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# Klaassen - Baktierienbefall von Holz - Schutzmechanismen an Gebäuden und Hafenanlagen
# *Bacterial decay of wood – protection mechanisms for buildings*

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## ABSTRACT

Within constructions, bacterial wood decay is mainly a problem for wooden pile foundations. The development of this type of constructions started centuries ago and enabled man to build and live in strategic and fertile areas. Although the building methods, the building materials and the building regulations changed especially over the last decades, worldwide wooden pile foundations still fulfil their function to support above ground constructions of which many belong to our cultural heritage. In the Netherlands wooden foundations are a national bench mark and Amsterdam is often regarded as the City on wooden piles. The pile population in service in the Netherlands is estimated at 25 million and as they are carrying many ordinary family houses and water building constructions their importance is far beyond that of building history. Although wooden foundation constructions can behave well, there are several threats that cause instability and bacterial decay is one of them. This paper describes the mechanism of bacterial decay in wooden pile foundations and the attempts to develop an effective practical and cheap method to stop bacterial decay in wooden foundations in service.

Keywords: bacteria, decay, foundations, conservation.

## 1 INTRODUCTION

For centuries wooden foundations were used to support buildings in areas with weak soils. Despite their instability, estuaries, riverbeds and some of the peat lands were attractive living habitats because of their strategic position. The first settlements with small and light houses relied on soil improvements with closely spaced short piles. The dimensions and the weight of the buildings increased in time and asked for other construction of foundations with higher bearing capacity. Presently wooden pile foundations can be seen all over the world supporting many historical constructions like the old city centre of Venice near the Adriatic sea and river Po, the Indian Taj Mahal built in 1631, the 370 years old Royal Palace on the Dam square in Amsterdam and a huge number of common constructions (e.g. family houses in several Western Dutch cities, in highly populated Asian areas like Tokyo and Nagasaki; industrial buildings like the Speicher city of Hamburg or a sugar factory in Leeuwarden). Also many civil engineering constructions obtain their stability from wooden piling and are common in many harbour areas as quay walls, bridge heads and locks e.g. Boston near the Atlantic ocean and the river Charles, Rotterdam in the Dutch Rheine and Meuse delta. Beside the mentioned areas a substantial number of wooden foundation constructions were used near the Baltic sea e.g. Copenhagen, Stockholm, Saint Petersburg near river Neva, Helsinki near river Vantaa, Gdansk near the Vistula River complex (Aldrich and Lambrechts 1986, Ceccato and Simonini 2013, Christin 2013, Janse 2000, Keiser 2019, Klaassen et all 2005, Lionetto et all. 2014, Makoto Kimura personal communication 2014, Zhussupbekov, personal communication, 2013).

In the last century building regulations have been developed in order to increase proven safety of constructions. For foundations this led to an increase of the load bearing capacity resulting in a more common use of concrete piles and longer piles. As the early wooden pile foundation constructions were developed on the basis of experience, they are often thought not to be able to fulfil the actual requirements causing discussions when the actual status has to be evaluated. In the Netherlands in the last decades the number of wooden foundation constructions that were replaced increased. This was caused by the large problems that appeared from the nineties of last century onwards with the stability of houses in the cities of Haarlem, Dordrecht and Zaandam, which are mostly pine foundation piles of about 100 years old. Information on the actual stability of the construction was needed to enable the development of sustainable restauration or renovation building strategies. Until now thousands of wooden piles were investigated resulting in a rapid increase of knowledge on the foundation itself and on deterioration processes occurring in the Dutch situation. Untreated pine or spruce are the main timber species used as piles with head diameters of 10 – 30 cm and lengths varying between 4 and 18 meters. The foundation construction is always located under the ground water table (Klaassen 2014, Klaassen and Creemers 2012).

This paper summarizes the main causes of settlement of constructions standing on wooden piles and describes the results of the attempts to develop a conservation method against bacterial decay.

# 2 MAIN DETERIORATION PROCESSES

It is estimated that in the Netherlands approximately 25 million wooden piles are still functioning within foundation constructions. Approximately half of all these piles support civil engineering constructions and the other half are under buildings. Their ages vary between 600 and 50 years but most constructions are 80 to 120 years old. In the last 20 years over 10.000 piles were inspected and the wood quality of about 6000 piles was determined (Klaassen 2014). From all this work four main causes for foundation problems were recognized.

The first one is an inappropriate foundation construction where the cohesion of the construction is lost because of insufficient connection between the individual wooden elements or an insufficient connection between the foundation construction and the upper construction. Furthermore the position of the piles can be inappropriate: they are not fully concentrically positioned under the building walls or they even are positioned outside the building walls.

Negative skin friction is the second cause that results in too high settlements. In the Netherlands, not earlier than 1940 this extra load was recognized and taken into account in the design of the foundation construction. In older constructions, especially there where the street level was elevated by extra sand layers, the soil bearing capacity for the foundation construction appeared too low, resulting in settlements of 2 - 3 mm/year during many years. If the settlement was uniform for the building as a whole, the building was maintained but street level adaptations were necessary. In other cases massive repairs were needed. One should realise that settlements because of negative skin friction are long lasting processes that generally decrease in time. However settlements can increase again due to lowering of the groundwater table (climate change), extra elevation or temporary water extractions.

The third cause is a too low groundwater table which enables fungi to become active and deteriorate the upper foundation timber. The Netherlands are a patchwork of polders, each with its own water management. To establish a specific ground water level one has to deal with a variety of concerns e.g. dry streets as general starting point; the variety of different ground floor levels of buildings within one area where a submerged foundation for one owner can result in a wet cellar for another owner; farmers prefer a low ground water table in order to increase their crop growth; unexpected circumstances like broken sewerage systems, evaporating trees and increasing drought because of climate change; the creation of polders results in a general trend that the height of the street level in the west of the Netherlands is decreasing because of soil layers compression as a result of lower groundwater tables.

The fourth and final cause is wood decay under water by bacterial activity. In contrast to fungal decay, bacterial decay is not restricted to the upper part of the foundation construction but it is active along the whole pile axis and it is not related to drought but is strongly related to the quality of the wood (Klaassen 2008, Klaassen and Creemers 2012).

## BACTERIAL WOOD DECAY

Main type of bacterial wood decay occurring in foundation piles is caused by erosion bacteria. The patterns of bacterial wood decay are described not earlier than 30 years ago by Daniel & Nilsson (1986). In the decades that followed, the process of decay was studied and the first isolations of the degrading species were done in the beginning of this century (Björdal & Nilsson 2008). Where fungal decay is caused by single species, bacterial decay is caused by a consortium of species. A chain where each species relies on adjacent species. Active bacterial decay is established only when the species intermix and as the species are immobile they rely on external sources to move them. In wooden foundation piles this external source is water movement in the wood and therefore most permeable wood structures are most sensitive for erosion bacterial wood decay. These bacteria are common in all kinds of (wet) soils and are active in poor environments (e.g. less or no oxygen, limited amount of nitrogen), where fungal growth is difficult. They infect the wooden elements from the outside and enter the wood with flowing water. Their wood degrading velocity is slow e.g. in one year they can severely degrade a wood layer of maximum 1 mm. The mean severely degrading velocity in spruce piles is 0,18 mm and in pine piles is 0,32 mm per year (Klaassen 2014). As wood degrading bacteria rely on water transport they are active in the sapwood only. The heartwood of most timber species is water tight which reduces the bacterial activity in the wood until almost zero.

Where fungal decay occurs at the pile head only, bacteria degrade piles over their full length. Klaassen and Overeem (2012) show on a limited number of about 50 piles that the degree of bacterial decay varies between the pile head and tip. In most cases the degree of bacterial decay is most severe at the pile head but more research on extracted piles should be done for a better understanding of the processes that

causes a decay gradient over the pile axis. For the time being in the assessment of wooden piles it is assumed that the degree of bacterial decay at the pile tip is half of that at the pile head.
The degree of decay can be described on the basis of the anatomical degrading patterns and Klaassen (2008) showed a high correlation between the moisture content of bacterially degraded water saturated softwood and its compression strength. His model to estimate compression strength from the moisture content has an R2 of 0.78. The possibility to estimate compression strength provides an additional tool in the assessment of wooden foundation construction.

# 3 STABILITY QUANTIFICATION OF FOUNDATION CONSTRUCTIONS

Because of the deterioration processes the quality, and also the load carrying capacity, of all wooden foundations will decrease in time. As its present and future impact on the stability of the construction varies tremendously, a quality classification is needed, which indicates the present quality and future expectations, at least when the ownership will change and before construction, renovation and restauration building activities start.
The common method used in the Netherland is according to the F3O standards, done in an inspection pith and relies strongly on the use of a test hammer and wood sample analysis.
The test hammer is an apparatus that shoots a needle like pen (5 mm in round diameter and 50 mm length) into the wood. The velocity of the pen is calibrated

*Figute 1: Test hamer*

*Figure 2. Increment borer (diameter 10 mm)*

to be 5,05 (±0,11) m/s and the weight of the needle block is 460 (± 39) g. The execution of the measurements with the test hammer are easy and quick, also in a watery environment like a foundation pit. This enables the researcher to achieve several measurements of each of the wooden elements of the foundation construction (Fig. 1). The test hammer is developed to indicated the thickness of the soft shell, which is the outermost layer of a wooden element that is wood severely degraded by bacteria. It is assumed that bacteria degrade wooden elements homogeneously from the outside towards the inside.

Wood samples are taken with an increment borer (Fig 2) and in the laboratory the wood species, density, amount of sapwood, moisture content (actual and water saturated), type and degree of decay is determined. The results give information on the activity and the velocity of the bacterial decay. The actual moisture content gives an indication of the risk of too low ground water tables.

As the soft shell lost more than 80 % of its strength the pen of the test hammer always fully penetrates this layer. In situations where the bacterial decay is not active, there is a sharp boundary from the soft shell towards the sound, strong timber. The penetration depth of the pen is in this situation always ±5 mm around this boundary. However, in situations where the bacterial decay is active, there is a gradual increase in strength from the soft shell until the sound timber. In this situation, the penetration depth of the pen is less accurate. Not only the severely degraded wood is penetrated but also a part of the wood where the degree of decay is less. So in these situations the penetration depth of the pen can be deeper than the depth of the initial bacterial decay in the pile.

Therefore the interpretation of the measurements with the test hammer should always be done in combination with the wood research of the increment core which makes the gradient of decay visible.

The load bearing capacity of the timber pile should be calculated at that point over the pile length where the load is at maximum. The length of wooden foundation piles is adapted to the depth of the stable sand layer. The constitution of the weak soil penetrated by the piles consist of a variety of peat and or clay layers each with their own weakness and stability. The compression of the weak soil layers and increasing sand fill (in order to elevate the street level) create an extra load at the upper pile part, the so-called negative skin friction load. At the lower part of the pile the soil layers contribute to the bearing capacity, the so-called positive skin fraction. On the basis of the sounding graphic the position in the pile can be determined where the negative skin friction changes towards a positive skin fraction. This is the position in the pile with the highest load, the so- called neutral point (see Fig. 3).

At the neutral point the sound pile diameter is calculated using the degree of decay at the pile head, the taper value and assuming that the degree of decay at the tip is half of that at the pile head (Klaassen et al. 2017).

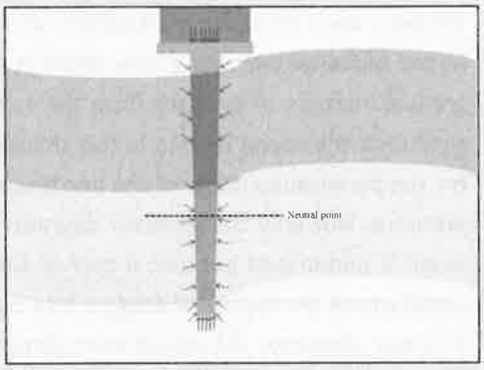

*Figure 3. Location of the neutral point in a timber pile in service*

# 4 CONSERVATION

## 4.1 NUMBER OF HOUSES TO BE TREATED

It is estimated that in the Netherland approximately 500.000 houses are standing on a wooden foundation. Half of all piles are pine and the other half is spruce. Permeability is the main property that affects bacterial decay activity in wood. If water transport through a stem is possible the consortium of bacteria is mixed and stays active. Wooden foundation piles always connect two water open sand layers which are separated by water tight layers (e.g. peat, clay). If there is a water potential (e.g. rain) and if the wood is open, water will flow. Pine sapwood has an extreme open structure and is therefore sensitive to bacterial decay, whereas the structure of spruce and especially dried spruce, is closed and therefore less sensitive to bacterial decay. The heartwood of both spruce and pine is not permeable and therefore not sensitive to bacterial decay within the life time of a foundation construction. During the last 25 years a database was established with more than 8000 records of Dutch foundation piles and this database shows that spruce and pine appear equally and that there is a significant amount of piles of which the sapwood layer is not fully severely degraded. This leads to the estimation that approximately 250.000 houses have piles which are sensitive to bacterial decay and of which the foundation construction may collapse within the next 25-125 years. Many of these houses have a monumental status. As a new foundation costs approximately €75.000, the expected repair costs could amount to 10-20 billion euros. So the development of an in situ conservation method could save a lot of money, could save cultural heritage and could prevent enormous social and economic problems.

## 4.2 THE METHOD

In order to stop the bacterial decay the bacterial consortium should be disintegrated or the wood structure should be closed, at least at the pile head. Klaassen (2008) already showed that the main water flow in the piles is axial and that the radial flow is negligible. In our study we focus on a simple but effective way to close the wood structure. The first attempt was done using blue stain infection. During the analyses of the wood samples of 8000 Dutch wooden foundation piles we found that in pine piles with blue stain infection the degree of bacterial decay was always very limited. In order to test the hypothesis that blue stain infection could contribute to the closure of the wood structure a pilot water flow experiment was installed. Pine stems of approximately 25 cm in diameter and 30 cm long where used. An epoxy coating was applied on the unbarked surface and a collar at the upper cross section was established. On the upper cross surface there was continuously a water layer of 2 cm and the water flow through the pile was determined. The water flow in piles with blue stain was higher than in unstained piles. But in time a slimy layer appeared and with this layer the water flow in all piles decreased.

In a second and third edition of this water flow experiment the production of the slimy layer was stimulated with oxygen and sugar, the closure of the wood structure was done with water glass and a water flow sensor was calibrated.

In an oxygen rich environment the sapwood sugars delivered enough nutrients for micro-organisms to establish a slimy layer that closed the wood structure. However the closure was not stable and within 7 weeks the closure of the wood structure was decreasing again. A stable closure lasting at least for 9 weeks was established by exposure to a sugar solution of 50 g/l for four times six hours. With increased exposure to sugar the closure was fast and more stable. Also the closure with water glass was fast and stable and especially after fixating with calciumchloride.

The water flow sensors which were installed by Prof. Steppe (university of Gent), turned out to register under water all water flow velocities which appeared in the lab.

# 5 CONCLUSION

There is a large amount of houses in the Netherlands that may show damages in the near future because of bacterial decay in their wooden foundation piles. The laboratory experiments have shown that there are possibilities to conserve sensitive piles, as they appear in foundation constructions, against bacterial decay. The treatment can be based on the use of oxygen in combination with sugar or on a water glass treatment. With both treatments the permeability of the piles can be significantly reduced so that additional bacterial activity in the piles can be prevented. The next step is to treat piles in use and already a sensor is calibrated to monitor the effect. If the results of the pilot are positive a method can be developed to establish an effective conservation in situ under houses, without having to remove the people.

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