On the right is the head of the Modesto Canal. The excess water entering the canal is allowed to escape over a long concrete spillway wall. Beyond this are waste gates, and then the regulator, which

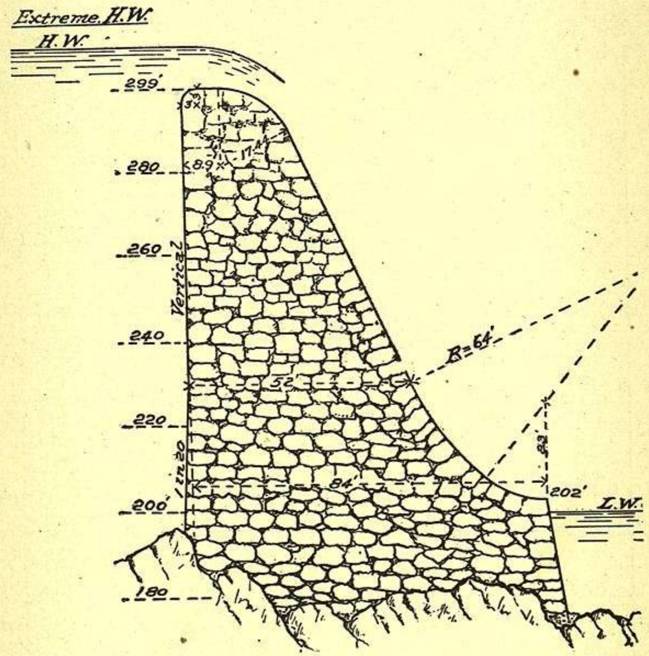


FIG. 41.—Section of masonry dam at La Grange, California.

permits the desired quantity to enter the canal. On the left is indicated the position of the Turlock Canal, which comes out from a tunnel, the size of this regulating the amount which can enter the canal.

Structures of this kind, when well built, may be considered absolutely safe. There are, however, a number of precautions to be taken, which, if neg-

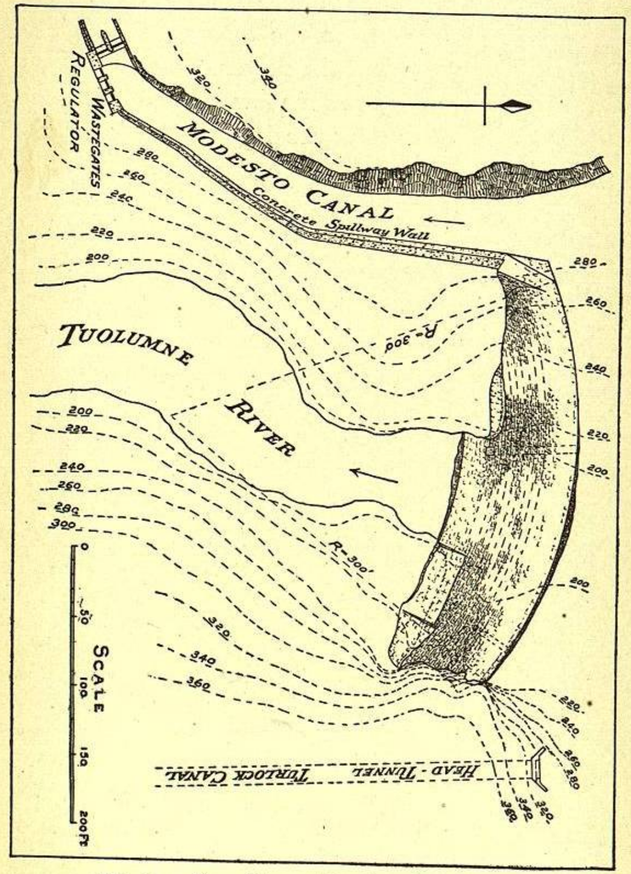
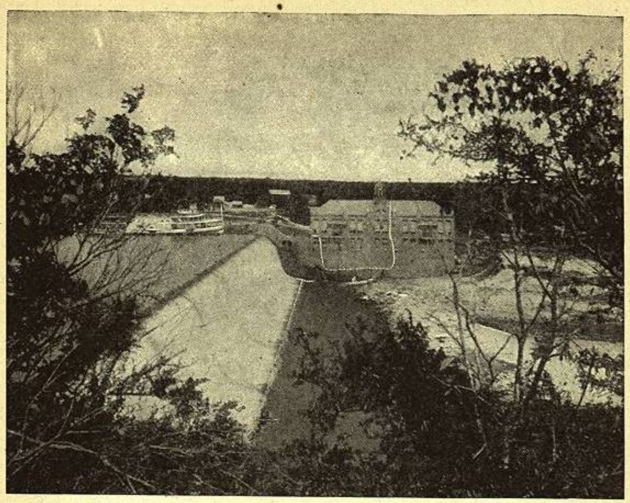


FIG. 42.—Plan of dam at La Grange, California.

lected, may be fatal, as shown by a few accidents which have occurred. The most notable of these in recent times is the failure of the Austin Dam in Texas, views of which are shown on Pl. XXVI. The upper picture is of the dam, looking across Colorado River toward the power house above the city of Austin. The lower view is from the opposite direction and shows the fragments of the dam immediately after its failure during the flood of April 7, 1900. At that time water to the depth of 11 feet was pouring over the top. Apparently a section of about 500 feet in length slid forward. This has been attributed to various causes, but the general explanation is, that beneath the dam was a layer of soft rock into which water penetrated during the flood, tending to float the dam, and weakened its strength to such an extent that it slid forward upon the yielding surface. This dam was located at a point of disturbance of the bedded limestone, and in the vicinity of what is known by geologists as a fault or zone of fracture, so that leaks or so-called springs appeared below the dam at one end, these being doubtless due to water finding its way into the shattered rocks and out at the first point of escape.

ROCK-FILLED DAMS.

Besides the masonry dams carefully laid by hand, a number of rock structures have been built in which the attempt has been made to lessen



A. DAM AT AUSTIN, TEXAS; LOOKING TOWARD POWER HOUSE.

B. PORTIONS OF AUSTIN DAM IMMEDIATELY AFTER FAILURE.

the expense by throwing in the stone, letting them take such position as they will, not filling the interstices with cement. These are known as rock-filled dams. The upper face must be made water-tight by an impervious wall of masonry, wood, or metal. The pile of rock behind this face serves to hold it in place and prevent it from being washed away. It is necessary to provide such structures with ample wasteways, so that the waters will not overflow the top and wash out the loose rock, weakening the structure. This has happened in the case of the Walnut Grove Dam in Arizona, where a sudden severe storm or cloudburst over-topped the structure, washed out the loose rock which held up the impervious face, and allowed the entire volume in the reservoir to burst out, overwhelming the settlements below.

When a person is standing on the side of a deep canyon, the thought occurs: Why not throw down a part of the walls of the canyon by means of enormous blasts, and allow the material to choke up the bottom of the gorge, and thus pond the water back and overflow the valley above? This experiment has been tried, and great quantities of rock have been thrown into a stream channel by titanic explosions of dynamite. The difficulty encountered, however, has been that the water quickly finds a way through this mass of loose material, and cannot be held for a sufficient length of time to repay the cost of outlay.

It is necessary to provide some form of impervious wall in the loose rock, or a tight cover at its upper face. To construct this after the material is in place is exceedingly difficult, since the accumulated rock tends to hold back the water and interfere with the construction of the retaining wall.

In southern California several dams have been successfully constructed by a modification of this method, these being at localities where the flowing water has not been sufficient in quantity to interfere with the work. Chief among these are the Morena and Lower Otay dams, easterly from the city of San Diego. After the heavy explosions, the ground immediately above the rock heap was cleaned away to bed rock and a concrete base prepared for the insertion of a steel plate. This plate was continued upward across the narrow canyon, being protected on each side by a thin layer of asphaltum and a thickness of concrete against this. On both sides of the plate was placed the loose rock (Pl. XXVII, *A*), this being lifted and deposited in position by means of derricks and overhead cables. The completed structure consists of a substantial pile of rock, the impervious steel plate preventing leakage.

As indicated by the preceding statements, the most desirable structures for holding water are those built of substantial masonry. It occasionally happens, however, that dams of this kind cannot be built for lack of suitable material conveniently

located, and other forms of structure must be considered. For this purpose earth, timber, iron, and steel are sometimes employed. Steel has been used through the interior of a dam, as just noted, and also for the entire structure, strength being given, not by the weight of rock, but by a system of bracing similar to that employed in ships and great buildings. There is no difficulty as to the original strength, but doubt has arisen in the minds of many engineers as to the permanence of the work, because of the possible effects of rust or other forms of deterioration.

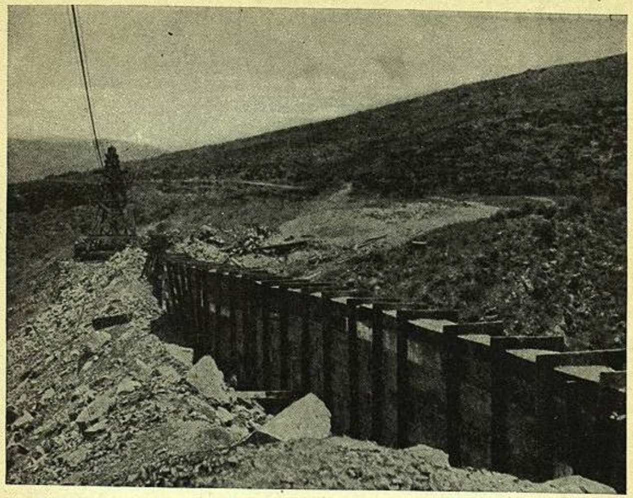
Timber dams are widely used, especially for lumbering operations and for mill purposes. These have been built in great numbers upon rivers flowing from forested regions, where timber is plentiful. They are usually of relatively low height, and consist of logs framed to form cribs, these being filled with large stones and thus held in place. The upper face of these dams is covered with a sheathing of planks, making the dams nearly water-tight.

Timber or log structures of this kind are used to a small extent in the arid region, but they are temporary expedients, resorted to with the idea of replacing them by better works as soon as the irrigators acquire the means with which to make a more substantial dam. As used for this purpose, they are for the most part at the outlets of small natural lakes, partly closing these and raising the water at the time of the spring floods. These timber dams are designed to accomplish the desired end temporarily at the least possible cost. A view of one of these temporary dams is given on Pl. XXVII, *B*.

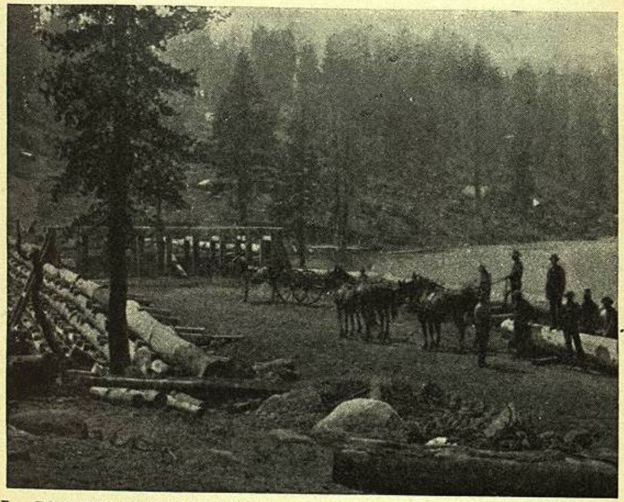
EARTH DAMS.

Earth is largely used for holding water in localities such as those upon the edge of the Great Plains, where there are broad basins or shallow depressions into which water can be taken from local floods. It is usually necessary to provide a very long and relatively low bank to increase the storage capacity of these basins, as in this situation there is rarely any rock or timber. Earth must, therefore, be used, carefully compacted and piled up in such quantities that the water cannot seep through.

Percolation through an earth bank is prevented by carefully preparing the foundations, to secure a perfect union between the underlying earth and the material placed upon it. All loose soil and vegetal matter must be removed from the foundation of the earth bank, and along the centre a deep trench dug. This trench is then filled with clay, carefully worked into place. This is designed to cut off the water which otherwise might seep beneath the foundations. The clay or puddled wall is continued upward through the centre of the dam, forming an impervious sheet, which prevents any leaks from extending through to the lower side. The preparation of this puddled wall requires great-



A. LOWER OTAY DAM, CALIFORNIA, SHOWING METHOD OF PROTECTING STEEL PLATES.



B. CONSTRUCTION OF TIMBER DAM AT BLUE LAKES, CALIFORNIA.

est care and attention, as upon it depends largely the safety of the structure. A leak once started through an earth dam may enlarge rapidly, the flowing water eating away the loose material with increasing rapidity.

Ample provision must be made to prevent the possibility of the water overtopping the bank at any point, as this is easily eroded and would be washed away in a few hours. To do this, a broad wasteway is usually cut across a portion of the natural rim of the basin, this being several feet lower than the top of the artificial bank. By providing a broad place of escape across hard, undisturbed material, a sudden flood can be released before it overtops the embankment.

Outlets for such reservoirs are sometimes provided at the lowest point in the dam, especial care being taken to make this point of weakness as strong as possible. It has been found preferable in some instances to tunnel through some other part of the basin rather than to run the risk of leakage around or along an outlet built in the artificial bank itself.

Earth reservoirs of large capacity have been built in this way, and also innumerable small ponds or tanks for stock water or for irrigating gardens and orchards. These tanks are made from 100 to 500 feet in width, and are frequently filled with water by means of one or more windmills, as described on page 268. They are frequently made on the surface of the ground by scraping the earth from the outside, depositing this carefully in layers, and wetting and rolling, or trampling, it firmly into place. The banks thus built have a slope on

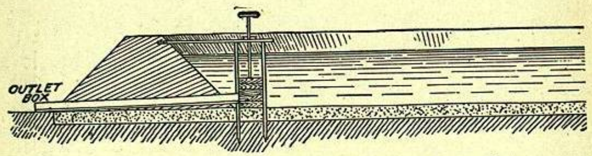


FIG. 43.—Portion of earth reservoir showing outlet.

each side of at least $1\frac{1}{2}$ or 2 feet horizontal to 1 vertical. The layers of dirt are so placed as to be lower in the centre of the wall, the finer material being, if possible, kept here as each layer is put into place or still better, a puddled wall of clay is put through the centre of the dirt bank.

These tanks may be either circular or rectangular in outline. An outlet is usually provided at the lowest point by inserting a substantial masonry or tile drain with gate, or a stout wooden box, care being taken to compact the earth around the outlet.

Frequently when a small reservoir of this kind has been completed, it leaks so rapidly that the water disappears before it can be used. It is then necessary to puddle the bottom with fine earth or clay, sometimes straw and stable manure being used. Cattle, horses, sheep, or goats are turned into the reservoir, and are fed there or kept moving

around, trampling the muddy bottom until it has been completely worked over. In this way it is soon rendered water-tight, especially if fine silt or muddy water is kept in the reservoir for some time.

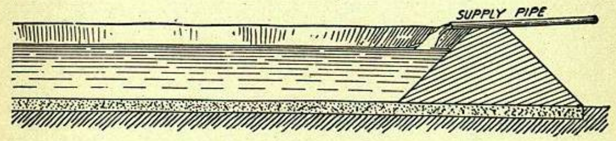


FIG. 44.—Portion of earth reservoir showing inlet.

The illustrations, Figs. 45, 49, and 50, show easily constructed devices for an outlet and gate for one of these small reservoirs. It is usual to construct this outlet of boards or plank, in the form of a long box from 8 to 18 inches in width and height. For permanence it is preferable to use a

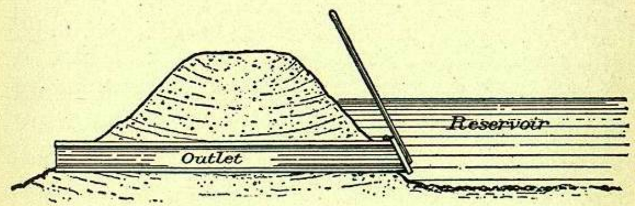


FIG. 45.—Section of reservoir bank showing outlet.

pipe of metal or cement, but the cheaper wooden outlet will suffice for a number of years. Around this outlet the clay and fine earth is very carefully packed to prevent leaks. On the upper end of the outlet is placed some form of gate or a simple