The exposed portion of the plates was covered with a plank sheathing to protect it from the sun, and from falling rocks. Plans are being prepared to still further extend the dam to a height of 150 feet, enlarging its storage capacity nearly three times. The investment has been profitable, as the value of the crops produced by the reservoir water the first year was estimated at $40,000.

Cheesman Rock-fill Dam.—On the site of the dam which has since become famous the world over as one of the highest and finest types of masonry dam in existence the Denver Union Water Company started in 1900 to build a rock-fill dam with a facing of steel plates, riveted together on the up-stream slope. This dam was located on the South Platte River in Colorado, and was to have been 210 feet high, and 600 feet long on top, with a base width of 450 feet,—the lower slope being $1\frac{1}{2}$ to 1 and the upper slope, hand laid, $\frac{1}{2}$ to 1. This was to be covered with 12 inches of concrete as a backing for the steel-plate face, which was to be riveted to 6-inch I-beams, to be anchored into the rock-fill with anchor rods 5 feet long.

Work was begun in 1898, and continued until May 3, 1900, at which time the masonry toe wall had reached to a height of 38 feet above the stream-bed, and the rock-fill behind it was 26 feet higher at the crest. During this construction the water of the river was diverted through a tunnel which was to be used as the main outlet of the reservoir. This tunnel is 7 feet wide, and 6 feet high, for about half its length, to its junction with an inclined spillway tunnel, whence its size increased to 8 feet wide, and 9 feet high, the total length being 470 feet. This tunnel was controlled at the upper end by a balanced valve, set over the tunnel mouth, at an incline of 30° from the horizontal. Fig. 43 shows the construction of this valve, which consists of four hoods or chambers of cast iron, resting on a heavy framework of T-beams, and opening out into the tunnel at the bottom. A continuous shaft passes through all the hoods from end to end, upon which are fastened heavy disks of cast iron, so placed as to close all the openings in the hoods when the valve is shut, and uncover openings at each end of each hood when the shaft is moved. The valve closes by gravity, but is opened by hydraulic pressure conveyed to the cylinder at the upper end of the gate through lead-lined steel pipes from a small reservoir located at a considerable height on the adjacent mountain side above.

Destruction of the Dam.—In the latter part of April, 1900, an unprecedented rainfall of 9 inches, added to the melting snows, caused a flood on May 3, so far exceeding the capacity of the outlet tunnel as to overtop the masonry toe wall, and wash away the loose rock-fill below. But for this unforeseen contingency the dam would doubtless have been

successfully completed, and would have had every prospect of enduring stability, as ample spillway capacity had been anticipated in the plans, to provide against future overtopping. When thus completed it would have been the highest rock-fill dam in the world. The failure of the structure naturally discredited that particular type of dam for that locality, and the engineer who had planned it. New engineering talent was brought into requisition and a masonry dam was built on the site which is a structure entirely creditable to its builder, but involving a very much greater capital outlay. The existing dam is described in the chapter on masonry dams.

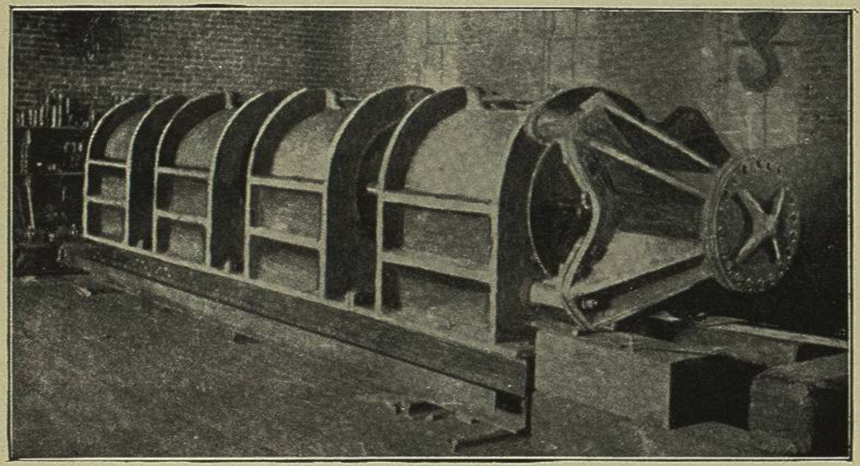

FIG. 43.—BALANCED VALVE USED FOR RESERVOIR OUTLET, CHEESMAN DAM, COLO.

The English Dam, California.—Among the earlier constructions of the rock-fill type was one known as the English dam, situated on the headwaters of the Middle Fork of the Yuba River, in California, at an elevation of 6140 feet, which was destroyed June 17, 1883. The reservoir was formed by means of three timber crib-dams, and covered an area of 395 acres, impounding 650,000,000 feet of water. It was supplied by the run-off from a drainage area of 12.1 square miles, reaching to the summit of the Sierra Nevada. The middle dam, the largest of the three and the one which was subsequently destroyed, had a vertical height of 100 feet on the interior, and 131 feet on the exterior, above the deepest part of the foundation. Its thickness at base was 185 feet, length on top 331 feet, and bottom length about 50 feet. The original construction consisted of a crib made of tamarack logs, 79 feet high, 100 feet thick at base, with inner slope of 60° from the horizontal, the crib being filled with rock, and the whole structure faced with plank. It was built in 1856, and repaired in 1876–77, by tearing out the decayed portion of the old crib and replacing it with new timbers. At the same time an addition to the thickness and height was made by building a stone facing on the outside, laid up as a dry rubble wall, on a slope of 44°. This wall was carried up to a height of 14 feet above the top of the original dam, meeting a similar wall laid on the inner slope. The upper 7 feet was formed of a substantial timber cribwork. The addition to the dam cost $70,000, and the entire cost of the three structures was $155,000, or $10.40 per acre-foot of storage capacity. The high-water mark, or the spillway-level, was 14 inches below the top of the upper cribwork. From the time the repairs were completed until the destruction of the dam, about five years, no signs of weakness or leakage were manifest, and the water-level was raised annually to the high-water mark. On the evening before the break the water-level was 2½ inches below the spillway. The first intimation given of the break was at 5.30 A.M., when the watchman heard two violent explosions, and on reaching a point where he could see the dam he observed the water pouring through a wide breach in the upper cribwork. It was inferred that the break had been caused by dynamite. In a few moments the water cut an immense gap through the structure to its very foundation and the entire contents of the reservoir were emptied inside of an hour. The flood-wave caused a rise of 40 feet at a point 43 miles below. At Marysville, 85 miles below, the rise observed was but 2 feet 8 inches, and at Sacramento the extreme rise was but 8 inches. The damage done by the flood was estimated at about $4000 to some wheat-fields that were overflowed. The flood was 24 hours in reaching Sacramento, and the total time in passing that point was 26 hours. Had the break occurred in time of flood the opinion is expressed by A. J. Bowie, M.E., that it would not have been observed by a marked increase in the level of the larger streams of the Sacramento Valley—the Feather and Sacramento rivers.* While the composite character of this structure, and its age at the time of its failure, would lessen confidence in its stability, it is the only one of its type which has given way, and the circumstances seem to point to malice rather than inherent weakness as the possible cause of its failure.

The volume of water released by the breaking of the dam was about 600,000,000 cubic feet, which exceeded by nearly 20% the contents of the South Fork reservoir whose failure produced the frightful Johnstown, Penn., disaster in 1889, and that there was no loss of life resulting from it and very slight property damage is quite remarkable.

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* Transactions Technical Society of the Pacific Coast, vol. II. page 10.—A Paper on the Destruction of the English Dam.

The Bowman Dam.—The timber-crib rock-filled dams of the mining regions of California are well illustrated by the Bowman dam, located on the South Fork of Yuba River, and impounding the drainage from 19 square miles of the higher Sierras.

The dam was built in 1872 to the height of 72 feet in a manner similar to the original construction of the English dam, consisting of a timber crib of unhewn cedar and tamarack logs, notched and bolted together and filled with small stones. The slopes on each side were 1 on 1, and the face was made with a skin of pine planking, laid horizontally. In 1875 the dam was raised to the extreme height of 100 feet, by adding an embankment of stone to the lower slope, wide enough to carry the entire structure, including the crib-dam, to the desired height. The outer face of this embankment was made as a hand-laid dry rubble wall in which stone of large size were used. This wall is 15 to 18 feet thick at base, and 6 to 8 feet at the top, the stone weighing from ¾ ton to 4½ tons. Vertical ribs were bolted to the wall on the water-face, with ¾-inch rods, 5 feet long, and to these the plank were spiked. These were 9 inches thick, in three layers, for the bottom 25 feet, 6 inches thick for the next 35 feet in height, and 3 inches thick on the upper 36 feet. The outlet to the reservoir is arranged by three 18-inch wrought-iron riveted pipes, about 25 feet long each, extending from the inner face of the dam to a culvert, built in the dam from the lower side to the gates placed at the outlet end of these pipes. The combined discharging capacity of the pipes is 280 second-feet, when the reservoir is full. They discharge into a covered sluice or flume in the bottom of the culvert, 21 inches high, 7½ feet wide. The gates are approached by a walk above this flume. The culvert is 8 feet high, 7.5 feet wide at bottom, 5½ feet at top, made of dry rubble side walls, covered with heavy granite slabs, 18 inches thick, 6.5 feet long.

The dam is 425 feet long on top, and has a base thickness of 180 feet. Its contents are 55,000 cubic yards, and its cost was $151,521.44.

Like many of the earlier types of rock-fill dams it was built with an obtuse angle in the center, whose apex is pointed up-stream. This angle is 165°. Its purpose was evidently to give a fancied additional security, and was the nearest approach to the arched form which could conveniently be given to such a structure.

The reservoir covers an area of nearly 500 acres, when full, and has a maximum capacity of 918,000,000 cubic feet or 21,070 acre-feet. Its cost was therefore an average of $7.19 per acre-foot of storage capacity.

The annual precipitation at the Bowman dam, as recorded for sixteen years prior to 1887, ranged from a minimum of 44 inches to a maximum of 120 inches, the mean being about 72 inches. The watershed is of a character to yield maximum run-off estimated at 75% of mean precipitation. Maximum floods from melting snows reach 5000 to 7000 cubic feet per