One of the first requisitions in a concrete reservoir is to make it water-tight. The writer did not see how he could be sure that it would be water-tight if he so designed it, that the cracks in the concrete were predetermined. The only remedy seemed to be to make the walls so thick, and of such a composition, that their tensile strength would never be exceeded.

Having this in mind when we came to the design of the reservoir for Rockland, Mass., we decided to use an especially rich mixture of concrete, a thickness of wall which would insure that the ultimate tensile strength of the concrete would not be reached when the reservoir was filled, to use an increased amount of vertical reinforcement especially between the base and the walls, and to install a steel dam at each horizontal joint between each day's work to prevent any direct seepage of water through the joint, provided it entered it. The hydrated lime was omitted, as we considered the proposed density of the concrete did not require it for unpermeability, and also that where it had been used previously it had caused an unsightly efflorescence on the wall wherever there had been seepage. The plastering was omitted as we considered that any rigid coating upon this mixture of concrete was unnecessary, but instead, we applied three coats of soap and alum solution, commonly known as Sylvester Compound, to fill pinholes due to air bubbles, etc.

The thickness of the wall at the base was determined as follows:

We assumed that a 1:1:2 concrete in tension was good for approximately 400 lbs. per sq. in., that the working stress in the steel, if by any chance the full tension was thrown upon it, would be 16,000 lbs. per sq. in.. and that the ratio of moduli of elasticity between steel and concrete was 10, so that if the concrete was stressed to 300 lbs. per sq. in. the steel would be stressed to 3,000. The tension at the base of a standpipe 46 ft. in diameter and 104 ft. in height when filled with water would be $62\frac{1}{2} \times 104 \times 23 = 149{,}500$ lbs. per ft. in height. At 16,000 lbs. per sq. in. this would require 9.35 sq. ins. of steel per foot in height at the base, which was the section used. We made the thickness of wall 36 ins. at the base, the sectional erea of concrete being $(36 \times 12) - 9.35$ equal to 422.65 sq. ins.

Let x equal unit stress in concrete, and 10 x the unit stress in steel, then $422.65 + 9.35\ (10x) = 149{,}500$ lbs.; solving x equals 290 lbs., which was considerably lower than the ultimate strength of 400 lbs. which we assumed. As we could find no tests of concrete in tension, we decided to have some made of large-sized briquettes at the Watertown Arsenal. We thereupon ordered our superintendent of construction on the Rockland job to make up some briquettes of special design, having a minimum cross section of 4 ins. square. These briquettes were made of the same material and in the same manner as the concrete was made for our regular work, the 1:1:2 concrete being taken from the mixture while the regular work was going on.

We also made twelve 6-in. cubes for testing the compressive strength of the same concretes. The test pieces were made between August 1 and September 8, and the tests were made 60 days thereafter, between October 29 and November 7. The average tensile strength of the 1:2:4 concrete was 113 lbs. per sq. in. of the 1:1½:3, 202 lbs. per sq. in. and of the 1:1:2, 281 lbs. per sq. in., there being no great variation from this average in any one of the tests. The average compressive strength of the cubes were as follows: 1:2:4, 2,280 lbs. per sq. in.; 1:1½:3, 3,657; 1:1:2, 4,845. Upon examination of the fractured tension pieces it was evident that the increasing ratio of tensile strength when the richness of mixture was increased was due to the larger amount of mortar in cross section in the 1:1:2 concrete. As this concrete showed very few stones at the fractured section, while the 1:2:4 concrete showed a large number, it was plain that the adhesiveness of the mortar to the stones was not equal to the cohesiveness of the mortar.

In regard to the tensile specimens we quote from the paper made by the engineer in charge of the test:

No change in the specimens was observed until rupture occurred. This took place quietly on a plane approximately perpendicular to the axis of the specimens and followed the surface of the gravel in nearly all cases.

From the results obtained we checked our previous assumptions. The average tensile strength of 1:1:2 specimens was 281 lbs. per sq. in. We assumed that in large-sized sections this possibly would be increased 25 per cent., and that if these sections were reinforced by steel, that a further increase in strength of at least 10 per cent. might be expected. Our first assumption was made by reason of the fact that large-sized specimens in compression usually showed about this percentage of increase over small ones, and our later assumption was based on the following theory:

If an unreinforced section is subjected to tension, when its ultimate strength is approached a crack will develop at the line of least resistance, and the fracture will always occur at this point.

If the section is reinforced, the ultimate fracture will not necessarily be at the point where the first crack developed, as the strain would be distributed nearly equally over the entire section by the reinforcing steel, and the fracture would take place at a plane in which was located the resultant of a number of weaker areas of concrete.

We however, assumed our original figure of 281 lbs. increased by first 25 per cent. and then 10 per cent., making a tensile strength of 386 lbs. per sq. in., which was probably nearly its actual value in the wall. It has been previously shown that the maximum tensile stress in the concrete would be 290 lbs. per sq. in., and the corresponding tensile strength in the steel 2,900 lbs., ao that there would be a margin of about 30 per cent. left for a factor of safety in the concrete without approaching the limitation of the steel. If, however, our assumptions had been wrong and no tensile stress whatever was taken by the concrete, which would be unreasonable, then we still had steel enough to take all the stress at 16,000 lbs. per sq. in. or its ordinary working value.

Applying this same line of reasoning to the Manchester reservoir, it is found that the tension at the base is divided proportionately between the steel and the concrete would be approximately 3,500 and 350 lbs. per sq. in., respectively. We have assumed that the ultimate tensile strength of the concrete plus the tensile be 202 + 25 per cent. + 10 per cent., equal to 278 lbs. per sq. in., so that it is evident that the extensile strength of the concrete of the reservoir wall is exceeded, and that the vertical cracks developed might be expected.

We further find that at a point 25 ft. up, the tensile strength of the concrete plus the tensile stress in the steel just equals the stress due to water pressure at this point, and it was at about this place that the vertical cracks in the plastering disappeared.

There was never any trouble with the Lisbon Falls reservoir. A few damp spots appeared at first on the surface, but these soon disappeared. This reservoir is 62 ft. high and 50 ft. diameter, and the walls are 20 ins. thick at the base; 1:1½:3 concrete was used and a 12,000-lb. per sq. in. working stress on the steel was assumed. The assumptions previously made would show a stress in the con-