Wooden Artifacts in Cemeteries: A Reference Manual

by

Anthony & Associates, Inc.
P.O. Box 271400
Fort Collins, Colorado 80527

for

The Historic Preservation Commission
City of Aspen, Colorado

and

The National Center for Technology and Training
645 University Parkway
Natchitoches, Louisiana 71457

NCPTT Grant No. MT-2210-07-NC-04

September 2008

Acknowledgements

Anthony and Associates Inc. would like to thank the many people who were willing to volunteer their time and knowledge for the completion of this project. In particular, we would like to thank Dean Reudrich with Historic North Carolina, Patricia Suggs of the Beaufort Historical Association, Kathy Stockton of the City of Cripple Creek's Historic Preservation and Planning Department, Steve White and Art Tremayne of the Cripple Creek Maintenance Department, Nancy McDonald, a Cripple Creek Historic Preservation Commissioner, and Amy Guthrie and Sara Adams of the Historic Preservation Commission for the City of Aspen, Colorado. We also acknowledge the financial support of the National Center for Technology and Training that made this work possible.

Ronald W. Anthony, Wood Scientist, Anthony & Associates, Inc.
Kimberly D. Dugan, Preservation Specialist, Anthony & Associates, Inc.

September 10, 2008

Table of Contents

Introduction: Saving Wooden Artifacts in Cemeteries

This project is about saving historic wooden artifacts in cemeteries. Cemeteries are important repositories of local and national history, valued not only for the stories they tell, but also for their emotional and civic connections. Cemeteries in the United States range from large, well-funded and well-maintained historic sacred grounds to forgotten, or nearly forgotten, patches in the rural landscape. In all these locations, monuments and other artifacts are constantly under assault from the forces of sun, wind, rain, snow, ground water, pollution and vandalism. For cemetery stewards, this constant assault creates a tremendous challenge – to forestall the deterioration of irreplaceable civic and personal historic resources.

To aid cemetery stewards, whether paid or volunteer, numerous references on the weathering and maintenance of stone and metal artifacts exist (e.g. Winkler, 1986; Matero, Curtis, Hinchman and Peters 2002). However, wooden artifacts, such as grave markers and enclosures, present a particularly dire problem. Not only do they deteriorate more rapidly than stone or metal artifacts, there is very little information available to aid the cemetery steward or conservator in making informed treatment decisions. Further, these wooden artifacts are often found in the smaller, rural cemeteries that are cared for by volunteer stewards with little technical training. Even when under the care of a conservator, deteriorated wood is often simply replaced with new wood (Paine, 1983).

The wooden grave markers and enclosures created by early pioneers or less affluent families without access to long-lasting monuments are in danger of being lost to the effects of time. We need better means to protect these cultural resources. This document fills the current void – the lack of easily accessible information on the conditions and conservation of wooden artifacts in cemeteries. Additionally, this document identifies the research priorities necessary to develop state-of-the-art methodologies and technologies for cemetery conservation.

Mechanisms of Wood Deterioration

Weathering

Weathering of wood is the result of the action of cyclic wetting and drying, exposure to ultraviolet (UV) light and erosion of the wood through wind-blown debris (a process similar to sand blasting). Weathering is a long-term process and is a significant factor in the deterioration of wooden-artifact components, often resulting in the loss of lettering on grave markers. The weathering process changes the appearance of wood exposed to the elements but the process is slow enough that collapse of a wood member due to decay or insect attack generally occurs long before weathering becomes a major factor in the wood failure. We typically think of weathered wood as aesthetically pleasing because, unlike decay or insect attack, it seldom damages the wood enough to require replacement.

Weathering is often the primary mode of deterioration of wooden artifacts in cemeteries because wood in cemeteries is typically exposed to precipitation and direct ultraviolet light. Weathering is readily apparent from the grey and brown surfaces of the wood and the small splits that develop during the weathering process.

Figure 1. A grave marker with the gray wood typical from UV exposure and weathering-caused cracks and checks that allow moisture penetration.

Figure 2. The top of a grave enclosure corner post showing splits developing from cyclic moisture or freeze/thaw episodes.

As noted above, the weathering process consists of cyclic moisture and associated shrinkage and swelling of the wood, coupled with exposure to high ultraviolet light and erosion of the wood by wind-blown debris. Initially, the wood grays or darkens and small seasoning checks and splits begin to develop on the wood surface that allow for moisture penetration. These turn into longer splits due to cyclic wetting and drying of the wood or freeze-thaw action. As moisture is absorbed into the wood, the wood expands, generating more splits and establishing a favorable environment for active wood decay.

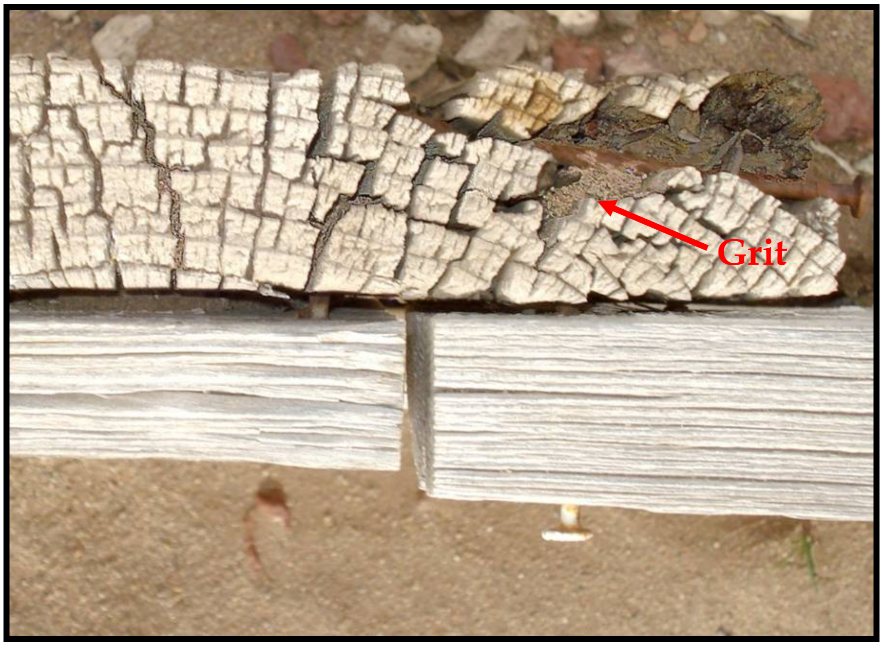

Figure 3. Detail of a grave enclosure post with weathering and sand and grit accumulating within the crevices.

In addition to the graying from UV exposure and swelling, shrinking, checking and splitting due to moisture intrusion, wind-blown debris facilitates the weathering process by continually eroding fibers on the exposed wood surface. As the weathering process continues, individual wood fibers on the surface begin to slough off the artifact. The lighter-colored earlywood in the growth rings erodes faster than the darker, denser latewood bands, resulting in a rough surface texture.

In addition to individual fibers sloughing off, small wood chips are lost as the checks and splits meet. The exfoliation of small pieces of weathered wood exposes fresh surfaces which are then exposed to the weathering process. This process is slow and varies by wood species and the amount of environmental exposure. In general, however, wooden artifacts lose up to a quarter inch of thickness per century of exposure, depending on the wood species. In addition to exposure, the weathering rate is greatly influenced by wood density, climate and soil conditions.

Figure 4. Examples of weathering ranging from some surface checking and slight discoloration (a through c) to extensive erosion of the softer earlywood (d through f).

Where moisture can penetrate the wood, shrink-swell and freeze-thaw cycles can loosen the connections to the point where gaps develop. As the gaps increase in size with cyclic moisture effects, more wood surface is exposed to ultraviolet light and contact with moisture, thereby accelerating the rate of deterioration. Decay fungi will eventually find their way into the exposed wood. Weathering of the wood over time (decades) will make it possible for decay fungi to enter the wood through the many small checks and splits. Eventually, the decay process, which is much more rapid than weathering, will become the dominant means of deterioration.

Figure 5. A small, almost unrecognizable, key-shaped foot marker with organic debris collecting within heavily weathered and insect-damaged crevices.

Figure 6. A grave enclosure corner post with debris collecting in a deteriorated area. This is an example of weathering that can lead to cavities susceptible to decay.

Moisture

Moisture is not so much a mechanism of deterioration as it is the means for forms of deterioration to develop and progress. Moisture stains are not an indication of damage to the wood but a record of the wood being exposed to water either repeatedly throughout its life or for an extended period of time. Moisture can cause nails and screws to rust, also staining the wood. As previously mentioned, moisture aids in the weathering process by causing wood to swell or shrink, generating checks and splits as the wood fibers expand or retract. Wood that is not exposed to environmental weathering or in contact with a source of moisture can remain stable for decades or centuries. Wood that reaches a moisture content of 20 percent or more is at risk for decay fungi and insect attack. Wood with a moisture content higher than 30 percent has a high probability of decay and insect infestation.

Figure 7. Stains on a grave enclosure caused by the combination of moisture and a chemical reaction between extractives in the wood and the metal fasteners.

Mold and Mildew

Molds and mildew are types of fungi that do not deteriorate wood but can cause surface discoloration. Most molds and mildews are green, orange, or black and are powdery in appearance (Levy 1979). Sapstain or bluestain fungi can penetrate deep into the wood and stain it blue, black, or gray, but similar to surface-staining molds, they do not weaken the wood. If spores are present, they can grow very quickly on moist wood or wood in very humid conditions. Since the conditions that are favorable for growth of molds and mildews are the same as for more destructive decay fungi, the wood discoloring organisms should be considered as warning signs of potential problems.

Figure 8. The back of a painted wooden grave marker with green mold growth.

Lichens and Moss

Lichens are unique organisms that can grow on wood but typically do not harm the wood fibers. Lichens are actually two, and sometimes three, types of organisms living in a symbiotic relationship. Lichen fungi generally pair with various types of algae and/or cyanobacteria to create what appears to the naked eye to be a single organism. Lichens typically follow three growth patterns. Crustose lichens have a hard, crunchy exterior and are so tightly attached to what they grow on that they can't be removed without damaging the underlying material. Foliose lichens, which are much more loosely attached to their substrate, are lobed and may appear somewhat leaf-like. Fructicose lichens are usually branched and often look like small plants growing upward or they can hang down from their locations in long strands (Desbenoit, Galin and Akkouche 2004).

Lichens grow from spores and tend to grow very slowly. They need an undisturbed surface, indirect sunlight and moisture to develop. Thus, they often grow on porous surfaces such as wood and many types of stone. The fungal components of the lichen do not parasitize living plant cells, break down wood cells or provide gateways for other pathogens to enter wood fibers (Goerig and Chatfield 2004). Lichens, therefore, should not be considered as harmful to the long-term preservation of wooden artifacts in cemeteries.

Figure 9. Lichens growing on a grave enclosure corner post.

Figure 10. Crustose lichens (orange and gold) and foliose lichens (green and purple) growing on the top rail of a grave enclosure.

Figure 11. Fructicose lichens and green mold growing on grave enclosure pickets.

Mosses are non-vascular plants that can thrive on a variety of porous, moisture retentive surfaces such as brick and wood. Mosses grow from spores that are distributed by air currents and are generally found in damp, low-light conditions. Most mosses require near-constant moisture levels to survive. Mosses do not damage wood fibers; however, the presence of moss is an indicator of a continuous high moisture environment, and the sponge-like composition of the moss plant traps moisture at the wood surface. If mosses are present on grave markers or enclosures, moisture levels are likely to be very high and decay fungi are probable. Moss is easily removed from cemetery artifacts, but mechanical removal will spread rhizomes and spores. Mosses can more effectively be controlled through decreasing the amount of available water or moisture and increasing the amount of direct sunlight.

Figure 12. Moss on a grave enclosure. Pencil is for scale.

Figure 13. A variety of lichens and moss growing on a log stump, indicating high levels of moisture and low levels of sun exposure.

Decay Fungi

All wood is subject to a variety of deterioration mechanisms, the most prominent of which is wood-decay fungi. Wood-decay fungi excrete enzymes that break down wood fibers, which can ultimately lead to the inability of the wood to perform its intended function. Most wood-decay fungi are only able to grow on wood with a moisture content greater than 20 percent and are unable to damage adjacent dry wood (Levy 1979). However, there are two types of fungi that are able to destroy dry wood by pulling water through several feet of root-like strands (called rhizomorphs) to moisten the wood enough to allow for decay processes to occur. Fortunately, these destructive dry-rot fungi are rare and found in limited geographic areas of the U.S. (Old House Web [OHW] 2008).

Figure 14. Cottony white fungal fruiting body found on a marker.

More common white-rot, soft-rot and brown-rot fungi are the typical causes of wood deterioration. Both white-rot and brown-rot fungi can produce a cottony white growth on the surface of the wood that should not be confused with non-destructive white mold or mildew. Brown-rot fungi will cause wood to darken and appear brittle and cracked. Wood affected by brown-rot fungi will ultimately shrink, twist and become dry and powdery. White rot fungi leads to fibrous, spongy wood that appears bleached or drained of color. Wood affected by white-rot begins to shrink only after advanced decay has occurred (OHW, 2008). Soft-rot fungi generally occur in wood with high water and nitrogen content and are commonly found in fence posts and other wooden artifacts that are in contact with the ground and can "recruit" nitrogen from the soil. Soft-rot acts as its name implies and destroys the structural integrity of wood by degrading the cellulose and hemicelluloses, the materials in wood that form the "skeleton".

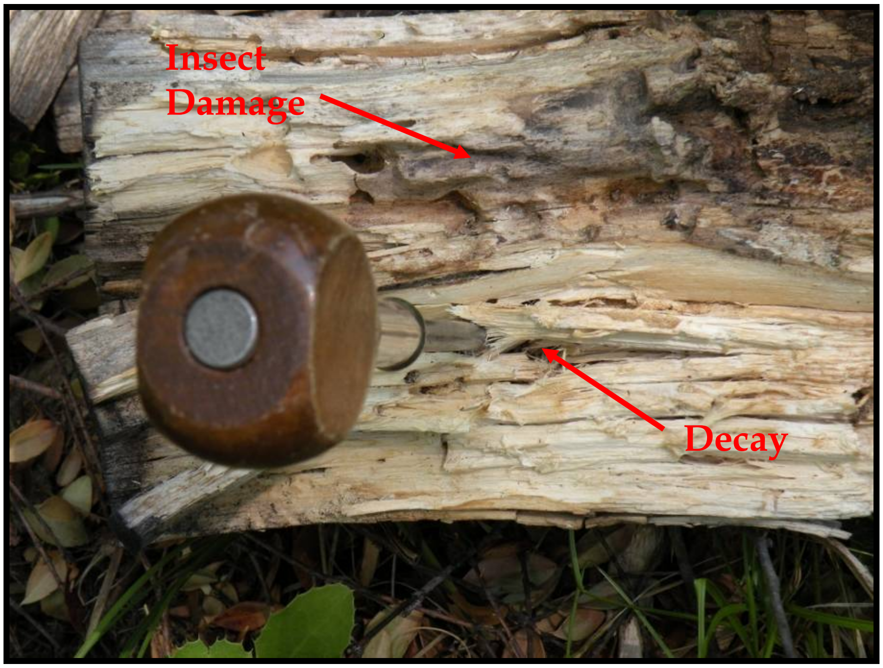

Figure 15. Example of decay (bottom half) and minor insect damage (top half) on the face of a marker at ground level. Awl illustrates ease of penetration into the decayed wood.

Figure 16. Fruiting body found in association with a decaying wooden marker. Awl is shown for scale.

Larger wood members, like corner posts of grave enclosures, depending on wood species will frequently rot on the interior with no visible sign of the deterioration. Moisture absorption though the buried end of the post, seasoning checks or drilled holes provides a highly favorable environment for decay fungi to attack the interior of the wood member. Deterioration through decay is a particular concern where the wood is in contact with the ground or other materials, such as porous stone, that may facilitate moisture absorption into the wood.

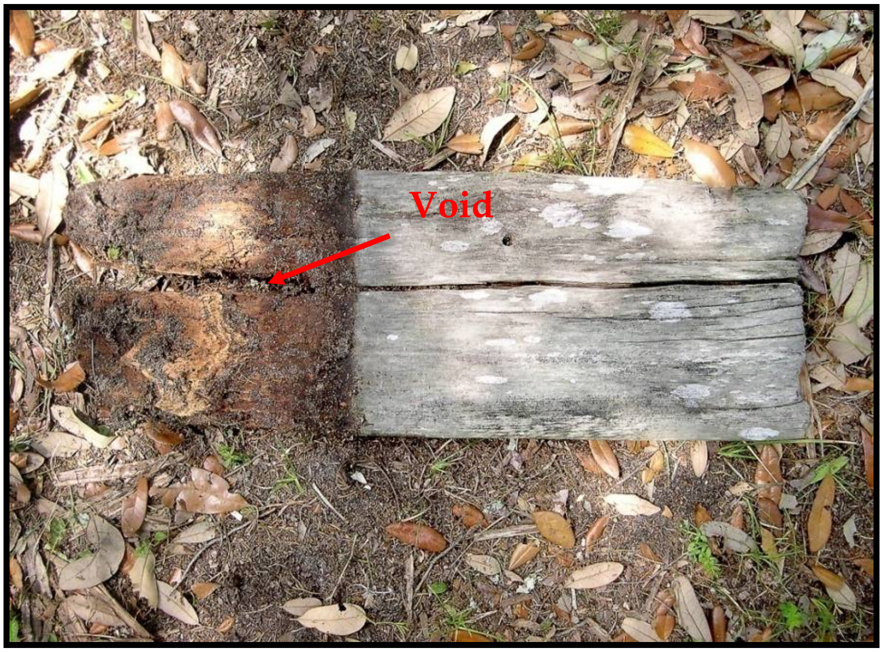

Figure 17. An example of moisture wicking along the grain of a grave marker and creating a void below ground as the decay progresses.

Decay fungi break down the wood components over time. The early stage of decay (incipient decay) is characterized by discoloration and an initial loss of integrity of the wood. No voids are present. Probing with an awl or a screwdriver may find the wood to be soft or punky. As the decay progresses, the wood integrity deteriorates until small voids develop. These small voids continue to extend primarily along the wood grain (where it is easier for moisture to move through the wood) but also progress across the grain.

Figure 18. Evidence of advanced decay – the wood is soft and easily breaks apart.

As wood weathers, the exposed end grain continues to swell and shrink as it goes through wetting and drying cycles, opening larger and larger gaps for moisture, and subsequently decay fungi, to penetrate the wood. Over time, individual boards may succumb to decay. This process will continue until the artifact, such as a grave enclosure, eventually collapses from loss of integrity of the boards.

Figure 19. A grave enclosure in partial collapse due, in part, to decay of the corner posts at ground level.

Larger voids develop where the decay started and the boundaries of the incipient decay continue to extend, reducing the integrity of the wood and, potentially, compromising the ability of the wood to provide the structural support required. Advanced decay in the wood is the result of moisture absorbed into the wood through either ground contact or small cracks and drying checks on the wood above ground.

Figure 20. A grave enclosure corner post with signs of internal decay.

Insects

With the exception of termite infestation, insect attack is generally a minor contributing factor to the deterioration of the wood. Insect attack by termites or other wood borers will reduce the cross section of a wood member by either digesting or tunneling through the wood. With decay, there is usually a gradual transition from sound wood to punky wood to a total loss of wood fiber (a void). Unlike decay, insect damage tends to have an abrupt transition between affected and unaffected areas of the wood. The mechanism of deterioration is different for insect attack but as with decay fungi, moisture is generally required and the result is a loss of integrity of the wood.

As termites are the primary cause of wood failure due to insect attack, special attention should be paid to monitor and identify potential infestation. A number of termite species can damage wood and wooden artifacts in cemeteries. These species include subterranean termites, drywood termites, and dampwood termites.

The subterranean termite is the most common insect attacker of wood. These termites require moist wood to survive and typically damage the interior core of wood members first, so an infestation often goes unnoticed. Subterranean termites tend to eat softer earlywood first, leaving latewood in ridges around their galleries. These termites often enter wood members through wood in contact with the soil, but they can survive in wood with no soil contact provided the wood remains moist.

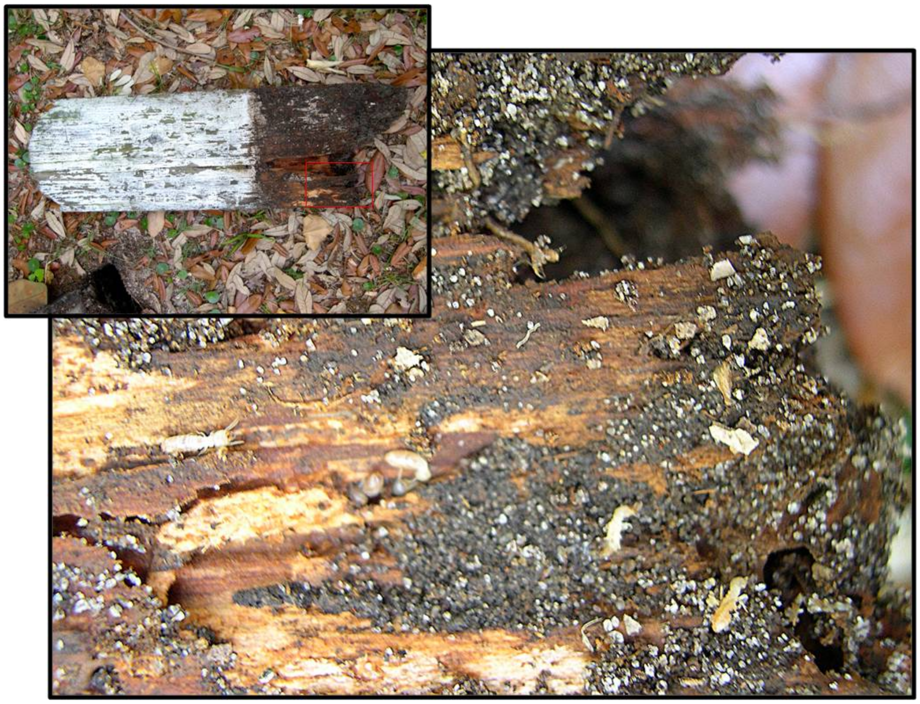

Figure 21. Subterranean termites found on the in-ground portion of a wooden grave marker.

Figure 22. Loss of wood in the underground portion of a grave marker by subterranean termites.

Drywood termites are most commonly found in the southwest and parts of southern Florida. Drywood termites require no contact with the soil or any additional source of moisture. Typically, the first sign of an infestation is fecal pellets collecting at or near the base of wood members. The fecal pellets are hard and less than 1 mm in length and vary in color from light gray or tan to very dark brown. Interior galleries tend to be broad pockets or chambers connected by smaller tunnels that cut across latewood. Irreparable damage to wooden elements can be caused by drywood termites in 2-4 years, depending on the size of the element and the size of the infestation.

Figure 23. Typical drywood termite galleries discovered after breaking through a thin shell of sound-looking wood. Note the collection of fecal pellets.

Dampwood termites are most commonly found along the Pacific Coast. Although they typically are not as destructive as subterranean termites, with ideal conditions they can cause even greater damage. Dampwood termites usually build their colonies in wood that is already in the early stages of decay. As long as the wood has a high moisture content, the colony will not require contact with the ground. In relatively sound wood, the galleries will tend to follow the softer earlywood, however, if decay is more advanced, the galleries tend to become larger and cut through harder latewood. Fecal pellets tend to be the same color as the wood being eaten and, in very damp wood, stick to the sides of the galleries.

Figure 24. Drywood termites, magnified 500%. Image from http://wwwtermitetreatment.com/.

There are several other types of wood-boring insects that can damage wood and wooden artifacts in cemeteries, such as carpenter ants, wood-boring beetles, bees, and wasps (Table 1).

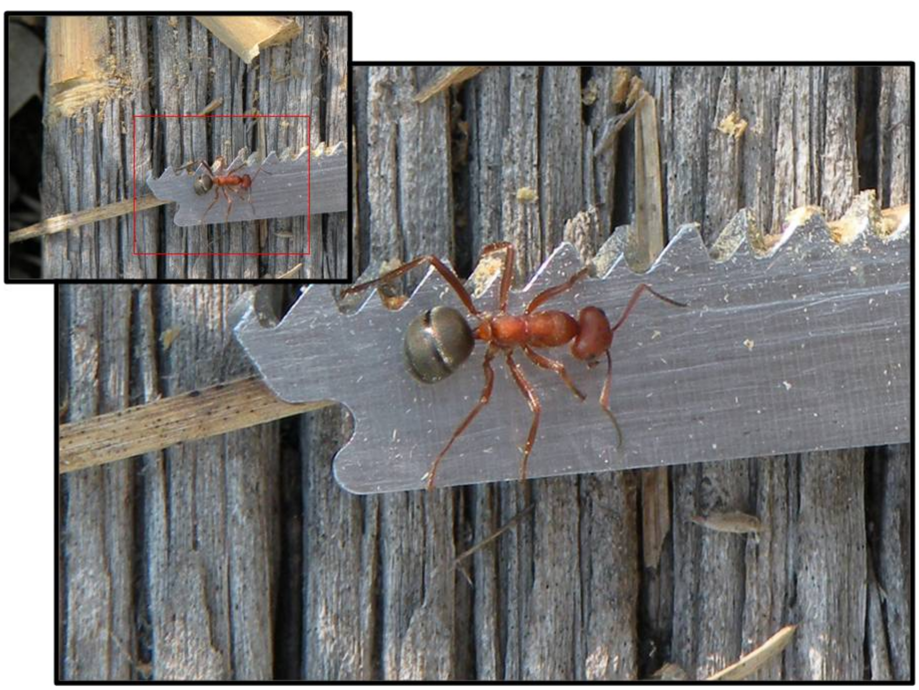

Figure 25. Detail of a carpenter ant. Carpenter ants are typically 3/8 – 1/2 inch in length.

Table 1. Identification of Common Bees, Beetles and Wasps that Attack Wood
(Table adapted from Levy 1979)

Shape and Size of Exit/Entry Hole	Wood Type	Age of Wood Attacked*	Appearance of Frass in Tunnels	Insect Type	Is Re-infestation a Concern?
Round 1/50″ – 1/8″	Softwood and Hardwood	New	None Present	Ambrosia beetles	No
Round 1/32″ – 1/16″	Hardwood	New and Old	Fine, flour-like, loosely packed	Lyctid beetles	No
Round 1/16″ – 3/32″	Bark/sapwood interface	New	Fine to coarse, bark-colored, tightly packed	Bark beetles	No
Round 1/16″ – 1/8″	Softwood and Hardwood	New and Old	Fine powder and pellets, loosely packed; pellets may be absent and frass tightly packed in some hardwoods	Anobiid beetles	Yes
Round 3/32″ – 9/32″	Softwood and hardwood (bamboo)	New	Fine to coarse powder, tightly packed	Bostrichid beetles	Rarely
Round ½″	Softwood	New and Old	None present	Carpenter bee	Yes
Round 1/6″ – ¼″	Softwood	New	Coarse, tightly packed	Horntail or woodwasp	No
Round-oval 1/8″ – 3/8″	Softwood and Hardwood	New	Coarse to fibrous, mostly absent	Round-headed borer	No
Oval 1/8″ – 1/2″	Softwood and Hardwood	New	Sawdust-like, tightly packed	Flat-headed borer	No
Oval ¼″ – 3/8″	Softwood	New and Old	Very fine powder and tiny pellets, tight	Old house borer	Yes

*New wood is defined as unseasoned wood or lumber. Old wood is seasoned or dried lumber

Unlike termites, carpenter ants do not feed on wood but rather burrow into wood to make nests. Carpenter ant infestation is most typically noticed by the presence of the large (¼ inch to ½ inch long) reddish-brown to black ants. Damage to the wood is typically in the interior, but there may be piles of fibrous, sawdust-like frass in or around checks and splits. Galleries within the wood generally follow the grain.

In general, wood that has been damaged by wood-destroying insects will have noticeable exit and entry holes. These holes tend to be round or oval and vary in size from $1/50^{th}$ of an inch to ½ inch, depending on the insect species. Often, frass (wood powder) and fecal pellets can be seen near or within the holes. The table above provides introductory information on how to identify insects based on the entry and exit holes and frass left behind. However, proper species identification and mitigation options may be difficult to determine and can be a task for entomologists and/or exterminators.

Mechanical Damage

In addition to wood deterioration through decay fungi, weathering, and insect attack, wooden artifacts in cemeteries frequently get damaged by people, animals, tree roots, falling trees, ground maintenance equipment, and fire. People can inadvertently knock over or move grave markers, or intentionally steal or vandalize them. Animals can knock markers down, scratch the surfaces, or even chew on surfaces and in-ground portions. Tree roots and ornamental plantings that are no longer maintained can damage markers by dislodging them or growing into or through them. In cemeteries within wooded areas, falling trees can crush or break wooden markers and grave enclosures. Grass trimmers and lawnmowers can nick the sides of fragile wooden markers and fences. Additionally, fires, either controlled burns or wildfires, can damage or destroy wooden markers and grave enclosures.

Figure 26. A fallen tree grazed this marker on the way down, damaging the top of the marker and pushing it partially out of the ground.

Figure 27. A cemetery fence post damaged by fire.

Figure 28. A grave enclosure corner post damaged by fire.

Figure 29. A grave enclosure damaged by decay and overgrowth of an invasive shrub in combination with decay of the corner posts.

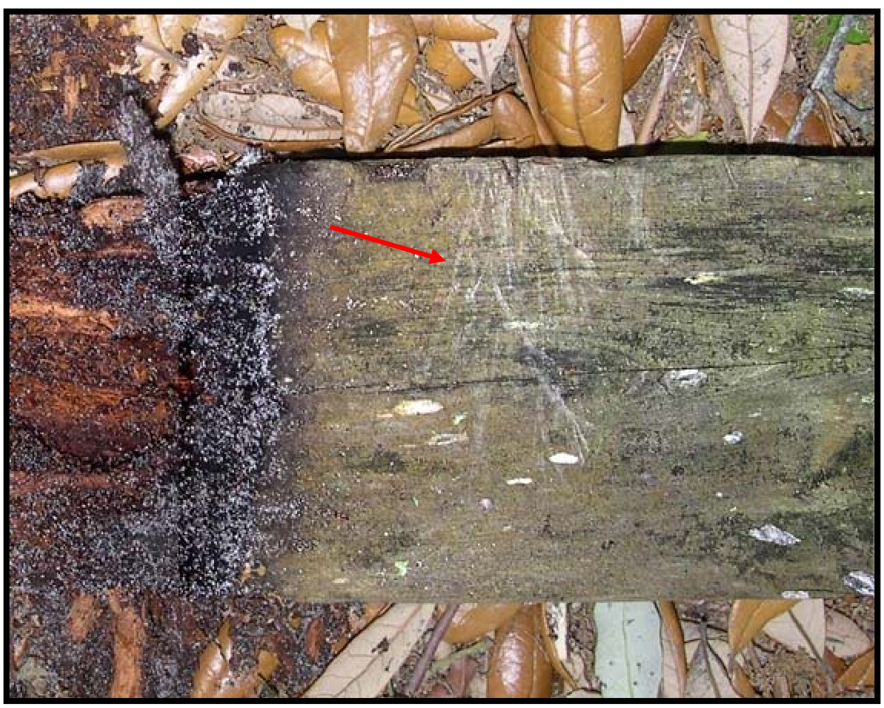

Figure 30. A grave marker showing damage from a weed trimmer.

Figure 31. Damage on the edge of a wooden marker caused by a weed trimmer.

Figure 32. A wooden plaque marking a grave with the surface chewed off by animals.

Methods for Identifying and Monitoring Problems

Visual Inspection

Any assessment of wooden marker condition should begin with a visual inspection. Visual examination of the wooden artifacts within cemeteries allows for identifying components that are missing, broken or in an advanced state of deterioration. Missing components are those which have been removed or have fallen away, frequently due to extensive deterioration. If missing components were intended to provide structural support, such as corner posts for a grave enclosure, their replacement may be essential to prevent long-term damage to the structure. Visual inspection also allows for the detection of current moisture problems above ground, as evidenced by wood that appears wet to the eye or feels moist to the touch. Further, visual inspection enables detection of external wood decay fungi or insect activity as determined by the presence of decay fruiting bodies, fungal growth, insect bore holes or wood substance (frass) removed by wood-destroying insects. Visual inspection provides a rapid means of identifying areas that may need further investigation and should be the first step in assessing wood conditions.

Probing

Probing the wood with a pick or an awl enables rapid detection of voids in the wood that may not be visible on the surface. Internal decay or insect damage is often masked by the lack of evidence on the exposed surface of the wood. For advanced decay, where large internal voids are present near the surface, probing allows for detection of potentially serious deterioration. Even for the early stage of decay, termed incipient decay, probing is beneficial. Probing can often reveal areas of incipient decay in wood markers or members, which have experienced sufficient deterioration due to decay fungi to allow for easy entry of a probe although no void is yet present. Wood without incipient decay tends to offer more resistance to probing due to the higher density and more intact internal wood structure. Probing is often typically conducted where markers or fence-posts meet the ground and in or near wood joints and connections.

Figure 33. Probing at the base of a marker with an awl to check for deterioration.

Figure 34. An awl at the base of a grave marker. Based on the length of penetration, this marker has approximately ½ inch of punky wood below the ground surface.

Moisture Detection

Prolonged exposure to moisture can produce undesirable conditions and long-term maintenance issues for wood members. Excessive shrinkage or swelling, checking, loose connections and decay are typical problems. Moisture content measurements can be taken using a resistance-type moisture meter such as the Delmhorst J2000 model at locations where decay is suspected. Resistance-type moisture meters use pins that may be insulated or un-insulated; insulated pins provide a moisture content reading at the depth the pins are inserted, while un-insulated pins will record the highest moisture content throughout the depth of penetration (which may be at the surface if measured after precipitation). Resistance meters that use insulated pins must be inserted into the wood parallel to the grain to provide a moisture content reading below the wood surface.

Dielectric meters do not have pins and may be used to attain moisture content readings where punctures of the wooden element by pin probes may be undesirable. The Wagner 606 is an example of a pin-less dielectric meter. However, dielectric meters provide an average moisture content of the zone penetrated by an electric field. The depth of penetration from the measuring field ranges from ½ inch to 1 inch, depending on the model. Thus, dielectric meters are best suited for utilization on thinner elements as the electric field cannot penetrate deeply enough to provide accurate moisture content readings on larger elements.

Moisture content measurements identify wood with favorable moisture levels for the growth of wood-decay fungi. Generally, if the moisture content is less than 20 percent, wood-decay fungi are unable to grow. While fungi may be present at lower moisture contents, they are unable to continue to deteriorate the wood without additional moisture. Moisture contents from 20 to 30 percent indicate areas of concern where moisture is sufficient for fungi to grow but not sufficient to indicate advanced decay. Moisture contents above 30 percent are often an indication of advanced decay with internal voids and/or surface deterioration. When taking moisture content readings, the user should be aware of recent precipitation or watering that may affect the reading.

Figure 35. Taking moisture readings on a grave marker using a resistance-type meter. Image (a) shows a reading being taken at the base of the marker; (b) shows the digital readout of 10 percent; (c) shows another reading being taken at the top of the marker (where the moisture content reads 6 percent); and (d) shows the base of the marker after it was removed from the ground – the base is in exceptionally good condition with very minor deterioration, consistent with the low moisture content readings.

When to Call the Experts

Many of the visual inspection and probing techniques can be learned and taught to cemetery stewards to help monitor the condition of wooden artifacts. Experts should be called following visual inspections that determine there may be a problem with no easily identifiable solution. Wooden markers and enclosures have historical and cultural significance and every reasonable effort should be made to preserve these artifacts. Expert advice should be sought if there are moisture problems where the source of moisture cannot be identified or mitigated, insect infestation, other indications that there may be decay problems, and situations where advanced decay has damaged or destroyed elements.

Wood technologists or wood scientists often use a method of detection called resistance drilling to assess wood condition. Resistance drilling is a quasi-nondestructive technique for determining the relative density of wood. It is best suited for determining internal problems in timber or large members that do not show obvious signs of deterioration or surface decay. Any internal void or early stage of decay at the location drilled can be detected by determining the relative density of the wood. The relative density is printed on a strip of paper as a small diameter needle penetrates the wood. The technique is very reliable for quantifying the extent of voids when used in combination with other techniques to rapidly locate areas of probable deterioration.

Figure 36. Resistance drilling a corner post of a wooden grave enclosure.

Experts, whether they be wood technologists or scientists, preservationists, or conservators cannot only facilitate in the identification of any problem areas, they can also help to quantify the extent of the damage and offer potential options for maintenance, repair, and when necessary, replacement. By following some basic recommendations for the care of wooden artifacts in cemeteries, however, cemetery stewards can extend the life of the wooden artifacts in their care by preventing or slowing the deterioration process.

Corrective Measures

Controlling Water

As previously discussed, moisture is the primary means through which weathering, decay fungus and insect infestation cause wood deterioration. The key to preserving and extending the life of wooden artifacts in cemeteries is to control moisture levels as much as possible. This means inspecting irrigation systems for leaks and noting the location of water spigots and sprinkler heads. Spigots that are located near wooden markers or grave enclosures should be moved or at the very least, carefully monitored when in use. The direction of spray from water sprinklers should be carefully assessed and alterations to the direction and intensity of flow made if necessary to prevent water saturation of the ground near wooden artifacts and to prevent wooden markers, fences and other artifacts from getting wet.

Figure 37. A water sprinkler located directly next to an old wooden marker that is showing signs of decay at the base.

Vegetation Management

Often, wooden markers get lost in the volunteer trees, shrubs, and grasses that spring up following their placement, or get covered over by untended ornamental plants. This overgrowth creates a moist microclimate conducive to decay fungi. This microclimate is created by a number of factors. Denser shade reduces surface temperatures of markers and other artifacts and allows water vapor released from transpiration to condense more rapidly on the markers. Concentrations of leafy vegetation also can reduce air flow around the wooden objects, decreasing evaporation. Dense clusters of vegetation drop leaves that release nitrogen as they decompose and attract decay fungi. Dense vegetation also increases the risk of fire.

Figure 38. The vegetation in this cemetery is so dense that a rake must be used to search the ground for markers.

Coatings to Retard Moisture

Ultraviolet light, wind-blown debris, moisture and extreme temperature variation all contribute to the weathering process and subsequent fungal decay and/or insect attack of wooden artifacts in cemeteries. Some artifacts were originally coated with paint or a lime wash. For these artifacts, proper application of opaque coatings such as lime-based white-wash and latex-based or oil-based paints or can dramatically reduce the potential impacts of these factors. Opaque coatings, provided they can be applied for full coverage, block 100 percent of sunlight's damaging UV rays and prevent the exfoliation process from occurring. Opaque coatings also serve to seal small cracks and crevices, thus preventing debris build-up and subsequent moisture penetration and retention. Paints provide a water-resistant barrier and seal exposed end grain surfaces, reducing the total amount of moisture that may wick into a marker, grave enclosure, or other artifact.

Oil-based or alkyd paints are the most resistant to water penetration; however, oil-based paints require turpentine clean-up and tend to get brittle with age. Latex paints are water soluble and create more flexible polymers that, while less resistant to water penetration, are better able to accommodate dimensional changes in wood.

Lime-based washes, or white-washes, have long been used on adobe and masonry surfaces and were often historically applied to both masonry and wooden artifacts in cemeteries. However, while some research has been conducted on the effects of lime-bashed washes on masonry, very little is known about the effects of lime washes on wood. White-wash is moisture permeable; on masonry, white-wash serves to harden the substrate and allows the underlying material to breathe (Chicora Foundation Inc.). Lime washes are alkaline and therefore somewhat biocidal, and the qualities of lime do not promote fungal and bacterial growth (Swearingen 2004). Lime-based white wash also reduces the surface temperature of wood exposed to direct sunlight by 20° F over untreated wood and nearly 6° F less than wood coated with latex paint (Watts 2007), but the extent of any wood-protecting qualities is unknown. White wash is known to be considerably less durable than oil or latex paints; however, it may be a historically accurate finish and therefore a more appropriate coating.

Figure 39. A freshly painted grave enclosure. Note the deformed pickets due to the tree root growth.

Although paints provide a high level of protection to wooden artifacts, the application of such products has significant drawbacks. Paint in and of itself cannot prevent decay fungi if conditions are favorable for growth. Visitors may object to the look of freshly painted markers or fences. Also, painting a marker may not be historically accurate and is a process that is not easily reversible. Additionally, painting markers requires regular maintenance that some cemeteries with small budgets or those that operate on a volunteer basis may not be able to perform.

Ultraviolet Light Blockers

Ultraviolet (UV) light blockers may provide an alternative to dramatically changing the look of wooden artifacts by painting or applying an opaque coating. UV light blockers are available in transparent finishes that minimize changes in the wood's appearance. UV light blocking finishes generally contain iron oxide pigments that help to deflect harmful UV rays and minimize damage to the wood by solar radiation.

While UV light blockers do not change the appearance of wooden artifacts as dramatically as opaque finishes, such products still impact the visual appearance of the artifacts. Finishes tend to be glossy and/or deepen the color of the wood. Also, UV finishes do not adhere well to weathered wood and may require sanding and/or frequent (biannual) applications. As alterations to the physical appearance of grave markers are typically undesirable, the use of products that contain UV light blockers should be carefully considered.

Water Repellents and Water Repellant Preservatives

Water repellents are penetrating wood finishes (as opposed to film-forming wood finishes such as paint) that can increase the durability of wood by decreasing its ability to absorb moisture. Waxes, oils, or similar water-repelling substances are used to inhibit moisture absorption, which in turn can minimize the growth of decay fungi. Water repellents also decrease swelling and shrinking cycles that can lead to cracking and warping (Williams and Feist 1999). Water repellents offer no protection from harmful UV light exposure and do not contain products that inhibit mold, mildew, or other fungal growth (mildewcides or fungicides). Because water repellents only penetrate the first few cellular layers of the wood, applications will not last long (less than 6 months) and are in general, not recommended for cemetery artifacts.

Water repellant preservatives are similar in formulation to water repellents. Typical preservatives contain a fungicide, a wax or other water-repellent, a resin and a solvent. Water repellant preservatives can be applied by brush or by dipping. Such application methods do not allow for deep penetration of the preservative, however they can provide some protection against decay in elements that are exposed above ground, particularly when applied to the end-grain and between joints. These finishes offer short-term protection against decay and slow the weathering effects of moisture and UV light. Because preservative treatments can only penetrate a thin layer of outer wood on lateral surfaces, preservative-treated members that are below ground or in contact with water will not last long and application in such situations is not recommended (Williams, Knaebe, and Feist 1996).

Water repellents and water repellant preservatives are not, in general, recommended for application on cemetery artifacts. Preservatives may darken the wood or cause it to look wet, altering the appearance of culturally and/or historically significant objects. Additionally, treatments may last as little as 6 months and therefore require frequent, long-term maintenance. Finally, wood preservative treatments are not adequate to protect wood that is in contact with the ground or with water from decay, and as such offer little benefit to grave markers and enclosure fence posts.

Repairs

If damage due to decay or insect attack is severe enough to affect the structural integrity of a wooden grave enclosure, a cemetery fence, or has caused a wooden marker to collapse, repair or replacement of elements or portions of elements may be necessary. It is recommended that a professional carpenter be used to make any repairs to the wood. Prior to any repair work, however, the conditions that led to the artifact's failure should be mitigated to prevent repeat failure or further damage. When repairing a deteriorated marker, fence, enclosure, or other artifact, efforts should be made to retain as much original material as possible.

There are a variety of possible repairs for wooden markers and other wooden artifacts, but typically, the wood that is below ground on a grave marker or enclosure fence-post will degrade long before the rest of the element. In some cases, it may be desirable to repair the marker or post by removing the damaged portion and attaching a new below-grade piece. The repair should not impair the aesthetic effect of the original artifact and the replacement wood should be reclaimed material of the same species, density and type of cut.

To determine the appropriate species for repairs, a sample of the original artifact must be removed and sent for analysis. Samples can be sent to a number of private consultants for a fee or to a public or government institution such as the U.S. Forest Products Laboratory Center for Wood Anatomy Research that can provide species analysis free of charge.

Samples should be taken from sound wood and should measure a minimum of ¼ inch wide x ¼ inch deep x ½ inch long. The soundness of the wood sample can be determined by rolling it between the fingers; if the wood breaks apart, it should not be submitted and a new sample will need to be taken. To extract a sample, use a sharp knife, craft saw blade, and/or a chisel to make two cuts across the grain of the element. These two cuts should be a minimum of $^{3}/_{16}$ inch deep and ½ inch apart. A specimen can be split out by prying up at one of the incised points with a knife, or if a chisel is used, the edge of the chisel can be placed in one of the cuts and then angled down the grain towards the other cut. A sharp tap with a small hammer or rock should provide enough force to remove a good specimen from the host element. All samples should be taken from an inconspicuous spot such as the underside of a bottom rail or the inside of a corner post near ground level. For markers, try to remove a sample from the area that is being repaired. Each sample should be recorded, labeled and bagged separately prior to shipment for analysis.

Figure 40. Cutting a sample from a grave enclosure rail.

Figure 41. The sample after removal from the enclosure rail. Ant and saw blade are for scale.

Repairs may be spliced to remaining sound wood using a variety of wood joints and/or wooden dowels. An epoxy resin can be used to insure adhesion between the pieces; however, epoxies tend to inhibit moisture flow through the member and may cause the repair to fail at a much faster rate than if no adhesive is applied. Additional research needs to be conducted to determine alternatives to epoxies for this type of application.

For additional protection, borate rods can be inserted into holes drilled into the bottom end grain prior to re-installation. Borates are low-level toxicity preservatives that are used to improve the durability of both new and in-service wood products. Borates are not an alternative to pressure-treated wood that will be in ground contact. They require moisture to migrate through the wood so they are placed in the wood where moisture is likely, such as near the exposed end grain, near the bottom face of elements close to ground contact and at exposed, wood-wood connections where members meet, including replacement splices. Borates also effectively control termites, carpenter ants, a variety of beetles, and many other wood boring insects. To install borate rods, holes are drilled on the bottom or below-grade lateral face of markers or enclosure posts (to reduce the probability of moisture infiltration), the rods are inserted and the holes are filled with either a pressure-treated wood plug or a plastic threaded plug (to aid in inserting additional rods during future inspection cycles). These rods are typically effective for 3-10 years depending on environmental conditions, but they should be regularly inspected and used as part of a cyclic, long-term maintenance program.

Replacement

There may be occasions when it is not possible to repair an artifact, such as a grave enclosure with a fence post too badly deteriorated to repair or missing entirely. With artifacts of considerable historical or cultural significance, the choice may be made to place the wooden artifact in a museum or curation facility and install a modern replacement. A second example of when replacement may be chosen over repair is when a grave marker is missing due to vandalism. Regardless of the reason, the choice to replace an original artifact should always be made judiciously.

When creating a replacement, the wood utilized should be reclaimed material of the same species that matches as closely as possible the original wood's density and type of cut. Dimensions and detailing should match the original dimensions and the profile and should not be altered. The replacement member should be dated in an inconspicuous spot to aid future preservationists in determining historic fabric. Borate rods may be inserted into the end grain or in a lateral face that will be below the ground surface following installation to extend the service life of the replacement artifact, using the techniques and inspection cycle described above.

Alternative Materials

Because wood exposed to moisture is not exceedingly durable, it often seems illogical to replace deteriorated wood with wood of the same species, or even wood at all. Often, the desire to replace wooden artifacts with a more durable material seems the most economical and logical approach. According to the Secretary of the Interior's Standards for preservation, "the preferred treatment is always replacement in kind, that is, with the same material" (Myers and Hume 1984). Because this approach is not always possible, the use of a compatible substitute material may be considered if the "form, detailing, and overall appearance of the substitute material conveys the visual appearance of the historic material, and the application of the substitute material does not damage, destroy or obscure historic features" (Myers and Hume 1984).

Figure 42. Historic wrought iron and wooden grave enclosures flanking an out-of-place grave enclosure made out of vinyl.

However, the use of a substitute material, such as replacing a wooden grave enclosure with one made out of vinyl, changes the character-defining features of a cemetery, alters the "historic visual relationship" between the grave markers and the cemetery and damages the historic character of the cemetery. Wooden markers, grave enclosures, fences, and other wooden cemetery artifacts are historically significant because "the materials and craftsmanship reflected in their construction are tangible and irreplaceable evidence of our cultural heritage. To the degree that substitute materials destroy and/or conceal the historic fabric, they will always subtract from the basic integrity of historically" significant artifacts (Myers and Hume 1984).

A Few Comments on Repair Attempts

There has been very little research conducted on the long-term success of repairs made to wooden markers and other cemetery artifacts. For a variety of reasons, repairs may fail at a much faster rate than the failure of the original artifact: wood used for repairs may have a greater percentage of softer earlywood than original artifacts and may therefore be more susceptible to weathering. Dissimilar wood species may be susceptible to insect attack or decay. Adhesives used in the repair process may interfere with natural wicking and evaporative processes within a member and may prevent moisture from escaping below the repair, or joints that are not properly crafted may allow moisture penetration and the development of decay fungi. For these reasons, any repairs will need regular inspection and maintenance to monitor conditions for signs of problems or failures. Prior to implementing any repair, several factors should be considered in addition to the wood. These factors are discussed below.

Documentation and Planning

First and foremost, cemetery caretakers should have a maintenance plan and budget in place so that repairs can be monitored over the long term and supplementary repairs or alterations to the repairs can be made in a timely manner. Any repair efforts should be conducted in a systematic way with full documentation of the process after a complete conditions assessment has been performed. The documentation should include maps of the locations of repaired artifacts, drawings, photographs of the artifacts before, during, and after the repair process, and a written report detailing the scope of work.

Soil Conditions and Microclimate

Environmental factors are also a concern when deciding upon the appropriate repair methodology. Certain soil conditions such as poor drainage or highly acidic soils can dramatically impact the success of repair attempts. Additionally, the microclimate around individual artifacts can vary significantly. Be familiar with moisture distribution patterns, nearby plant, shrub, and tree growth patterns, typical temperature and humidity conditions and the slope or grade surrounding the artifact prior to conducting any repair work. If possible, cut back overgrown vegetation and improve poorly graded soil to increase ventilation and drainage.

Repairing Elements with In-Kind Materials

The long-term success of repairing cemetery artifacts by removing the decayed, below- ground portion and attaching a new wooden base is questionable at best. The following photos represent a collection of grave markers that were treated with a linseed oil and turpentine bath and repaired between 1992 and 2000; a return visit in 2008 demonstrated that the majority of the repairs, if not all of them, had failed.

Figure 43. A previously repaired grave marker that has failed and is no longer in situ.

Figure 44. A detail of the repaired end of the marker in Figure 43; the epoxy remains even though the below ground portion of the marker has deteriorated.

Figure 45. The back side of the same grave marker from Figures 43 and 44. This side was in ground contact and is significantly deteriorated after an unknown length of time on the ground.

Figure 46. The repaired end of the marker (from Figures 43, 44, and 45) shows that the epoxy is in good condition but the wooden dowels have rotted away.

Figure 47. Another grave marker with a repair that has failed and is no longer in situ.

Figure 48. The repaired end of the marker from Figure 47 shows evidence of subterranean termites and epoxy that remains despite the degradation.

It is important to note that these repairs did not involve the use of borate rods, which can improve the service life of wood in contact with the ground. While the success of borate rods within a cemetery application is not known, the known benefits of borate rods indicate considerable potential in historic preservation efforts in cemeteries.

Repairing with Alternative Materials

In many cases, the portion of the artifact that is in contact with the ground has been completely destroyed by decay or insects and repairing the artifact with the same materials simply is not a feasible solution. While this approach does not follow the Secretary of the Interior's guidelines, it may be worthwhile to consider alternatives for objects that simply cannot be repaired. Consider a popular grave marker in Beaufort, North Carolina. The story of a little girl's death at sea, her father's promise to bring the girl back to her mother, and the subsequent placement and burial of her body in a rum keg is one that piques considerable interest and draws a number of visitors to this small coastal cemetery. However, the below-grade portion of the little girl's grave marker has deteriorated. In order to keep the grave marker on display, an alternative base was built utilizing copper rods or tubes.

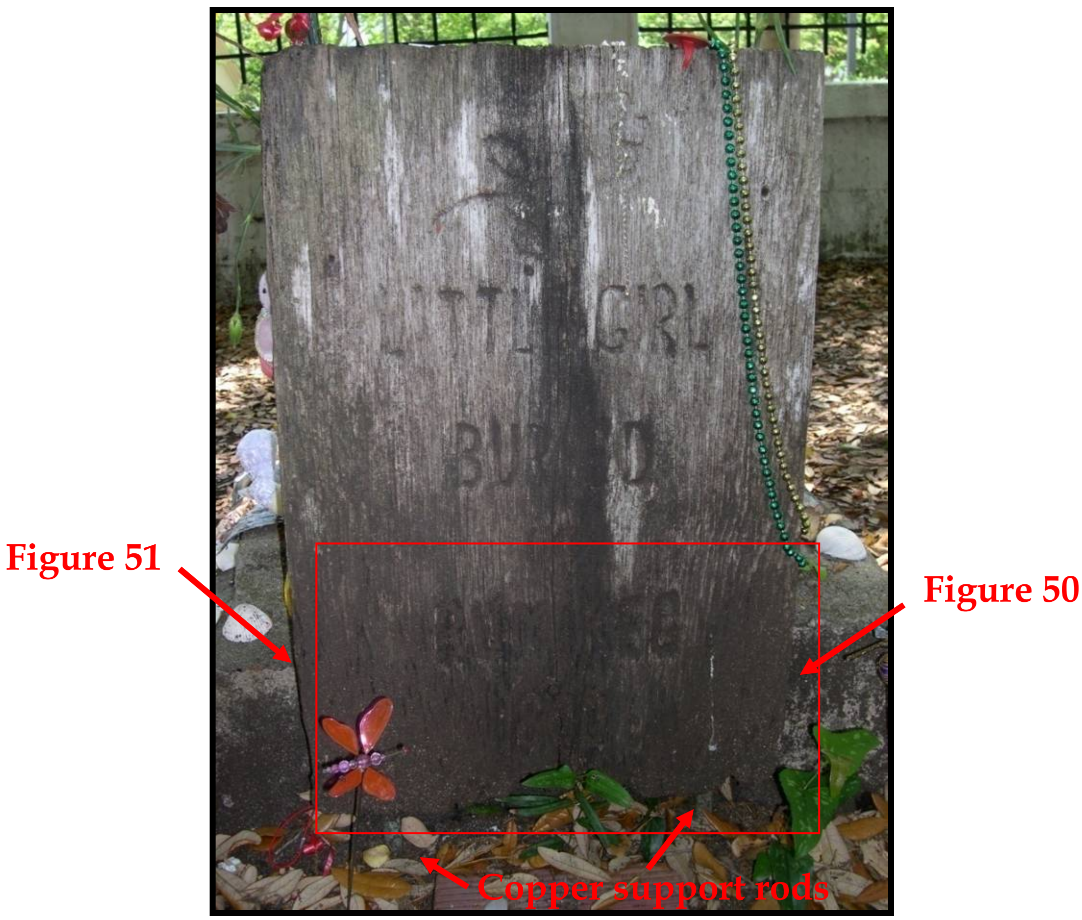

Figure 49. The grave marker of the little girl buried in a rum keg. Note the copper support rods.

Figure 50. A detail of the base of the marker showing two copper supports. The wooden marker is no longer in contact with the ground. Note the screw on the face used to hold the historic marker in place and the check likely caused by its installation.


Figure 51. A close-up of the side view of the repair showing the wood the marker has been sandwiched to and the copper pipe, along with organic debris.

The unfortunate consequence of this repair is that the marker can only be viewed from one direction; the repairs cover a portion of the other side. Additionally, the screws used to hold the marker in place were placed on the front face of the marker and are easily visible and may have contributed to a check that runs along the face. If such a repair is necessary, every effort should be made to place fasteners judiciously so as to have the least visual and physical impact on the artifact. Simply installing the screw from the other side would have kept this marker in more pristine condition. Despite these drawbacks, however, the marker remains on display and is somewhat protected from further degradation because it is no longer in contact with the ground.

Similar types of repairs have been made at other cemeteries. At Mount Pisgah Cemetery in Cripple Creek, Colorado, a maintenance plan has been in place for the past several years that includes painting and repairing wooden markers and enclosures. Bases of grave enclosure corner posts that are deteriorated below ground are typically replaced with channeled steel rods. Alternatively, bases of natural rock are placed under the deteriorated posts to prevent structure collapse and moisture absorption into the failed element. The maintenance and repair program at Mount Pisgah has kept the vast majority of wooden artifacts from extensive deterioration. Minor adjustments to their maintenance procedures, such as boring insertion holes for the metal rods into the end grain of the corner posts rather than attaching the rods to the exterior and leaving stones used as supports unpainted, are suggested.

Figure 52. The deteriorated base of a grave enclosure corner post has been replaced by a channeled metal rod and natural stones, painted white.

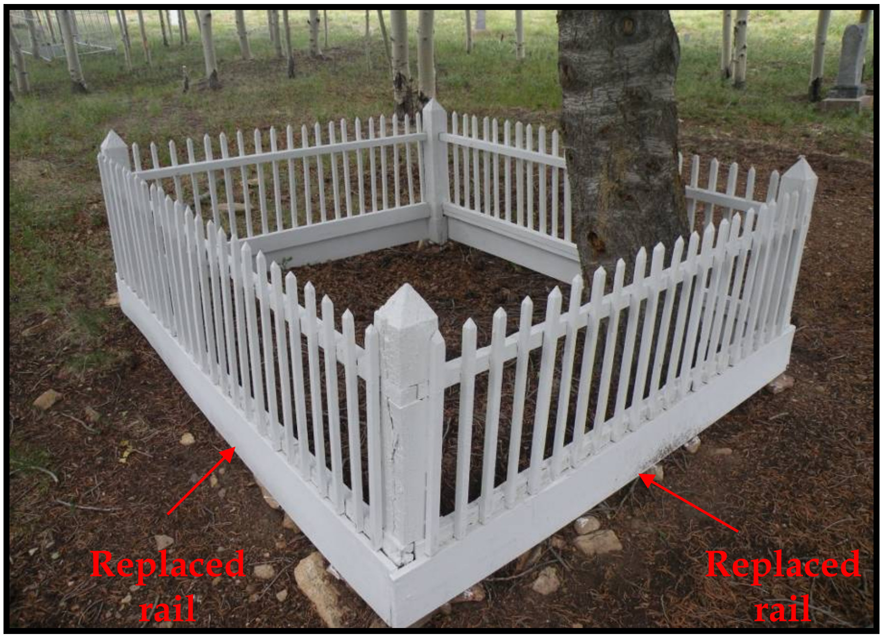

Figure 53. This grave enclosure has had its base rail replaced and the degraded corner posts now sit on stone piers.

Figure 54. The top photograph shows a grave marker and grave curb. The original wooden marker was replaced with one of plywood, a material not suited for exterior conditions. The bottom photograph is a close-up of the top of the marker; through the paint the effects of weathering and the beginning of de-lamination are evident.

Surface Treatments

If some sort of surface treatment has been decided upon, the artifact should be removed from the site and allowed to dry in a sheltered but well ventilated area after a thorough brushing with a natural bristle brush to remove as much dirt and debris as possible without damaging friable surfaces. Moisture readings can be taken with a hand-held meter to determine when the wood has stabilized, which will likely occur 10-14 days following its removal. Once the artifact has been cleaned and relative moisture levels have stabilized, a surface treatment can be applied.

Application through dipping is generally the most effective method, although brushing can work for objects that are too big to dip. In addition to the wood preservatives and ultraviolet light blockers, there may be preservative benefits to other substances. A combination of heated linseed oil and turpentine has been utilized on wooden cemetery artifacts to try to reduce the occurrence of moisture wicking and decay. Other similar attempts include the use of glycol as a vehicle to allow rapid absorption of the coating by the wood. Linseed oil will turn the artifact dark brown or black as it ages, however, and as an organic oil, may encourage the growth of mildew and decay fungi. In addition to being toxic, turpentine and glycol are flammable, making their application one that should not be implemented without a thorough understanding of the potential hazards.

Encasement

An additional alternative, given the high rate of deterioration that can occur in wooden artifacts due to extreme environmental conditions, is to consider encasing fragile or extremely weathered markers in glass or acrylic to maintain the integrity of the inscription and protect the wood from further abrasion. Although this is not typically done in cemeteries, this method can be used to protect fragile wood exposed outdoors and may be an option in situations where it is desired for fragile markers to remain on display.

Summary

It can be disheartening to realize that there is nothing currently in existence that will completely stop the weathering and decay processes on cemetery artifacts. However, through regular maintenance and routine inspections and assessments, the further decay of wooden artifacts can be slowed substantially and their service lives can be extended. More importantly, the unique history and cultural significance of wooden markers, grave enclosures, and other artifacts can be preserved for future generations to experience.

Bibliography / Additional References:

American Society of Civil Engineers (1982). *Evaluation, Maintenance and Upgrading of Wood Structures: A Guide and Commentary*. New York: American Society of Civil Engineers.

Avarami, E. C. (1993). *Preserving Wood Features In Historic Buildings, An Annotated Bibliography,* U. S. Dept. of the Interior, National Park Service, Washington D. C.

Center for Wood Anatomy Research, Forest Products Laboratory, USDA Forest Service (Unknown). *Wood Identification Procedures*. Madison, Wisconsin. http://www2.fpl.fs.fed.us/WoodID/idfact.html.

Chicora Foundation, Inc. (Unknown). *Whitewash*. http://www.chicora.org/whitewash.pdf.

Desbenoit, Brett, Eric Galin and Samir Akkouche (2004). Simulating and Modeling Lichen Growth. *Eurographics* 23:3.

Feilden, B. M. (1994). *Conservation of Historic Buildings*. Oxford, Boston: Reed Educational and Professional Publishing Ltd.

Forest Products Laboratory, Forest Service and U.S. Department of Agriculture. (2000). *Wood Handbook: Wood as An Engineering Material*. Washington, D.C.: U.S. Government Printing Office.

Goerig, David J., and James A. Chatfield (2004). 10 Things You Should Know about Lichens. *Ornamental Plants Annual Reports and Research Reviews 2004.* Special Circular 195, The Ohio State University Bulletin, Extension Research. http://ohioline.osu.edu/sc195/029.html.

Hoadley, R. B. (2000). *Understanding Wood: A Craftsman's Guide to Wood Technology*. Newtown, CT: The Taunton Press.

Larsen, K. E. and N. Marstein (2000). *Conservation of Historic Timber Structures: An ecological approach*. Oxford: Butterworth-Heinemann.

Levy, Michael P. (1979). *A Guide to the Inspection of Existing Homes for Wood-Inhabiting Fungi and Insects*. Department of Housing and Urban Development, Office of Policy Development and Research. Washington D.C.

Matero, Frank G., Stephen Curtis, John Hinchman and Judy Peters (2002). *St. Louis Cemetery No. 1 Guidelines for Preservation & Restoration*. http://cml.upenn.edu/nola/pdfs/GuidelinesEnd.pdf.

Merchant, Michael (2003). *Insects in the City: Carpenter Ants Around Homes*. FastSheet Ent-1001, House and Landscape Pest Series, Department of Entomology, Texas A&M University, College Station, TX. http://citybugs.tamu.edu/FastSheets/Ent-1001.html.

Mitchell, Phil. *Methods of Moisture Content Measurement in the Lumber and Furniture Industries*. Wood Products Notes. Department of Wood and Paper Science, College of Forest Resources, North Carolina State University. Raleigh, North Carolina. http://www.ces.ncsu.edu/nreos/wood/wpn/methods_moisture.htm.

Myers, John H., revised by Gary L. Hume (1979, revised 1984). Preservation Brief No. 8: *Aluminum and Vinyl Siding on Historic Buildings: The Appropriateness of Substitute Materials for Resurfacing Historic Wood Frame Buildings.* National Park Service, U.S. Department of the Interior.

National Trust of Australia (NSW), Guidelines for Cemetery Conservation. http://www.nsw.nationaltrust.org.au/cemsappd.html

Old House Web (2008). *Termites, Ants and Other Wood-Destroying Organisms*. http://www.oldhouseweb.com/stories/Detailed/10324.shtml

Paine, C. (1983). Restoration of the Billings Estate Cemetery. *Bulletin of the Association for Preservation Technology*, Vol. 15, No. 4, pp. 60-65

Ridout, B. (2000). *Timber Decay in Buildings: The Conservation Approach to Treatment*. London; New York: E & FN Spon.

Strangstad, L. (1995). *A Graveyard Preservation Primer.* American Association for State and Local History Book Series, AltaMira Press.

Swearingen, John (2004). *Le Décor – St. Astier Lime Paints*. GreenHomeGuide. http://www.greenhomeguide.com/index.php/product_detail/422/C134.

Termite Treatment Directory (2008). http://wwwtermitetreatment.com/.

Texas Preservation Guidelines, Texas Historical Commission. http://www.thc.state.tx.us/publications/guidelines/Preservecem.pdf

Vail, Karen M., Edward E. Burgess and Charles Pless (2002). *Wood-Destroying Organisms Licensing Manual: WDO*. http://eppserver.ag.utk.edu/psep/secondlevel/thirdlevel/WDO/WDOindex.htm.

Watts, Anthony (2007). *Bad Paint Job = Rising Surface Temperatures Part 2: A Test of Wood Surface Temperatures Related to Paint*. http://www.norcalblogs.com/watts/2007/05/bad_paint_job_rising_surface_t.html.

Weaver, M. E. and F. G. Matero (1997). *Conserving Buildings: Guide to Techniques and Materials, Revised Edition*. New York; Chichester; Weinheim; Brisbane; Singapore; Toronto: John Wiley & Sons, Inc.

Williams, R. S., M. T. Knaebe and W. C. Feist. (1996). *Finishes for Exterior Wood: A Comprehensive Guide to the Painting/Staining and Maintenance of Homes, Decks, Log Structures and More.* Madison, Wisconsin: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Williams, R.S. and William C. Feist (1999). *Water Repellents and Water-Repellant Preservatives for Wood*. Madison, Wisconsin: U. S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Winkler, Erhard M. (1986). The Measurement of Weathering Rates on Stone Structures, A Geologist's View. *Bulletin of the Association for Preservation Technology*, Vol. 18, No. 4, pp. 65-70.