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Modern Practice in Wood Stave Pipe Design and Suggestions for Standard Specifications*

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Synopsis.

The object of this paper is to give engineers an idea of the difference between the various grades of wood pipes; to set forth a standard set of specifications for the assistance of engineers who have had no opportunity to become versed in their design; to safeguard those who contemplate building such pipe; and, further, to remove doubt from the minds of those who view wood pipe as one of the vagaries of engineering practice and a medium to be resorted to only in temporary and cheap work. If it can be shown that, to secure good results, the great difference in the quality of the materials used should be completely borne in mind, and if engineers can be led along a correct and standard course in the design and in the selection of these materials, this paper will have accomplished its object. To this end, specifications involving the latest and most approved practices are given in the Appendix.

* Presented at the meeting of May 16th, 1917.

Note.—The author of this paper is now in the Military Service of the United States, and is prevented by his duties from contributing a closing discussion.
The elements causing success or failure in wood stave pipe are taken up step by step, as follows:

1. Kinds of wood used,
2. Grade of lumber used,
3. Method of curing lumber,
4. Method of treating lumber,
5. Location of pipe when built,
6. Size and spacing of bands,
7. Methods used in erection, and quality of workmanship.

The foregoing headings are discussed as applied to the two types now in use, namely, continuous-stave pipe and machine-banded pipe, and a plea is made for the adoption of uniform specifications, dividing each type into Classes A, B, and C.

The Appendix contains the specifications, for the two types and three classes of pipes, which are proposed as a basis for adoption by engineers.

In 1898, the late Arthur L. Adams, M. Am. Soc. C. E., presented to this Society a paper* entitled, "Stave Pipe—Its Economic Design and the Economy of Its Use." This was the first important presentation of wood stave pipe design, and it brought forth a great deal of discussion. Mr. Adams prophesied the value that wood pipe would attain in hydraulic engineering, and was the first to give it its proper place with reference to cost, life, and capacity. He placed it first in economy of construction, first in carrying capacity, and second only to cast iron in length of life. These statements were rather startling to most engineers at that time, as they considered his deductions based on insufficient data. In 1906 Mr. Adams presented another paper† discussing the famous pipe of the Astoria City Water-Works. The discussion on that paper gave to engineers for the first time an idea of what could be expected of wood stave pipe. However, it was thought that a few more years must elapse before the real economy of such pipe could be determined. This was conservatism, for which engineers are noted, and proved to be a wise policy. Mr. Adams foresaw the value of wood pipe, but experience showed that all such pipe could not be placed in one class. Development with years made it evident that careful design and selection of material were necessary, without which complete pipe failures would result. The indiscriminate use of various woods, which time showed to be unfit for good pipe construction, proved that it was wise to make haste slowly.

Though Mr. Adams foresaw the ultimate success to be reached by wood pipe, he did not foresee the rapid strides, and consequently the hasty, unscientific, and indiscriminate use of all kinds of materials; and these proved totally unsuited for pipe design, and threatened to turn success into failure.

In various engineering journals, in recent years, much space has been devoted to this subject, and the articles written have thrown considerable light on what had been but a hazy understanding in the minds of most engineers. The advantages and disadvantages of wood stave pipe have been discussed, but these discussions have only led to greater confusion and doubt as to the best way to use it. Consequently, a most valuable asset to hydraulic work has been shoved into the background and considered as a type to be used only in special cases.

In all the discussions it is noticeable that there are no references to cases where wood stave pipe has been constructed or operated successfully, or unsuccessfully, for a number of years. Actual cases where it has been in service long enough to give an idea of its durability are wanted by engineers. With this information, they can give some assurance that, if such pipe is used, it is the proper construction.

In most of the articles referred to, statements like the following are the general rule: "Experience shows that staves must be completely and continuously saturated, and that intermittent or partial saturation leads to decay;" "a stave pipe is extremely short-lived, even when made of the very best selected wood, under partial saturation, especially in warm, humid atmospheres." Warm, humid atmospheres are often encountered in localities in which engineers may have wood pipe under advisement, and conditions of partial saturation or drying out of the pipe during a portion of each year are often unavoidable. Such statements, therefore, are misleading, as the general impression is that favorable conditions for wood pipe are few, and, under all other than favorable conditions, it will probably be short-lived. This is not

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* Transactions, Am. Soc. C. E., Vol. XLII, p. 27.
true of well-designed wood pipe, and especially does it give a false idea of its usefulness when made from the proper materials.

A few cases that contradict the general impression regarding such pipe under conditions of intermittent flow and partial saturation are well illustrated by the following:

1.—Supply line of the Utah Lake, Land, Water, and Power Company, at Mt. Nebo, Utah. A half pipe or flume and a 48-in. pipe built in May, 1893. Intermittent and partial flow during a few months of the year. At maximum flow under 70 ft. head. Pipe entirely above ground, and for part of the way bracketed against a rock cliff, with exposure to the south and the full heat of the sun. Inspection in October, 1914, showed pipe to be without decay. Clear redwood staves.

2.—Discharge line from sugar factory of Los Alamitos Land Company, Los Alamitos, Cal. Mr. H. C. Lawrence, Chief Engineer. Built in 1902. Used only for 4 months of the year. Discharge for refuse from factory, operating under no pressure. Mr. Lawrence states that the line is in very good condition; a few bands show corrosion, and a good many have been replaced. He estimates that the pipe will have a life of 50 years. Clear redwood staves.

3.—Sewer for Palo Alto, Cal. Built in 1898. Continuous flow, from one-half to three-quarters full. Pipe extends across salt marshes bordering San Francisco Bay; exposed at low and covered at high tide. Portions of line buried completely, half buried part of the way, and remainder exposed on the surface. Edwin Duryea, M. Am. Soc. C. E., in his discussion on Mr. Adams' paper of 1906, stated that this pipe showed not the slightest decay, though the bands had corroded badly. Air exposure, contact with the humus in the soil, saline soil, and partial saturation only, seem to have had no bad effect on the pipe, which is to-day in perfect condition and operating continually. A portion of the line buried in sandy soil had to be repaired a few years ago, some of the top staves requiring replacing, due probably to the sandy soil drawing out what little saturation these staves received. Clear redwood staves.

4.—Water supply pipe line for San Diego and Coronado, Cal. Built in July, 1900. 13,550 ft. of 40-in. and 26,300 ft. of 30-in. carry water from Otay Dam to these cities. Maximum pressure, 295 ft.; minimum, 150 ft. Pipe buried for entire distance in alkali flats, but above ground where several deep ravines are crossed on trestles. Examination by writer in 1916 showed staves to be in perfect condition. Mr. O. D. Fees, Superintendent in charge of line during construction, accompanied the writer, and stated that the wood was considerably harder than when first put in. It is quite possible that solubles carried in the water have entered and have been deposited in the pores of the wood. This is redwood pipe.

5.—Leaching tanks in the plant of the Krieg Tannery, San Francisco. Built in 1859. A number of tanks above ground leaching into those below ground. Removed in January, 1914, found to be in perfect condition, replaced, and now in service. Redwood staves used.

6.—A redwood flume built in 1888 for the Cuyamaca Water Company, San Diego, Cal., has much of its original lumber in place to-day.

7.—Two 32-in. inverted siphons, one 20 and one 15 years old, in the line of the Yakima Valley Canal Company, North Yakima, Wash., which operates during the summer only, showed tapered ends of staves in upper part decayed when the pipes were torn out to be replaced by a 48-in. line to increase the capacity. Redwood staves were used in all three pipes.

The writer's criticisms of the articles relating to wood pipe will have to be modified because of the recent publication* of a paper by D. C. Henny, M. Am. Soc. C. E., Consulting Engineer for the United States Reclamation Service. In this paper Mr. Henny made the first attempt to segregate the various types and grades of wood pipe. He presents valuable data as to what can be expected of the average wood pipe, made from various materials, and operating under various conditions.

The discussion, however, should be carried still further, and the facts regarding manufacture and design that will give the pipe the expected life should be investigated and presented, so that engineers can determine intelligently the type that will best fulfill their conditions.

Wood pipe is too often classed as a whole, irrespective of the material from which it is made, no attention being given to the fact that there is as much difference between the various makes as between cast-iron and steel pipe, in fact, more. It is quite possible to make a

* In the Reclamation Record.
run of steel or iron with identical quantities of impurities, thus obtaining practically uniform products. Wood, on the other hand, is the most variable material known to the structural engineer, and is acknowledged as such. Yet, in discussing wood pipe, no distinction is made as to quality, which depends on the kind of lumber used in the staves.

On work of any magnitude, where prominent engineers are consulted, conduits are generally chosen after deep study, and the results usually prove worth the expense of expert investigation. There are countless conduits, however, throughout the United States, where cheapness has superseded economy, and the resulting failures have shaken the faith in the type. Wood pipe has suffered the most. The many conduits with staves of inferior wood and poor manufacture have made engineers and others skeptical of this type of construction.

Wood pipe of the stave variety—and this is the only type considered to-day—was primarily a product of the West, although first invented and built in the New England States. The high freight rates on steel (which had to come from the East) made steel pipes very expensive, and the large quantities of timber available in the West made the use of wood an economical necessity. To build stave pipe, timber must first be available, and then the proper machinery to mill the staves, otherwise, it would not pay to use this type, except in those few cases where large projects warrant the cost of erecting machinery to mill the staves. Companies with timber holdings and mills of their own were naturally in the best position to manufacture such pipe. As a consequence, this business drifted into their hands, and they undertook it merely to sell lumber, only a few companies being formed to construct such conduits.

To-day it is possible for individuals to obtain materials and bid on wood stave pipe contracts, and such work is often undertaken at absurdly low figures in competition with experienced companies, which, knowing their business, are unable to secure the work except at a heavy loss. The successful bidder does the work to the best of his ability, but, as the building of continuous-stave pipe requires years of experience, he loses money, the pipe manufacturers are unable to keep in the business, and the purchaser secures a pipe that never proves a success. It is the duty of the engineer to protect his employer against such conditions, and to do so he must be fortified with good specifications and must enforce compliance with them.

The elements causing success or failure in wood stave pipe include:

1. Kinds of wood used,
2. Grade of lumber used,
3. Method of curing lumber,
4. Method of treating lumber,
5. Location of pipe when built,
6. Size and spacing of bands,
7. Methods used in erection, and quality of workmanship.

Redwood, fir, cypress, and pine are in general use, and make pipes of different characteristics. The pipe is also affected by the sap, pitch, or knots in the staves. The method of curing—kiln or air-drying—also influences the quality. Treating lumber with creosote, or surface painting, also affects the final result. The location determines to a certain extent the type of pipe to be chosen, and the size and spacing of the bands and the methods used in erection make a first-class or a useless pipe out of the materials available. If an engineer knows only the general methods of construction, and not the fine points, he cannot build a wood stave pipe line as well as a company which has had years of experience, and is likely to have trouble.

A discussion of the merits or demerits of such construction is misleading unless based on a clear specification. It is known, of course, that wood pipe kept constantly saturated will last indefinitely, but, as such cases are not always found, one must consider what will happen under other conditions. Fir and pine are pitchy woods, and it is impossible to obtain commercial run lumber without sap, pitch, pitch seams, pitch pockets, and knots. Under conditions of partial saturation, this lumber will not last, and, even with saturation, the pitch and sap will be the cause of deterioration. Most failures are attributable to this fact. There are conditions under which fir or pine will have a long life and give perfect satisfaction. For instance, erected on cradles, allowing the air to circulate freely around it, pipe will give satisfaction if the climate is dry, so that mosses, etc., caused by dampness, do not accumulate on the exterior. Pipe under heavy pressure in compact soil will last indefinitely. Mr. Henny has given the following tabulation:
Wood | Condition | Years
--- | --- | ---
Fir | Uncoated, buried in tight soil | 20
" | " | 4-7
" | in air | 12-20
Redwood | buried in tight soil, loan, sand, and gravel | (More than 25)
Fir | Well-coated, buried in tight soil | 25
" | " | 15-20

Cypress makes a most excellent and durable pipe, and is the only competitor of redwood with reference to length of life and endurance under alternately wet and dry conditions. If cypress is selected so as to eliminate sap, it probably is as long-lived as redwood; at least, it is near enough to avoid discussion. The disadvantages of cypress are:

First, the quantity of standing timber is extremely limited, and it is estimated by conservative lumbermen that all the commercially available cypress will be cut during the next 10 years. Thus, those who have cypress are constantly raising their prices to correspond with the advancing rise of stumpage.

The second disadvantage is in the wood itself. It grows in swamp land, and the butts of the trees are usually under water. A cypress tree is the product of four or five small trees growing together. The result is that the sap does not come as it does in redwood, entirely around the circumference of the tree, extending inward only 2 or 3 in., but it occurs throughout the clear part of the log, in streaks or strips. It is common to see clear cypress with yellow sap streaks running through the center at intervals of about 4 in. This has brought about the peculiar condition, that cypress has a grade higher than clear, and (the writer believes) is the only lumber which is thus graded. “Tank” grade is the highest in cypress, and contains knots but eliminates sap. Cypress knots are smaller and harder than those of redwood, and are not as detrimental.

It is extremely difficult to get cypress for pipes, because of the sap, and, where sap is eliminated, the price of the wood is so high that it cannot compete. Cypress pipes are rare.

Redwood is the best known material for wood pipe, and its longevity is excelled only by cast iron. The acid or other peculiar constituent of this wood acts as a preservative or micro-organism destroyer, and protects and preserves it.

The cases of redwood pipe already cited illustrate its adaptability, whether laid on the surface of the ground, partly or completely buried, or run through salt marshes or tropical swamps in direct contact with the soil humus. Direct exposure to the rays of the desert sun, and alternate wetting and drying when the pipe is used intermittently in irrigation systems, do not lessen its efficiency.

A thorough study of the conditions under which a proposed pipe will operate and an investigation of the materials best suited to withstand these conditions, should be made before specifications are written. These important points should be kept in mind in order to insure specifications that will cover the conditions closely.

Engineers should first decide the nature of the conduit they intend to build; that is, whether it is to be a permanent structure or is to last only 5 or 10 years, after which time it is to be abandoned or replaced by a conduit of increased carrying capacity. Then the nature of the local conditions relative to the pipe line should be ascertained, including climate, humidity, temperature, extreme and average pressure, nature of soil, probability of the pipe being buried or laid on the surface, and other details; and then specifications for the materials can be written.

There is great necessity for uniformity in drafting specifications, and for an understanding of the requirements for securing pipe that will fulfill the needs of the proposed work. At present practically every piece of work is covered by specifications embodying different fundamentals. This is most noticeable in a comparison of specifications for various projects of the Reclamation Service. On some of these a distinction is made between redwood and fir pipe, bids being asked for coated fir and uncoated redwood, though in other projects no such distinction is made, these woods being placed on an equal basis.

This question of the coating offers the largest field for disagreement, most engineers being of the opinion that both redwood and fir pipe should be painted in order to obtain good results; on the other hand, many who have had experience with uncoated redwood claim that painting it is unnecessary.

The thickness of the staves is another point of difference, and has been settled theoretically and practically with widely varying results. There is some difference of opinion as to the spacing of bands, depending on the assumed factor of safety, which factor in turn is determined by
the greater or less conservatism of the engineer. In the specifications for the staves is found the greatest divergence, and without justification. It is not evident why pitch and knots should be allowed in fir and not in redwood staves. Another objectionable feature in some specifications is the provision for rigid supervision of the bands, though adequate stress is not laid on the requirements for the shoes, which, after all, must be capable of developing the full strength of the band. The tongues are seemingly the smallest item of continuous-stave pipe construction, but, nevertheless, are by no means the least important. In machine-banded pipe there is absolutely no basis for the present-day so-called specifications.

The result is that some pipe lines are well, and some poorly, designed, the latter very often being the least economical. The purchaser, paying for what he believes to be the best type obtainable, secures a piece of work which proves a failure. These failures hurt the owner and undermine the faith in such construction. A great many engineers have little or no idea of how to design a wood stave pipe, and when it is necessary for them to draw up specifications they seek everywhere for information and acquire and compile a heterogeneous mass of data which are mostly useless.

For the assistance of engineers who have had no opportunity to become versed in wood stave pipe design, and to safeguard those who contemplate building such pipe, specifications should be standardized. The Appendix contains the specifications suggested as the foundation for a standard.

Sap and pitch in the staves mean a short life for the pipe, as deterioration will start first in sap wood, pitch seams, or pitch pockets, and spread rapidly to the clear wood. Pine and fir cannot be secured commercially without these defects, and, therefore, are fundamentally inferior to redwood, in which absolutely clear staves can be easily obtained. At repeated intervals, heavy applications of some protective paint with disinfectant qualities will allay the danger of deterioration in fir and pine, but proof that their ultimate life will equal that of redwood has not yet been obtained.

The thickness of staves should next be considered. Of course, the thicker the stave the better the pipe, but this has economical limits. A thickness of ½ or ¾ in., more or less, should not be the subject of controversy between engineers. The best criterion of the required thickness of staves is actual experience. Throughout one section of pipe there will be staves of entirely different characteristics, including grain, resistance to percolation, and ease of penetration. Slash grain, vertical grain, quarter-sawed staves, heart wood, etc., all have their influence on the thickness required, and, with such a great difference in the characteristics of each stave, a small difference in thickness does not affect the quality of the finished pipe.

In designing staves there is more than the thickness to be considered. Economy is the other essential feature. In common practice, stock sizes of lumber are chosen which will give the most economical number of staves to the linear foot of pipe. For instance, for a 36-in. pipe, 2 by 6-in. lumber is chosen. A maximum thickness and width of stave is obtained from lumber of this size, and a certain number of feet, board measure, is obtained in the cross-section of the pipe. If 2 by 4-in. stock is chosen, in comparison with 2 by 6-in., the result may be a saving in the board measure, but the cost of erection of the pipe will be increased considerably on account of the greater number of staves to be handled. If 2 by 8-in. is used, a saving in erection is obtained, but the greater waste in lumber offsets the saving in erection. The result is that 2 by 6-in. is the most economical size. The maximum that can be obtained from this stock piece is the thickness to be specified. It should be remembered, however, that this maximum will be less than that obtained by laying out the stave on paper, showing it cut from 2 by 6-in. stock of exact dimensions. The stock as it comes from the mills, dry and ready for stave manufacture, will probably measure not more than 1½ by 5½-in. Allowing enough for milling, the thickness of the stave will be reduced. Common practice and experience in stave milling should always be considered. If greater thicknesses are wanted, a higher price may be expected, as uneconomical sizes of lumber must be used, or a higher price must be charged to cover the selection of wider and thicker stock.

The stave has to resist the percolation and the penetration of the water. It should be sufficiently thick to prevent excessive percolation, and, at the same time, there should be perfect penetration. It is difficult to determine this thickness. If the staves have rings showing wide, alternate spaces of hard winter wood and soft summer wood, there will be great danger of excessive percolation, the water finding its way out through the soft wood between the hard rings. If the wood is very
hard, there will be great difficulty in the stave receiving complete saturation, due to the absence of capillary action. A soft wood will take up water like a blotter, but a close-grained wood will effectively resist percolation. This is very important in determining the lumber to be used.

Fir and pine, being hard woods compared with redwood, and being coarse-grained, having wide rings of hard and soft wood, enter the classification of woods giving excessive percolation, with slow and incomplete penetration. This is caused by the water passing rapidly through the soft summer wood, appearing in drops on the outer surface of the pipe, and of penetrating but slowly, and often through only a fraction of a stave, along the hard winter rings. The result is a stave showing percolation and incomplete penetration at alternate points throughout its cross-section.

Redwood is very soft and cellular, and pipe made from clear stock will be free from percolation and will receive complete saturation, even under very light pressure.

There is such a great variation in the quality, grain, and degree of hardness of even the same kinds of woods, that it is impossible to secure a pipe in which the penetration and percolation will be of the same degree in every stave. In the same section of pipe, soft staves with good penetration and no percolation will be found adjacent to hard staves with poor penetration and excessive percolation. It is obvious, therefore, that a refinement of stave specifications to the point of \( \frac{1}{4} \) or \( \frac{1}{8} \) in. more than a practical working thickness is entirely unnecessary.

In the Appendix practical working thicknesses for staves are given, and it is recommended that engineers give them their attention when drawing up specifications. By a practical working thickness is meant that which can be secured from the stock sizes of lumber making up the most economical pipe.

The best selection of a stave, therefore, is the result of experience with those thicknesses which give maximum penetration and minimum danger of percolation.

It should be remembered that fir or pine staves require greater thickness than redwood, in order to resist excessive percolation, and the result is not altogether beneficial, as the penetration is less likely to be complete.

The difference in required thicknesses of fir or pine and of redwood staves applies more particularly to machine-banded pipe, because the thicknesses for continuous-stave pipe are determined primarily by construction conditions, rather than by reason of penetration and percolation.

One objection to wood pipe is the danger that it may dry out if the water is drawn off. To avoid this, the staves should be thoroughly dry, so that, when properly erected and cinched tight, there will be no leakage. The pipe should be tight and stay tight. If wet staves are used, no swelling can be relied on for making a tight line, and the requisite pressure between the staves to prevent the passage of the water must be the result of cinching the bands. This is practically impossible. The lumber, therefore, should be perfectly dry before being used. It should be dried by the natural or air-drying process, not by the forced or kiln-drying process. By air-drying only is perfect, sound, strong lumber obtained. Kiln-drying makes brittle and lifeless lumber. Air-drying requires time, and, as lumber should be seasoned for at least a year for the best construction, a large stock of it should be available at all times.

The old method of drying lumber (in Maine and Michigan) was by the use of live-steam kilns. These are still used in the Northwest for drying fir and pine, as such treatment is necessary in curing pitchy and sappy woods. The kilns are large rooms, along the floors of which there are perforated steam pipes into which live steam is turned. The lumber placed in such a kiln is literally cooked. Redwood when first marketed had never been kiln-dried, but when the demand became too great for the supply of air-dried lumber that could be kept on hand, kiln-drying was adopted. Redwood treated by this process was flinty, and could be broken into splinters over the knee. Such methods of drying are now being used by some of the redwood mills, but lumber thus treated should never be allowed in pipe construction. The later method of kiln-drying is by indirect heating with steam. Steam is introduced into pipes laid on the floor of the kiln, and air with a certain humidity is admitted into the kiln at a given temperature, is heated by passing up around the steam pipes, and, rising through the lumber, removes the moisture. The air then passes down the compartments at the sides of the kiln where the water it contains is condensed, and the cooled air is again brought down to the heating
pipes. A circulation of air is thus effected by which the lumber is dried. This is far superior to the old method. The introduction of green lumber into a kiln and the forced removal of the water causes a forced and sudden hardening and closing of the pores, checking, splitting, and rendering the wood brittle. Air-drying is a natural seasoning, the slower the better, and is brought about by the wind blowing through properly stacked lumber. When securing lumber for pipe staves, there should be a strict investigation into the methods of drying used by the mills. For correct pipe design, only air-dried lumber should be specified.

In regard to the protection of the staves by applications of coatings of paint or disinfectant, little of value can be cited. Many claims are made for the benefits derived from various coatings, but sufficient data are yet lacking for reliable conclusions. It is certain that such protection increases the life of fir, pine, or other woods containing sap and pitch, but its merits on a redwood pipe have not yet been proved. Though uncoated fir and pine, except under conditions of complete and continued saturation, have proved short-lived, similar pipes coated with a mixture of tar and asphaltum have given far better service, and in many cases appear to be in perfect condition. More than this is not known. The oldest lines, on the other hand, made of redwood, have never been coated with any protective coating, and are still in perfect condition.

A coating, to be effective, should be applied diligently and often. At least two coats should be applied primarily, by conscientious workmen or by some pneumatic process. As in all painting, the personal equation of the workman is 75% of the job. A coating of at least 1/16 in. should be the result of the first painting, and repeated examination should be made of the line, and the pipe painted every year or so.

Steel bands can be obtained to-day from practically all the large steel mills. These bands are manufactured according to standard specifications; if other specifications are used the cost is greatly increased, and very often it is practically impossible to obtain them. Engineers should bear this in mind, as they will save the pipe constructors much trouble and the purchaser much needless expense by using the standard specifications. The band commonly used is of mild, open-hearth steel, having a tensile strength of from 55,000 to 65,000 lb. per sq. in., with a button head at one end and at least 5 in. of cold-rolled thread on upset ends at the other. The requirements for pipe bands are included in the standard specifications in the Appendix. Specifications often call for pure iron bands, but, as pure iron is made only in very limited quantities, mostly in Norway and Sweden, it is evident that it would be impossible to comply with such specifications.

The size of the band steel and the spacing of the bands on the pipe are, after all, the most important factors affecting the strength of the pipe. Common practice requires the bands to be spaced so that they will have a factor of safety of four against breaking due to tension caused by the water pressure, though some specifications call for a factor of safety of five. The latter requirement adds greatly to the cost without benefiting the pipe. The factor of safety of four gives ample protection against failure under water pressure through rupture of the bands, but the point to be borne in mind is that the pipe may fail on account of the bands sinking into the wood and allowing the longitudinal joints between the staves to open, thus causing leaks. The failure of the pipe in bearing, however, in pipe more than 10 in. in diameter, is prevented if the bands are spaced with a factor of safety of four in the tension formula. The two formulas to be used in spacing the bands on the pipe relate to the tension in the bands and the bearing of the bands and staves. In the bearing formula the value to be determined by experiment is the strength of the wood in bearing. This has generally been taken to be greater for fir than for redwood, but experiment shows that staves in a saturated condition, as would occur in a pipe in place, have practically the same strength in bearing. This approximates a working stress of 800 lb. per sq. in. If the spacing of the bands is checked by both formulas it will be found that all pipes more than 10 in. in diameter will be designed according to the tension formula, and that the bearing will be amply cared for under this condition.

In the design of every pipe line there will be two or three sizes of bands that may be used, with their corresponding spacing, and it is necessary to choose the most economical. The smaller the band the closer the spacing, and the closer the spacing the better the pipe. Economy limits this to a certain extent, as the smaller bands cost more than the larger ones, and erection costs increase with the number of bands handled. A certain maximum spacing should not be exceeded, in good pipe design, and the size of the band may be cut down to hold
this spacing to a minimum, maintain the factor of safety, and still give economical erection. To hold to the maximum spacing with a large band wastes metal, but may be found to be most economical on account of the higher price of small bands. Erection has an important influence on the size of the bands on light-pressure pipe with the maximum allowable spacing, because, if small bands are used, it may be found impossible to cinch them tight enough to prevent seam leaks, and the threads on a great many bands will be stripped before the staves can be drawn together tightly enough to prevent such leakage. Heavy bands are required to draw the staves together, but after they are in place the initial tension in the bands is dissipated, and the only stress is that due to water pressure.

By no means the least important feature is the design of the shoes for cinching the bands tightly in place. These should be stronger in body than the bands, in order to develop the full strength of the latter. There should be a thorough investigation of the shoes, and, unless a special test is made, those that are standard and have been tested repeatedly should be used. It is folly to have bands spaced with a high factor of safety and then use shoes which are weaker in design than the bands they hold together. A case is known where this happened, and approximately 300 tons of steel were absolutely wasted. On some recent municipal work for a large western city a similar case of inferior shoes has lessened the efficiency of the conduit.

The tongues prevent the staves from working out at the butt joints, and are intended to form an effective water seal where the staves butt together. They are generally made of band iron, 1½ in. wide, No. 12 or No. 10 gauge, or ½ in. in thickness, cut ½ in. longer than the width of the stave measured along the slot. This allows ⅛ in. to project into each adjoining stave, effectually preventing water from working around the joint. When the pipe is first cinched up, prior to rounding out the staves to the true circle, these tongues are set farther than this ⅛ in. into the adjoining staves. Then, when it is attempted to round out the pipe, that is, hammer the stave from the inside to proper position, the tongues will tear the staves badly, and decay first starts where lumber is bruised or torn. Contact is all that is needed for a perfect water seal, and if the tongues are cut ⅛ in. longer than the width, that is, cut to allow an initial projection of ⅛ in. in the adjoining staves, a water-tight joint will be secured with less damage to the wood during the rounding out of the pipe. There is little likelihood that the tongues will rust out, as air does not reach them readily; however, they are generally coated with an asphaltic base paint.

The rod of the least diameter that can be used on light-pressure pipe, with maximum spacing, can only be determined by experience, and should not exceed the sizes given in Table 1.

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<td>24 to 36</td>
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<td>48 to 72</td>
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<td>72 to 96</td>
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<td>96 to 132</td>
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<td>132 to 144</td>
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</table>

When the maximum spacing is used, extra bands should be placed over the butt joints to reinforce the pipe at these points. Many pipe failures have resulted from allowing too wide a spacing as a maximum, and such conduits, under a heavy back-filling, failed by the arch of the pipe collapsing. A maximum spacing of 18 in. has been used, but this does not make a pipe. A spacing of 12 in. has been used with success, but the best results are obtained with a maximum of 10 in.

The coating for the bands and shoes is determined by the conditions and the life to be expected of the pipe. For the bands of fir and pine pipe an asphaltum coating is sufficient, as the bands will outlast the staves. On redwood, contrary to the general impression, the life of the pipe will invariably be the life of the bands. The life of the pipe, therefore—or its economy—depends on the coating first applied to the bands; in after years the pipe should be well inspected and the bands repainted and replaced when necessary. A coating having an asphaltic base is most commonly used, and gives perfect satisfaction. Under normal conditions bands thus coated last from 10 to 15 years, after which time it will probably be necessary to replace them occasionally, although, as a whole, they will outlast steel pipe, as the metal is concentrated in a round band which presents a minimum surface to corrosion. Covering with red lead is recommended for severe conditions, bands having been found as bright under the red lead as when first erected, even after 20 years’ service. In Central America coating
with red lead is found to be well suited for protection against the ravages of tropical climatic and soil conditions, and exposure to the salt air during steamer transit. Galvanizing may be used, but, on account of its excessive cost, is not common. In the Hawaiian Islands galvanizing is used exclusively, together with redwood lumber, and such design has been found to give practically the only pipe that will stand up under the conditions there.

No attempt will be made to outline the best methods of constructing wood stave pipe, because there are so many details that require attention and experience that, unless an engineer is familiar with such work, he will do better by securing the services of reliable pipe constructors.

Machine-banded or wire-wound pipe has come into use since Mr. Adams presented his last paper on wood stave pipe, and has found a ready market in the West, on account of its economy. It is factory made, in sizes from 2 to 24 in. inside diameter, and is designed for heads up to 400 ft. The sections are from 8 to 24 ft. long, and have the necessary couplings or collars for connecting them.

Since this type made its appearance, some time ago, there has been practically no improvement, and the old specifications and methods of manufacture are still followed. In spite of its many imperfections in design and manufacture, this type has made a wide field for itself, and is found in every branch of hydraulic work. Unless steps are taken to correct its weaknesses, however, it will rapidly lose favor on account of its numerous failures. These failures have not been altogether the result of poor manufacture, but have been due to an endeavor to reduce the cost. This was done to such an extent that good manufacture and design were impossible.

It is subject to the same criticism as continuous-stave pipe. Conduits of poor design and poor material, or material unsuited for the work, have given the impression that wood pipe as a whole is unsatisfactory and short-lived.

Modern machine-banded pipe is made with heavy staves, generally kiln-dried, banded with galvanized wire, from No. 6 to No. 80 gauge, spaced according to the pressure. The wire is securely fastened to the pipe with pressed-steel clips or staples, or both. Each section is dipped in asphalt and rolled in saw-dust, the asphalt effectually covering the wire and staves, and the adhering saw-dust permitting it to be handled readily. The sections of light-pressure pipes are joined with inserted or slip-joint connections, being sometimes reinforced with a steel band equipped with a shoe for cinching tight. On high-pressure pipes (generally for more than 100 ft. static head) collars are used. These collars are made in a manner similar to the pipe, the sections being tapered and driven firmly into them. On pipes of large diameter, operating under heavy pressure, the collars have individual bands fitted with shoes for cinching. Riveted steel or cast-iron collars, with or without bells, are also used.

The foregoing describes the pipe generally made by all manufacturers of this type, and represents standard practice. Numerous failures have rendered the recommendation of this type doubtful. If investigations were made into the actual causes of the failures, the reasons would be plain, similar designs would be avoided, and there would be rigid inspection of the manufacture. In outlining the results of the methods of manufacture, it will be well to mention the reason that fir pipe is the butt of the criticism. Fir is the pipe that has failed, the oldest lines having been built not more than 10 years, the greater number being of comparatively recent date. When these pipes were made, fir was chosen as it was the cheaper wood, and there was no criterion as to longevity. The greater number of failures possibly originated at the joints. The outer edges of the staves in the collars, when wood collars were used, decayed rapidly owing to the fact that fir needs saturation for preservation, and saturation was not secured at those places. Cast-iron and steel collars were the remedy, but have not proved successful, owing to their high cost, the increased weight, and the difficulty of making tight connections and plugging leaks. Riveted steel collars can be used to advantage on fir or pine pipe, as they will last as long as the staves, in which the sap wood decays rapidly.

Redwood collars of the individual banded type are used for repairing pipes which have failed at the joints. The decayed fir collar is cut off, and the redwood staves are put in position and cinched tight. This method requires no further attention, and can be applied successfully at any joint where there is decay. The wire is cut away and securely stapled, and the redwood collar is put in position.

The use of the inserted or slip-joint pipe is not to be recommended. Such a connection weakens the end of every section, because nearly one-half of the shell of the pipe is cut away to make the joint. A
reinforcing rod is often used to draw the joint tight, but if the male and female tenons are eccentric, leakage cannot be avoided. There is also great danger of injury to the pipe by handling, before and during shipment, as well as in laying; the weakened ends are not reinforced, and often split off with rough handling. The collar connection is to be preferred, as it will insure a better and stronger pipe, and the greater length of life will warrant the increased cost.

Most of the serious failures have occurred when the water has been drawn out of the conduit for any length of time; this has caused the staves to dry out and the pipe to fall to pieces. Failures by the galvanized wire breaking, mainly at the twist splices, are serious, as the entire section of pipe on which such a splice occurs must be removed.

As a remedy for failure by decay, machine-banded pipes are now painted or dipped in a protective coating, but the same conditions exist here as with the continuous-stave pipe, and pitch seams and sap wood will cause failure, even in coated staves. Coating not only adds to the cost of manufacture, but increases the weight materially. Machine-banded pipe, being essentially a factory product, its cost is affected greatly by freight rates, as shipment from factory to site of erection determines the economy of its use in a great many cases. In this type redwood has a distinct advantage over fir or pine, as it is unnecessary to apply an artificial coating to preserve the staves; therefore, having no coating of tar or asphalt, and well-seasoned redwood being very light, it has a very low shipping weight. The coating often serves to cover defects in material and manufacture. Fir and pine pipe should be inspected rigidly before acceptance; and redwood pipe should be left open to inspection and thus save the difference in weight and the cost of dipping. Painting the wire is useless. When the pipe is built it is impossible to be so careful in handling that none of the paint will be scraped off. The wire exposed in one spot leaves a weak place at which corrosion may start. As the wire is wound under heavy tension, there can be no protective coating on it where it touches and is embedded in the wood; for that reason only a small part of its surface is coated.

To prevent machine-banded pipe from drying out and collapsing, thorough drying of the stave material and proper winding are necessary. By the use of thoroughly dried wood, wound under heavy tension in the wire, with close spacing to draw the staves together, securely and completely, high-grade pipe is obtained. Tests in winding redwood pipe show that a tension of 25,000 lb. per sq. in. in the wire embeds it securely in the wood and draws thoroughly dry staves together properly without crushing the fiber under the wire or along the edges of the staves. A tongue slightly longer than the groove also assists in making the pipe water-tight when exposed to the sun after the water is drawn off. Exhaustive tests at the plant of the Redwood Manufacturers Company, at Pittsburg, Cal., showed that this tension produces a pipe having greater strength, in resisting possible over-loads, than if wound under less tension, and that higher tension crushes the wood fibers. This initial tension in the wire entirely disappears after winding, and the ultimate tension is that due solely to the water pressure.

The secret of correct manufacture is the thorough seasoning of the wood. Such a pipe can be laid directly on the surface of the ground and exposed to the heat of the sun without injury. A slight tongue and groove in the sides of the staves prevents their displacement if they shrink. This should occur only to a slight extent under most severe conditions, if the staves are properly dried and a proper process of winding is used.

Kiln-dried wood should not be used for machine-banded pipe. Pitch and sap should not be allowed, nor should untreated or uncoated fir or pine be used. Redwood does not need treatment to insure a life at least as long as treated fir or pine. Fir or pine pipe should be supplied with cast-iron collars with bell hubs for caulking. On redwood pipe redwood collars may be used, and as the wood does not rely on saturation for preservation, machine-banded and continuous-stave collars may be used to advantage. Inserted joint connections may be used, but will not give as good service as collars.

In choosing a thickness of stave, it is only necessary to use that which will resist percolation successfully and can be built into a pipe. Staves must have sufficient thickness to resist the stress caused by the high tension in the wire during the process of winding. If they are of redwood, there will be no danger of decay within 15 to 25 years, which is the life of galvanized wire.

For more than 18 months the writer has investigated tests of machine-banded pipe made at the plant of the Redwood Manufacturers Company, and the results have been most startling as well as gratifying. Continued experiments on various sizes of pipes under various pressures have shown that redwood pipe made according to the specifications for
Class A, of the given thickness of stave, and wound with the stated sizes of wire, will be absolutely water-tight, and, if designed with a factor of safety of four against the wire breaking and a value of 800 lb. per sq. in. for bearing, it will withstand successfully a 200% over-load of the pressure for which it was designed. An 8-in. pipe, with a shell only \( \frac{3}{4} \) in. thick, and wound with No. 8 wire (0.162 in. in diameter), with a spacing of 2\% in. from center to center, to withstand a 75-ft. head, has operated successfully under a greater head than 200 ft. Further, this same pipe, wound for various pressure heads, has been connected to the boiler feed pump, in the engine-room at the factory of the Redwood Manufacturers Company, and subjected to pressures varying constantly between 15 and 75 lb., has withstood successfully, and is still operating with, over-loads as high as 80 lb., and has shown no leakage.

Wood pipe failures, when occurring in the body of the pipe, generally appear first along the longitudinal seams, which open up, allowing leakage. This is caused by the wire sinking into the wood; in other words, the bearing between the wire and the wood being destroyed, the staves move outward and the seams open. When this occurs the pipe is a failure. After such failure the staves return to their normal positions on release of the pressure, and the pipe will still operate successfully under the pressure for which it was designed.

It makes no difference whether the thickness of a stave is 1 or 2 in.; after the outer \( \frac{1}{4} \) or \( \frac{3}{8} \) in. has decayed, the staves move outward and the pipe fails. With thin staves, however, which can receive more perfect saturation, the maximum life is obtained.

The process of winding the wire on the pipe and drawing the wood together with the proper tension in the wire, actually determines the thickness of the staves. If the latter are too thin, they cannot be drawn into a firm seat against each other, but will buckle; the limiting thickness must be determined by experiment. During winding, a constant and uniform tension should be kept on the wire, drawing in the staves sufficiently to make all joints absolutely tight without crushing the wood. The closer the wire is spaced in this winding the better the staves are drawn together, and the tension required to do so is a minimum. A gauge, registering the actual tension in the wire, should be directly in front of the operator of the winding machine. The tension varies, of course, with the diameter of the pipe and the spacing of the wire. It is quite proper to give some guaranty of wood pipe design to the purchaser. When buying cast-iron or steel pipe, the head the pipe will withstand is known, but in wood pipe design and manufacture there are so many uncertainties that, without some guaranty of its strength, an engineer is at a loss to know its quality. He can check up the size of the wire and the spacing, but knows nothing as to the care in manufacture. If a pipe, guaranteed, say, for 50 or 100% over-load, can be obtained, the engineer then has a basis on which to work, and this is the ultimate method of correct manufacture to be expected. To secure a theoretical and practical basis for the design of machine-banded pipe and to determine an over-load for a guaranty, was the object of the tests just mentioned.

A radical departure from customary methods of pipe design is necessary to secure desired results. It must be remembered that, in mending a hoe handle, the farmer takes a small fine wire and wraps it as close as possible around the fractured part. He does not take a heavy wire and wind the handle with wide spacing. The correct principle of pipe winding is similar: Use small wire closely spaced, giving sufficient steel with such spacing as to insure a factor of safety of at least four against rupture under tension in the wire. A closer spacing is required on small pipe to prevent the wire from sinking into the wood because of insufficient bearing area. The use of small wire increases the bearing area between wire and wood. The reason for this can be readily understood, but the lasting quality of the small wire has to be considered.

Repeated tests and consultations with high authority on wire manufacture, and a study of the reasons, would show that the smaller wires are as well protected with galvanizing as the larger ones, and, if anything, a little better. The Western Union test, taken as a method of comparing the galvanizing on various sizes of wire, gave results which favored the smaller wires. The authorities, who are the wire manufacturers, state that the smaller wires are better galvanized because more care is taken with them in order to secure a product of the very highest grade. The reason is that, on account of the smaller wires being in greater demand, more care is taken to secure a uniform and high-grade product. In any factory output, market conditions
must be considered, and in the wire market small wire is of the best quality. Another reason for the use of small wire is the danger of destroying the galvanizing on large wire when winding pipe of small diameter. It is common to find a path of spelter directly under the pipe winding machine when winding small pipe with heavy wire, the result of the galvanizing spalling off. It is also found to spill off in splicing with the old twist, or Western Union splice. Splicing is necessary when coming to the end of the coil of wire while winding a section of pipe, and is of frequent occurrence when winding heavy-pressure pipe where close spacing is required. In making this splice the wire is twisted around its own diameter, and this injures the zinc coating.

Maximum efficiency is secured where there are no splices. Electro-welding with re-galvanizing has been tried, but the re-galvanizing is unsatisfactory, and, until better methods are obtained, splices should be eliminated. All fastenings of wire in place on pipe should be galvanized. Pressed-steel clips will rust if not protected.

The essential feature for success in machine-banded pipe is the proper use of the proper materials. The wrong use of a good material will be as productive of failure as the use of poor material.

With high-grade lumber and a high-grade wire, with which every precaution is taken for protection against corrosion, and with scientific methods of pipe winding, thinner staves and smaller wire may be used. If reliance can be placed on the manufacturers, such methods will result in economy.

The foregoing comments and suggestions are not intended to serve as a theoretical basis for pipe manufacture, but to point out the methods in use to-day by the various manufacturers. The detrimental features are pointed out, the scientifically based principles are outlined, and the specifications in the Appendix are suggested for securing uniform practice, thus enabling engineers to know what type they will obtain when they call for bids.

The specifications should be based on the use to which the pipe will be put. No engineer would think of calling for 1:2:4 concrete for rough foundation work, where water-tightness and strength are only secondary considerations. Neither would he specify a 1:3:6 mix for concrete conduits, where both density and maximum strength are required. It is the same with wood pipe. For cheap lines of short duration, such as construction work, when the pipe will be abandoned after a few months or a year, a low-grade uncoated fir or pine pipe may be chosen. On temporary work requiring a life of 5 or 6 years, a good grade of uncoated fir and pine pipe may well serve. For 8, 12, or 15 years' service, a good, properly painted fir pipe may be used to advantage. For permanent work, redwood should be selected, or fir or pine of high-grade staves kept saturated and well painted.

Owing to the various grades of work in which fir or pine pipes are used, alternate specifications are given, but, as redwood would only be selected for permanent work, and for some conditions in which fir or pine would fail, such as in low-pressure work, only one specification is given for this wood, and this covers the highest grade.

It is sincerely hoped that this paper may lead to a definite idea of the merits of wood pipe and the adoption of uniform specifications.

In writing specifications for wood pipe, various pipes will be designated by classes, based on the nature of the work they are to do.

Continuous-Stave Pipe.

Class A.—A pipe having a maximum life, under all conditions, and this will be 25 years when receiving no care whatsoever; a life greater than 25 years, if under continuous operation; and a probable life of 50 years, or more, if in continuous operation under at least a moderate head, if the bands are given attention and corroded ones are renewed. This includes pipe made from clear, air-dried redwood.

Class B.—This class includes coated pine or fir, in such a situation as to be open to continuous inspection, so that it may be given constant attention, comprising re-painting staves and renewing bands.

This pipe will be placed under Class A, on theory only, as experience has not yet confirmed such an assumption.

Class C.—This class will have a maximum life of 10 years and an average life of 7 years. It will include uncoated fir, pine, or other suitable wood.

Machine-Banded Pipe.

Class A.—This class will have a life of from 15 to 25 years when receiving no attention; a longer life under ideal conditions, as when laid in soils having the least possible corrosive effect on the galvanized wire, and when operating under pressure, so as to insure complete saturation of the wood. Pipes of this class will be guaranteed to
withstand severe conditions of over-load, such as in hydro-electric work, general water-works for city supply, and high-pressure pumping lines; and will be guaranteed to withstand an over-load of 100% under test.

It will include pipes of clear, air-dried, redwood, manufactured according to the specifications in the Appendix.

Class B.—This class will have a life of at least 10 years, and a probable life not exceeding 15 years. It will include pipe made of redwood, or of coated fir or pine, etc., manufactured according to present-day standards, as indicated by the specifications covering this class.

Class C.—Pipes of this class will be used for temporary work only, and may be manufactured from redwood, fir, pine, or any other wood, with or without coating, as desired.

APPENDIX.

Specifications for Continuous-Stave Pipe, Class A.

The staves shall be of clear, air-dried, California redwood, seasoned at least one year in the open air, and shall be free from knots (except small knots appearing on one face only), sap, dry rot, wind-shakes, pitch, pitch seams, pitch pockets, or other defects which would materially impair their strength or durability. The sides of the staves shall be milled to conform to the inside and outside radii of the pipe; and the edges shall be beveled to true radial planes. The staves shall be milled from stock sizes of lumber, the net finished thickness of the stave, for the various diameters of pipe, shall be as given in Table 2. The ends shall be cut square and slotted to receive the metallic tongues which form the butt joints. The slots shall appear in the same position on each stave, and shall be cut to make a tight fit with the tongues in all directions. The staves shall have an average length of at least 15 ft. 6 in., and not more than 1% shall have a length of less than 9 ft. 6 in. Staves shorter than 8 ft. will not be accepted.

The metallic tongues to insert in the slots in the ends of the staves shall be made from 1/4 by 1/8-in. band iron, and shall be cut 1/8 in. longer than the slot in the stave, so that, after the pipe is cinched, they will penetrate the adjoining staves, thereby making a watertight joint.

The bands for pipes of large diameter shall be in two sections; those for the smaller sizes shall be in one section. The bands shall be spaced on the pipe with a factor of safety of at least four, and shall consist of round, mild-steel rods, connected with malleable-iron shoes. Either open-hearth or Bessemer steel may be used. The phosphorous content in open-hearth steel shall not exceed 0.06; in Bessemer steel it shall not exceed 0.10. The ultimate strength shall be from 55 000 to 65 000 lb. per sq. in. Steel having an ultimate strength of more than 65 000 lb. per sq. in. will not be rejected provided it shows an elongation of not less than 20% in 8 in. The yield points shall not be less than one-half the ultimate strength, and shall be determined by the drop of the beam of the testing machine. A minimum percentage in 8 in. of 1400 000 divided by the ultimate tensile strength shall be taken as the elongation; but, the following modifications shall be made for bands less than 1/8 in. and more than 1/8 in. in diameter.

(a) For each increase of 1/8 in. in diameter greater than 1/8 in. a deduction of 1 shall be made from the specified percentage of elongation.

(b) For each decrease of 1/8 in. in diameter less than 1/8 in. a deduction of 1 shall be made from the specified percentage of elongation.
The rods or bands shall be capable of bending 180° around a diameter equal to that of the specimen tested, without fracture on either side. All threads shall be cold-rolled, United States Standard; the threaded portion of the band shall have an ultimate strength equal to that required for the rods. The nut shall conform to the Colorado Fuel and Iron Company's standard* for the respective diameters, and shall be tapped so as to make a snug but easy running fit. The bands shall be provided with button heads, according to the Colorado Fuel and Iron Company's standard,* and the heads and the sections under the heads shall not fail at less than is required for the body of the rod when tested through a U-slot. One bending and two tension tests shall be made on the rods for each melt of open-hearth steel, and one bending and one tension test for each blow of Bessemer steel rolled. Two bands for each blow or melt shall be tested against the head and thread. The bands shall be subject to rejection if the actual weight of any lot varies more than 5% above or below the theoretical weight of that lot. The bands shall be free from any injurious seams, flaws, or cracks, and shall have a workman-like finish.

The shoes shall be of the Allen type, fitting closely to the outside curvature of the pipe, and designed so that, after the bands are cinched tight, they will lie in a plane at right angles to the horizontal axis of the pipe. The shoes shall be clean castings, made from the best grade of malleable iron, free from flaws, tags, or blow-holes; and shall have a tensile strength of about 40,000 lb. per sq. in. The shoes shall be guaranteed to be stronger under test than with which they are to be used.

The coating for all metal work—shoes, bands, or tongues—shall be a high-grade preservative paint, of such consistency that it will not run in hot weather or peel off in cold weather.

The coating for the bands shall be hot, and the bands shall remain in the liquid for sufficient time to insure that they will attain the same temperature as the liquid.

When a conduit is to be erected in a tropical climate, similar to that of the Hawaiian Islands, the Philippines, Central America, etc., all metal work shall be protected with red lead or galvanizing. The red lead shall be of the best quality, containing approximately 10% of litharge to insure drying without scaling. The bands, coming from the rolls, shall be dipped in linseed oil to prevent the formation of mill scale prior to the application of the red lead. The galvanizing shall be of a standard quality, giving a full and complete coating to the metal over its entire surface.

The diameters of the rods and the maximum allowable spacing shall be as given in Table 2.

* Or other specified standard—the C. F. & I. being that generally accepted.
Specifications for Continuous-Stave Pipe, Class B.

The staves for uncoated redwood pipe shall be the same as those specified for Class A, continuous-stave pipe.

The staves for coated pipe shall be of yellow fir (Douglas fir), redwood, or such other wood, acceptable to the engineer, as may be specified by the bidder at the time of submitting his proposal. The wood shall be sound, straight-grained, and free from dry rot, pitch seams, pitch pockets, checks, wind-shakes, bruised ends, sap wood, and other imperfections which would impair its strength or durability. Through knots or knots at the ends or edges of staves will not be allowed. Sound knots and knots not exceeding \( \frac{1}{2} \) in. in diameter, not falling within the foregoing limitations, nor exceeding three within a 10-ft. length, will be accepted. Before milling, all lumber shall be seasoned by air-drying for not less than 60 days, in open piles, or by thorough kiln-drying. The sides of the staves shall be milled to conform to the inside and outside radii of the pipe; and the edges shall be beveled to true radial planes. The ends shall be cut square and slotted to receive the metallic tongues which form the butt joints. The slots shall appear in the same position on each stave, and shall be cut to make a tight fit with the tongues in all directions. The staves shall have an average length of at least 10 ft., and not more than 1 in. shall have a length of less than 9 ft. 6 in. Staves shorter than 8 ft. will not be accepted. The specifications for the tongues, rods, and shoes, and for the coating of the metal work shall be the same as for Class A pipe.

Redwood pipe need not be protected with any artificial coating. Pipe made of fir or other wood shall be coated. This coating shall be continuous and heavy; it shall be not less than \( \frac{5}{8} \) in. thick, and shall consist of more than one individual coat of a mixture of asphaltum and tar. The first coating shall be allowed to dry thoroughly before the application of the second. The coating shall be hard, tough, durable, perfectly water-proof, and strongly adhesive to the metal and the staves. It shall show no tendency to flow under a summer temperature, and shall not become brittle, so as to crack or scale, under a freezing temperature. The coating shall be well spread and rubbed in with brushes, or shall be applied as a spray under pressure; but, in either case, all cracks, checks, or other surface irregularities shall be thoroughly covered and filled.

Specifications for Continuous-Stave Pipe, Class C.

The staves shall be of Douglas fir, redwood, or other wood acceptable to the engineer. The wood shall be sound, straight-grained, free from dry rot, checks, wind-shakes, and other imperfections which would impair its strength or adaptability for pipe construction. Sap will not be allowed on more than 10% of the inside face of any stave, and in not more than 10% of the total number of pieces. The sap shall be bright, and shall not occur within 4 in. of the end of any piece. Pitch seams will be permitted in not more than 10% of the total number of pieces, if showing on the edge only and if not longer than 4 in. or wider than \( \frac{1}{4} \) in. Through knots or knots at the edge or within 6 in. of the ends of the staves will not be allowed. Sound knots not exceeding 1 in. in diameter, not falling within the foregoing limitations, nor exceeding three within a 10-ft. length, will be accepted. Before milling, all lumber shall be seasoned by air-drying for not less than 60 days, in open piles, or by thorough kiln-drying. The sides of the staves shall be milled to conform to the inside and outside radii of the pipe; and the edges shall be beveled to true radial planes.

The remainder of the specifications are as outlined for Class B pipe, except that the coating of the pipe may be omitted.

Specifications for Machine-Banded Pipe, Class A.

The staves shall be of clear, air-dried, California redwood, seasoned at least one year in the open air, and shall be free from knots (except small knots appearing on one face only), sap, dry rot, wind-shakes, pitch, pitch seams, pitch pockets, or other defects which would materially impair their strength or durability. The sides of the staves shall be milled to conform to the inside and outside radii of the pipe; the edges shall be beveled to true radial planes, and shall also have a small tongue and groove. After the staves are built up in sections, the ends shall be cut square, and a smooth tenon shall be turned on the end of each section, to make a tight fit with the collars or couplings. The sections shall be in random lengths from 8 to 30 ft. The staves shall be milled from stock sizes of lumber. The net finished thickness of the stave, for the various diameters of pipe, shall be as given in Table 3.

Both pipe and wire-wound collars, when such are used, shall be wound spirally with a heavily galvanized steel pipe-winding wire. This wire shall be of such a size, and spaced at such a distance (according to the head under which the pipe will operate), as to give a factor of safety of at least four against breaking. This wire shall also be of such a size, and spaced at such a distance, as to give a bearing surface which will make the pipe safe against failure by the wire sinking into the wood under pressure, which might cause the pipe to leak along the longitudinal joints. The sizes and spacing of the wire for the various sizes of pipe operating under different pressure heads shall be as given in Table 3.

The ends of the wire shall be fastened securely to the pipe with pressed-steel or malleable-iron clips, which shall be protected against
### Table 3—Machine-Banded Pipe

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<th>Diameter of Pipe, in inches</th>
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<td>Class A</td>
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<td>Classes B and C</td>
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in a glass vessel containing not less than one pint of the standard solution, and allowed to remain for one minute. They shall then be removed, washed in clear water, and wiped dry with soft cotton cloth or waste. This process shall be repeated three times, making four immersions in all.

A saturated solution of sulphate of copper, having a specific gravity of 1.186 and a temperature of 65° Fahr., shall be taken as the standard solution. The temperature of the solution during the test shall not be above 68° Fahr. If a bright copper deposit appears on the steel after the fourth immersion, thus indicating that the wire is exposed, the galvanizing represented by the samples shall be considered faulty. Three of these immersions without showing signs of copper, shall be considered as the test for the pipe winding wire.

Wooden collars or other couplings shall be furnished under the following specifications:

Continuous-stave and machine-banded collars shall be made in the same manner as the pipe, the staves being 6 or 8 in. long, depending on the diameter of the pipe. Pipe from 2 to 6 in. in diameter, inclusive, shall have collars 6 in. long; pipes of larger diameters shall have collars 8 in. long. The continuous-stave collar shall be banded with 3-in. round, mild-steel rods, held together by straight-pull, malleable pipe shoes, and a nut. The machine-banded collar shall be wound with the same wire as the pipe, and in the same manner, but the wire shall be spaced closer in order to make it stronger than the pipe.

For the inserted joint connection, each section of pipe shall be mortised and tenoned with a male and female joint.

Inserted joint connections shall be used on pipe operating under pressures not exceeding a static head of 25 ft. and in sizes up to and including pipe of 12 in. inside diameter. All other sizes, and the aforementioned sizes under higher heads, shall have machine-banded collars when operating under static water pressure, or under a pumping pressure in which there will be no excessive pulsations. In all cases, machine-banded collars shall be preferred to the inserted or slip joint. On pipes having an inside diameter of 12 in. or greater, in pumping lines for hydro-electric work, where over-load, pulsation, or hammer are very likely to occur, continuous-stave collars shall be used.

All pipe shall be guaranteed to withstand an overload of at least 50% when operating in flow lines not subject to over-load strains of any kind, and shall be guaranteed to withstand a 100% over-load when operating under all other conditions.

**Specifications for Machine-Banded Pipe, Class B.**

The staves shall be of clear, air-dried redwood, uncoated, or of fir protected by a coating having an asphaltic base, and rolled in saw-dust.
The staves for uncoated redwood pipe shall be the same as specified for Class A machine-banded pipe.

The staves for coated pipe shall be of yellow fir (Douglas fir), redwood, or such other wood, acceptable to the engineer, as may be specified by the bidder at the time of submitting his proposal. The wood shall be sound, straight-grained, and free from dry rot, pitch seams, pitch pockets, checks, wind-shakes, bruised ends, sap wood, and other imperfections which would impair its strength or durability. Through knots or knots at the ends or edges of staves will not be allowed. Sound knots and knots not exceeding \( \frac{3}{4} \) in. in diameter, not falling within the foregoing limitations, nor exceeding three within a 10-ft. length, will be accepted. Before milling, all lumber shall be seasoned by air-drying for not less than 60 days, in open piles, or by thorough kiln-drying. The sides of the staves shall be milled to conform to the inside and outside radii of the pipe; the edges shall be beveled to true radial planes, and shall be provided with a small tongue and groove. After the staves are built up in sections, the ends shall be cut square, and a smooth tenon shall be turned on the end of each section, to make a tight fit with the collars or couplings. The sections shall be in random lengths of from 8 to 24 ft., the limits for redwood pipe being from 8 to 20 ft. and for fir pipe from 8 to 24 ft.

The thickness of the staves of redwood pipe shall be the same as specified for Class A pipe.

For pipe of fir and other woods the thickness of the staves shall be as given in Table 3.

The pipe shall be wound spirally with a special, heavily galvanized, steel pipe-winding wire, and spaced with a factor of safety of four. The effectiveness of this shall depend on the diameter of the pipe and the pressure. Further, the wire shall be of such a size, and spaced at such a distance, as to insure the pipe against failure by the wire sinking into the wood and allowing the longitudinal seams to open.

The ends of the wire shall be fastened securely with pressed-steel or malleable-iron clips, which shall be protected against corrosion by galvanizing or Sherardizing. The wire shall have a tensile strength of from 50,000 to 65,000 lb. per sq. in., and an elastic limit of not less than 50% of the ultimate strength, and shall be wound under sufficient tension to be firmly seated in the wood without crushing the fibers.

Redwood pipe may be furnished with connections of the same type as specified for Class A pipe. If fir or other woods are used, cast-iron collars shall be provided for connecting sections of pipe. These cast-iron collars shall be of pure, gray iron, of the highest grade, free from tags, blow-holes, or other imperfections which would impair their strength. The inserted joint connections may be used under the same conditions as specified for Class A pipe, but shall be heavily coated with protective compound after erection. If wire-wound collars or continuous-stave collars are used, they shall be made of redwood staves.

Redwood pipe need not be protected with any artificial coating. Pipe made of fir or other wood shall be coated. This coating shall be continuous and heavy; it shall be not less than \( \frac{3}{16} \) in. thick, and shall consist of more than one individual coat of a mixture of asphaltum and tar. The coating shall be hard, tough, durable, perfectly water-proof, and strongly adhesive to the metal and the staves. It shall show no tendency to flow under a summer temperature, and shall not become brittle, so as to crack or scale, under a freezing temperature. The pipe shall be hot-dipped, and its tenoned ends shall be protected during the dipping so as to prevent the mixture from getting on the inside of the pipe. After the pipe has been dipped it shall be rolled down an incline covered with fine saw-dust in order to cover it and enable it to be handled without the coating sticking to surfaces with which it comes in contact. The guarantees shall be the same as those applying to Class A pipe.

**Specifications for Machine-Banded Pipe, Class C.**

The staves shall be of Douglas fir, redwood, or other wood acceptable to the engineer. The wood shall be sound, straight-grained, and free from dry rot, checks, wind-shakes, wane, and other imperfections which would impair its strength or adaptability for pipe construction. Sap will not be allowed on more than 10% of the inside face of any stave, and in not more than 10% of the total number of pieces. The sap shall be bright, and shall not occur within 4 in. of the end of any piece. Pitch seams will be permitted in not more than 10% of the total number of pieces, if showing on the edge only and if not longer than 4 in. or wider than \( \frac{3}{16} \) in. Through knots or knots at the edge or within 6 in. of the ends of the staves will not be allowed. Sound knots not exceeding \( \frac{3}{4} \) in. in diameter, not falling within the foregoing limitations, nor exceeding three within a 10-ft. length, will be accepted. Before milling, all lumber shall be seasoned by air-drying for not less than 60 days, in open piles, or by thorough kiln-drying. The sides of staves shall be milled to conform to the inside and outside radii of the pipe; the edges shall be beveled to true radial planes, and shall be provided with a small tongue and groove. After the staves are built up in sections, the ends shall be cut square, and a smooth tenon shall be turned on the end of each section, to make a tight fit with the collars or couplings. The sections shall be in random lengths of from 8 to 24 ft.

Both pipe and wire-wound collars, when such are used, shall be wound spirally with a heavily galvanized steel pipe-winding wire, and spaced with a factor of safety of not less than four. The wire shall
also be spaced for each diameter so as to insure the pipe against failure by the wire sinking into the wood and allowing the longitudinal seams to open.

The ends of the wire shall be fastened securely with pressed-steel clips. The wire shall have a tensile strength of from 60 000 to 65 000 lb. per sq. in., and an elastic limit of not less than 50% of the ultimate strength, and shall be wound under sufficient tension to be firmly seated in the wood without crushing the fibers.

Inserted joint connections may be used for a pressure of 100 ft. or less; on higher pressures wire-bound collars shall be used. All pipe shall be guaranteed to withstand a 50% over-load of the pressure for which it is designed.
Attention is also called to a slight error in Mr. Partridge's description of grades. Although it is true that, in the listing of the grades by the Southern Cypress Manufacturers' Association, the grade "Tank" appears first in the book of specifications, as a matter of fact Grade "A" is really higher than "Tank." In cypress there is no such grade known as "Clear." The manufacturers of cypress regard the Grade "A," in the heavier thicknesses, as being better than the "Tank" grade in the same thickness, for the reason that knots are eliminated on the face side of "A," whereas any number of water-tight knots are admitted in the grade of "Tank."

Mr. Partridge is probably correct in his surmise that 4-in. "Tank" stock is better material than 4-in. Grade "A" for pipe staves, for two reasons: First, an occasional piece of Grade "A" would have a very slight quantity of sap on the reverse side, whereas "Tank" would be strictly free from sap, although it would contain knots. Second, the "Tank" stock, in the heavier thicknesses, can be purchased at a lower price than the Grade "A" of the same thicknesses. As indicated by Mr. Partridge, the mere presence of knots does not influence in any way the value of "Tank" stock for stave purposes.

Attention is also called to a slight variation in the author's nomenclature from that generally accepted as standard by such organizations as the American Society for Testing Materials, the American Railway Engineering Association, and the Forest Service and other Government bureaus. The terms usually applied as standard for the two grades of wood formed by a tree during the year are "springwood," for the soft wood formed early in the year, and "summerwood," for the hard wood formed later in the year. Many readers will doubtless confuse Mr. Partridge's names of "summerwood" and "winterwood" for the more usual terms of "springwood" and "summerwood."

The writer would like to ask the author for a further explanation as to why penetration is insisted on for a stave. The writer may not understand the meaning of the word "penetration," but assumes that it means the thorough absorption by the stave of water or whatever liquid is passed through the pipe. If any figures are available, as the result of tests, it would be of interest to know on what basis the statement is made that a dense piece of pine, for instance, will not make as good a pipe as a piece of redwood, or other material, of similar density.

Mr. F. Bell, Esq. (by letter).—The following general ideas along the lines of this paper are based on the writer's experience in wood stave pipe design and construction.

The writer finds it to be generally true, as Mr. Partridge has outlined, that there is little authentic knowledge among engineers relative to either continuous-stave or machine-banded pipe, as it is considered somewhat of a specialty, although coming more and more into use in modern engineering practice.

Ideas regarding such pipe are at variance in different parts of the country. In general, the specifications and design are under the influence of the locality in which the engineer intends to build. In the Northwest, we find strong adherents to pipe made from Oregon pine and Douglas fir; in the Southwest, redwood; and in the East, Canadian pine and yellow pine. This is due mostly to the sales talk of the representatives of the various manufacturers of pipe, and the engineer has to be guided more or less by what he hears rather than by actual experience or standards. Wood stave pipe has passed the stage where it can be considered as a specialty; and it is certainly time that general practice and standard specifications should be worked out.

The author's presentation of the subject is complete, but, of course, with reference to the specifications, there may be more or less disagreement. As a start, however, the writer believes the paper will furnish a reasonable basis for the best practice.

It is generally admitted that, for purposes of durability, redwood is logically the best. The writer does not believe there will be any discussion on this point. He has heard engineers criticize this lumber on account of its softness, but, for wood pipe, such criticism is hardly worth considering, as the strength depends on the band spacing, and when the pipe is made up, there seems to be no material difference in rigidity when redwood and harder woods are compared.

The author does not mention yellow pine as a good lumber for wood stave pipe, but this is hardly worthy of important notice, as such wood is too scarce to be a logical material, and would be put in a class with cypress.

In the eastern part of the United States, the general practice is to use thick staves and flat bands for machine-made pipe, but in the West round steel wire is used. A selection between these two styles should be based on local requirements. For continuous-stave pipes, the eastern style is not in keen competition. It is mostly in specifications for pipe of large diameter that standard practice is needed.

The writer agrees with Mr. Partridge that redwood need never be given a coat of preservative, provided clear lumber is used, according to his specifications. On the other hand, in pipe constructed of other kinds of lumber, a preservative coating is necessary, if longevity is wanted. Redwood, under all general conditions, will easily outlast bands and wire winding, without any preservative application.

The writer is familiar with the North Yakima development, mentioned in the paper, as well as the sewer at Palo Alto, Cal. The North Yakima pipe underwent about as rigid a test for durability as would be found in any practice, and, from studying this particular case, it appears that the drying of the lumber is one of the most important
Mr. Bell. — Mr. Partridge states that, because of the process of kiln-drying versus air-drying is, of course, familiar to all engineers; but the writer again agrees with Mr. Partridge that, if possible, air-dried lumber should be used, although very good results are obtained with kiln-dried.

In the matter of machine-handed pipe, the drying is even a more important factor, because there is no chance to “sink up” in case of shrinkage, and the strength and durability depend on the bearing surface and winding tension of the wire.

The author's remarks on the importance of butt joints should also be emphasized, as in continuous-stave pipe this is generally where trouble starts first, and it is also one of the drawbacks in having wood pipe built by men who do not understand the finer details of construction.

The writer knows of a case (which happened within the last few months) of a contractor who had his own staves milled by the ordinary process, bought his own bands, and attempted to put it in his own pipe according to his idea as to specifications and methods. This pipe, no doubt, will be unserviceable in a very short time, and, consequently, engineers who come in touch with this particular case will be influenced against wood pipe in general. This is why the writer believes that the author's remarks should be given favorable consideration. If standard specifications and practice are put in the hands of engineers, there will be a much more favorable attitude in general toward wood pipe, and it will be given the place it deserves as an engineering utility.

Mr. Partridge's classifications are very fair for all kinds of pipe. Naturally, the redwood man claims that his pipe is the best, the fir man his, the pine man his. The only way for the engineer to decide is to make a comparison of numerous structures. On the basis of data gathered from a number of wood stave pipes, it is thought that Mr. Partridge has rounded out the matter very well. The specifications tables in the paper would be what the writer would use if he were designing a pipe line.

The writer has found by experience in many cases that a wood stave pipe has cost the designing engineer much more than it would if he had used the most economical specifications; and, in a majority of cases, the engineer has lost, in the long run, by sacrificing price to permanency, by failing to adopt the specifications and the style of pipe needed for the conditions under which he is designing, having been talked into “something just as good.”

If careful unprejudiced consideration is given to this paper, engineers will feel that standards should be generally recognized, and that the proper styles, classifications, and lumber should be given level-headed consideration. As it is, all are depending too much on the influence of representatives who are talking up the various kinds of pipe, and, naturally, where one lumber predominates, the designing engineer will be influenced in his specifications.

D. C. H. H. * M. AM. SOC. C. E. (by letter).—From a report by the writer to the U. S. Reclamation Service in July, 1915, on the life of wood pipe, the author has quoted a tabulation in which an attempt was made to condense the information collected from past experience and special investigation. It is well to quote also from the two paragraphs in the report immediately preceding this tabulation, which read as follows:

"The investigation has had in view especially the life of pipe as affected by the durability of the wood. * * * The information collected is based mostly on reports received from managers or owners, and in small part on personal observation. It is not as complete as is desirable, which, however, is not due to failure to elicit further information.

"Reviewing the information as grouped under its headings, it may be estimated that under conditions of continuous water pressure the life of various kinds of pipe may be as follows:"

The last item of the tabulation refers to the estimated life of wood in fir pipe, well-coated, buried in loose soil, and maintained under continuous water pressure. Some additional information has come to hand since the date of the report, which, although not directly applicable, may be considered of some importance.

During October, 1916, the writer made an examination of wood pipe lines—part of an irrigation system in the vicinity of Pasco, Wash., constructed in the spring and early summer of 1910. The pipe portion of the system consists of 43 miles of continuous-stave, uncoated, fir pipe, 30 and 36 in. in diameter, and 12 ½ miles of machine-banded, coated, fir pipe, from 10 to 24 in. in diameter.

Decay in the uncoated pipe had made it necessary to rebuild 8% of the line during 1915 and 53% during 1916. Examination in October of that year showed that serious decay had then affected the remaining 68% of the pipe. It had attacked principally the bastard grain wood and wood with a coarse vertical grain, such as is derived from the top of the tree. No serious decay was found in the close-grained wood with vertical grain, and staves of this kind had been used in the reconstruction.

This is stated merely as incidental to experience with machine-banded pipe, repairs on which, up to the time of examination, had been confined to the replacement of wood sleeves. Only a small percentage of this pipe was open to inspection. This, however, showed that some of the wood in the pipe itself had been attacked, the defect being confined largely to individual staves in the upper half of the pipe. To what extent the condition of the small portion of pipe examined may be indicative of that of the remainder is problematical.

* Portland, Ore.
It was noted that, in several places where decay had occurred, there were in evidence hundreds of insects resembling ants. Whether these were cause or effect could not be determined.

All the pipe is buried in loose, sandy soil. The winter climate is mild, and the summer is hot, the temperature frequently rising above 100 degrees. The coating appeared to be the manufacturers' standard, consisting of asphalt and tar.

This pipe is not included under the conditions predicated in the tabulation quoted, as during 5 months of the non-irrigating season it is not maintained full. It is probable, however, that this fact is only in small part responsible for the decay observed. It will be necessary to examine a larger portion of this pipe, or await the results of experience with it, before dependable conclusions can be drawn. Nevertheless, its early decay in spots affords ground for reducing the life estimate, of well-coated fir pipe under very unfavorable conditions, from the figures given in the tabulation to 10 years or even less.

The author has presented his case with clearness and ability, and the virtues of redwood in pipe construction are well brought out.

Although the paper mentions the variability of wood of the same species, it does not specifically deal with the variations to which redwood itself is subject. The wood in the lower 30 ft. of a large redwood tree is exceedingly close-grained. It sinks in water, and is remarkable for its long life. Fence posts made of it have lasted more than 50 years.

Higher in the tree, the grain gradually becomes coarser, and near the top it shows fewer than ten rings to the inch. It also becomes lighter, and, although no specific tests are known to the writer, it is probable that the life of redwood as well as fir becomes shorter as the grain becomes coarser. In the past, specifications have sometimes called for sinker redwood, but, from a practical mill standpoint, this is almost impossible to supply in large quantities. However, in scientifically drawn specifications, it may be in point to limit the coarseness of the grain, the more so as the superior lightness of the coarse-grained wood offers a temptation for its selection (where freight charges become an important item), to a contractor not concerned about the ultimate life of the pipe.

In the Northwest, some makers of wood pipe are now equipped to furnish reenforced or otherwise treated fir staves. The writer sees no reason for not advancing pipe built of fir properly treated from Class B to Class A of the author's specifications, although sufficient time has not yet elapsed to demonstrate fully either the complete correctness of this or the most economical treatment available for producing the desired result.

The proper reenforcing of pipe staves is not only expensive in itself, but also adds heavily to the freight charges and, to some extent, to the cost of pipe erection. In some sections of the country such pipe appears to have been installed successfully with untreated redwood.

It is also as yet an open question as to what is the life of exposed fir pipe, and to what extent its life is extended by surface coating. The only case of decay of such pipe, which has come to the writer's attention is that of a pipe built on a ridge in Utah (listed as No. 16 in the writer's report), and this was after 12 years of service. This pipe was not coated, and other uncoated pipes of this kind showed no decay after 14 years; and the writer has found, in the New England States, sound stave pipe, built probably of native pine, and resting on piers, in regard to which the time of construction reached back beyond the memory of any one who could furnish information.

On the other hand, the author has noted decay in exposed redwood pipe in Southern California, maintained full only during the irrigation season, and less than 15 years old.

The author's statement regarding the superiority of air-drying over kiln-drying is undoubtedly true, so far as past commercial methods are concerned. It is understood, however, that the subject of kiln-drying has been under scientific investigation for several years, and it is not improbable that commercially feasible methods will be perfected which will be free from the objections of wood injury to which reference was made.

So far as continuous-stave pipe is concerned, there is no serious disadvantage in the use of lumber not fully dry, and a rigid adherence to the requirement of one year's air seasoning may tend to place a serious limit on reasonable competition, or even make it impossible to obtain the material within the time required.

The author believes that the use of inserted or slip-joint pipe is not to be recommended. The only pipe of this kind examined by the writer was made of fir and, so far as the joints are concerned, was entirely successful. Pipe of this kind on the Sunnyside Project of the Reclamation Service successfully withstands a pressure of 150 ft. No injury was noted in handling or laying, contrary to the author's fears, which, however, may apply more specially to the weaker and softer redwood.

It is noted that, in the classification suggested by the author, Class A pipe is to have a life of 25 years or more under all conditions. On further thought he will undoubtedly desire to place some limitation on these conditions, as he must be aware of several instances of buried and exposed redwood pipe which, owing to the fact that it is not completely water-filled at all times, in combination possibly with the use of coarse-grained wood, has shown a comparatively short life.

Some 30 years ago, when continuous-stave pipe was first introduced into the Western States by the late Charles P. Allen, of Denver, Colo., it was looked on by most engineers as of doubtful utility. It has gradually established itself as a legitimate type which can be adapted to
Mr. Henry.

relatively permanent or temporary uses, as requirements or financial advantage may dictate.

Experience as to its life and usefulness is fast accumulating, and renders it possible to proceed with a steadily growing sense of security as to results, to which the able exposition of fundamental principles by the author is a valuable addition.

Mr. Rust,* M. Am. Soc. C. E.—This is a most opportune time to advocate the use of wood in place of steel for all construction purposes, wherever possible, with due consideration for safety; and, from the title of this paper, the speaker was most hopeful that it would fill a much needed want. However, on closer examination, the paper is most disappointing, as it is evidently an attempt to advocate the use of redwood in place of Douglas fir for wood pipes, and it does not offer proper proofs for such statements as “Douglas fir and pine are fundamentally inferior to redwood.”

Although, in the early days of the use of such pipe in the West, redwood was practically the only material considered, recently, Douglas fir has been more generally used. On this account the highly desirable object of such a paper will be defeated, and engineers having independent experience and realizing the circumstances will hardly treat it seriously. It will be unfortunate if the discussion turns merely into a contention between the makers of redwood and Douglas fir pipe, as is likely, because the choice of material is not the most important feature, and, under proper conditions for any wood pipe, either of these woods should be satisfactory.

There is no doubt that redwood will resist decay much better than Douglas fir or long-leaf pine, when used in any location where it will not be saturated with water; but it has always been considered a condition necessary to the successful use of wood pipe that the wood be kept saturated and the pipe full of water practically all the time. This is really not a difficult condition to meet, and will not cause the rejection of wood pipe in many cases where it might otherwise be used. If the pressure is too low or the pipe cannot be kept filled, a different construction can probably be used, which will give better satisfaction, with a comparatively lower first cost. The contention, however, that even redwood pipe should be used where the staves are not to be kept saturated practically all the time can hardly be sustained, and although it may have proved satisfactory in some such cases as the author notes, there are many other cases where it has decayed from this cause, although they have not been mentioned in the paper.

There are other causes of failure besides decay, and there are objections to the use of redwood. The wood is softer and much more brittle than pine or fir. It cannot stand as great compression, and, in consequence, such pipe is more subject to leakage, to overcome which a comparatively larger number of bands should be used.

The Great Northern Power Company has four redwood pipes, each about 3,000 ft. long. The first three were constructed about 10 years ago, and evidently an insufficient number of bands were used for this material. The pipes leak quite badly in places, and the bands have to be tightened frequently. This is a more serious matter than would at first appear, as the pipes are covered, and it is expensive to excavate the back-filling in order to tighten the bands. In fact, it is now found that merely tightening the bands will not remedy the trouble, as they sink into the soft wood so that the leakage soon becomes as bad as ever. The fourth pipe, which was built about 3 years ago, had a much larger number of bands, and thus far it has been satisfactory.

It is reported that the failure of the redwood pipe used by the City of Provo was caused by the bands under pressure sinking into the wood to such an extent as to cause very serious leakage. Recently, a number of engineers have used Douglas fir on rather large and important pipe lines, not only because they considered that where the wood was kept saturated, Douglas fir would last as long as redwood, but also because it is stronger, will stand more distortion without leakage, and is much cheaper.

The Guanajuato Power Company has also had some trouble with one of its redwood pipes on account of the silt in the water scoring the bottom of the pipe. There has been considerable wear along the bottom staves, particularly at some of the butt joints, where a small pocket has been eaten into the staves, about one-third of the way through. This pipe has been in use for about 10 years.

One of the largest users of wood pipe is the Denver Union Water Company, which has about 100 miles, ranging from 24 to 60 in. in diameter. The Company’s first large pipe, laid in 1880, is of long-leaf pine, and is still giving good service. The next pipe, laid a couple of years later, is partly of pine and partly of redwood. Since that time, Douglas fir has been used in all the wood pipe built by the Company, and it has evidently been found very satisfactory.

There are also various examples of pine pipe in the East, which have proved satisfactory, one of which might be mentioned. The D. E. Converse Company, at Glendale, S. C., has a 78-in. pipe made of short-leaf pine, which has been in use for 26 years. There is back-filling around the lower half of the pipe, and there is comparatively light, only a few feet head. Although some decay has taken place on the outside of the staves, the pipe is still in use and still satisfactory.

The author speaks of fir and pine being coarse-grained, but such wood is hardly suitable for pipe, and is not used where the specifications

* New York City.
are properly drawn and the material properly inspected. In fact, there is now a specification covering the density of fir, which it is to be hoped will be generally adopted. Fir and pine staves have not been made any thicker than those of redwood, and have been quite satisfactory under high pressure.

A large quantity of kiln-dried fir has been used for pipe, and has proved satisfactory. No doubt kiln drying does make redwood very brittle; it should be air-dried. This, however, is a disadvantage of redwood rather than of fir.

The speaker has no desire to advocate the use of fir in preference to redwood, as he considers the latter equally satisfactory under proper conditions. However, it would be a mistake to create an unfair prejudice in favor of one as against the other.

There has been considerable discussion lately as to whether wood pipe should be buried or left exposed, and as to whether the outside should or should not be painted. There is no doubt that a pipe should be buried completely at least 2 ft. below the surface, or left entirely exposed. However, in the latter case, the necessary supports are a matter for serious consideration, especially for pipes of large diameter on soft ground.

In a dry climate, where a pipe is buried in a dry, sandy, or pervious soil, the ground will absorb the moisture from the outer shell of the wood, so that it cannot be kept saturated, and this causes a condition favorable to decay. Painting the outside of any pipe under such conditions would be most advisable, but if the pipe is laid in wet soil, where the ground itself is always saturated, it does not seem logical to paint the wood. Also, it is advisable to keep the pipe away from all vegetable matter and growing plants, the roots of which will absorb moisture from any wood and cause it to decay.

Crosstie may be advisable to meet some of these special conditions. It is now being used to some extent, as crosstie fir under ordinary conditions costs only a little more than redwood.

As to the statement that "a coating, to be effective, should be applied diligently and often", it has generally been considered necessary to coat a pipe only where it is buried, in which case, of course, it is impossible to paint it often.

Regarding the standard specifications for bands submitted by the author, as stated, it is quite common practice to use a factor of safety of 4 against breaking due to tension caused by the hydrostatic pressure. However, this does not allow anything for the additional tension required to keep the staves tight and prevent leakage; and a factor of safety of 5 should be used, or some additional allowance should be made for the extra tension required for tightness.

A working stress of 800 lb. per sq. in. for the bearing strength of the wood is excessive. It has been found that one of the causes of decay is the bruising of the wood through excessive pressure on the bands. A working stress of 400 lb. per sq. in. would probably be more satisfactory, and would not require the addition of any large number of bands, except in the cases of pipes of small diameter. It hardly seems reasonable to use a larger working stress in this case than that usually considered good practice for other structures. The experience of the Great Northern Power Company, already mentioned, bears out this contention.

Regarding the thickness of the staves in Table 2, there is a jump from 24 to 38 in. at a diameter of 6 ft. The Douglas fir manufacturers have an intermediate standard thickness of 3 in., which can be used for pipes from 6 ft. up to 9 or 10 ft. in diameter. This has been quite satisfactory, and makes considerable saving in the quantity of wood required for pipes between these sizes. There seems to be no reason for not using an intermediate standard thickness of 3 in. with redwood.

Regarding the author's proposed specifications dividing wood pipe into three classes, A, B, and C, according to the wood used, apparently the only reason for this is to have an opportunity of putting redwood in a supposedly much superior class by itself, which, of course, would give the manufacturer of redwood pipe a good excuse for asking higher prices for his product.

It would be much more logical to vary the thickness of the staves, the band spacing, and other details which have more effect on the cost of a pipe, and to have three tables such as Table 2, one for each of the different classes. Otherwise, the specifications are those generally proposed by the manufacturers of redwood pipe.

As stated by the author, there is no reason for not making the specifications for fir as strict as those for redwood. However, this is the fault of the lumber mills. The proprietors of Douglas fir mills have not shown themselves to be very broad-minded in many ways, and have done nothing to encourage the use of wood pipe.

It would be of considerable advantage if the wood stove pipe manufacturers had an association, organized on the same lines as the Portland Cement Manufacturers' Association, which would be in a position to give disinterested and authoritative data regarding wood pipe on which engineers could depend; and it would result, no doubt, in the use of a much larger quantity. It would also be of considerable help to engineers if manufacturers would keep a stock of pipe or pipe material on hand at some point in the East, so that in case of emergency it would not be necessary to wait a month or two in order to obtain material from the West.

Wood stove pipe has been in general use in comparatively important works for about 30 years. This should be a sufficient length of time for engineers to judge of its permanence, the precautions to be taken
with it under different conditions, and to determine what constitutes a safe design. However, as the author states, many engineers in the East still regard such pipe with suspicion, owing chiefly to reported failures which, when investigated, show either that wood pipe should never have been used, or that proper precautions had not been taken to meet the special conditions. There has been ample experience with such pipe, and much information has been published regarding it. It is now possible to find out what constitutes good practice, and, of late, there have not been as many failures reported as in the early years of its use. At the present prices, wood stave pipe costs only about one-third or one-fifth as much as steel pipe, under conditions where either could be used.

F. M. Robbins, Esq.—It has been suggested that there is a lack of cooperation among the wood stave pipe manufacturers. This is true; and it has held back the development to which good wood pipe is entitled. A closer association would result in the elimination of the poorer pipe which causes most of the unpleasant notoriety. It is not a question of redwood or fir, but of proper design and construction, as investigation shows that most failures in wood pipe are due to design by inexperienced engineers, or construction by outside contractors. A standard specification for wood stave pipe is urgently needed to guide the engineer and eliminate the contractor who builds on a price basis only in keen competition with the established pipe builders.

As stated in the paper, there is “provision for rigid supervision of the bands, though adequate stress is not laid on the requirements for the shoes, which, after all, must be capable of developing the full strength of the band.”

The cases cited are only a few of those in which shoes were used which developed only partly the strength of the bands. The cost of the shoe is insignificant as compared with that of the band, and yet its weight, on lines where price competition is keen, is frequently reduced to a point where the value of the steel wasted amounts to several times that of the shoes, and the pipe banding is less than half as efficient.

Furthermore, tons of excess weight have been buried where the shoes were heavier than needed, or where the metal in them was not properly distributed.

Standard lines of properly designed and thoroughly tested shoes have been developed, and these can be used with safety where the specifications are rigid enough to admit no variation or substitution by the contractor.

The specification for pipe shoes advanced by Mr. Partridge is much better than those heretofore offered, but it is not yet as rigid as it should be. The advance in malleable iron has made it possible to secure an even better quality, and the specification should read: “Shall have a minimum tensile strength of 45,000 lb. per sq. in., and a minimum elongation of 71% measured in 2 in.”

The strength of the shoe should be stated definitely as the elastic limit, there having been cases where this was evaded by using the ultimate strength of the shoe as compared to the elastic limit of the band.

The coating of malleable iron is a question that will bear further investigation, as, generally speaking, malleable iron does not corrode, to an appreciable extent, after the first or surface oxidation. The coatings now applied are unnecessary in ordinary circumstances; and, under abnormal conditions, galvanizing or coating with red lead should be recommended.

William J. Boucher, *Assoc. M. Am. Soc. C. E.—The use of wood stave pipe is somewhat limited in the East, but a pipe of this material has been completed recently for the water supply of Watervliet, N. Y., under the direction of G. R. Solomon and P. H. Norcross, Members, Am. Soc. C. E. In New York City, however, there is a type of stave pipe which is hidden from the public view so completely that comparatively few are aware of its existence. Reference is made to the sewer outlet barrel pipes built under the piers on the North and East River fronts. As a sewer outlet at the bulkhead wall would be very objectionable, all sewers are extended to the pier head by constructing the wood barrel for the full length of the pier at the foot of the street in which the sewer is built. These wooden pipes have been the subject of special study by the Bureau of Sewers of New York City for some time, and are now standardized. Of course, such pipes need not be designed for the high pressures encountered in water supply systems, as the sewers seldom flow full. They are built of creosoted lumber in order to protect them from the effects of alternate wetting and drying, due to the rise and fall of the tides. The invert is frequently at or near mean low water (in order to obtain as much fall as possible), and this causes the upper portions of the barrel to be submerged only for the short period of high tide. Fig. 1 shows the design for one of the most recent sewers.

The following are the standard specifications of the New York City Bureau of Sewers:

**Specifications for Wooden Barrel Sewer.**

“Wooden barrel sewers shall be built of creosoted wooden staves held in place by galvanized metal bands, and supported by timber framework.

“All the timber used in the construction of the barrel staves shall be sound commercial short-leaf yellow pine, free from the following...”

* New York City.
Mr. Boucher.
defects: large, loose, unsound or hollow knots, through shakes or round shakes, worm holes and knot holes. All pieces shall show, either, one heart face or two-thirds heart on both sides.

"Timber required for the permanent support of the sewer shall be long-leaf yellow pine of the quality known as 'Merchantable,' graded in accordance with the rules known as the 'Inter-state Rules of 1905, Adopted by the New York Lumber Trade Association.'

"The barrel staves shall be accurately milled on all sides to exact shape, so that they will form a sewer with tight joints true to the required dimensions.

"The Contractor shall make such tests of the materials and samples as required, and afford every facility requested for measuring tanks, cylinders, gauges, etc., and for taking and analyzing samples as often as may be deemed necessary, including the use of a properly equipped laboratory and other necessary apparatus. The manufacturer shall equip his plant with all necessary gauges, appliances, and facilities to demonstrate that the requirements of the specifications are being fulfilled.

"Upornotice from the Contractor that it is ready for inspection, all timber and staves (after the staves have been milled) shall be examined at the one time prior to creosoting. Rejected timber shall be separated from that approved, and the approved timber only shall be creosoted. The Contractor shall give ample notice to the Engineer so that he may arrange for inspecting the creosoting at the place of manufacture.

"The creosoting of the timber shall consist of two operations:

"a.—The preliminary application of steam and vacuum.

"b.—The injection of a minimum average of 18 lb. of oil into each cubic foot of timber. In addition to this minimum average, additional oil shall be injected into the timber, depending upon the physical condition of the timber, sufficient to render it possible to meet the 5% absorption test specified herein.

"The preservative to be used shall be a distillate of coal gas or coke oven tar, and shall be free from all adulteration and contain no raw tar, filtered or unfiltered, or pitches, petroleum compound, or any other tar products.

"It shall be completely liquid at 38° cent. and shall have a specific gravity at that temperature of not less than 1.03 nor more than 1.08.

"It shall contain not more than 2% of matter insoluble by hot extraction with benzol and chloroform.

"On distillation, which shall be made according to the Borough President's standard method of tests, the description of which is on file in the office of the Engineer, the distillate, based on water free from oil, shall be within the following limits:

"At 210° cent., not more than 5 per cent.
At 235° cent., not more than 8 per cent.
At 315° cent., not more than 8.5 per cent.

"The distillate between 210° cent. and 235° cent., shall yield solids on cooling to 15° cent. The preservative shall contain not more than 3% of water.

"Samples of the preservative taken from the treating tank during treatment shall at no time show an accumulation of more than 2% of sawdust, dirt, or other foreign matter. Due allowance shall be made for such accumulation of foreign matter by injecting an additional quantity into the blocks.

"Before being treated, the timber shall be air-dried to such an extent that its weight per cubic foot does not exceed 50 lb.

"Live steam shall be admitted into the cylinder, and applied to the timber, and gradually raised during a period of 1 hour, to a boiler gauge pressure of 15 lb. at 185° Fahr., and maintained for a period of 2 hours for the timbers weighing 40 lb. per cu. ft.; or it shall be gradually raised during a period of 2 hours to a boiler gauge pressure of 25 lb. at 220° Fahr. and maintained for 5 hours for the timbers weighing 50 lb. per cu. ft.; then a vacuum of about 28 in. shall be applied for 15 hours for the timbers weighing 40 lb. per cu. ft., and for 24 hours for the timbers weighing 50 lb. per cu. ft., with the temperature of the cylinder maintained at 150° Fahr. For intermediate weights of timber the above treatment shall be varied as directed. Timbers whose average weight per cubic foot varies by more than 5 lb. shall not be treated in the same charge.

"Oil at not less than 150°, nor more than 190°, shall then be admitted into the cylinder, and the pressure gradually raised during a period of 3 hours to 165 lb., or until an average minimum of at least 18 lb. of oil per cu. ft. has been forced into the timber, and, if necessary, an amount in addition thereto sufficient to render it possible to meet the 5% absorption test specified herein. During this period the temperature of the oil shall not be allowed to fall below 165° Fahr. The free oil shall then be expelled from the cylinder.

"After treatment, the timber shall be held in the cylinder for about 1 hour, and shall then be withdrawn. The treated timber shall be protected from the direct rays of the sun, and shall be loaded for delivery within 48 hours after withdrawal from the cylinder.

"After delivery, but before placing in the structure, the timber shall show such water-proof qualities that, after being dried in an
oven at a temperature of 100° Fahr., for a period of 24 hours, weighed, and then immersed in clean water for a period of 24 hours, and again weighed, the gain in weight shall not exceed 5 per cent.

“The barrel sewer shall be built so as to form a continuous structure, unless otherwise directed. If built as a continuous structure, each stave shall be placed so as to form a lap of at least 4 ft. with the adjoining stave. Each stave, as put in place, shall be nailed to the adjoining stave, in place, with tinned-wire nails 7 in. long, spaced at intervals not exceeding 3 ft. Staves shall be thoroughly fastened to each other and to the frame and chocks, and shall be not less than 20 ft. in length, except at closures.

“All joining, framing, and mortising shall be done in a workmanlike manner. Holes, of the sizes required, shall be bored for all spikes and bolts.

“The acceptance of material at the plant of the manufacturer is tentative only, and the City reserves the right to reject shipments, in whole or in part, after delivery on the line of work, if the material fails to comply with the requirements of the plans and specifications.

“Galvanized wrought-iron or steel bands, saddles, hangers, manhole covers and frames, angles, bolts, washers, etc., including all metal required in the permanent structure, shall be furnished, placed, and adjusted as shown on the plans and in accordance with the requirements of these specifications.

“The steel and wrought iron shall comply with the requirements, and be subject to the tests provided in the standard specifications most recently adopted by the American Society for Testing Materials.

“The bands, saddles, hangers, manhole covers and frames, shall be brought to true dimension and shape indicated on the plans before galvanizing. The extra thickness of the band shall be obtained by ‘upsetting’ the ends. Allowance shall be made in threaded articles so that the parts may screw together after galvanizing without recutting the threads. Samples of the metal to be used in the structure shall be submitted for test and approval before galvanizing. Approved metal shall be galvanized as follows: the iron and steel surfaces must first be cleaned of all scale and rust by means of steel brushes and a dilute sulphuric acid bath. When cleaned, the metal shall be plunged into a bath of molten zinc covered with sal-ammoniac.

“The galvanizing must show an even distribution of zinc over the entire surface of the steel or iron, bright in color, and not blotchy in appearance. At least 1 lb. of zinc shall be applied to every 6 sq. ft. of surface.”

J. C. RALSTON,* M. AM. SOC. C. E. (by letter).—A more or less continuous experience of nearly 18 years in the use, design, and operation of wood stave pipe, and a fairly intimate knowledge of manufacturing methods, during which time the writer has had to do, in a consulting capacity, with more than 3,800 miles of all sizes, including more than 40 miles of continuous stave pipe of an average diameter of 70 in., impels him to discuss briefly certain phases of

Mr. Partridge’s paper, and to call attention to some incorrect statements and immature conclusions.

The author says, on page 442:

“In machine-banded pipe there is absolutely no basis for the present-day so-called specifications.”

This needs no comment other than to add that the specifications suggested in the Appendix are not equal to those of the best practice. The basis, foundation, groundwork, or controlling principle on which the author’s or any other engineer’s specifications for wood pipe are drawn, is the same, namely, the need for a wood pipe.

The evolution of the wood pipe specifications has passed through a long period, and has engaged the efforts of such distinguished engineers as the late J. D. Schuyler, J. T. Fanning, A. L. Adams, Members, Am. Soc. C. E., and others, not to mention any of the present-day lesser lights, and it is known that they found a very substantial and satisfactory basis for both the specifications and the pipe.

Again, in reference to fir (yellow pine, Oregon pine), on page 451, the author states that the oldest lines have been built not more than 10 years.

It is useless to encumber the record with a long list. Two or three citations may be permissible: The Garoga River Project, in Fulton County, New York, is noteworthy. This power plant was built in 1890, and survived until a fire destroyed the mill in 1908. The original project comprised a triangular timber crib dam (Fig. 2), about 15 ft. high, much the same as those of the simpler types constructed by Mr. James F. Smith, Chief Engineer, in 1818 and 1819, for the Schuykill Navigation Company—structures which served from 40 to 50 years. The dam was connected to the mill about 600 ft. down stream by a 30-in. wood stave pipe, through which the water was delivered to an overshot wheel about 10 ft. in diameter. The pipe staves were of hard pine, 2-in. scantling, jack-planed on their edges to the proper bevel, and then assembled. The bands or hoops were of 2-in., 18-gauge, old-process, puddled iron, and were as well preserved as the staves when the line was put out of commission. Angles in the pipe line were turned through wood stave pipe wells, after the manner of a sewer. The line has fallen into decay since the mill was burned in 1908.

Aside from the historical engineering interest of such a well-designed piece of work, as well as its significance as a forerunner of the hydraulic end of the modern power plant, the three outstanding features of interest at present are that the staves were of hard pine, that they were in substantially as good a state of preservation as the iron bands at the end of 20 years, and that the line had a life so much longer than 10 years.

* Spokane, Wash.
In 1913, a new power project replaced this primitive plant, and
includes about 9 miles of 78-in. wood stave pipe under a maximum
head of 160 ft. (Fig. 3.) After an extensive inquiry into the merits
of various woods, Douglas fir was selected for this pipe.

Another of the pioneer lines in wood stave pipe construction is
that built by the late Mr. Fanning, at Manchester, N. H., in 1874.
This was a buried line, and was put in operation in the spring of
that year. It continued in operation for 40 years, and was finally
displaced, not because the pipe was in bad condition, but because a
new power installation with a higher head and a new location had
to be chosen. Mr. Fanning's line was 72 in. in diameter, and was
of 4-in. "hard pine staves * * * cut from pitch-pine plank."#

Here, again, is another notable example of hard pitch-pine staves
serving for four decades instead of one.

Another classic example is the Ogden pipe line. It contains 37,000
ft. of Douglas fir stave pipe, 72 in. in diameter, under a head of from
55 to 117 ft., and was constructed in 1896.

Henry Goldmark, M. Am. Soc. C. E., describing this line, stated,
among other things, "A new departure, too, is the use of Douglas fir
in place of California redwood. The former timber is much harder
and stiffer."* D. C. Henny, M. Am. Soc. C. E., in the ensuing
discussion, remarked, "The use of Douglas fir in stave-pipe construc-
tion can hardly be called a new departure, as almost all the stave
pipes built in Washington, Oregon, and British Columbia were con-
structed of that material." The late Arthur L. Adams, M. Am. Soc.
C. E., in a continuance of the same discussion, added, "The author
[Mr. Goldmark] is mistaken in thinking the stave pipe [Ogden line]
a pioneer, either in its diameter or in the use of Douglas fir for staves.

Several conduits 8 ft. in diameter have previously been built, while
the same quality of timber has been repeatedly employed."

Here, then, are prominent engineers engaged in discussing this
kind of pipe with Douglas fir staves, and not redwood, 20 years ago;
and, later, in the U. S. Forest Service Bulletins, there are references
to Douglas fir or Oregon pine as "the most important of American
woods", and "as a structural timber it is not surpassed."

The writer presumes to assert that had the author known more
history, and had he been familiar with woods other than redwood,
he hardly would have made the following misleading statements:†

"In all the discussions it is noticeable that there are no references
to cases where wood stave pipe has been constructed or operated suc-
cessfully, or unsuccessfully, for a number of years. Actual cases

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‡ Pages 450 and 451.
where it has been in service long enough to give an idea of its durability are wanted by engineers."

* * * * * * * * *

"Fir is the pipe that has failed, the oldest lines having been built not more than 10 years."

Yet, at the same time, he admits that "Fir and pine are pitchy woods." The inescapable but (the writer is persuaded) unintentional paradox by the author is that pitchy woods are long-lived. The superior physical and mechanical qualities of Douglas fir are now well known to the Profession, and it is unjust, misleading, and not in the interest of scientific truth for the author to state directly and by repeated implications that Douglas fir is inferior to redwood. Both are excellent woods, the best known for stave material. Although the writer's experience of 18 years in stave pipe construction definitely commits him to Douglas fir, he would not belittle the excellent qualities of redwood. If he did, he could cite examples wherein redwood lines have been repaired with Douglas fir staves. Doubtless, instances might also be cited involving the opposite practice.

Side by side and under identical conditions, one wood will last as long as the other, except in the case of continuous stave lines, when Douglas fir will take the premier position. Not only is this the writer's mature judgment, but the latest practice of some of the leading engineering corporations, and some of the most eminent consulting engineers confirm the latter part of this statement. Thus, the two largest continuous stave lines in the West, 162 and 168 in. in diameter, respectively, Figs. 4 and 5, and the largest in the Atlantic States, 144 in. in diameter, two of which are for commercial plants and one for railroad electrification, built within the last 3 years, are of Douglas fir. One of the Western lines is buried, the others are above ground.

In the matter of the wire-wound type, from 2 to 24 in. in diameter, used in domestic water supplies, the greatest annoyance has arisen in cases where the purchaser has insisted on the cheapest possible pipe, with sap staves and light wire, regardless of the assurance that heavier wire and selected, sapless staves would give better and longer service. In the course of time—the purchaser having been displaced by a new operator and the purchaser's demands forgotten—criticism, and sometimes condemnation, of all wood pipe has resulted.

It is true, as the author suggests, that the nature of the back-fill often has much to do with the life of the pipe. Careless or ignorant methods in laying the pipe and in back-filling the trenches are the cause of trouble and reduced life. The most important consideration, next to the quality of the pipe, is the selection of clean earth
back-fill devoid of vegetable mould, roots, grass, sod, or other unstable material, as well as its proper compaction, preferably for the full depth of the trench. Percolating swamp waters are very destructive. Their carbon dioxide is the arch enemy of wire, rods, and steel pipe, although not particularly harmful to the stave wood. The life of a buried pipe is always increased materially when percolating waters, free or entrained oxygen, leaching processes, or the formation of alkaline salts are excluded. The writer has examined municipal pipe lines which had been laid for 10, 12, and 14 years under compacted clay back-fill, and found the galvanizing on the wire as bright as when it left the factory; and the tar coating on the stave had to be scraped away, in order to reach the wood, which was in perfect condition. An indefinite life could almost be ascribed to such lines.

The writer can well understand how such careful methods of back-filling might largely account for the well-preserved specimens of wood pipe that have been exhumed, from time to time, in London and some of the older American cities, which had been buried from one to two centuries.

On the other hand, the writer has examined lines, the porous back-fill of which had been percolated and partly washed away by continuously flowing swamp water, and has found that the wire banding had been destroyed in 3 years. Thus, there are other elements than the selection of good materials, or the manufacturer’s technology, which profoundly affect the life of wood stave pipe.

The use of wood stave pipe and the science of its construction, when left in the hands of experienced engineers, now rests on a sound, intelligent, and definite economic basis. Its use is no longer experimental or a makeshift. Neither are its design, materials, manufacture, or erection invested with the uncertainties ascribed by the author. It is true that in wood pipe, as in nearly all classes of engineering products, poor materials and workmanship are sometimes found, but that does not condemn the type, nor is the technology of the subject so impoverished that it can be metamorphosed by the one-sided specifications suggested by the author.

Except in the most obvious cases of temporary service, there should be only one standard of excellence, namely, the best. The variables in dimensions, strength, and materials are fixed by service demands, and are well understood and simple.

Contrary to the author’s statements, the quality and kind of material in the staves are well defined in the manufacturers’ and in the latest Reclamation Service specifications. The following is quoted from Specifications No. 74-D, U. S. Reclamation Service, Shoshone Project, Wyoming, dated March 26th, 1917, and may be taken as representative of good practice:

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**FIG. 4.—FOURTEEN-FOOT LINE OF MONTANA POWER COMPANY, NEAR GREAT FALLS, MONT., OF DOUGLAS FIR.**

**FIG. 5.—ANOTHER VIEW OF 14-FOOT LINE OF MONTANA POWER COMPANY,**
"All lumber used in staves shall be Douglas fir. It shall be sound, straight-grained, and free from sap, dry rot, checks, wind shakes, and other imperfections that may impair its strength or durability. Pitch seams will be permitted in not more than 10% of the total number of pieces, it showing on the edge only, and if not longer than 4 in. nor wider than \( \frac{\sqrt{2}}{4} \) in.; no through knots or knots at edge or within 6 in. of ends of staves will be allowed; sound knots not exceeding \( \frac{3}{8} \) in. in diameter, not falling within the above limitations, not exceeding three in number within a 16-ft. length, will be accepted. All lumber used shall be seasoned by not less than 60 days air drying in open piles before milling, or by thorough kiln drying. All staves shall have smooth planed surfaces, and the inside and outside faces shall be accurately milled to the required circular area."

The foregoing fixes the quality and kind of material. The thickness of the finished stave will depend on the diameter of the pipe and the pressure under which it serves. Stave thickness varies from 1 in. in the smallest machine-banded pipe to 4 in. in the largest continuous stave pipe.

The paper and suggested specifications ineptly seek to give the impression that all first-class stave pipe should be made only from clear, one-year, air-dried redwood, and that only the inferior grades of pipe may be made of Douglas fir. This is noticeably conspicuous in the suggested "Specifications for Continuous-Stave Pipe, Class A," and the "Specifications for Machine-Banded Pipe, Class A." In both these Class A types, the writer quite agrees with the author that, where redwood is used, it should be a clear, air-dried product, for the reason, as seems implied, and as is indeed true, that kiln-dried redwood is brittle and structurally inferior. The writer's best judgment and experience, however, are (and a marked preponderance of the best practice throughout the country confirms him) that Douglas fir, either air- or kiln-dried, should also have been specified, unless it was the author's purpose to write exclusively a redwood specification. If, however, he desired to write a standard, Class A, wood stave pipe specification, then, in the interests of engineering fact, practice, and non-partisan purpose, Douglas fir should not have been omitted. If redwood is to be substituted for Douglas fir, then, considering equivalent strength, if the safety factor is closely involved, as well as the greater porosity of the former wood, the thickness of the redwood stave should be correspondingly increased.

It is granted that the grain in redwood is not so coarse as in Douglas fir, but the mechanical ultimate of redwood are less than in fir; yet it should be noted that the soft or winter-growth portion of each annual ring in redwood is much more porous than the similar soft portion of each annual ring in Douglas fir. Nevertheless, the
whole question of percolation and saturation in either material is largely academic, if not fanciful. Both woods, or any wood, will become saturated and remain so, as long as the pipes are full of water under a sensible pressure. The best practice now fixes the thickness of the stave as such that, when the requirements of saturation and strength are satisfied, the question of percolation automatically disappears. Any decrease in the standard thickness of stave, either in fir or redwood, should not be permitted.

The writer has never seen nor heard of a case of “excessive percolation” in any pipe, except where the staves were thinner than standard practice. Some redwood machine-banded pipe has been manufactured with unusually thin staves, but it is believed this practice is questionable and should be discouraged.

It is only in the case of intermittent service, such as in irrigation lines, where saturation becomes important. Here, happily, a definite solution of the problem is at hand at a slightly increased cost, that is, to creosote the staves, both fir and redwood, just as the best practice now requires that the wooden sleeves of wire-wound standard pipe shall be creosoted, because of a less perfect saturation in the sleeve than in the pipe.

The writer partly agrees with the author when, on page 451, he says:

“The greater number of failures possibly originated at the joints. The outer edges of the staves in the collars, when wood collars were used, decayed rapidly owing to the fact that fir needs saturation for preservation, and saturation was not secured at those places.”

If the author’s dictum had been more precise, and he had said that the ends of the staves in the collars decayed more rapidly than the walls of the pipe, owing to the fact that all woods need saturation to secure the best preservation, then the writer would agree with him. Redwood does not enjoy a special dispensation of immunity from decay. Metal collars are not a success, and are more or less obsolete. The open-tank creosoted wood collar has proved superior and satisfactory. It should be borne in mind, however, that when the entire pipe is to be creosoted, the process of creosoting must then be with the closed-tank, pressure method, and that the average oil content must be not less than 8 lb. per net cu. ft. of wood. The open-tank or dipping method for collars is used successfully where the pipe proper is not creosoted. The reason is obvious. Clear kilndried Douglas fir, when given the open-tank treatment, will get a thorough penetration in the end grain to a substantial depth. The penetration into the side of the stave will vary, depending on the nature of the lumber and the location of the annual rings in relation to the surface of the stave. Collar troubles arise from decay that sets in on the ends of the staves and works back, finally undermining the wires. If the ends of the staves in the collars are protected by open-tank treatment, from 90 to 95% of the protection afforded by pressure treatment is secured at a greatly reduced cost. Pressure creosoting, fortunately, permits the use of sapwood in staves, and where such method is used, the specifications should be correspondingly changed. The writer believes that properly creosoted wood pipe for high-class permanent work will meet with great favor, and has an encouraging future.

An instructive series of tests was recently made by the Engineering Department of the West Coast Lumbermen’s Association, in cooperation with the University of Washington, on twenty-three Douglas fir staves, taken at random, which had been in continuous service for 16 years on the Cedar River pipe line of the City of Seattle. On the sections of pipe examined, and from which the staves were taken, “there was not a single stave in either pipe section which showed any signs of decay.” The specimens were tested in compression parallel to the grain to determine their crushing strength. The staves had been under 22 lb. hydraulic pressure for that length of time. They gave an average dry weight of 30.8 lb., and a maximum average crushing strength of 3,870 lb. per sq. in. The size of the average specimen taken from each stave was 1.63 by 5.55 in. The average number of rings per inch was 18.

Douglas fir, having a weight of 30.8 lb. per cu. ft., may be expected to have a crushing strength of approximately 4,400 lb. per sq. in.*

If the original strength of the staves fulfilled this expectation, then, after 16 years of continuous saturation at a pressure of 50 ft., they exhibited 85% of the strength of new fir. Inasmuch as the mechanical qualities of Douglas fir, with the usual safety factor of 4, are never reached, except when staves are made thinner than required by standard practice, this 12% reduction in strength is of no consequence in fir stave stock.

In the matter of curing the stave stock, extensive tests, as well as experience, have shown that the resultant difference between air-dried and properly kiln-dried Douglas fir staves is altogether negligible. In fact, there are some features of kiln-drying more favorable than air-drying, notably among others, is the tendency which this process has to develop the full extent of pitch pockets more visibly than by air-drying, whereby such defects are more easily detected by the inspector, thus making the culling process more certain. At least one of the leading Pacific Coast pipe factories has developed a special kiln method which seems to give excellent results. The ordinary dry-kilns of the lumber companies, and the methods of kilning by such companies are not suitable to the proper curing of pipe staves. Special kilns and their proper operation are the sole

factors in the curing of Douglas fir stave stock, in order to make it as good as if air-cured.

It is proper, and no doubt customary, to give all wire-wound pipe, both fir and redwood, a bath in hot tar or asphalt before it leaves the factory, and, while the coating is still hot, to roll the pipe over a bed of saw-dust. This treatment is a preservative, and adds to the life of any pipe; but, even if it had no preservative quality, its value as a protection against abrasions, rough handling, and the wear and tear incident to transit, is a wise and time-honored practice. The author’s contention that such treatment “increases the weight materially” is misleading, as it does not generally affect the shipping charges. The fact is that, in most cases of the standard freight car, the total weight of a load of pipe is less than the minimum car-load weight prescribed by the railroads.

Although continuous stave pipe is a comparatively simple structure, it is a mistake to assume that it can be assembled or laid without the use of expert and experienced supervision, preferably by the manufacturer’s engineer, if he is an experienced man. George L. Watson, Assoc. M. Am. Soc. C. E., concludes an excellent article\(^*\) with a warning to all general contractors to keep hands off, and leave all wood pipe to a regular pipe contractor. The writer is familiar with several large jobs, partly completed by local or general contractors, which had to be pulled down and relaid by an expert.

On page 439, we read: “Fir and pine are pitchy woods, and it is impossible to obtain commercial run lumber without sap, pitch, pitch seams, pitch pockets, and knots.” The Shoshone Pipe specification, which the writer has quoted in this discussion as being representative, and which he recommends, does not call for “commercial run lumber,” but for a stock of definite and select quality. He has never known of commercial run lumber, either fir or redwood, being used for first-class pipe.

That part of the author’s suggested specification for Class A, Continuous-Stave Pipe, relating to redwood stave stock is not specific enough, and allows too much latitude in the character of the material. Redwood, like fir, should be straight-grained, devoid of checks and wanes, and should have no knots at the edges of the staves, nor within 6 in. of the ends, nor any defects which may impair its strength or durability. (The expression, “materially impair” should not be used.) Moreover, the width of the metallic tongue should be 2 in., because of the alleged tendency of redwood to shrink endwise.

Finally, the basis of classification, given on page 457, in terms of longevity, seems to be more pedantic than empiric, and, therefore, should have small place at this time.


O. P. M. Goss,\(^*\) Assoc. M. Am. Soc. C. E. (by letter).—The writer has read this paper with considerate interest. It contains some very interesting suggestions, and is believed to be a step in the right direction, at least in so far as it suggests the standardizing of specifications covering the design and construction of wood stave pipe. This subject, however, is very important, and should receive thorough consideration before any definite specification is approved.

There are, for example, certain statements in the paper which are not based on the natural laws underlying the most approved use of wood. In offering the following comments for consideration, the writer has endeavored to set forth certain facts which cannot be ignored in the general discussion of wood stave pipe.

On page 459 the author states:

“Fir and pine are pitchy woods, and it is impossible to obtain commercial run lumber without sap, pitch, pitch seams, pitch pockets, and knots. Under conditions of partial saturation, this lumber will not last, and, even with saturation, the pitch and sap will be the cause of deterioration. Most failures are attributable to this fact. There are conditions under which fir or pine will have a long life and give perfect satisfaction.”

Pitch does not in any way cause the deterioration of timber. Tests of recent date, made at the U. S. Forest Service Laboratory, indicate that wood containing resin deteriorates a little less rapidly, on the average, than that which is free from this substance. The following quotation is taken from a recent report issued from the U. S. Forest Products Laboratory, at Madison, Wis.:

“Relation of Resin to Strength and Durability.—Data on the effect of resin on durability were worked up for 105 samples of long-leaf pine. The results, when considered as averages for four durability classes, indicate that increasing amounts of resin tend to be directly correlated with increased durability. Individual blocks do not necessarily bear out this relation, showing that there are other factors involved.”

The following quotation is from page 441 of the paper:

“The cases of redwood pipe already cited illustrate its adaptability, whether laid on the surface of the ground, partly or completely buried, or run through salt marshes or tropical swamps in direct contact with the soil humus. Direct exposure to the rays of the desert sun, and alternate wetting and drying when the pipe is used intermittently in irrigation systems, do not lessen its efficiency.”

The writer cannot see how any one can make such a broad statement, and particularly that “alternate wetting and drying when the pipe is used intermittently in irrigation systems” does not lessen its efficiency. Again, tests made recently at the U. S. Forest Products

*Seattle, Wash.
Laboratory indicate that all woods are subject to decay under adverse conditions. It could only be considered good engineering when conditions are prevented which would tend to make any wood less durable. Heartwood from the California big trees, at the end of a 12-month test, showed a loss in weight of 35.1%, due to deterioration. This wood is not the same as redwood, but is similar, and is used here in the absence of similar data for redwood. Western red cedar, an unusually durable wood, under similar conditions, showed a loss of 21.3%, but it is reported that the samples were too wet to give a fair test, which indicates that 21.3% loss is lower than a fair test would have shown. Port Orford cedar, readily conceded to be one of the most durable woods, showed a loss of 22.6%, which, again, is lower than the value would have been had the specimens been less saturated. Douglas fir showed a loss of 28.1%, according to these tests. Deterioration, in this case, also, was somewhat retarded by an excess of moisture. These results show that the most durable woods are likely to decay if subjected to adverse conditions. Due to this fact, no wood pipe, regardless of the species from which the staves are made, should be laid under unfavorable conditions without taking practical precautions against decay of the wood fiber.

On page 444 the author states:

"Fir and pine, being hard woods compared with redwood, and being coarse-grained, having wide rings of hard and soft wood, enter the classification of woods giving excessive percolation, with slow and incomplete penetration. This is caused by the water passing rapidly through the soft summer wood, appearing in drops on the outer surface of the pipe, and of penetrating but slowly, and often through only a fraction of a stave, along the hard winter rings. The result is a stave showing percolation and incomplete penetration at alternate points throughout its cross-section."

Douglas fir, as a matter of fact, is one of the most difficult woods to penetrate with a liquid, and, in this respect, might about as well beclassed with metal as with pine. In creosoting timber, throughout the United States, there has seldom if ever been found a wood which has required so much scientific study to secure thoroughly satisfactory impregnation as has been the case with Douglas fir. In the treatment of ties of this wood, it is highly desirable to perforate the sides of each tie with fine holes, uniformly spaced, in order to get an effective injection of creosote oil.

It is usually specified that pipe staves of Douglas fir shall be practically free from all defects, which means that this stock must not be cut from the center of the log, which usually contains most of the knots and other defects. Due to this fact, the staves are cut from the fine-grained material found on the outer portion of the large fir logs, and not from the coarser-grained material, which is almost always confined to the center portions of the tree.

In the selection of pipe staves, care is taken to eliminate coarse-grained material. No difficulty whatever is experienced in eliminating practically all the sap wood, and, in pipe properly manufactured, the sap is never allowed to occur on the outer portion of the stave. Sap is not considered a defect on the inner portion, in a line which is in continuous service, because of the fact that, under this condition, it is always thoroughly saturated.

In Douglas fir staves of medium and fine growth, the summer and spring wood bands of the annual ring are so close together that if either is thoroughly saturated the adjacent one must also be wet.

The soft portion of the annual ring of redwood is more porous than the corresponding part of Douglas fir, as shown by Figs. 6 and 7. Redwood holds a natural moisture content of about 80% and the normal moisture content of Douglas fir is 33%, based on the dry weight of the wood in both cases. These facts indicate a greater porosity in redwood than in Douglas fir. As a matter of practice, however, neither of these woods is justly subject to criticism from the standpoint of excessive percolation.

The author refers to the "soft summer wood and hard winter rings." Technically, the summer wood is the hard part of the annual ring, and is formed during the dry period of the tree's growth; that is, through the late summer and early fall. The soft or porous portion of the annual ring is the spring wood, and is formed in the early spring and summer, when moisture in the soil is abundant and the growing rate of the tree is most rapid.

On page 445 the author states:

"The lumber, therefore, should be perfectly dry before being used. It should be dried by the natural or air-drying process, not by the forced or kiln-drying process. By air-drying only is perfect, sound, strong lumber obtained. Kiln-drying makes brittle and lifeless lumber. Air-drying requires time, and, as lumber should be seasoned for at least a year for the best construction, a large stock of it should be available at all times."

As a matter of fact, better results may be secured by correct methods of kiln-drying Douglas fir lumber than by air-seasoning it. Like any other process of manufacture, kiln-drying has its successes and failures. With a fundamental knowledge of wood and of the law governing successful kiln-drying, entirely satisfactory results are now obtained. It is possible to kiln-dry Douglas fir staves in such a way as to leave them in perfect condition for use. This kiln-drying may be, and is, done to-day so as to produce faultless lumber with its full
original strength, in fact, much more than its original green strength, as it comes from the kiln.

Small specimens of long-leaf pine, \( \frac{3}{8} \) by \( \frac{3}{8} \) in. in cross-section, air-dried for 98 days and re-soaked in water for 47 days, showed a crushing strength of 2,213 lb. The same material (matched pieces) after being kiln-dried 55 days and re-soaked in water 63 days exhibited 2,268 lb. Air-dried, re-soaked specimens of red spruce, handled in exactly the same way, showed a strength of 1,553 lb., and for the kiln-dried, re-soaked, 1,606 lb. Chestnut was also used in this test, and exhibited 1,482 lb. for the air-dried, re-soaked, and 1,573 lb. for the kiln-dried, re-soaked pieces. These figures show that proper kiln-drying does not injure the strength of the wood, as compared to air-seasoning; and it must be remembered that these tests were made on specimens which were water-soaked after being kiln-dried and air-dried, which makes the tests particularly applicable to pipe staves in service.

Mr. H. D. Tiemann, of the U. S. Forest Products Laboratory, one of the best versed men in the United States on the theory of kiln-drying lumber, states:

"While air-drying is undoubtedly the safest method, the process is ordinarily so slow, requiring a year or longer, according to species and size, that forced 'artificial' drying becomes a business necessity. Moreover, air-drying is by no means always to be preferred to kiln-drying from the standpoint of the quality of the product."

The writer has made tests on Douglas fir and western hemlock, similar to those quoted from Circular No. 108 of the U. S. Forest Service, showing that kiln-drying operations do not affect adversely the strength of either of these species, as compared to air-seasoned material. This may not be true in the case of redwood or cedar, as the structure of these woods is very different, and the cells appear to collapse under the application of heat very much more readily than with Douglas fir or pine.

On page 446 the author states: "For correct pipe design, only air-dried lumber should be specified." This seems to be so far out of line with good practice that it needs little comment. Practically all the Douglas fir lumber which is put into pipe is thoroughly kiln-dried before use, and any one familiar with this material knows that, under conditions which are favorable to any wood pipe, it gives the best of service. The author discusses machine-banded pipe, and refers to the difficulty experienced with the banded couplings, due to their lack of durability. He suggests that fir pipe couplings be discarded and replaced by couplings of redwood. This is not the best solution of

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this problem. A better method is to creosote thoroughly the staves of pine, fir, or redwood before making up these collars. This will give them durability even greater than that of the pipe line itself under complete saturation. This is strictly an economical and efficient method, and is to-day being practiced by at least the most progressive pipe manufacturers on the Pacific Coast.

The following is quoted from page 451:

“The use of the inserted or slip-joint pipe is not to be recommended. Such a connection weakens the end of every section, because nearly one-half of the shell of the pipe is cut away to make the joint. A reinforcing rod is often used to draw the joint tight, but if the male and female tenons are eccentric, leakage cannot be avoided.”

The writer has used a considerable quantity of machine-banded Douglas fir pipe with the inserted couplings, and has found it to give thorough satisfaction. As to the strength of these joints, the writer has had no experience which would indicate that they are not sufficiently reinforced. Redwood staves are usually thinner than those of fir or pine, and this, together with the fact that redwood is weaker than Douglas fir or pine, might account for the lack of satisfaction given by this type of pipe. It is an entire success when made of Douglas fir, in accordance with present standards.

The writer cannot see any reason for leakage due to the tenons or cups being slightly eccentric with regard to the axis of the pipe, so long as they are circular and well manufactured. In his experience, no difficulty from leakage has been found.

Douglas fir has considerable advantage over redwood in strength in compression across the grain. The average strength of these woods* is 570 lb. per sq. in. for Douglas fir and 625 lb. for redwood. These figures show redwood to be approximately 92% as strong in side bearing as Douglas fir.

On page 457 the author states: “For permanent work, redwood should be selected, or fir or pine of high-grade staves kept saturated and well painted.”

It would be inviting trouble not to apply the clause “kept saturated and well painted” to redwood, as well as to fir and pine. It is the weak points in a wood pipe that cause the trouble, and in good engineering these weak points should be eliminated by proper means. Wood staves used under low heads or under intermittent service should be creosoted by the pressure process. If, for any reason, this is impossible, a brush treatment with hot creosote, or carbolineum, should be applied to the edges and ends of the staves, and also to the entire outer portion of the pipe line. This treatment should be followed with a hot asphalt or tar coating thoroughly applied.

On page 446, the following is found:

"In regard to the protection of the staves by applications of coatings of paint or disinfectant, little of value can be cited. Many claims are made for the benefits derived from various coatings, but sufficient data are yet lacking for reliable conclusions. It is certain that such protection increases the life of fir, pine, or other woods containing sap and pitch, but its merits on a redwood pipe have not yet been proved.

"A coating of at least 1/16 in. should be the result of the first painting, and repeated examination should be made of the line, and the pipe painted every year or so."

It is safe to say that a protective coating or preservative properly applied will increase the life of any wood pipe. Mr. Partridge states that in fir and pine pipe it is necessary to apply a preservative coating "every year or so." The writer knows of no Douglas fir or pine pipe lines which have been coated as often as this. In fact, it would be impracticable and entirely unnecessary to paint a wood pipe line "every year or so" when such line is buried in the soil. If the proper material is used, the protective coating should remain on the pipe at least 15 years under such conditions. The writer has seen Douglas fir stave pipe uncovered 24 years after it had been laid, and the asphaltic coating was still in good condition. If the pipe is used above ground, it would not be necessary to paint it oftener than once in 5 years, because the natural conditions would tend to retard decay.

Untreated wood stave pipe has demonstrated its value when used with a thorough knowledge of the underlying principle controlling the efficient use of wood. There is in store for such pipe, however, a development which is now making its appearance and will materially change present practice, and that is the creosoting of the staves under pressure as a means of eliminating decay.

Considerable effort has been made by the Engineering Department of the West Coast Lumbermen’s Association, particularly during the last 3 years, to improve the methods of creosoting Douglas fir in its various forms. One of the forms already studied is staves. In the methods of treatment which have been applied in the past (the old boiling or steaming processes), previous to the recent developments in the art of creosoting Douglas fir, there has been considerable loss in strength in compression perpendicular to the grain, due to the creosote treatment. This loss, of course, was not desirable in the case of staves, which depend on the strength of the wood in side bearing to resist the water pressure. There was a loss in strength of 30% or more in the staves as a result of either of these treatments. However, by the process now in use—the "boiling under a vacuum method"—which greatly reduces the temperature of the oil during treatment, or simply treating under low temperatures, there has been no loss in the strength of the staves.

The West Coast Lumbermen’s Association recently completed some strength tests on staves which had been creosoted by this mild-temperature method of treatment. Twelve Douglas fir staves were selected, which were entirely free from sap wood, and twelve other staves were chosen as nearly like the first group as possible, except that they contained various quantities of sap wood. All these staves were 6 ft. long, and were kiln-dried. A section 1 ft. long was cut off the end of each stave and retained for a control test. The remaining portions of each of the twenty-four staves were treated in the following manner:

They were warmed in creosote oil for 4 hours at 170° Fahr., and pressed from 0 to approximately 100 lb. per sq. in., until they had received about 16 lb. of oil per cu. ft.

The oil was then heated from 170 to 230° Fahr. in 3 hours, and held at this latter temperature for 1 hour. The staves were then removed.

The final heating bath was for the purpose of removing the surplus oil and cleaning the stave.

**TABLE 4.—BAND BEARING TEST ON DOUGLAS FIR STAVES, NATURAL AND CREOSOTED. STAVES SOAKED IN WATER ONE MONTH BEFORE TEST.**

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<tr>
<th>Condition of stave</th>
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<th>0.030 in. Diameter</th>
<th>0.049 in. Diameter</th>
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**STAVES CONTAINING SAPWOOD.**

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**STAVES ALL HEARTWOOD.**

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After this treatment, the staves were free from excess of oil and easy to handle. They were then placed in a water tank with the untreated pieces, and all were soaked for about 30 days. Then both the natural and creosoted staves were subjected to a band pressure test. In making this test, four sizes of bands were used, as shown in Table 4. Each band was 3.35 in. long, and was pressed into the stave, for the entire length of the band, in a direction perpendicular to the grain of the wood, until it was embedded over an area equal to 60 and 90° of the arc. Figs. 8 and 9 illustrate the method of making the test. The loads required to cause this depth of compression are shown in Table 4. Each stave, natural and treated, was subjected to tests with bands of each size. The results show clearly that creosoted staves of all heartwood as well as those of mixed heartwood and sap wood have strength values even greater than those obtained from the test of natural wood. The results are particularly significant, as the test approaches about as closely as possible the actual condition of staves in a pipe line in service. The creosoted staves uniformly show a slightly higher strength than the untreated staves tested under the same conditions. These results demonstrate clearly the fact that it is possible to creosote Douglas fir staves and retain all their original strength. They also indicate clearly the practicability of permitting sap wood in staves which are to be creosoted. In the staves tested, the penetration of the creosote oil in the sap wood was very complete in every case.

Recent experimental work conducted by the writer has also shown the practicability of perforating the outer surface of Douglas fir staves with small holes systematically spaced, as shown in Fig. 10. The resistance of the oil passing into the wood along the grain is practically nil compared to that found in forcing the oil in across the grain. The fine holes, through which the depth of penetration and the distribution of oil is controlled, are so small and spaced so regularly that they do not reduce the strength of the wood when tested in compression perpendicular to the grain. The result of these perforations is that the depth of penetration and the distribution of the oil can be thoroughly controlled—two very important factors in securing the greatest efficiency from creosoted timber.

Mr. Partridge does not discuss at any length the possibility of the entire elimination of decay in wood stave pipe by an efficient pressure treatment of the staves with coal-tar creosote. This subject should be thoroughly investigated at once, as the proper use of creosote promises to extend greatly the field of usefulness of such pipe, and give it a reliability never before possessed. The writer is fully convinced of this, after having studied the subject very carefully. A large number of test results are available, and more should be obtained.
The final cost of a creosoted stave pipe line in place will be approximately 20% more than that of an untreated Douglas fir line, and about the same as that of an untreated redwood line. A number of large items remain constant, regardless of the cost of the staves. The steel bands, the excavation, the back-filling, engineering, overhead, transportation, and other costs remain constant regardless of whether or not the staves are creosoted. This added cost of 20% for a Douglas fir line may be assumed to buy a guaranty of greater permanency for any line, regardless of conditions under which it is built.

![Diagram of arrangement of perforations which will result in complete penetration of creosote oil equal to depth of perforations.](image)

The writer recommends a thorough investigation by the Society of the possibilities of creosoted wood stave pipe. Creosote promises to revolutionize the use of wood stave pipe and put it even more firmly in a class with the most durable pipe known, and yet leave it with almost all its present advantages as to low first cost and low coefficient of friction. The writer has discussed this subject with Joseph Jacobs, L. J. Stannard, and Marvin Chase, Members, Am. Soc. C. E., the latter recently appointed Irrigation Engineer for the State of Washington, all of whom see great possibilities for the creosoted stave form of construction. Mr. Chase recently built approximately 8,200 ft. of 60 and 6½-in. (inside diameter) creosoted wood pipe for the Wenatchee Reclamation District, in the Wenatchee Valley, Washington, and this line gives promise of most excellent results.

Before any standard specifications are adopted, the American Society of Civil Engineers should thoroughly investigate this subject through a committee capable of going deeply into it.

W. H. R. Nimmo,* ASSOC. M. AM. SOC. C. E. (by letter).—The writer, having had occasion to deal with numerous lines of wood pipe, especially of the machine-banded type, for town water supplies,

* Hobart, Tasmania.
has been much interested in this paper. Wood pipes as used in Tasmania, whether of the continuous-stave or machine-banded type, are almost always constructed of fir, known locally as Oregon fir. Although some engineers are fully aware of the superiority of redwood, yet, owing to its greater cost, pipes of this timber cannot be obtained from stock, and it is necessary to have them manufactured especially for each job. In the smaller sizes, up to about 6 in., redwood pipes cannot usually compete with cast iron or reinforced concrete. This State possesses some fine timbers, which may possibly prove superior to redwood, yet, at the present time, owing to lack of a sound forest policy, they cannot be obtained as cheaply as Oregon fir.

Machine-banded pipes, after receiving a first coating of bituminous composition, are usually wound spirally with a strip of Hessian, and are then given a second coating of composition and rolled in sawdust. The Hessian covering and second coating increases the cost slightly, and is omitted in some cases.

If galvanized wire of good quality is used, a factor of safety of four against breaking is considered sufficient. In computing the stress on the winding, the question arises as to the exact diameter of the pipe to be used. In a wood pipe, which is saturated, the joints between the staves must contain water under pressure, and in designing such pipes, the writer assumes that the pressure varies uniformly from the full pressure at the inner surface to zero at the outer surface, and the mean diameter of the pipe is used in computing the stress in the wire. This is a matter of no importance in a large pipe, but, in small sizes, its effect on the size of the wire is appreciable. The writer has not seen the question dealt with by any authority.

In the case of continuous-stave pipe, the design of shoes has not always received sufficient attention. A type of shoe is sometimes used in which the tension of the two ends of the band are not in the same vertical plane, thus adding a horizontal bending stress to the direct tensile stress in the bands near the shoe.

A combination of inserted joint with a collar is now generally used on machine-banded pipes, and has been found to be fairly satisfactory.

The increase in shipping weight due to the coating may not be of great importance. Freight by sea is usually charged by measurement, and special rates by rail can frequently be obtained for complete carloads. The smaller freight and handling charges on wood pipe, as compared with other kinds of pipe, however, are often the determining factors in its selection.

In all specifications for machine-banded pipes, a clause should be inserted requiring each pipe to be clearly branded with letters indicating the job, and figures indicating the head for which it is intended. The writer knows of cases where pipes intended to be laid near the intake of a line, under a low pressure, have been carelessly laid in places where the pressure was comparatively high, resulting in considerable trouble in maintenance.

E. A. Moritz,* Assoc. M. Am. Soc. C. E. (by letter).—The author states that the primary purposes of his paper are: (a) to give engineers an idea of the difference between the various grades of wood pipes; (b) to set forth a standard set of specifications for the assistance of engineers who have had no opportunity to become versed in their design; and (c) to safeguard those who contemplate building such pipe. His purposes appear to have been very well accomplished and, on the whole, the paper is well worth careful study by any one who is without information or experience in wood stave pipe design. The writer would issue only one caution to the uninitiated, and that is, that the author appears to give undue prominence to the value of redwood as compared with fir, which may be due to the fact that he may have had less experience with the latter. This tendency will be discussed later.

The writer will confine himself to pointing out some statements which are not exact or which are open to differences of opinion. One of these is that redwood is the best known material for wood pipe. This may have been true 25 years ago, but its accuracy, at the present time, is questioned. There are at least five large companies on the Pacific Coast which manufacture fir pipe exclusively, and only two which manufacture redwood pipe. The writer has no statistics at hand, but it is not unlikely that the output of fir pipe far exceeds that of redwood.

In regard to redwood pipe, the author says:

"Direct exposure to the rays of the desert sun, and alternate wetting and drying when the pipe is used intermittently in irrigation systems, do not lessen its efficiency."

This appears to be an inaccurate statement, but if the author means that such conditions do not hasten the decay of the wood, he will find few engineers to agree with him.

The author cites various specifications of the U. S. Reclamation Service as examples of the embodiment of different fundamentals for the purchase of similar materials, and states that, in some of these, redwood is placed on an equal basis with uncoated fir and, in others, with coated fir. This is an incorrect understanding of the practice of the Reclamation Service, which is to compare redwood, coated fir, and uncoated fir on their merits, as influenced by the peculiar local conditions surrounding each installation. That is, when competitive bids are asked for the three different classes of materials, the prices

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* Denver, Colo.

† The discussions by Messrs. Moritz and Miller were presented before the Colorado Association of Members, Am. Soc. C. E., at its meeting of June 9th, 1917.
The writer cannot agree with Mr. Partridge, however, when he states (page 457) that machine-banded, Class A pipe "will have a life of from 15 to 20 years when receiving no attention; a longer life under ideal conditions, as when laid in soils having the least possible corrosive effect on the galvanized wire, and when operating under pressure, so as to insure complete saturation of the wood." This statement may or may not be true. It may be assumed that the life of clear redwood, completely saturated, is exceedingly long, and if the pipe is placed in a soil which permits of the staves being continually saturated, there is no doubt that they will last for 25 years, or even much longer.

The lack of permanency in machine-banded pipe is due to the corrosion of the wire, which is of comparatively small sectional area. As shown in Table 3, machine-banded pipe is at present manufactured in diameters up to 24 in., with sizes of wire varying from No. 12 in the 3-in. size to No. 4 in the 24-in. size, the spacing of the wires varying with the pressure, as there tabulated.

By referring to Table 2, on continuous wood stave pipe with ordinary band steel, it will be noted that the usual type is made successfully in diameters up to 144 in., and that the corresponding diameter of the band on the 24-in. pipe is 2 in. The wire on the machine-banded pipe is galvanized. On the ordinary pipe, the bars may or may not be; usually, they are not.

It has been the writer's experience that, in the lighter gauges of metal, the corrosion of steel, when exposed to atmospheric and soil conditions, is extremely rapid, even though the metal is galvanized.

Much has been heard lately of the so-called pure irons, which are said to resist corrosion to a marked degree. The advertisements by the manufacturers of these materials would almost lead one to believe that the oxidation of iron and steel is a thing of the past. On close observation, one can readily see that these companies shield themselves behind a good coat of galvanizing. It has been stated recently by a representative of one of the largest manufacturers of this so-called pure iron, which, in reality, is a low-carbon steel made in an open-hearth furnace, that 60% of their tonnage is galvanized. The writer does not wish to give the impression that the product put out by these companies is inferior. He does wish, however, to emphasize the point that, in a practical sense, the virtue, or resistance of this metal to corrosion, is due to the galvanized coating—not to the purity of the base metal, as represented in most of these advertisements. The skill of the press agents employed by these manufacturers is in advance of that of their chemists and artisans. It may be said that in the defeat of corrosion, purity in the base metal is undoubtedly desirable, but the requisite purity is practically or commercially unattainable.

When one studies the subject of corrosion from the point of view of the electrolytic theory, it is readily seen that it is very difficult to
It is practically impossible to eliminate all impurities; it is also difficult to render the steel perfectly homogeneous. As a result of the dissimilarity in the composition of the molecules, electric currents are set up, under certain conditions, which decompose any water present into its constituents, hydrogen and oxygen.

It may be considered that waters carried by wood stave pipes are weak electrolytes, due to the salts held in solution. It must be remembered, also, that ordinary waters are saturated with dissolved oxygen and carry carbonic acid in solution. These waters also have extremely variable degrees of alkalinity. Electrolysis and corrosion, therefore, go hand in hand, ever tending to restore these products to the more stable compounds found in Nature.

The writer has seen extra heavy wrought-iron pipe, in reality steel pipe, which was used to carry Pintsch gas to the railroad cars, rust out completely in 18 months. This pipe was laid in ashes in the railroad yards, and the conditions for rapid corrosion were ideal, the pipe being buried in a relatively concentrated electrolyte. This pipe failed, or rusted through, near the joints where the mechanics had applied their Stillson wrenches in screwing up the pipe, thereby breaking the outer skin. This condition was finally corrected by embedding the pipes in cement mortar. Similar pipes in clay soil have been in use for 15 years without showing serious effects from oxidation.

In the purification of coal and water gas, hydrated oxide, or iron rust, is used to remove the sulphurated hydrogen. The oxide is made from cast-iron filings or machine-shop borings. The filings are piled and wet down with water, and a small quantity of common salt is usually added. In a very few hours great heat is evolved as the chemical action or oxidation proceeds. It is necessary to control the temperature of the mass, as the efficiency of the final product is lowered if high temperatures are permitted. This is done by spreading the oxide in thin layers. The mass is sprinkled from day to day with an ordinary garden hose. It is also turned over periodically so as to expose new surfaces to atmospheric influences. In the course of about 30 days or 6 weeks the oxide is ready for use. This oxide is found to be of slightly different chemical composition from the ordinary precipitated oxide. It is much cheaper, however. The writer cites the foregoing in order that those not familiar with the gas industry may know how quickly the complete oxidation of iron may take place.

It may be stated, therefore, that it is not well to fix arbitrarily the life of a wood stave pipe, as, say, from 15 to 25 years, without knowledge of its location and the chemical characteristics of the soils to which it may be subjected, as the life may be long or short, depending on these governing conditions.