

Timber Bridge Inspection and Decay

Timber bridges are still common on local roads, forest roads and in parks, and decay remains their main cause of deterioration. This course is built on Chapter 13, Bridge Inspection for Decay and Other Deterioration (Ritter and Morrell), and Chapter 14, Maintenance and Rehabilitation of Timber Bridges, of Timber Bridges: Design, Construction, Inspection, and Maintenance (Ritter, USDA Forest Service EM 7700-8, 1990). It covers the organisms that attack wood, the tools used to find exterior and interior deterioration, inspection sequence and reporting, preservative and in-place treatment issues, and how decay findings are turned into residual section for rating. The source dates from 1990: tool technology has advanced and the regulatory status of some preservatives named in it has changed, so treat chemical names as historical and check current labels and agency rules. Worked numbers are labeled illustrative.

Learning objectives

- Describe decay fungi and insects
- Use sounding, drilling and coring
- Recognize preservative treatment issues
- Rate timber components

Why timber inspection is different

Ritter and Morrell open Chapter 13 by calling wood "an amazing combination of polymers" with both strength and durability, but one that is subject to deterioration from the time it is formed in the tree. Pressure treatment has greatly extended service life, yet, they write, decay is still the primary cause of timber bridge deterioration.

They also make a point about management. Many owners install a timber bridge and "walk away," then blame the material when it deteriorates, when poor design, construction and management were probably major factors. Alert inspectors who record condition, followed by timely maintenance, prevent small problems from becoming repairs or replacement.

Three things set timber inspection apart from steel or concrete:

- **The worst damage is often hidden.** Decay frequently starts inside a member, at a fastener hole, a check or a cap connection, and the outer shell can look sound until it breaks.
- **Early decay is the most important to find and the hardest.** The chapter says detecting incipient decay is the most difficult but most important part of inspection, because that is when it can be controlled most effectively.
- **Decay is a biological process with known requirements.** If the inspector understands what organisms need, the likely locations of attack become predictable.

The chapter says timber inspection is a learned process that needs some knowledge of wood pathology, wood technology and timber engineering. This course gives the essentials. It assumes general inspection knowledge from courses such as BR-I01.

The four objectives are to describe decay fungi and insects; use sounding, drilling and coring; recognize preservative treatment issues; and rate timber components using the residual section found in inspection.

What wood-destroying organisms need

The chapter lists four requirements for biotic agents: moisture, oxygen, suitable temperature and food. Each must be present. Remove any one and the wood is safe from biotic attack.

Moisture. "Dry rot," the authors note, is a misleading term, since wood must contain water for most biological attack. Wood below the fiber saturation point, about 30 percent moisture content, generally will not decay, although some specialized fungi and insects attack drier wood. Above fiber saturation, free water collects in the cell cavities and many fungi can begin to degrade the wood. Swelling is believed to make cellulose more accessible to fungal enzymes. Repeated wetting and drying, or continuous wetting, can also leach toxic heartwood extractives and some preservatives.

Oxygen. Except for anaerobic bacteria, all these organisms need oxygen. Starving them of it is usually impractical because most fungi survive at very low oxygen levels. The exception is wood that is fully submerged or below the water table. Untreated piling in fresh water often decays to the water line but remains sound below it.

Temperature. Most organisms do best at 70 to 85°F. Activity slows below freezing and above about 90°F, though some species tolerate up to 104°F. The chapter says it is generally accepted that 75 minutes at 150°F will eliminate all decay fungi established in wood. Temperature cannot be controlled on a bridge, but decay is more serious in warm climates. Temperature and rainfall are combined in a climate index for decay hazard.

Food. Most agents eat the wood. Preservative treatment poisons the food source, so attack can occur only where the treatment envelope is inadequate or broken. Naturally durable heartwood has some resistance at first, but weathering and leaching reduce it quickly. The chapter's conclusion: maintaining an effective preservative treatment is essential.

Regional hazard. When local information is lacking, the chapter correlates decay potential with rainfall and temperature. The Southeast, with heavy rainfall and moderate temperatures, has high decay potential, as does the Pacific Northwest coast because of its rainfall. Areas with less than about 25 in. of rain a year or short growing seasons have reduced potential. Local conditions can still vary considerably.

Fungi: mold, stain and the three decays

Fungi grow through wood as microscopic threadlike hyphae that pass through pits or penetrate cell walls, secreting enzymes that break down cellulose, hemicellulose or lignin. When a fungus has enough energy it forms a fruiting body that releases spores. Spores are carried so widely that they are on most exposed surfaces, so any wood can be attacked when conditions allow. The chapter divides wood fungi into mold, stain and decay fungi.

Mold and stain fungi. These colonize wood soon after cutting and keep growing while moisture stays above about 25 percent for softwoods. They feed on cell contents, not the cell wall, and do not adversely affect strength, though some stain fungi reduce toughness and increase permeability, which is why stained wood is generally rejected for structural grades. Their importance to an inspector is that they show conditions favorable to decay, and some may slowly detoxify surface preservatives, opening the way for decay fungi.

Brown rot. Brown-rotted wood is brownish and, when advanced, brittle with numerous cross checks, resembling heavily charred timber. Brown rots attack cellulose and hemicellulose and modify the lignin, with weight loss approaching 70 percent. Because cellulose gives the cell wall its strength, brown rot causes large strength losses very early. The wood may look sound with only 1 to 5 percent weight loss while some strength properties are reduced by as much as 60 percent. The enzymes

diffuse far from the hyphae, so strength loss can extend well beyond visible decay. The chapter calls brown rots among the most serious for these reasons.

White rot. White-rotted wood may be whitish or light tan with dark streaks and, when advanced, soft enough that fibers peel away. White rots attack all three cell wall components, with weight loss up to 97 percent, but strength loss is roughly comparable to weight loss, and the enzymes stay close to the hyphae, so early stages are less noticeable.

Soft rot. Soft rots usually confine attack to the outer shell, in wood that is continuously wet or of changing moisture, sometimes in low oxygen. Most need extra nutrients, from sources such as fertilized soils. The chapter says they are normally not associated with significant strength loss in bridge members.

Bacteria. Bacteria can soften and increase the permeability of untreated wood that stays very wet, and some degrade preservatives. The chapter says bacterial decay does not appear to be a significant hazard to the pressure-treated timber typically used in bridges.

Stages of decay. The chapter classifies decay as incipient (no visible signs, but properties may already have changed), intermediate (softened, discolored, little strength left) and advanced (virtually no strength, with pockets or voids, or wood dissolved).

Insects: termites, ants, beetles and bees

Of the 26 insect orders, the chapter says 6 cause wood damage. Termites, beetles, and bees, wasps and ants cause most of it. The general signs are tunnels or cavities, often holding wood powder or frass (insect feces), and "powder posting," a pile of frass on the outside of the wood. Insects can also carry stain and decay fungi into the wood, so insect activity may indicate decay as well.

Termites

The chapter counts over 2,000 termite species, found where average annual temperature is 50°F or higher. They are social insects with a queen, soldiers and workers; the workers do the wood damage. Colonies range from several hundred to a million or more members. They need wet wood, food, high carbon dioxide and oxygen. Three families matter in the continental United States:

- **Subterranean termites** attack almost any wood but need a moisture source and nest in the ground. They reach wood above ground through earthen tubes that shield them from light and carry moisture. Damaged wood has many tunnels through the springwood but no exit holes. A sharp tap may show that only a thin veneer remains. Tunnels are filled with frass and debris and look dirty. The chapter gives a conservative estimate of \$1.5 billion a year in U.S. damage. It also warns about the Formosan termite in Southeastern states, which can attack preservative-treated wood, forms large colonies and sometimes nests in moist wood out of ground contact. (Its range may have changed since 1990.)
- **Dampwood termites** are common in the Pacific Northwest. They need very wet wood and are often found with decay. Their tunnels are fairly large, hold small amounts of pellet-like frass and look cleaner than subterranean damage. Removing the moisture source or using treated wood in ground contact prevents or stops them.
- **Drywood termites** attack extremely dry wood, 5 to 6 percent moisture content, out of ground contact. Tunnels are large, smooth and clean, with no difference between springwood and summerwood. They chew "kick holes" to push debris out and then reseal them, so debris collecting below a hole is a good sign of attack. Their range is relatively small, and structural fumigation is reported to work.

Carpenter ants

Carpenter ants use wood for shelter, not food, in colonies of up to 100,000. Their tunnels are clean and free of frass, and fibrous frass collects at the base of the member. Table 13-2 of the chapter separates them from termites:

Feature	Termites	Carpenter ants
Body segments	Equal (no narrow waist)	Constricted waist
Workers	Cream-colored	Dark
Wings	Equal	Unequal
Tunnels	Contain frass	Clean
Food	Digested wood	Sugar and insects

Beetles

Beetles are the largest insect order, and nine families cause substantial wood damage. Many attack only living trees or fresh-cut logs. The chapter discusses them because an inspector may see their old damage and mistake it for active deterioration.

The **powder post beetles** (Anobiidae, Bostrichidae and Lyctidae) are larvae that leave small tunnels packed with powder-like frass. Anobiids and bostrichids attack moist wood and untreated construction timber, and emerging adults reinfest the same piece. True powder post beetles (Lyctidae) attack hardwoods above 8 percent moisture content and push frass out of the wood, where it collects underneath. The chapter says preservative treatment or sealing the surface prevents Lyctid infestation. It also notes that the **old house borer** damages structural timber along the coastal Southeast.

Carpenter bees

Carpenter bees bore galleries 5 to 18 in. long and 0.3 to 0.5 in. wide. The chapter reports that they have attacked wood treated with aboveground retentions of inorganic arsenicals. Treatment alone, in other words, does not guarantee freedom from insect damage.

What to record

For any insect finding, record the member and location, the type of evidence (tunnels, exit or kick holes, frass and its character, earthen tubes, live insects), whether the frass looks fresh, and whether there is associated moisture or decay. Frass color and texture help with identification, but EM 7700-8 does not say how to judge whether an infestation is active. Old damage and active damage can look alike, so describe what you see and leave the diagnosis to a specialist when it matters.

Marine borers

The chapter says marine borers cause over \$250 million of damage a year to marine structures. It cites a loss of \$25 million in San Francisco Bay in the 1920s. It classifies U.S. marine borers into three groups, pholads, shipworms and Limnoria, and adds a newer concern, Sphaeroma.

- **Pholads** are clamlike mollusks. They are about 2.5 in. long, make entry holes about 0.25 in. across and bore pear-shaped holes. *Martesia striata* is a tropical species. Where pholads occur, the chapter says dual treatment with creosote plus a waterborne arsenical is needed.

- **Shipworms** enter as larvae through tiny holes and then grow inside the wood. *Teredo navalis* reaches 3.5 to 7 in. long and 0.5 in. in diameter; *Bankia setacea* reaches 59 to 71 in. long and 0.8 in. in diameter. Entry holes stay at or below 0.06 in., and tunnels have a white calcareous lining. A shipworm can close its hole with a pallet and survive 7 to 10 days out of water. Because the outside shows almost nothing, the chapter says visual detection is unreliable. A pile can be riddled while looking sound.
- **Limnoria** (gribbles) are small crustaceans. The chapter counts 20 species, 3 of them damaging in the U.S. *L. tripunctata* attacks creosoted wood south of San Francisco Bay and along the whole east coast. They make tunnels about 0.12 in. across near the surface. Wave action erodes the weakened surface and exposes new wood, which produces the classic hourglass shape of piles in the tidal zone. Attack can also extend to the mudline when oxygen and salinity allow.
- ***Sphaeroma terebrans*** is found in Florida and tolerates copper preservatives.

Inspecting for marine borers

The chapter says low tide is the best time to inspect substructures in seawater. Low-tide inspection works best for *Limnoria*, which attack the outside of members. Use a scraper and probe to remove fouling organisms so you can examine the surface around bolt holes and where members meet. Signs of damage are hourglass-shaped piles in the tidal zone, bore holes, general softening of the wood, and loose bolts and bracing.

Intertidal inspection is less effective for shipworms because their entrance holes are so small. The chapter calls sonic instruments the best method for evaluating shipworm damage, and it notes that X-rays are particularly useful for finding insect and marine borer damage. Work below the water line needs a diver, a high level of skill and good coordination. It falls under underwater inspection practice, which is outside this course.

To judge the borer hazard at a site, the chapter suggests hanging sacrificial blocks of untreated wood at various depths around the substructure and pulling them periodically to look for attack. Do not rely on driftwood, because you cannot know where it came from. Exposed samples assess the hazard and also monitor it over the long term.

Where marine borers are present, preservative choice matters even for inspection holes. Where *Limnoria* are a risk, the chapter says surfaces and plugs should be treated with waterborne salts. Where pholads may attack, it advises both creosote and waterborne salts.

Physical agents of deterioration

Wood is also degraded by nonliving agents: mechanical abrasion or impact, ultraviolet light, by-products of metal corrosion, and strong acids or bases. These usually act slowly but can be serious in particular locations. The chapter says physical damage can be mistaken for biotic attack. The absence of fungi, insects or borers, and the general appearance of the wood, point to a physical cause. Physical agents also damage the preservative treatment, which exposes untreated wood to biotic attack.

Mechanical damage is called probably the most significant physical agent. It is most often vehicle abrasion, which wears the deck, wearing surface and wheel guards and reduces the effective section. More severe damage comes from long-term overloads, foundation settlement, and debris or ice in the channel. The chapter illustrates severe debris-flow damage to a glulam bridge and a large crack in a sawn beam caused by vehicle overloads.

Ultraviolet degradation chemically breaks down lignin near the surface. Light woods darken and dark woods lighten, but the damage is shallow. It affects strength little except where repeated loss of damaged wood eventually reduces member size. On

end grain, earlywood erodes between the latewood rings.

Corrosion. The chapter says wood degradation from fastener corrosion is often overlooked, especially in marine settings where saltwater galvanic cells speed it up. Moisture reacts with iron in the fastener to release ferric ions that attack the cell wall. The fastener then acts as an electrolytic cell. Acidity at the anode hydrolyzes cellulose and severely reduces strength nearby, and the affected wood looks dark and soft. Wet conditions at first favor decay as well. As corrosion continues, metal toxicity and low pH eventually drive fungi out of the immediate zone, although decay may continue a short distance away. Galvanized or non-iron fasteners limit the problem. In practice, dark, soft wood around bolt holes calls for probing and coring, and may mean the connection has lost bearing capacity.

Chemical degradation. Strong bases attack hemicellulose and lignin and leave the wood bleached white. Strong acids attack cellulose and hemicellulose, darkening the wood and making it look fire-damaged. The chapter says these normally reach a bridge only through accidental spills.

A practical point: several physical agents look like other problems. Acid damage looks like charring, and charring looks like advanced brown rot. Corrosion-softened wood looks like decay. The tools in the next sections, and the setting around the damage, are what separate them.

Detecting exterior deterioration

The chapter is blunt that "there is no magic box" for judging a timber structure. Several tools used together give a reasonable estimate. In practice an inspector uses only a few, chosen by budget, experience and the problems expected, and no equipment replaces a well-trained inspector. Exterior deterioration is the easiest to find. The four common methods are visual inspection, probing, the pick test and the Pilodyn. Once these locate damage, other methods are needed to confirm it and define its extent.

Visual inspection

Visual inspection needs strong light. It finds intermediate or advanced surface decay but not early decay, so the chapter says it should never be the only method. The visual signs it lists:

- **Fruiting bodies** prove fungal attack but not its extent. Since they are uncommon on bridges, the chapter says they almost certainly mean serious decay when present.
- **Sunken faces**, local depressions over decay pockets near the surface.
- **Staining or discoloration** from water exposure, including rust stains from hardware. Both are good indications of wetting.
- **Insect activity**: holes, frass and powder posting, which may also signal decay.
- **Plant or moss growth** in splits, cracks or soil buildup, showing that nearby wood has been wet enough to decay for a sustained period.

Probing

Probing with a moderately pointed tool such as an awl or knife finds decay near the surface through excessive softness or little resistance. Interpreting it takes experience. Water-softened sound wood is softer than dry wood, and soft species such as western redcedar are hard to assess.

Pick test

A pick, awl or screwdriver is driven a short distance into the wood and used to pry out a sliver. Sound wood is fibrous and splinters across the grain. Decayed wood breaks abruptly, which the chapter calls "brash," or crumbles. Studies cited in the chapter show the test is reasonably reliable for surface decay. Its drawback is that each test removes a large sliver, which then needs preservative.

Pilodyn

The Pilodyn is a spring-loaded device that drives a hardened steel pin into the wood, with penetration depth as the measure of decay. The chapter says it is widely used in Europe, where soft rot is more common, and that it can give an accurate assessment of surface damage if corrected for moisture content and species.

Detecting interior deterioration

Interior decay may show no outward sign, so the chapter describes a range of tools, from a hammer to radiography, plus moisture meters to find conditions that favor decay.

Sounding

Sounding is striking the surface with a hammer and listening. It is one of the oldest and most common methods. A trained inspector reads dull or hollow sounds as possible large voids or decay. The chapter's cautions: factors other than decay affect the sound; sounding gives only a partial picture; and it will not detect incipient or intermediate decay. It is still useful for quickly finding seriously decayed members, but suspected decay must be confirmed by boring or coring.

Moisture meters

A resistance-type moisture meter measures electrical resistance between two pins driven into the wood. Readings must be corrected for temperature and are most accurate between 12 and 22 percent moisture content. Pins are available for depths up to 3 in. The meter does not detect decay, but it is recommended for an initial check of suspect areas. Readings over 30 percent indicate conditions suitable for decay, unless the wood there is treated and the treatment envelope is unbroken. After an unusually long dry spell, the chapter says 20 to 25 percent should be treated as potentially hazardous.

Shigometer

The Shigometer sends pulsed current through a twisted-wire probe placed in a small drilled hole and detects the drop in resistance associated with decay. Zones where readings fall to 50 to 75 percent of sound wood are then bored. It works well in living trees, but the chapter says wood in service is normally too dry for it. Studies still found it reasonable under proper conditions with trained operators.

Drilling and coring

The chapter calls drilling and coring the most common methods for detecting internal deterioration in bridges. Both find voids and measure the thickness of the remaining sound shell.

- **Drilling** uses a 3/8 to 3/4 in. bit in a power or hand-crank drill. Power drilling is faster. Hand drilling gives a better feel and may find pockets better. The inspector notes where the bit suddenly goes easier (torque release) and examines the shavings for decay. Knots, resin pockets and abnormal grain must not be mistaken for decay. If decay is found, the hole can be used to apply remedial treatment.

- **Coring** with an increment borer gives a solid core to examine. It can also measure preservative penetration and retention. Cores from structures not yet showing decay can be cultured for decay fungi. Finding fungi usually means incipient decay that should be treated, and the chapter notes many labs offer culturing. Culturing is not practical for external decay because of the many fungi near the surface.

Drilling and coring usually confirm areas flagged by moisture meters or other methods, then define the extent of decay. The chapter suggests drilling for the initial search and coring once decay is found, to find its limits and take samples. Tools must be sharp, and the inspector should carry spare bits and borers. Dull tools crush fibers and break cores in ways that can be mistaken for decay.

Shell-depth indicator

This is a metal bar, notched at the end and marked in inches. It is put into an inspection hole and drawn back along the side so the hook catches the edges of voids. The result is the depth of the solid shell, which the chapter says can be used to estimate residual strength. That measurement is the link to rating, discussed later in this course.

Sonic, X-ray and tomography

The chapter describes sonic wave velocity, acoustic emission and stress-wave methods as promising (in 1990) but notes that where defects are found, other methods are still needed to determine the cause. X-rays find internal voids and are particularly useful for insect and marine borer damage, but cost, radiation safety and the need for expert interpretation have largely ended their use in wood. Tomography scanners for poles were prototypes then. All of these have advanced since 1990, but the chapter's principle still holds: a nondestructive reading points to an anomaly, and drilling or coring identifies it.

Post-inspection treatment

Splinters, probe holes and borings can let decay in if left untreated. The chapter says:

- Treat all surface damage with liquid or paste preservative.
- For bore holes, squirt liquid preservative into the hole, then plug it with a preservative-treated dowel slightly larger than the hole.
- Creosote or copper naphthenate is generally enough for most bridge inspections. Where *Limnoria* are present, treat surfaces and plugs with waterborne salts. Where pholads may attack, use both creosote and waterborne salts.

Failing to do this, the chapter warns, can speed up decay. Check that any preservative used is currently registered and allowed by your agency, since the products named date from 1990.

Where decay starts: high-hazard locations

The chapter says decay is most likely where wood moisture is high and where breaks in the preservative envelope, or poor penetration, let organisms in. Signs of high moisture, and sites around fasteners, checks and mechanical damage, should be treated as areas of high decay potential.

End grain. End grain takes up water much faster than side grain. Permeability along the grain is 50 to 100 times greater than across it. Decay depends on moisture right at the infection, so a member can be dry along most of its length and badly decayed where untreated wood is exposed and water is trapped. Wood that looks dry may have been wet in the past and may already be decayed. Moisture also changes with the seasons and with maintenance or drainage changes.

Signs of wetting. Visual signs include watermarks, staining and light mud stains. "Intuitive" signs are horizontal surfaces, contact areas, depressions and other features that trap water.

Checks. Seasoning checks are common in large sawn members and less so in glulam. Even very small openings let decay organisms in. The chapter shows a sawn curb with interior decay that started in checks on its top surface.

Fasteners. Holes for bolts, nails and other hardware trap water, which capillary action draws deep into the end grain. Connections are more susceptible because fasteners are often placed in field-bored holes that were not properly treated.

Mechanical damage. Rough handling, overloads, vehicle abrasion and settlement break the treated shell. Depending on its location and extent, mechanical damage may also affect capacity directly.

These four points are a direct application of the preservative-treatment theme. Pressure treatment protects only the shell it reached. Every later cut, bore, check or gouge exposes untreated wood, and that is where decay starts.

Inspection procedure: from the office to the deck

The chapter divides inspection into preinspection evaluation, field inspection, and reports and records.

Preinspection evaluation

This office review collects the bridge's history. Previous inspection reports are among the best sources because they show current condition and where damage was found before. As-built drawings, or design drawings if as-builts are missing, give dimensions, species, grade and the type and retention of preservative. Specifications, material certifications, inspection records and even shipping invoices also help. Talk to people who know the site. Local experience is the best guide to decay potential.

Planning the field work

No inspection can economically examine every component. The inspector chooses the most probable locations of deterioration. If deterioration is found, its extent is defined and more locations are checked. The chapter says that if high-hazard zones are clean, other areas are unlikely to be affected. For example, it may not be practical to examine every deck fastener over every beam, so a representative sample of the worst-exposed ones is checked first. The plan must be systematic, and when several inspectors are involved their responsibilities must be clearly defined to avoid gaps or duplication.

The preferred sequence follows construction: an initial survey, then the substructure from the bottom up, then the superstructure underside, then the deck and rails. Working upward lets the inspector see members behave under load before inspecting them.

Initial survey

Walk across and around the bridge looking for obvious distress. Changes in longitudinal or transverse deck elevation may mean foundation movement or deck swelling. Slanted posts or separated rails may mean deck swelling or superstructure movement. Note drainage on the approaches, blocked deck drains and how well the deck and wearing surface protect what lies below. This is also when to make initial sketches and set the directions used to record findings.

Substructure

The chapter calls the substructure probably the most susceptible part. Soil-contact members are almost constantly wet, the soil holds fungal spores and woody material, and there is a lot of field cutting, drilling and penetrating fasteners. Key points:

- The most likely decay locations are near the ground line, at cap-to-column connections, and at connections for bracing, tie rods and backwall or wingwall planks.
- Remove soil around a representative number of members. In very wet or submerged soil, decay is generally limited to near ground level because of the lack of oxygen. In moderately dry soils it may occur at depths of 2 ft or more.
- Use visual observation and probing for surface damage, and drilling or coring to define it. Use sounding with drilling or coring for internal decay, never sounding alone.
- Check backwalls, wingwalls and bracing for breakage or bulging from earth pressure.
- Inspect pile and post tops. The chapter says tops cut at an angle in the belief that water will run off actually expose more untreated end grain. Check metal caps for holes or tears, because a damaged cap lets water in but restricts drying.
- Pile and bent caps are horizontal surfaces that trap debris and water. The cap-to-column connection is especially important: drift pins or bolts reach deep into the column end grain, and water from the cap can cause substantial internal decay with little exterior sign. The chapter shows a pile that looked sound until the cap was removed.
- Look for crushing at bearing points on the cap. It traps water and damages the shell, and it can indicate overload or load redistribution from settlement.

Superstructure underside

Inspect everything from below before going to the deck, since the deck and wearing surface hide critical parts. Work by zones rather than components to limit moving ladders or a snoopers. Water from the deck collects at interfaces, connections and checks, and decay there may show little on the surface.

- Use a moisture meter to find wet zones and make at least one boring in each high-moisture area. If decay is found, bore more to define it. If no decay is found but penetration is shallow or moisture is above 30 percent, take a core for culturing.
- The deck-beam interface is one of the most frequent decay areas. The hazard is highest where nails or lag screws penetrate the beam top. Glulam deck panels attached with bolted brackets do not penetrate the beam and add no significant hazard.
- Asphalt wearing surfaces filter runoff, so water stains under the deck are harder to see. If significant decay is found on beam tops, the chapter advises removing deck sections.
- Large checks or delaminations are uncommon in glulam and may indicate more severe structural problems.
- Check bearings that trap water or show crushing, and fasteners for bracing and diaphragms. Sagging, splintering or excessive deflection may mean mechanical damage or advanced decay.
- Surface decay on the side or bottom of a sawn beam in an apparently dry location is usually caused by incomplete preservative penetration of the heartwood, a treatment issue rather than an exposure issue.
- Nail-laminated decks often delaminate under dynamic load. Even where strength is unaffected, the gaps let water reach the beams. Nail-laminated and plank decks have the highest internal decay risk. Glulam panels fabricated before treatment are lower risk unless fastened with spikes or lags after treatment.

Deck top, rails and curbs

The deck top suffers traffic wear and collects water and debris. The chapter says partial wearing surfaces protect least, because the gap between running planks traps debris and moisture. Water can stand on watertight glulam or stress-laminated

decks between running planks, and moisture gets trapped under steel plate or full-plank surfaces fastened after treatment. Asphalt protects until it cracks from excessive deflection. Deck moisture averages about 20 percent but is often much higher. Where it is high, take cores near fasteners, and remove wearing surface if needed.

Rails and curbs are often ignored, the chapter says, though they matter for user safety. They are exposed to weathering, checking and impact, and are usually installed last with more field cutting and boring. A very likely decay location is an approach rail post embedded in concrete. The chapter shows such a post decayed, with the concrete spalled by freezing water trapped in the post cavity.

Reports and records

The chapter says the report is the only means of communicating what was found. It serves to:

1. identify conditions that limit capacity or make the bridge unsafe;
2. build a chronological record and provide data for structural analysis when conditions change;
3. identify current and future maintenance needs through early detection of defects; and
4. provide a reference for future inspections and comparison.

It is also a legal record that may matter in later litigation. Each report should include a title page; drawings or sketches with all components labeled; a condition assessment by component; a narrative summary; and recommendations for maintenance and corrective action. Large structures suit a notebook format, small ones standard forms. A complete report should be prepared every time, even if nothing seems to have changed.

For timber specifically, the chapter says it is critical that all decay and its location be accurately and completely described. That means the component, the location along and across the member, and the longitudinal and transverse dimensions of the decayed wood. It also helps to note the probable source of water and its path to the decay. Record signs of weakness: excessive deflection, crushing, buckling, cracking, loose joints or displaced members. Recommend further investigation when you lack training or equipment for something. Use sketches and photographs freely, with at least a roadway photo looking down the bridge and a side elevation. Summarize general condition and significant deficiencies, and estimates of repair materials and labor may be included.

A good timber decay record, for example: "Bent 2, pile 3 (from upstream), 0.5 ft above ground line, upstream face: torque release at 2 in. depth in 3/4 in. drill hole; shell-depth indicator shows 1.5 in. sound shell around a void about 6 in. across; void extends from 0.5 ft below to 1.5 ft above ground line in four holes (sketch 4). Moisture 38 percent at 2 in. Water source: ponding at ground line. Holes treated and plugged." (Illustrative entry.) The engineer can rate the pile from that.

Preservative treatment issues and in-place treatment

Many findings in timber inspection are really treatment findings. From Chapters 13 and 14, an inspector should look for these treatment issues:

- **Breaks in the treated shell:** field cuts, field-bored holes, checks that open past the treated zone, mechanical damage, and inspection holes left unplugged.
- **Incomplete penetration,** especially into heartwood of sawn members, which shows up as surface decay in apparently dry locations. Cores can measure penetration depth and retention.
- **Exposed end grain** at pile tops, angled cuts, beam ends and rail posts.

- **Organisms that tolerate treatment:** Formosan termites, *L. tripunctata* on creosoted wood, *Sphaeroma* with copper, and carpenter bees in arsenical-treated wood above ground.
- **Leaching and detoxification:** wetting cycles can leach preservatives and heartwood extractives, and stain fungi and bacteria can degrade surface preservatives.

Maintenance categories

Chapter 14 divides timber maintenance into preventive maintenance (conditions for decay are present but decay has not started), early remedial maintenance (decay is present but does not yet affect capacity) and major maintenance (members have moderate to severe strength loss and repair or replacement is mandatory). An inspector's findings should make it clear which category applies.

Surface treatments

Chapter 14 describes surface treatments as protection for newly exposed untreated wood, or as a supplement to the original treatment. They are most effective before decay starts, applied to checks, splits, delaminations, mechanical damage and field-fabricated areas. Their shallow penetration limits them against established internal decay. Liquids are brushed, squirted or sprayed. The chapter names heated creosote as probably the most common, with penta and copper naphthenate also used. Pastes are used at the ground line of posts and piles, from several inches above to 18 to 24 in. below the ground line, then wrapped with polyethylene or another impervious material. Wet wood absorbs less, and the chapter cites tests showing improved treatment of wet wood at double the normal 3 to 5 percent concentration. Although field tests showed protection for up to 20 years or more, it recommends reapplying bridge surface treatments every 3 to 5 years.

Fumigants

Fumigants are placed in prebored holes and volatilize into toxic gases that move through the wood, killing decay fungi and insects. The chapter says they can diffuse 8 ft or more along the grain in vertical members and about 2 to 4 ft in horizontal members. Points relevant to inspectors:

- Fumigants must go into sound wood. In porous wood or near the surface, gas is lost to the air. The boring pattern should avoid fasteners, checks, badly decayed wood and other openings.
- Holes in piles are bored at a steep downward angle (45 to 60 degrees) toward the center to avoid crossing checks. In horizontal members, holes are bored in pairs straight down to within 1-1/2 to 2 in. of the bottom, on both sides of large checks, with pairs no more than 4 ft apart.
- Holes are plugged with tight-fitting treated dowels, leaving 1.5 to 2 in. of room with liquid fumigants.
- The chapter reports Vorlex and chloropicrin remaining effective 10 to 15 years in properly treated solid wood, with Vapam somewhat less. Until better data exist, it recommends a 10-year treatment cycle with inspection every 5 years. Active decay found in inspection means the fumigant has fallen below a toxic threshold and retreatment is needed, usually through the same holes.
- Keep accurate records of all in-place treatment: date, location, chemical and dose. Some states require this. Metal tags on members help, but they can be stolen and should not be the only record.

Chapter 14 also stresses that these chemicals are toxic. They must be used according to state and federal law and applied only by trained, licensed personnel. Product names and registrations have changed since 1990, so the inspector's job is to record what was found and treated, and the agency decides what products may be used.

From findings to rating: strength loss and residual section

Section 13.5 of the chapter connects inspection to load rating. Decay causes progressive strength loss that depends on the area infected and the stage of decay. At the intermediate and advanced stages, no strength remains in the infected area, and the affected zone can be defined with some certainty. At the incipient stage, detection is much harder. The chapter cites studies showing strength loss from some brown rot fungi as high as 50 to 70 percent at weight losses of 3 percent or less.

That matters for bridges, the chapter explains, because most bridge decay is brown rot; incipient brown rot is hard to detect; brown rot effects extend well beyond visible decay; and brown and white rot cannot be told apart in the field. Its recommendation: assign no strength to wood showing evidence of decay at any stage. This may be slightly conservative, but the chapter calls it the only safe approach, because cores may miss part of the infection and decay will continue unless it is arrested.

Turning shell measurements into section properties

In practice, the inspector measures the sound shell with drilling, coring and the shell-depth indicator, and the engineer computes section properties using only that sound wood. The examples below are illustrative geometry, not code checks. Allowable stresses, load factors and rating methods come from the governing AASHTO and agency documents, which this course did not review.

Example 1, illustrative: hollow pile. A 12 in. diameter pile has an internal void, and the shell-depth indicator shows a 1.5 in. sound shell all around, leaving a 9 in. diameter decayed core counted as zero.

- Full area = $\pi(12^2)/4 = 113.1 \text{ in}^2$. Void = $\pi(9^2)/4 = 63.6 \text{ in}^2$. Sound area = 49.5 in^2 , or 44 percent of the original.
- Full section modulus = $\pi(12^3)/32 = 169.6 \text{ in}^3$. Hollow section modulus = $\pi(12^4 - 9^4)/(32 \times 12) = 116.0 \text{ in}^3$, or 68 percent of the original.

The lesson: decay at the core costs more axial area than bending resistance, because the outer fibers carry most of the bending. But a 1.5 in. shell is also vulnerable to local crushing, splitting and further decay, and the void found in one plane may not be uniform up the pile. Several holes around and along the member are needed to justify an assumed uniform shell.

Example 2, illustrative: stringer decayed at the top. A 6×16 in. (nominal shown as actual for simplicity) sawn stringer has decay at its top, under spiked deck planks, to a depth of 2 in. across the full width. Counting that 2 in. as zero leaves a 6×14 in. section.

- Section modulus: original $6(16^2)/6 = 256 \text{ in}^3$; reduced $6(14^2)/6 = 196 \text{ in}^3$, or 77 percent.
- Shear area: original 96 in^2 , reduced 84 in^2 , or 88 percent.

The loss in depth reduces bending capacity more than shear capacity, and it also affects stiffness and the deck fastening. If decay is local, near the bearings for example, the engineer compares the reduced section with the demand at that location, not with midspan moment.

Example 3, illustrative: decay at a cap connection. A bent cap shows crushing at a bearing point, and coring finds decay 3 in. deep under the bearing. The issue here is bearing perpendicular to grain and the connection, not flexure. The record needs the bearing area, the depth and extent of decay, and the condition of the drift pin and the column top below.

What the inspector owes the rating engineer

- Actual member dimensions, species and grade if known (from drawings or markings), and the type of member (sawn, glulam, nail-laminated or stress-laminated).
- For each decay finding: location, sound shell thickness in several directions, length of affected zone, and how many holes defined it.
- Moisture readings and the water source, so the engineer can judge whether decay will continue.
- Mechanical damage, crushing, checks, splits, delaminations, and loose or corroded connections.
- Any treatment done, so the next inspection knows where the plugs are.

Because decay keeps growing unless arrested, a rating based on residual section should be paired with a maintenance recommendation. Use early remedial treatment if capacity is not yet affected, and major maintenance or load posting if it is.

Field checklist

A short checklist distilled from Chapters 13 and 14. Adapt it to agency forms.

- **Office:** previous reports, as-builts, species, grade, preservative type and retention, treatment records, local decay hazard.
- **Kit:** strong light, hammer, awl or pick, moisture meter with temperature correction, hand and power drill with sharp 3/8 to 3/4 in. bits, increment borer and spares, shell-depth indicator, preservative and treated dowels slightly larger than the bit, scraper (marine), camera and sketch sheets.
- **Survey:** deck profile, rail alignment, drainage, wearing surface condition.
- **Substructure, bottom up:** dig at the ground line on a representative number of members; check pile tops and caps, cap-to-column pins, bearing crushing, bracing, backwalls and wingwalls; in salt water, inspect at low tide for Limnoria, and use sonic methods or a specialist for shipworms.
- **Underside:** moisture readings and borings at deck-beam interfaces, fasteners, checks, bearings and bracing connections; look for delamination, sag and splintering.
- **Deck and rails:** wearing surface gaps and cracks, cores near fasteners where wet, rail posts in concrete, curbs and wheel guards.
- **Every hole:** treat and plug.
- **Report:** location and dimensions of every decay zone, water source, sound shell, photos (roadway and elevation at minimum), maintenance category and recommendations.

A final reminder from the chapter: record all deterioration accurately, whatever its apparent effect on capacity. The decision about its structural significance belongs to the engineering analysis, and that analysis can only use what the inspector wrote down.

Key takeaways

- Decay needs moisture, oxygen, suitable temperature and food; wood below about 30 percent moisture content (fiber saturation) generally will not decay, and breaks in the preservative envelope let organisms reach untreated wood.
- Brown rot, the most common bridge decay, can cut some strength properties by up to 60 percent at 1 to 5 percent weight loss and extends beyond visible decay, so EM 7700-8 assigns no strength to wood showing decay at any stage.
- Visual inspection, probing, the pick test and sounding find surface or advanced damage; moisture meters flag hazard; drilling and coring, with a shell-depth indicator, confirm and define interior decay.

- Concentrate on ground lines, pile tops and caps, cap-to-column drift pins, deck-to-beam fastener holes, checks, bearings, field-bored holes and rail posts set in concrete; inspect from the substructure upward.
- Treat every inspection hole with preservative and plug it with a treated dowel, record the extent and water source of all decay, and base ratings on the measured sound residual section.

References

1. Ritter, M.A., Timber Bridges: Design, Construction, Inspection, and Maintenance, USDA Forest Service EM 7700-8, 1990
2. USDA Forest Products Laboratory, Wood Handbook: Wood as an Engineering Material, FPL-GTR-282, 2021
3. FHWA, Bridge Inspector's Reference Manual (BIRM), FHWA-NHI-12-049, 2012 (as revised)
4. Ritter, M.A., and Morrell, J.J., Chapter 13, Bridge Inspection for Decay and Other Deterioration, in Timber Bridges: Design, Construction, Inspection, and Maintenance, EM 7700-8, USDA Forest Service, 1990.
5. Ritter, M.A., Chapter 14, Maintenance and Rehabilitation of Timber Bridges, in EM 7700-8, USDA Forest Service, 1990.

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.