Biodegradation of Untreated Wood Foundation Piles In Existing Buildings Part 1 – Investigation

By Milan Vatovec, P.E., Ph.D. and Paul L. Kelley, P.E.

When wood foundation piles deteriorate, they can become incapable of supporting the buildings founded on them. This article, Part 1 of a 3-part series on pile biodegradation, discusses the available investigative techniques aimed at quantifying, understanding, and preventing biological deterioration of untreated wood foundation piles that result in settlement of numerous buildings in historic cities throughout the U.S.

A large number of existing masonry and other structures built close to a century ago in numerous cities, predominantly in the northeastern U.S., bear on untreated wood-pile foundation systems. Due to insufficient soil bearing capacity, piles were typically driven through soft soils (i.e. urban fill) into stronger load-bearing strata, which are often more than 20 feet below the ground surface.

At the time of construction, piles were generally cut-off below the lowest expected elevation of the groundwater table. When most of these structures were built, chemical preservatives did not exist, and the protection strategy was based on the common assumption that no significant fungal deterioration - the main biological-deterioration mechanism - can occur due to lack of oxygen in a submerged condition.

However, groundwater levels in many cities receded over the years, resulting in exposure of pile tops to oxygen, subsequent accelerated deterioration, and ultimately, significant settlement of structures. Groundwater depletion can be attributed to many factors, the most significant of which is creation of man-made underground structures that cause localized water drawdown (i.e. leakage into sewers, basements, subways, etc.).

Figure 1: Cracks over doors or floor/frame misalignments are usually good indicators of settlement problems.

Recently, localized groundwater drawdown and the ensuing potential for accelerated foundation deterioration have been recognized as a very costly issue in older, historic cities. Also, questions have recently been raised about service-life limits of untreated wood piles (caused by alternate deterioration mechanisms), even if pile tops remain submerged throughout their entire service life.

Figure 2: To access the piles, dewatering is often required. Depending on the pit size, only a limited number of piles can be accessed.

Problem Detection

Detection and quantification of settlement problems is not simple. For example, if numerous stepped cracks in exterior masonry, sloped floors, and uneven door frames are observed (*Figure 1*), it can be reasonably concluded that the building is likely experiencing differential settlement. Combining these observations with the knowledge that the building is supported by untreated piles (if drawings are available), and that it is located in a known groundwater-depletion area, one can start to suspect the wood piles. However, based on this knowledge alone, it would still be impossible to determine whether the settlement is caused by wood-pile deterioration or by the overall pile down-drag.

Figure 3: Piles should be probed from various angles and penetration depths should be recorded.

In the other extreme, the buildings may not show any outwardly visible problems for extended periods of time, yet the piles can be seriously compromised, even to the point where they have lost structural capacity to adequately carry load. This could be the case if the building is settling uniformly due to absence of variably stiff supports or constraints within the footprint, if the support is temporarily provided by (or transferred to) soil, undamaged piles, or the adjacent-building foundations, and/or if the building distress was repaired in the recent past. Therefore, the only reliable method to assess the foundation is to expose representative wood piles through excavation of exploratory test pits, and examine the pile tops up-close.

Problem Quantification

Up-Close Investigation

Once exposed (*Figure 2*), an engineer must evaluate the condition of the piles and the prevailing environment in order to extrapolate the findings to the remaining piles and to the building as a whole. This is often a difficult task, given

Figure 4: Due to limited access to piles, only a limited number of cores can be obtained.

the intricacies associated with variability in wood and soil properties, multitude of deterioration mechanisms, limited sample size, etc.

The engineer should set out to methodically obtain all available information. This includes carefully documenting the geometry of the foundation walls and pile caps, pile layout (size and spacing), and soil makeup. Soil and water samples can be collected for future sieve, ph, and other analysis. Groundwater elevation and any fluctuations should be recorded. Any potential effects of pumping on the groundwater table should be evaluated and, if found to influence groundwater levels, eliminated before readings are taken again.

Piles should be visually and photographically documented, and any signs of distress, discoloration, deterioration, or loss of wood material noted. The inspector should determine whether the piles are in contact with the pile cap, and over what percentage of the cross-sectional area. Also, an attempt should be made to document the amount and type of deterioration at the very top of the pile, and whether any compression (crushing), or softening of the wood has occurred at the top. In many cases, settlement occurs due to drastically different material characteristics of the very top of the pile (top ½ inch or so), even though the remainder of the pile is assessed as sound.

Piles should be probed in a systematic manner with a sharp object, and depths of penetration recorded (*Figure 3, see page 9*). In addition, piles should be cored at various locations (*Figure 4*) to extract samples (usually ¼ or ½ inch diameter cores through the pile center) for subsequent laboratory work. Also, to determine the relative remaining strength of the pile in situ, a resistograph, a core-boring instrument that registers the "resistance" of the core as it is penetrating the pile, can be used. The instrument detects "soft" areas of wood, and, if used properly, can yield useful results.

If possible, entire pile cross sections, approximately 2-3 feet long, can be extracted and taken to the laboratory for additional testing (*Figure 5*). Temporary shoring may be needed during this operation, depending on the stability of the granite or other foundation elements above the cut pile. After extraction of the pile top, the remaining pile "stub" can be load-tested in accordance with ASTM standards to estimate the overall load-carrying capacity of the foundation system. Using the pile cap as a reaction, loads (applied by hydraulics) and deflections can be continually measured until the pile can no longer take additional load.

Figure 5: Removal is often difficult because the pile may be carrying significant load. The underside of the pile cap may require shoring to maintain stability.

In addition to the load test, non-destructive test methods, such as impact-echo, can be used to estimate pile length(s). The length of the pile is estimated based on the time the impact signal, sent through the top of the stub, needs to return after it rebounds from the pile tip. Other stress-wave-based, non-destructive tests have reportedly been found useful in detecting areas of deteriorated wood on the pile interior. It is debatable if the gradual change in material characteristics from the surface inwards, typical for wood piles, can be captured with these instruments, and whether the remaining strength can be accurately estimated, but these methods might be useful in determining locations for core sampling.

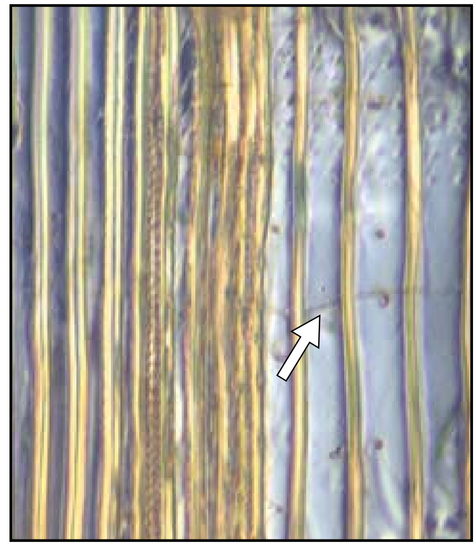

Figure 6: Microscopic evaluation identifies fungal hyphae penetrating cell walls.

Before the pit is backfilled, the removed pile section(s) should be replaced with another structural element, designed and inserted so that it will be able to transfer the same amount of compressive load as an undamaged pile. The "replacement section" could either be a concrete element, a steel element, or a steel element encased in concrete.

Laboratory Work

In cases where deterioration is not extensive and clearly not due to obvious lengthy depletions of groundwater table, information obtained in the field, regardless of how comprehensive, will not necessarily allow an engineer to determine the type, extent, and significance of the decay problem, as well as

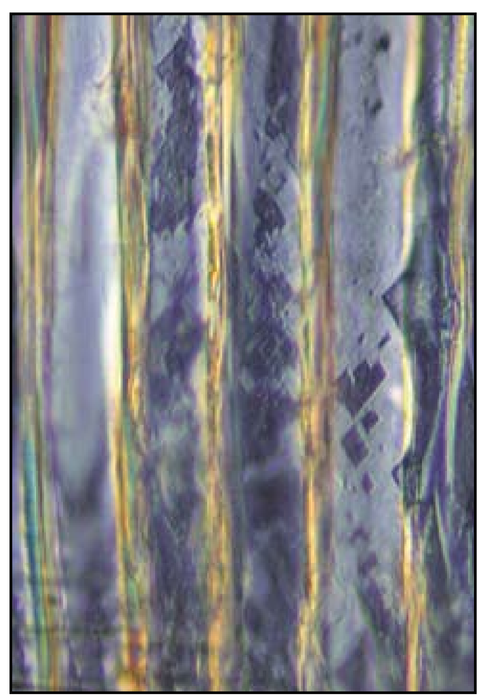

Figure 7: Diamond-shaped cell-wall erosion typical for soft-rot decay.

the appropriate remedial action. For instance, what appears and feels like only surface-damaged wood, may be incipiently-decayed material that has already lost a significant percentage of its strength. Therefore, hand-tool probing and visual inspection are often insufficient to "quantify" the real condition of the material.

Follow-up laboratory investigation, if budget allows it, often involves detailed macroscopic evaluation of samples obtained in the field, microscopic analysis of pile samples for presence of fungal hyphae and for cell-wall erosion evaluation (including bacterial action) (*Figures 6* and *7, see page 10*), and mechanical-strength tests of small samples.

Compressive strength tests on standardized small clear specimens (*Figure 8*), strategically retrieved from various pile locations, can reveal strength and stiffness trends across the pile length and cross section, including the relative depth and extent of deterioration. The attack typically occurs from the outside of the pile inward, and from the top down. Also, by comparing test values to published strength and stiffness values for a given species and moisture content, compressive tests can offer insight into the overall loss of strength or stiffness due to deterioration.

Additionally, entire pile cross sections can be tested in compression until failure (*Figure 9, see page 12*). These tests can be good indicators of the remaining strength of the pile, but determination of the remaining stiffness, often the critical element to understand the potential for settlement, can be difficult if variable zones of soft, deteriorated wood exist across the cross section. If only one pile cross-section is obtained in the field, doing a number of small-clear specimen compressive tests will usually yield better and more comprehensive information than doing one full-section test.

In general, without accurate interpretation of laboratory results, determination of the extent, significance, and future risks associated with the deterioration would be extremely difficult.

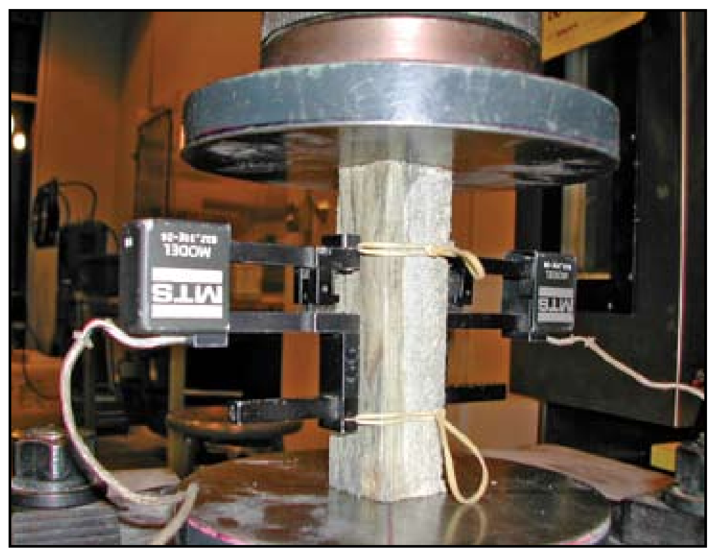

Figure 8: Compressive test of small clear specimens. Load and displacement is measured throughout the test.

In the Office

Before finalizing the evaluation and providing recommendations for future action, an engineer should attempt to obtain any other available information that would potentially help explain the conditions found at the building. This typically includes search of local history books and building-department

Figure 9: Load test of a full pile cross section.

records to determine if neighboring buildings, presumably of similar construction, have had similar problems. Past violations, pile-repair permits, or extensive façade repairs (potentially done to hide settlement cracks) could be good indicators of past problems, which would in turn, indicate potential for problems at the building in question. Searches through other databases, such as governmental agency web sites with observation-well or other groundwater data, can help understand the groundwater trends, and in turn help understand the magnitude or potential for the long-term problem at the property in question.

Conclusions

Once a wood-pile settlement problem is suspected, the only reliable method to assess the type and extent of biodeterioration is to examine the piles in situ and during subsequent laboratory tests. This information will allow an engineer to sufficiently estimate the overall condition of the foundation system, and whether the piles are adequate to continue carrying the building loads. In addition, thorough investigation will allow better understanding of the biodeterioration mechanisms, of the prevailing environment in which they operate, the likelihood for continuing deterioration, and identification of the appropriate repair method.

However, the overall current approach to identifying the problem and the appropriate further action can at best be characterized as a belt-and-suspenders approach, a game of clues in search of the appropriate answer. Outside of the obvious, clear-cut cases of decay due to known groundwater depletion, the evaluation process is difficult and requires immense hands-on experience. Guidance from previous research is scarce, proven methods do not exist, and almost every project ends up providing a unique set of challenges. More research is needed to expand the current state of knowledge.▪

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Part 2 in this series of articles will focus on the common untreated pile biodeterioration mechanisms. Part 3 will discuss remediation methods.

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