Life Expectation of Wooden Foundations - a Non-Destructive Approach

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Abstract

For centuries, worldwide, wooden foundations were used under building constructions in areas with weak soils. In the western part of the Netherlands still many family houses and monumental constructions are supported by wooden foundations and some of these buildings showed severe settlement in the last decades. Main causes were decline in groundwater table, too high pile loads and wood decay under water. A non-destructive inspection strategy was developed to assess the status and predict the performance for the next at least 25 years of wooden constructions. Application of this approach on hundreds of buildings in the Netherlands yielded important knowledge on possible causes and dynamics of (bacterial) degradation. This is essential to develop strategies for conservation and restauration of wooden pile foundations.

Keywords: wooden foundations, monuments, bacterial wood decay, too low groundwater table, negative skin friction

1. Introduction

For hundreds of years wooden foundations were used for constructions on weak soils in peat-land areas, around estuaries and near rivers all over the world. In the last century their role has been taken over by concrete, which has a high load capacity, durability and design flexibility. However, a substantial part of the man-made building constructions is still standing on wooden piles and ranges in ages from decades until several centuries. Those old constructions proof that wood can be a durable material for foundations but need attention for safeguarding reasons of the large population of buildings they support.

2. Wooden foundations, worldwide

Although a worldwide survey on the number of piles in service is lacking, for several countries areas with a high concentration of pilings are identified. These were or still are in mostly fertile areas often at a strategic location, densely populated and with a long building history. In Germany, wooden pilings can be for instance found in Hamburg in the warehouse district (‘Speicherstadt’) close to the harbor or in Berlin under the Parliament House (‘Reichstag’). In the coastal cities of the Nordic countries wooden foundations are frequently found under family houses and larger buildings, with the exception of Finland where wooden pilings are rare. In Sweden, wooden foundations are common in large cities like Gothenburg, Malmö and Stockholm. In Norway several centuries old horizontal foundations are known from Bryggen (Bergen) and in Denmark many old city centres are almost fully founded on wooden foundation piles. In Estonia cities like Tartu, Pärnu, Haapsalu orientate in the large coastal swamps do have a high concentration of wooden foundations and in Russia, central parts of large historic cities like St. Petersburg (Hermitage) and Archangelsk are standing on wooden piles. In the UK, relatively few buildings are founded on timber piles but there are records of the use of wooden foundations in Hull, Bristol, parts of Northern Ireland, the Docklands of London, bridges and churches in various parts of the country. As in the UK, wooden piles are not common in France. However they appear in the alluvial valley oriented cities (e.g. Bordeaux, Nancy), under numerous bridges on Loire, Seine and Garonne rivers and under some major national historic heritage type buildings (e.g. Paris: Grand Palais, Orsay station, parts of the Louvre). In Italy, Venice is the most prominent city where wooden piles are used. Also outside Europe there are records of pile concentrations like in India (Taj Mahal), Japan, China and on the Atlantic sea coast of Northern America e.g. Boston.

3. Wooden foundations, the Dutch situation

Compared to other countries, in the Netherlands a lot of information is available on the history and actual status of wooden foundations. Large parts of the Netherlands can be regarded as Estuaries of the river Rheine and Meuse and from the Roman period onwards these areas were densely populated. First (Roman period) short oak, ash or alder piles were used in simple foundations of small and light buildings. Starting in the middle ages when the population increased and larger cities developed more stable foundations were needed under larger houses. In the second half of the 19th century double piled beam construction with piles of 11 meter long were developed in Amsterdam whereas in Rotterdam single piled beam construction with piles of 18 meters long were used. Around the beginning of the 20th century, when cities expand, a huge amount of piles was use in the Western Dutch cities. Until 1925 all Dutch foundations were made of wood and the number of houses standing on wooden piles at that time was about 425.000. Between 1925 and 1950 most foundations consist of wooden piles with a concrete upper part. After 1950 concrete piles became common and gradually substituted the use of wooden piles until 2010. After 1925, 365.000 houses were built on wooden piles foundations. As most of these houses are standing on a minimum of 20 wooden piles the actual number of wooden piles supporting Dutch houses is estimated to 16 million. As water constructions (quay walls, bridgeheads) are also supported by wooden piles the total number of piles in service is mostly likely doubled up.

3.1 Huge problem

In the last decades discussion started on the stability of the Dutch wooden foundations due to a couple of incidents. In Amsterdam, the stock exchange “Beurs van Berlage” (1898) showed severe cracks only eight years after construction and several repair measurements were necessary to stabilise the building [1]. From 1970 onwards, in historic cities like Haarlem, Zaanstad, Dordrecht, Gouda, Amsterdam and Rotterdam, foundations of houses, constructed between 19th and early 20th century showed severe damage due to rot. Costly reparations and sometimes even complete restauration or rebuilding measures had to be undertaken. Consequences for house owners are massif: a new foundation for an ordinary family house costs approximately € 60.000 which is 10 - 30% of the value of the house. The Dutch government is reluctant in adopting the problem due to the fact that urban-development measures, i.e. hydrological changes as consequence of national building projects, can form part of the problem and could lead to compensation claims of between 10 and 30 billion Euro

within the next 50 years if estimations that half of all houses standing on wooden piles are threatened will turn out to be true.
As a consequence of the ongoing problems the demand for inspections to assess the quality of wooden foundations increased rapidly during the last few decades. Information gained from such inspections is a valuable source for investigating causes and mechanism behind degradation of wooden pile foundations and to come up with measures to prevent quality losses of wooden constructions.

3.2 Causes behind degradation of wooden pile foundations
Based on a dataset of hundreds of studied buildings in the Netherlands, three factors have been identified which largely affect the quality of wooden pile foundations, (1) a decline in ground-water table; (2) too high pile loads and (3) wood decay under water. These factors can act independently, but often occur together.

3.2.1 (Temporary) decline in ground water table
Wooden foundations generally perform well under anoxic conditions. If the upper part of the wooden foundation construction is getting above the ground-water level, oxygen supply through air will allow wood degrading fungi to be active. The velocity and intensity of the decay is determined by the duration of exposure of the foundation timber, the amount of timber or part of the pile exposure to air, the wood species and the water-holding capacity of the soil. It is estimated that the maximum degradation velocity of soft-rot fungi that attack water-saturated wood from outer part towards the inside of the pile is approximately 10 mm/year, whereas brown- and white-rot fungi which attack drier wood act much faster by penetrating with a maximum of 100 mm/year radially into the pile. A decrease in ground-water table often occurs as a consequence of insufficient water management by the local government. The western part of the Netherlands exists of a patchwork of polders, each with its own pumping system and specific street- and groundwater level. For security reasons it is asked that the lowest ground water table should be at least 50 cm above the upper part of the foundation. However, differences between the street level and the upper parts of the foundation are sometimes marginal which means that the ground water table has to be adjusted within a range of 20 cm. Too low groundwater levels can also appear locally because of broken sewerage systems that act as drainage as they are situated below the groundwater level. Other causes of local low groundwater levels are evaporating trees (in spring and summer) or building pits.

3.2.2 Too high pile loads
If the bearing capacity of wooden foundations supporting above ground constructions is too low, this results in settlement. This is partly due to the lack of geo-technological knowledge at the time of construction. Until 1950 additional load on the piles due to attaching of applied sandy layers was not taken into consideration when calculating the bearing capacity. The problems with the “Beurs van Berlage” were related to this phenomenon (negative skin friction). It was built on a closed branch of the river Amstel, flattened with a thick sand layer. This sand layer compressed the underlying weak Amsterdam peat and clay soil and increases the load on the piles beyond their bearing capacity. The “Beurs van Berlage” is just one example but as sand layers were often used as backfill to develop new building areas, the problem is widespread over the Western part of the Netherlands.

3.2.3. Wood decay under water

Until the eighties of the last century it was believed that no decay was possible when wood was stored under water. Colonisation by bacteria of pounded wood was not considered as wood decay [2]. Bacteria were thought to cause an increased permeability by attacking the pit membrane but were not considered as wood degraders. Only in the beginning of the 1980ies [3] proved that bacteria are able to degrade the woody cell wall. Wood degrading bacteria live in consortia of several species and are common in a wide varieties of soil types. Their decay velocity is typically slow but as they do not need oxygen they are active in environments that are unfavourable for fungi. In all wooden foundation piles investigated, bacterial decay was found over the full pile length, however the degradation intensity showed strong variation [4]. Some old piles showed an outermost degraded layer of 1 mm after being in service for 100 years, whereas in other piles, within 50 years a degraded outermost layer of 50 mm developed [4, 5, 6].

Wood-degrading bacteria are immobile and need water flow for entering and colonising the wood as well as for intermixing with their consortium species. Permeability of the wood and groundwater flux, are therefore believed to be key parameters to determine the velocity of bacterial decay [6]. Permeable woods, like alder, poplar and the sapwood of pine and oak are typically susceptible to bacterial decay. A case study of the Amsterdam situation, showed that on a local level not the variety in hydrology or soil chemistry but the variation in amount permeable wood related to the intensity of bacterial decay [7].

Bacterial wood degradation is a long-term process. It proceeds much slower than fungal attack, which can reach a maximum degradation speed of 1 mm/year in radial direction. In contrast to fungal decay where the activity is mainly influenced by the environment (availability of oxygen), the activity of wood-degrading bacteria is related to wood quality (permeability); round wood timbers often have sharp boundaries between permeable and non-permeable structures, i.e. sapwood and heartwood. If such a boundary is reached by the wood degrading bacteria, their activity drops considerably.

4. Inspection innovations, the Dutch non-destructive method

In order to get a reliable evaluation of the stability of a wooden foundation, common methods are used for judging the settlement, the coherency of a building and dynamics of the groundwater level. To understand the causes of decay and predict the performance of a foundation for the next at least 25 years more detailed information is needed on the geotechnical bearing capacity of the piles in the soil, of the bearing capacity of the timber and on the additional load related to negative skin friction. Soil data are extracted from sounding profiles and information on wood quality is gathered in a foundation pit. In the pit the piles are first visually inspected on the presence of cracks, decay and connection with other construction elements. Then the thickness of the weak peal around the piles is determined with a test hammer. For studying the status of the wood cores (diameter 10 mm) are taken with an increment borer from bark to pith. The cores are analysed in the lab by detecting the timber species, timber quality, moisture content, wood density as well as the depth, type and gradient of decay along the core. From these measures the status of the wood is derived. For this the sound diameter of the individual foundation construction elements is calculated and the sound diameter over the element length is estimate from top to tip of the pile. Moreover the mean bacterial decay speed and the appearance of boundaries in the timber are used to predict the progression of the wood decay in the coming 25 years. Based on the wood and soil data calculations are made on 1) the geotechnical bearing capacity at the pile tip and 2) bearing capacity of the timber at that location, over the pile length, were the highest load will occur. Special modification factors have been developed (on the basis of the fibre structure of wood, the allowance of some compression in horizontal elements) to calculate a more realistic load transfer in the connections between horizontal and vertical elements.

5. Conclusion

A realistic estimation of the actual and future stability of wooden pile foundations is essential to develop strategies for conservation and restauration. In individual cases, it is also relevant when a building is sold, renovated or reconstructed. Furthermore it prohibits unnecessary demolition of constructions or replacements of foundations. The example of the Netherlands illustrates that systematic analyses of knowledge gained from inspections can advance the understanding of underlying processes which in turn can be used to prevent damage and promote conservation. It is assumed that, if such the proposed inspection techniques will be applied in the Netherlands a quarter of the expected reparation cost in the next 50 year can be saved.
Although the specific situation with respect to the causes of degradation can vary in wooden foundations in different countries, the proposed inspection techniques can be easily adapted and applied to various contexts with the potential benefit restauration and conservation of wooden pile foundations worldwide.

References

1. W Kramer, 'The Amsterdam stoke exchange of Berlage – history and repair–' (Dutch), Waanders drukkers, Zwolle, 2003.
2. S M Jutte, 'Wood structure in relation to excessive absorption - a literature survey- ', Houtinstituut TNO, Delft, 1971.
3. T Nilsson and D Holt, 'Bacterial attock occuring in the S_2 layer of woody fibers', Holzforschung Vol 37, pp 107-108, 1983.
4. R K W M Klaassen, 'Speed of bacterial decay in waterlogged wood in soil and open water', International Biodeterioration and Biodegradation, Vol 86, pp 129-135, 2014.
5. R K W M Klaassen editor, 'Final report EU project BACPOLES EVK4-CT-2001-00043: Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites', Wageningen, 2005.
6. R K W M Klaassen, 'Bacterial decay in wooden foundation piles: patterns and causes. A study on historical pile foundations in the Netherlands', International Biodeterioration and Biodegradation, Vol 61, No 1, pp 45-60, 2008.
7. R K W M Klaassen and B S Overeem, 'Factors that influence the speed of bacterial wood degradation', Journal of cultural heritage, Vol 13s, pp 129-134, 2012.