Report on

Continuous Stave Pipe

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Use and Advantages of Wood Stave Pipe

For large water supply pressure conduits, three kinds of pipe are in common use:

Cast Iron Pipe,
Riveted or lock-bar steel pipe.
Wood stave pipe.

For sizes larger than 48 in. to 60 in. diameter, cast iron pipe is impracticable, and large water-power pressure conduits are usually constructed either of steel pipe or of continuous wood stave pipe. In the majority of cases, depending somewhat on local cost of labor and material, continuous wood stave pipe will be found to be much cheaper than either cast iron or steel conduits. This is especially true for conduits of larger sizes under light or moderate pressures.

There are a number of other advantages incident to the use of wood stave pipe.

First. It is cheaper than either cast iron or steel pipe, particularly in the larger sizes and light or medium pressures.

Second. Its durability under ordinary conditions is equal to that of steel pipe and when properly constructed and used under favorable conditions its life is equal to or even greater than that of cast iron pipe.

Third. Metal is used only for the purpose of securing resistance to pressure and with upset bands the full efficiency of the metal is realized. This as compared with an efficiency of only 60 to 75% for riveted steel pipe.

Fourth. Continuous wood stave pipe is much more stable than steel pipe against deformation from its own weight when full or from the weight of backfilling material. It is also less subject to danger of collapse when empty or when partial vacuum is accidentally formed in the pipe while it is being emptied.

Fifth. The material can be shipped and hauled knocked down and the weight per foot of length for a given size and pressure is much less than steel pipe. It can thus be transported readily into localities which would be inaccessible for steel pipe.

Sixth. Vertical and horizontal bends of moderate radius can be made by springing the staves without the use of special designed angles and joints, as in the case of riveted steel pipe.

Seventh. It has a perfectly smooth interior surface without joints or rivet heads and its carrying capacity with a given friction loss is from 10 to 20% greater than for riveted steel pipe, and from 2 to 5% greater than for new lock-bar steel or cast iron pipe.

Eighth. Its carrying capacity is not subject to reduction by interior deterioration or tuberculation in the same manner as that of cast iron pipe. Hence it is not ordinarily necessary to provide excess carrying capacity in the new pipe in order to maintain a given capacity after a period of years.

Ninth. It is a better non-conductor than cast iron or steel pipe and can safely be laid above ground or in shallow trenches under conditions such that cast iron or steel pipe would be liable to freeze.

Tenth. It is not corroded by gases or sulphur, salt or other minerals commonly occurring in water.

Relative Durability of Continuous Wood Stave Pipe, Steel and Cast Iron Pipe

The economical value of a conduit depends not only on its first cost but also on its life and cost of maintenance. It is commonly assumed that cast iron forms the most durable material for a pressure conduit. In proof of this, European experience is often quoted with reference to a limited number of cast iron pipes at Versailles, which have been in use from two hundred to two hundred and fifty years, and other pipes elsewhere used for somewhat shorter periods. Experience with cast iron pipe in this country has not covered any period as long as one hundred years as far as known. We do not dispute the conclusion commonly accepted that the life of cast iron pipe under favorable conditions is as great as one hundred years. It appears, however, that there are certain examples of wood pipe hitherto overlooked.

The well known durability of bored logs formerly extensively used for water mains has often been cited in illustration of the lasting qualities of wood as a material for the walls of pressure conduits. Such pipes have been in use in various places for periods of 60 to 100 years or more and have shown little deterioration. The walls of such pipes are, however, relatively very thick compared with the diameter of the bore, and they do not appear to afford as good an example for comparison with wood stave pipe as the wooden casings of ancient wells in Egypt. In the Dakahla Oasis in the Libyan Desert many deep artesian wells have been used since pre-historic times to obtain water for date palm irrigation. Some of these wells probably antedate the Roman occupation of Egypt in 30 B. C., while the majority were constructed by the Romans and have been in continuous use for 1,500 to 2,000 years. These wells are cased with sunt wood (acacia nulatica) pipe about 14 inches in diameter with very thin walls, which are surrounded with packed clay. It is often found that these pipes are in as good condition now as when originally put in, these pipes illustrating the conditions favorable to great durability of wooden pipe, i. e., continuous saturation by flowing water, and exclusion of the air by the surrounding clay. Nearly everyone has seen wood stave penstocks in New England which were constructed from 50 to 80 years ago, and which are in good condition if they have been kept in constant use.

As a further illustration of the durability of wood under suitable conditions, mention may be made of branches of trees resembling cyprus, dug up from a bog by the writer in 1912. The fibre of the wood was sound and had retained its aromatic odor, although its age must have been several thousand years.

It is entirely true that much has been learned in recent years regarding the conditions favorable to durability both of wood stave and steel pipe. Hitherto the life of both of these classes of pipe has been commonly taken at from 30 to 50 years with 40 years as a good average. It appears that with proper precaution the life of wood pipe may be made indefinitely great. While there is some disagreement, the consensus of opinion among leading engineers who have had experience with wood stave pipe during the past ten or fifteen years seems to be about as follows:

First. The pipe is more durable in dense or clayey soils than in sandy or open soils; or put in another way, it is more durable where it is subject to continuous saturation by ground water in the soil around the pipe, if buried, than where it is partially saturated and partially exposed to air in the pores of the soil.

Second. The pipe is most durable when permanently filled with water and with the staves completely saturated from the inside.

Third. Wood stave pipe is apparently more durable when entirely exposed above ground than when partially buried, as decay takes place more rapidly at the intersection of the pipe with the ground surface than it does either above or below ground.

Wood stave pipes commonly are not painted but the experience of the United States Reclamation Service seems to indicate that a coating of red oxide paint assists in retaining the moisture in the staves of exposed pipe and prevents their decay. The staves should be thin enough so that they will be completely saturated, but staves of more than ordinary thickness will be thoroughly saturated under relatively high heads.

Staves, Materials, Thickness and Bending

Materials principally used for continuous wood stave pipes are California redwood and Douglas fir; the latter is also known as Oregon or Washington yellow fir. In the Eastern states, Canadian white pine is used to some extent. Redwood is of finer grain than Douglas fir and gives no trouble from percolation, although in any case the loss by percolation through pores of the wood aids in keeping the staves saturated and is immaterial in wood staves of proper thickness. Staves sawed with bastard grain have apparently greater swelling power or compressive strength than either edge grain or diagonal grained staves. Edge grain and bastard grain staves are also less subject to percolation and splitting than diagonal or quarter-sawed staves. Practice varies somewhat as to the thickness of staves to be used under given pressure for given size pipe. The following considerations should govern the thickness of staves to be adopted in a given case.

First—The thicker the staves the greater the stability of pipe against deformation by its own weight and accordingly the staves must be thicker for large than for small diameters of pipe.

Second—The staves should be thick enough to prevent material loss by percolation, and accordingly should be thicker for heavy than for lighter pressures.

Third—The staves should not be so thick as to prevent their being thoroughly saturated. This and considerations of economy require the use of as thin a stave as is compatible with the first two conditions named. Thinner staves permit the use of bends of somewhat smaller radii but also increase the danger of leakage between the stave joints. It appears that the water-tightness of the joints is somewhat dependent on the thickness of the staves, although the edges of the staves are usually beaded.

The following rule serves as a general guide for determining the approximate thickness of staves to be used in any case. The actual thickness of staves may be made equal to the nearest 1/8″ or 1/4″ greater thickness than shown by the rule.

Thickness of Staves, Inches=

$$1'' + \frac{\text{Head in Feet}}{100} + \frac{\text{Diam. of Pipe, Inches}}{100}$$

Example: Thickness of staves for a 70″ pipe under a head of 80 feet should be

$$1 + \frac{80}{100} + \frac{70}{100} = 2\ 1/2''.$$

The minimum radius of bends which may be made with continuous pipe increases with the diameter of the pipe and with the thickness of the walls. As an approximate rule.

Minimum Radius, Feet $= 4 \text{ to } 5 \times (D + 4t^2)$.

D = Diam. of pipe, inches.
t = Thickness of staves, inches.

For example a 30″ pipe with 1 1/2″ staves can safely be bent to a radius of about $4.5 \times (30 + 4 \times 1.5^2) = 175.5$ ft.

To prevent deformation of the pipe by its weight and that of the water contained, it should be supported through an arc extending about 55° each side of the vertical axis.

Materials for staves of wood pipe should be selected with the greatest care and subject to the most rigid specifications. Recent experience seems to show that durability of the pipe and maintenance charge probably depends more upon use of sound and perfect wood in each and every stave than upon anything else. Staves should be made of live timber entirely free from all dead wood, rotten knots, dry rot, shakes, cracks or other imperfections. Pitch seams not extending more than one-quarter of the way through the thickness of the stave, and small tight sound knots not over 3/4″ and 1″ in diameter and not occurring oftener than one in four feet of stave, are sometimes allowed. Also sap on the inside of the stave is sometimes allowed but all-sap wood should be excluded. Timber should be thoroughly seasoned before being milled into staves. Kiln-dried lumber is generally preferred. Staves should be dressed on both sides to true circular arcs and should be uniform in thickness and width throughout the entire length of each stave. Staves should be straight-grained and free from warp or wind. The more care there is exercised in the selection of staves the better the results will be in the long run.

Bands—Their Strength, Proper Size and Length

There are several formulae which have been derived for finding the proper size and spacing of bands for wood stave pipe. Practically the bands are always made from a limited number of commercial sizes of iron and calculations by none of these formulae lead to the exact sizes. Further-more, the formulae give only one size band as being applicable to the particular size of pipe and pressure; whereas as a matter of fact there are usually several sizes of bands and spacings of same which might be used in a given case, each of which contains the same amount of metal per foot length of pipe, and all of which are safe against both pressure and crushing of the wood.

The two principal considerations governing the size and spacing of bands are as follows: First—The area of section of the band per foot length of pipe must be such as to safely withstand the water-pressure plus the stress in the band due to swelling of the wood when saturated. Second—The size and spacing of the bands must be such as not to produce undue crushing of the wood.

When the bands are cinched with the wood dry, the resistance of the wood to compression exerts a stress on the bands which may be as great as 1,650 to 2,000 lbs. per square inch of edge surface of the staves. When the pipe is filled with water the water-pressure causes expansion which largely releases or relieves this pressure, but as the staves become saturated a new pressure due to the swelling of the wood of the staves is exerted. The swelling pressure is commonly taken at 100 lbs. per square inch of edge surface of the staves.

Taking into account both the stress due to water-pressure and that due to swelling of the staves, the following formula has been derived for determining the necessary area of cross-section of metal in the bands per inch length of pipe.

Table Showing Minimum Practicable Band Spacing for Continuous Wood Stave Pipe; also Maximum Spacing Consistent With Safety Against Crushing the Wood.

TABLE I. (Original by Robert E. Horton, M. Am. Soc. C. E. Copyrighted 1914.)

Diameter of Band, Inches	Minimum Practical Band Spacing		Maximum Band Spacing in Inches for Pressures Shown in the Column Headings										Area of Section of Band, Sq. Inches	Wt. of Band, Lbs. per Ft.
	Inches	Decimals	10	20	30	40	50	60	70	80	90	100		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1/4	1	1.000	10.	5.	3.33	2.50	2.00	1.67	1.43	1.25	1.11	1.00	.0491	......
5/16	1 1/8	1.125	12.5	6.25	4.17	3.12	2.50	2.08	1.79	1.56	1.39	1.25	.0767	......
3/8	1 1/4	1.250	15.	7.50	5.00	3.75	3.00	2.50	2.14	1.87	1.67	1.50	.1104	......
7/16	1 5/16	1.3125	17.5	8.75	5.83	4.38	3.50	2.92	2.50	2.19	1.94	1.75	.1503	......
1/2	1 3/8	1.375	20.	10.0	6.67	5.00	4.00	3.33	2.86	2.50	2.22	2.00	.1963	......
9/16	1 7/16	1.4375	22.5	11.25	7.50	5.62	4.50	3.75	3.21	2.81	2.50	2.25	.2485	......
5/8	1 5/8	1.625	25.	12.50	8.33	6.25	5.00	4.17	3.57	3.12	2.77	2.50	.3068	......
11/16	1 11/16	1.6875	27.5	13.75	9.17	6.88	5.50	4.58	3.93	3.44	3.06	2.75	.3712	......
3/4	1 3/4	1.75	30.	15.0	10.00	7.50	6.00	5.00	4.29	3.75	3.33	3.00	.4418	......
13/16	1 7/8	1.875	32.5	16.25	10.83	8.13	6.50	5.42	4.64	4.06	3.61	3.25	.5185	......
7/8	2	2.00	35.	17.50	11.67	8.75	7.00	5.83	5.00	4.38	3.90	3.50	.6013	......

NOTE.—To secure water tightness it is desirable to use closer band spacings than those shown in the table underneath the indented black line.

$$a = \frac{PD+200\ t}{2\ T}\ F$$

Where a = Required area of band section per inch length of pipe.

P = Pressure in lbs. per square inch.

D = Diam. of pipe in inches.

t = Thickness of staves in inches.

T = Ultimate tensile strength of bands in lbs. per square inch. (This is commonly taken at 60,000 lbs.)

F = Factor of safety. (This is usually taken as 4 for exposed pipes, increasing to 5 for pipes subject to water-hammer or for pipes buried in earth.)

Example:

For pipe 60″ in diameter with 100 ft. head or 43.3 lbs. per square inch pressure, with staves 2 1/2″ in thickness,—the required area of bands per inch length of pipe with factor of safety of 4 would be:

$$a = \frac{43.3 \times 60 + 200 \times 2\ 1/2}{2 \times 60{,}000} \times 4 = .1033 \text{ sq. inches per}$$

inch length.

Experience shows that in order to avoid dangerous crushing of the wood the bearing pressure between bands and staves should not exceed about 800 lbs. per square inch of contact between the band and stave. For round bands the width of contact

Table Showing the Sectional Area of Bands per Inch Length of Pipe for Different Sizes and Spacings of Round Steel Bands

TABLE 2. (Original by Robert E. Horton, M. Am. Soc. C. E. Copyrighted 1914.)

Diameter of Band		Area of Band Section Sq. Inches	Spacing of Bands between Centers—Inches									
Inches	Decimals		1	1½	2	2½	3	3½	4	4½	5	5½
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
				Square Inches Band Section Area per inch Length of Pipe.								
¼	.25	.0491	.0491	.0327	.0245	.0196	.0163	.0140	.0122	.0109	.0098	.0089
5/16	.3125	.0767	.0767	.0510	.0383	.0307	.0256	.0219	.0192	.0170	.0153	.0139
⅜	.375	.1104	.1104	.0736	.0552	.0441	.0368	.0315	.0276	.0245	.0220	.0200
7/16	.4375	.1503	.1503	.1002	.0751	.0601	.0501	.0429	.0376	.0334	.0300	.0273
½	.5	.1963	.1963	.1309	.0981	.0785	.0654	.0560	.0491	.0436	.0392	.0357
9/16	.5625	.2485	.2485	.1657	.1242	.0994	.0828	.0710	.0621	.0552	.0497	.0452
⅝	.625	.3068	.3068	.2045	.1534	.1227	.1023	.0876	.0767	.0682	.0613	.0557
11/16	.6875	.3712	.3712	.2475	.1856	.1484	.1237	.1060	.0928	.0825	.0742	.0675
¾	.75	.4418	.4418	.2945	.2209	.1767	.1473	.1262	.1104	.0981	.0884	.0803
13/16	.8125	.5185	.5185	.3456	.2592	.2074	.1728	.1481	.1296	.1152	.1037	.0942
⅞	.875	.6013	.6013	.4009	.3006	.2401	.2004	.1715	.1503	.1336	.1202	.1093

between the band and stave should be about equal to the radius of the band.

From these data the following formula is obtained for determining the maximum permissable spacing between bands of given size under a given pressure:

$$S = \frac{400\,d}{P}$$

Where S = Maximum permissible spacing of bands, inches.
d = Diameter of round bands, inches.
P = Pressure, lbs. per sq. inch.

For example:—for 1/2″ bands under 100 ft. head, or 43.3 lbs. pressure per square inch, the maximum permissible distance between centers of bands would be 4.62 inches.

The accompanying table, No. 1, computed by this formula will show at a glance the maximum spacing of bands of a given size under any pressure from 10 to 100 lbs. per square inch. As a rule the maximum spacing of bands for the lightest pressure is 10 to 12 inches but for heavier pressures the bands should in all cases be made small enough so that they can be spaced somewhat more closely in order to secure water-tightness. Column 2 of the table shows approximately the minimum distance at which the bands can be placed, allowing room for the shoes. For a given size band any spacing may be used which falls between the limits shown in the table; as for example, for a 1/2″ band under 40 lbs. pressure per square inch, the spacing may be anywhere from 1 3/8 to 5″.

TABLE 3. **Relative Discharging Capacities of Wood Stave and Other Pipes**

PIPE	Co-efficients Used in Formula: Kutter's Formula	Co-efficients Used in Formula: Hazen-Williams	Moritz	Relative Capacity Wood Stave Pipe = Unity: Kutter	Relative Capacity Wood Stave Pipe = Unity: Hazen-Williams	Relative Capacity Wood Stave Pipe = Unity: Moritz
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Continuous Wood Stave Pipe, New	N = .010	C = 1.20	1.00	1.000	1.00	1.00
Old or Poor Wood Stave Pipe.....	N = .011	....	....	.908	....	....
Best New Straight Cast Iron Pipe..	N = .010	C = 1.40	.975	1.000	1.167	.975
Fair Value Good Cast Iron Pipe...	N = .013	C = 1.00	....	.769	0.833	....
Best New Rivetted Pipe..........	N = .015	C = 1.10	.875	.667	.917	.875
Good Rivetted Pipe..............	N = .017	C = 1.00	....	.588	.833	....
Lock Bar Pipe...................	N = .013	....	....	.769	....	....
Vitrified Pipe..................	....	C = 1.10	....	....	....	....

Having determined by the formula given the area of metal in band section required per inch of pipe, the different sizes of bands which will give the required area of metal with different spacings may be taken directly from Table No. 2. In the example used for 60″ pipe under 100 ft. head, the area of metal required is .1033 sq. inches per inch. From Table No. 2 it is found that this amount of metal can be obtained by the use of any one of the following combinations:

1/2 ″	bands	at	about	2″	centers.
9/16″	"	"	"	2 1/4″	"
5/8″	"	"	"	3″	"
11/16″	"	"	"	3 1/2″	"

From the Table No. 1 of maximum and minimum practicable band spacing, it appears that all of these come within the required limits. So far as strength and safety are concerned, any size band from 7/16″ to 3/4″ or even larger may be used. The exact size to be chosen would depend somewhat on cost of labor and material. Smaller bands spaced closely are conducive to water-tightness but larger bands at wider spaces are probably somewhat more durable. For this case 5/8″ bands would be satisfactory.

As a general guide in the selection of band sizes and stave thicknesses, the table by Adams is presented. (Page 88.) Having determined the best size of band to use in a particular case, the exact spacing should be calculated by the formula,

$$S = \frac{A}{a}$$

Where S = Distance between band centers, inches.

TABLE 4.

Table Showing Velocity Under Different Conditions and Relative Discharging Capacity for Wood Stave Pipe, according to Different Formulaē and Authorities

FORMULA OR TABLE	12-Inch Pipe			48-Inch Pipe			96-Inch Pipe		
	Friction, Ft. per 1,000			Friction, Ft. per 1,000			Friction, Ft. per 1,000		
	0.2	2.0	10.0	0.2	2.0	10.0	0.2	2.0	10.0
Table A—Basis of Table not given	....	2.70	6.11	1.96	6.40	14.50	2.90	9.30	....
Table B—H. C. Coale, Kutter's Formula—n=.011 except for small pipe	.925	2.93	6.54	1.98	6.28	14.00	3.11	9.83	....
Table C—C. S. Alverson, Eytelwein's Formula	....	2.44	5.45	....	6.31	14.12	....	....	....
Table D—J. B. Lippincott, Kutter's Formula—n=.009 to .014	.791	2.66	5.96	1.69	5.49	12.27	2.40	7.66	17.12
Table E—Kutter Formula—n=.009 to .010	.88	2.73	6.10	....	....	....	....	....	....
Table F—Kutter's Formula—"n" not given	.85	2.73	6.10	2.21	....	....	....	....	....
Tables here given, Moritz Formula	.70	2.52	6.18	1.86	6.66	....	3.02	10.80	....

A = Area of band section, sq. inches.
a = Required band area per inch of pipe.

In the example used for 5/8″ bands,
A = .3068 Square inch. a, as already given = .1033 sq. inch and

$$S = \frac{.3068}{.1033} = 3 \text{ inches, about.}$$

In placing the bands they are sometimes hammered into the pipe to give them the required bearing in preference to cinching as great force would be required to draw the bands into the wood. Ratchet wrenches can be used to advantage for cinching. Ordinarily bands are bent to exact radius at the mill but can be shipped straight and bent on a suitable form at the place of erection. They should be dipped in hot asphalt or other suitable metal coating after bending.

The length of the upset ends should be at least 4 inches for pipes of small diameter and 4 1/2″ to 5″ for large pipes. The pipe will usually set up before cinching 1/8″ to 1/4″ larger than the finished diameter. The length of the band required for a given pipe exclusive of the head and upset end should be taken as equal to the circumference of a circle whose diameter is the interior diameter of the pipe, plus twice the thickness of the staves, plus at least one-half the diameter of the band. This allows for indentation of the band into the wood after cinching and also for stretch of the band. For small pipe, single bands with head on one end and upset on the other are commonly used. For larger pipe two bands are used, or in some cases, one band only with both ends upset and threaded. The thread on both ends reduces the amount of draw of the band around the pipe in cinching. Where two semi-circular bands are used, one is sometimes button-headed at both ends; the other upset and threaded at both ends, or both may be alike, each with one head and one thread end.