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TESTS OF CLAY AND CEMENT PIPES

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T E S T S

OF

CLAY AND CEMENT PIPES

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IN

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BY

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APPROVED BY.

I N D E X

TABLES:

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I N T R O D U C T I O N.

This work was taken up with two objects in view, First:--To obtain a definite uniform and practically intrepretable set of data on the essential properties of our western sewer pipe, and drain tile. By western pipe is meant any that is manufactured or that finds a market in this intermountain region. Second:--To ascertain as far as possible tests which may be best accepted as standard, so as to give a uniformity to sewer pipe and drain tile testing, and thereby make all results definite and practically valuable. This work includes, external pressure tests, internal pressure or hydraulic pressure tests, and absorption tests.

In order to insure definite and uniform results the University purchased an Olsen testing machine designed purposely for the testing of clay and cement pipe. The machine has a bed plate 48" square and an allowable opening 48" high, which allows the testing of pipe up to 30" (inside diameter).

Of these tests the external pressure test is at present the most important one. Since with sewers or in general water pressure lines, it is considered bad practice to allow any pressure at all internally. This, because the joints can not be made to reliably stand pressure and a pipe line is no more efficient than its joints. In the case of a sewer becoming clogged, the pipes would seldom be subjected to a pressure greater than 10 pounds per square inch or 23 foot head, the depth of the man-hole. The internal pressure tests show that this demand as far as bursting pressure is concened is far on the side of safety, even when the counter-acting effect of the external pressure is neglected. The importance of internal pressure tests is the test for sweating or permeability of the pipe, and this more as a comparison of the pipe properties than considered as a leak, since in all possibilities the pores soon become filled and the pipe made impermeable. Could the joints be made as strong as the pipe, which would allow clay and cement pipe to be used in low pressure lines, then the internal pressure tests would possibly be of first importance. If the absorption or permeability of a pipe does allow a penetration of the sewage these qualities must not be overlooked; but a discussion of this phase of the question is hardly in the field of this paper.

To augment the comparison and thereby make the data of more practical value, the University invited all the western manufactures to send a set of samples for the tests. Of these the Denver Fire Clay, the

Utah Fire Clay, and the Utah Glazed Cement Pipe Companies responded.

Considerable testing of clay and cement pipe has been done heretofore, chiefly by the larger cities, the manufactures and the colleges. As a rule the manner of testing varies widely even with individuals. The Department of Experimental Engineering of the Iowa State College has apparently gone into the problem more than any one else, they having worked out a set of specifications for standard tests on the bearing strength and absorption. These specifications were followed in the present tests, there being no reason to diverge from them except in a minor detail in the method of applying the load to the plunger, in the compression tests.

The work was done in the Department of Mechanical Engineering under the direction of Professor E. H. Beckstrand, to whom the writer extends his acknowledgements for help and suggestions received during the tests and the working up of the results. Due credit must also be given the manufactures who not only furnished the pipe for the tests but gave many suggestions that aided greatly in the work.

VITRIFIED CLAY PIPE DEFINED.

Fire clay in general is composed of silica, alumina, ferric or ferrous oxide, magnesia, alkalies, and combined water plus organic matter. The combination of the silica and alumina with the fluxing impurities, the alkalies, lime, and iron form compounds, capable of fusion. The fusion point varies widely in the different fire clays, depending on its fluxing properties, ranging from 1200° F. to 2500° F. or even higher.

There are three distinct stages in the process of fusion, viz.--Incipient fusion, vitrification, and viscosity. As the clay is heated up it reaches a stage when the surfaces of the small particles become fused, the particles themselves holding their individual form. The whole now becomes combined together by these fused surfaces thus forming a hard compact mass. This stage is known as the point of incipient fusion. If the heat is continued beyond this temperature the particles themselves become fused and the whole settles into a monolithic, vitrified body; this is the vitrification point. If the temperature be still raised the whole becomes viscous and unable to hold its form and begins to flow; it is then said to have reached the point of viscosity.

The range between the point of vitrification and viscosity is very important in the manufacture of clay pipe. If this range only covers from 80° to 100°

the pipe stands in danger of reaching the point of viscosity, since it is difficult to control the temperature within a few degrees. To guard against the loss which would come if the pipe reached the melting point, the tendency is to keep the temperatures below the point of vitrification which produces a pipe more porous and of a lower strength than if vitrified.

The range between these two points, the vitrification and point of viscosity depends to the greatest extent on the quantity of lime in the clay. Clay with a low percentage of lime may have a difference of as much as 600° F., while with a high lime content it might be less than 100° F.

The color of the vitrified pipe depends on the iron. If the clay is burned in an oxidizing atmosphere the iron will change to the ferric condition and the clay will be colored red. While if the atmosphere is reducing,the ferrous compounds will be formed and the pipe changed to a buff or bluish-black. The ferric iron also has the feature of giving up part of its oxygen at high temperatures which also has the tendency to turn it dark. The color may, however, be turned red during cooling if air is allowed to enter the furnace. If burned at a high temperature this is most likely the case when the middle of the pipe wall is black and the outer edges red. The same coloring might also occur if during burning there is insufficient air to oxidize the iron.

The glaze on the vitrified pipe is obtained by throwing salt on the fire at the end of the burning. this gives the pipe a glassy surface, a sodium-silicate being formed; the pipe high in silica producing the best glaze.

A general description of the manufacture of clay pipe may be of interest. The clay is first ground to a fineness that will pass through a 12 mesh screen. This is done in a dry pan which consists essentially of a circular pan 7 or 8 feet in diameter with a perforated bottom around which two iron wheels weighing about 4,000 pounds, travel. The clay then,after being screened,goes to the wet pan where it is tempered, i.e., is mixed with water and worked to a moulding consisting which is about that of stiff putty. The wet pan is similar to the dry pan except that it has a solid bottom. From the wet pan it is elevated to the charging floor where it is fed into the moulds.

An idea of the mould may be obtained from the Fig. 1. The clay is fed into the cylinder A at the top. The steam cylinder B drives the plunger P, thus moulding the pipe by forcing it through the ring opening O. The bell of the pipe is moulded first by securing the form F, in position at the mouth of the moulds.

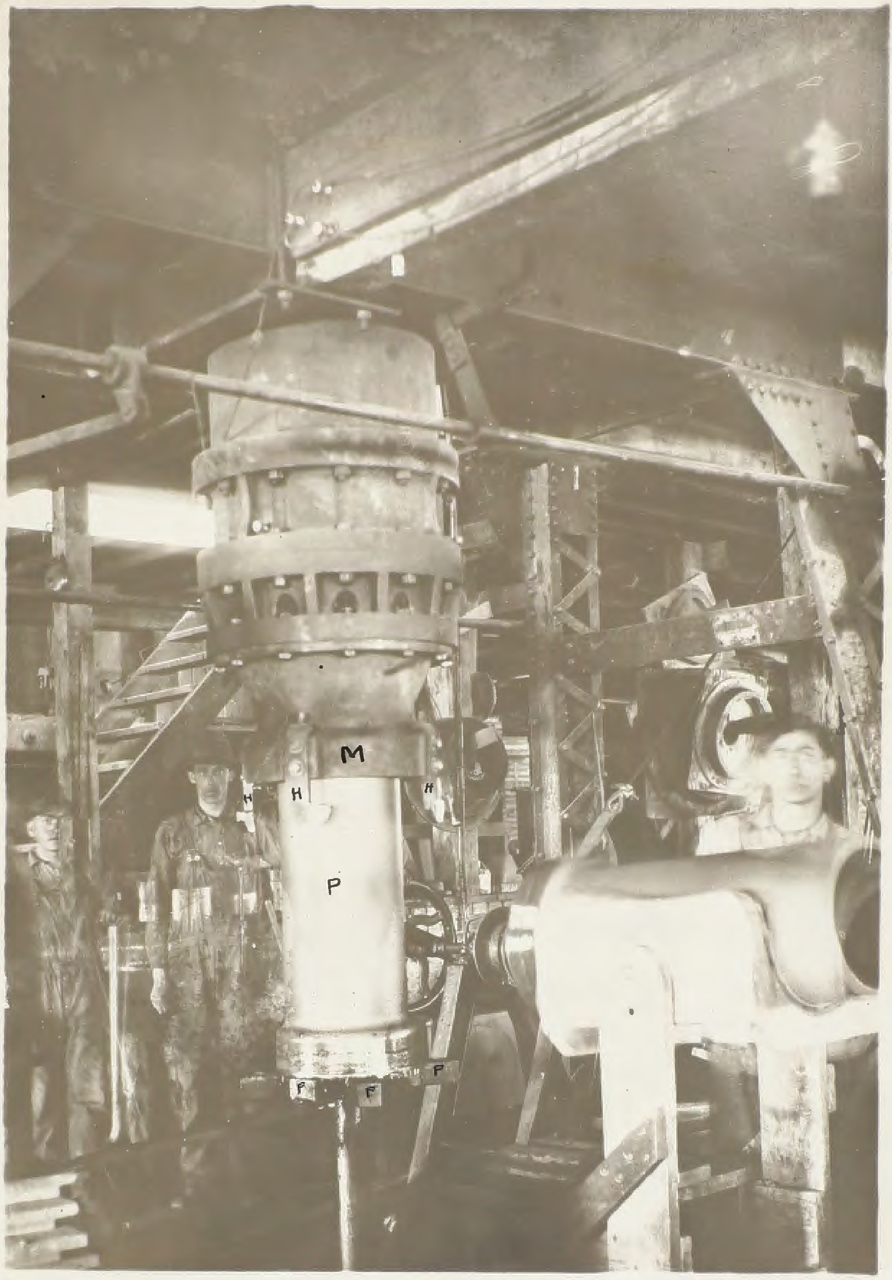
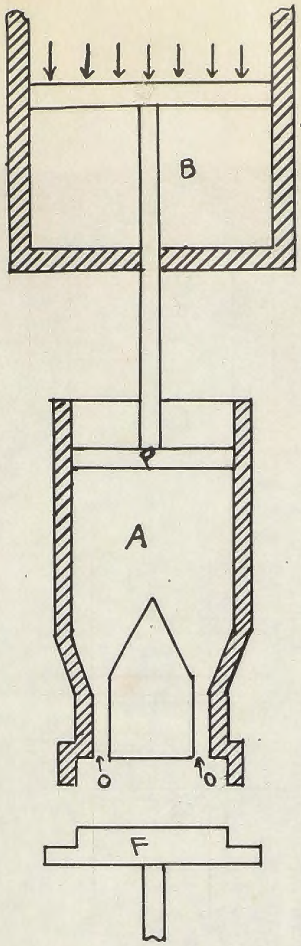


PHOTO. No.1.
VITRIFIED CLAY PIPE MOULDING MACHINE
UTAH FIRE CLAY



Fiq.1

After moulding the bell, the standard F moves down acting as a support for the pipe. When the pipe has issued to a sufficient distance it is stopped and cut off with a wire or knife. Photograph No1, shows a pipe partly moulded. P is the pipe, F the bell form, H the hooks for securing F, and M the mouth of the moulds

Before burning the pipe it is cured by slowly drying it in a warm room. The pipe is burned in down draught kilns, the temperature ranges at about 2200° F. The actual fire lasts about four days, two days being required to cool the kilns off.

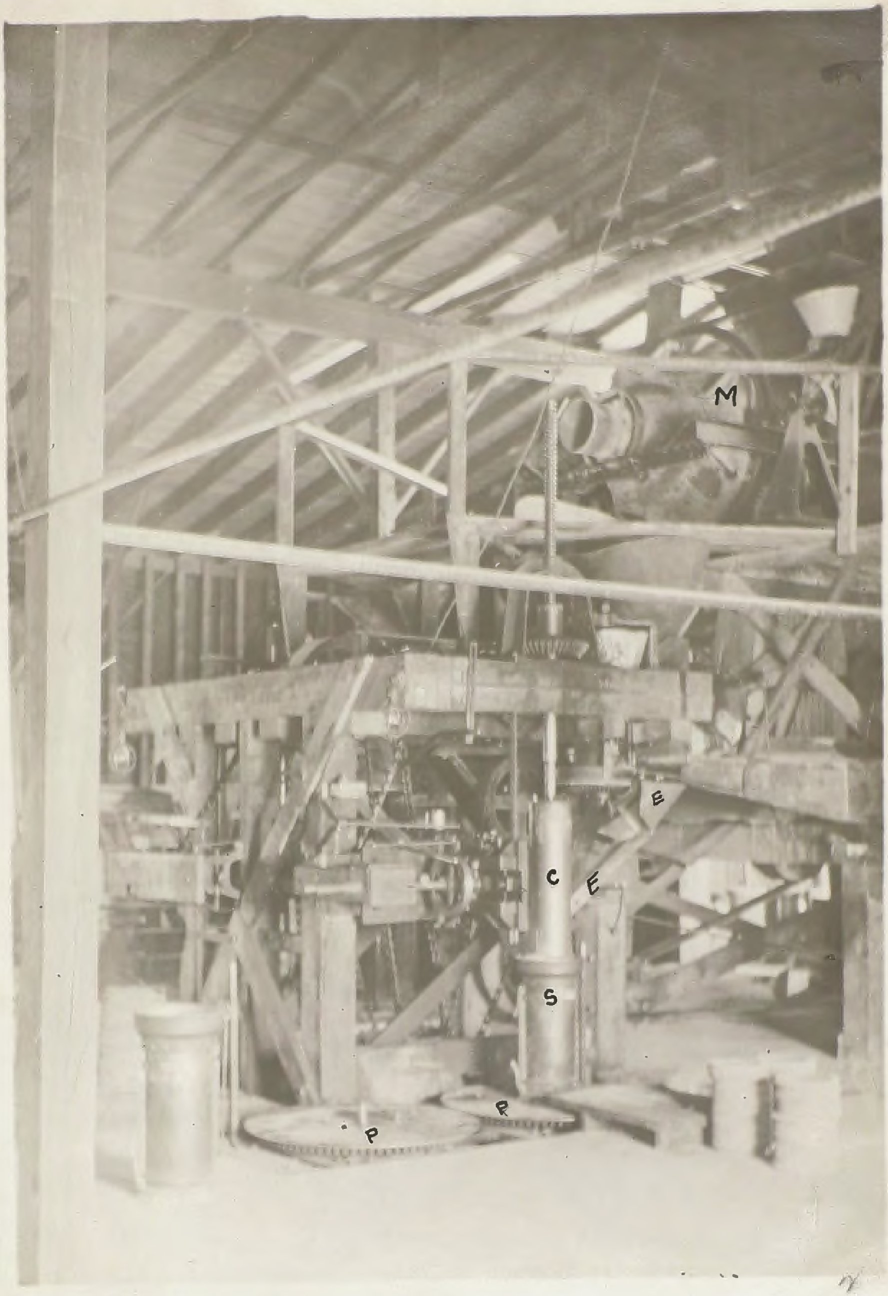


PHOTO. No. 2
GLAZED CEMENT PIPE MACHINE
UTAH GLAZED CEMENT PIPE COMPANY

GLAZED CEMENT PIPE DEFINED.

As the concrete is worked into the molds in the making of glazed cement, or machine made pipe, as it is sometimes called, the pipe is kept revolving about the core of the moulds. The finest constituents of the mix are in this way brought to the inner surface of the pipe wall, thus producing a hard polished impervious lining. From this lining originated the name Glazed Cement Pipe. The manufacture of glazed cement pipe is about two years old and during that time the quality has been improved to a point that places it in competition with the vitrified clay pipe.

A description of its manufacture may give a better idea of the pipe. Photograph No.2, is a view of one side of the double machine of the Utah Glazed Cement Company; S is the shell of the mould which revolves about the core C. The hammer H, actuated by a cam at C tamps the concrete into the moulds as the shell revolves, the core remaining still. The shell is attached to the revolving platform P. There are two platforms for each machine. While the mould on one platform is being filled, the shell on the other containing a completed pipe is being removed and an empty shell attached. When a pipe is completed the core

C is drawn as is shown in the photograph, the platforms are then shifted, thus moving the completed pipe from under the core and bringing the empty shell in its place. The completed pipe is then carried to the steam room and the shell removed.

All machine made pipe is made from a dry mix, i.e., the concrete is just moist. This constituency is necessary for the concrete to pack in the moulds under the hammer so that it will be able to support itself when the shell is removed. The concrete is mixed in the mixer M and is fed into the mould in a continuous stream through the spout S.

After the concrete has hardened sufficiently, which takes about 24 hours, water is sprayed on the pipe and the steam is then turned on. The steam has to rise through a trough of water which causes it to be wet. The pipe is thus cured in a warm wet atmosphere. The curing usually lasts from 8 to 15 days.

All pipe from the Utah Glazed Cement Pipe Company was of the following mix:

1 - part cement

2 - parts sand and gravel mixture

The sand and gravel mixture was composed of:

2 - parts gravel

3 - parts sand

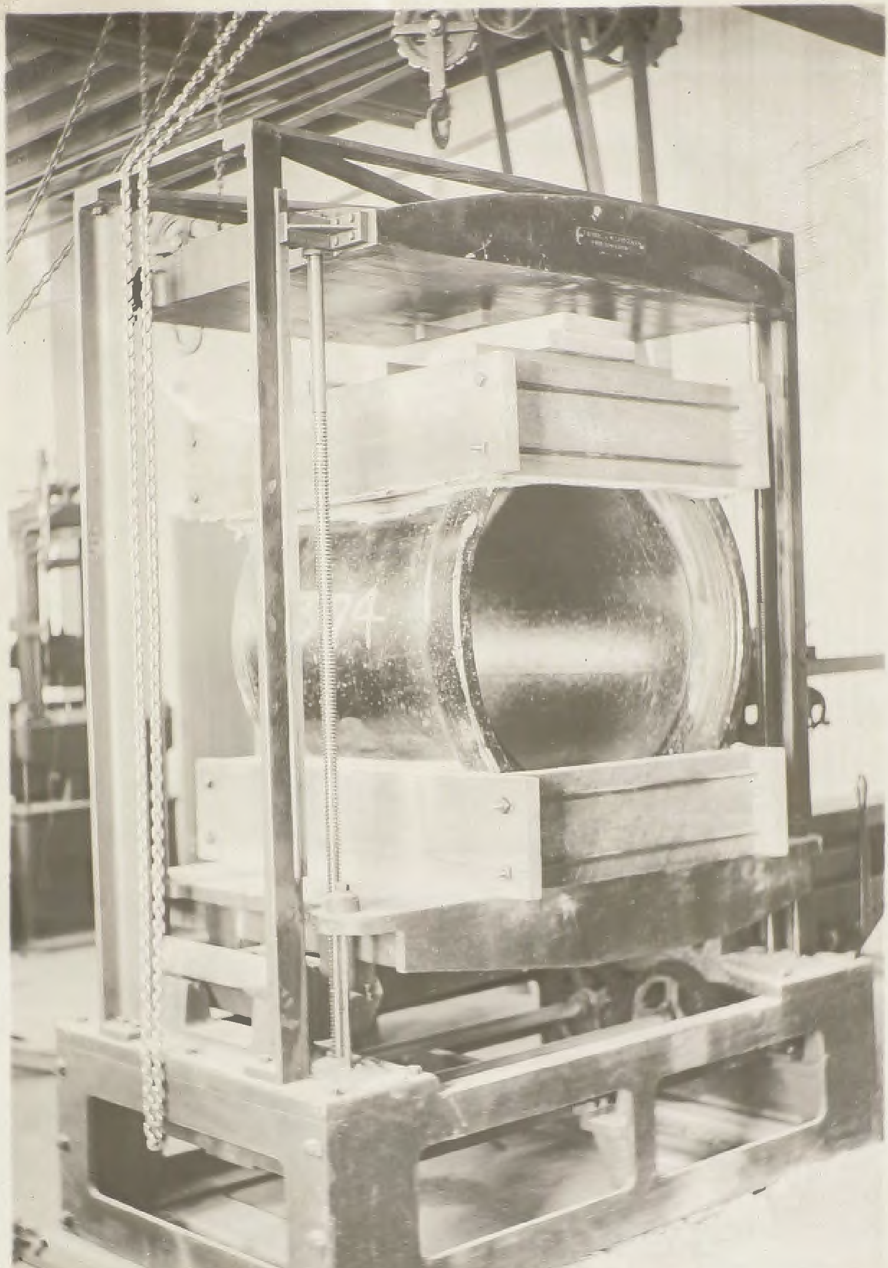


PHOTO. No.3.

PIPE READY FOR TESTING
Showing placement of pipe and frames, and arrangement of central bearing.

EXTERNAL PRESSURE TESTS.

Definiteness and uniformity of loading are the essentials of testing for the external pressure strength of pipes. The bteaking load must be applied in such a manner that it presents the same conditions for each and every pipe tested. Of the methods yet used or suggestedthe one recommended by the Engineering Experiment Station of the Iowa State College appeaared to best fill these requirements, and is the one used in the tests of which this paper treats.

This method consists of bedding the pipe below and above in sand for one-fourth of the circumference, measured on the middle line of the pipe wall; and applying the load through these sand bearings. The method is well illustrated in photograph No.3, F and F' are the frames containing the sand, P is the plunger which fits inside the top frame F' and bears directly on the sand. The load is applied to the plunger from the machine head H, by the central bearing B. A cloth attached to the lower side of the top frame prevents the sand from escaping between the frame and the pipe. The top frame is slightly raised so as not to bear at all on the pipe.

It has been suggested by many persons who saw the tests that the pipe should be entirely imbedded in the sand and thus more nearly parallel the actual conditions of the trench. The Bureau of Sewers of the city of Brooklyn tried this method. The pipe was placed with a firm bed of sand underneath, eight inches of sand bedding on top and a bedding of sand of one-third the diameter of the pipe on each side. A twelve inch pipe under these conditions to satisfy the specifications, had to stand a crushing pressure of 3,000 pounds per linear foot without cracking. All sizes larger than twelve inches were required to sustain a pressure of 4,500 pounds per linear foot. The Bureau found that with this method there was an indefiniteness of loading on the pipe due to the fact that it is not possible to place the sand around the pipe so that it would always have an equal bearing in all directions. This uncertainty of the distribution of the pressure on the pipe, and the fact that this method, too, is only comparative rather than producing the exact conditions of the trench, lead the Bureau to use a more simple and definite manner of testing, that known as the Knife-edge test.

In the Knife-edge test, the bottom of the pipe is bedded in sand through an arc of 60° and the pressure applied at the top by a plaster-of-Paris form, one inch wide by one and one-quarter inches thick, made of a one to one mixture of plaster-of-Paris and sand. Still another arrangement used by Brooklyn is to use two plaster-of-Paris strips 60° apart instead of the sand bearing at the bottom. Either of these methods have the disadvantage of the plaster-of-Paris strips not conforming to the unevenness and irregularities of the different pipes, and the excess trouble of placing and fastening these strips.

Marking and Measuring:

The samples on being received at the laboratory were given a laboratory number. These were given in series so that each company's pipe could be easily told by the number; e.g., all numbers below 300 designate the Utah Fire Clay Company's pipe; numbers from 300 to 400 disignate the Denver Fire Clay Company's pipe; and numbers from 400 to 500 designate the Utah Glazed Cement Company's pipe.

Dimensions of the pipes were all carefully taken, special care being spent at the pipe's critical points, i.e., where the determining stresses of the pipes strength occur. Perhaps it may appear that undue exactness was taken for materials of such varying properties as clay and cement. But exactness in this case might give us a key to the reason of some of these varying properties, if so, the extra time was well spent. At least, close measurement gives an idea of the irregularities of both the clay and the cement.

To systemize the measuring and placing of the pipe it was marked off in quadrants measured on the middle line of the pipe wall. This was quickly and easily done by means of two straight edges fastened (Fig.No2) together at right angles and each graduated from the center outward. The quadrant was then marked by a point horizontal to it on the outside of the pipe. These quadrant points were then numbered by dots thus: . - .. - ... - .... - as shown in Fig. 3, and chalk lines drawn through the quadrant points to aid in placing the pipe.

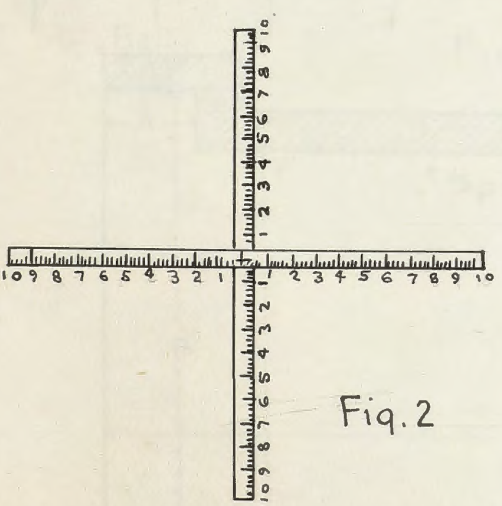


Fig. 2

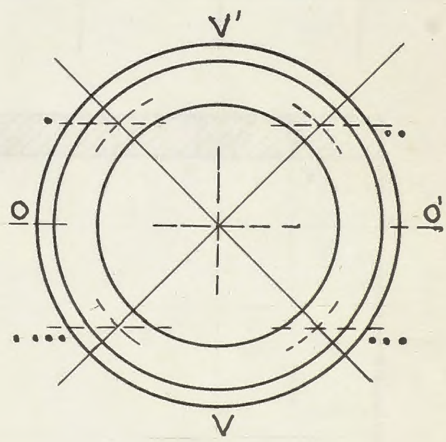


Fig. 3.

The pipes were placed in the sand with . and .. at the top. The greatest stress, as will be proven later, comes at the top and bottom of the pipe, between . and .. and ... and ...., i.e., at V' and V Fig.3, and through these points the following measurements were taken, length over all, depth of bell, thickness of bell, and thickness of spigot. Fig. 4, is an example of the measurements taken of each pipe; the upper row of values are for the top of the pipe at V' and the lower row for the bottom of pipe V.

No	Wght	Length over all	Dpth of Bell	Dia. of Bell	Thickness of Bell	Inside dia. of Spigot Bell End	Inside dia. of Spigot Spgt End	Thickness of Spgt	Crushing Prsure	Rmks
316	95.5	32.8	2.6	13.02	.92	9.92	9.80	1.02	7170	
		32.9	2.7	13.06	.92	10.20	9.86	1.10		

Fig. 4

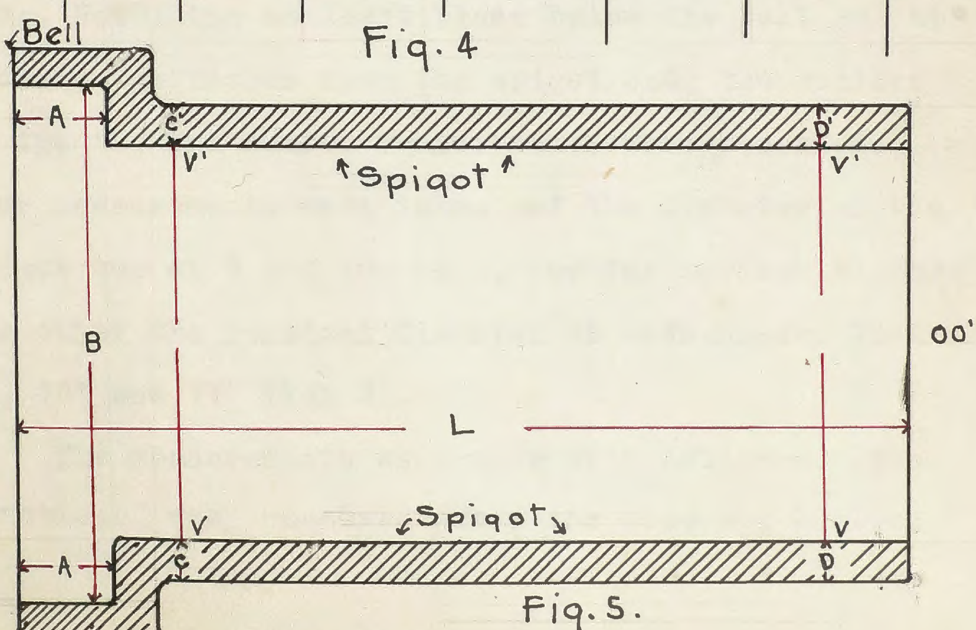


Fig. 5.

The pipe as soon as received was placed in the laboratory which was kept at room temperature, thus giving it a chance to dry out before being weighed and tested. This was not possible, however, with the cement pipe since it was tested within a couple of days of the time it was received and was still damp when tested.

The length of the pipe was taken to the nearest tenth of an inch by means of a rule with an attached hook as shown in No.6. The depth of the bell was measured

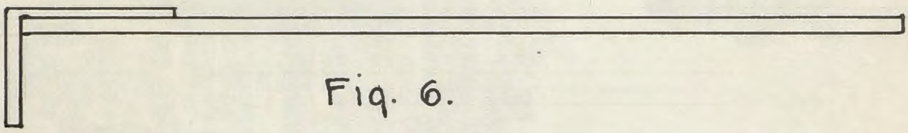


Fig. 6.

to the nearest tenth of an inch and at about the middle of the shoulder; its thickness was taken near the shoulder and to the nearest one-hundredth of an inch. The thickness of the spigot was taken at C (Fig. No.5) the smallest place below the bell and at D about two inches from the spigot end; the smaller of the top and bottom measurements were recorded. Four measurements were taken of the diameter of the spigot two at G and two at D, one the horizontal and the other the vertical diameter at each place, that is, OO' and VV' (Fig 3).

The measurements were made with calipers. The thickness was measured after the pipe was broken.

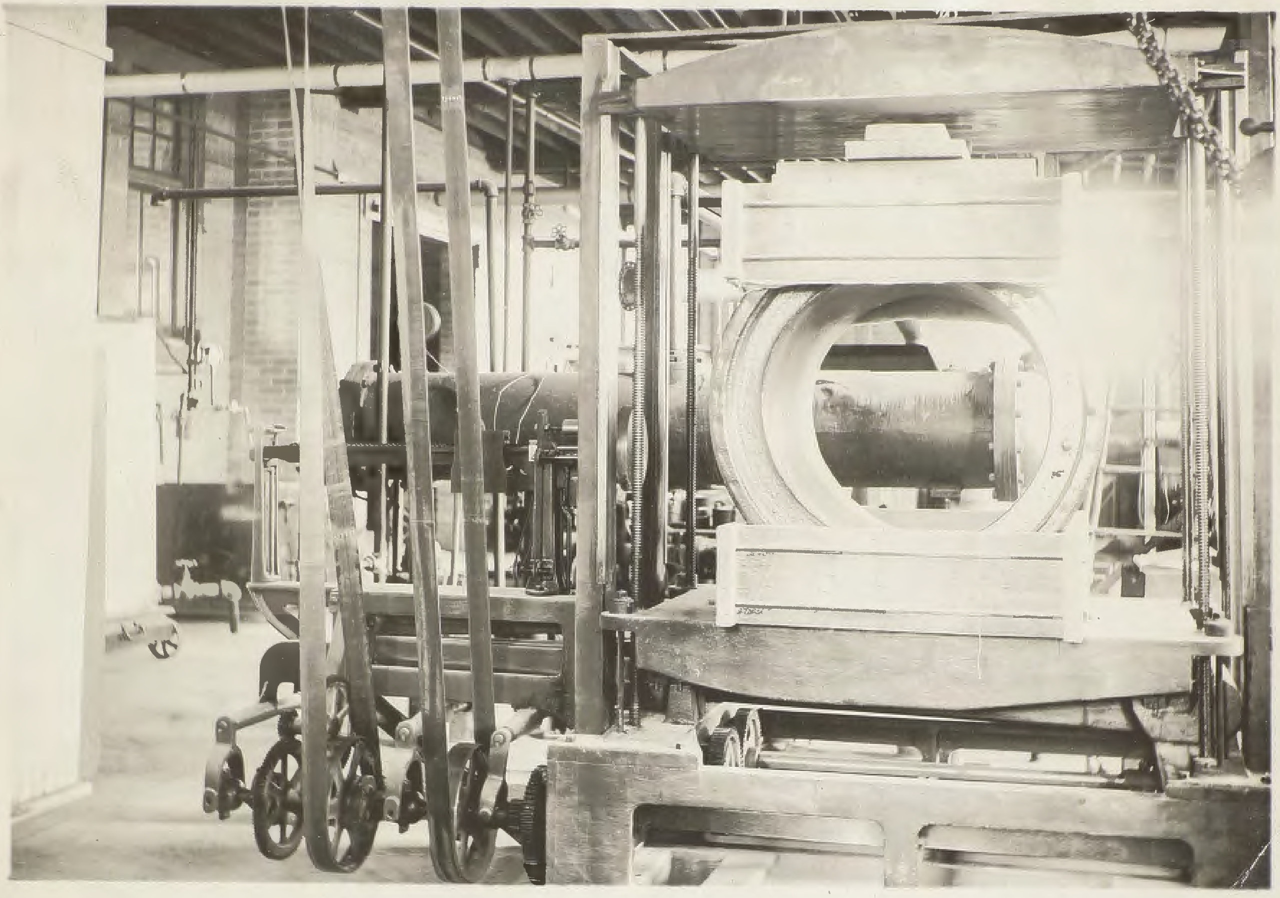


PHOTO. No. 4.
SIDE VIEW OF TESTING MACHINE

PHOTO. No. 7
MANNER OF HANDLING AND PLACING A LARGE PIPE

Any pecularity in the burn, glaze, or brake were noted under remarks. And when possible the place it occupied in the furnace during burning, that is, whether top or bottom pipe was also noted. This fact it was thought might possibly help in the selection of pipes from their physical appearance.

Testing:

Photographs NO's 3 and 4, show clearly the general design and working parts of the machine. The machine adds to the applied load the weight ot the sand and pipe and hence it was necessary in each test to subtract the weight of the bottom box and three-eights the weight of the pipe from the reading; five-eights of the weight of the pipe, and the top box being considered as part of the load. The speed of the machine was used which required from one and one-half to two minutes to apply the load. It was found, however, that the time of applying the load as long as it was applied steadily, and without interruption made no noticeable difference in the results.

Plate No.1, is a drawing of a sewer-pipe frame; the drain tile frame being the same except that it is not notched for the bell. The frames were all constructed to satisfy the specifications recommended by the Iowa

State College. (See appendix) The size of the top frame for a pipe was found graphically thus: CC' Fig No.7 is the one -forth of the circumference of the middle line of the tile wall, a line drawn through CC' parallel to OO' is cut by the outside circumference of the bell at B and B'. The distance BB' is the necessary width of the frame for the bell. The thickness BS is then added inside this frame to make it fit the spigot. It is not necessary to make a special bottom frame for each pipe since the pipe can be bedded in the sand satisfactorily if the frame is for a larger pipe.

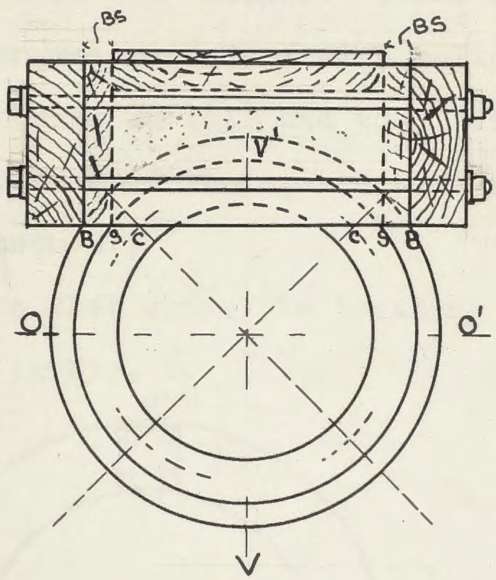


Fig. 7.

For all pipe up to 12 inches in diameter the cloth on the top frame for holding the sand may be attached in one piece as shown in Fig. 8, the trouble of refilling the frame for each test is in this way eliminated. For all pipe over 12 inches it is best to attach the cloth in four pieces which are large enough to lap so they will hold the sand well. This requires the frame to be filled each time, nevertheless, it is more easily and accurately fitted on the large pipe than if the cloth is in one piece, and it is possibly as quick.

The pipe is best bedded in the sand on the lower side by working or tamping it around the pipe with a flat iron bar about one-quarter of an inch thick by one inch wide. It can is this way be given a perfectly even bearing at all points.

Two square iron bars (1" x 1") were used for applying the load to the plunger. These proved more satisfactory than rollers since with rollers the top roller has a tendency to roll and thus shift the position of the load. And the square bars allow ample freedom for adjustment.

The stresses that cause the breaking of the pipe walls are shown in Fig. 9.

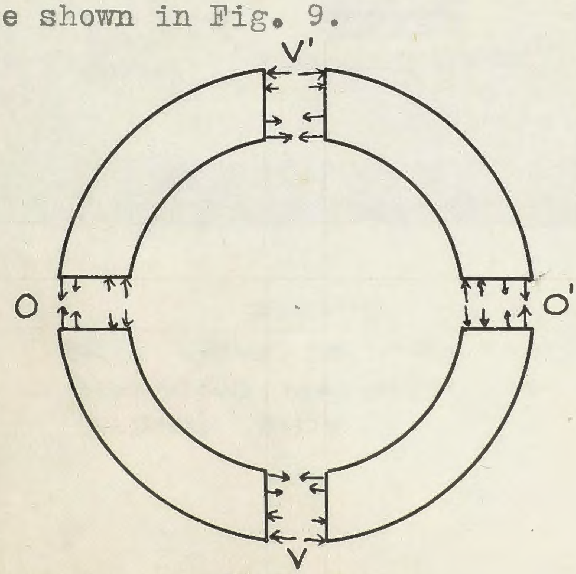


Fig. 9.

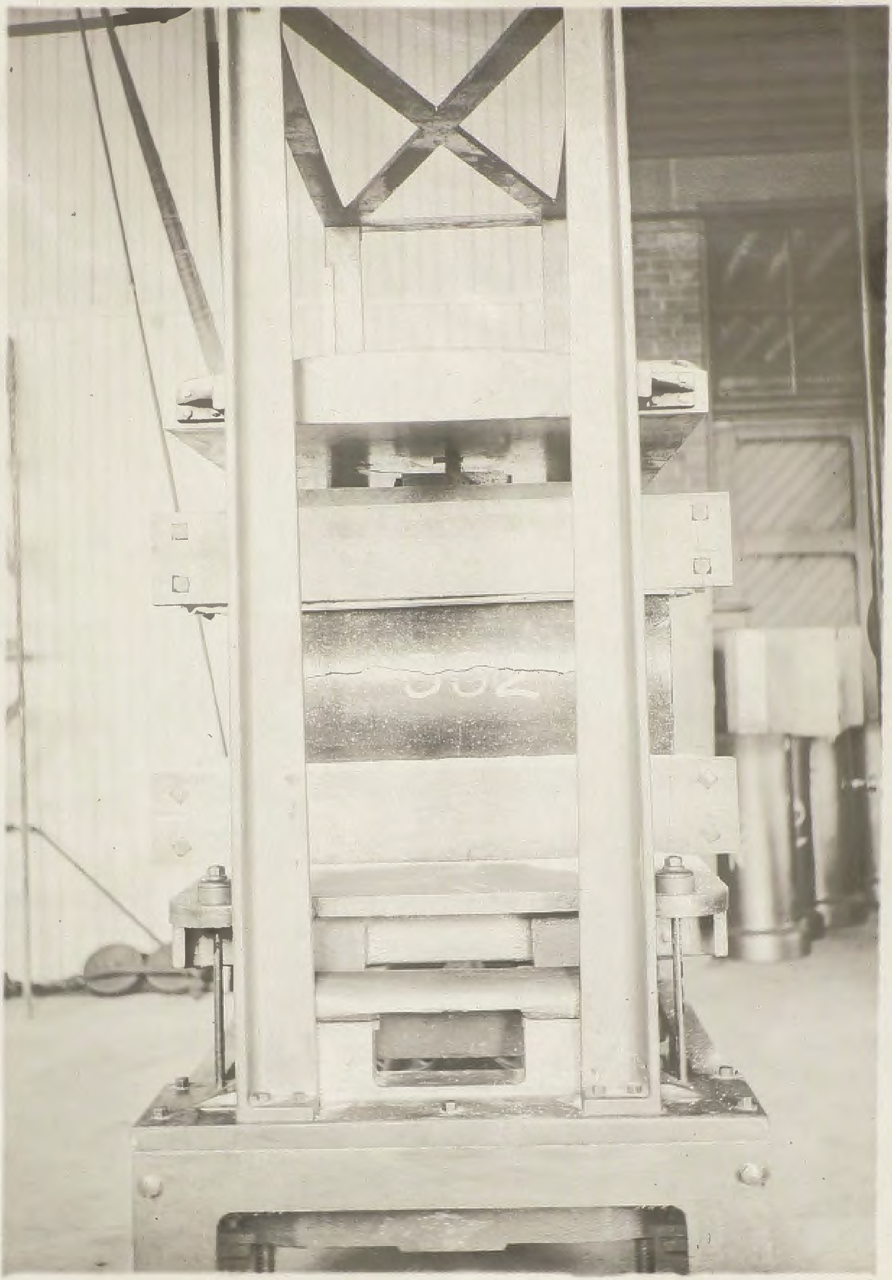


PHOTO. No. 6.
SIDE VIEW OF PIPE AFTFR RUPTURE
SHOWING MANNER OF BREAKING
ALONG SIDE.

PHOTO. NO.5.

THE FOUR QUADRANTS OF A BROKEN PIPE SHOWING THE REGULARITY WITH WHICH THEY BREAK.

We have tension in the outer circumference and compression in the inner circumference at points O and O' and compression in the outer and tension in the inner circumference at the points V and V'. In breaking, these points of stress are well defined, nearly all pipes breaking along lines passing through them. Photograph No.6, shows the position of the crack along the side; Photograph No.5, shows the four quadrants of a broken pipe.

Theoretically, the greatest stress occurs at the upper or lower points of the pipes, V and V', However, in the tests no difference in the time of breaking of the side and upper points, even in the larger pipes could be noticed. Nor was there any appreciable deflection in a pipe before rupture, showing the material to be practically inelastic.

Calculation of Stresses:

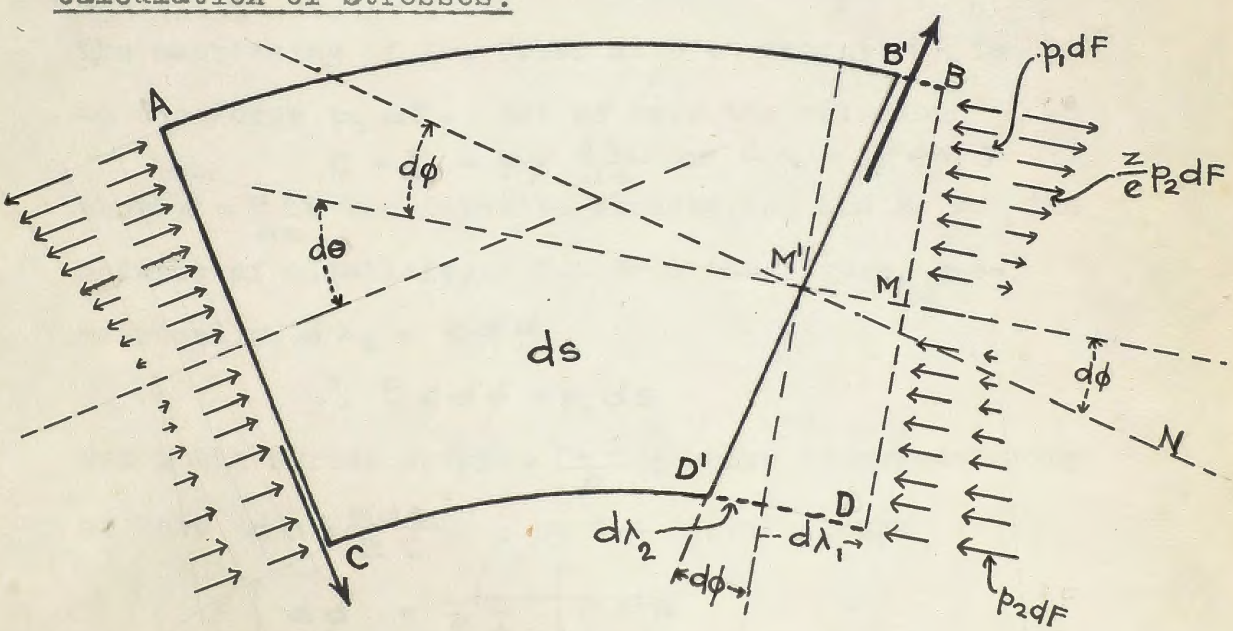


Fig. 10.

Consider any small portion of the pipe wall between two consecutive cross-sections. And consider it as having the form A B C D Fig. 10, before being strained. Let OM = ds be the original length of this portion, considering all fibers as having the same length ds (which is nearly true). Before strain the tangent lines at O and M make the angle $d\theta$ with each other. When under strain the fibers are all shortened and equal length due to the thrust. And are shortened or lengthened, depending on which side of the netural axis they are on, an amount $d\lambda_2$ at the outside fibers, and proportionately as they approach the netural axis. Consider the section at O to remain fixed then when under strain the section BD takes the position B'D' and the tangent line at M which remains perpendicular to B D takes the position M' N. The angle between the tangent lines is then increased an amount $d\phi$ PM'N. The shortening of the fiber at D an amount $d\lambda_2$ is due to the force $p_2 dF$. But we have the relation

$$E = \frac{p}{\epsilon} = p \Big/ \frac{d\lambda_2}{ds} \quad \text{or} \quad d\lambda_2 = pds/E$$

where $\epsilon = \frac{d\lambda_2}{ds}$ the relative elongation and E = the modulus of elasticity. But from the figure, geometrically, $d\lambda_2 = e\,d\phi$

$$\therefore \; E e\, d\phi = p_2 ds$$

But M the stress couple $= \frac{p_2 I}{e}$; hence by substituting we have $d\phi = \frac{M ds}{EI}$; or the total change

$$= \int d\phi = \frac{1}{EI}\int M ds$$

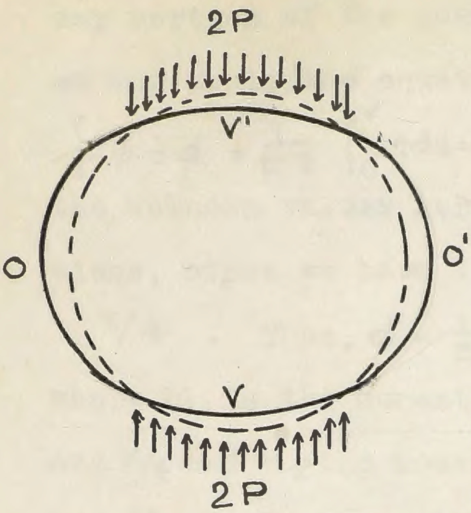


Fig.11

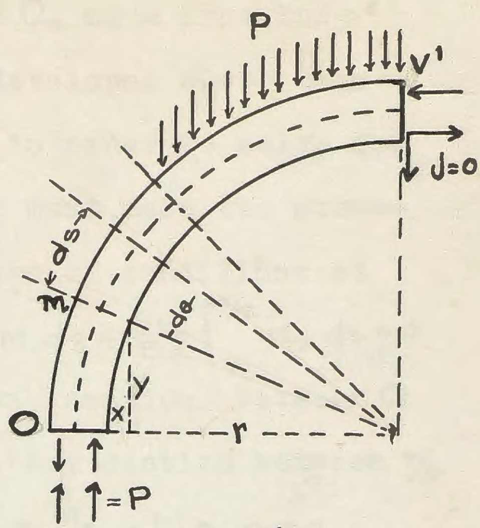


Fig.12.

Now consider Fig. 11, as a section of a pipe of thickness t and length l the heavy line being an exaggeration of its form when loaded and the dotted line its form before being strained. Consider the whole load acting, as $2P$ and distributed over one-quarter of the circumference as shown. Take as free body, the upper left hand quadrant as shown in Fig.12; the external forces acting on it are,--a thrust P and a moment M_o at O, and the applied force P and the moment M_v at V. The shear at $V' = O$ which is seen by summing up the vertical components.

Now when a section of the pipe, Fig. 11, is under stress the tangent lines O and V are not changed in direction, i.e., they are still vertical and horizontal and remain 90° apart. Hence, $\phi\int_0^{\pi/2} d\phi = 0$ that is, the total change of angle between O and $\pi/2$ is $= O$. Therefore, if we consider O as the origin and consider any portion of the quadrant O_m as a free body we may apply the equation developed above thus

$\int d\phi = \phi = \frac{1}{EI}\int_0^v M ds = 0$ But in order to solve for the unknown values here, we must make two summations, since we have a change of conditions at $\pi/4$. Thus, $\phi = \frac{1}{E}\int_0^{\pi/4} M_1 ds + \frac{1}{EI}\int_{\pi/4}^{\pi/2} M_2 ds = 0$

where M is the moment at any section between O and $\pi/4$ and M_2 = the moment at any section between $\pi/4$ and $\pi/2$. We have then $M_1 = Px - M_o$ and

$M_2 = P_x - M_o - [x - (r - r\cos\pi/4)]^2 p/2$; where $x = r(1-\cos\theta)$ and $ds = rd\theta$

Substituting the values of M_1 and M_2 we have

$$\theta = \frac{1}{EI}\int_0^{\pi/4}[Pr(1-\cos\theta) - M_o]rd\theta + \frac{1}{EI}\int_{\pi/4}^{\pi/2}\{[Pr(1-\cos\theta) M_o - [r(1-\cos\theta) - (r - r\cos\pi/4)]^2 \tfrac{P}{2}\} rd\theta = 0$$

$$= \int_0^{\pi/4}[Pr^2(1-\cos\theta) - M_o r]d\theta + \int_{\pi/4}^{\pi/2}\{[Pr^2(1-\cos) - M_o r[r\cos\pi/4 - r\cos\theta]^2 Pr/2\cos\pi/4\} d\theta = 0$$

Note $\left(p = \frac{P}{r\cos\pi/4}\right)$

$$= [Pr^2(\theta - \sin\theta) - M_o r\theta]_0^{\pi/4} + [Pr^2(\theta - \sin\theta) - M_o r\theta - [\cos^2\pi/4\,\theta - 2\cos\pi/4 \sin\theta + \theta/2 + \tfrac{1}{4}\sin 2\theta]\frac{Pr}{2\cos\pi/4}]_{\pi/4}^{\pi/2} = 0$$

$$= [Pr^2(\pi/4 - \sin\pi/4) - M_o r\pi/4] + Pr^2(\pi/4 - \sin\pi/4 + \pi/4 + \pi/4 - M_o\pi/4 - [\cos^2\pi/4 \cdot \pi/4 - 2\cos\pi/4(\sin\pi/4 - \sin\pi/4) + \pi/8 + \tfrac{1}{4}(\sin\pi - \sin\pi/2) = 0$$

$$= Pr^2(.7854 - .7071) - .7854\, M_o r + Pr^2(.7854 - 1 + .7071) - M_o r\, .7854 - [.7071^2 \times .7854 - 2.7071(1 - .7854) + \frac{3.1416}{8} + .25(-1) = 0$$

$$= .0773 Pr^2 - .7854\, M_o r + Pr^2\, .4925\, M_o r - [.3927 - .3035 + .3927 - .25]\, .7071\, Pr = 0$$

$$= 2 \times .7854\, M_o r = .4051\, Pr^2 = 0$$

or $M_o r = .4051\, Pr/2 \times .7854 = 2.578\, Pr.$

To find M_V take moments about V this gives

$$Pr - M_0 - r\cos 45° P/2 - M_V = 0$$

$$M_V = Pr - .2578\,Pr - .3135\,Pr = .4287\,Pr$$

If now we consider a section of unit length, that is, $l = 1$, and thickness t we have, substituting in the fundamental equation, $M = pI/e = \frac{1}{6}t^2p$ where p is the stress per unit area in the outer fiber. Hence, substituting in the above equation we get $\frac{1}{6}t^2 p = .4287\,Pr$ or $p = 2.5722\,Pr/t^2$ where P is one half the total load applied. Thence, if P' is taken as the whole load we have $p = 1.2861\,Pr/t^2$ Let p be called the Modulus of Rupture in pounds per square inch.

The Iowa State College specifications give the formula $p = Pr/t^2$ for finding p. This is less than the one worked out above by the factor 1.286. Both formulae give high values for the tensile strength per square inch. To illustrate, the average of p of all the cement pipe tested is 1035 pounds per square inch by the formula $p = 1.286\,Pr/t^2$ and 804 pounds per square inch by the Iowa State College formula $p = Pr/t^2$. The highest value given for any one cement pipe is 1475 and 1147 pounds per sq. inch by the respective formula; and the lowest value for any one pipe 460 lbs. and 358 lbs. per sq. inch. The mixture in all cases is 1 part sand to 2 parts sand and gravel mixture; the sand and gravel mixture being 2 parts gravel to 3 parts sand.

Tests were not made on this particular mix to ascertain its actual strength per square inch, but tests were made of neat cement of the same brand as the pipes were made of, Ogden Portland, and these gave an average of less than 750 lbs. per sq. inch tensile strength at 5 months old, the cement being mixed damp and tamped in the moulds. And since the tensile strength of a mixture of cement and sand and gravel could not be stronger than neat cement, one may safely conclude that both formulae give high results. The tests for vitrified clay drain tile gave about the same values for p as the vitrified clay sewer-pipe, which shows that the bell has little effect on the strength of the pipe.

In selecting a standard formula, the formula $p = Pr/t^2$ is preferable to the more theoretical one, $p = 1.286Pr/t^2$ since it gives values more nearly correct and is simpler. Judging from the strength of cement the writer would suggest the formula $.5Pr/t^2$ as being about right. But until we are certain of the strength of the materials it appears advisable to use the simpler one, Pr/t^2 . Whichever formula is used, we obtain a comparison of the strength of the materials; and since, there are other uncertain factors in the test of the strength of a sewer-pipe, a comparison is about all we can rely on; and therefore, the formula Pr/t^2 appears as the most satisfactory for the adoption as a standard.

Calculation & Tabulation of Results:

Fig. 4, is a sample of the dimensions taken for each pipe. The dimensions given in the tables are the average of those taken of which Fig.4, is a sample. The average dimensions were used in all calculations. In the tables of "External Pressure Tests," all the pipes of the same size are placed on the same page. This arrangement will help in the comparison and selection of pipes.

The "Breaking Load per Linear Foot," was found by multiplying the total breaking load by twelve and dividing by the length of the pipe in inches.

The "Radius to the Middle Line of the Pipe,"wall is the average diameter of the spigot plus the average thickness of the pipe wall divided by two.

The "Modulus of Rupture," in pounds per square inch was calculated by the formula Pr/t^2, where P is the breaking load per linear inch, r the radius to the middle line of the pipe wall in inches, and t the thickness of the pipe wall.

The "Equivalent Depth of Earth," was found by the formula $D = L/100\,d\cos 45°$, where D the equivalent depth of earth, L the breaking load per linear foot, 100 the assumed weight of a cubic foot of earth, and d the diameter of the outside of the pipe. The part of the equation $d\cos 45^\circ$ is the width of the sand bearing = to inside width of the top frame (nearly). We may then define the "Equivalent Depth of Earth," as the height of a section of earth necessary to break the pipe, where the earth weighs 100 lbs. per cu. ft., and the section of earth covers one forth of the circumference of the pipe. Of course in actual service other factors enter which help to determine the pressure on the pipe; for instance, the supporting value of the earth itself, the kind of earth, and the way the pipe is placed in the trench. Hence, we cannot take the value given in the tables to mean that it is not safe to bury a pipe beyond the "Equivalent Depth of Earth," given. But from these equivalent depths we get a direct comparison of the supporting ability of the pipe when in actual service. To illustrate, the 4" inch cement pipe has an average breaking load of 2481 pounds and the 30 inch cement pipe 3530 pounds per linear foot. Now the equivalent depth of earth given for the 4 inch is 78.6 ft. and for the 30 inch 16.5 ft., which slows us directly that the thickness of these pipes are not in proportion to the load the pipe is required to carry

Discussion:

Curves plotted from the tables bring out most vividly the distinguishing features of the pipes. Plate II is a set of curves with the thickness of the pipe wall as abscissae and the modulus of rupture, the tensile strength per square inch, as ordinates. The curves are all plotted to the same abscissae but each curve has a different set of ordinates. This is done so that the points of each curve are kept distinct. Each point is marked with the size of pipe it represents. The curves then furnish a ready means of studing the pipe.

The Denver Fire Clay pipe is seen to be comparatively regular in strength, the different sizes not varying far from the curve. The curve shows however, that the strength of the pipe, i.e., the tensile strength in pounds per square ince, becomes less as the thickness of the pipe wall increases. This feature is especially noticed with the single and double strength pipe. (The double strength are marked with D). The 10 and 12 inch single strength show an average tensile strength of from 150 to 200 lbs. per. sq. inch higher than the double strength pipe. This variation may be accounted for in two ways,--1, The larger pipe when being moulded is not placed under as high a pressure as the smaller sizes, since the opening through which the pipe issues is wider with the large pipe than the smaller pipe, the pounds per square inch therefore, being less. 2-The larger sizes may not be as well burned as the smaller sizes. It may be that a combination of 1 and 2 bring about the result.

The points on the curves for the Utah Fire Clay show that both the strength of the sewer-pipe and drain tile varies more than the Denver pipe, yet on the whole shows a materially higher strength, some pipes running exceptionally high others only ordinary. Just opposite to the Denver pipe, the Utah pipe gets stronger as the wall increases in thickness. This possibly may be to the higher burning with the Utah pipe since it all showed higher vitrification than the Denver Pipe.

In the tests, as tabulated in the tables for absorption, the particular kind of burn was noted, in hopes of obtaining information on which conclusions as to what burn produced the best pipe, could be based. The results show that except in a general way, no conclusive rules can be drawn. One time a pipe with a red burn would stand an exceptionally high load and another time would fail under a low load; which was also true with the pipes having a black burn. However, it might be said that with the Utah Fire Clay pipe the pipe with a light gray burn or a burn just changing from a light red to gray was nearly always the best pipe. This pipe had a compact wall with few air spaces, and as a rule ran high and comparatively regular.

The Denver pipe is characteristically different from the Utah pipe. It is made of a much coarser material, it does not have as high a vittification, its burn is regularly red, and its glaze is much heavier. The coarsness of the material, the stage of vitrification, the constituents of the clay itself, notwithstanding other influencing factors all effect the strength of the pipe. Therefore, a suggestion as to why the Denver vitrified pipe as a whole is not as strong as the Utah vitrified pipe would be unqualified. The glaze has no effect on the strength of a pipe, it helps, however, to make the pipe impervious.

The curve representing the pipe of the Utah Glazed Cement shows the cement pipe to have the widest variation in tensile strength of any of the pipe. The cement pipe varied considerably in age, yet this did not have the effect on the strength one would expect. The curve shows some of the older pipe falling below the new pipe in strength. One test, however, seems to show considerable gain in strength with age. A set of The Utah Glazed Cement Company's 6 inch pipe which had been in the laboratory all winter and which was about 11 months old was tested for a comparison of the 6 inch two-months old pipe. The 11 months old pipe proved to have a tensile of over 50 percent higher than the two months old pipe, but only 7 percent higher than the normal. Hence, chances are that the new 6 inch pipe was extra ordinarily poor as one would judge from its place on the curve.

The curve shows that the cement pipe is made stronger in the smaller sizes than in the larger sizes. This is because in the larger size the concrete is not pounded as well into the moulds as in the smaller sizes.

The thickness of the wall in the cement pipe is not graded proportionately to the size of the pipe, the 6 and 8 inch, the 10 and 12 inch, and the 21, 18 and 24 inch pipe, having the same thickness respectively. The pipe is made this way so that one pipe will just fit in the pipe a size larger, no regard being paid to the needed strength or the economy of the material. This is brought out forcibly by the curves for the "Equivalent Depth of Earth."

These curves, Plate III, are plotted with the

"Equivalent Depth of Earth," as abscissae and the "Thickness of Pipe Wall," as ordinates, each curve having a different set of ordinates. If the thickness of the pipe were made in conformity with the load, the pipe is required to carry, the curves would be vertical; or in other words, the equivalent depth of earth should be constant and the thickness of the pipe wall should be proportional accordingly. The cement pipe curve shows the inconsistency of making the thickness of the pipe wall of different sizes of pipe the same thickness. The other curves show the thickness of the vitfified clay pipes more uniform, yet equally out of proportion. The curves should in fact slope the other way from the vertical, since the supporting effect of the earth is much less with the larger pipe than in the smaller pipe. A load passing over a small pipe buried in the ground would increase the stress in a small pipe comparatively little; where as, on the other hand, unless burried deep the larger pipe would receive the greater part of the load, since the increased span of the earth would greatly decrease its supporting effect.

Comments on the Method Used:

As far as uniformity and accuracy this method of testing sewer-pipe and drain-tile is highly satisfactory

It places all sizes of pipe under the same conditions. It works as well with sewer-pipe as drain-tile, it having the advantage of distributing the load equally over the bell or any unevenness of the pipe. Close observations shows that with properly made frames and care in applying the load it is reasonably definite. The results by this method are readily intrepreted into practical data, since the loading resembles closely the adverse conditions of the trench. But the method is cumbersome, it requires considerable rigging up, a special top frame being necessary for each size of pipe. It lacks simplicity; care must be taken in making and placing the frames, in fixing the bearings of the pipe, the method requiring for the best results a perfect acquaintance of the method by the operator.

The writer believes that a simpler, yet possibly, as satisfactory a method of testing sewer-pipe and drain-tile could be arranged by using two concentrated or narrow bearings. A method used by Professor A. N. Talbot and recommended by him in the Engineering Record, April 6th, 1912, for the testing of drain-tile has the merits of simplicity and for drain-tile, accuray and uniformity. It consists in applying the load Fig.13, by two strips of wood, a piece of hose being used to take up the unevenness of the pipe. Other similar methods mentioned earlier in the paper have more than two bearings which arrangement takes from them simplicity and definiteness.

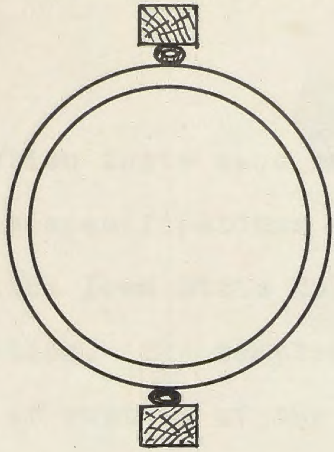


Fig. 13.

It is believed that a method similar to Professor Talbot's could be satisfactorily applied to sewer-pipe. Even if the load did not come on the bell the writer, after close observation of the way pipes break, believes that there would be little or no difference in the crushing strength of the pipe, since the proportional stress would be transmitted to it through the pipe. The tests on drain-tile show that the bell has very little effect on the strength of the pipe. Therefore, to make the bearing symetrical it could be arranged as far back of the spigot end as the length of the bell. Or it might be possible to test it by having the bearing a foot or some such proportional length. The point the writer wishes to make is that he believes sewer-pipe can be tested satisfactorily by using two narrow bearings similar to those illustrated above.

ABSORPTION TESTS.

Method:

The absorption tests were carried out according to the specifications (see appendix) recommended by the Iowa State College as Standard Test for Absorption. The samples were all taken along the line of rupture of the upper side about the middle of the pipe. The ovens used for drying the samples were the ordinary drying ovens heated by Bunsen Burners. The oven was held above 212° F. usually from 220° F. - 225° F. According to the specifications all specimens were dried until they ceased loosing moisture. The vitrified clay pipe could be easily dried in from 12 to 15 hours, the loss in weight running at less than a tenth of one percent. The cement pipe contained considerable moisture, the newer pipe reaching as high as 3 to 4.5 percent. It took about 60 hours to dry the larger samples and 30 hours to dry the smaller samples of cement pipe depending on the amount of moisture they contained. To find out whether the larger samples of cement pipe were saturated after 24 hours in water, the samples were replaced in water after weighing and left for 36 hours longer, making in all 60 hours. The extra gain in weight in no case exceeded 0.5 of one percent.

Calculations and Tabulations:

The percent absorption was found by dividing the difference in weight of the sample when dry and after 24 hours in water, by the weight when dry. The percent is given to a hundredth of one percent though the weight was only taken to the nearest tenth of one percent. This was done since it gave a more exact method of finding the average.

For convenience the "Kind of Pipe," is repeated in these tables. The "Modulus of Rupture," is also repeated and placed opposite the percent absorption in order to show any relation that might exist between the density of the pipe and its strength. A description of the pipe wall placed in the tables gives a ready means of comparing the burn and the other properties of the pipe.

Discussion:

The curves, Plate IV, are plotted with the "Thickness of Wall," as abscissae and "Percent Absorption," as ordinates. Each curve has its individual set of ordinates, so as to keep the points of each curve distinct as is done in Plates II and III. These curves all have the reverse direction to those of Plate II, plotted between the "Modulus of Rupture" and "Thickness of Pipe Wall," with the exception of the Utah Fire Clay's drain-tile which, neglecting the drain-tile, shows distinctly that the strength of the pipe is proportional to its density. Why the drain-tile should not follow the same law as the other vitrified pipe is most likely due to its peculiar burn which was quite different to the Utah sewer-pipe.

The above facts might be followed by a suggestion as to one condition in the burning that would help to bring about such a relation, i.e., the relation of the strength to the absorption, special reference being made to the Utah Fire Clay pipe. The clay used by the Utah Fire Clay contains considerable organic matter. In burning, if the temperature is raised too rapidly this is not all burned out before the clay reaches the vitrification point. Therefore, if this burns after the pipe reaches the vitrification point the tendency is to produce air spaces in the pipe or in other words make it porous. The burning of this organic matter at a high temperature also tends to reduce the iron compounds and thus produce a black pipe. Now the reduced iron apparently has a greater cementing value than either of its oxides. But if the carbon is present in too great an amount, it produces an abundance of air spaces, thus weakening the pipe. But if present in just the right proportion to produce a light gray burn, reducing a portion of the iron but at the same time not producing to many air spaces there results a combination that produces the stronger pipe.

Several sets of whole pipe were tested to see if when the glaze was unbroken the absorption would be any different from when taking a regular sample. The results show that there is no difference, the per-cent being as high with the whole pipe as with a piece.

Suggestions:

Though the larger samples were shown to become nearly saturated after 24 hours, the writer would suggest that the time of immersion be increased to 48 or even 96 hours. By this time the thickest samples would have a chance to become thoroughly saturated and thus more nearly give the conditions found in service.

INTERNAL PRESSURE TESTS.

Outline:

It was the plan to test all sizes of both the vitrified clay and the cement pipe up to and including the 12 inch pipe. As in the external pressure tests five pipes were to be tested of each size. The Denver Fire Clay only sent five pipes of each size. It was decided to use three of the five for external pressure tests and the other two for internal pressure tests. The Utah Fire Clay sent a full set of each size. The Utah Glazed Cement sent four 4 inch and five 6 inch pipes; of these it was doubtful whether the six inch was a fair sample. Tests, however, were made on them, but the data on only two sizes did not seem of sufficient weight to base any conclusions.

Testing:

Fig. 14, illustrates the arrangement of apparatus. The heads H and H' were made of cast-iron and were held by a central iron rod R.

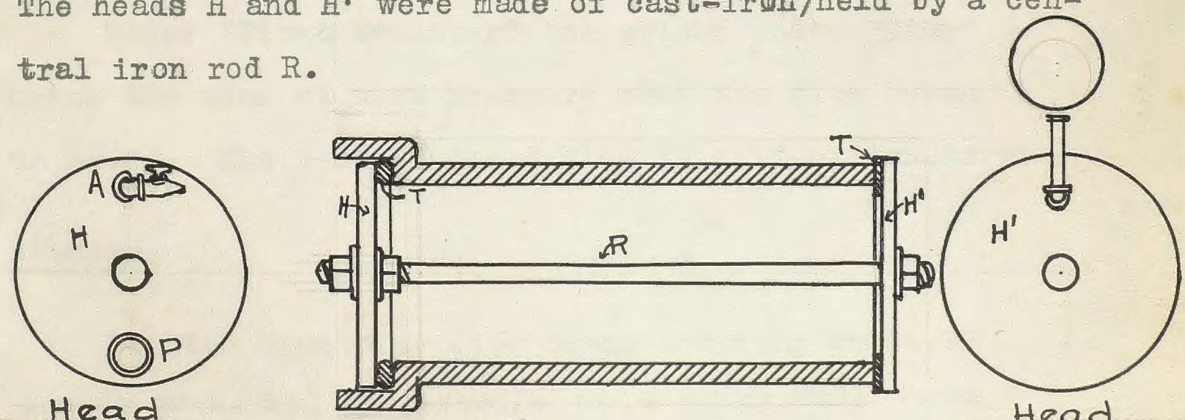


Fig. 14.

Heavy rubber gaskets T were used to take up the unevenness of the pipe. The pressure pipe P was attached to the lower side and the air cock A on the upper side of the head on the bell end. The pressure gauge G was attached on the upper side of the head on the spigot end. The pressure was taken directly from the water mains, which during the test ranged from 150 to 170 lbs. per sq. inch. Any pressure above this was obtained by using a hand pump. The pressure was regulated mostly by using the air cock A as a release valve. The pressure was started at and increased by increments of 10 pounds, and was held for ten minutes at each pressure. The time was noted when moisture first appeared on the surface. With the exception of the four inch pipes, 61 and 68, the pressure was increased until the pipe ruptured, the bursting pressure of 61 and 68 being beyond the highest pressure obtainable, 270 pounds.

Tables:

Under "First Sweating" the column under "Time" means the time at that pressure that the pipe began to sweat. The rest of the tables is self explanatory.

Results:

No Utah Fire Clay pipe began sweating under 20 pounds pressure, the average value being well above

40 pounds. And only one Denver Fire Clay pipe began sweating at the ten pound pressure, the average for first sweating being above 20 pounds. One would conclude from these facts that specifications requiring that a pipe shall not show moisture after 10 minutes at 10 pounds pressure would be none to exacting.

These tests confirm the relation shown in the other tests, that the strength is proportional to the density, that is, the higher the impermeability of the pipe the greater its strength. The pipe with the gray or the light reddish gray burn is also shown by these tests to be the best pipe.

It is noticeable that the pipe as a rule begins sweating first near the spigot end. In moulding the pipe the bell is moulded first and is placed under comparatively high pressure. After the bell is moulded the form F, Fig.1, lowers and the pipe issues from the moulds. The only pressure this part of the pipe is placed under is that required to push it through the opening of the moulds; and in case it does not rest on the support F, this pressure is reduced by the pipe hanging. It may be that seams are thus made in the pipe which do not perfectly close when the pipe is burned.

CONCLUSION.

The tests all show that there is a direct relation between the strength, the absorption and the permeability of the pipe wall. The external pressure tests furnish a close estimate of the pipes strength, and the absorption tests of the pipes porosity. The internal pressure tests bring out the weakest points of a pipe. If there is a seam or fault in a pipe the external tests readily show it. When a pipe bursts from internal water pressure it is the weakest point that gives way. Whereas, with the external pressure tests we obtain nearer an average of the pipe's strength. Forinstance, a fault common only to a single pipe if it does not happen to come on the line of rupture makes practically no difference to the pipe's strength. Even a fault in the line of rupture averages up with the other points of the pipe, since the pipe's strength is dependent not alone on one but two lines, the top and bottom of the pipe, the places of greatest stress. While in the internal tests the pipe splits at the weakest point regardless of its strength at any other place. We would say, than, that the external tests tend to pick out the class of pipe, the internal tests the individual pipe. However, the tests for general sweating readily shows the class of pipe. But the bursting point of a pipe is individual and not comparative.

Tests on the Utah Fire Clay pipe only covered sizes up to the 18 inch pipe. Therefore, to draw a comparison of the material of the different companies pipe averages were taken of the modulus of rupture and absorption of sizes only up to and including the 18 inch pipe. Which averages are as follows:

Utah Fire Clay -	Modulus	of	Rupture	1383	Absorp.	404
Denver Fire Clay -	"	"	"	1197	"	419
Utah Glazed Cement -	"	"	"	808	"	7.79

Which shows the Utah Fire Clay to have an excess strength over the Denver Fire Clay of 186 lbs. per sq. in. and over the Utah Glazed Cement of 575 lbs. per sq. in.; and the Denver an excess over the Cement of 389 lbs. per sq. in. Or in terms of percent, the Utah Fire Clay exceeds the Denver Fire Clay by 47% in strength and the Cement by 71%; and the Denver exceeds the Cement by 40.8%.

The average of the absorption tests show the Cement pipe to have a percent absorption higher by 3.2% than the Denver and 3.79% then the Utah; and the Denver to have a 0.55% higher absorption than the Utah Fire Clay pipe.

It would be interesting to determine in future tests whether the Clay or Cement pipe were any different in strength when thoroughly soaked than when dry.

The data from these tests is on the best grades of vitrified clay and cement pipe manufactured by the companies who donated it. Looking over the data one notices that, though it is of the best grade there is a wide variation in the quality of the different pipes. There is among the best grade a good, a better, and a best. Why? What is one pipe better than another? Can all pipes be made the best grade? Throughout these tests a close out-look has been kept for the characteristics of the best pipe.

The tests show what can be expected of the best pipe. Specifications can be drawn up from the data with a corresponding rigidity. Rigid specifications will demand a close study of the manufacture of the pipe by the manufacturer. If, through, the information given in these tests, a better pipe goes to the public, if from these tests the manufacturer obtains information that will help him to make the best pipe, then the writer will feel well paid for his work.