Behaviour of Wooden Pilings in Long Time Service

Comportement des Fondations en Bois en Service pour Longtemps

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SYNOPSIS Timber is one of the oldest materials for foundations. Investigations of more than 50 pilings from locations in Germany showed a significant influence of the specific site conditions on the behaviour of the timber. The most common species employed in Central Europe are oak, spruce, and scotch pine, to a lesser degree fir and larch. Under salt water conditions the tropical hardwoods azobe, greenheart and angelique are used. Timber has good strength properties and a high durability if constantly kept below ground water table. Under fresh water only the sapwood will be infested by bacteria which lower the strength properties slowly over decades. In salt water marine borers act as wood destroying organisms. In ground contact above the ground water table fungi will heavily attack timber and lead to severe deteriorations within a short time. Therefore lowering of the ground water table for periods over one month must be avoided.

INTRODUCTION

Timber is one of the oldest materials for foundations in soils of insufficient bearing capacity. Since ancient times timber pilings were used for the foundations of whole towns and pile-dwellings. There are well-known examples for the very early use of such timber foundations for human settlements (van Giffen, Bohmers, 1949; Huber, Jazewitch, 1958). Many old buildings dating from the middle ages are still existing including some famous monuments (Varossieau, 1949).

However, the strength of wooden foundations often is diminished mainly due to fungal attack. Consequently large efforts became necessary to preserve buildings of historical interest.

This paper will demonstrate the suitability of timber for foundations and elaborates on the reasons for an early breakdown. The presentation is based on the common knowledge of the behaviour of timber in ground and in water contact as well as on the experience of the authors, who, during the last 15 years, have investigated more than 50 pilings of over 20 wooden foundations from 10 different sites in Germany.

In the literature only a few publications deal with this specific problem (Boutelje, Bravory, 1968; Boutelje, Göransson, 1972; Eslyn, Clark, 1976; Harmsen, Nissen, 1965; Scheffer, Duncan, Wilkinson, 1969; Varossieau, 1949).

INVESTIGATIONS

Investigations of wooden foundations are required in particular

- as regards estimates of their remaining service life (e.g. Harmsen, Nissen, 1965)
- to check the conditions of pilings in areas where extensive underground engineering measures resulted in a sinking ground water table.
- to find possible reasons for damages on buildings.

For this work mainly three methods are commonly employed:

- taking bore-cores without opening the ground. This method gives no reliable results because the boring meets the piles only randomly and no careful investigation of the pile-head is possible.
- opening the ground for visual inspection of the pile-heads and mechanical tests with a sharp tool.
- laboratory investigations of the strength properties of piles. Such tests give the most reliable results, especially if several piles from different parts of the foundation can be taken.

Laboratory tests, however, are rarely feasible because mostly it is impossible to take samples of sufficient size from piles still in service without influencing the standing building. Systematic investigations on series of pilings out of use (Eslyn, Clark, 1976) add to our knowledge on the behaviour of wooden foundations, though it is difficult, to have available respective material at the scientific laboratories.

TIMBER SPECIES FOR PILINGS

Timber is a very suitable material for pilings. One of its outstanding qualities is the good relation between strength properties and density (table I). No other supporting material such as iron or concrete has a strength to density ratio nearly as favourable as wood. The shape of timber is also advantageous for pilings.

TABLE I

Density, compression strength and natural resistance of some timber species used for piling (according to DIN 68 364; compression strength in moist condition (u > 3o%) according to Kollmann, 1951; the data are based on small samples without defects)

Timber species	Density g/mm^3 u = 12%	Compression strength N/mm^2 u = 12%	u > 3o%	Natural resistance of heartwood[1)]
Angelique (Basralocus) Dicorynia guianensis	o.76	7o		very durable
Azobe (Bongossi, Ekki) Lophira alata	1.o6	95		very durable
Fir Abies alba	o.47	4o	23	non-durable
Greenheart Ocotea rodiei	1.oo	1oo		very durable
Larch Larix decidua	o.59	48	25	moderately durable
Oak, white Quercus robur	o.67	52	35	durable
Pine, Scotch Pinus sylvestris	o.52	45	25	non-durable to moderately durable
Spruce Picea abies	o.47	4o	23	non-durable

[1)] in ground contact above water table: very durable / durable / moderately durable / non-durable / perishable

Used top-end down the surface friction is markedly increased.

Furthermore timber shows considerable resistance against organic and inorganic influences if constantly kept below ground water table.

Last not least timber can easily be handled and worked at the site.

The most common timber species used for foundations in Central Europe were oak (Quercus sp.), spruce (Picea abies) and scotch pine (Pinus sylvestris), to a lesser degree fir (Abies alba) and larch (Larix sp.). Even nowadays these species are used for timber foundations. At one site (Hannover) also beech (Fagus sylvatica) was found in parts of a large foundation. In other regions several local species are of importance. Under salt water conditions the tropical hardwoods Azobe (Bongossi, Ekki = Lophira alata), Greenheart (Ocotea rodiei) and Angelique (Basralocus = Dicorynia guianensis) are presently used because of their high resistance against marine borers.

The cross sections of oak, pine, larch and of the three tropical hardwoods show a lighter colour in the outer part called sapwood, than in the inner one, called heartwood. This darker coloured heartwood has a higher resistance against fungal attack and will not be colcnized by bacteria. Contrary, spruce and fir have no coloured heartwood. Usually the European species are used as round timber including sapwood, the tropical species as sawn timber without sapwood.

The main timber properties relevant for foundations are given in table I. The data for density and compression strength are almost identical for sapwood and heartwood. The sapwood of all species is susceptible to fungal attack and may be infested by bacteria.

As seen from table I the properties of the timber species vary to a large extent. The compression strength closely correlates to the density whereas no such correlation exists to the natural resistance. This property depends only on the presence of certain extractives in the heartwood of the respective timber.

The behaviour of the timber in the ground varies between different species not only according to their natural resistance. In addition, the specific conditions of the site are of importance. In table II the residual compression strength of some pine piles after different periods of service life is listed to demonstrate the range.

The testing results fully correspond to those of visual observations. Obviously the type of soil and the ground water considerably influences a possible biological deterioration. Thus at one site frames made from beech - which is an extremely susceptible species - showed no bacterial growth whilst lower lying pine piles were infested. Similar variations were reported by Eslyn and Clark (1975, table III).

TABLE II

Residual strength of pine-pilings from different sites

Site	Pile	Service life	Strength[1] N/mm² heart	Strength[1] N/mm² sap	Remark
A	1	7o	26	2o	tidal zone, no marine borers
	2	7o	19	9	
B		8o	16	3	partly above GWT[2]
C		12o	19	6	same pile as Fig.5
D	1	>14o	13	8	
	2	>14o	27	1o	Fig. 2, zone A
	2	>14o	3o	11	Fig. 2, zone B

1) Average compression strength in moist condition according to tests at the Inst. of Wood Physics and Mechanical Wood Technol. of the Fed. Res. Centre for Foresty and For. Prod.; average value of sound samples according to Kollmann (1951): 16...25...39 N/mm².

2) Ground water table.

TABLE III

Variation (%) of average crushing strength in specimens from piles after 85 years service life below water and published average values for the same species (data according to Eslyn, Clark, 1976)

Position of samples	Pinus resinosa	Pinus strobus	Larix laricina
top disc			
outer third	-54	-40	-21
middle	-26	+ 2	- 2
inner third	-36	- 8	-15
bottom disk			
outer third	-30	-30	-28
middle	-36	+ 2	- 4
inner third	-40	-11	-20

AGENCIES OF DETERIORATION

Despite of their suitable properties wooden foundations may be deteriorated by several agencies. The effect of the strength properties ranges from negligible to total breakdown depending on the specific ground conditions and the timber species used (see Fig. 1).

Most important is the level of the ground water table in relation to the piling. All parts above the water table are subject to severe attack mainly by wood destroying fungi. They reduce the timber strength to a high extent within a comparatively short time. Under extremely unfavourable circumstances, attacked pilings may lose their supporting function even within one year. It should be noted, however, that on some sites investigated the buildings showed no effect even after several years of lowered ground water table.

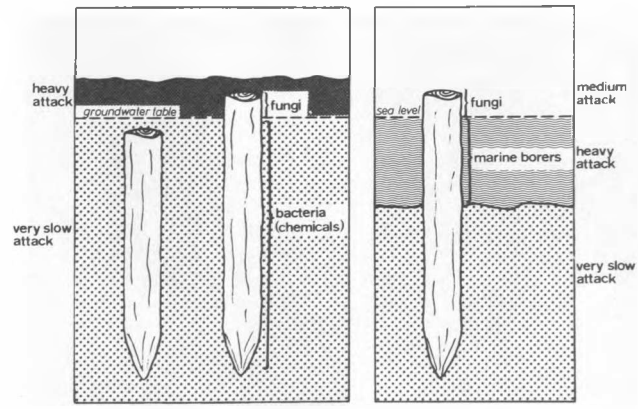

Fig. 1: Influence of site conditions, particularly the ground water table, on wooden pilings

Timber in fresh water or in soil below ground water table, however, is not attacked by fungi. Only bacteria will infest the sapwood of the timber but normally they are by far less harmful. In addition to bacteria certain aggressive chemicals dissolved in the water may influence the timber to some extent. Timber in salt water may be attacked by marine borers leading to severe damage.

Wood destroying fungi

Wood destroying fungi belong to the basidiomycetes, ascomycetes or to the fungi imperfecti. They initiate an intensive decay resulting in a remarkable loss of strength even at an early stage of decay. Finally this leads to a complete deterioration of the attacked parts of the piling (Fig. 2 and 3) due to the decomposition of the wooden cell wall (Fig. 4).

According to the type of decay and the physiological properties of the wood destroying fungi these can be divided into two main groups:

- the basidiomycetes which include e.g. brown rot, white rot and pocket rot fungi,
- the soft rot fungi (ascomycetes and fungi imperfecti), which cause a quite different type of wood deterioration, called "soft rot" due to the typical smooth surface of the attacked timber.

For the purpose of this paper it is not necessary to go into details for differentiating these two groups.

In order to attack timber all types of fungi require a certain moisture content and amount of oxigen. For soft rot fungi the humidity must be higher and the demand for oxigen is lower than for basidiomycetes. Both types are unable to develop in dry timber. Therefore no fungal attack occurres below surface or ground water table. Above this level, however, at least

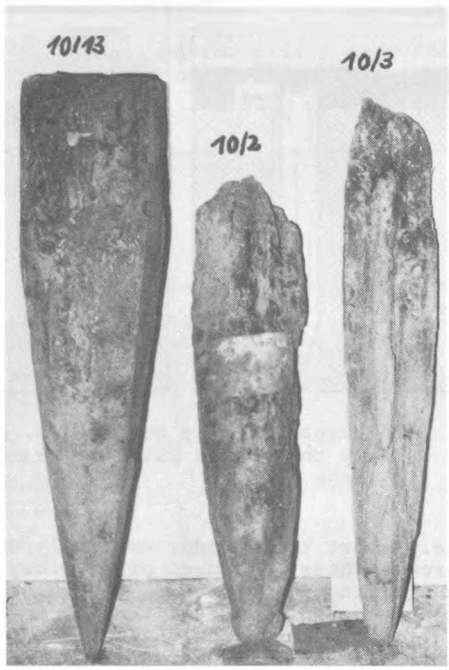

Fig. 2: Pilings from the Cathedral of St. Martin, Landshut, after more than 550 years of service life (see also the contribution of Hilmer, Fig. 2 and 3) Piling 10/13: good condition; 10/2 and 10/3: heavy deterioration at the pile-head

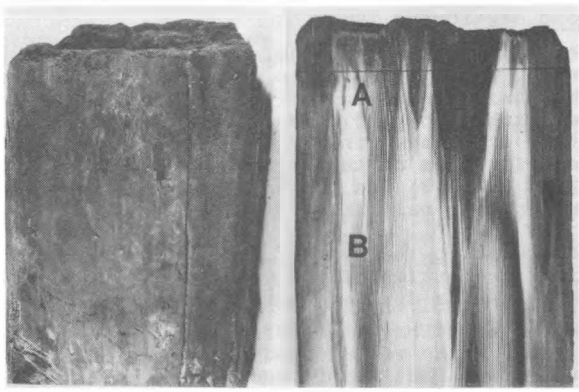

Fig. 3: Piling with heavy deterioration at the head and sound timber in lower parts. A and B refer to the zones of strength tests (see table II)

one of the groups will find ideal living conditions (Fig. 1). On the other hand timber will not be attacked in dry condition.

For most fungi the attack is limited to the sapwood, but some will also continue into the heartwood. The intensity of heartwood attack depends on its natural resistance.

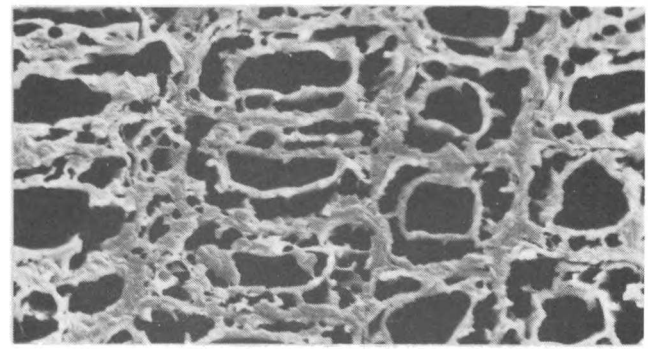

Fig. 4: Micrograph of heavily deteriorated timber (spruce, cross section)

Bacteria

Contrary to fungi, anaerobic bacteria are able to subsist in water-saturated timber. They grow rather slowly and corrode the cell wall only step by step. As a result limited deterioration takes place over decades. Such timber maintains its original shape in wet condition. When dried it collapses to an extent controlled by the degree of degradation (Fig. 5). Timber attacked by bacteria will show a soft surface which, after a very long time in service, will already yield to finger pressure.

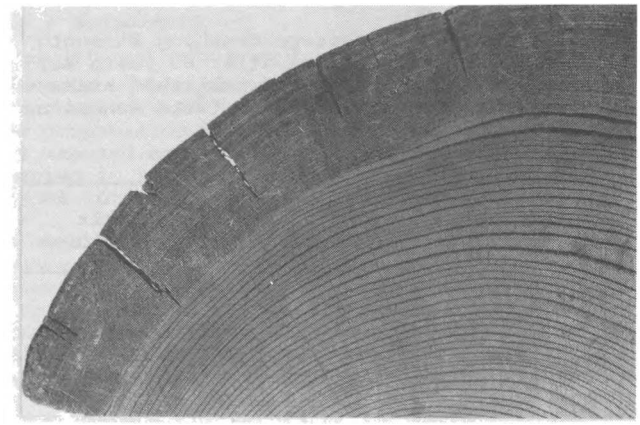

Fig. 5: Dried cross section of a pine pile after 120 years of service life. Bacterial attack in the sapwood

In general bacteria will merely attack the sapwood of the piles while the more resistant heart wood remains sound (Fig. 5). Sapwood strength properties of the timber in long-time use will be diminished (tables II and III). The degree of the loss in strength within a certain wood species depends to a very high extent on the specific site conditions. Some of the piles investigated by the authors after some 50 years in the ground showed a marked weakening of the surface while others appeared almost unchanged. This variation corresponds to the differ ent strength properties of old piles reported in

the literature.

Termites and other insects

With regard to pilings in tropical, subtropical, and mediterranean areas also termites have to be taken into consideration. Parts of the timber in the soil above ground water table may be attacked by subterranean termites which can destroy the wood within a short time. Other insects are of rare occurrence and shall be neglected in this context.

Marine borers

Timber in salt water can be heavily attacked by different marine organisms including special marine fungi. Most important are several genera of ship worms (Teredo, Bankia, Martesia) or Crustaceae like Limnoria. Shipworms are hardly visible on the pile surface due to very small entrance holes but they may badly deteriorate the interior. Marine borers need a minimum salinity, as e.g. 7 o/oo for Teredo (Bavendamm, Schmidt, 1960). In the foundation of the sluise (see Fig. 6) which connects the sea with a side-arm of a river, the two piles nearest to the sea-side flood gate showed a marked attack of Teredo navalis while the subsequent piles were impaired to a much lesser degree. In the centre of the sluise only sporadic attack occurred.

Chemicals

Only little is known about the influence of chemicals in the ground water on the strength properties of foundations. In general timber is rather resistant against chemicals if the pH of the contact medium is about 7 or slightly below. A high pH-value, however, markedly enhance a reduction in strength. From investigations of piles from different sites it may be inferred that timber, after long-time service

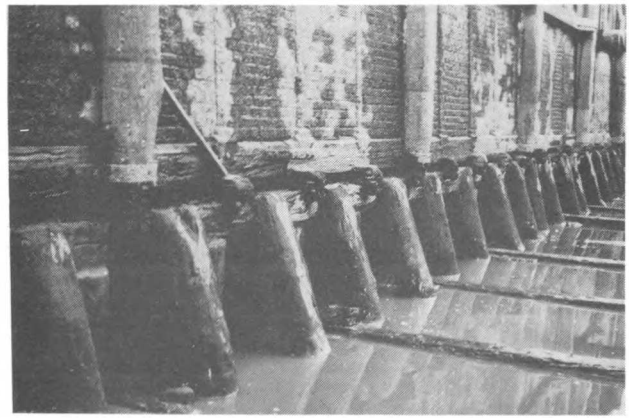

Fig. 6: Foundation of a sluise

in the soil, may also be influenced by chemicals. It is presumed, that in general a simultaneous attack by bacteria and chemicals takes place. This could explain the distinct differences in the residual strength of piles from different sites after comparable service time.

EFFECT OF GROUND WATER LOWERING

As the ground water table (GWT) sinks below the head of the piles or other parts of the foundation the moisture content will slowly decrease and oxigen will become available. Thus the conditions are suitable for a fungal attack and a rapid deterioration may take place as shown

TABLE IV

Influence of the duration of different ground water table (GWT) on the durability of pile foundations

periods for foundation parts above water table	water saturation[1)]	fungal attack	effect[2)]
none	complete	none	no
very short e.g. tidal zone	complete	none	no
weeks to months	almost complete	negligible	no
	slightly diminished	starting	no
	markedly diminished	distinct	beginning deterioration
more than half a year	markedly diminished	heavy	deterioration

[1)] Depending from the specific soil conditions

[2)] on European timber species with low or moderate natural resistance

above (see also Fig. 2 and 3 and table II site B). The critical time lapse between the lowering of the GWT and the start of fungal attack differs widely according to the specific soil conditions, especially its water holding capacity. The capillarity of the timber is by no means sufficient to ensure water saturation above GWT. Oscillating water levels will reduce the danger of fungal attack if the intervalls are short enough to maintain the moisture content of the timber. Piles removed from the tidal zone of the harbour of Hamburg, for instance, showed no degradation (see also table II site A).

Table IV roughly summarizes the main correlations. As a result all measures leading to a lowered GWT for a period longer than one month could be harmful to wooden foundations. A permanently low GWT will lead to a total deterioration of the foundation due to fungal attack and therefore has to be avoided by all means.

Preservative measures for timber in the soil above GWT are difficult to accomplish and of limited effect. During short periods of low GWT, e.g. due to engineering measures, the vicinity of the piles could be wetted. In the case of a permanently low GWT only chemical wood preservatives will give satisfactory results. But their application is expensive as the timber itself has to be treated. Soil treatment is not only inefficient, but would in addition create severe pollution problems.

For remedial treatment of piles in-situ special preservatives may be introduced via bore holes of a suitable pattern. Replacement timber should be treated in pressure plants according to existing specifications. However, the application of wood preservatives requires much experience and should be done only in close cooperation with specialists. Although important questions related to wood preservation go beyond the scope of this contribution and therefore will not be discussed herein.

CONCLUSION

Timber is a very suitable material for foundations which will last for centuries when permanently remaining below the ground water table or surface water level. Lowering the ground water table for long periods must be avoided. A permanently low level will result in complete deterioration of all wooden parts in the soil above this level. Remedial preservative measures are extremely difficult to accomplish. For new wooden foundations with uncertain ground water table either highly resistent tropical timber species or pressure-treated timber should be employed.

REFERENCES

Bavendamm, W., Schmidt, H. (1960). Tierische Holzschädlinge: Holzbohrmuscheln (Teredinidae). Holz Roh- Werkst. 18, 229-232.

Boutelje, J.B., Bravery,A.F. (1968). Observations on the bacterial attack of piles supporting a Stockholm building. J. Inst. Wood Sci. 4, 47-57.

Boutelje, J.B., Göransson, B. (1972). Decay in wood construction below the ground water table. In: Bio-deterioration of Materials, Vol.2, ed. by A.H. Walters and E.H.Hueck-van der Plas. Appl. Sci.Publ., 311-318, London.

Eslyn, E., Clark, Joe W. (1975). Appraising deterioration in submerged piling. In: Organismen und Holz, ed. by G. Becker and W. Liese. Beih. 3 zu Mat. und Org. 43-52.

Van Giffen, A.E., Bohmers, A. (1949). Toepassing Van Het Hout in Het Voorhistorische Europa, Gedurende Het Neolithicum, De Bronstijd, De Oude Ijzertijd, De Romeinse En De Volksverhuizingstijd. In: Hout in alle Tijden, Part 1, ed. by W. Boerhave Beckmann. pp. 267-328. Deventer: N.V. Uitgevers - Maatschappij, Ae. E. Kluwer.

Harmsen, L., Nissen, T.V. (1965). Der Bakterier angriff auf Holz. Holz Roh- Werkst. 23, 389-393.

Hilmer, K. (in press). Saving old buildings. 10 th Intern. Conference on soil Mech. and Found. Eng. Stockholm 1981.

Huber, B., Jazewitsch, W. v. (1958). Jahrringuntersuchungen an Pfahlbauhölzern. Flora 146, 445-471.

Kollmann, F. (1951). Technologie des Holzes und der Holzwerkstoffe, 2nd ed. Part 1. Berlin, Göttingen Heidelberg: Springer.

Scheffer, T.C., Dungan, C.G., Wilkinson, T. (1969). Condition of pine piling submerged 62 years in river water. Wood Pres. News 47, 22-24.

Varossieau, W.W. (1949). Opgegraven en Aangetast Hout Uit Biologisch Oogpunt Bezien. In: Hout in alle Tijden, Part 1, ed. by W. Boerhave Beekman. Deventer: N.V. Uitgevers - Maatschappij, Ae. E. Kluwer., pp. 329-387.