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CONCRETE PIPE

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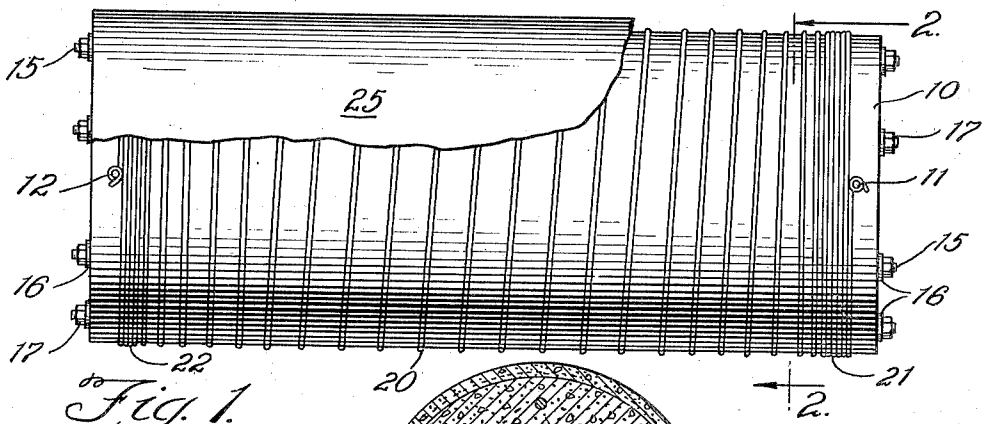


Fig. 1.

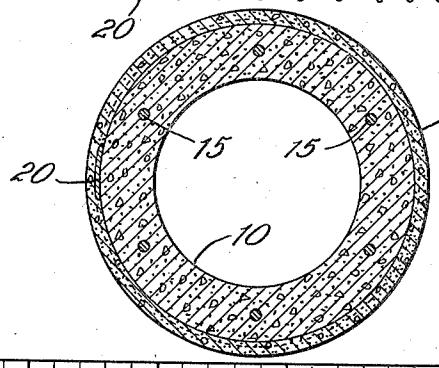
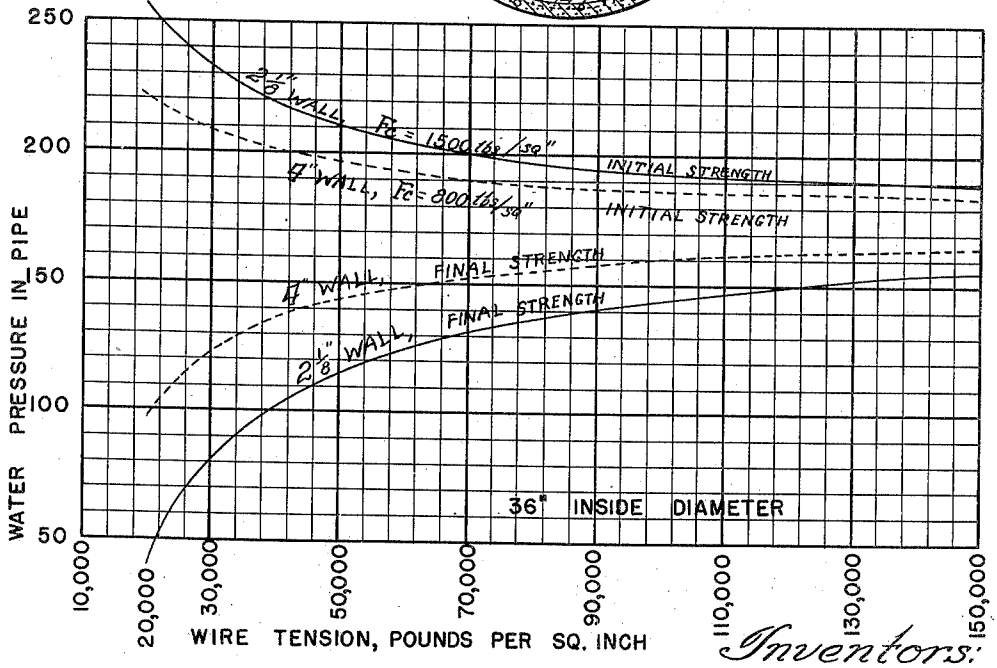


Fig. 2.

Fig. 3.



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CONCRETE PIPE

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5 Claims. (Cl. 138—84)

This invention relates to reinforced concrete pipe and to a method for making the same. In the manufacture of concrete pipe considerable difficulty has been experienced in using the pipe for any substantial water pressures. Obviously, because of the relative cheapness of concrete as compared with steel, it is desirable to use as little steel and as much concrete as possible. On the other hand, great difficulty has been experienced with such pipe because of certain phenomena peculiar to concrete. In the case of steel and other elastic media it is well known that the deformation or strain is proportional to the load or stress within the elastic limits of the material and substantially independent of time, assuming that ordinary temperature conditions obtain. In the case of concrete, however, this rule does not hold. While the concrete does have a sort of elastic limit, the well known Hooke's law of stress and strain does not hold strictly.

When the concrete is first mixed and permitted to set, there is a shrinkage which theoretically extends over extremely long periods of time. In practice, however, a major portion of the shrinkage occurs within the first 28 days of curing under normal conditions, that is, at about 70° F. with moisture. There are cements and curing processes in which the corresponding aging is secured in a quicker time, as for example, under elevated temperature conditions. However, it is understood that in the curing periods mentioned for normal curing, that is at 70° F., the corresponding period for quick curing methods is contemplated.

The shrinkage of the concrete does not follow a proportional law, but probably involves an exponential function with the major portion of the shrinkage occurring the first few days of the cure and thereafter a steady decrease in the rate of shrinkage takes place until after about 28 days, which is the normal curing period under normal conditions, the rate of shrinkage is so slow that it becomes impractical to store the concrete and age it. However, allowance for the further shrinkage of concrete must be made. Upon the rewetting of the concrete some expansion takes place but this expansion does not compensate for all of the shrinkage.

In addition to the shrinkage of concrete, which might be termed one of the intrinsic characteristics of the material, there is also a characteristic which depends upon the loading of the concrete and which might be termed an external characteristic. This external characteristic represents the departure from Hooke's law within the so-called elastic limits of the concrete. It has been observed that concrete under load gradually yields as if some plastic flow of the concrete occurred. Thus, if a certain predetermined loading is imposed upon a concrete structure, the initial deformation is followed by a gradual and slow secondary deformation due to the load. The reverse is also true, so that if a concrete structure is deformed a fixed amount, the force necessary to maintain this deformation will gradually decrease in value from the initial value down to a substantially constant minimum value.

In connection with the reinforcement of pipes, it is old to wind wire or dispose steel bands around concrete pipes. The wire or bands are in suitable tension, thus tending to compress the concrete material of the pipe. Inasmuch as the compressive strength of concrete is considerably greater and a more reliable factor than the tensile strength, it is obvious that a pipe of this character may be, in theory, designed for certain desired loads. Thus, the internal water pressure in the pipe will tend to expand the concrete which has been prestressed so that it is possible theoretically to reduce the stresses in the concrete to zero. Beyond that, it is undesirable to extend the hydraulic pressure since the tensile strength of the concrete is poor.

The compressive action of each wire or band, while localized at the point of application, is generally distributed over the concrete material on both sides thereof so that within a short depth as measured from the outside, the compressive force of the metal may be assumed to be uniformly distributed over the entire concrete surface.

While such reinforced pipe has been known for some time, there has been no successful commercial application made therefrom.

Thus, considering a steel wire wound around a concrete pipe in a helical formation, it is clear that the tension of the wire is obtained by a small elongation thereof. It follows, therefore, that any tendency for the concrete to shrink or flow from under the wire will permit the wire to shorten like a spring and reduce its tensile strain so that the ultimate compressive force exerted on the concrete is reduced. Thus, if a concrete pipe made under ordinary normal conditions, such as obtain in the industry at the present time, is wound with wire before the pipe is at least seven days old, the natural shrinkage of the concrete is sufficient to vitiate the compression obtained by the wire when originally wound as heretofore proposed. Heretofore, wire of this

type has never been applied at more than 20,000 pounds per square inch of wire. It has always been assumed that the amount of tensile strain in the wire is unimportant in itself and that by disposing a sufficiently large number of coils of the wire equally, desirable results may be obtained. This, however, is greatly in error and is responsible in a large measure for the failure of such reinforced pipe to be in general successful use.

As pointed out above, if such wire is applied at the stresses heretofore suggested, and used on a pipe which is less than even 28 days old, the aging pipe within a short time permits the wire to shorten up so much that there is little if any stress remaining. This is true in spite of any rewetting of the concrete with a resulting expansion. In addition thereto, even if a pipe which has been properly aged is wound by wire at 20,000 pounds or less, the effect of the flow of the concrete away from the wire over a period of a year or longer will be such as to reduce the initial stress in the wire to a value so small that the carrying pressure of the pipe is reduced to a negligible figure.

We overcome the objections heretofore encountered in reinforced concrete pipe by adhering to the following conditions. The concrete pipe itself may be made in the ordinary fashion such as prevails at the present time for concrete water pipes. In order for the pipe to withstand any substantial pressure, and by that we mean anything over 25 pounds per square inch, the wire reinforcing should not be applied on the pipe prior to an aging of seven days under normal conditions and a corresponding period under quick curing conditions. For high water pressures the period of aging should be longer and between 14 and 28 days. The average compression on the concrete exerted by the reinforcement should preferably be not more than about 25% of the ultimate compressive strength of the concrete and for ordinary concrete should not be more than between 1000 and 2000 pounds per square inch depending, of course, upon the character of the mix. This provides a safety factor of about 4 or 5 to 1 in a case of the average concrete.

The average compression referred to above may be computed by the following formula

$$Fc=\frac{AsFs}{Ac}$$

where As is the cross sectional area of the steel wire in square inches, Fs is the tensile stress in pounds of the steel wire per square inch of cross section and Ac is the wall thickness of the concrete pipe in inches multiplied by the reinforcing pipe pitch in inches.

Finally, the reinforcing wire itself is wound on the concrete pipe at a minimum tension of 30,000 pounds per square inch of cross section and preferably goes up higher. At the present time, it is possible to tension commercial grades of steel wire as much as 150,000 pounds per square inch, without exceeding the elastic limit thereof. The higher the initial tension of the wire, the greater the approximation of the original characteristics of the pipe to the final characteristics of the pipe.

The actual wire tension may advantageously be about from 50–75 per cent of the elastic limit of the steel in case the liquid inside of the pipe is subjected to sudden sharp pressure peaks above the normal working pressure. In such a case, the pressure peak may be great enough to overcome the precompression of the concrete due to the wire reinforcement and put the concrete in tension. If the tension exceeds the concrete limit, then a crack in the concrete develops. In such a case, it is advantageous for the reinforcing wire to have enough reserve elasticity so that even if the concrete cracks, and the wire is elongated, still the wire itself is not strained beyond its elastic limit. As soon as the pressure surge subsides, the reinforcing wire contracts to the length normal for the conditions in the pipe. The concrete being under compression again tends to close the crack or cracks. In the course of time autogenous or self healing will close up the crack permanently and the pipe is as good as ever.

During the manufacture of the concrete pipe itself, longitudinal reinforcing rods or wires of steel are disposed in the pipe wall. Preferably the steel has elastic limits of 40,000 pounds per square inch or higher. The concrete setting around the rods tends to grip the rods very tightly. These rods perform a dual function. After the reinforcing wire is wound around the pipe there is a tendency for longitudinal elongation to occur. Part of this represents the natural resultant of the compression of a more or less elastic medium; i. e. secondary stresses in the concrete, and part is due to a plastic flow. Longitudinal reinforcing rods oppose this tendency to elongate.

In addition, there is outside or trench loading. Thus, the pipe lying in a trench may have some top or side force tending to bend it lengthwise. This transverse bending moment must be resisted. Inasmuch as such moments tend to induce tension in certain portions of the pipe, it is clear that steel reinforcement is desirable. The rods function to take up such types of loading.

By disposing a large number of small diameter rods in the concrete, it is clear that the bonding area between concrete and steel may be so great that the natural grip between the two may be relied upon solely to take advantage of the steel reinforcing. Thus 100 pounds per square inch of such area may very easily be relied upon and in some instances this adhesive force may be relied upon to as much as 300 pounds per square inch. Hence, it is possible to reduce the elongation of the pipe due to precompression and also provide trench loading protection by simple rods.

In other cases, the ratio of surface to cross section of the steel rods may be lower so that tension in the rods is necessary to precompress the concrete longitudinally. In such a case, the compression longitudinally of the pipe should be just enough to compensate for the elongation tendency and provide trench loading protection. Any substantial excess compression will create a circumferential tension component in the concrete and to that extent reduce the desirable characteristics of the pipe. In general, compression necessary to balance the elongation force may be experimentally determined. Thus, the complete pipe with reinforcement around it may be measured to see how much force is necessary to maintain the length at a constant value. Or the force between two longitudinally spaced points may be measured before and after wire winding by strain gauges to determine the elongation.

In any event, the determination of the force necessary to prevent appreciable elongation of the

concrete pipe after the reinforcing wire is applied may be determined and the necessary reinforcement applied longitudinally. In some cases as much as 200 or 300 pounds per square inch pressure is necessary over the concrete end surface and in other cases just the presence of steel rods alone is sufficient.

Of course, as taught in connection with the reinforcing wire around the pipe, the most efficient use of longitudinal steel reinforcement would demand a few rods tensioned to a substantial value so that the elongation component of the completed pipe would be just neutralized.

Referring to the drawing:

Figure 1 shows a reinforced pipe with the outer covering broken away to expose the wire reinforcing.

Figure 2 is a section on 2—2 of Figure 1.

Figure 3 shows curves showing the relationship between wire stress and pipe loading before and after plastic flow.

Referring to Figures 1 and 2, a concrete pipe 10 has pins 11 and 12 suitably anchored therein at the opposite ends thereof. This pipe is preferably provided with a plurality of longitudinal steel reinforcing rods 15 embedded in the concrete pipe during the manufacture thereof. These rods may be threaded at the protruding ends and may be provided with large washers 16 and nuts 17 which can be drawn up tightly enough to tension the rods and thus compress the pipe longitudinally if necessary. Or the compression may be dispensed with in some cases as pointed out above.

Disposed around the outside of concrete pipe 10 is a reinforcing wire 20 of steel wound thereabout in helical formation. Near the ends of the pipe the coils are closely spaced as at 21 and 22 and the wire is anchored at pins 11 and 12 in any suitable manner. Wire 20 is of steel having suitable tensile strength for the purposes disclosed herein and may be wound on in any suitable manner such as for example disclosed in our application, Serial No. 176,604, filed November 26, 1937, Patent No. 2,175,479 of Oct. 10, 1939. This wire is under a tension of at least 30,000 pounds per square inch and preferably a higher value. The amount of tension in the wire may be varied to suit individual requirements such as the winding machine, the amount of steel and size of wire to be used, and other factors. As is well understood, the tension in the wire and the pitch of the wire coils determine the compression imposed upon the concrete pipe wall and thus determine the useful water pressure which may be withstood. Preferably, the tension in the wire for different size pipes or for pipes used for various water pressures may be maintained at a constant unit value and the characteristics of the pipe determined by merely controlling the pitch. It is also understood that the wall thickness of the pipe is adjusted to the proper value in accordance with the formula heretofore given to prevent excessive compression of the concrete.

After the concrete pipe has thus been wound and the wire anchored, a layer of concrete 25 may be disposed over the wire to protect the reinforcement against weather. The layer is not relied upon to aid the pipe in withstanding the water pressure for which it is designed.

Referring to Figure 3, the two curves in full lines show the characteristics of a concrete pipe 36 inches inside diameter having a wall thickness of 2⅛ inches. The curves are plotted to show the relation of increase in reinforcing wire tension against various water pressures to be withstood by the pipe. The pipe is designed so that the average compression on the concrete calculated by the formula is about 1500 pounds per square inch. Hence, as the wire tension is increased, the pitch is increased. Thus, referring to the formula, the quantities Fc and Ac both are constant. Fs is increased so that As must decrease.

Thus, considering the top full line curve with the reinforcing wire wound at 20,000 pounds per square inch, the resulting pipe theoretically can handle an internal water pressure of 250 pounds per square inch. This value is at the time the pipe is made. Going down to the lower full line curve, it is seen that due to shrinkage and plastic flow of the concrete, the reinforcing wire tension has reduced enough so that the concrete pipe is only good for 50 pounds per square inch. With customary safety factors of 3 or 4, a pipe capable of withstanding only 50 pounds per square inch of water pressure would not be used in practice for water pressures of more than 15 or 20 pounds per square inch.

As the tensile strain on the wire is increased, the water pressure which the new pipe can handle drops off. However, it will be noted that the loss of characteristics of the pipe due to shrinkage and plastic flow decrease quite rapidly over a tension of 30,000 pounds per square inch and up. Thus, at the extreme tension of 150,000 pounds per square inch, the 2⅛ inch pipe can initially withstand about 190 pounds per square inch of water pressure and only about 30 pounds of this water pressure are lost due to plastic flow. As the tension on the wire increases, the amount of wire used decreases and at the same time the decrease in the characteristics drops off so that at high wire stresses, a superior pipe results with the saving of steel.

The same considerations apply to the dotted line curves which are for a four inch pipe having an inside diameter of 36 inches. In this particular case, the average compression on the concrete was limited to 800 pounds per square inch. Again it will be noted that above 30,000 pounds per square inch of tensile strength in the wire the drop in characteristics in the pipe decreases quite rapidly.

These curves are based upon data and formula obtained as a result of experiments. Due to the variation in concretes some variation in results will occur.

The above curves assume no external loading on the pipes. In practice, allowance must be made for earth and traffic loading. To that extent, the permissible internal pressure must be reduced from the calculated or plotted pressure. In this connection reference may be made to Bulletin No. 22 of the University of Illinois containing an article by Arthur N. Talbot entitled "Tests of cast iron and reinforced concrete culvert pipe," and "The supporting strength of rigid pipe culverts" by M. G. Spangler in Bulletin 112 of Iowa State College of Agriculture at Ames, Iowa.

It is understood, of course, that instead of a continuous helical wire reinforcement a series of separate bands or wires may be disposed, providing, of course, the conditions heretofore set forth will be adhered to. It is also understood that when the wire reinforcement is stated as being on the outside of the concrete pipe, it means merely with reference to the stresses of the pipe proper and does not necessarily preclude the application of a covering coating such as layer 25 herein.

What is claimed is:

1. A reinforced concrete pipe comprising a pipe section of concrete having formed therein a plurality of longitudinal reinforcing rods, said pipe having been aged for a period corresponding to between 7 and 28 days at 70° F. in a moist atmosphere prior to the application of any further reinforcement, and having as an outer reinforcement a helical steel wire tensioned at least to 50,000 pounds per square inch with the wall thickness of the pipe and the pitch of the helix being so chosen that the average compression in the concrete is equal or less than one-third of the ultimate compressive strength of the concrete, the reinforcing wire around the pipe being elongated to such a degree that natural shrinkage of the wire due to plastic flow of concrete is minimized.

2. A reinforced concrete pipe comprising a pipe section of concrete having formed therein during the manufacture thereof a plurality of longitudinal reinforcing rods, which pipe has been aged for a period corresponding to between 7 and 28 days at 70° F. in a moist atmosphere prior to the application of any further reinforcement, and having as a reinforcement on the outside thereof a plurality of steel wire coils at spaced intervals with the wire tensioned to between 50,000 and 150,000 pounds per square inch but within the elastic limit of the coil, and having a wall thickness and the spacing between adjacent wire coils so chosen that the average compression on the concrete is of the order of one-third or less of the ultimate compressive strength of the concrete, the reinforcing wire around the pipe being elongated to such a degree that natural shrinkage of the wire due to plastic flow of concrete is minimized.

3. A reinforced concrete pipe comprising a pipe section of concrete having formed therein initially a plurality of longitudinal reinforcing rods, said concrete having been aged for a period corresponding to between 7 and 28 days at 70° F. in a moist atmosphere prior to the application of any further reinforcement, a reinforcement around the outside of said pipe comprising a plurality of steel wire coils at spaced intervals with the steel wire being tensioned at least to 50,000 pounds per square inch, means on the ends of said longitudinal reinforcing rods for compressing the concrete longitudinally of the pipe, said longitudinal rods being so spaced and so tensioned, said wire coils being so spaced and the wall thickness of the pipe being so chosen that the average compression on the concrete is of the order of one-third or less of the ultimate compressive strength of the concrete, the reinforcing wire around the pipe being elongated to such a degree that natural shrinkage of the wire due to plastic flow of concrete is minimized.

4. The pipe of claim 3 wherein the longitudinal reinforcing rods are so tensioned as to substantially neutralize the force tending to elongate the pipe after it has been wound with wire.

5. The pipe of claim 3 wherein the steel of the coils has an elastic limit exceeding the working stress by a substantial margin whereby on overloads of pipe pressure, said concrete will crack before the coils have reached their elastic limit and subsequently under normal pressure conditions, the coil contraction will bond the concrete to form an autogenous junction and close the cracks.

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