EXPERIENCE WITH CEMENT-LINED CAST IRON PIPE[1]

By J. E. Gibson[2]

Cement has been used for lining thin shelled wrought iron or steel pipe a long time. As early as 1865, and probably earlier, this kind of pipe was made under United States patent by Finius Ball, George H. Norman, and others, and this pipe is still being used by a number of water works plants in New England. The Philadelphia Suburban Water Company has over five hundred miles of this type of pipe manufactured under patents granted Dr. D. Goffe Phipps, Hydraulic Engineer of Bridgeport, Conn. A most excellent paper on this subject by Leonard Metcalf appears in the New England Water Works Association Proceedings of March, 1909.

Cement-lined cast iron bell and spigot pipe was, I think, first used in Charleston by the writer in 1922, although at about the same time this same kind of pipe was being made in England. Since that date considerable of this pipe has been laid. In Charleston, we have laid upwards of twenty-five miles, and there are a number of other plants, throughout sections of the United States, where filtered water of aggressive or active type is prevalent, using cement-lined pipe.

At first the process of lining was the same as that used for lining the thin shelled wrought iron pipe first referred to; namely, by the up-ending of the pipe and the placing of a projectile shaped bullet or trowel in the bottom, placing the necessary amount of natural cement mortar into the pipe and on top of the projectile, and then drawing the projectile rapidly through the pipe, the cone or projectile shaped end acting as a trowel to force the cement mortar out against the walls of the pipe. Great care had to be exercised to see that the mortar was properly mixed, had the requisite amount of water, and proper setting qualities so that the lining would not bag or run after the bullet had been pulled through.

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The thickness of the lining by this process was about $\frac{3}{16}$ inch for the 4 to 10 inch pipe, and $\frac{1}{4}$ inch for 12 inch and above.

This process of lining was in use only a short while when it was supplanted by the centrifugal method, and Portland cement with a small percentage of sand was substituted for the natural or Rosendale cement. The process of lining centrifugally consists of placing the pipe on a pair of trunnions and revolving it at the rate of about 300 revolutions per minute. The mortar consists of any good grade of American Portland cement with 20 to 30 per cent of clean, sharp sand passing a No. 20 mesh screen, mixed preferably in a mechanical mixer, and then introduced into the pipe. The mortar is introduced into the pipe which is to be lined by the use of a gauge formed by splitting a 2 inch pipe about along its longitudinal center line, the requisite quantity of cement having been previously measured out and placed in the 2 inch split pipe for its entire length. As soon as the pipe has reached the proper speed, the mortar is emptied from the container or trowel pipe by turning it over and then distributed over the inner surface of the pipe by using the gauge pipe as a trowel. The size of the trowel pipe is determined by the quantity of mortar required for the desired thickness of lining and the size of the pipe which is to be lined. Care must be used to distribute the mortar equally over the surface of the pipe and to cover entirely the surface of the pipe. As soon as the mortar is equally distributed, the gauge pipe is removed, and the speed of the pipe is increased, and its revolution on the trunnion, due to the roughness of the outside, gives a tamping effect, which effectively brings the water to the inner surface of the mortar and drives out any entrained air, giving an intimate contact between the mortar and the walls of the pipe. The work, if properly done, gives a very smooth, semi-porcelain like lining which sets up very rapidly, permitting the pipe to be removed within a few minutes from the lining machine to the storage yards.

Portland cement being superior to the natural or Rosendale cement, it was believed that the thickness of the lining could be materially reduced, and this was done. The lining was tentatively adopted as $\frac{1}{16}$ inch for all pipe from 3 to 24 inches diameter, with a tolerance of $\frac{1}{32}$ inch. It was found, however, that this was too thin (of which notice will be taken later), and recently we have changed our specifications to require $\frac{1}{8}$ inch for pipe from 3 to 16 inches in diameter and $\frac{1}{4}$ inch for pipe above 16 inch in diameter, with a tolerance of $\frac{1}{16}$ inch.

In the old process, where the projectile bullet type of lining was used, it was found that the eccentricity of the pipe or deflection in its length did not materially affect the thickness of the lining, as the bullet was on a flexible rope and the mortar tended to hold it in the center of the pipe without regard to whether the pipe was straight or not; but with the centrifugal method of lining, it is found that if the pipe is out of round or not straight, the lining tends to take the centrifugal center so that the lining is at times eccentric; that is, much thinner on one side than on the opposite side. This is overcome where the lining is placed in a centrifugal type casting such as the deLavaud, Mono-cast, and sand spun cast pipes.

It is naturally our desire to leave a favorable feeling toward cement-lined pipe, but we would be failing in our duty to the users if we did not call to their attention some of the difficulties experienced with linings that were too thin.

Naturally, in making any form of castings, it is impossible to obtain a perfectly smooth finish; in fact, we feel that too smooth a surface is far from being desirable when it is intended to cement-line the castings. If the interior surface of a cast iron pipe before lined or coated were inspected by means of a microscope, it would probably resemble very much the "bad-lands of the Dakotas" as to roughness. This offers an admirable condition for the adhesion of the cement mortar to the surface of the pipe, but unfortunately, some of these pimples extend further from the surface than others, and when we attempted to make a thin lining—$\frac{1}{16}$ inch with a tolerance of $\frac{1}{32}$ inch—it was found that a lot of these pinnacles protruded through the lining and immediately began to form tubercles. Again, in some cases referred to, the lining became eccentric, and instead of having an average of $\frac{1}{16}$ inch thickness throughout, it was reduced almost to the thickness of paper on one side of the pipe, abnormally thick on the opposite side, with the result that more pinnacles projected through on the thin side than on the other. As a rule, however, the rusting took place on top of the pinnacles, forming a mushroom over the lining, and did not force the lining off; so notwithstanding the fact that perfect protection was not obtained, we feel that it was much better than that afforded by the old tar coating as we know it. Where all the pinnacles were protected with a lining of cement, however thin, tuberculation or rusting did not occur so far as we have been able to observe.

By increasing the thickness of lining to $\frac{1}{8}$ inch with a tolerance of

$\frac{1}{32}$ inch, which would give ordinarily a minimum thickness of $\frac{3}{32}$ inch, we are confident that no pinnacles will protrude, and that the carrying capacity of the pipe will be maintained indefinitely.

The first cement-lined pipe laid by the Charleston Water Department was in the fall of 1922, and tests made of some 6 and 16 inch pipe, lined by the method first employed using natural cement, gave values of "C" in Hazen's and Williams' formula varying from 128 to 141 in the case of the 6 inch pipe, and tests made of the 16 inch pipe a year later gave a value varying from 127 to 133. In the test on the 6 inch pipe, the quantity of water flowing was measured by means of a standard Crest type meter, and in the case of the 16 inch test, by pitometer. The friction losses were measured by means of U tubes, using carbon tetrachloride for the lower loss of heads and mercury for the higher. Piezometric pipes were run between points of measurement so that all instruments were located at one point in order that errors would be reduced to the minimum. All results are based upon 32 observations (the number of observations at each test) and average taken of all.

In 1924, we laid some 6 inch pipe lined with Portland cement by the centrifugal process. Tests made immediately after laying this pipe gave values for "C" in Hazen's and Williams' formula of 125 to 146, with velocities from 1.25 to 5.5 feet per second. In this last series of tests, the first two tests were made using carbon tetrachloride at $1\frac{1}{2}$ specific gravity, and considerable trouble was had with fluctuations in the manometer tube. You all appreciate how hard it is to get readings of a manometer when the liquid in the two legs is fluctuating violently. The average of all readings gave a value of 137 and omitting the first two readings, the average value was 144. Tests made this past May (practically two years later) on this same pipe covering a range of velocity from 0.9 to 4.8 feet per second, gave an average value of "C" in Hazen's and Williams' formula of 139 with a minimum of 134 and a maximum of 145. This shows the minimum to have been 96 per cent of the average and the maximum 104 per cent of the average, and the results as compared with the former test, including the two first tests, were 96.5 per cent and excluding the first two tests, 102 per cent. Sample of this pipe which has now been in use for two years is here on exhibit for the members to see. This pipe was broken out the line to insert a Tee and special to connect up meters for measuring the quantity of water discharged.

Our conclusion in the matter is that for a filtered water supply of a peaty or aggressive nature, cement-lining offers a wonderful improvement over ordinary tar-coated pipe in that it will maintain its carrying capacity indefinitely. While tests covering pipe only a few years old, such as the above, are not conclusive in themselves, inspection and tests made on the old wrought iron shell cement-lined pipe first referred to in this paper, which has been in the ground from twenty-five to fifty years under similar waters, shows no incrustation. Since cast iron pipe under the same circumstances shows a loss in capacity of anywhere from 20 to 80 per cent, it is indicative that similar conditions will be maintained in the cast iron cement-lined pipe.

Needless to say, where it is intended to line cast iron pipe, it should not be tar-coated. Some engineers in specifying a cement-lined pipe have insisted upon its being tar-coated on the outside, which adds to the expense. Upon investigation, I have reached the conclusion that the coating on the outside of the pipe is really an incidental matter, as Dr. Angus Smith, the original inventor of the tar coating, was attempting to protect the interior of the pipe from tuberculation and incrustation. It was found that to dip the entire pipe was a cheaper process than to apply the coating in any other way, and of course, this process coated the outside as well as the inside. Further, none of the gas companies so far as we can learn ever attempt to coat their cast iron mains on the outside and depend upon the natural protection of the gas with the entrained oils and tar for the protection inside. The life of their pipe seemed to be as great as that of the water pipe, so we reached the conclusion that it was not necessary to go to the expense of attempting to tar-coat the outside of our water pipe and have not in the past four years laid any cement-lined pipe with outside protective coating.

Malcolm Pirnie, consulting engineer for the West Palm Beach Water Company, has laid considerable cement-lined pipe in recent years and has had some trouble due to the lining being too thin and the pinnacles of iron protruding through the lining, which condition I have already referred to. While we have experienced no complaint ourselves, it has come to our notice that somewhere in New England they had complaint of discoloration of alumium vessels from water that was drawn from cement-lined pipe.

In closing I would refer you to the paper by Leonard Metcalf in the Journal of the New England Water Works Association of March, 1909; also paper by Charles W. Sherman on Cement-Lined Cast Iron Pipe in the Journal of the New England Water Works Association on March, 1926; the annual reports of the Commissioners of Public Works, Water Department, Charleston, S. C., for the years 1923 and 1924; and a paper by me in Engineering News-Record of September, 7, 1922, Volume 89, No. 10.

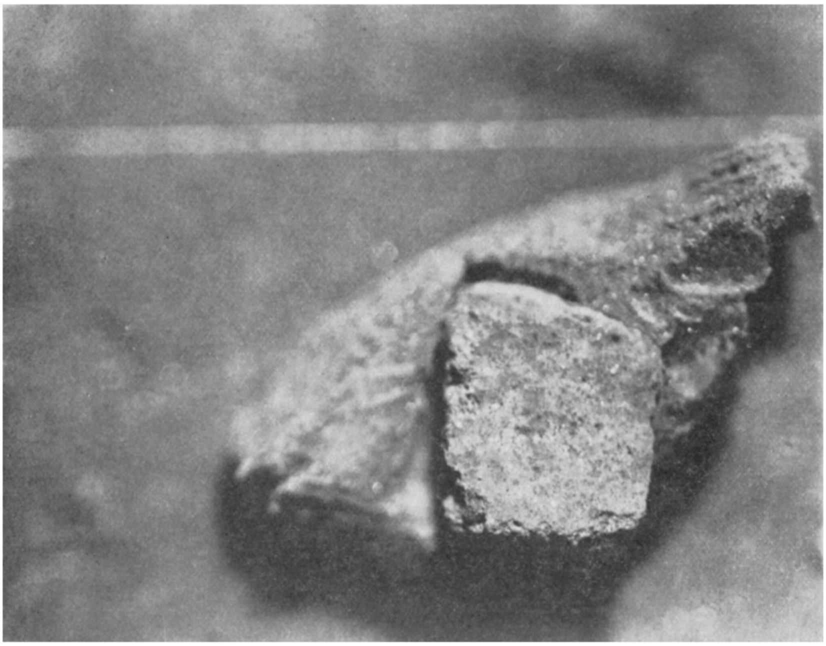

FIG. 1. LINING MADE BY "BALL" OR "BULLET" METHOD, USING "NATURAL" CEMENT

This lining varied in thickness from $\frac{1}{32}$ to $\frac{3}{16}$ inch. (Magnification by ten diameters.)

DISCUSSION

H. Y. CARSON:[3] Mr. Gibson's able presentation is a good résumé of the experience with cement lined cast iron pipe since he started its use in Charleston, South Carolina, in 1922.

This development or improvement is, of course, one in which the makers of cast iron pipe are very greatly interested, because it has

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yielded an acceptable solution of an old water works problem, increasing the durability and service value of cast iron pipe, and above all, preventing a loss of capacity through tuberculation. The greater assurance of maintaining a high flow that will not decrease over a period of many years is extremely important.

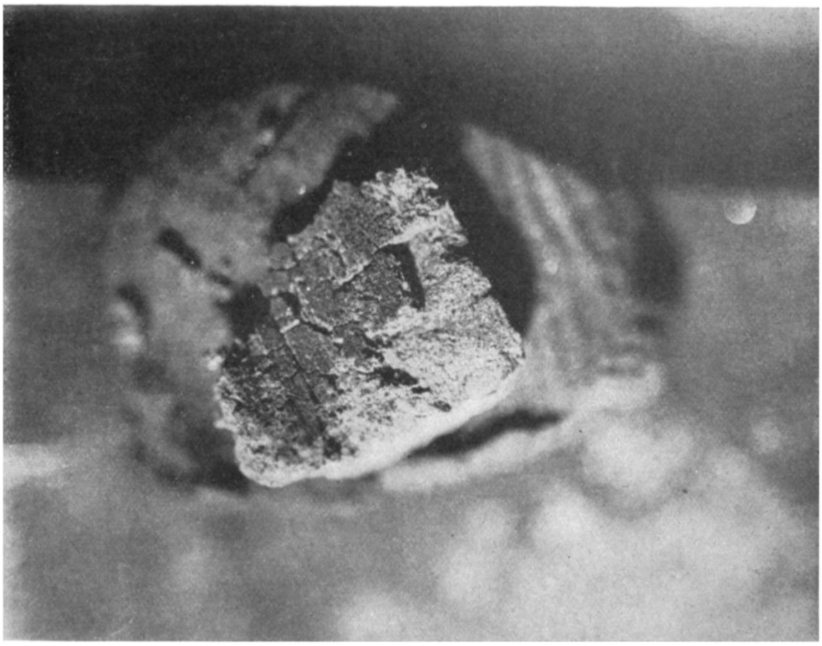

FIG. 2. SPECIMEN OF SAME TYPE OF CEMENT LINING USED IN PIPE AT DANVERS, MASSACHUSETTS, FOR THIRTY-NINE YEARS, THREE MONTHS

This lining was exceedingly smooth when first removed but upon drying in air shows a porous outer shell $\frac{1}{64}$ inch thick (the dark portion) which was easily crumbled and detached from underlying structure. (Magnification by ten diameters.)

It is the speaker's opinion that the newly organized Committee of this Association whose duty it is to report on Cement-Lined Cast Iron Pipe will be of real service by recommending a standardized practice based upon the available information. Tentative specifications have already been prepared, and much has been done, but further exact knowledge will be needed in order to gain improvement.

Theoretical considerations indicate that only a very thin lining of cement is needed on the inside walls of cast iron pipe effectively to keep down or prevent tuberculation. Practical considerations, however, dictate that an average thickness of $\frac{3}{32}$ inch is necessary, because a tolerance or variation in thickness of $\frac{1}{32}$ must be allowed for the eccentricity or other irregularities that normally occur in all pipe which are to be lined with cement. Perhaps other con-

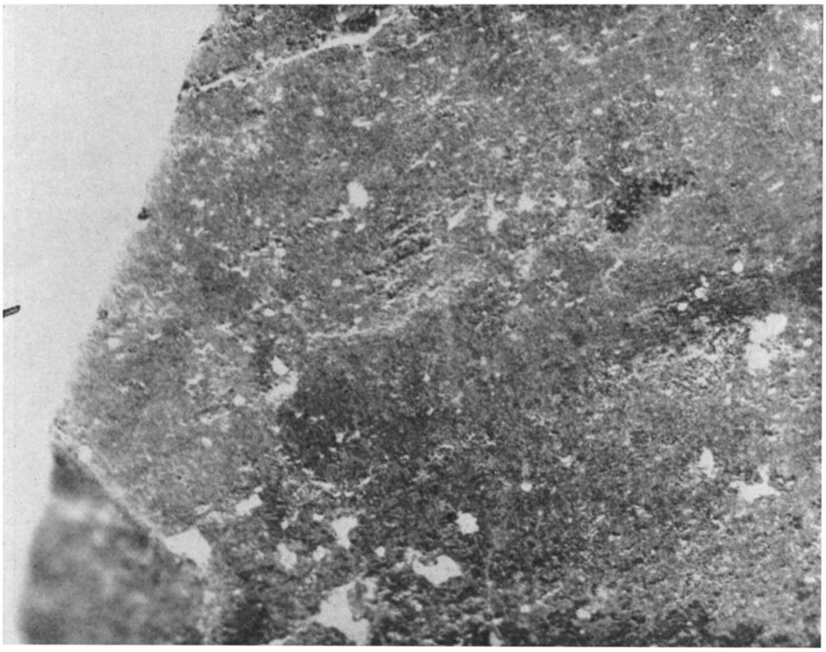

FIG. 3. CEMENT LINING MADE OF NEAT "NATURAL" ROSENDALE CEMENT $\frac{1}{2}$ INCH THICK, USED IN WATER LINES OF TALLAHASSEE, FLORIDA, FOR TWENTY YEARS

Note that outer surface is somewhat leached out the same as old lining from Danvers, Massachusetts. (Magnification by ten diameters.)

siderations are essential, such, for example as the ability of the water to dissolve away the cement over a long period of years.

It was with this last named thought in mind that the speaker made a careful study of linings under the microscope, and as some of the things found may be of interest they are here given.

The specimen, figure 1, shows a surface of a small section taken from a cement lined pipe made by using Rosendale (natural) cement which was applied by pulling a special trowelling device or ball through the bore of the pipe and thereby placing a lining of neat cement varying in thickness at different points in the periphery of the pipe from $\frac{1}{32}$ to $\frac{1}{16}$ inch.

Some of this same type cement lined pipe had been used at Danvers, Mass., for thirty-nine years and three months, and when first

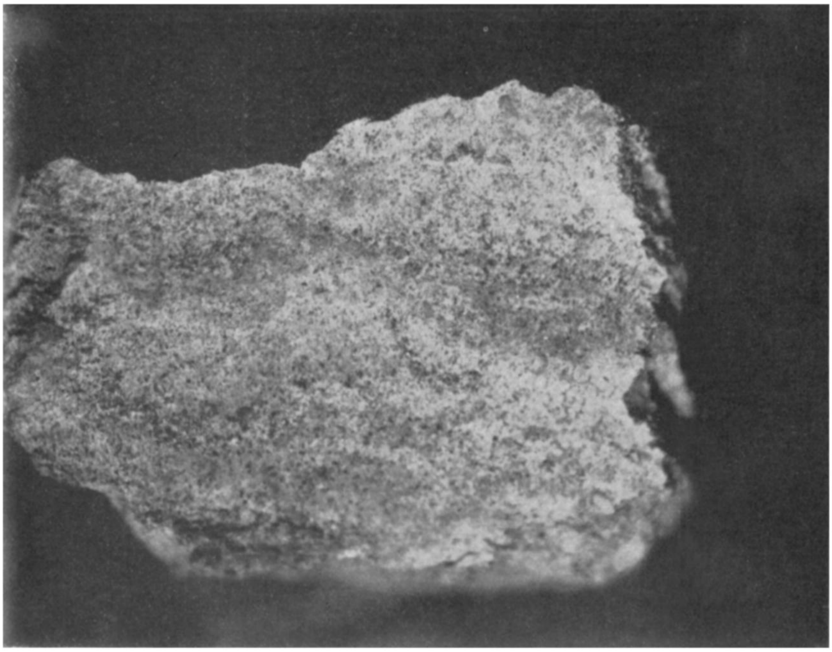

FIG. 4. CEMENT LINING BY $\frac{1}{8}$ INCH THICK APPLIED TO 20 INCH CAST IRON PIPE STRUCTURE

Of this lining 75 per cent is Atlas Portland Cement plus 25 per cent clean, sharp sand, made as per specification of West Palm Beach Water Company. Surface about the smoothness of porcelain. This lining was cured by covering ends of pipe with canvas and preventing loss of moisture during period of 24 hours. (Magnification by ten diameters.)

observed after removing from service the lining appeared to be smoother with old age. A chemical determination of various portions scraped from the lining showed it to have a slight increase in CO_3 content as compared to new linings, and moreover, the CO_3 content increased in the lining section as the wetted side of the cement was approached. The cement next to the metal of the pipe walls had apparently remained unchanged by time.

After this lining had become thoroughly dry in air, the outer shell about $\frac{1}{64}$ inch thick (see figure 2) had the appearance of shrinking or shriveling and even of detaching itself from the underlying cement structure. This underlying structure, although it had been in use for more than thirty-nine years, was apparently unaffected.

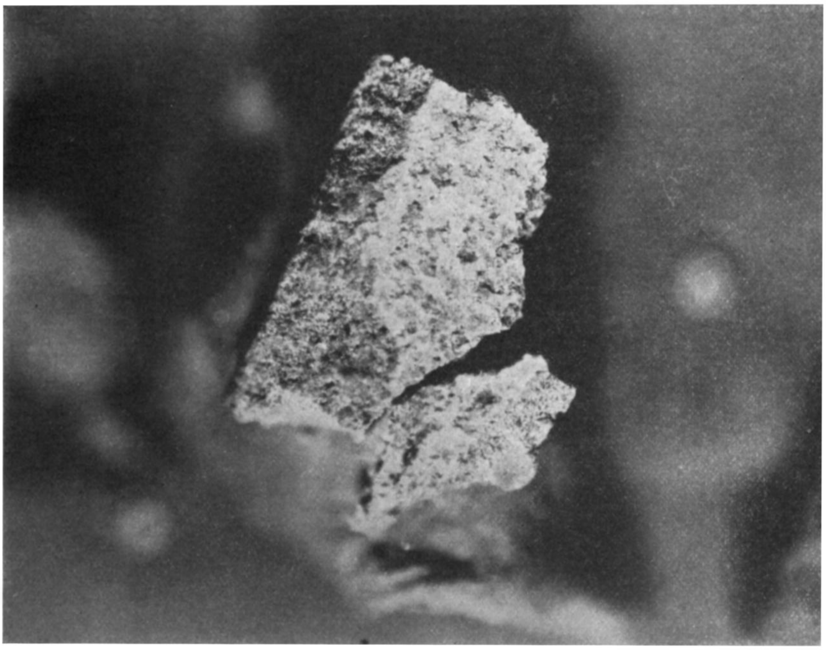

FIG. 5. CEMENT LINING BY $\frac{1}{16}$ INCH THICK, AS APPLIED TO 4 INCH CAST IRON PIPE

Structure of this lining is 75 per cent Atlas Portland Cement plus 25 per cent clean, sharp sand. This surface has a rougher feel to the hand than that shown in figure 4. Under the microscope we find small cavities which do not appear to the naked eye. These cavities probably caused by deficiency of water in cement at period of first hour after beginning to set. (Magnification by ten diameters.)

The outer $\frac{1}{64}$ inch shell is the part of the lining referred to above which showed by chemical analysis to have picked up CO_3 from the water and at the same time had given to the flowing water some which no doubt the water had dissolved. Possibly the soluble calcium hydroxide had been given up to the flowing water by the cement.

In figure 3 a sample of 4 inch cement pipe is shown which is in use at Tallahassee, Florida, for twenty years. This pipe was made and installed by the American Pipe and Construction Co. of Philadelphia, and the lining shown is $\frac{1}{2}$ inch made of neat Rosendale (natural) Cement. Like the specimen shown in figure 1 used at Danvers, Mass., it had been affected by the flowing water to a depth of about $\frac{1}{100}$ inch. It may be observed from the photograph that the Florida water did not discolor the outer surface of the cement as had the water in New England. Perhaps this can be explained by the difference in color between the two waters—that in New England being somewhat like tea.

Cement linings made centrifugally have not always been equally smooth in the outer texture of the surface as can be seen by examining figures 4 and 5. That shown in figure 4 is of about the same degree of smoothness as ordinary porcelain, and is at present typical of the lining described by Mr. Gibson as being used at Charleston, South Carolina, and by Mr. Pirnie as being used at West Palm Beach, Fla.

In conclusion, the speaker repeatedly finds that in the unfiltered municipal water supplies the acid, or other dissolving properties of the water, has not damaged the cement linings to any marked extent. We do not know, of course, what new conditions may be imposed by pumping filtered and chlorinated water into the cement lined distributing mains, but to be on the side of reasonable safety it would seem wise (at least until proved otherwise) to use cement linings which have a minimum thickness of $\frac{3}{32}$ inch. This means that the specified average thickness must be $\frac{1}{8}$ inch as brought out in Mr. Gibson's paper.