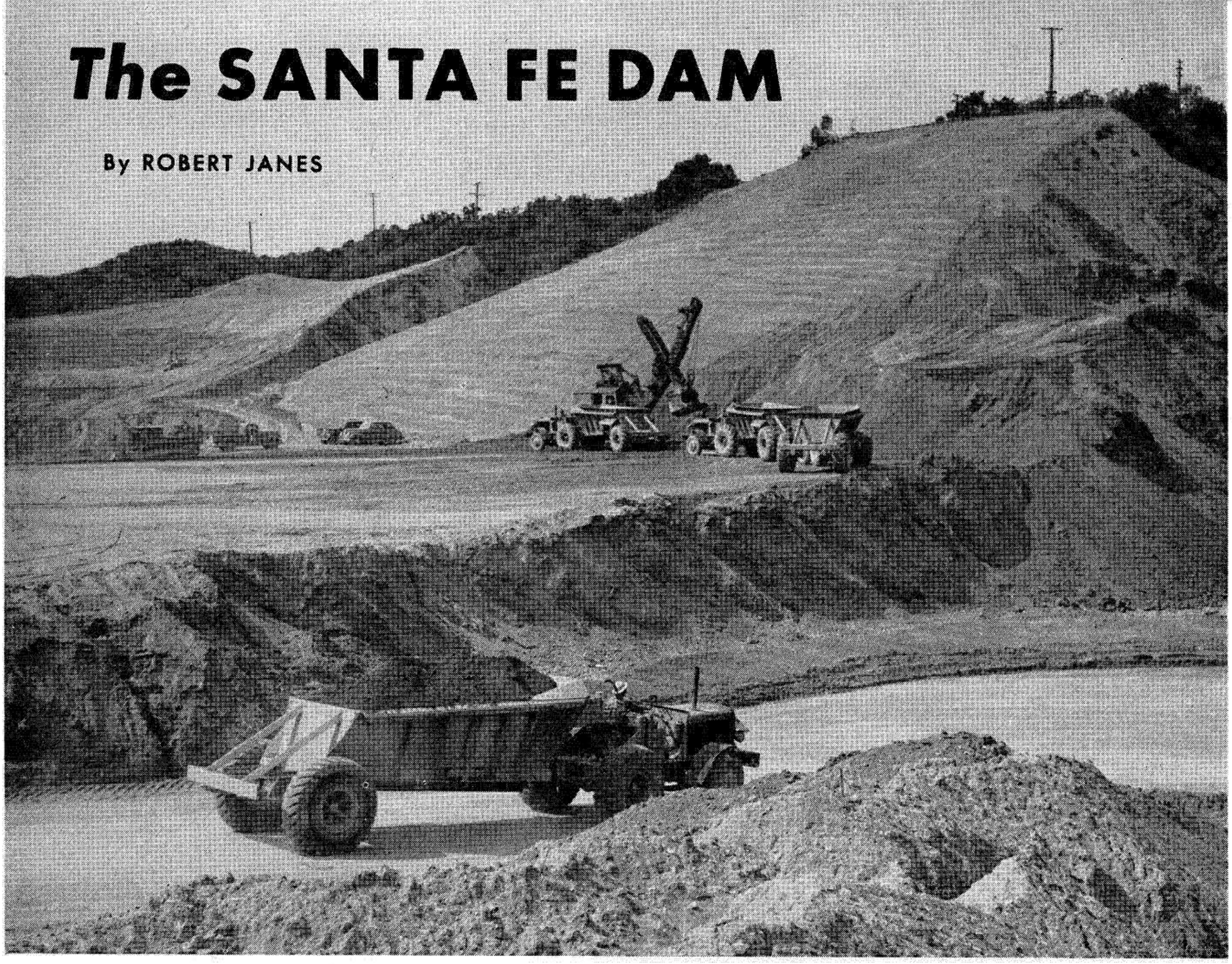
The SANTA FE DAM

By ROBERT JANES



Clay borrow pit four miles north of the Santa Fe Dam.

HUGE dams in the past eight or 10 years have become familiar sights to millions of people in the United States. Notable among those constructed in the last decade are Boulder Dam in Nevada, Norris Dam in the Tennessee Valley system, Dennison Dam in Texas, Fort Peck in Montana, Bonneville in Oregon, Grand Coulee in Washington, and Shasta in California. The more spectacular among these dams have been constructed of mass concrete, so that we are accustomed to think of this type of dam as being the most modern, the ultimate—till now at least—in dam design. Progress in design and construction methods, however, has not been confined to dams made of concrete. It has, in fact, been particularly noteworthy in the field of earth dams, which, because of greatly improved compaction equipment and soil analysis, could now replace many a dam constructed earlier from more costly materials.

Santa Fe Dam is an earth-fill dam. Located on the San Gabriel River just below the mouth of the canyon east of Pasadena, it forms a horseshoe four and one-half miles in length around the many branches of the San Gabriel, which at this point meanders over a thick blanket of alluvium brought down during the centuries. Since it is without the benefit of supporting canyon walls, it is necessarily three sided—open only at the upper end to allow the water to enter. Fifteen million yards of earth, three times the volume in Boulder Dam, was excavated to make this gigantic barrier, yet its maximum height of 92 feet appears insignificant alongside Boulder's 752 feet.

In cross-section the dam consists of five zones. Zone I is composed of approximately 1,000,000 yards of impervious clay-sand material, imported from a borrow pit north of the dam, necessitating an average haul of four miles. This core is keyed into the native alluvial deposit by excavating the latter to a depth of 10 to 15 feet, and then backfilling the resultant trench with the clay. The clay core has a maximum width of 40 feet at the base, narrowing to 10 feet at the top. Due to the difficulty of securing sufficient excavating equipment, most of the material for the core was excavated in a rather novel fashion. As the borrow pit was in a foothill location with fairly steep slopes, advantage was taken of the difference in elevation by constructing a timber loading trap, or tunnel, through which trucks to be loaded could pass. In the roof of the structure were gated openings, air operated. With the gates closed, material was dozed into position above the gates by bull-dozers and carryalls. Upon arrival of a truck, the gates were opened, allowing this material to drop into the truck. Since the material was always pushed downgrade, the task was simple for this type of equipment. Besides eliminating the necessity of maintaining a shovel at the location, which, because of the nature of the operation, was limited to a one-shift basis, this system allowed each truck to be loaded in a very few seconds instead of the two minutes or more required for a shovel to load the same truck.

The trucks used on the operation were of the bottom-dump type, carrying an average of 15 cubic yards, or 26 tons of earth. Upon arrival at the dam embankment, the material was dumped in Zone I in a long windrow while the truck was in motion, the length of the windrow being predetermined to give the correct depth of material when spread out by the grader, which followed the dumping operation and spread the material in a uniformly thick blanket of six inches. Then followed the compacting operation upon which the imperviousness of the dam depends. Spreading was followed by thorough harrowing of the earth, removal of any rocks larger than four inches, and watering. Harrowing and watering processes were repeated until it was determined that the optimum moisture content (that percentage of moisture at which maximum compaction could be obtained) was reached. This was followed by eight passes of the sheepsfoot roller, at which time full compaction was obtained. Daily tests of compacted material showed an average density of 144 pounds per cubic foot. When this figure is compared with the 150 pounds per cubic foot usually associated with reinforced concrete, or more aptly with the 140 pounds per cubic foot accepted for unreinforced concrete, the excellence of this method of compaction is clearly evident.

On either side of Zone I was placed a narrow layer of transition material, forming Zone II, and composed of about 30 per cent clay and 70 per cent pervious material. The purpose of this zone was to eliminate planes of sudden changes from pervious to impervious material which would tend to become seepage channels over a period of time.

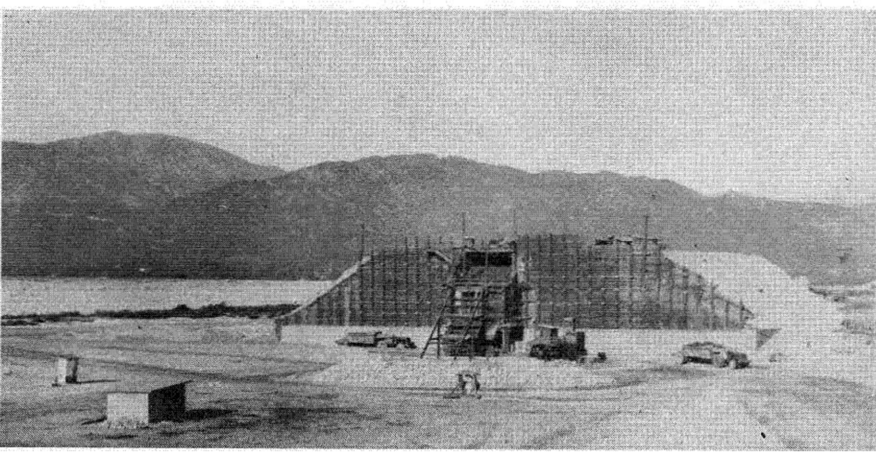
Beyond Zone II on either side is Zone III, making up the bulk of the dam volume. This material was excavated from the center of the horseshoe which makes up the dam, thereby adding to the reservoir capacity. It is strictly native alluvium except that boulders over five inches in size were first removed. Joining Zone II, which has a slope of 1:4, Zone III has a slope, both on the upstream and downstream sides, of 3:1. On the upstream face of Zone III there was placed a four-foot-thick layer of coarse rock from five inches to two feet in diameter, which serves the purpose of protecting the slope from wind and wave erosion. This was termed Zone IV. On the downstream face there was placed a much larger rock zone, comprising Zone V. Only two feet in thickness at the crest of the dam, it has a slope varying from 3:1 at the top to 5.5:1 at the toe, making the thickness of the dam at the toe line a maximum of about 700 feet. Materials for Zones III, IV, and V, comprising 90 per cent of the embankment fill, were obtained from the reservoir area. This material was excavated by three, two and one-half cubic yard Diesel-powered shovels and two electric machines, one four-yard and one six-yard. It was then loaded into trucks and hauled to the screening plants, or "grizzlies." After separation into two sizes, the material less than five inches in diameter was transported to the fill by additional trucks, where it was dumped, spread in 12-inch layers, and thoroughly flushed with water. No compaction other than that obtained from the pneumatic-tired truck equipment was required.

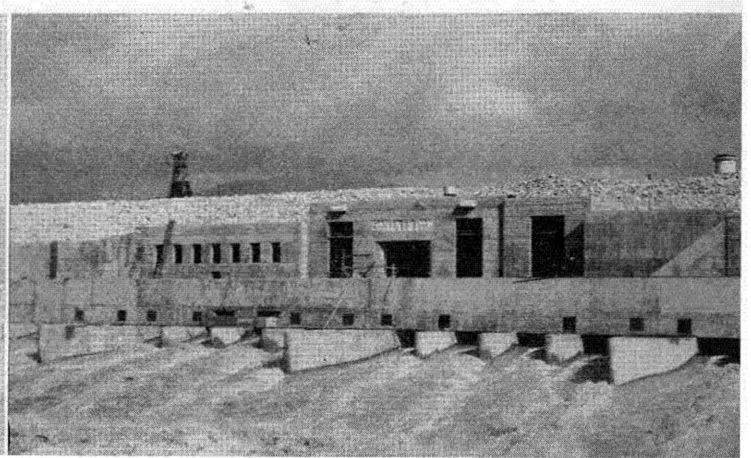
It will readily be seen that the separation of 11,000,000 cubic yards of material into two sizes presented a difficult problem, simply because of the large volume handled. For the purpose, four separate grizzly plants, two of which are illustrated, were constructed during the 24-month life of the job. The first plant was a conveyor type. Excavated rock was dumped into a hopper placed below normal ground level. From the hopper a six-foot-square hole in the floor of the hopper allowed the material to drop onto an apron feeder constructed with manganese steel wearing plates. In essence this was a conveyor with a length of but nine feet, and served to transfer the material from the hopper to the rubber conveyor belt with a minimum of shock and with a constant feed. After delivery to the conveyor, the material was transported to an elevation of some 40 feet above ground and dropped upon a series of inclined rails spaced very closely together at the head and flaring outward down the slope. The material flowing over the bars thus separated itself, that under five inches in size dropping through, while that over five inches was carried on over the bars and was received by a separate bin. The receiving bins were elevated sufficiently to allow trucks to drive beneath the bins and obtain their loads through the use of roller gates operated by compressed air.

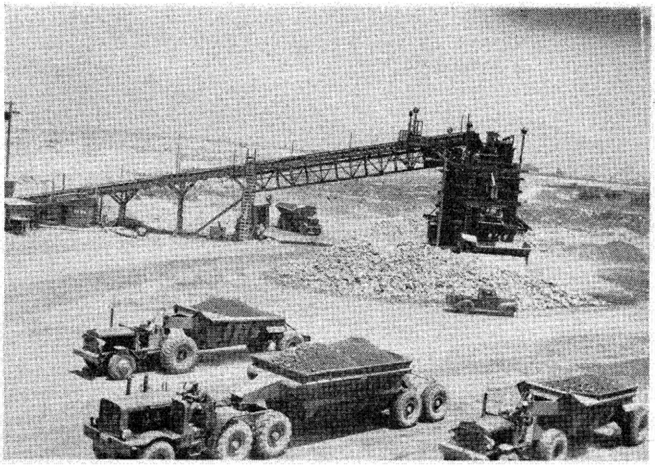
The final design of the inclined stationary bar grizzly involved a considerable amount of experimentation. The initial design used a patented type of movable bar grizzly, consisting of a series of parallel bars on a very flat slope of only four or five degrees. The bars were hinged at the upper end and fastened to an eccentric at the lower end, imparting vertical reciprocating motion with an amplitude of two inches to the lower end of the bars, and so arranged that while one bar was at the maximum height, the adjacent bars were at their minimum elevation. The design did not function satisfactorily for two reasons:

1. The material was of such a nature (rounded and very hard) that rocks tended to be wedged between the bars. Attempts were made to improve the operation, with meager success, and after two weeks of operation, an experimental stationary bar grizzly was constructed, which, after considerable evolution proved to be of satisfactory design. It was found that a slope of 26 degrees was best suited to the material. Less than this slope gave rise to sticking of material, while with a larger angle undesirable amounts of fine material were carried down with the coarse. Considerable flaring of the bars also was found necessary to prevent wedging of rocks, and in order to obtain maximum flare the bars

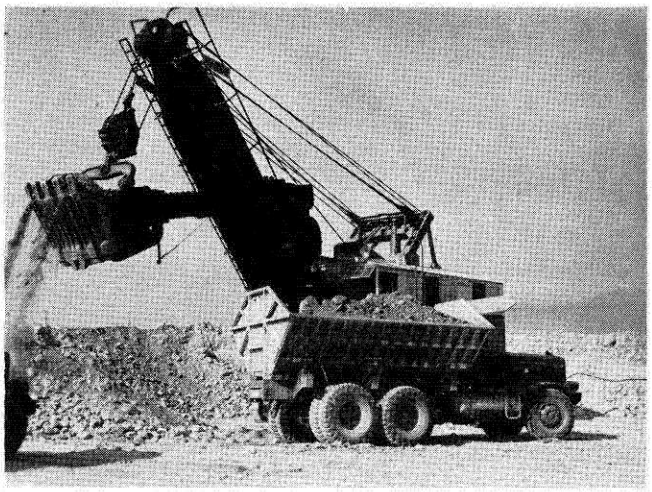
AT LEFT: Ramp-type "grizzly" or screening plant. AT RIGHT: Flood water leaving outlet works conduit. Dam under construction in background.



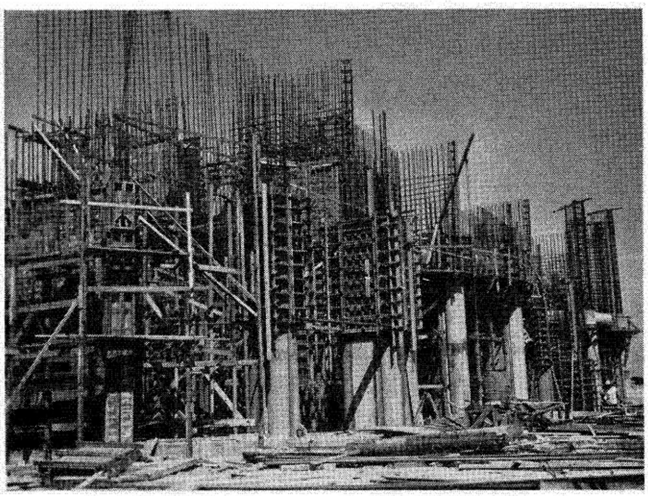




Conveyor-type "grizzly" or screening plant.



Loading a 25-cubic-yard side dump truck with a six-cubic-yard electric shovel.



Outlet works under construction, showing the upstream end, intake gate structure.

were constructed in two lifts. Spaces between bars approximated two inches at the top and seven inches at the bottom of the bars.

2. The large rocks moved the length of the bars so slowly that a thick mat of rock covered the bars at all times. Thus fines that should have gone through the bars were carried along with the rock and dropped into the wrong bin.

The second grizzly, and subsequently grizzlies three and four, were constructed with the benefit of the experience gained from the first unit. They differed, however, in one major respect. Instead of the conveyor system for elevating material, succeeding plants were of the ramp type, in which trucks delivered material direct from the excavation to the grizzly bars by driving up a two-degree ramp, eliminating the need for costly elevating equipment with its attendant maintenance.

The major operating problem was in scheduling operations for the most efficient use of equipment, and the maintenance of equipment to minimize the lost time due to idle units. Tire maintenance and inspection was a problem large enough to warrant a separate tire department, since the total mileage rolled up in one day of operation was equivalent to one tire being driven 80,000 miles. Forty-eight trucks were used, of three types. Best all-around unit was the bottom-dump type, previously described, which had two distinct advantages: it could dump on the embankment while still in motion, leaving its load spread out over a large area, and when dumping at the grizzly plant it required only two or three seconds to release the catch and allow the load to drop out, while the other types of truck used hydraulic jacks to tilt the dump body, an operation requiring 20 to 30 seconds. Of this type there were nine end-dump units of 10-cubic-yard capacity, and 13 side-dump units rated at 25 cubic yards that were used.

In addition to the dam embankment itself, a reinforced concrete outlet works and a mass-concrete spillway in the west leg of the dam were constructed. The outlet of 16 gated openings seven feet square in cross-section, with steel trash racks at the reservoir end, empty into a stilling basin at the downstream side. This stilling basin reduces the velocity of the water before it is allowed to continue down the San Gabriel channel. The conduits, about 500 feet in length, allow the stream flow to be controlled from zero to a maximum of 17,000 cubic feet per second. An access gallery located above the conduits permits passage between the gate chamber at the upstream end and a service building housing power and lighting units for the hydraulically-operated gates at the outlet end.

The spillway consists of a concrete weir, 1,200 feet in length, with an elevation 21 feet lower than the crest of the dam. Its maximum discharge capacity is 200,000 cubic feet per second. As in the outlet works, the water going over the spillway crest plunges into a stilling basin in which the velocity is reduced before it is allowed to proceed downstream. Together the two concrete structures required the use of 200,000 cubic yards of concrete and 6,000,000 pounds of steel reinforcing.

Bids for the construction of Santa Fe Dam were taken by the United States Engineering Department, under whose direction the dam was built, in June, 1941. Low bid of slightly less than $9,000,000 was entered by a combination of contractors consisting of the Morrison-Knudsen Company, Winston Bros. Company, J. F. Shea, and Ford J. Twaits. Construction began in August of the same year, and the structure was essentially completed in July of 1943. Lack of steel for the gates has delayed the 100 per cent completion for the duration. Except for delays due to difficulty in obtaining reinforcing steel, construction proceeded smoothly and according to schedule until the week of January 20,

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finger. And when the rain has wet the kite and twine, so that it can conduct the electric fire freely, you will find it stream out plentifully from the key on the approach of your knuckle. At this key the phial may be charged; and from electric fire thus obtained, spirits may be kindled, and all the other electric experiments be performed, which are usually done by the help of a rubbed glass globe or tube, and thereby the sameness of the electric matter with that of lightning completely demonstrated."

In a further letter written in September, 1753, he says: "In September 1752 I erected an iron rod to draw the lightning down into my house, in order to make some experiments on it." He carried on these experiments for some months to learn whether the clouds were positively or negatively electrified, and after many trials he says:

"I concluded that the clouds are *always* electrified *negatively*, or have always in them less than their natural quantity of the electric fluid.

"Yet notwithstanding so many experiments, it seems I concluded too soon; for at last, June the 6th, in a gust which continued from five o'clock P. M. to seven, I met with one cloud that was electrified positively, though several that passed over my rod before, during the same gust, were in the negative state."

The foregoing shows what most commendable scientific care he took in his experiments and what caution he used in drawing conclusions.

But he did not stop with making scientific experiments. His active and practical mind was not satisfied until he had applied it to the useful end of the invention of the lightning rod, as indicated in the first paragraph of the letter of October 19, 1752, quoted above.

After his definite proof of the identity of lightning and electricity he was recognized by the most distinguished English scientists by being elected to the Royal Society, and was presented for the year 1753 the Copley medal of the Society, the highest honor within the gift of the world's most illustrious scientific body.

Santa Fe Dam

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1943, at which time heavy and prolonged rains caused flood conditions of major proportions to develop along the river channel. During this week the highest rainfall intensity recorded to date in the United States was measured in the mountains a few miles east of the dam, where 25 inches of rain fell in 24 hours. Tremendous quantities of material were washed down into the reservoir area, and wide gullies were cut in the upper end of the reservoir borrow pit. Floating debris partially choked up the trash racks, causing the water to be backed up in the reservoir and threatening two of the grizzly plants with inundation, but quick work of removing trash with a dragline eliminated the hazard. Construction work was halted by this and succeeding storms for a total of five weeks and clean-up work continued for many weeks more; yet in spite of delays, construction was completed four months ahead of schedule.

Principal credit for maintaining the production schedule regardless of delays was due to the fine spirit of co-operation between the contractors, represented by Project Manager R. F. Rasey, and the U. S. Engineering Department. J. G. Morgan was resident engineer for the government.