Biodegradation of Untreated Wood Foundation Piles In Existing Buildings

Part 2 – Deterioration Mechanisms

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Wood-destroying fungi are the predominant damaging biodeterioration agents affecting the performance of untreated wood piles supporting historic buildings today. At the end of the 19th and beginning of the 20th centuries, when this type of building construction was common in urban-fill areas in the northeastern U.S., biodeterioration was not anticipated. Piles were generally cut off below the lowest expected elevation of the groundwater table, and the protection strategy was based on the common assumption that no significant fungal deterioration can occur due to lack of oxygen in a submerged condition. Unfortunately, groundwater levels in many cities receded over the years, resulting in exposure of pile tops to oxygen, subsequent accelerated biological deterioration, and ultimately, the significant settlement of structures.

Figure 1: Pile deterioration is so severe that contact with the underside of the pile cap is lost. Note the pencil-top shape indicating attack direction (outside-in).

Part 1 (STRUCTURE® magazine, June 2007) of this three-part series described common investigation procedures and methodologies for assessing the type and extent of deterioration, as well as risk for future settlement damage. This second installment discusses wood destroying fungi and other biological deterioration agents and the associated main deterioration types, as well as how they relate to predominant conditions found in soil environments.

Wood Destroying Fungi

Contrary to boring-type damage caused by insects and marine borers, microbiological attack by fungi (and bacteria) causes wood to undergo chemical changes that result in degradation of mechanical properties, loss of material, and, if left unaddressed, complete destruction.

For a fungal attack to occur, special conditions have to exist. Wood-destroying fungi require sufficient moisture, sufficient oxygen, favorable temperature, and available food source to flourish. If any of these components are not present, deterioration will be greatly impeded. Some varieties of fungi are more tolerant of extreme conditions – for example where little oxygen is available. However, unfavorable conditions typically reflect on the rate of attack and the damage is very slow.

Fungal deterioration is also cumulative over time. In other words, when conditions are favorable, deterioration occurs. When conditions worsen – for example, when the groundwater rises above the pile tops and stays high for prolonged periods of time (in excess of 2-3 months) – the decay attack would become dormant. If conditions become favorable again, the attack would resume. Theoretically, piles could have already experienced a certain level of deterioration, but that deterioration could have happened decades ago. There are no scientific methods to microscopically or otherwise date-stamp decay damage.

In addition, the actual extent and rate of decomposition will depend on a number of additional variables, including:

- soil makeup,
- nature of oxygen exposure (water fluctuation),
- presence of chemicals in the soil or water,
- wood species and their natural decay resistance, and
- individual pile properties (*Figure 5, see page 55*).

For example, pile tops surrounded by clays can last much longer without significantly decaying even if the groundwater drops, because oxygen is less available in clay than in sands and other more-permeable soils typically found in urban fills.

Therefore, estimation of the length of exposure and duration of biologial attack, determination whether the attack is active or not, and approximation of the remaining pile service life is sometimes very difficult based on observed damage alone (whether macroscopic or microscopic). (*Part 1 in this series on pile biodeterioration describes the investigative process and methodology, including how to consider the multitude of potentially significant factors that influence pile deterioration.*)

Recently, development of wood preservatives has helped minimize the effects of biodeterioration in sensitive, high-risk applications such as utility poles, marine piers, or foundation piles.

Unfortunately, wood piles driven into soils before preservatives were invented cannot be effectively treated in situ, and therefore cannot benefit from recent technological advancements. Sadly, sporadic research has been done to date to address this issue. Very little is known about the actual types and rates of deterioration, or about the conditions needed for deterioration. No effective prevention methods exist, and repair of damage remains very costly and difficult.

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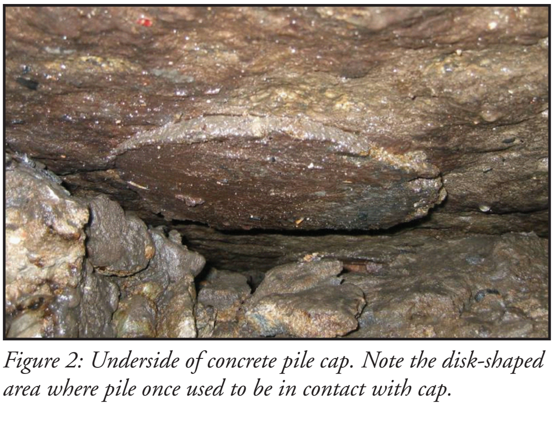

Figure 2: Underside of concrete pile cap. Note the disk-shaped area where pile once used to be in contact with cap.

White and Brown Rot

Figure 3: This interior pile, once the column footing was removed, showed no resistance to probing. Groundwater receded a long time ago.

Due to the severity of their attack, white and brown rot were until recently considered the only significant biological wood-destroying agent. When the conditions for their growth are favorable, they dominate any other form of biological attack. White and brown-rot fungi prefer prolonged non-submerged conditions, with soils rich in oxygen that becomes available after the groundwater table drops. If the wet-soil driven wood moisture content is in the 40% to 70% range, wood-cell lumens will not be completely saturated. On the other hand, the proximity of groundwater does not allow the wood to completely dry out, and deterioration can be "fueled" for a long time, until environmental conditions change. Under these conditions, white and brown rot will quickly consume the wood material. Complete destruction of the pile cross section can happen in three to seven years of cumulative exposure. Because of such severe consequences, brown and white rot are considered the most economically significant biological agents for untreated piles in soils. Prolonged exposure to oxygen due to groundwater-table drop is considered the number one threat to untreated wood piles.

When in advanced stages, white and brown rot damage can be identified and assessed by field investigation alone, without the need for additional laboratory investigation. Typically, in such cases:

- the appearance and structural makeup of the exposed piles are obviously altered;
- pile tops are soft and punky;
- shape and cross section near the top are changed - i.e. pencil-top-like, or a complete disconnect with the underside of pile caps (*Figures 1* and *2*);
- piles provide no significant resistance to probing (*Figure 3*) and provide no meaningful support for the structure; and
- the groundwater table is often found to be below pile tops, or even worse, the soils can be dry (*Figure 4*). This also probably means that the groundwater table had likely dropped and stayed low for prolonged periods of time, exposing the pile tops to oxygen and allowing significant deterioration.

In other, less severe cases, it can be very difficult to determine what type of deterioration is present, and what the predominant environment in soils surrounding piles is based on in-situ observations alone. For instance, if conditions favorable for growth of brown and white rot existed only a short time, the extent of decomposition would not be very obvious, and the actual damage may not be apparent, could resemble other types of damage, or could only become visible if the piles are dried out.

In such cases, the evaluation procedure described in Part 1 of this series will likely be required to determine the significance and type of attack.

Soft Rot

If the frequency of groundwater-table fluctuation is high, such as in soils affected by tidal action, the nature of attack and biological agents causing it will likely be different than described above. When pile tops are alternately submerged and then exposed to oxygen on a daily basis, the moisture content of wood remains too high for white and brown rot fungi to thrive.

Figure 4: Excavation revealed decayed piles. Groundwater was not encountered and the soil is dry.

The wood-cell lumens are saturated with water and oxygen is scarce – available on a twice-daily basis predominantly near the pile surface. Under such conditions, species belonging to a variety of fungi known to cause soft rot will likely be the main source of deterioration. Soft-rot fungi, whose "attack" is significantly slower than that of the white or brown rot species, can succeed in these conditions.

Soft rot got its name because of softening of the wood surface under attack. Contrary to some traditional beliefs, pile damage due to soft rot can be significant and confined not only to the surface, especially if conditions as described above existed for a number of years. Piles under a soft rot attack typically retain their visual appearance (*Figure 6, see page 56*), but the changed mechanical properties, including obvious softness to probing, can extend deep into the cross section.

Although exposure to oxygen (by water drawdown) and subsequent attack by wood-destroying fungi is by far the most significant mechanism for pile deterioration, very slow deterioration, attributed either to bacteria or to soft rot, can occur in situations where piles were thought to be constantly below the groundwater table since installation. Unlike marine or bridge-pier applications, where piles are exposed to flowing and potentially more oxygen-rich water, the depth of soft rot attack in submerged and buried piles (or piles below the mud line in pier applications) is usually limited to the pile surface and would typically not exceed ½ inch of penetration. This is likely because the availability of oxygen in stagnant groundwater in soils is very low. Soft rot penetrations in excess of 1 inch were observed only where piles were thought to be under such conditions for a very long time (200 years or more).

Even though generally not expected to be a major contributor to the building-settlement problem, shallow fungal penetration and the associated superficial softening can also result in settlement. In addition to "attacking" the pile sides and working its way in towards the center, biological decay will also simultaneously attack the pile top, assuming that access is available. The space between the pile and underside of the pile cap is typically not sealed, the contact is not perfect, and therefore the "passage" through the pile top is potentially available. Pile tops will therefore also be subject to material-property change and softening, and some settlement can occur concurrently, even before the pile as a whole loses sufficient strength and stiffness. Experience indicates that all settlement caused by biological deterioration begins this way. The attack remains superficial, the settlement rate will be extremely slow, uniform, and will likely go unnoticed. If followed by additional deterioration, which results in further loss of cross section and degradation of mechanical properties, more significant movement and problems can be expected.

Bacteria

Bacterial attack on wood is probably the least understood deterioration mechanism. As mentioned before, some forms of bacteria can slowly degrade wood in anaerobic conditions. Similar to soft rot damage in submerged environments, bacterial damage remains superficial unless the piles have been in service for a very long time. Bacteria have been documented as capable of causing significant pile damage even in fully submerged conditions. The majority of these studies, however, are related to marine piles, and not buried piles supporting buildings. Bacterial damage, which is often found in piles together with soft rot, macroscopically resembles that of soft rot (i.e. it results in decomposition and softness of wood matter on the pile surface first). In fact, based on in-situ observations alone, it is difficult to determine whether the observed superficial damage is due to soft rot damage, bacterial damage, or a combination of both.

Marine Borers

Marine borers are usually recognized as a threat only to marine and bridge pier piles where wood is exposed to flowing water. However, they also appear to be able to attack building piles in soils below the groundwater table. During a recent project that involved a waterfront structure, significant pile deterioration caused by limnoria (gribbles) was found in a number of interior piles. The piles are buried in soil located on the land side of a granite seawall, and portions of some of the piles (mostly located within the tidal zone) were literally consumed by the borers (*Figure 7, see page 56*).

Figure 5: Exposed piles appear to be in good condition. Piles are thought to have continually been in a submerged condition – no damage is expected.

Portions of the backfill around the pile caps were found to be loose broken bricks with large voids. It is possible that some of the attacked piles were exposed to flowing tidal water through the porous brick backfill, and therefore to the borers. This project showed that a marine-borer attack cannot be excluded as a biodeterioration agent in buried piles with special soil conditions.

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Chemical Hydrolysis

Another potentially important wood-deterioration mechanism is the little-understood hydrolysis process, which is based on degradation of cellulose molecules due to prolonged exposure to water – in essence the water dissolves carbohydrates. This phenomenon, partially evidenced in archeological wood (wood cell structure can collapse when exposed to oxygen after centuries of submergence), has not been quantified or sufficiently evaluated in buried timber-foundation applications. This mechanism is likely very slow and not a factor unless piles are submerged for well over a century.

Discussion and Conclusions

This article presents a summary of various biodeterioration mechanisms encountered in practice and in literature. Identifying and understanding deterioration of wood piles, including all intricacies associated with their exposure during service life (morphological limitations of biological agents, rates of deterioration, etc.) should allow an experienced engineer to select an appropriate method for foundation remediation, if needed.

However, the current state of knowledge in this field has serious gaps with potentially significant economic consequences. For instance, current thinking suggests that the service life of wood piles is indefinite, as long as they are constantly kept fully submerged. However, it appears that given enough time, some of the slow deterioration mechanisms like bacteria or soft rot can eventually compromise the piles; albeit it is not fully understood how much time and what conditions are required.

Also, the exact nature of deterioration mechanisms, the rate of deterioration in favorable vs. unfavorable conditions, the rate of strength and stiffness loss, and significance of extraneous and internal parameters influencing deterioration (e.g. soil and wood type, presence of chemicals, dynamic of groundwater fluctuation, depth in soil, etc.) are typically not understood well enough to provide exact means for estimating remaining service life of foundation systems. The evaluation is further complicated because of the potential for existence of several concurrent or symbiotic degradation mechanisms, all of which might not be eliminated by a particular repair strategy. The great variability in wood pile properties and their response to various environments does not help the engineers either: often adjacent piles of the same species, presumably exposed to identical conditions in service, will exhibit completely different levels of deterioration. Alternatively, piles thought to be exposed to oxygen for a substantial time will exhibit much less deterioration then expected.

In addition, the available evaluation techniques are limited: reliable remote (from grade) or truly non-destructive (including chemical) methods for evaluation of piles do not exist. Also, there are no known methods for evaluation of changes (over time) in wood mechanical or chemical properties in situ. Finally, even when the piles are exposed through excavation, visual observation alone, and even microscopic examination of samples obtained from cores, do not allow for accurate estimation of the actual remaining strength of piles.

Figure 7: Marine-borer damage to a buried pile exposed through excavation (above). Limnoria exoskeleton is shown to the right. Live borers were also found.

To effectively and more globally tackle untreated-piles deterioration problems, it is important to streamline the current knowledge and direct future research toward resolving some of the key issues summarized above. The potential magnitude and economic impact of this problem is immense, especially in older cities with large historic building stocks.▪

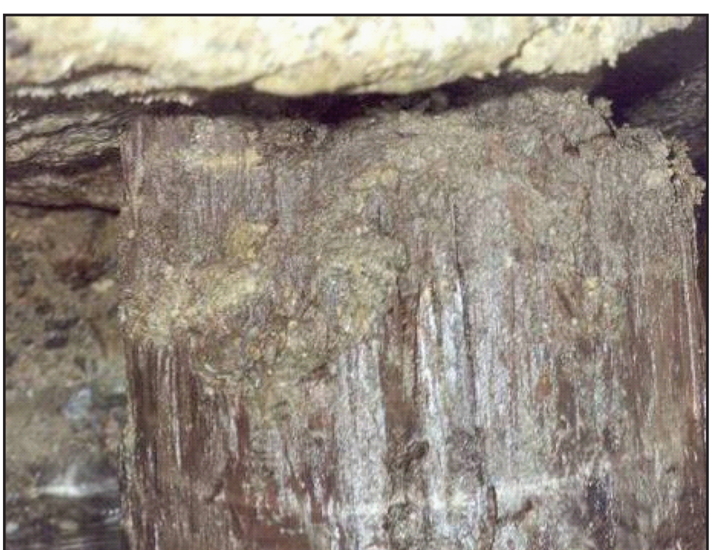

Figure 6: Pile appears in good condition, but later analysis found the pile to be significantly deteriorated. Groundwater is drawn down by pumping.

Part 3 of this series will discuss available remediation methods.

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