TIMBER DESIGN
IN
WATERFRONT CONSTRUCTION

by
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Timber design in waterfront construction remains largely an art where knowledge of exposure conditions is important to assure durability. It is important for engineers designing with timber to master this art if they wish to be good designers. Also, since metal fastenings are required in timber construction, an understanding of the behavior of steel and iron in sea water environment is essential.

Ever since man has been able to cut timber to suit his purposes, he has used this natural material to build his shelters, bridges and vessels. Even today, timber is quite competitive with the newer materials because of its natural properties of resilience, light weight and ease of fastening and gluing. Timber in waterfront construction was quite unsatisfactory in the early days and therefore was avoided since marine borer attack would destroy untreated timber quite readily, except in a few cases, such as oak, where the bark gave protection as long as it stayed on. This resulted in the use of stone and masonry, which is quite evident in European and Mediterranean ports. On the other hand, in fresh water timber was found to be very durable and therefore pile foundations using timber are found in many large structures. Fortunately, when timber exposed to sea water is buried in mud, silt, sand or clay, the marine borers will not attack. As a result, a good many waterfront structures were founded on untreated timber piles, backfilled and protected by the soil with a masonry structure on top.

In the field of ship construction, man was required to devise means of protecting the wooden hulls of vessels so that borers would not attack. Therefore, sailing ships were sheathed with sheets of copper, and very often a coating of tar or ship's felt was applied to the hull before the copper sheets were fastened. This resulted in an effective protection but required re-sheathing every two to three years since the copper would often be torn off by the abrasion of ice or floating debris. The art of sheathing has endured and is used for protecting the hulls of wooden fishing trawlers. In many cases, this amounts to covering the hull of the vessel with ship's felt and then putting on strips of tropical hardwood, such as greenheart, which is relatively immune to borers in temperate waters.

Tarred ship's felt is a by-product of the wool industry in Great Britain and Ireland, and to our knowledge, this felt has never been penetrated by marine borers as long as the felt was kept intact by structural boards or sheet metal.

Coal tar was used in early days as a coating to protect wood. In order to improve adhesion and obtain some penetration of the wood, the tar was dissolved in various solvents which could be absorbed by the wood fibres. However, it was not until pressure treatment was developed that large amounts of preservative could be forced into the sapwood as is now done with creosote oil and coal tar. The ability to penetrate depends a great deal on the type of wood selected. The tabulation shown in Fig. 1 gives an outline of the ability of various domestic woods to retain creosote. One problem with creosote oil is that it will eventually leach out, leaving the wood exposed to attack. This has been improved upon by using a mixture of creosote and coal tar in which the tar seals in the creosote so that the leaching is reduced. Then the use of full cell processes, in which the timber is put under vacuum to cause as many pores as possible to be filled with the preservative, has resulted in a remarkable resistance to attack.

Of all the domestic timbers, yellow pine is still by far the best to accept treatment because it has a great deal of sapwood which readily takes treatment in comparison with other types of timber which have very little sapwood. A few other timbers such as yellow birch will accept a reasonable amount of treatment.

The writer has seen many unsatisfactory installations where treatment was called for on heartwood timbers, and in

Woods with Good Retention	Uses
Yellow Pine - Sap and Summer Wood only	Piling, Shims
Loblolly Pine	Sheathing, & Bracing
Jack Pine	Bracing, Sheathing & Piling
Red Oak (with careful treatment)	Fender Piles, Shims
Red Pine	
Woods with Light Retention	
Birch	Shims
Hemlock	Cribbing
Woods with No Retention	
Fir	Flooring, Beams & Piling
White Oak	Fenders Beams & Piling
Yellow Pine-heartwood	Beams & Piling
Spruce	Piling
Woods Resistant to Marine Borers Without Creosote	
Azobe	Beams
Manbarklak	Beams
Greenhart (Temperate Regions Only)	Piling and Beams
Oak and Hemlock piling while bark stays on	
Angelique or Basra Locus	

Fig. 1 Creosote Retention of Common Structural Woods

spite of insizing, the penetration was not more than 1/32". It is futile to specify that woods be treated if the wood cannot accept treatment. However, time and again Douglas fir is seen which has been sawn square and subjected to treatment. It is pitiful to see the results. Recently, there has been considerable success in the treatment of Douglas fir plywood by pressure treatment in which the treatment has penetrated through 1" thick plywood. This material is being used for sheathing wooden hulls and appears most promising.

Tropical hardwoods, such as greenheart, azobe and manbarklak, resist very well the attack of teredo and limnoria in our North Atlantic ports, but are not as effective in warmer waters south of Norfolk, Virginia. These heavy dense woods are best used in submerged structures where twisting and distortion will not take place. The warping and splitting of these dense woods in atmospheric exposure is very severe. Their great strength and modulus of elasticity make them excellent for underwater construction.

The design of timber structures is usually dependent on metal fastenings to achieve strength and rigidity between the various timber elements. Today, great strides have been made in developing adhesives which bond timber more strongly than the strength of the basic wood. However, the durability of metal fastenings is as vital to this discussion as is the wood itself, since they cannot be avoided in waterfront construction. Generally, most fastenings are of ferrous metals, such as mild steel, wrought iron or cast iron. These may or may not be galvanized. There have been many instances where the use of galvanizing is misunderstood. In general, a galvanized fastening stands up very well when only exposed to the oxidation of the atmosphere. It is good in the splash zone, but whenever galvanizing is utilized for structures where the fastening remains under water, rapid dissolution of the zinc by electrolysis results. This has even been seen to take place in fresh water.

Cast iron, where it can be used, has proven to be very durable in sea water. It is cheap and will outlast forged or rolled steel by many years. Cast steel is substantially more durable in sea water than either forged or rolled steel.

The use of machine bolts in waterfront construction is very common, but, in the opinion of the author, it is much less costly to use ordinary drift iron in which the fastening is basically the friction between the timber and the iron bar. We do not hesitate to construct dwellings using nails so why should we change our approach when it comes to waterfront construction? The ability of timber to hold drift bolts is amazing, and the fact that the bolt is imbedded in the wood protects it against oxidation. When domestic timbers are used, drift bolts should be inserted in holes about 1/16" smaller than the drift. If tropical hardwoods are used, the interference should not be more than 1/64".

When small pieces of steel are used, they are subject to oxidation if exposed to air. However if they are imbedded in wood, oxidation is of very little consequence. Also, if small pieces are electrically separated from other large steel bodies, they do not normally suffer from electrolysis. For the above reasons, drift bolts of iron or steel are very durable. On the other hand, machine bolt heads and nuts will readily corrode away leaving only the imbedded shank. It is therefore wise to design fastenings in such a way that most stresses pass from timber to timber with minimum reliance on the iron fastenings except where they are imbedded in the wood. Marine organisms cause corrosion where they attach themselves to iron surfaces. This is a factor in the deterioration of bolt heads and nuts.

Waterfront structures utilizing timber are usually best when composite construction is used. The timber deck of a wooden pier will suffer badly from decay due to rain water and the lack of immersion of the deck in the sea water since it is the salt in the sea water which acts as a preservative. It is therefore preferable when building piers to utilize timber piling in the sea water and reinforced concrete for the upper structure. It is already known that concrete suffers severely from freezing and thawing, which makes concrete piles in a tidal range very unsatisfactory. However, in tropical locations this is not a problem. Structural steel in sea water, although quite impressive immediately after construction, has proven to be short-lived and costly to maintain. There is a zone about 2 feet below low water in which the oxygen content appears to cause very serious attack on structural steel. This was found at the Army Base in Boston and on structural steel cradles in Halifax. As can readily be understood, cleaning and painting structural steel 2 feet below low water is for all intents and purposes impossible without enormous expenditures. Encasing the steel with concrete is not very satisfactory since the concrete will spall in this zone. It is therefore most desirable to use timber if possible in this very difficult location. The only alternative would be to use massive rock or concrete construction.

Figs. 2, 3, and 4 illustrate the effects of exposure at various levels and show suggested means of protecting against adverse effects.

When nails and spikes are driven into a piece of soft wood, the ability of the wood to compress without splitting is taken for granted and the holding capability of this nail is a function of the modulus of side grain compressibility. Very dense hardwoods cannot be spiked as readily because of their much greater compressive strength and if a nail is forced in the wood, it will split due to intense tension across the grain combined with a notch effect.

The author has been very interested in the elastic behavior of timbers in side grain compression. This is particularly important in the field of dry docking of ships where

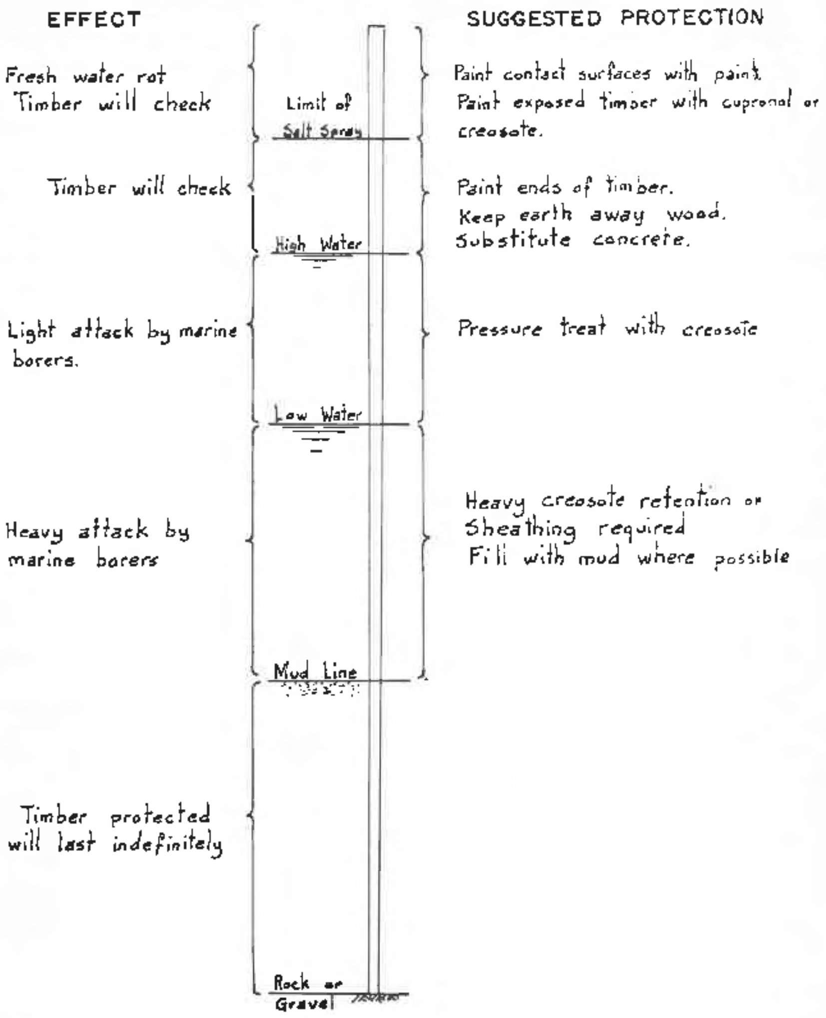


Fig. 2 Timber Exposed to Sea Water

wooden blocking is used to provide an elastic compressible support between the ship and the dry dock. To better understand the nature of timber behavior in side grain compression, tests were made on five domestic timbers, one being tested in the dry and one set in the wet. Curves of stress vs. strain are shown in Figs. 5 - 9. The amazing thing about timber in side grain compression is its ability to yield with-

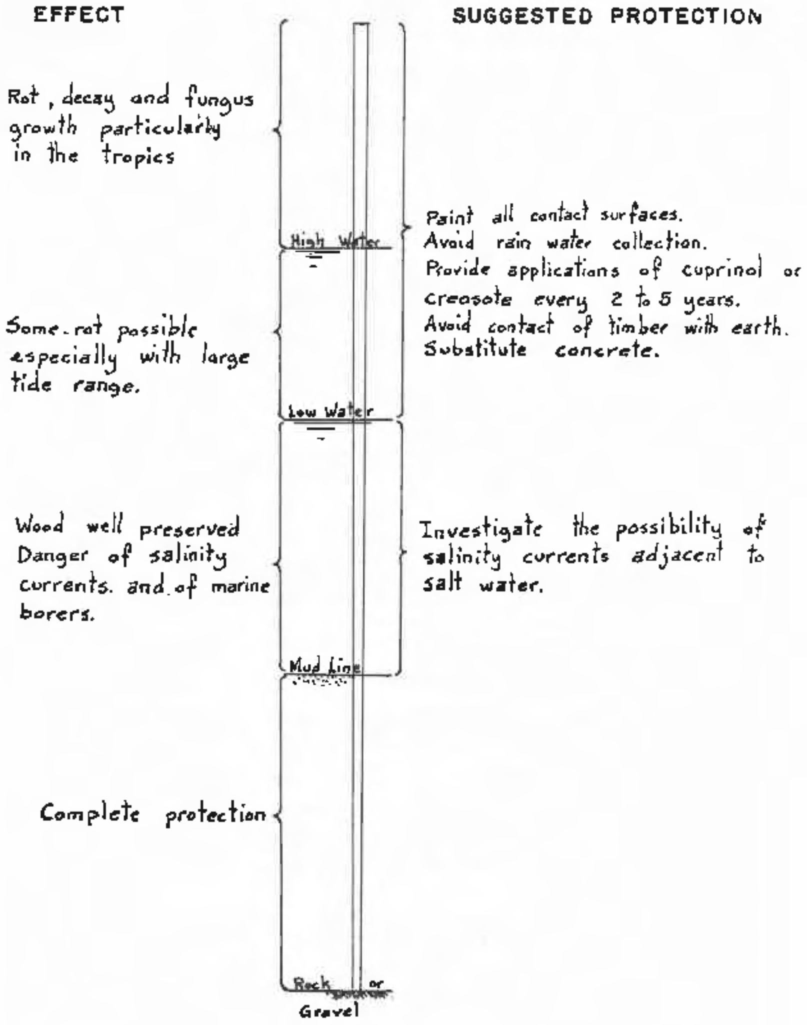


Fig. 3 Timber Exposed to Fresh Water

out failing. In general, there is a zone of elastic compression, then a zone of considerable compression in which the fibers are actually yielding and the pores of the wood are closing, and finally there is a zone of high resistance when the pores of the timber are, for all intents and purposes, closed. This behavior puts a new light on the allowable side grain compression which may be used in design. The tests were made

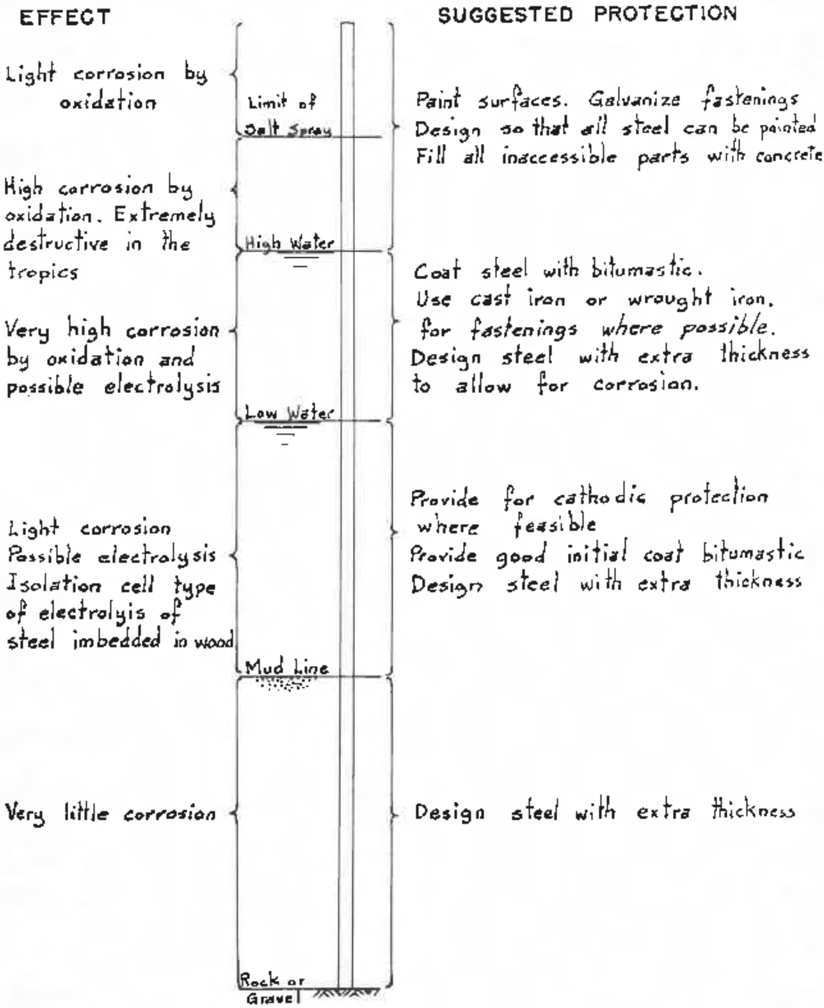


Fig. 4 Steel Exposed to Sea Water

on random samples 8" x 8" x 20" with loading applied quite slowly to permit the wood to yield. It was remarkable to see the crushed wood recovered 75% to 90% of its original thickness about 30 minutes after load was released.

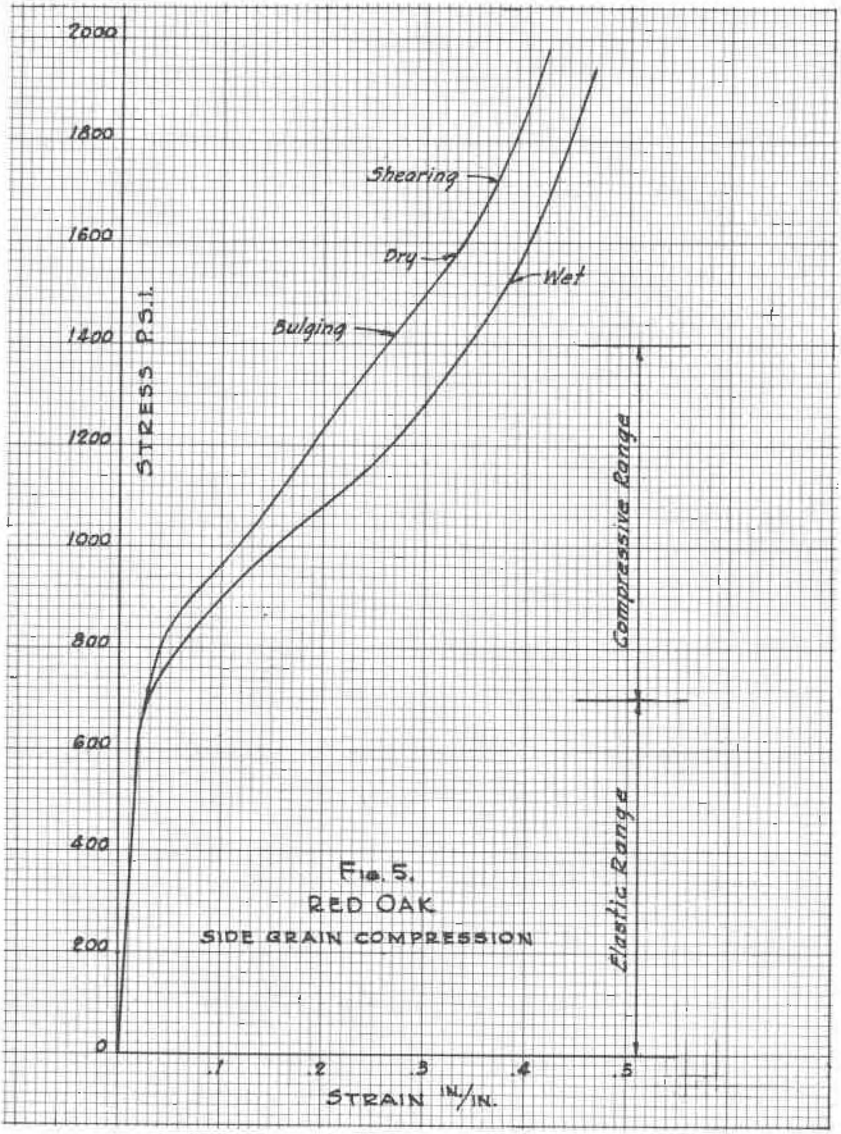
2000
1800
1600
1400
1200
1000
800
600
400
200
0
STRESS P.S.I.
.1
.2
.3
.4
.5
STRAIN IN./IN.
Shearing
Dry
Wet
Bulging
Compressive Range
Elastic Range
FIG. 5.
RED OAK
SIDE GRAIN COMPRESSION

Fig. 5

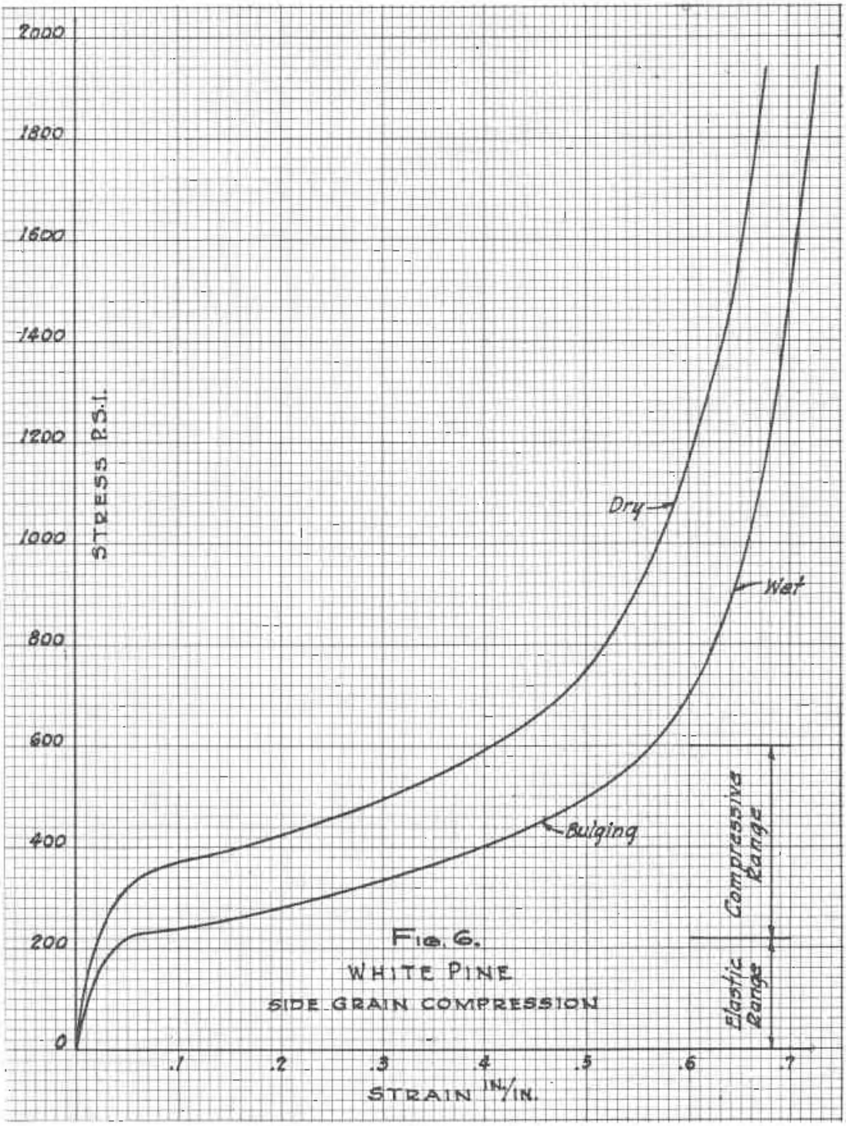

2000
1800
1600
1400
1200
1000
800
600
400
200
0
STRESS P.S.I.
Dry
Wet
Bulging
Compressive Range
Elastic Range
FIG. 6.
WHITE PINE
SIDE GRAIN COMPRESSION
.1
.2
.3
.4
.5
.6
.7
STRAIN IN/IN.

Fig. 6

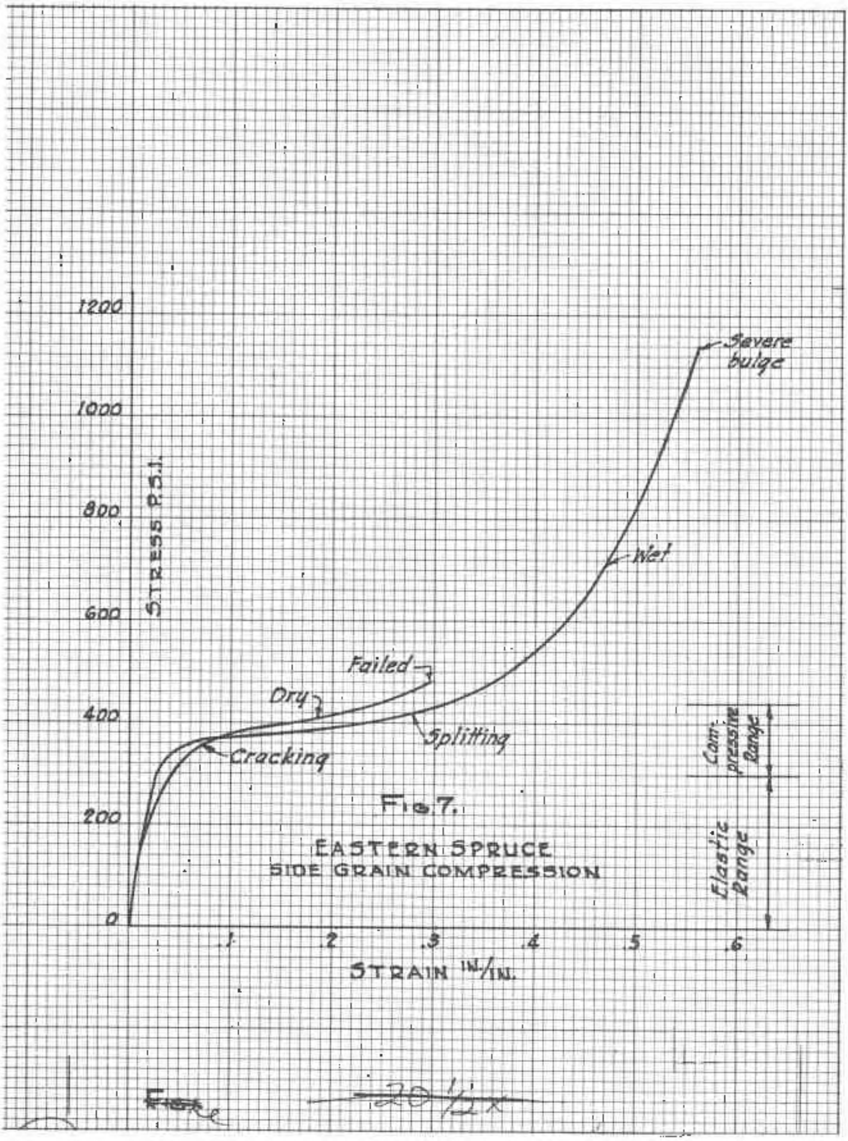
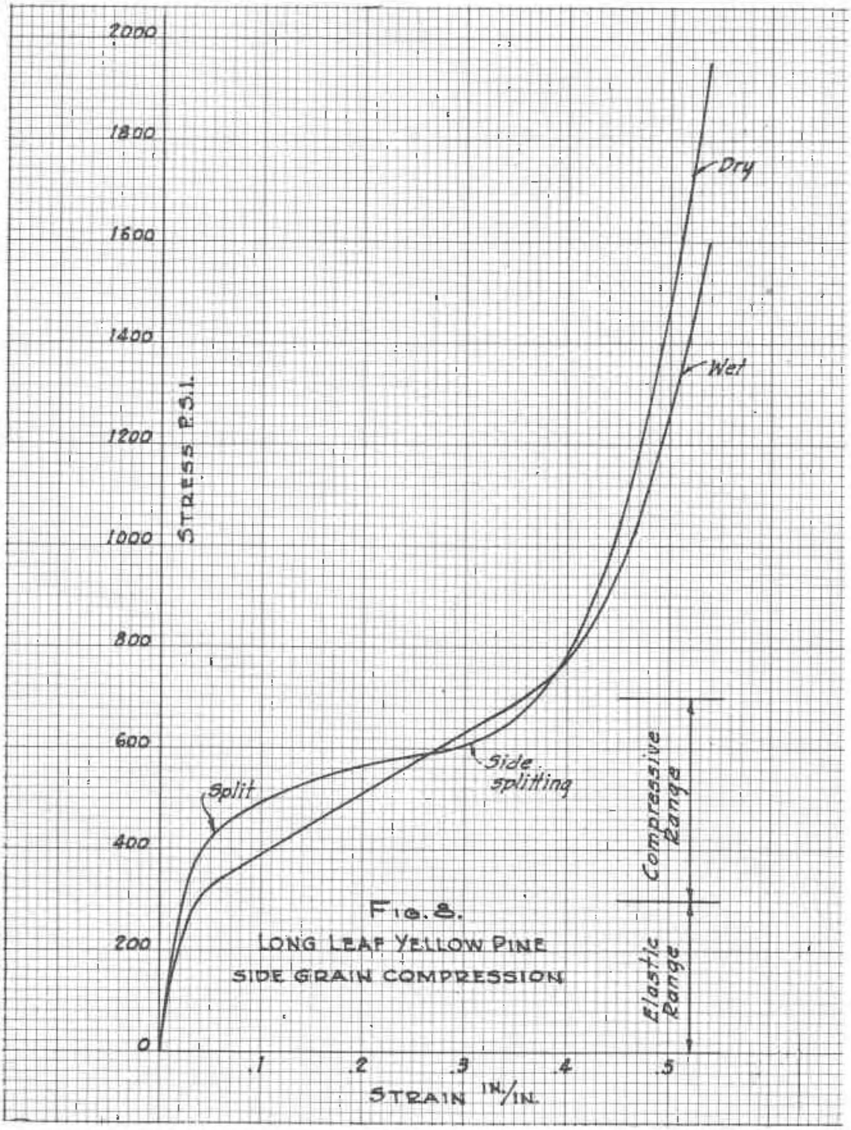

1200
1000
800
600
400
200
0
STRESS P.S.I.
.1
.2
.3
.4
.5
.6
STRAIN IN/IN.
Severe bulge
Wet
Failed
Dry
Splitting
Cracking
Compressive Range
Elastic Range
FIG. 7.
EASTERN SPRUCE
SIDE GRAIN COMPRESSION
~~20 1/2 x~~

Fig. 7



2000
1800
1600
1400
1200
1000
800
600
400
200
0
STRESS P.S.I.
.1
.2
.3
.4
.5
STRAIN IN/IN
Dry
Wet
Split
Side splitting
Compressive Range
Elastic Range
FIG. 8.
LONG LEAF YELLOW PINE
SIDE GRAIN COMPRESSION

Fig. 8

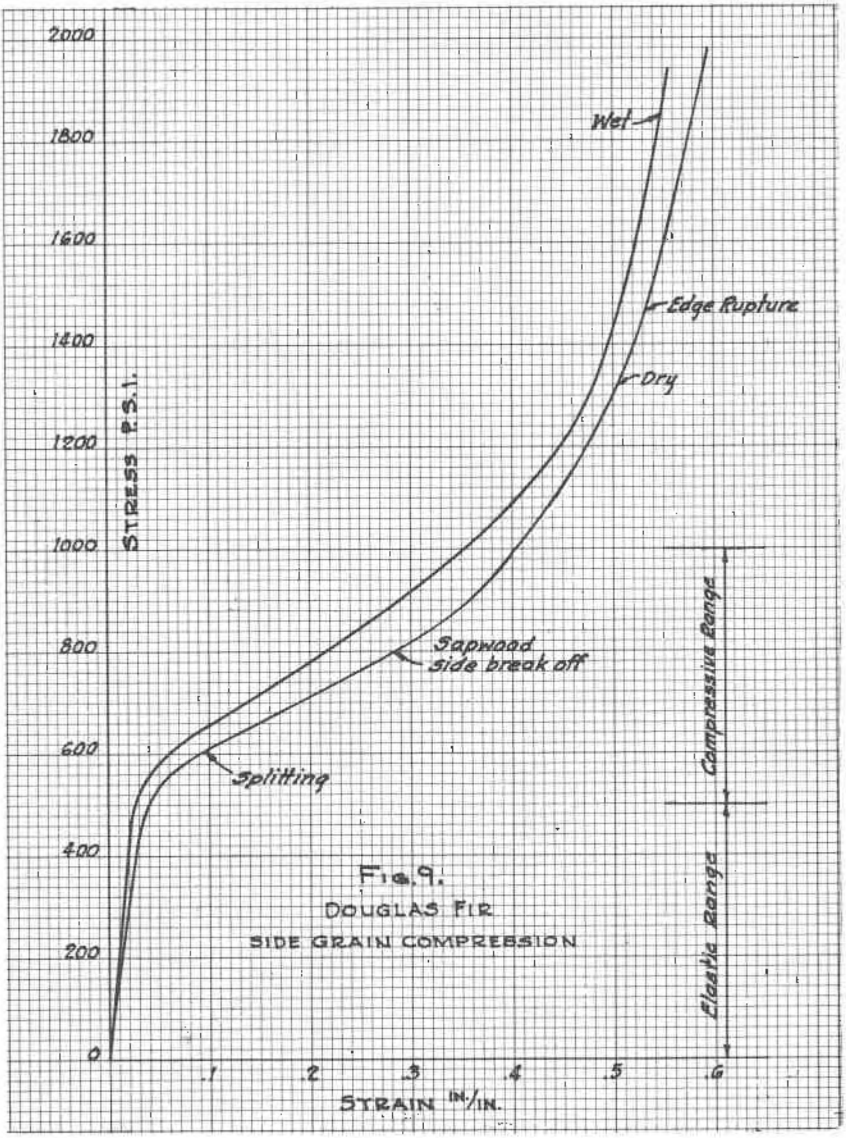

2000
1800
1600
1400
1200
1000
800
600
400
200
0
STRESS P.S.I.
Wet
Edge Rupture
Dry
Sapwood side break off
Splitting
Compressive Range
Elastic Range
FIG. 9.
DOUGLAS FIR
SIDE GRAIN COMPRESSION
.1
.2
.3
.4
.5
.6
STRAIN IN./IN.

Fig. 9

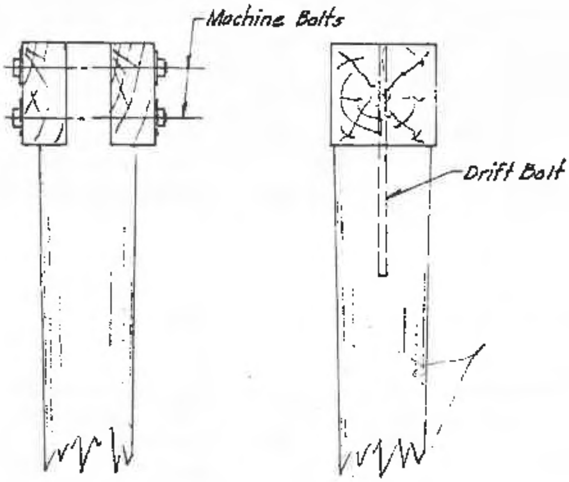
The author feels that more testing of a greater variety of timbers in a manner similar to those reported in this paper would be worthwhile to undertake and hopes that the information already presented will be beneficial to engineers working with timber both in design and in field construction.

Kind of Timber	Elastic Range		Compressive Range	
	Stress in P.S.I.	Modulus P.S.I.	Stress in P.S.I.	Modulus P.S.I.
Red Oak Dry	0-700	32000	700-1400	2700
" " Wet	0-700	32000	700-1400	2200
White Pine Dry	0-220	9000	220-600	750
" " Wet	0-220	6250	220-600	540
Eastern Spruce Dry	0-300	12000	300-440	400
" " Wet	0-300	12000	300-440	330
L.L. Yellow Pine Dry	0-300	13000	300-700	700
" " " Wet	0-300	11000	300-700	1200
Douglas Fir Dry	0 500	19000	500-1000	1150
" " Wet	0 500	15000	500-1000	1350

Note - Wet timber immersed in water 48 hours.

Test samples were 8" x 8" x 20"

Fig. 10 Modulus of Compressibility
Side Grain Compression - Domestic Timber



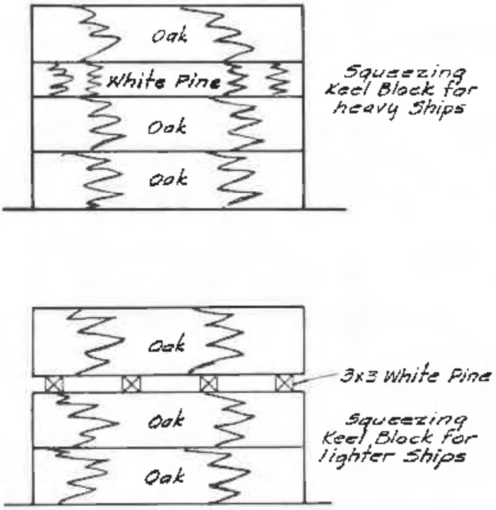
BOSTON DIVIDED CAP

Limited bearing capacity
Exposure to decay
Expensive

SOLID CAP

Maximum bearing capacity
Pile head fully covered
Low Cost

Fig. 11 Comparative Method of Capping Piles as Practiced in New England



SUGGESTED COMPRESSIBLE KEEL BLOCKS FOR SHIPS WITH IRREGULAR KEELS
-B-

Fig. 12 Application of Highly Compressible Woods to Limit Maximum Load of Ship Keel on Blocks

Fig. 13 Spruce pile attacked by limnoria on the exterior and by teredo on the interior. The portion attacked was above the mud line. The portion of pile to full dimension was protected by mud. Here is an example where an eaten pile was salvaged by cutting away the damaged wood and installing a solid timber cap above the re-cut pile.

Fig. 14 MacMillan Wharf, Provincetown, Mass. This wharf is a good example of composite construction utilizing creosoted yellow pine piles with cast-in-place reinforced concrete caps. The longitudinal stringers were precast to minimize form work over water and to enable rapid assembly of the deck system. Forms were then placed between the stringers for pouring a 6" reinforced concrete slab to tie all of the caps and stringers together.

Fig. 15 The lowest point in the concrete is 2' above high water so that the concrete is never immersed in sea water which would otherwise cause spawling due to freezing and thawing. The timber piles are always exposed to complete wetting so that decay will not start due to the combination of creosote and salt preservation.

Fig. 16 Tanker wharf consisting of five dolphins at Bucksport, Maine, in the Penobscot River. The low-cost timber piles with the heavy concrete cap provides a stable structure for mooring tankers. The concrete cap shelters the structural piles against rain water decay and at the same time ties all of the battered piles so that they will act together. The mass of the concrete is above highest water so that maximum effective weight will exist for stability. The piles between low water and the concrete were treated with copper naphthanate solution against rotting. These piles are untreated fir since they are in the fresh water of the Penobscot River. This in another example of the advantage of composite construction using timber and concrete.