Two men were kept on the dump directing the stream of material and building up the outer edges of the slopes to the proper lines, while the others were chiefly engaged in ground-sluicing. With looser or deeper soil, or under conditions permitting the use of a jet of water under pressure, the cost of loosening, which in this case was the chief item of expense, would be reduced to a nominal amount.

It is apparent that an embankment built in this manner is compacted as thoroughly as it could be by any process of rolling and is not subject to further settlement. It is also manifest that the finer materials are by this process precipitated in the interior of the fill, next to the discharge-outlets for the water, and that the particles are in a general way graded in size from the outside toward the center. In this dam all of the stand-pipes are placed inside of the center line, as shown by the section of the dam (Fig. 75), and therefore more of the coarse and permeable bowlders and gravel are placed on the outer half of the embankment, where they afford

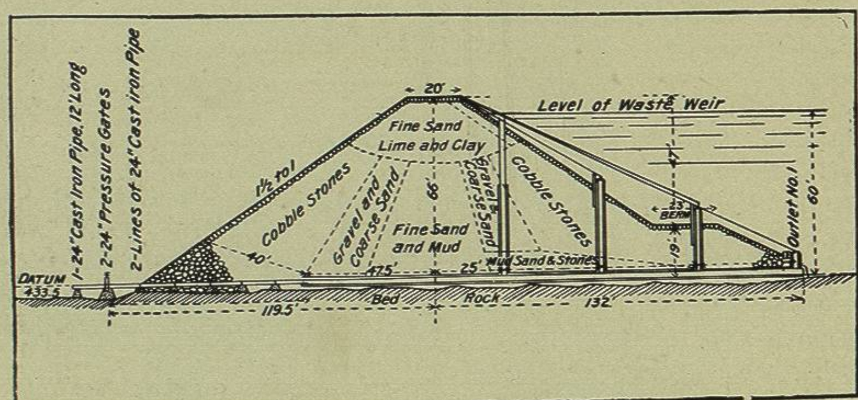


FIG. 75.—CROSS-SECTION OF LA MESA DAM.

ready drainage to the percolation that might find its way through the dam. (See Fig. 75.) Thus the failure of the structure through the ordinary process of supersaturation and the sloughing of the outer slopes is rendered highly improbable if not impossible. A dam built in this way is tested as it grows by the pond of water standing on top of it and the rising lake behind it, and if any weakness exists it is sure to be discovered and remedied by the operation of natural laws.

This dam is not entirely free from leakage, although as the water comes through quite clear it causes no anxiety and shows no tendency to increase. The leakage measures 100 gallons per minute when the water in the reservoir stands at the 54-foot level, and 23 gallons per minute when the water stands at 46 feet.

The reservoir-basin is large enough to impound 18,890 acre-feet if the

dam be raised to the 140-foot contour. Such a dam, of safe dimensions, would contain 682,000 cubic yards, and its construction has been seriously considered, the material to be obtained by excavating the interior of the basin, conveying it to the dam by the hydraulic method and then hoisting it in place by mechanical means.

The elevation of the base of the dam is 433.5 feet above sea-level, and a 24-inch wood-stave pipe, 6500 feet long, banded to withstand 180 feet maximum pressure, connects it with a 15-inch steel main that is laid from the end of the main flume to San Diego. The location and elevation of the connection of these pipes has practically determined the 43-foot contour in

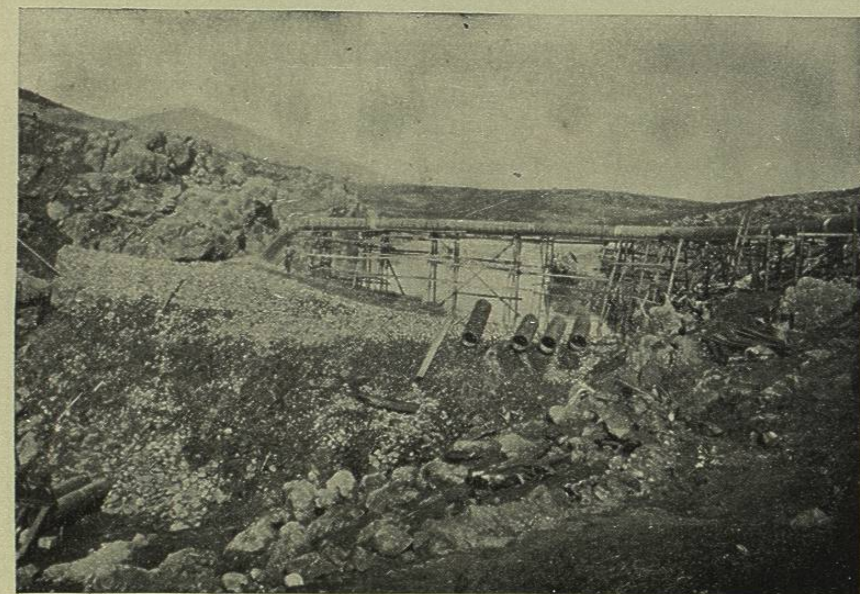


FIG. 76.—LA MESA HYDRAULIC-FILL DAM, SHOWING PIPE DISCHARGING MATERIAL ON THE DAM.

the reservoir as the lowest level to which the water will ordinarily be drawn when used for city service, unless a more direct connection be made. In times of scarcity the water below the 43-foot level has been pumped from the reservoir.

Crane Valley Hydraulic-fill Dam, California.—Some years ago the San Joaquin Electric Company erected a power-plant on the San Joaquin River, 34 miles north of Fresno, to utilize water brought from the North Fork of the San Joaquin to the power station. The power-drop at this place is 1410 feet, and the plant is remarkable as one of the first to make use of so high a drop, as well as for the long distance of the transmission of power, as the company deliver electricity to Hanford, a distance of 70 miles, as well

FIG. 77.—VIEW OF CRANE VALLEY DAM-SITE, SHOWING OUTLINES OF HYDRAULIC-FILL DAM.

FIG. 78.—VIEW OF CRANE VALLEY DAM-SITE, FRESNO COUNTY, CALIFORNIA.

as to Fresno. The plant was designed and built by J. J. Seymour, C.E., president of the company, and by J. S. Eastward, chief engineer, under contracts with the General Electric Company. The plant was entirely successful until a severe drouth developed such an unprecedented shortage in the low-water supply as to diminish the possible power output below the demands upon it. To remedy this deficiency, and the annual shortage during three or four months in average years, the company undertook the erection of a storage-dam for impounding the flood run-off of the North Fork. The dam was planned and supervised by J. M. Howells, C.E., and is a structure purely of the hydraulic-fill type. The general dimensions of the original plan were as follows:

Maximum height	100 feet.
Length on top	720 "
Width on top	20 "
Slope on water-side	2 : 1.
" " lower side	1.5 : 1.
Width of canyon at base	50 feet.
Width 60 feet higher	300 "

Water for sluicing was brought to the dam-site a distance of 5 miles, by flumes and ditches. The volume used was 15 second-feet (750 miner's inches), which was delivered to the summit of a hill overlooking the dam and 200 feet above it. This hill, which furnished the materials for building the dam, was surveyed and explored by borings to determine the quantity and quality of available earth for the purpose. The hill has an underlying base of granite, which has disintegrated very irregularly, leaving hard exposures at various points, while in places the depth to solid rock is very great. This disintegrated material is sandy in places, and in spots it has passed into the clayey stage, while fragments of granite still lie bedded intact, furnishing rock for the outer paving of the embankment. Hard bed-rock is exposed over nearly the entire area covered by the dam. It is of granite throughout, hardest near the level of the stream, where erosion has polished it smooth and glassy. Higher on the sides it is not so hard, but has made an excellent foundation. Advantage has been taken of a cut, blasted out from the solid rock, at a level 14 feet above the stream-bed, by an old mining company for a ditch grade, in which to place the outlet-sluices. This cut was arched over with masonry for the entire width of the dam, and served to carry the flow of the stream during construction. Gates were set in this cut on the center line of the dam, to be closed when the dam was finished and storage began. The gate-stems extend up through a circular shaft, 22 inches in diameter, 3 inches thick, reaching to the top of the dam. This shaft is made of

successive rings of cement pipe, 6 to 12 inches in height, which were added one at a time, as the dam rose. During construction this shaft served to draw off the surplus water from the pond formed on top of the embankment, after its load of material had dropped on the rising dam.

In preparing the foundations the center line of the dam was excavated to bed-rock and all loose material removed for a width of 20 feet from the center line on the up-stream side. Then a concrete wall, 2 feet in thickness, and about 2 to 5 feet in height, was built on bed-rock, into which was firmly imbedded the footings of a wooden core-wall, of doubled

Fig. 79.—Crane Valley Dam. Showing Wooden Fence, or Center Diaphragm, which was Carried Up to a Height of 30 Feet above Bed-rock.

1-inch surfaced sheeting. This wooden partition was continued to a height of some 30 feet above the base of the dam, its object being mainly to prevent the stratification of material deposited by the water from extending across the center of the dam from either side. It was also designed as a check against percolation through the dam.

It had been intended to carry this partition to the top, but as the dam building progressed it was found that stratification could be effectually prevented by a system of cutting into the plastic material of the central part of the dam by pushing down broad wedge-shaped planks or paddles, 1 inch thick, 12 inches wide. This was systematically carried on while sluicing was in progress, and in continuous lines, at intervals of 2 feet, parallel with the center of the dam on the up-stream side, for a width of 20 feet out. As the workmen were able to shove the paddles into the mushy mass to a depth of 10 feet or more, the cleavage across the stratification was repeated over and over again. On the withdrawal of the paddle the fine silt would immediately fill the hole, and thus alter the composition of the mass.

The result of this kneading process was so satisfactory that on the sides of the canyon, at an elevation of 60 feet from the base, the wooden

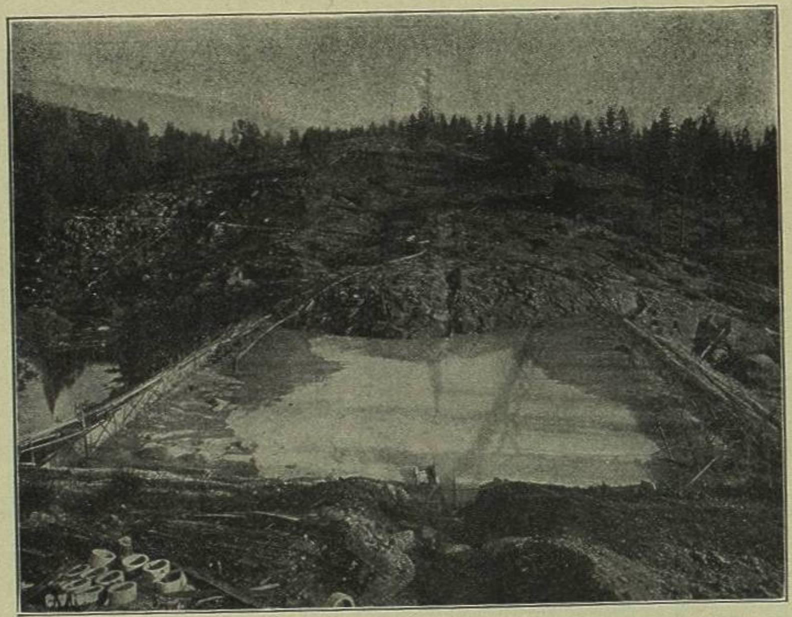


FIG. 80.—CRANE VALLEY DAM SHOWING DISCHARGE OF SLUICED EARTH AT END OF CONVEYING FLUME.

core-wall was carried no higher than 6 feet above the concrete foundation.

A porous cement conduit, or pipe 3 inches diameter, was laid on top of the concrete wall against the wooden sheeting on the down-stream side, throughout its entire length. At the lowest point in the stream-bed the pipe from either side connected with a 6-inch cement pipe laid on the bottom outward to the toe of the lower slope. These pipes were designed for drainage, but through a series of mishaps they came near causing the destruction of the dam. During a sudden freshet which threatened to overtop the dam, it became necessary to use powder to blow out a wooden gate that had accidentally closed the outlet culvert. The explosion shattered the 3-inch drainage pipe at one point

over the culvert, and started leakage of muddy water carrying sand through the 6-inch outlet. This continued until it carried out sufficient material to produce a crater in the dam, conical in shape, reaching to the top, and discharging over 1000 cubic yards of the finer material of the center portion of the dam before it was finally checked. As the dam had then reached a height of 70 feet, and the reservoir was nearly full the situation was alarming. The cavity was hastily filled with gravel, sandbags, etc., and the leakage finally ceased. A shaft was

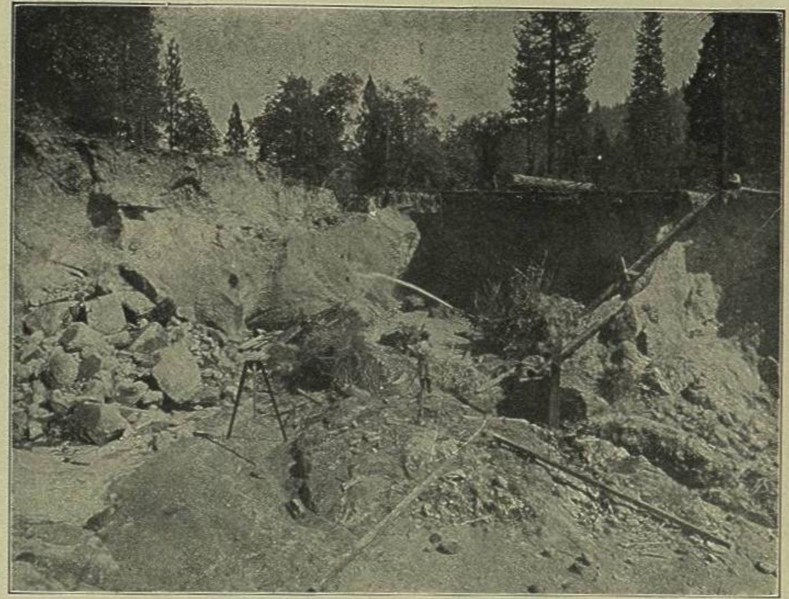


FIG. 81.—CRANE VALLEY HYDRAULIC-FILL DAM. SHOWING METHOD OF LOOSENING THE MATERIALS SLUICED INTO THE DAM.

then sunk down to the break, and the fact discovered that the break had been self-mended by being plugged with roots and leaves that had been washed into the dam in the process of sluicing, rather than by the sandbags and other fillings that had been thrown into the cavity.

Owing to long delay in securing permission to use the ditch, which passed through a United States Forest Reserve, it was necessary to begin sluicing by means of a pump. A steam-pump with a capacity of 2.25 second-feet was installed on the bank of the stream, above the dam-site, and delivered water through an 11-inch riveted steel pipe to a "Little Giant" monitor with $2\frac{1}{2}$-inch nozzle at the borrow-pit, 75 to 110 feet above the stream.

About two-thirds of the total amount of material placed in the dam was conveyed by the water pumped. When the permit to use the ditch was finally granted, the remaining third was ground sluiced in by the use of the flumes that were employed for the conveyance of pumped water. These flumes were laid on a grade of 6%, which was the minimum permissible for free operation with the comparatively small volume of water delivered by the pump. The flumes were made of 1-inch pine boards, 12 inches wide, 10 inches deep, covered on top except across the dam, where the cover was omitted. With this small flume, and the small quantity of water used, it was not possible to convey any rock to the dam, or material coarser than fine gravel, even on 6% grades.

Two sets of flumes were used, one on either side, in alternation. When one side of the embankment was raised to a height from which the heavier particles, making their own gradients toward the center, approached the center as closely as was deemed expedient the stream of material was shifted to the flume on the opposite side, which was then raised accordingly. At the base of the dam the coarser sand was not allowed nearer than about 40 feet from the center line, but as the dam rose and its top width decreased this distance was decreased correspondingly.

After both sides had been raised to the same level, by an even distribution on each, all the way across, the water-level of the pool, always remaining in the center of the embankment, was then raised by adding one of the cement rings to the circular drainage shaft, through which the surplus water was allowed to escape. This raised the water-level of the central pool about 13 inches. The process of sluicing was then repeated. As the dam approached the 60-foot level this was found to throw the water-line too near the edges of the dam, and rings 6 inches in depth were added thereafter. The flumes were so placed that when the dam had reached an elevation equal to the lower end of the flume, which was of course on the further side of the dam from which the excavation was taking place, the line of the flume was at the outer edge of the embankment. The flume was then raised, moving it toward the center of the dam sufficiently to allow the process to be repeated on the higher level. The trestles supporting the flumes were made of 2″×4″ plank, which could generally be pried out of the sand and used again. A handspike with a sharp iron spur bolted to the end would suffice to start any one of the posts of the trestle from its bedding in the sand. The flumes were thus raised about 10 feet in elevation each time.

At short intervals slotted openings were made in the bottom of the flume through which a driblet of water was allowed to run. This carried with it a large percentage of the coarser sand, which was thus deposited where it could be cast by shovels to the slope line.

The discharge from the flume to the dam of the greater portion of the

water with its load, was made at convenient points by side gates in the flume, formed of a short section of the side board sawed in such a way that it could be swung across the flume, turning out the entire flow at that point. From these points of discharge the sand and silt were distributed on light grades until the central pool was reached, when precipitation of the sand took place at once, forming bluff banks under the water near its edge, while the fine silt particles were distributed across the pool.

The construction was suspended when the dam reached a height of about 70 feet, where a temporary spillway was available over a gap

Fig. 82.—Borrow-pits from which Material was Sluiced to the Crane Valley Dam in Background.

in the crest of the horseshoe shaped hill, around which the river formerly flowed. It is planned to be extended later to the full height of 100 feet.

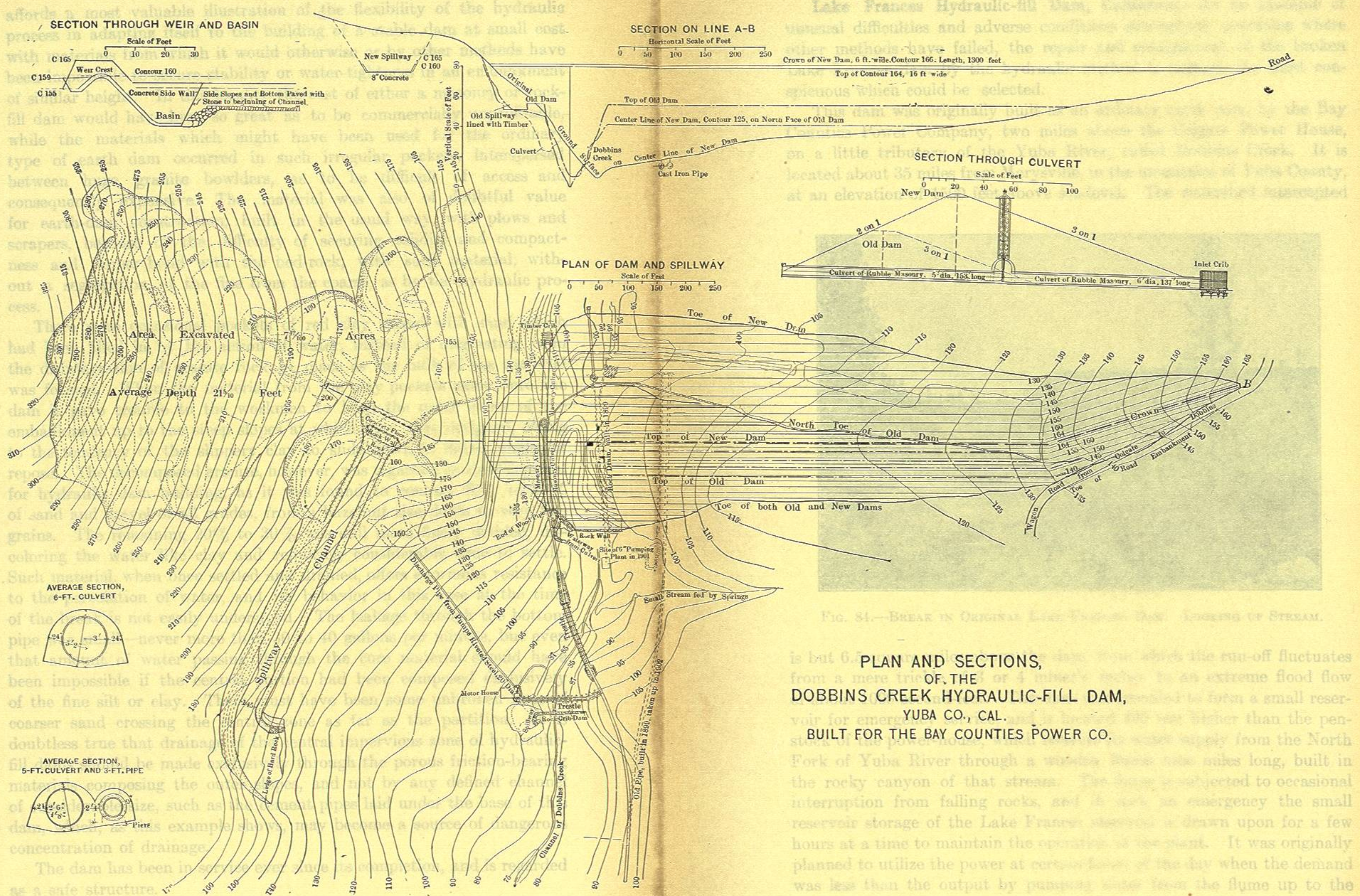
On completion of sluicing, the embankment was rip-rapped on both faces with broken stone, partially taken from the temporary spillway, and partly gathered from the adjacent hillsides.

The preliminary estimates of cost of the dam contemplated an expenditure of $25,000 for the 100-foot structure. At that time the necessity for pumping was not considered. The actual cost of the work done could not be definitely ascertained.

This example of hydraulic-fill dam building, considering the class of material available and the conditions under which it was constructed, affords a most valuable illustration of the flexibility of the hydraulic process in adapting itself to the building of a stable dam at small cost with materials from which it would otherwise or by other methods have been impossible to secure stability or water-tightness in an embankment of similar height. In this locality the cost of either a masonry or rock-fill dam would have been so great as to be commercially unprofitable, while the materials which might have been used for the ordinary type of earth dam occurred in such irregular pockets, interspersed between huge granite bowlders, as to be difficult of access and consequently expensive. The material was also of doubtful value for earth-dam construction, built in the usual way, with plows and scrapers, because of the difficulty of securing solidity and compactness and proper bond with the bed-rock, with such material, without a segregation of the fine from the coarse, as by the hydraulic process.

There were occasional pockets of red clay mixed with sand which had been filled in by the action of water, instead of originating from the disintegration of granite rock in place as the bulk of the material was formed. When the material from the clay pockets came onto the dam it gave trouble to the workmen to keep the outer edges of the embankment up to the steep slopes at which they were designed, owing to the tendency of the slippery clay to slide down to flatter angles of repose. The decomposed granite, however, was regarded as ideal material for hydraulic dam building, as it was found to contain 70% to 80% of sand and gravel of all grades, from a hazelnut size down to very fine grains. The remaining 20% to 30% was still more finely divided, discoloring the water like clay and requiring considerable time to settle. Such material, when once settled and drained, offers enormous resistance to the percolation of water, and its behavior in this case at the time of the break is not easily understood. The leakage through the bottom pipe was small—never more than 30 to 40 gallons per minute, but even that amount of water passing through the core material should have been impossible if the central portion had been composed exclusively of the fine silt or clay. There must have been some unbroken lines of coarser sand crossing the central zone as far as the partition. It is doubtless true that drainage of the central impervious zone of hydraulic-fill dams should be made exclusively through the porous friction-bearing materials composing the outer slopes, and not by any defined channel of considerable size, such as the cement pipes laid under the base of this dam, which, as this example shows, may become a source of dangerous concentration of drainage.

The dam has been in service ever since its completion, and is regarded as a safe structure.



PLAN AND SECTIONS
OF THE
DOBBINS CREEK HYDRAULIC-FILL DAM,
YUBA CO., CAL.
BUILT FOR THE BAY COUNTIES POWER CO.

FIG. 83.

[To face page 115.]