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Controlling Decay in Waterfront Structures

Evaluation, Prevention, and Remedial Treatments

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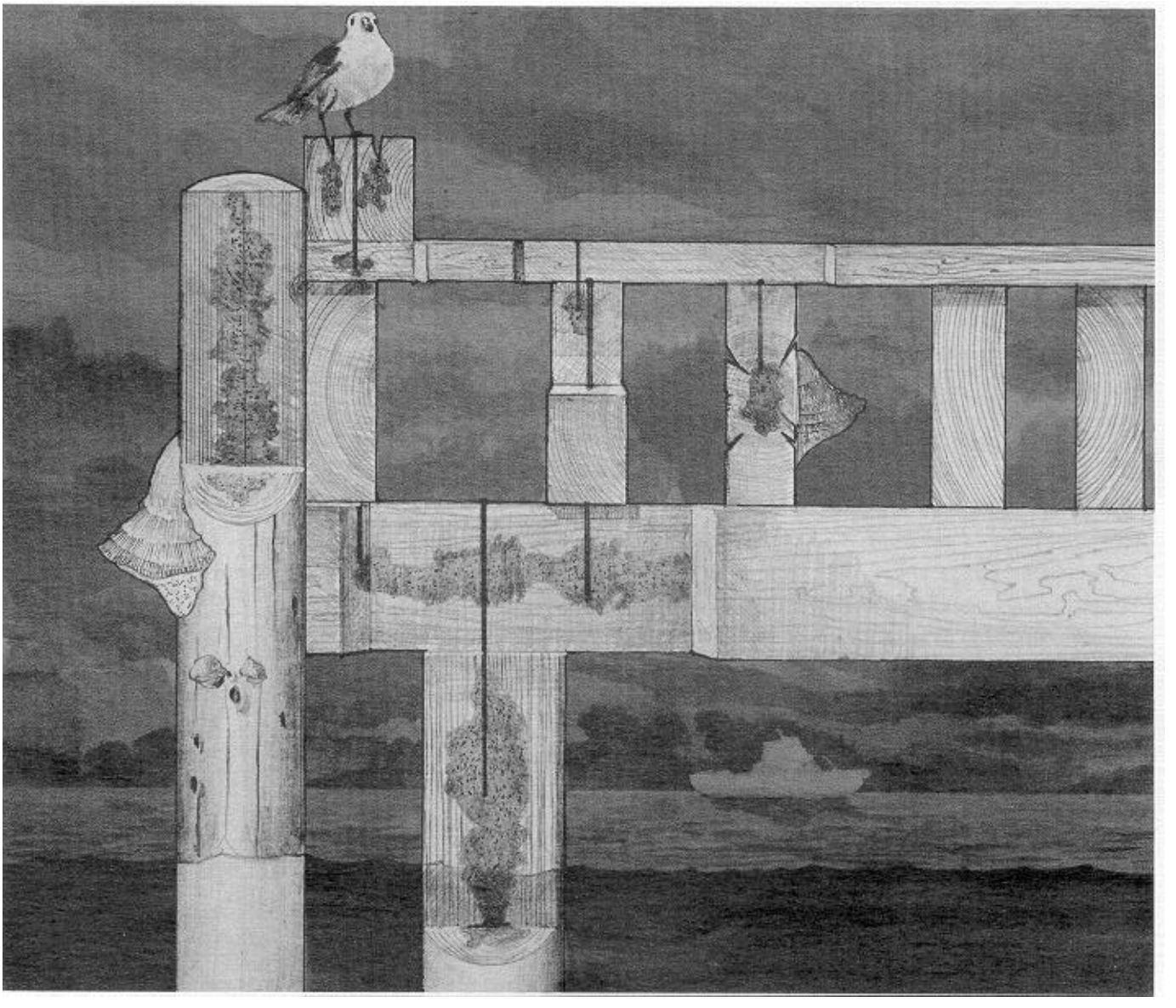

Abstract

Decay in waterfront structures results in expensive repair or replacement of the damaged components. This manual describes the problems caused by decay and ways to avoid or control decay. The information presented is directed toward personnel who inspect and maintain waterfront structures. The manual describes (1) types of deterioration and underlying causes, (2) construction practices that contribute to decay, (3) decay detection, and (4) decay prevention, including remedial measures for decayed structures.

Keywords: Wood decay, waterfront structures, wood maintenance, wood inspection

Note

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Controlling Decay in Waterfront Structures

Evaluation, Prevention, and Remedial Treatments

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Introduction

The primary purpose of this manual is to provide information on the characteristics of decay in wood components of waterfront structures and on the means to avoid or control decay. Most measures to protect wood are directed against three types of destructive agents: (1) biological (destructive utilization of wood by various micro-organisms such as decay fungi), (2) physical (damage by breakage or deformation), and (3) chemical (such as electrolytic breakdown around iron fasteners). Biological deterioration definitely constitutes the largest proportion of damage to structures.

Proper construction and utilization of appropriate preservative-treated materials are the primary ingredients for a long-lasting structure. However, good construction needs to be backed up by good maintenance. Deterioration often advances slowly and is not immediately obvious. By the time deterioration is apparent, the trouble may be widespread. Routine inspection can identify potential or actual problems before they become severe. Corrective measures at early stages may entail minor expenses, but if the deterioration is allowed to continue, the result may be costly major repairs or even complete demolition of the structure.

Data derived from a well-organized and executed inspection and maintenance program can be valuable for planning new construction that will be free from the conditions that favor deterioration. Comprehensive information about the current condition of the structures can also prevent expensive replacements and loss of service time during repairs. Thus, when the total cost and service value of military and commercial marine installations are considered, the relatively small sums of money expended for decay-inhibiting construction, adequate routine inspection, and proper preventive maintenance are clearly cost-effective.

This manual is concerned almost exclusively with biological deterioration caused by decay fungi in the above-water portions of waterfront structures. Below-waterline decay is not a problem. The manual is divided into three major areas: (1) deteriorating agents, (2) decay detection and evaluation, and (3) decay prevention and remedial treatment. Many portions of the information were derived in collaboration with the Department of the Navy.

Causes of Deterioration

Wood does not deteriorate as a result of aging alone. The service life of all commonly used construction timbers depends on their protection from a variety of deteriorating agents by means of construction and maintenance procedures suited to the physical and climatic features of the construction site. Deterioration of wood usually falls into one of three principal categories: (1) biological, (2) physical, and (3) chemical.

Biological Causes

Biological damage to above-water parts of waterfront structures is caused directly or indirectly by the activity of fungi and insects that utilize the wood for food or nesting material.

Decay Fungi

Decay fungi are primitive plants that obtain their food from wood (Fig. 1); they cause by far the greatest amount of damage to the above-water components of waterfront structures. In fact, the service life of waterfront wood is most commonly terminated as a result of decay. If wood is kept in a damp condition for any length of time, it becomes infected with fungi that cause decay. The rate of wood degradation depends on the species of fungus and the kind of wood. Degradation results in loss of weight and strength of the wood.

The growing stage of the fungi is characterized by microscopic threads called hyphae that develop from germinating spores, which are analogous to seeds. The hyphae penetrate and ramify within the wood and cause the chemical and physical changes recognized as decay. Under suitable conditions, fungi produce spore-bearing structures called fruit bodies, from which the fungus generally reproduces and spreads. Many decay fungi can be recognized as mushrooms or bracket-shaped fruiting bodies on the surface of the infected wood. Thousands of microscopically sized spores, analogous to seeds of higher plants, are produced in the fruit bodies and released into the air. When the temperature is mild, spores contacting susceptible moist wood can germinate and cause new infection.

Conditions for Growth — In common with most organisms, decay fungi require oxygen and favorable moisture and temperature. Oxygen is ordinarily not a limiting factor except for wood that is under water or deep in the ground. Wood moisture contents from about 40 to 80 percent based on ovendry weight are most favorable for decay. These amounts of moisture occur only in green wood or as a result of wetting. Therefore, if wood is dried and then protected against wetting, it will not decay. For a recommended margin of safety, untreated wood should not be used in an environment with a moisture content exceeding 20 percent. Moisture absorbed from humid air alone (no condensation) will almost always meet this limitation. By contrast, very high moisture contents can prevent rather than favor decay. Thus, saturated wood that has been continuously under water can remain comparatively sound for many years. The high moisture level prevents needed access of oxygen to typical decay fungi.

Decay fungi differ in temperature for optimum growth. The optimum range for most decay fungi is from about 21°C to 30°C, although some species grow slowly at temperatures as low as 0°C and as high as 45°C. In many areas, low temperatures from late fall to early spring either minimize or prevent decay. The optimum pH is in the range of 4.5 to 5.5.

Above-ground wood is less susceptible to decay than wood in contact with the soil. This results in part from the typically drier environment and the fact that the wood is not in contact with decay fungi already established in the soil. The infection of above-ground wood depends almost solely on infection by fungal spores, which are relatively sensitive to environmental extremes and toxins. Natural wood extractives that are relatively low in toxicity or lower concentrations of wood preservatives will prevent spore infection as opposed to infection by fungi growing in and nourished by soil nutrients.

Classification — Typical wood decay fungi fall into two broad classes: brown rot and white rot. The brown-rot type of decay is much more common in waterfront timbers, which largely are pine or Douglas-fir. Brown-rot decay is usually not seen on the surface of timbers protected by preservative treatment or in untreated members, which are protected by intermittent surface drying. Typical brown rot can be recognized by the color and physical character of the decayed wood. Wood with advanced decay caused by brown-rot fungi is brittle, exhibits abnormal shrinkage when dry, is usually brown, and typically shows distinct cross-grain checks, similar to those on the face of heavily charred timber (Fig. 2).

White-rot fungi may occasionally be found in waterfront members made of hardwood species such as oak. The decayed wood does not shrink abnormally; it may be whitish or light tan and flecked with dark pencil-like lines (zone lines). Typically, wood is not checked (Fig. 3) and may have a distinctly soft and punky texture despite the absence of abnormal shrinkage.

Insects

Insect damage to the above-water components of waterfront structures is not nearly as common or destructive as decay, but it nevertheless needs to be recognized (Fig. 4). Extensive insect activity usually results

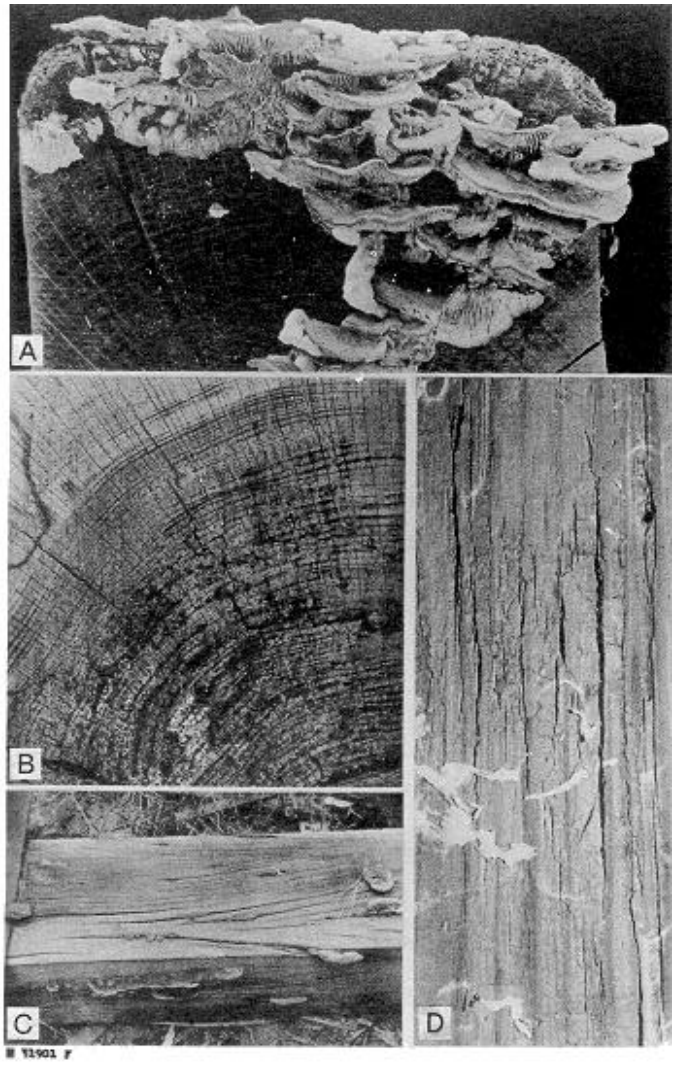

Figure 1—Examples of fungal growths and associated wood decay. (A) Fruiting bodies; (B) advanced wood decay; (C) fruiting bodies-obvious decay on wood surface; (D) fungal growth on wood surface and advanced decay shown by checks both across and with grain. (M 31901F)

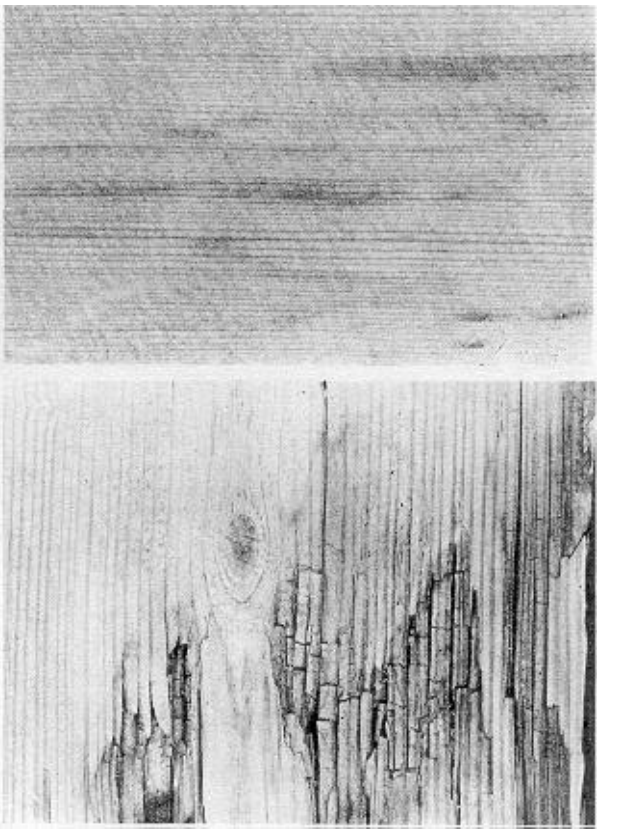

Figure 2—Stages of brown-rot decay (Top) Early stage-discoloration in surface and end grain (left). (Bottom) Late stage–cracked and collapsed wood. (M 124 928)

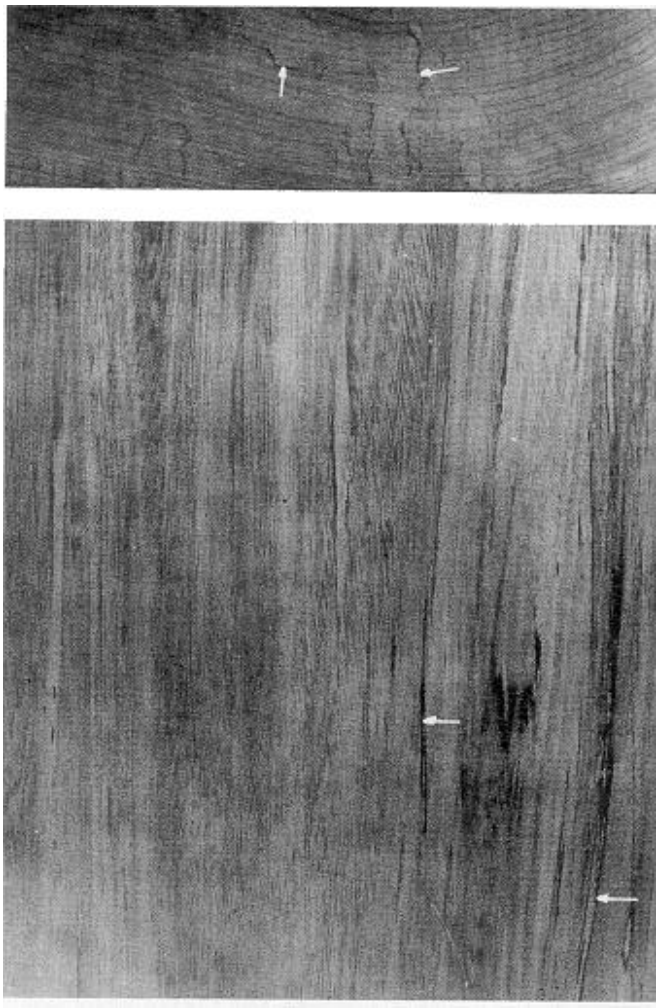

Figure 3—White-rot decay (Top) Mottling and dark zone lines (arrows) bordering the abnormally light areas in end grain. (Bottom) Side grain in same board. (M 124 927)

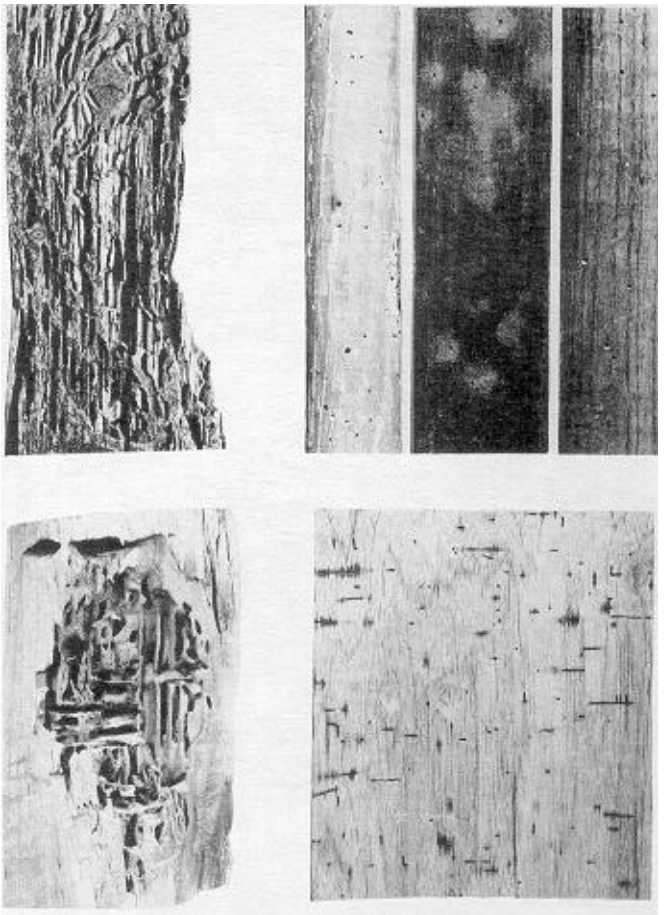

Figure 4—Types of insect damage most likely to occur in a building. (Upper left) Termite attack-feeding galleries (often parallel to the grain) contain excrement and soil. (Upper right) Powder-post beetle attack-exit holes usually filled with wood flour and not associated with discolored wood. (Lower left) Carpenter ant attack-nesting galleries usually cut across grain and are free of residue. (Lower right) Beetle at tack-feeding galleries (made in the wood while green) free of residue and surrounding wood darkly stained. (M 124 884)

in the distortion of shape and collapse of structural members. Various types of termites, beetles, carpenter ants, and bees utilize wood as a food source or for nesting purposes. Damage by wood-boring insects can usually be recognized without difficulty. Evidence of their presence may be entrance or departure holes, which vary in size according to the type of insect. In many instances, the accumulation of powdery material in the vicinity of the hole indicates insect activity.

In general, attack by termites is more destructive than that by other insects. Termites work inside the timbers, eating the wood and excavating large tunnels and galleries, which sometimes hollow out the timber completely. Termites never form exit holes on the wood surface; they carefully avoid damaging the surface. However, earthen tunnels or tubes on the wood surface, which conceal the passage of the insects from place to place in the wood, may indicate termite infestation. In the United States, termites are a problem mainly in the South, but they may be troublesome in any mild climate.

Physical Causes

Physical damage can result from overstressing, which causes excessive deflection of structural members or even failure to carry load. When wood members are loaded beyond their capacity for a long time, the fibers become permanently elongated in a process referred to as creep. Overload may be due to greater-than-design loading or to high moisture content of the wood, which reduces stiffness. Although deflection may not indicate loss of strength, the sag is usually permanent.

Wood is also overstressed by high-impact loading. Impact from berthing and mooring of ships is the chief cause of failure of fender piling. As wood dries, shrinkage may cause checks and splits. Checks may aggravate mechanical failure of deck surfaces subjected to considerable vehicular traffic.

Intermittent wetting by sea water occasionally causes a type of physical damage called shredding. The salt in the water accumulates and the resultant bulk causes the wood fibers to separate; the surface of the affected member consequently appears shredded.

Chemical Causes

If wood comes into contact with certain chemicals such as strong acids or alkalis, some of the wood constituents may be decomposed.

Wood rarely comes into contact with strong chemicals in waterfront structures, except in the case of accidental spilling. Most frequently, chemical damage of wooden components is associated with metal fasteners (Fig. 5). Wood adjacent to iron nails, screws, bolts, or other fasteners becomes blue-black and in time softens to varying degrees. This type of damage is commonly referred to as “metal sickness;” the chemical deterioration is often confused with decay caused by fungi. In advanced stages, the wood adjacent to fasteners appears to be charred and breaks into small, cubical pieces. A similar chemical effect has been observed around copper or copper-alloy fasteners.

Conditions for Decay

Decay Sites

For members exposed above water or ground, weather or seasoning checks can provide a locus for decay.

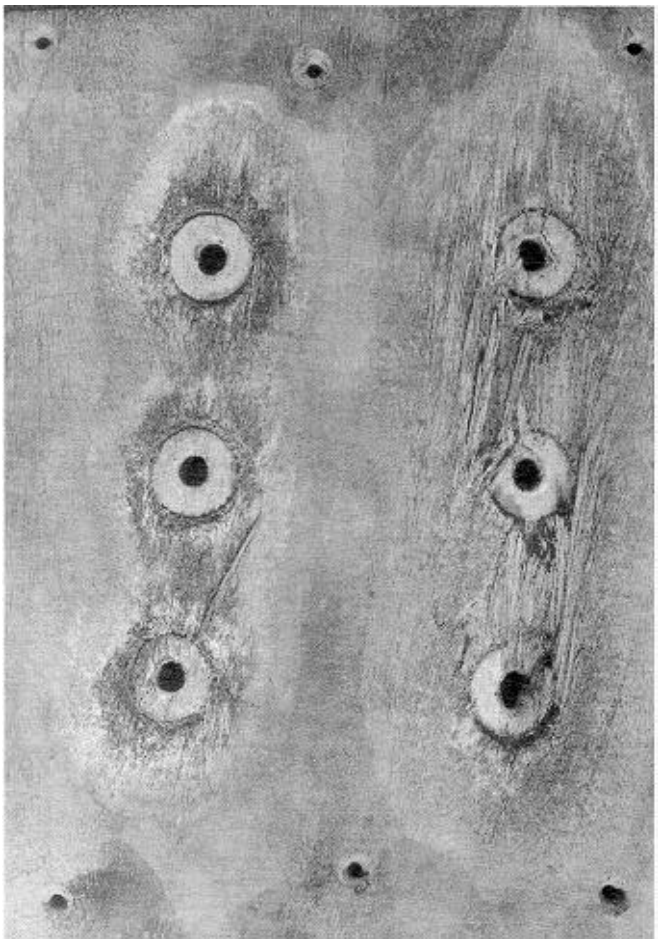

Figure 5—Chemical damage to wood caused by corrosion of metal fasteners. (M 144 736)

Large solid-sawn members are commonly subject to seasoning checks. When members are positioned horizontally as in decking, stringers, and curbing, any checks on their upper surfaces and some checks on exposed side surfaces become water traps if the members are subjected to rain or other forms of wetting. Vertically positioned members with comparable checks commonly remain dry since most checks can drain freely when wetted.

Another point of localized wetting in waterfront members that is conducive to decay is at wood-penetrating fasteners or hardware. Water, carrying fungus spores, may move in alongside bolts and nails and consequently wet and infect the interior wood. The rate of subsequent drying of the wood is comparatively slow, and so the wood tends to remain wet between rains. Predrilling timbers prior to pressure-preservative treatment can eliminate the danger of decay contributed by bolt holes.

Water penetration into wood can also be significantly influenced by the grain of the wood. End-grain (cross-cut) surfaces of wood absorb water much more rapidly than side-grain surfaces because permeability in the longitudinal (grain) direction tends to be 50 to 100 times greater than in the transverse (across-grain) direction. Thus, when water enters a bolt or fastener hole, it is absorbed largely along the grain where it can build up to critical amounts around the hole. Because of the prominence of end grain in wood, butt joints of untreated wood are especially vulnerable to wetting and decay.

Decks

Deck decay is illustrated in Figures 6 through 10. Practically all decking on waterfront structures is either Douglas-fir or Southern Pine. Conditions leading to decay in decks are the same for both species, but the rate of deterioration in untreated decks is considerably faster in pine than in Douglas-fir.

Surface Checks

Weather checking of the upper surface of planks is a conspicuous feature of decks that have been in service for a few years (Figs. 6,7). Checks can promote decay in two ways: (1) by creating cavities in which rainwater is trapped, thereby wetting the wood sufficiently to support attack by decay fungi, and (2) by penetrating a zone of treated wood and thereby exposing the underlying untreated wood to infection. Moreover, weather checks not only promote decay but may also erode the deck surface and increase the rate of deck wear from traffic.

The rate of decay from checks in deck planks as well as heavier wood members can accelerate over time. Over a period of years, incipient infection can get established in numerous checks without causing conspicuous breakdown of wood; once the attacking fungus is established in the interior of the wood, decay can proceed rapidly to the visible stages.

Exposed Ends

Decay can enter pressure-treated planks and timbers through the ends where untreated wood is exposed by cutting the members to length. If the untreated ends are butted together, a water-trapping butt joint is created and serious decay may result in a short time. Untreated wood ends should be protected by flooding with a strong solution of preservative.

Wetted Wood

Wetting decks and supports with fresh water may materially shorten their service life.

Double-Plank Construction

The double-plank type of construction is an invitation to decay because the two layers of planks provide an interzone in which water can be trapped. The deck should contain only a single layer of planking, and the planking should be spaced to let water pass through the deck freely.

Leakage Through Blacktop or Concrete Overlay

Although an asphalt or concrete surface may appear to provide a good protective cover against rain, it does not necessarily do this. Cracks frequently develop, particularly with blacktopped surfaces (Fig. 8), and rainwater consequently penetrates to the underlying planking and supporting wood members. The deck cover retards subsequent drying, making a favorable condition for serious decay.

Another place of decay-promoting leakage through blacktopped and concrete decks is between the track rails and the blacktopping or concrete in which the rails are embedded (Fig. 9). Such leakage can be especially hazardous because the depression in the blacktop

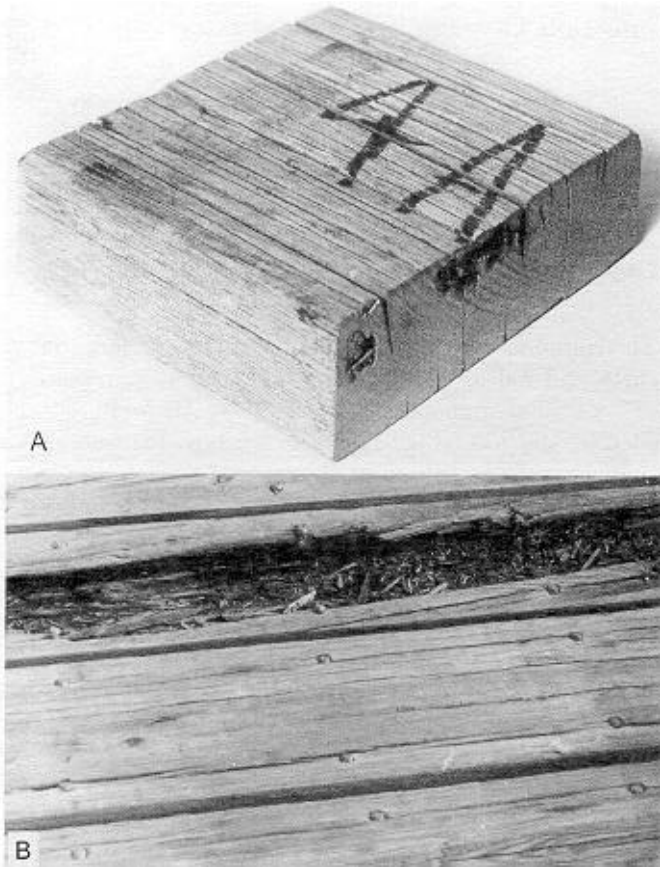

Figure 6—Weather checking in upper surfaces of pier and wharf planks. A, Cross section of Douglas-fir plank showing typical preponderance of checking on upper weather side and rot in some checks resulting from trapping of rainwater. B, Decay, promoted by weather checking, extending close to surface of Douglas-fir deck. (M 130 017)

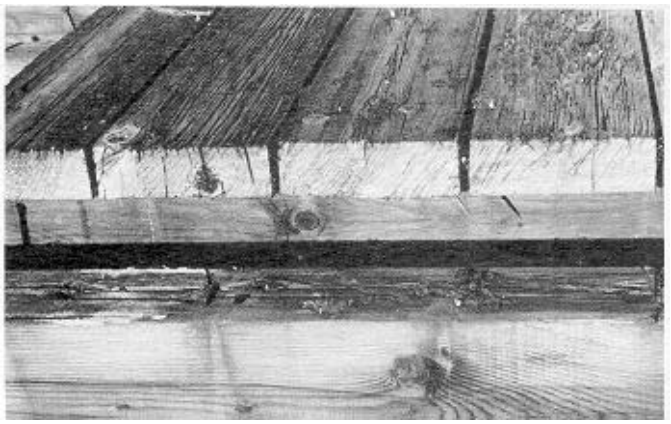

Figure 7—Cross-sectional view of planks showing decay in one check. Stringer with decay on upper surface also shown.

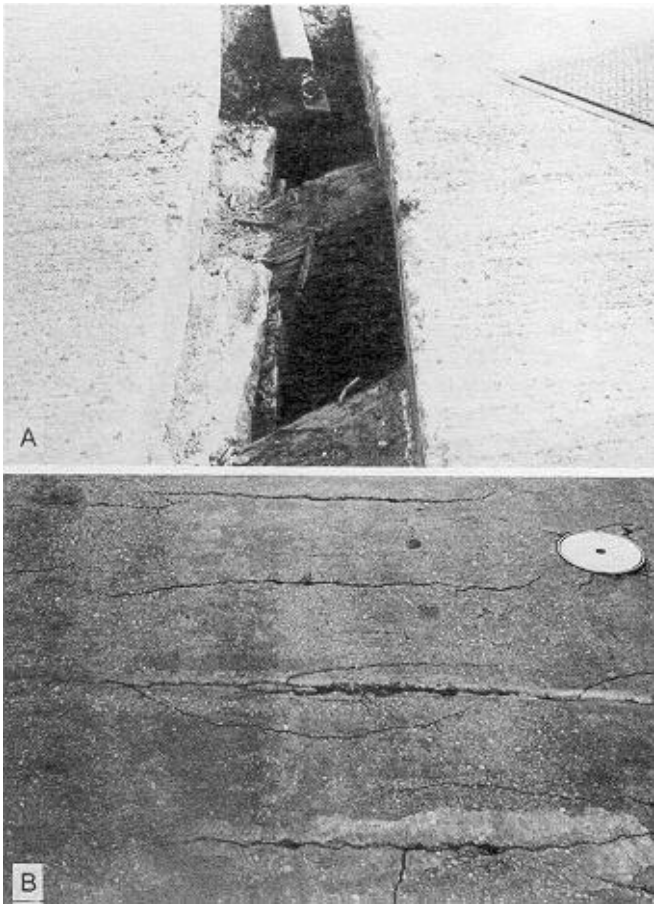

Figure 8—Blacktop cover should be properly constructed and maintained to adequately protect deck against rain wetting and decay. A, When the track area is depressed to accommodate wheel flanges, it tends to collect water from adjacent area. B, Cracked blacktop.

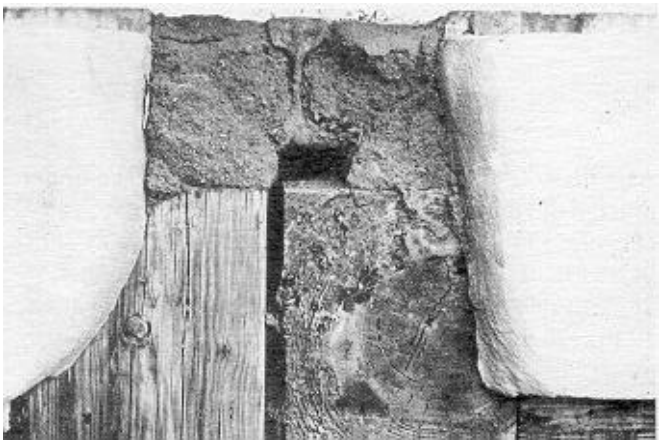

Figure 9—A concrete deck may leak at track positions and wet wood directly underneath. Here, decay has started along top of stringers.

or concrete adjacent to the rails, necessary to accommodate wheel flanges, has a funneling effect, tending to bring water from surrounding areas toward the rails.

Improper Positioning of Plank Heartwood

The heartwood-containing face of pine deck planks should be positioned downward because the heartwood may be poorly treated (Fig. 10) and because deck decay largely occurs in the upper zone of the planking as a result of weather checking. Heartwood from near the pith zone should also be positioned on the lower side of the planks because this wood is relatively weak and easily broken; hence, it performs poorly under traffic.

Curbs, Chocks, and Wales

Although they are not supporting members, curbs, chocks, and wales are large and relatively expensive timbers, fully deserving protective measures. Further justification for their protection is the high labor cost for replacement. Although comparatively accessible, such timbers resist removal because they are strongly attached to the structure and commonly carry a heavy complement of cables and pipes.

Decay of curbs, chocks, and wales can be prevented by deep preservative treatment, as is the case in treatment of pine sapwood. Decay in treated pine products is usually well-controlled irrespective of construction practices, mishandling, or long exposures. When the wood is not treated, or when the treatment is not very deep (as is typical in Douglas-fir), various conditions can lead to serious decay.

Seasoning and Weather Checks

As with deck planking, checks developing in the upper portion of curbs, chocks, and wales are the main cause of prolonged wetting and decay in these heavier members (Fig. 11). Both seasoning and weather checks are prevalent; because the members are large (at least 10 in. (25.4 cm) on a side), they are usually not fully air-dry before placed in service. The large size of the items moreover favors the development of especially deep checks. Such checks do not dry as rapidly as the shallower checks in planking, and thus, they present a more severe decay hazard. In treated Douglas-fir timbers, the larger checks typically extend well below the outer preservative-containing zone of wood (Fig. 11), exposing the untreated wood to infection.

Infection Through Bolt Holes

Bolt holes are also a common focal point for decay. When the holes are drilled in treated timber on the construction site, the drilling exposes untreated wood adjacent to the bolt (Fig. 12).

Lap-Joint Construction

The common lap-type joining of ends favors decay in curbs and wales. The half-lap joint is most common, and a similar connection, the oblique-scarf joint, is occasionally seen (Fig. 12). The lap-type joint accentuates the decay hazard at the ends of timbers in two ways: (1) by exposing a large amount of untreated interior wood in treated Douglas-fir timbers and (2) by creating a relatively large interfacial zone where water can be trapped. This kind of joint is also objectionable because effective on-site treating of newly exposed wood is especially difficult. Because much of the new surface is side grain, penetration of a preservative solution, applied by brushing or spraying, tends to be very shallow.

Curb Splits

Splits are occasionally formed in curbs as the result of stresses on mooring cleats (Fig. 13). Such openings favor decay in the same way as checks that develop from seasoning or weathering.

Improper Positioning of Timber Heartwood

As in deck planks, placement of a heartwood face can affect the hazard of decay in pine curbs, chocks, and wales. Heartwood is commonly present on one face; it receives little preservative. Consequently, timbers with heartwood should be positioned with the heartwood-containing face downward, where the fewest weather checks develop.

Stringers

Failure of stringers is obviously one of the costliest forms of damage to waterfront structures because these timbers are a major load-bearing component. To replace stringers, all members that they support must be removed. Most decay in stringers begins along the upper face, and even at early stages, decay may loosen deck spikes. Stringer decay generally originates in checks and splits caused by plank spikes and along driftpins (Fig. 14).

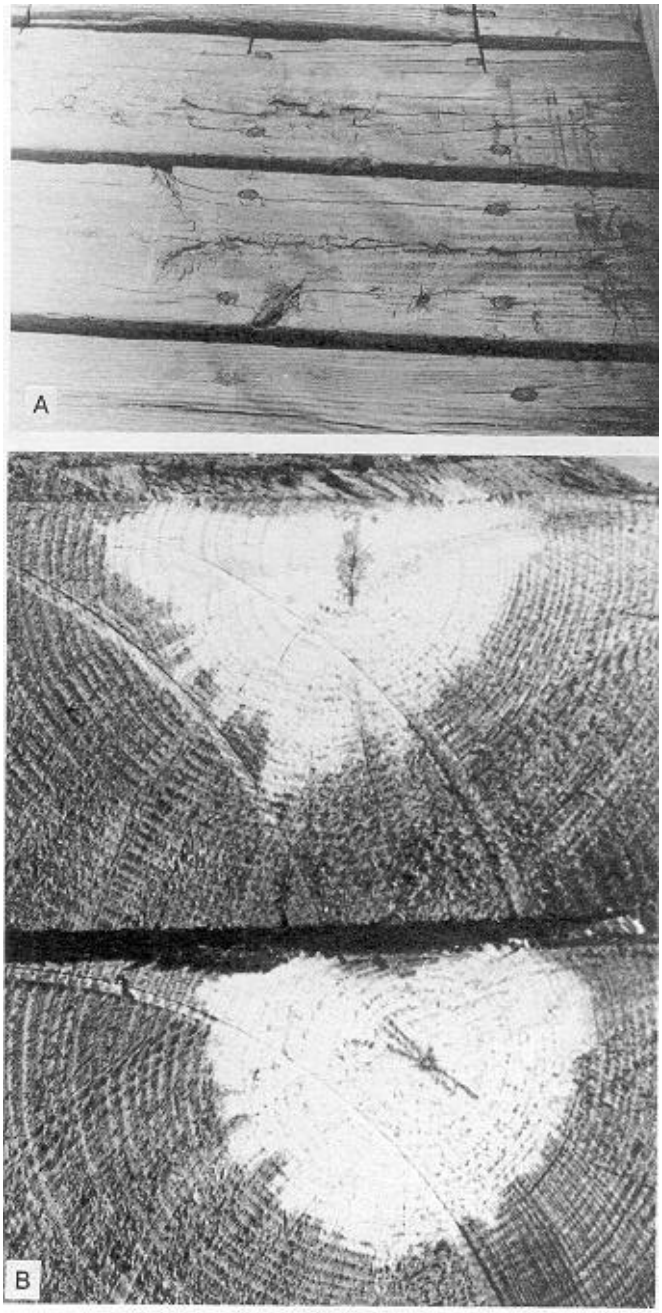

Figure 10—Heartwood and sapwood in Southern Pine deck planks. A, Deck plank with heartwood in upper surface and wood near pith, which cause an unusually cracked and weakened surface. B, Timbers in cross section showing typical distribution of preservative in heartwood and sapwood.

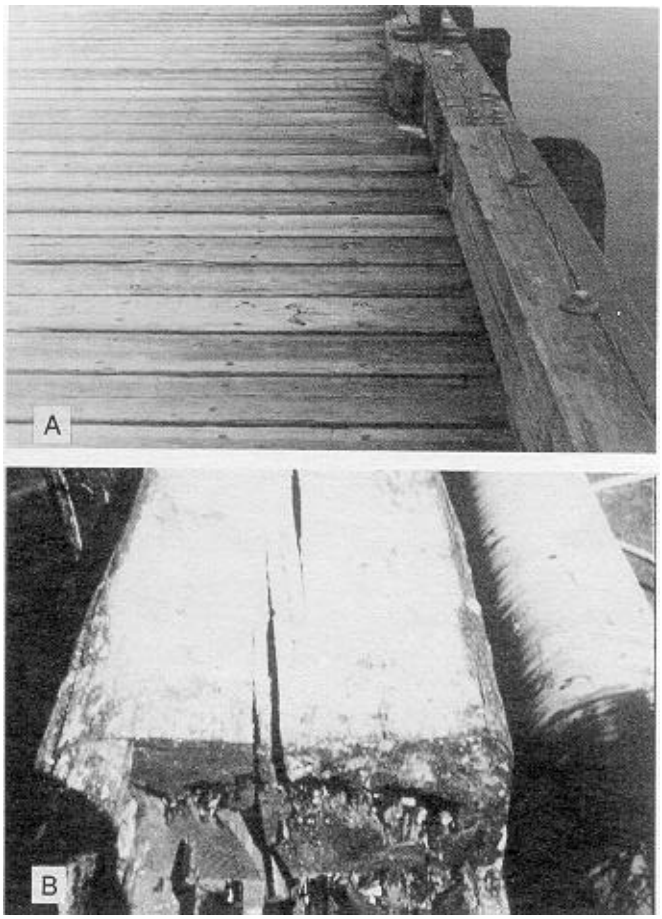

Figure 11—Potential decay sites for curb, chock, and wale timbers. A, Weather or seasoning checks in upper surface of Douglas-fir curb. B, Deep weather checks in pressure-treated curb penetrate the treated zone and subject interior wood to decay. (M 145 019)

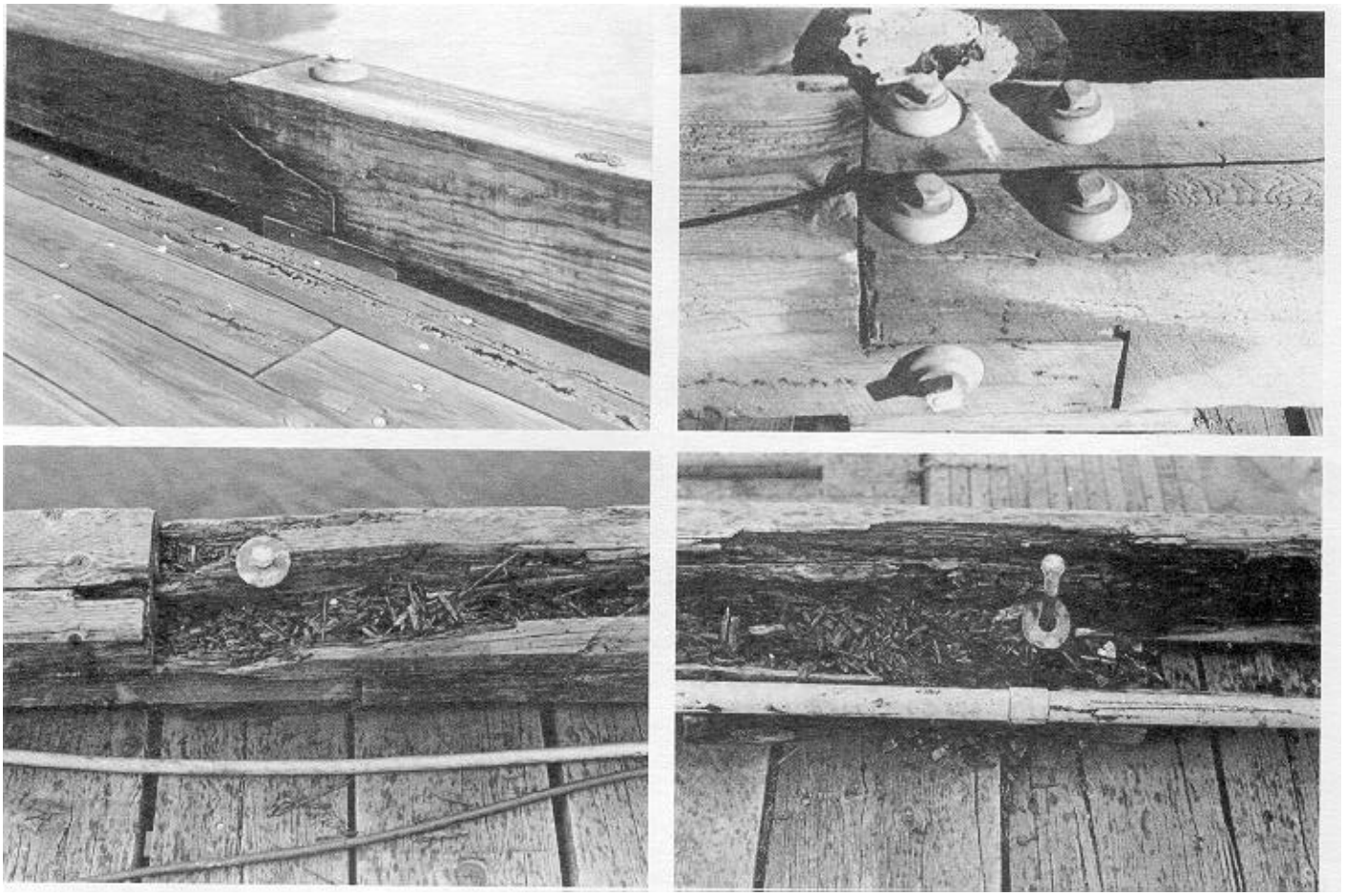

Figure 12—Half-lap-type end-joints and driftpins are prominent points of water entry into Douglas-fir curbs and whales and thus favor decay. (Upper left) Curbing fastened together with an oblique scarf joint. (Upper right) Joined curbs with two unnecessary features favoring decay: half-lap joint and four bolts used to attach curb to deck. (Lower left) Deteriorated half-lap joint between curbs. (Lower right) Rot in curb from wetting around driftpin.

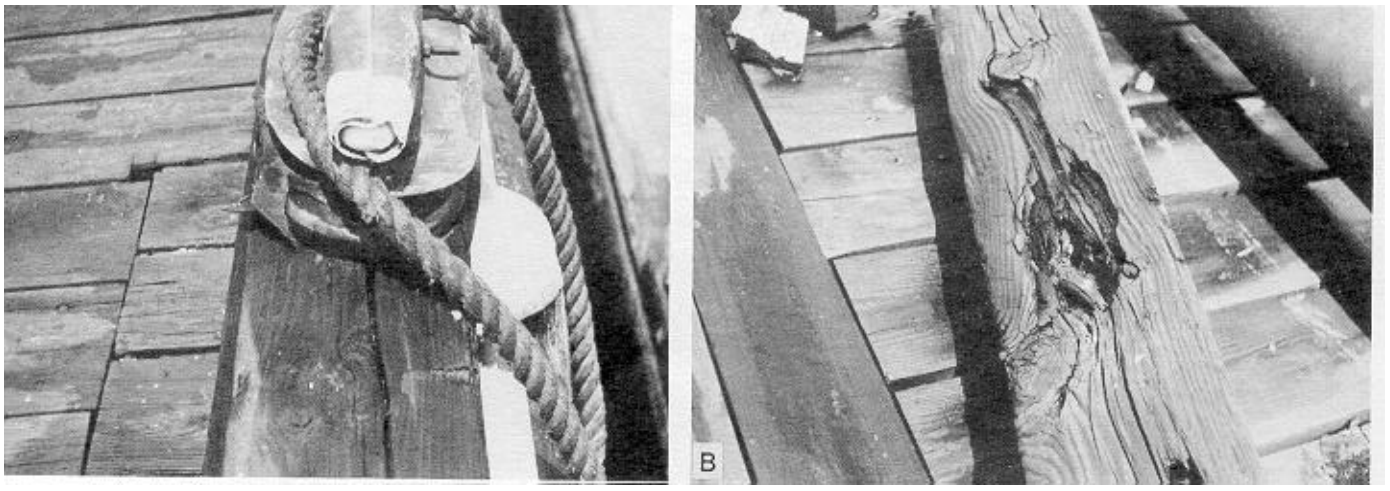

Figure 13—Curb splits caused by twisting and pulling of mooring cleats. A, Typical curb split produced by stressing of mooring cleat. B, Resultant decay.

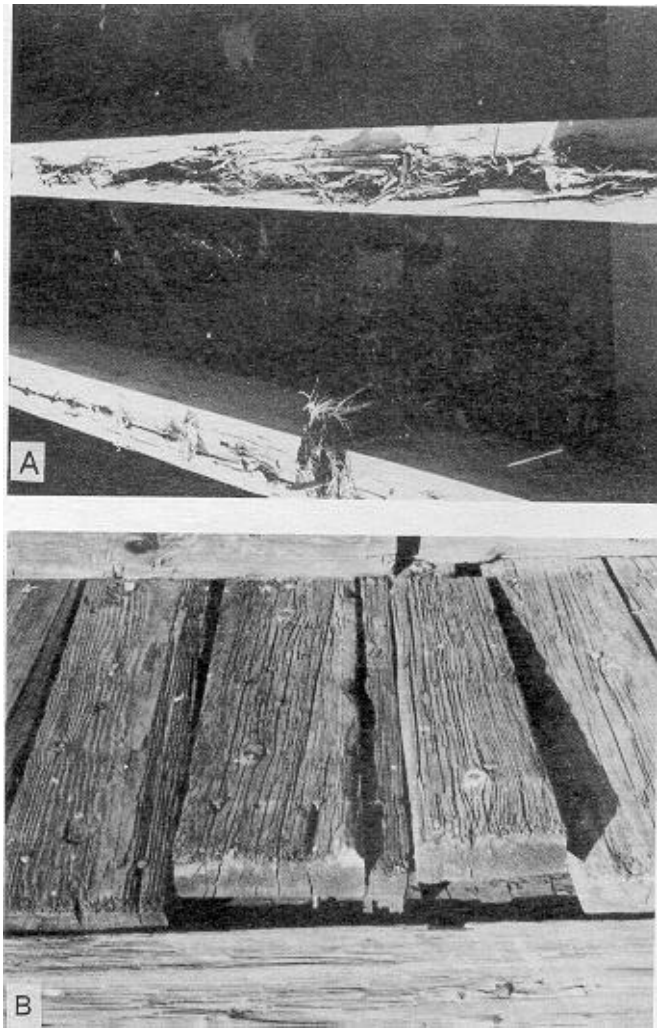

Figure 14—Typical stringer decay. A, Extensive decay in untreated Douglas-fir stringer. B, Loosening of deck planks on Douglas-fir stringers caused by rotting of wood holding stringer spikes.

Checks and Splits

Driving deck spikes directly into the wood generally causes a split in the stringer. The splits may be quite small and inconspicuous, but even so they furnish a place where water can collect. Splits are likely to be largest near the ends of the stringers. The tendency to splitting can be aggravated in two ways: by driving the spikes in line along the grain of the stringers and by using larger spikes than needed. Presumably, oversized spikes are used for convenience.

Water Entry Along Driftpins

Although holes are drilled for driftpins, thus precluding splitting of the stringer, water and fungi nevertheless can enter the stringer alongside the pin. The hole enlarges somewhat with time as the wood shrinks and swells with weather changes. This increasingly adds to the space between pier and wood, thereby creating more and more opportunity for wetting and decay deep in the stringer (around the driftpin).

Fender Piles

Premature failure of marine piling because of interior decay is a major problem, which leads to costly repairs or replacement of the wood. The U.S. Navy estimates that over $5 million a year are spent for pile replacement (personal communication, Robert Page, formerly Naval Facilities Engineering Command, 1973). The damage is particularly serious in fender piles, which are required to protect both the docking vessel and the pier or wharf from possible impact damage.

The problem is strictly one of treated piling, since untreated piles will fail from marine-borer attack before significant decay occurs. The principal woods used for fender piles are Douglas-fir and Southern Pine; oak is used in moderate quantity. Southern Pine fender piles that are treated according to recognized standards have little problem with decay; the treatment can penetrate deeply because most of the wood is sapwood (Fig. 15). Decay occurs mainly with other species, especially Douglas-fir, which have relatively narrow sapwood and therefore cannot be treated deeply (Fig. 15). Piles with narrow sapwood have an untreated heartwood center surrounded by a treated outer shell. The untreated heartwood can constitute a considerable portion of the total pile volume. Thus, the primary avenue of infection by decay fungi is through the timber ends where untreated wood is exposed after the piles are cut to desired height. Decay in Douglas-fir fender piles starts at the top and progresses downward into the central column of untreated wood. Rate of downward progress may be about 1/2 ft (15.24 cm) per year. Pile decay eventually extends to the high-water level, where water soaking of the wood inhibits further progress of the fungus. Practically all the above-water portion of the pile can become decayed on the inside without apparent decay on the exterior shell of treated wood. The resultant lack of interior strength undoubtedly is responsible for much pile breakage. Yet, this indirect but seriously damaging effect of decay seems to be largely unrecognized.

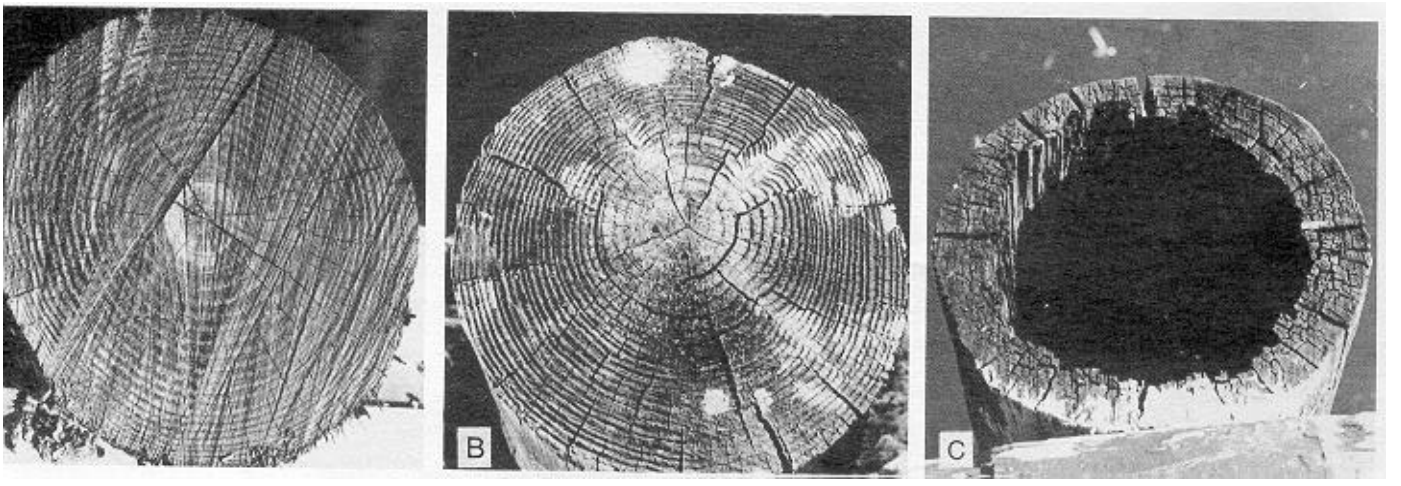

Figure 15—Effectively and ineffectively treated piling. A, Effectively treated Southern Pine piling. Little untreated wood is exposed by weathering checks, notching, or boring. B, Heavily checked Douglas-fir pile; checking developed in pile 5 years after installation. C, Typical interior rot in pressure-treated Douglas-fir pile not treated at cutoff.

Although those who maintain fender piles recognize that untreated wood exposed in cutting or boring on the construction site should be at least brush treated, they frequently do not know the limitations of this form of treatment and the need for a pile cover to supplement the preservative treatment. A cover alone is not likely to be effective (Figs. 16,17). Moreover, even those who are aware of the need for both preservative treatment and pile covers overlook certain requirements for the effective application of these protective measures. Prompt application of an appropriate preservative and cover to the cut surface can protect a pile top against decay. The treating must be done before decay gets established. Often, covers are applied without accompanying preservative treatment under the misconception that the covers will protect against rain and thus prevent sufficient moisture build-up for decay. Simply excluding rainwater from fender piles is not a dependable protection against decay. Decay fungi can get established early, and moisture already present in the pile is usually sufficient to support decay indefinitely.

Another practice that leads to fungal infection is notching of the pile to receive the ends of chocks or to accommodate planks used in constructing double-membered caps (Fig. 18). As noted with timbers, this cutting exposes untreated wood. Sometimes the fender piles are notched to receive the ends of the chocks more snugly than if they were simply butted against the pile. This practice has no real merit and therefore should be avoided, at least with Douglas-fir or oak piles, because in these species the notching generally will expose untreated wood. Moreover, the untreated pile wood cannot be protected in depth by superficial supplementary treating because the surface consists of side grain, which is penetrated only slightly by brushed or sprayed preservative solution. However, some evidence indicates that wood in joints can be adequately protected by shallow penetration of the preservative if the preservative is applied in high enough concentrations.

Decay Detection

General Inspection Procedures

Structures should be inspected routinely, and a record should be kept of the extent of decay and the kind of structural members affected by decay. Such a record is necessary for an efficient maintenance program.

The climate index map for decay hazard shows the effect of geographic location on the rate of decay (Fig. 19). The most severe location in the United States is the Southeast, where rainfall is plentiful and the weather is warm and humid. In the Northeast and Midwest, decay advances at a somewhat slower rate.

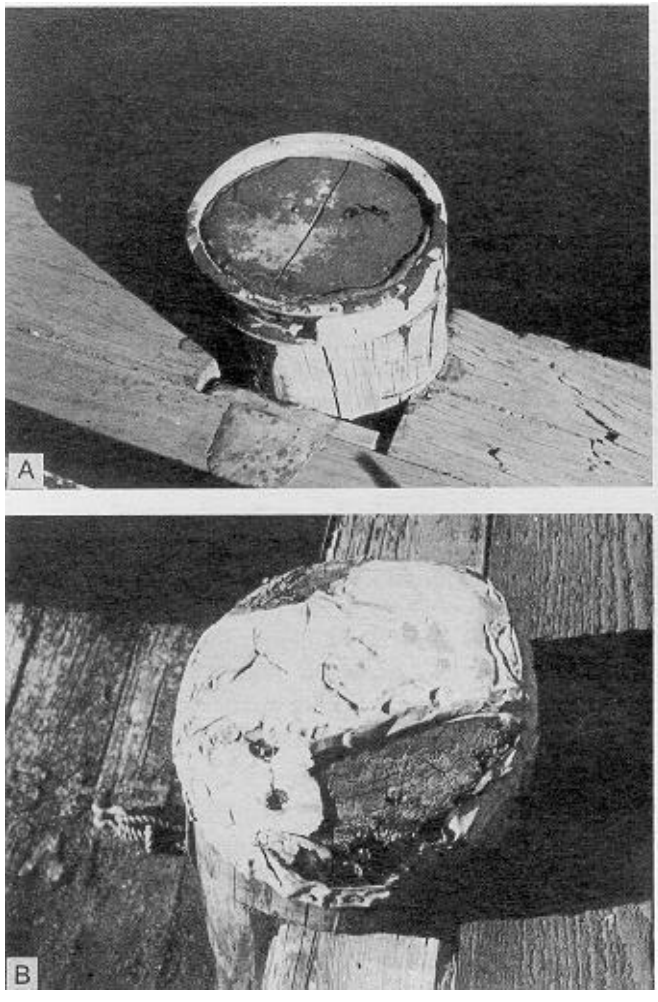

Figure 16—Covers for fender pile cutoffs. A, Pile capped with raised metal collar; hot bitumen was poured inside the collar. B, Copper cover rendered ineffective by hawser chafing and vandalism.

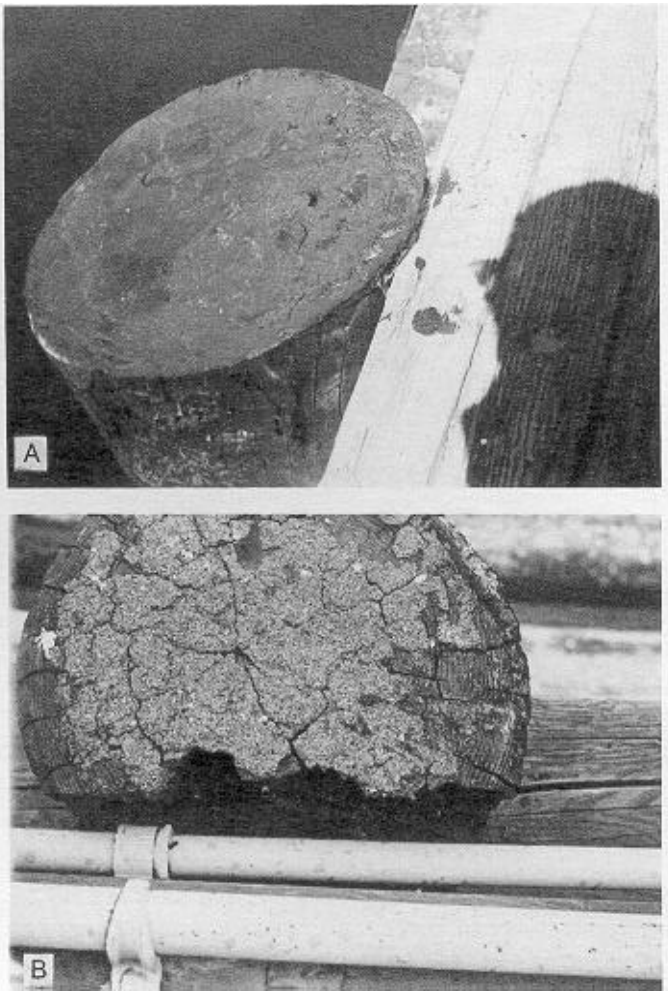

Figure 17—Bituminous coatings. A, Effective bituminous cover on Douglas-fir fender pile. B, Ineffective bituminous cover.

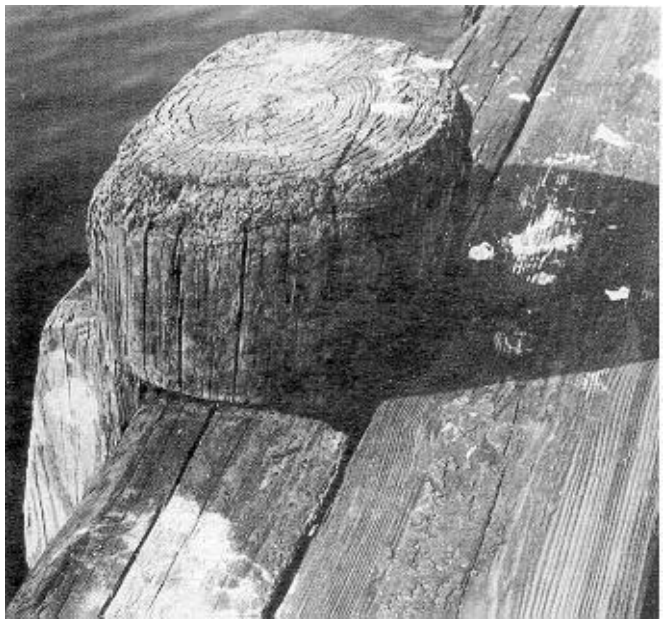

Figure 18—Piles notched to provide firmer contact between wale and pile or to provide shoulders to support clamps. This practice does not prevent decay.

Near the coast in the Northwest, decay hazard is moderate, but it can be severe on the coast. Most of the Southwest is very dry, so the decay hazard is minimal.

The inspector should formulate a general plan of procedure by collecting any drawings, specifications, and data pertinent to the service history of the items to be protected. The age, size, and design of individual waterfront structures dictate in part the inspection procedures and the equipment required for a thorough inspection. Any available records of previous inspections, damage, repair, member replacement, or structural modification should be noted with their respective dates.

The actual equipment necessary for examining waterfront structures is relatively simple. It should include hand tools for measuring, sounding, probing, drilling, and boring, and an instrument for measuring wood moisture content. A camera, ideally with flash attachment, is useful for providing a photographic record of unusual circumstances.

External Evidence of Decay

A good way to begin an inspection for decay is a visual search for decay manifestations, emphasizing locations or conditions most conducive to prolonged wetting (Fig. 20). Decay usually results in abnormal coloration of the wood. The first indication of decay is often brown streaks or blotches; purplish streaks are sometimes present (Figs. 2,3). As wood approaches advanced stages of decay, it loses luster and may exhibit pronounced changes in color. Of course, judgments based on color necessitate familiarity with the appearance of sound wood. Sound, healthy softwood has a pleasant, fresh, resinous smell, whereas decayed wood usually has a mushroom-like, stale odor. However, a musty, moldy smell, though indicative of damage conditions favorable to decay, does not necessarily indicate the presence of decay.

The presence of fruiting bodies or "mushrooms" usually indicates that decay has become well established in the members (Fig. 21). Advanced decay is also easy to recognize from changes in the physical appearance of the wood, such as localized depressions or sunken areas over decay pockets, which reflect loss of wood substance beneath, and cracking in cubical patterns, which results from wood shrinkage. Evidence of retained moisture over a period of time, especially at the junction of timbers, often indicates fungal attack.

Inspections for decay are most critical in those situations that favor decay. For example, visual evidence of hazardous moisture conditions calls for special attention. Evidence of persistent water may appear as watermarks. Rust stains on wood surfaces may also indicate excessive wetting, particularly if the source of the iron is a wood-penetrating fastener. Appreciable growth of moss or other vegetation on wood surfaces or in checks or cracks is evidence of potentially hazardous wetting.

A small measuring tape should be available to measure the extent of decay and width or length of checks and splits. Another helpful tool is a thin ruler, or feeler gauge, to determine depth of checks or condition of fasteners at joint interfaces. A moderately pointed tool such as an ice-pick or sharp-bladed screwdriver is useful for probing suspected areas of decay.

Methods for Finding Internal Decay

Simple methods are available for inspecting waterfront structures without sophisticated tools. These methods, which include "sounding," boring, drilling, probing, and measuring moisture content, may be used singly or in combination.

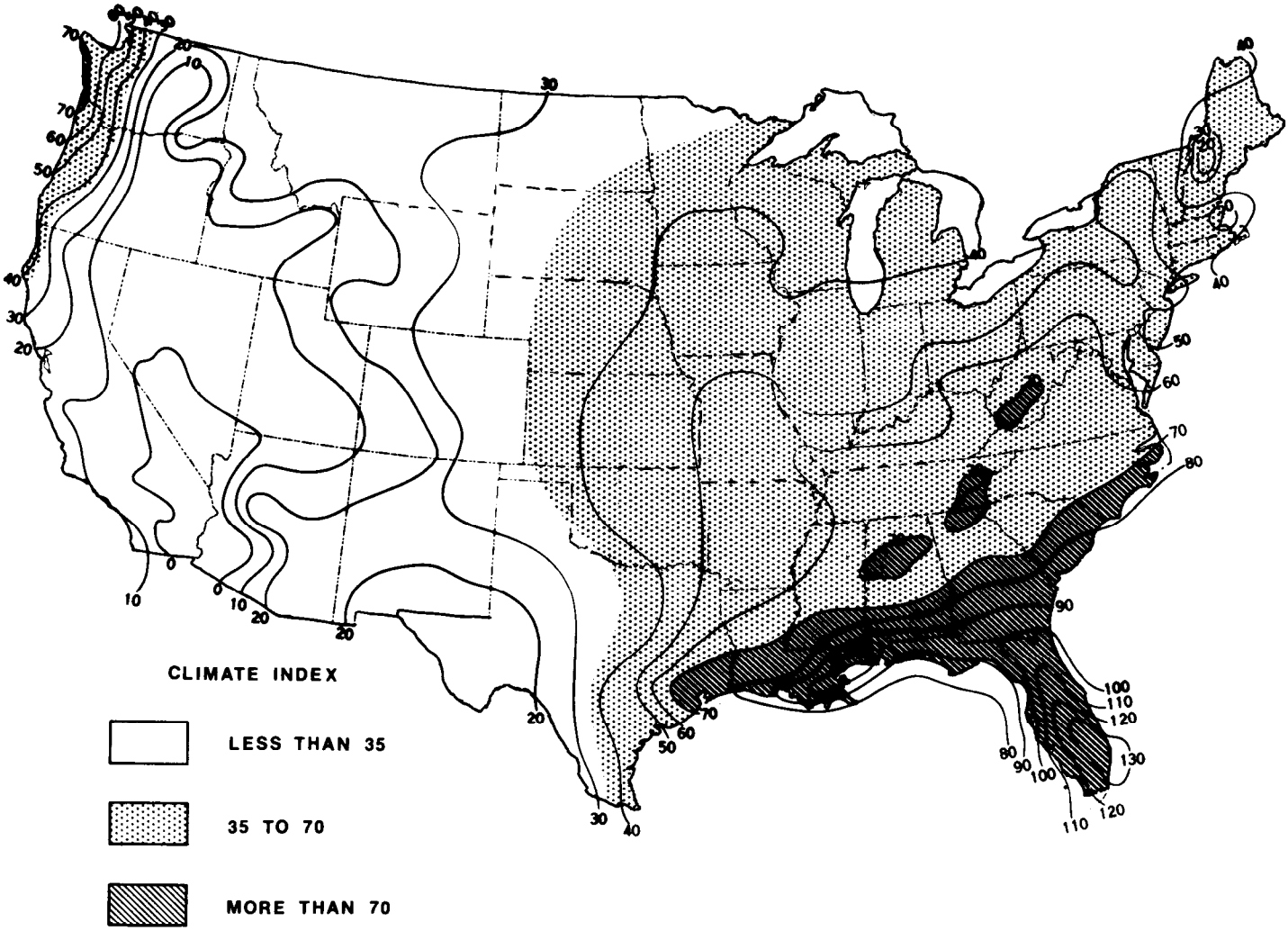

Figure 19—Climate index for decay hazard. Higher numbers indicate greater decay hazard. (M 144 642)

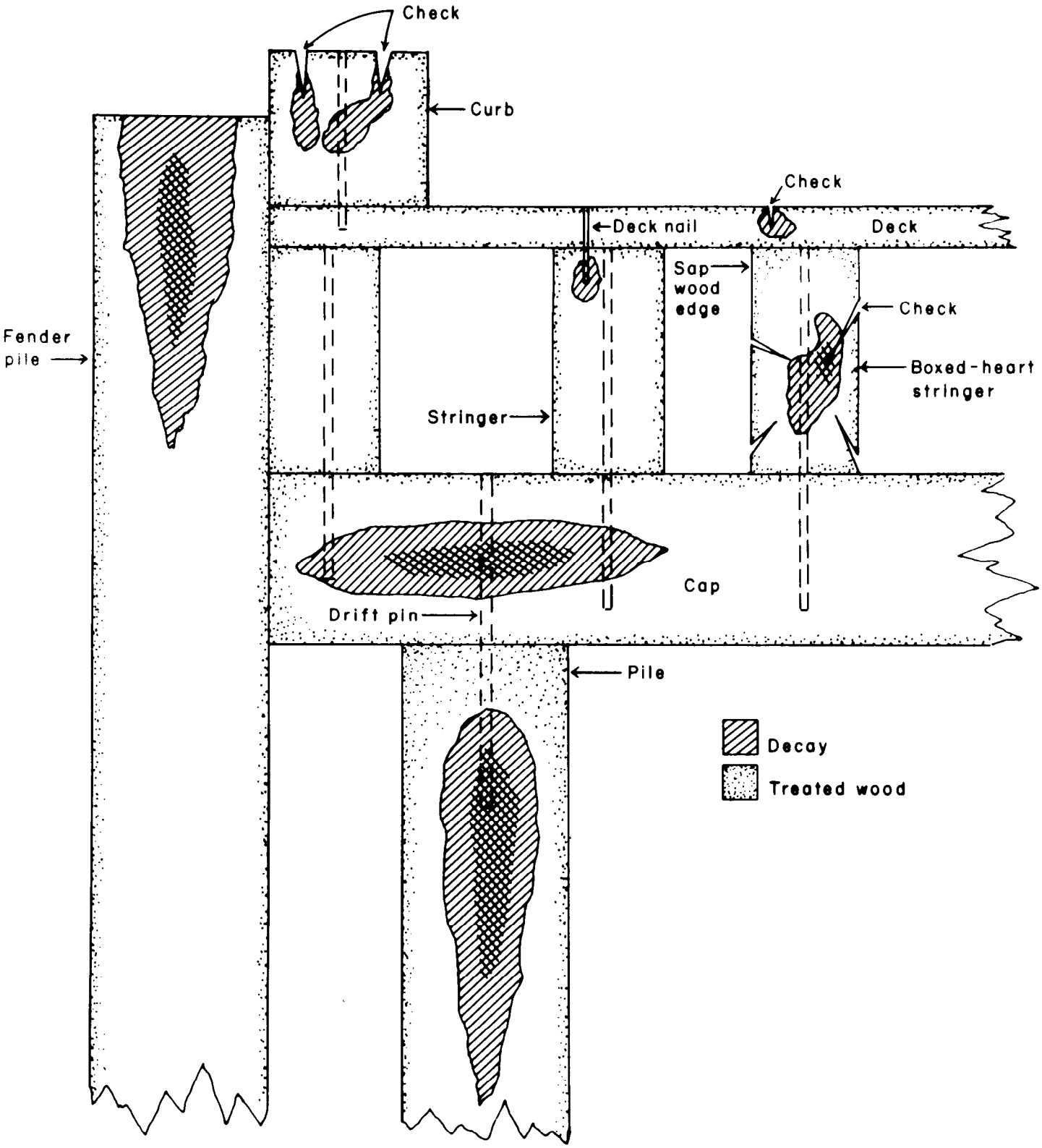

Figure 20—Schematic of typical areas of decay in decking, stringers, pile covers (caps), curbing, and piling.

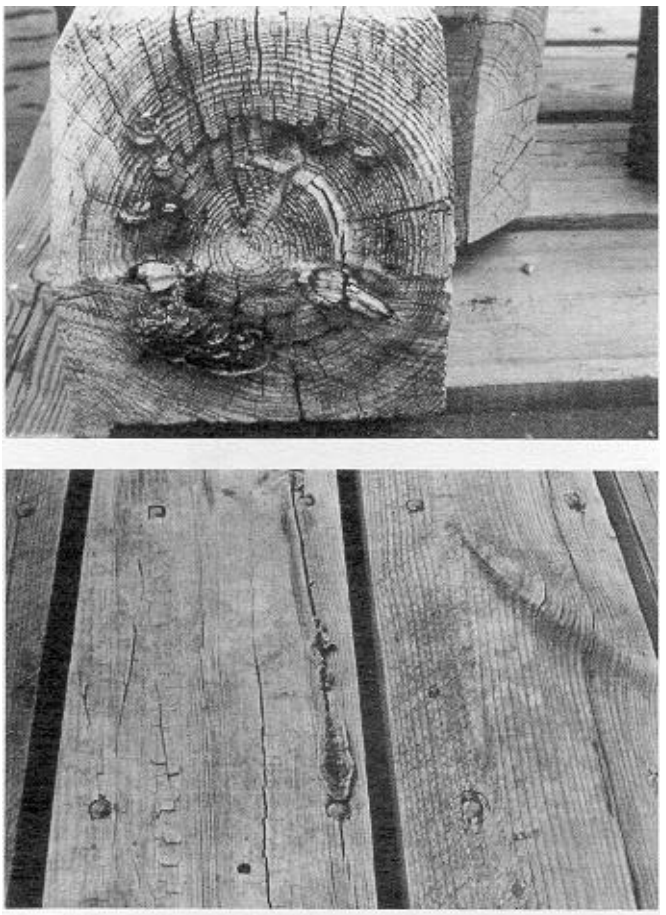

Figure 21—Decay fungal fruiting bodies in growing (fresh) condition.

Sounding

Sounding, by rapping on the member with a hammer, may indicate the presence of interior deterioration. If the hammer does not rebound or produces a dull or hollow sound, a considerable amount of the internal wood is probably decayed. This method requires considerable experience and can be considered truly diagnostic only where decay is relatively severe, where large members are decayed, and where the decay extends to areas near the surface. If sounding suggests internal decay, the wood must usually be bored to verify the diagnosis.

Boring

Boring with an increment borer is the most widely used technique for detecting internal decay. The advantage of this method is that the removed increment core provides an actual specimen in which the damage can be seen. This method should be limited to areas with conditions suitable for decay. A sharp boring bit should be used because a dull one tends to crush or break wood fibers and to change the appearance of the sample. Inspectors should carry extra drill bits; cutting edges are easily damaged beyond practical field maintenance when a bit strikes hidden fasteners. Bore holes may become avenues for decay, and so the holes should be properly treated. Following extraction of the core, a wood preservative should be squirted into the hole and the hole plugged with a preservative-treated wood dowel.

Similarly, a plug cutter can be used to examine internal wood for decay. Plug cutters of 1/8 to 1 in. (0.32 to 2.54 cm) diameter have been used. The 3/8-in. (0.96-cm) plug cutter is very popular because it is commercially available, it creates only a small hole in the member, and the samples obtained can be used in a biological assay if necessary. The holes should be filled with preservative-treated plugs. In addition, a preservative should be squirted into the holes before plugging. A saw is useful for cutting off plugs flush with the surface.

Drilling

Drilling into the member with a sharp 1/4-in. (0.63-cm) (approximate) bit can often be useful. A noticeable drop in resistance to the penetration of the drill indicates decay. Chips of decayed wood brought out by the drill tend to be darker and more easily crushed between the fingers than chips of sound wood.

Probing

Sometimes the outer surface of members consists of only a thin solid shell and the wood underneath is decayed. This condition can be detected by probing. Fungal decay causes wood to soften and lose its strength. If decay is suspected, the area should be probed with a pointed tool or a blade and the resistance of the wood compared with that of obviously sound wood. Areas where water is likely to be absorbed or trapped by wood, such as end-grain or side-grain faces adjacent to joints, should be probed. A moderately pointed tool such as an ice-pick or sharp-bladed screwdriver is useful for probing. Early decay may be detected by jabbing the probe into the wood and prying down. Sound wood, which is relatively tough, usually breaks out in long splinters, whereas decayed wood, which is brittle, breaks out abruptly across the grain in short pieces (Fig. 22).

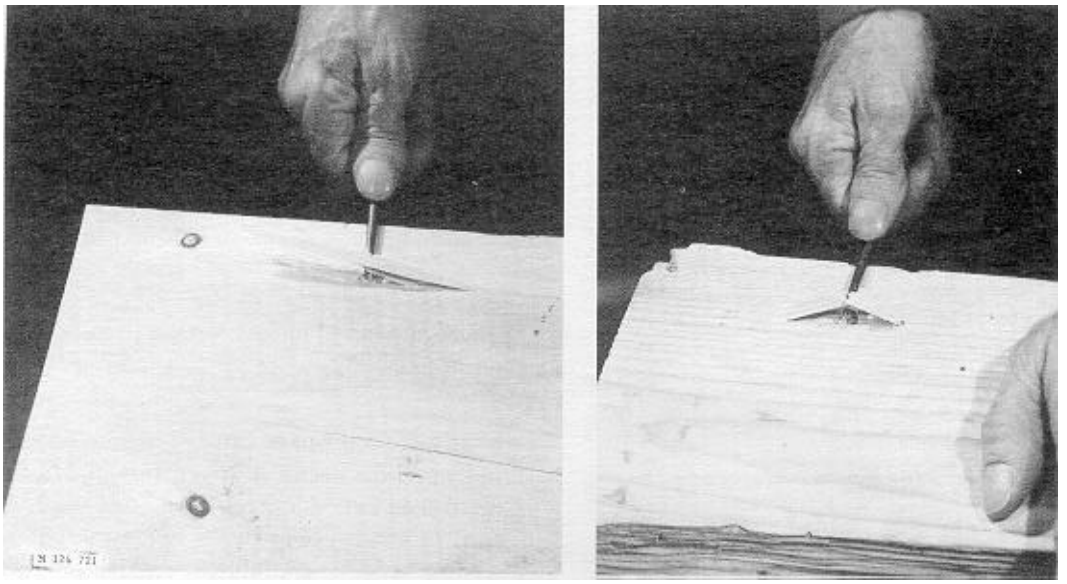

Figure 22—Probing test for early decay. (Left) Sound wood pries out as long splinters. (Right) Decayed wood breaks abruptly across grain without splintering. (M 124 721)

During inspection of wood, information about wood moisture content is often helpful. A resistance-type moisture meter is ideal for such a purpose because it is simple to use and nondestructive. A reading of >20 percent moisture content indicates that the wood is susceptible to decay.

Moisture meters employ two elongated probes or pins attached to a resistance meter. The meter is read at selected points as the pins are driven into the wood. Whether or not moisture conditions are conducive to decay can be determined by taking moisture readings at various sites with decay potential. Moisture readings above 25 percent after a few days of dry weather indicate that the wood is not safe, if untreated. Moisture meters are effective only up to a depth of 3 in. (7.62 cm), the maximum probe penetration.

For accurate readings, the meter should be frequently calibrated and the batteries should be checked to assure that the electrode coating is intact. When using the moisture meter in extreme cold or heat, the readings should be corrected for temperature and wood species. Thus, temperature should be recorded along with the meter reading. The meter manufacturer should supply the information necessary for the corrections. A moisture meter will not give correct readings in wood treated with chromated copper arsenate or ammoniacal copper arsenate or in wood that has been subject to wetting by sea water. The conductive elements in these materials cause erroneously high readings.

Sequential Process for Detecting Decay

1. Observe and record condition of wood. Initially, observe and record the general condition of piles, cross bracing, stringers, caps, curbs, wales, chocks, and decking. Probe suspicious areas for the presence of decay near the surface of timbers. Note any unusual damage, loose bolts, chafing about the waterline, deep checks, cracks, scars exposing untreated wood, and untreated cut-off tops and ends of pilings and other members. Also examine the surfaces for holes made by pointed tools, exit holes made by beetles, piles of sawdust left by carpenter ants, mud tunnels made by subterranean termites, or wings discarded by reproductive termites.

2. Sound members. Next, sound the members with a hammer, listening for an abnormal response. Suspicious areas should be bored to determine the nature of the defect. Sounding will detect only members with serious internal defects and should never be the sole method of inspection.

3. Drill members at suspicious sites. After sounding, drill or core members at sites where decay is suspected, emphasizing positions adjacent to the widest checks. Samples may be collected and submitted to a laboratory for analysis, such as culturing for decay fungi or preservative retentions. Aluminum foil, plastic bags, and glass or clear plastic vials are useful for transporting samples for further analysis.

4. Drill members at other sites. If decay is visible in the first core, drill or core the member at other sites to determine the distribution of the decay. Measure the depth of preservative treatment, depth of apparently solid wood, and size of the member. The residual strength of the member can be estimated from this information, and depending on how the structure is being used, decisions can be reached about future replacement or remedial treatments. If decay is present, remember that adjacent, apparently solid, untreated wood is probably in the early stages of decay.

5. Treat openings and plug holes. Treat all openings made during the inspection with a preservative solution or grease and plug the holes with preservative-treated dowels slightly larger in diameter than the inspection holes.

Decay Prevention

Preservative Treatment

Wood used under conditions conducive to decay requires preservative treatment for long service life. Two types of preservatives can be used: oil-type preservatives, such as creosote or petroleum solutions of pentachlorophenol, and waterborne preservatives, such as copper chrome arsenate and ammoniacal copper arsenate. In the preferred commercial treatment, the wood is impregnated with the preservative under pressure. Under some conditions of low-to-moderate decay hazard (e.g., above ground), the wood can be adequately treated by brushing, spraying, dipping, or steeping. However, once decay is established in a member, typical surface treating will not penetrate enough to eradicate the decay. In general, preservative treating is a preventive measure, not remedial. However, fungicides have been developed recently that penetrate deeply into structural timbers and eradicate internal decay. These treatments are applied as a liquid or solid in drilled holes, from which they migrate several feet (meters) as a toxic vapor.

Waterborne preservatives are desirable because they leave the wood clean, non-oily, and paintable. For waterfront members, the principal disadvantage of waterborne salt treatment, compared to the more widely used creosote or penta-oil treatments, is that it does not impart water repellency to the wood. Checking is also generally more severe in salt-treated than oil-treated timbers. On the other hand, some evidence indicates that checks created by certain waterborne treatments may facilitate the passage of fungitoxic materials.

For material of the size and thickness commonly used in waterfront construction, complete penetration of the preservative into the members is generally impractical and in some woods, impossible. Instead, most members are protected by impregnating the outer wood sufficiently to create a toxic outer barrier to fungal invasion. As long as this barrier is maintained without breaks, fungi cannot invade the untreated interior wood. The effectiveness of the preservative barrier is determined by two factors: the thickness of the treated wood shell (preservative penetration) and the quantity of preservative in the treated wood (preservative retention).

The wood of Douglas-fir trees consists mainly of heartwood, which is difficult to treat (Fig. 23). The trees have a relatively thin sapwood of which only small amounts are usually retained in heavy, solid-sawn members. Even small surface seasoning checks or small fastener penetrations, such as nails, may afford avenues for fungi to penetrate the treated zone and reach the untreated interior wood. Incising (a systematic pattern of punctures on the face-grain surfaces) is used to improve preservative penetration and retention in Douglas-fir heartwood, and it is usually specified in treating standards.

By contrast, Southern Pine members, which have a high percentage of sapwood, can usually be treated relatively easily and effectively without incising. The sapwood is readily treatable both in regard to penetration and retention of preservatives. However, the heartwood of Southern Pine, as that of Douglas-fir, is difficult to treat. The limited availability of large, solid-sawn Southern Pine timbers has resulted in the use of smaller, young-growth trees; glued-laminated members can be substituted for large members.

The moderate level of decay resistance characteristic of Douglas-fir and Southern Pine heartwood will afford some protection in above-ground exposures where infection is generally limited to spore germination and where periods of high wood moisture content are not commonly prolonged. However, much longer service life can be obtained if the heartwood is treated adequately with appropriate wood preservatives.

Maintenance Program

When tied to a competent inspection program, regular and timely maintenance is the most cost-effective

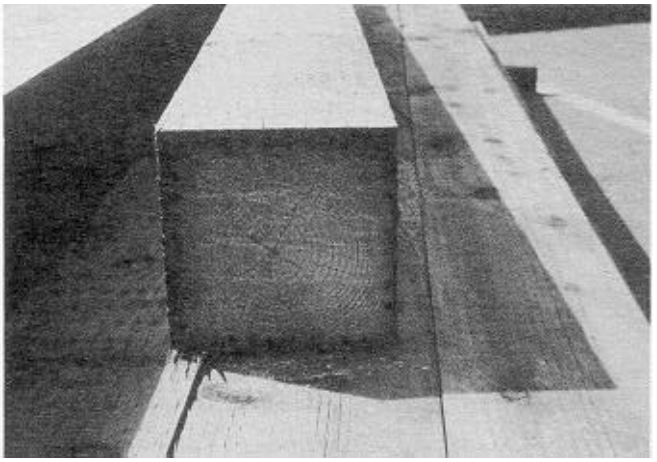

Figure 23—Cross section of incised Douglas-fir curb showing limited penetration of preservative.

approach for achieving long service life from existing structures. Unfortunately, maintenance is frequently neglected until major problems develop, which eventually require closing or replacing of the structure. When budgets are low, the first program reduced as a money-saving measure is often maintenance; ironically, reduced maintenance substantially increases costs in the long term.

Maintenance of waterfront structures is commonly defined as those activities necessary to preserve a structure and ensure the safety of users. In practice, all maintenance is either preventive or remedial. That is, it is intended to prevent a future problem or correct an existing one. Maintenance of waterfront structures may be divided into three arbitrary categories based on the severity or potential severity of decay: preventive maintenance, early remedial maintenance, and major maintenance.

Preventive maintenance involves keeping the structure in a good state of repair to reduce the probability of problems in the future. At this stage, decay or other deterioration has not started, but the conditions or potential for decay is present. Preventive maintenance for decay problems in waterfront structures has been largely neglected.

Early remedial maintenance is performed when decay or deterioration is present but does not affect the capacity or performance of the structure in normal service. At this stage, more severe structural damage is imminent unless corrective action is taken.

Major maintenance involves immediate corrective measures to restore the structure to its original capacity and condition. Deterioration has progressed to the point where major structural components have experienced moderate to severe strength loss, and repair or replacement is mandatory to maintain load capacity. At this point, preventive and remedial treatments to control decay are probably of little value. Therefore, this aspect of maintenance will not be addressed.

This section discusses several maintenance practices and methods applicable to waterfront structures. The principal aims of maintenance applied to decay problems should be both the control of established decay and the prevention of new infections. Because deficiencies can develop from many causes, each type of potential problem cannot be addressed individually. Rather, the preventive and remedial methods presented can be adapted to the specific circumstances of the structure.

Moisture Control

Moisture control can be used as an effective, simple, and economical method for reducing decay in waterfront timbers. To a large extent, moisture control involves a common sense approach of identifying areas with visible wetting or high moisture content, locating the source of water, and taking corrective action. In many cases, drainage patterns can be altered to prevent accumulation of water on decking. General cleaning of deck drains, deck, and other horizontal components can also maintain air circulation and prevent prolonged exposure to trapped moisture. When water enters through cracks or loose joints, covering with a bituminous mastic or sealer can effectively close off the location and prevent further water in-flow. Although little can be done to shield members exposed to weathering, caps or other protective devices can reduce the wetting of exposed end-grain.

Some attempts at moisture control, such as the use of roll roofing or sheet metal as water-diverting covers or caps, have not resulted in the improvement sought, and in some cases, these techniques have contributed to increased wetting. For example, roll roofing used as stringer covers under decking or as piling top covers under caps may initially reduce wetting; however, as the material ages and is used repeatedly, it becomes permeable to water. In either new or old condition, such material will inhibit the drying of any covered wood that was initially wet or that has become wet.

Another example of faulty pile-top shielding is the use of sheet metal inserts between bearing-pile tops and

caps. The metal is usually installed over the pile before the cap is placed in position. The drift pin depresses the sheet metal slightly as it is driven through the cap and into the piling and also creates a less-than-watertight hole in the metal. This results in a funneling of capillary water in the metal-to-cap interface to the piling wood around the driftpin hole. Nails through the metal into the pile top function in the same way.

Similarly, metal caps on fender piles are generally ineffective; they invariably rupture because of mooring hausers, vandals, or other causes (Fig. 16). Water trapped under the covering is slow to evaporate and adds to the decay hazard.

Bituminous or asphaltic mastics used as sealants or bedding compounds appear to be most effective for preventing wetting in cracks and joints and through wood end-grain (Fig. 17). As tightly adhering coatings, these mastics eliminate troublesome capillary spaces common with membranes and sheet metal covers. They may be applied appropriately as end-grain coatings, joint fillers or seals, and check-filling compounds, but only if the wood is no more than moderately wet or if avenues other than those sealed are available for drying. Care must be exercised in making such repairs. In addition, the repairs must be maintained to ensure a watertight coating or the problem may be compounded by formation of water entrapment areas under the coatings.

Mastics have the advantage of lower material and installation costs than metal or membranes. Mechanically damaged or weathered and defective coatings that are exposed and accessible can be repaired simply by adding more coating material. However, such materials will probably be more appropriately applied as preventive maintenance measures rather than solutions to existing decay problems.

On structures provided with asphalt surfaces, breaks in the surface may develop in service because of deck deflections, improper bonding, or poor construction practices (Fig. 8). When such breaks occur, they should be repaired as soon as possible to prevent continued and more serious deterioration. Cracking may result from several causes but typically results from differential deck deflections at panel joints or at member ends. When cracks appear, they should be thoroughly cleaned with a stiff brush and compressed air, and filled with emulsion slurry of liquid asphalt mixed with sand. Where pavement is broken or missing, surrounding pavement should be removed to a point where surfacing is sound and the pavement is tightly bonded to the deck surface. For best results, the repaired area should be square or rectangular with vertically cut sides. After the area is cleaned, a tack coat should be applied to the deck surface and the area patched with a dense grade of asphalt compacted to the elevation of the surrounding surface.

In-Place Surface Preservative Treatment

The purpose of in-place or supplemental treatments is to prevent or arrest decay in existing structures. Such treatments can provide a safe, effective, and economical method for extending the service life of waterfront structures. In-place treatments were seldom used in the past, partly because decay was not detected until it had become visible or a member had weakened or failed to some degree. Early detection of decay by frequent and thorough inspections eliminates this problem. Two types of in-place treatment are commonly used: surface treatment and fumigants. Surface treatments are used to prevent infection of exposed wood, and fumigants are used to treat internal decay.

Although maximum protection against decay is provided by pressure treating according to American Wood-Preservers' Association standards, in-place surface treatments can reduce the incidence of decay in (1) newly installed, untreated wood, (2) untreated wood exposed by weather checks or mechanical damage in poorly pressure-treated species such as Douglas-fir, and (3) untreated wood exposed when pressure-treated wood members are cut or drilled. This type of treatment is effective when applied before decay is established. In-place surface treatment can be used for maintaining structures because of its ease of application and effectiveness as a toxic barrier to new infection. However, the shallow penetration of surface treatments limits their effectiveness for established internal decay; in these cases, fumigants are much more effective in arresting decay. Such treatments are not intended to substitute for pressure treatment of new wood.

In-place preservative treatments consist of various liquid or heavier grease-type preservative compounds. The wood surface should be thoroughly saturated with preservative so that all cracks and creases are treated; however, care must be exercised not to apply excessive amounts that spill or run off the surface. The effectiveness of surface treating depends on the thoroughness of application, wood species, and moisture content of the wood at the time of treatment. Wet wood absorbs less preservative than dry wood during brush or spray

treatments. This factor is significant in waterfront structures because many areas that require treatment are subject to wetting. Field tests show that surface treatments in above-ground locations can effectively prevent decay for at least 20 years. For waterfront applications, treatments should be systematically reapplied at intervals of 5 to 10 years to ensure adequate protection from decay.

Decks

Surface treatment can substantially protect untreated Douglas-fir decks but not Southern Pine decks. Douglas-fir lumber is largely heartwood and has higher natural durability than Southern Pine, which is mostly sapwood. In research tests, Douglas-fir decking was kept essentially free of decay in Mississippi for as long as 19 years by flooding the upper surface with fluor-chrome-arsenic-phenol (FCAP) or pentachlorophenol two or more times using a small pressure sprayer (Table 1). Although pentachlorophenol was not effective on Southern Pine decks, FCAP provided almost as much protection for the wood as it did for Douglas-fir. Unlike pentachlorophenol, which diffuses little after penetration, water-soluble FCAP moves into checks as they open, thereby protecting the wood below the surface.

Supplemental treatment of decking would ordinarily not be warranted if the wood were pressure treated. In Southern Pine, weather checks rarely expose untreated wood; in pressure-treated Douglas-fir, weather checks do expose untreated wood, but decay in checks is seldom a problem. The durability of Douglas-fir can be attributed to the natural decay resistance of the heartwood and rapid drying of the shallow checks. Leaching of preservative into the checks may also contribute to durability.

Table 1—Decay of surface-treated Douglas-fir and Southern Pine decks after 19 years of exposure in Mississippi

Wood and treating solution[a]	Treatment time (year)	Number of units	Units in decay class (no.)[b] 0	40	60	80	100	Average rating
Douglas-fir								
Sodium penta, 5%	2-9	15	15	0	0	0	0	0
	2,6	10	3	3	1	0	3	48
Sodium penta, 5% + WR	2-9	15	15	0	0	0	0	0
	2,6	10	6	4	0	0	0	16
Penta in mineral spirits, 5% + WR	2-9	15	15	0	0	0	0	0
	2,6	10	8	0	2	0	0	12
FCAP, 4%	2-9	15	15	0	0	0	0	0
	2,6	10	8	0	2	0	0	12
(Control)		25	0	0	0	0	25	100
Southern Pine[c]								
Sodium penta, 5%	2-9	25	0	0	0	0	25	100
Sodium penta + WR	2-9	25	0	0	0	0	25	100
FCAP, 4%	2-9	15	15	0	0	0	0	0
	2,6	10	4	2	2	2	2	56
(Control)		25	0	0	0	0	25	100

[a] Penta, pentachlorophenol; WR, water repellent; FCAP, fluor-chrome-arsenic-phenol.

[b] Decay rated from 0 to 100. A rating of 80 indicates sufficient decay to warrant deck plank replacement.

[c] Penta-treated and untreated Southern Pine deck planks failed by year 7.

Curbs, Chocks, and Wales

Checks play an important role in the development of decay in large pressure-treated Douglas-fir timbers such as curbs, chocks, and wales. Decay may differ markedly in checks of Douglas-fir curbs pressure treated with pentachlorophenol or creosote compared to curbs treated with FCAP. In research tests, curbs treated with pentachlorophenol or creosote were decayed at the base of deep checks after 4 and 10 years, respectively. In contrast, curbs treated with FCAP showed no decay after 17 years. Thus, the service life of creosote- and pentachlorophenol-treated curbs with deep checks may not be much longer than that of untreated curbs. Although creosote curbs without checking have been reported to be free of decay for as long as 25 years, the lack of checking in these instances has not been explained.

The absence of decay in FCAP-treated Douglas-fir curbs with deep checks suggests a unique ability of FCAP to protect untreated, interior wood exposed by deep checks when the wood is not in contact with soil. One or more constituent chemicals apparently leach from treated to untreated wood in amounts sufficient to prevent infection by fungal spores. The outer surfaces of the wood are not decayed, indicating that sufficient preservative remains to protect these areas.

For curbs with deep checks, liberal application of preservative with a brush can provide protection to untreated wood at the base of checks. However, treatment will be successful only if the preservative is in the checks before fungal infection occurs. Moreover, treatment may need to be repeated occasionally as long as the checks deepen.

Piles

Premature failure of marine piling because of internal decay is a major problem, leading to costly repair and replacement of the wood. The damage is particularly serious in fender piles, which protect both the docking vessel and the pier or wharf from possible impact damage. In addition to preservative treatment, the decay hazard can be minimized by separating curbs and wales from the deck by filler blocks. The blocks prevent the large water-trapping zone created when timbers are in direct contact with the deck (Fig. 12).

For pile tops, most fungicidal treatments in combination with an intact cap will offer long-term protection against decay. The fungicide and cap must be applied immediately after the piles are cut off. If treatment is delayed, decay may penetrate deep into the piling, and the fungicide will not be effective.

Pile-capping materials should be chosen for ease of application, long-term flexibility, cleanliness after setting, and reasonable wear under docking stresses (e.g., hawser scrapings). Pile caps are commonly made from epoxy compounds, galvanized metal, bituminous compounds, roofing felt, heavy plastic, and fiberglass mesh cloth in combination with a bituminous material (Fig. 16,17). Galvanized metal, roofing felts, and plastic sheets are not recommended for capping materials because condensation or leaks can create ideal conditions for decay beneath the cap. Epoxy compounds fail as moisture barriers because their inflexibility results in early cracking of the caps. Moreover, epoxy compounds are costly and difficult to apply (must be applied in a two-component system). Bituminous compounds have proved best as capping materials because of their low cost and ease of application and repair.

Because pile caps on working piers are often damaged or pulled off by hawsers, the pile top should be treated by flooding with a preservative before capping. A waterborne preservative, such as ammonium bifluoride or FCAP, is apparently the most effective. These chemicals remain inactive as long as the cap remains sound, but they are activated in the presence of moisture. The preservative can also provide protection even when the pile cap remains intact. By penetrating the wood, the preservative can eliminate shallow decay below the surface caused by delay in covering the pile top.

Grease-type preservatives troweled onto the pile cutoff are also effective in preventing decay. The piling need not be capped. However, such preservatives would not be desirable in many situations because the slick pile top could result in accidents from slippage. The ease of application and cleanliness of waterborne preservatives make them preferable to oil-type preservatives.

Remedial Measures

Replacement

A member may need to be replaced when its residual strength is found to be inadequate. Two aspects of replacement deserve consideration. If extended service is anticipated, the replacement member should be pressure treated with an appropriate preservative and any

untreated wood exposed by cutting or boring thoroughly surface-treated. Because the removed member had decayed when exposed to the existing conditions, all members adjacent to the removed member should be checked for possible decay. Whether decay is suspected or confirmed, the in-place members should be copiously flooded with preservative before the new member is installed.

For practicality, only the defective part of a member may sometimes be removed and replaced. In such cases, the described recommendations for treatment of the replacement member apply. If the wetting that caused decay cannot be prevented, an adequate length of the defective material must be removed to ensure that the infected wood has been removed. Fungal infection may extend several inches in the grain direction beyond the visible limits of the decay. A rule of thumb in removing decayed parts of members is to include the visible decay plus an additional 2 ft (0.60 m) of adjacent wood in the grain direction. The newly exposed, cutoff face of the old member as well as the replacement member should be treated with preservative in place.

Reinforcement

When replacing a decayed member or part of a member is impractical (the replacement member cannot be easily fitted into the structure), a sister member or reinforcing element may be used to establish the needed load-carrying capacity. Where feasible, the old member or its defective part should be removed as a guard against spread of the decay into the new, contacting members.

As with replacement members, reinforcing members should be pressure treated, and any wood exposed by cutting or boring should be surface treated.

Fumigant Treatment

Despite pressure treatment with a preservative, large timbers such as curbs, chocks, and wales can develop internal decay through deep checks that penetrate the treated shell; decay can also enter piles through cutoff ends (Figs. 11,15). The problem is most serious with shallow-treated species such as Douglas-fir. Preservatives applied by ordinary flooding from a brush or spray only slightly penetrate the wood and so cannot stop decay.

Fortunately, a type of preservative has been developed that can move through and permeate wood that cannot be conventionally treated. The chemical, which migrates as a gas and is called a fumigant, offers a widely useful means for eliminating deep-seated decay. Fumigants can effectively supplement conventional preservatives because they can be introduced at the treatment plant.

Fumigants are applied in liquid or solid form in predrilled holes; they then volatilize into a toxic gas that moves through the wood, eliminating decay fungi and insects. Fumigants can diffuse in the direction of the wood grain for over 8 ft (2.4 m) from point of application in poles. Commonly used liquid fumigants are Vapam (33 percent sodium N-methyldithiocarbiamate), Vorlex (20 percent methlisothiocyanate, 80 percent C-3 hydrocarbons), and chloropicrin (trichloro-nitromethane). All three are registered with the Environmental Protection Agency for application to wood products. Solid chloropicrin and 100 percent methylisothiocyanate (MIT) are available in capsules or glass tubes. Solid fumigants provide increased protection against decay, reduce risk of environmental contamination, and can be used in previously restricted applications.

Like nearly all other pesticides and preservatives, fumigants are toxic to humans and must be handled properly. They should be handled by only trained personnel who fully understand necessary precautions and should be applied in accordance with State and Federal laws.

To be most effective, a fumigant should be applied at locations where it will not leak away or be lost by diffusion to the atmosphere. When fumigants are applied, the timbers should be inspected thoroughly to determine an optimal drilling pattern that avoids metal fasteners, seasoning checks, and severely rotted wood.

In vertical members such as piles, holes to receive liquid fumigant should be drilled at a steep angle (145° to 60°) downward toward the center of the member, avoiding crossing of seasoning checks. The holes should be no more than 4 ft (1.22 m) apart and arranged in a spiral pattern. With horizontal timbers, the holes can be drilled straight down or slanted; slanting is generally preferable because it prevents a larger surface area in the holes for escape of fumigant. As a rule, the holes should be extended to within about 2 in. (5.08 cm) of the bottom of the timber. If strength is not jeopardized, holes can be drilled in a cluster or in

pairs to accommodate the required amount of preservative. If large seasoning checks are present, the holes should be drilled on each side of the member to provide better distribution of fumigant (Fig. 24). Here also, treatment holes should be no more than 4 ft (1.22 m) apart. If fumigant leaks from a hole, the hole should be plugged; another hole should be drilled into sound wood or away from the check, if a check is the problem. As soon as the fumigant is injected, the hole should be plugged with a tight-fitting treated wood dowel, driven slowly to avoid splitting the wood. For liquid fumigants, sufficient room must remain in the treating hole so the plug can be driven without squirting the chemical out of the hole. The amount of fumigant needed and the size and number of treating holes required depend on timber size. Liquid fumigants can be applied from l-pint (0.53-1) polyethylene squeeze bottles, transferring the liquid from 5-gallon (21.1-1) stock containers to the bottles by suitably arranged tubing. Stock solution in a cylinder is sometimes dispersed to the wood directly from the cylinder. Licensed commercial fumigant treaters, following these guidelines, can be helpful in seeing that the fumigants are introduced appropriately and safely. A list of such treaters is available from the USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, and the Forest Research Laboratory, Oregon State University, Corvallis, Oregon.

Fumigants will eventually diffuse out of the wood, allowing decay fungi to recolonize. In ongoing trials on utility poles, Vorlex and chloropicrin have remained effective for as long as 15 years; duration of protection by Vapam has been somewhat less. In creosoted waterfront curbing, chloropicrin remained effective for at least 10 years whereas Vapam-treated timbers needed retreatment in about 5 years. Shorter periods of protection can be expected if the fumigants are injected close to fastener holes, splits, checks, or end grain, where the chemical can be more easily lost by diffusion to the atmosphere. When inspections detect the presence of active fungi, protection by the fumigant has declined sufficiently to warrant retreatment. One attraction of fumigant treating is that the wood can be retreated at periodical intervals in the same holes used for the initial treatment. The old plug is drilled or pulled, the new fumigant is added, and the hole is replugged with a new treated dowel.

Precautions

All wood preservatives and fumigants are toxic to humans. Therefore, special care is needed for in-place treatment and the products must be used in accordance with State and Federal laws. Environmental and health hazards are minimal when treatments are applied properly. The potential for environmental damage is higher in field locations because of variable conditions and the proximity to streams and other water sources. In-place treatments must be applied only by trained and licensed personnel who fully understand how to apply the treatments and what safeguards to employ. Those responsible for in-place treating should observe the following precautions.

1. Avoid breathing preservative dusts or sprays, and avoid bodily contact with preservative.

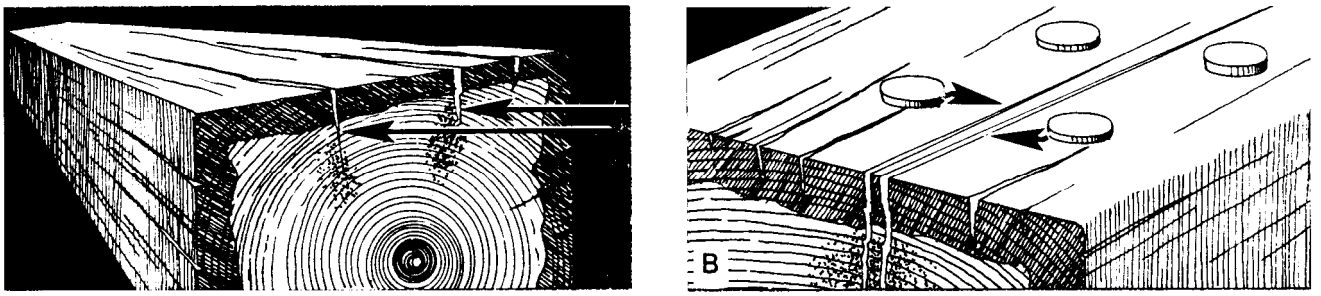

Figure 24—Deep seasoning checks can penetrate the shell of large pressure-treated exterior timbers. A, Internal decay caused by water trapped in checks. B, Plugged holes in timbers. Fumigant applied through holes stopped internal decay. Note that treating holes are located on both sides of deep checks.

2. Wear protective gloves and aprons when treating lumber or when handling lumber wet with treating solution.

3. Wash inside of gloves with water frequently.

4. Wash hands and other skin areas wetted by preservative with soap and water immediately.

5. Watch for special sensitivity to preservative, especially in persons using the preservative for the first time. Those who showing skin sensitivity should discontinue using the preservative.

6. Have a respirator or gas mask available when applying fumigants under adverse weather conditions.

In general, in-place treatment by local maintenance crews is limited by the scope of the treatment required. For routine maintenance, the amount of treatment required is usually minor, and local crews can be used when properly trained and licensed. For larger projects involving many timber members or an entire structure, the project should be contracted to licensed specialists in the field. Some companies have provided in-place treating services for many years and have excellent safety records. When selecting a contractor, records of previous experience and performance history should be carefully evaluated to ensure that the contractor is qualified for the job. Assistance in locating contractors may be obtained from treating organizations or from chemical manufacturers.

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