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► To cite this version:

Christian Brischke, Heiner Rolf-Kiel. Durability of European oak (spp.) in ground contact – A case study on fence posts in service. *European Journal of Wood and Wood Products*, 2009, 68 (2), pp.129-137. 10.1007/s00107-009-0364-7 . hal-00568246

HAL Id: hal-00568246

<https://hal.science/hal-00568246>

Submitted on 23 Feb 2011

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Draft Manuscript for Review

**Durability of European oak (*Quercus* spp.) in ground contact
– A case study on fence posts in service**

Journal:	<i>Holz als Roh- und Werkstoff</i>
Manuscript ID:	HRW-09-0034.R1
Manuscript Type:	ORIGINALARBEITEN / ORIGINALS
Date Submitted by the Author:	05-Jun-2009
Complete List of Authors:	Brischke, Christian; Leibniz University Hannover, Institute of Vocational Sciences in the Building Trade Rolf-Kiel, Heiner; Leibniz University Hannover
Keywords:	Decay, dimension, European use class 4, service life prediction, soil type, water holding capacity, white rot



view

Durability of European oak (*Quercus* spp.) in ground contact – A case study on fence posts in service

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Abstract

The durability of European oak (*Quercus* spp.) is under debate for a long time. In contrast to its classification as “durable” timber species according to EN 350-2 (CEN 1994), results from different comparative studies have clearly shown a lower durability, especially for in-ground exposures. To highlight this conflict more detailed, a case study on oak fence posts, which had been in service for 5, 10, 20, 30, and 60 years, was carried out. The posts were examined in terms of decay type and intensity, remaining cross section, wood moisture content, and different characteristics of the adjacent soil. The durability of the oak posts was affected by high variation. Posts prematurely failing after only five years were found as well as posts still serviceable after 60 years. Different findings of the study have the potential to increase the understanding of durability aspects in the future and might be considered for calibration and adaptation of field and laboratory tests methods in the future: The ground line turned out to be not the most severe exposure for posts, although it is generally assumed to be. Furthermore, no significant negative impact of remaining sapwood portions on the durability of the heartwood was found, but the important role of radial cracks for the initiation of decay became apparent. In this regard further potentially important factors for the in-ground durability are size and shape of timber components.

Die Dauerhaftigkeit Europäischer Eiche (*Quercus* spp.) im Erdkontakt – Eine Fallstudie an Weidezaunpfählen im Gebrauch

Zusammenfassung

Die Dauerhaftigkeit von Eichenholz (*Quercus* spp.) wird seit langer Zeit kontrovers diskutiert. Während es nach EN 350-2 (CEN 1994) als “dauerhaft” (Dauerhaftigkeitsklasse 2) eingestuft wird, haben Ergebnisse vergleichender Studien eine deutlich geringere Dauerhaftigkeit belegt, insbesondere bei Exposition mit Erdkontakt. Um diesen Widerspruch näher zu betrachten, wurde eine Fallstudie an Eichenzaunpfählen durchgeführt, die sich bereits seit 5, 10, 20, 30 und 60 Jahren im Gebrauch befanden. Die Pfähle wurden in Bezug auf Art und Intensität von Fäulnis, Restquerschnitt, Holzfeuchte und verschiedener Charakteristika des umgebenden Bodens untersucht. Die Dauerhaftigkeit der Eichenpfähle war durch eine hohe Variation gekennzeichnet. Frühausfälle nach nur fünf Jahren wurden ebenso beobachtet wie Pfähle, die nach 60 Jahren immer noch gebrauchstauglich waren. Verschiedene Erkenntnisse aus der Studie tragen zu einem besseren Verständnis der Dauerhaftigkeit von Eichenholz im Erdkontakt bei und ließen sich zur Kalibrierung und Anpassung von Labor- und Freiland-Prüfmethoden berücksichtigen. So stellte sich die als besonders kritisch erachtete Boden-Luft-Zone nicht als die Zone mit der stärksten Befallsintensität heraus. Weiterhin ließ sich kein signifikanter negativer Einfluss von Splintholzanteilen auf die Gebrauchsdauer der Pfähle nachweisen; die besondere Rolle radialer Risse in den Pfählen als Ausgangspunkt für Fäulnis wurde hingegen deutlich. In diesem Zusammenhang sei ebenfalls auf die Bedeutung von Dimensionierung und Form von Bauteilen auf die Dauerhaftigkeit im Erdkontakt hingewiesen.

1 Introduction

The timber of European oak (*Quercus robur* L. and *Q. petraea* Liebl.) is an appreciated building material and therefore it has been used since centuries. Its suitability for outdoor applications derives from its proverbial durability (Kollert 1991), and in fact it is classified as “durable” species (durability class 2, DC 2) according to EN 350-2 (CEN 1994). Thus, it is one of the most durable domestic wood species in Europe besides Black locust (*Robinia pseudoacacia* L., DC 1-2) and Sweet chestnut (*Castanea sativa* Mill., DC 2). Archaeological oak findings from Roman times (Haneca et al. 2005) as well as numerous half-timbered oak houses, which have still remained since the 16th century (Schepers 1994) also point to an outstanding durable timber species.

On the other hand, several authors reported on laboratory results indicating an inter-specific variability of European oak durability with remarkable percentages of moderately durable, poorly durable and not durable timber (Ayadi et al. 2001, Aloui et al. 2004, Guilley et al.

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2004, Humar et al. 2008). Results from soil bed tests against soft rotting and other soil-inhabiting micro-organisms also led to lower durability classes, e.g. DC 3-4 as reported by Van Acker et al. (2003). Comparative studies by Brischke et al. (2009) revealed significant discrepancies between results from different laboratory tests, field tests and the current European normative durability classification. In laboratory soil box tests as well as in in-ground field tests according to EN 252 (CEN 1990), oak was found to be non durable (DC 5), and even exposed above-ground in double layer tests it was only classified as less durable (DC 4). Soil box tests with different terrestrial microcosms gave a strong indication on the results to be expected in the field, because of similar types of decay organisms involved (i.e., mainly soft and white rot causing fungi). In contrast, laboratory resistance tests with basidiomycete monocultures were misleading as they suggest classifying European oak as a “very durable” timber. Though the various field studies showed that the durability of European oak heartwood seems to be fairly overestimated, they could not explain where this overestimation derives from.

Therefore, in this case study, oak posts, which had been in service between 5 and 60 years, were surveyed to obtain more information on the durability of oak timber under real life conditions. The posts were sampled at five different sites in North Rhine-Westphalia, Germany and assessed with respect to decay and wood moisture content. Furthermore, the in-use conditions were examined in terms of different soil parameters.

2 Materials and Methods

2.1 Sites and sampling of the posts

Oak fence posts were examined at five sites (feedlots) in the rural district Gütersloh, North Rhine-Westphalia, Germany, representing previous service lives of 5, 10, 20, 30, and 60 years. Round posts were included as well as splitted and double splitted posts. The geographic characteristics of the sites, and the corresponding number and type of fence posts sampled are summarized in Table 1.

The posts were carefully pulled out of the ground using a vertical hydraulic elevating device. Total length of the posts and depth of burying were determined, afterwards adherent soil was removed. For determination of remaining cross sections and wood moisture content, discs of 20 mm thickness were cut out of the posts at four different sections planes (30 cm above ground, at the ground line, 30 cm below ground, and 60 cm below ground, see Fig. 1).

2.2 Determination of remaining cross section

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1 The remaining cross section was determined in all four sections of all sampled posts.
2 Therefore, the wooden discs were sanded, scanned and the areas of the original heartwood
3 section ($A_{original}$) as well as the remaining undecayed heartwood section ($A_{existing}$) calculated
4 using “Adobe Photoshop CS3” (Fig. 2). As the original heartwood sections were unknown
5 due to different cross shapes and degrees of conicity of the posts, it was reconstructed
6 considering number, width and course of the annual rings in the different section planes. The
7 non-durable sapwood was not considered.
8
9

10 The percentage of the remaining cross section $A_{remaining}$ was calculated as follows:

$$11 A_{remaining} = \frac{A_{existing}}{A_{original}} \cdot 100 [\%]$$

12
13
14 In addition, the prevailing type of decay (white rot, brown rot, or soft rot) was identified for
15 each post and section plane according to EN 15083-2 (CEN 2005).
16
17
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19 2.3 Determination of wood moisture content

20 The wood moisture content was determined according to DIN 52183 (DIN 1977) for the inner
21 and outer part of the heartwood from each section plane at five posts per site. The specimens
22 were weighed (m_u), dried at 103 ± 2 °C until constant mass, and weighed again (m_0). The wood
23 moisture content (MC) was calculated as follows:
24
25
26
27

$$28 MC = \frac{(m_u - m_0)}{m_0} \cdot 100 [\%]$$

29 2.4 Determination of soil parameters

30 The soil at the different sites was sampled close to those posts which were used for wood
31 moisture measurements to determine its moisture content, water holding capacity, and pH-
32 value. Around each post, four single samples were taken using a sampling tube, which
33 allowed sampling in different depths (0 to -10 cm, -25 to -35 cm, and -55 to -65 cm)
34 corresponding to the section planes 0 cm, -30 cm, and -60 cm. Prior to the analysis, the four
35 single samples were merged to obtain one homogenous and representative total probe per
36 section plane.
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44 To determine the soil moisture content (MC_{soil}) 80-100 g moist soil were weighed (m_u), dried
45 at 103 ± 2 °C till constant mass, and weighed again (m_0). The soil moisture content was
46 calculated as follows:
47
48
49

$$50 MC_{soil} = \frac{(m_u - m_0)}{m_0} \cdot 100 [\%]$$

The water holding capacity (WHC) was determined according to ISO 11268-2 (ISO 2000). Therefore, the soil samples were air dried, pounded in a mortar, sieved (mesh size: 2 mm), and put into plastic tubes ($\phi = 40$ mm, $l = 10$ cm). The bottom of the tubes was covered with a synthetic grit and a filter paper (MN 640 W, Macherey Nagel, Düren). The filling height was 7 cm. The tubes were dipped in deionised water for 12 h to obtain water saturation of the substrate. Afterwards the tubes were put on a water saturated sand bath for 2 h to drain off. To determine the WHC of the substrate it was weighed (m_u), dried at 103 ± 2 °C till constant mass, and weighed again (m_0). The WHC was calculated as follows:

$$WHC = \frac{(m_u - m_0)}{m_0} \cdot 100 [\%]$$

The pH-value of the soil samples was determined in deionised water as well as in 0.01 molar CaCl_2 -solution according to ISO 10390 (ISO 2005). After suspending 10 g of each air dried and sieved sample for 2 h in 25 ml of the respective liquid, the pH was measured with a pH-meter (pH-Checker, Hanna Instruments).

3 Results and discussion

3.1 Remaining cross section

Regarding the mean remaining cross section as a measure for the degree of destruction of the posts, a high variation was observed between the different section planes as well as between the different sites and previous service lives, respectively (Table 2). The mean minimum remaining cross section decreased from site 1 (84.9 %) to site 3 (34.96%) with increasing previous service life, but was higher at site 4 (42.9%) after 30 years and at site 5 (40.9%) after at least 60 years in service.

Remarkable differences between the differently old posts became obvious when the posts were grouped according to their remaining cross section independent from the section plane. In Table 3 only the section with the smallest remaining cross section was considered: 40 % of the posts at site 1 had already lost more than 10% of their cross section due to decay, although they had been in service for only 5 years. In contrast, more than half of the posts at site 5 retained more than 50% of their cross section after at least 60 years in service.

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1 Furthermore it became evident that the section plane with the smallest mean remaining cross
2 section was not the same for the different sites (section 0 cm for site 2; section -30 cm for site
3 1, 3, and 5; section -60 cm for site 4). Therefore, each post was assigned to one of the
4 following groups with different courses of remaining cross section along the post axis:
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- 8
- 9 • Group 1: Remaining cross section increased from the bottom to the top of the post
- 10 • Group 2: Smallest remaining cross section between the ground line and 30 cm below
- 11 • Group 3: Remaining cross section decreased from the bottom to the top of the post
- 12
- 13

14 The percentage of posts assigned to these three groups can be seen in Table 4. In general, the
15 percentage of posts belonging to group 1 increased with ascending age of the posts. On the
16 other hand, the percentage of posts in group 2 decreased. Group 3 contained the smallest
17 number of posts; at sites 4 and 5 none of the posts followed the criteria of this group. This
18 assignment stands in contrast to the commonly accepted assumption, that the ground line is
19 the most severe exposure for a wooden component in ground contact [De Groot et al. 1979,
20 EN 252 (CEN 1990)], because here, supplies of atmospheric oxygen, soil water and nutrients
21 are plentiful (Levy 1987). In this study only the younger posts (site 1 and 2) were decayed to
22 the highest extent in this zone.
23

24 This finding became even more obvious when looking on the distribution of posts with
25 respect to the section plane with the smallest remaining cross section (Fig. 3). The percentage
26 of posts showing the smallest remaining cross section at the deepest part of the post increased
27 with the posts' age. Thus, in most instances posts and poles may fail at the ground line,
28 because at this point the bending moment is maximal, but it is not necessarily the zone of
29 most severe decay.
30

32 3.2 Type and distribution of decay

33 White rot was the dominating decay type at all sites, in many cases in combination with soft
34 rot: It was found on 95.2 % of the round posts and on 98.6 % of the splitted posts. In contrast,
35 brown rot was detected at only two out of 354 section discs in total. This dominating role of
36 white and soft rot on oak heartwood coincides with its poor performance in laboratory tests
37 with white rot fungi and in terrestrial microcosms with soft rot as main decay type (Brischke
38 et al. 2009).
39

40 Remarkable differences in the distribution and dissemination of decay were observed (Table 5
41 and Fig. 4). In most of the round posts decay started from the sapwood (95.2%), but also from
42 radial cracks (33.3%). Only 4.2% of the posts showed interior rot starting from the heartwood.
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1 The main starting points for decay in the splitted posts were radial cracks (98.1%), but in
2 58.1% of the posts not exclusively, but also from the heartwood.

3
4 The use of posts that include sapwood portions, which suffer from very low durability, is
5 supposed to be problematic as it may accelerate the infection of the post with wood-
6 destroying organisms. On the other hand, two contradictory assumptions can be made
7 concerning the role of sapwood for fungal infestation: 1. Heartwood will be infected faster, if
8 fungal mycelium is already established in the adjacent sapwood. 2. The sapwood ring acts as
9 a protective barrier, where decay fungi establish themselves, but do not or even very slowly
10 attack the heartwood portions, potentially because sap- and heartwood are susceptible to
11 different decay organisms. Although both hypotheses were not definitively approved, it
12 became evident, that remaining sapwood does not necessarily lead to a shortened service life
13 of the posts, as can be seen from the high percentage of splitted posts with decay starting from
14 the heartwood. As expected, on nearly all round posts decay started from the sapwood,
15 because it was surrounding these posts completely, and only a few showed interior heartwood
16 decay.

17
18 The role of deeper cracks acting as gates for water, fungal mycelium and spores into the wood
19 was often reported for preservative treated wood, where the treated shell frequently breaks up
20 through cracks (e.g., Helsing and Graham 1976, Morrell 1990), but may be transferred also to
21 untreated wood. However, quantitative studies on the meaning of cracks as starting points for
22 decay in untreated wood are rare and do rather indicate that their role is important (Clausen et
23 al. 2001, Augusta 2007).

24
25 Insect damage caused by *Phymatodes testaceus* L. was detected on 42.9% of the round posts
26 and on 43.2% of the splitted posts, but was mainly restricted to sapwood portions.

27 28 29 30 31 32 33 34 35 36 37 **3.3 Wood moisture content and soil parameters**

38 The wood moisture content of the posts generally decreased with increasing depth, whereby
39 only slight differences between the interior and exterior fifth of the posts were found (Table
40 6). Furthermore, the five sites were very similar in terms of the resulting wood moisture
41 content of the posts.

42
43 The moisture content of the soil varied between 7.7 and 29.5 % at the five sites. At sites 1, 4,
44 and 5 the soil moisture content decreased slightly with the soil depth, but was nearly constant
45 at sites 2 and 3 (Table 7). This finding coincided with the course of the water holding capacity
46 of the soils at the different sites: increasing with soil depth at sites 1, 4, and 5, and nearly
47 constant at sites 2 and 3. The pH values varied between 5.5 and 7.2 in deionised water and
48 between 4.8 and 6.3 in CaCl₂-solution. Although the soil moisture values represent only the

1 current status at the sites for one single day, it became obvious for all soil parameters that the
2 differences between the sites were only marginal. The only exception was site 5 showing a
3 high water holding capacity (46-61%), but low soil moisture contents (10-15%).

4 The complexity of the factors responsible for the intensity of decay at the posts became
5 apparent from the coefficients of determination for potential correlations between the wood
6 moisture content, the different soil parameters, and the remaining cross sections (Table 8).
7 Neither the wood moisture content, nor the soil moisture content and the water holding
8 capacity of the soil were correlated with the degree of decay of the posts ($R^2 < 0.8$).
9 Furthermore, even the soil and the wood moisture content seemed to be independent from
10 each other; the same for the water holding capacity and the corresponding moisture content of
11 the soil. Finally, also no correlation arose between the age of the posts and the remaining
12 cross sections (Fig. 5).

13 In contrast to in ground field tests, e.g., according to EN 252 (CEN 1990) it was not possible
14 to assess the extent of decay in terms of strength or mass loss, because the posts in this study
15 were very inhomogeneous in size and shape. Pursuant to the pick test according to EN 252
16 (CEN 1990), wood specimens are rated with respect to the depth and distribution of decay,
17 which allows at least a calculative comparison with those results (Table 9). Augusta (2007)
18 and Brischke et al. (2009) reported on numerous field tests with European oak heartwood in
19 and above ground. Hereby a steady increase in the mean decay rating was observed till all
20 specimens had failed, which stands in contrast to nearly identical mean remaining cross
21 sections found in this study at sites 3, 4, and 5 after 20, 30, and 60 years in service. Secondly,
22 decay started on oak heartwood immediately after its exposure in the ground without any time
23 lag necessary for leaching of extractives or any other kind of detoxification in field tests
24 (Brischke et al. 2009). This coincides with the unexpectedly early reduction of the posts'
25 cross section at site 1 of this study after only 5 years in service (Table 2, Fig. 5).

26 The extremely long service life of many posts at site 4 and 5 seemed to stand in contrast with
27 results of field tests according to EN 252 (CEN 1990), where the mean service life of oak
28 specimens did not exceed 8 years (Brischke et al. 2009), but may be explained by the
29 differences in size. There is still a controversial discussion about the influence of size and
30 shape of a wooden component on its durability: While in above ground exposures bigger
31 sized components seem to be compromised due to their lower capability to dry out after
32 wetting (Sell 1980), opposite effects are discussed for timber in ground contact: Leicester et
33 al. (2007) have shown that the impact of leaching of water soluble extracts or preservatives as
34 well as the superficial degradation by bacteria is less pronounced for bigger components. As
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1 in this study also remarkable decay was observed on posts after only 5 years in service, a
2 general rule for the impact of size or cross section of a component cannot be framed.
3

4 **Conclusion**

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8 The durability of oak and the service life of the posts, respectively, were affected by high
9 variation. Posts prematurely failing after only five years were found as well as posts still
10 serviceable after 60 years. Thus, a definite service life of oak posts to be expected in ground
11 contact was not indicated, and it seemed that the posts' service life is not simply correlated
12 with one of the soil parameters examined or the wood moisture content, respectively. On the
13 other hand, different peculiarities were observed and quantified: It was clearly shown that the
14 ground line, where moisture and oxygen conditions should be ideal for many fungi, was not at
15 all the most critical part of the posts; in fact it was 30 cm below the ground line. Furthermore
16 no significant negative impact of remaining sapwood portions on the durability of the
17 heartwood was found, but the important role of radial cracks for the initiation of decay
18 became apparent. In summary, it became obvious that case studies can seriously contribute to
19 a better understanding of decay processes and the reasons for wood durability. In regard to
20 this potential, important factors for the in-ground durability are size and shape of timber
21 components, which have not adequately been considered so far. For service life prediction of
22 timber components in general and for oak wood in particular further surveys seem to be
23 worthwhile and should include also above ground exposures. For calibration and adaption of
24 field and laboratory test methods valuable hints can be expected when aiming at a
25 methodology as close to reality as possible.
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Table 1. Geographic characterization of the sites, corresponding number of posts existent, and number, dimension, and type of posts examined (Standard deviation in brackets).

Tabelle 1. Geografische Charakterisierung der Standorte, zugehörige Anzahl vorhandener Pfähle, Anzahl, Abmessungen und Typ der untersuchten Pfähle (Standardabweichung in Klammern).

	Site 1	Site 2	Site 3	Site 4	Site 5	
Previous service life [a]	5	10	20	30	60+x ¹	
Location	Versmold-Bockhorst	Versmold-Bockhorst	Versmold-Bockhorst	Werther-Rotingdorf	Werther-Rotingdorf	
Latitude	52°4'29''	52°5'6''	52°4'29''	52°5'6''	52°5'6''	
Longitude	8°12'2''	8°12'2''	8°12'2''	8°25'16''	8°25'16''	
Altitude [m]	70	70	70	130	130	
Posts existent	44	67	18	66	25	
Posts examined	Round posts	0	1	10	7	3
	Splitted posts	2	9	2	18	3
	Double splitted posts	13	10	3	5	9
	Total	15	20	15	30	15
Mean length [cm]	189 (4)	190 (9)	195 (5)	174 (16)	168 (16)	
Mean length in ground [cm]	70 (6)	86 (6)	71 (4)	71 (16)	49 (16)	
Original heartwood cross section [cm ²]	130 (34)	134 (34)	168 (45)	104 (25)	85 (28)	

¹the posts have been in service for at least 60 years.

Table 2. Mean remaining cross section of the posts for the different sites and section planes.

Tabelle 2. Mittlerer Restquerschnitt der Pfähle für die unterschiedlichen Standorte und Schnittebenen.

Site	Previous service life [a]	Mean remaining cross section [%]				Minimum ²
		+30 cm	0 cm	-30 cm	-60 cm	
1	5	95.2	90.0	86.9	90.2	84.9
2	10	87.2	78.5	79.1	83.9	71.8
3	20	74.4	53.5	39.3	45.7	34.9
4	30	91.2	74.9	56.1	48.4	42.9
5	60+x ¹	90.6	73.5	40.9	77.5	40.9

¹ the posts have been in service for at least 60 years.

² refers to the section plane with the least remaining cross section of each post

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Table 3. Percentage of posts in classes of remaining cross section for the different sites.

Tabelle 3. Anteil von Pfählen in Klassen des verbliebenen Restquerschnitts für die unterschiedlichen Standorte.

Site	Previous service life [a]	Percentage of posts with remaining cross section x [%]			
		100 % > x ≥ 90 %	90 % > x ≥ 75 %	75 % > x ≥ 50 %	x < 50 %
1	5	60.0	26.7	6.7	6.7
2	10	5.0	45.0	40.0	10.0
3	20	0.0	0.0	26.7	73.3
4	30	0.0	10.0	50.0	40.0
5	60+x ¹	0.0	6.7	46.7	46.7

¹ the posts have been in service for at least 60 years.

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Table 4. Percentage of posts in groups with different courses of remaining cross section along the post axis for the different sites. Group 1: Remaining cross section increased from the bottom to the top of the post. Group 2: Smallest remaining cross section between the ground line and 30 cm below. Group 3: Remaining cross section decreased from the bottom to the top of the post.

Tabelle 4. Anteil von Pfählen in Gruppen unterschiedlichen Verlaufs des verbliebenen Restquerschnitts entlang der Pfahlachse für die unterschiedlichen Standorte. Gruppe 1: Restquerschnitt steigt mit der Pfahlhöhe an. Gruppe 2: Geringster Restquerschnitt zwischen der Boden-Luft-Zone und 30 cm darunter. Gruppe 3: Restquerschnitt sinkt mit der Pfahlhöhe.

Site	Previous service life [a]	Percentage of posts [%]		
		Group 1	Group 2	Group 3
1	5	20	60	20
2	10	20	65	15
3	20	60	33	7
4	30	67	33	0
5	60+x ^{1,2}	87	13	0
All		51	41	8

¹ the posts have been in service for at least 60 years.

² the depth of burying of the posts in group 1 at site 5 was less than 60 cm.

Table 5. Types of distribution and dissemination of decay in the posts.

Tabelle 5. Verteilungs- und Ausbreitungsformen der Fäulnis in den Pfählen.

Type of decay distribution	Percentage of posts [%] ¹	
	Round posts	Splitted posts
Starting from sapwood	95.2	13.5
Starting from heartwood	4.8	58.1
Starting from radial cracks	33.3	98.1

¹A post was assigned to one of the groups if at least half of the section discs fulfilled the criteria

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Table 6. Mean wood moisture content of the interior and exterior fifth of the posts in different section planes for the different sites.

Tabelle 6. Mittlere Holzfeuchte im inneren und äußeren Fünftel der Pfähle in den jeweiligen Schnittebenen an den unterschiedlichen Standorten.

Site	Previous service life [a]	Mean wood moisture content [%]							
		Interior fifth of the post				Exterior fifth of the post			
		+30 cm	0 cm	-30 cm	-60 cm	+30 cm	0 cm	-30 cm	-60 cm
1	5	21	47	65	83	20	50	92	102
2	10	20	53	73	84	17	54	88	101
3	20	19	34	85	93	17	30	103	118
4	30	18	42	86	110	17	56	107	129
5	60+x ¹	17	47	97	100	17	42	96	107

¹the posts have been in service for at least 60 years.

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Table 7. Mean moisture content, water holding capacity, and pH of soil surrounding the posts in different section planes and for the different sites.

Tabelle 7. Mittlere Feuchte, Wasserhaltekapazität und pH-Wert des Bodens in unmittelbarer Nähe der untersuchten Pfähle in den jeweiligen Schnittebenen an den unterschiedlichen Standorten.

Site	Previous service life [a]	Mean soil moisture content [%]			Water holding capacity [%]			pH in deionised water	pH in 0.01 m CaCl ₂
		0 cm	-30 cm	-60 cm	0 cm	-30 cm	-60 cm	all	all
1	5	22	19	19	50	44	35	7.2	6.3
2	10	14	15	16	44	42	40	5.5	4.8
3	20	20	22	22	50	50	50	5.9	5.2
4	30	28	27	21	49	46	39	6.1	5.5
5	60+x ¹	15	12	10	61	54	46	5.8	5.3

¹the posts have been in service for at least 60 years.

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Table 8. Interrelationship between the different investigation parameters, expressed as coefficient of determination R^2 for linear smoothing functions, at the different sites.

Tabelle 8. Zusammenhang zwischen den verschiedenen Untersuchungsparametern ausgedrückt als Bestimmtheitsmaß R^2 einer linearen Ausgleichsfunktion für die unterschiedlichen Standorte.

Site	Previous service life [a]	Coefficient of determination R^2					
		Variable 1			Variable 2		
		Remaining cross section [%]	Remaining cross section [%]	Remaining cross section [%]	Soil moisture content [%]	Water holding capacity [%]	Water holding capacity [%]
		Wood moisture content ² [%]	Soil moisture content [%]	Water holding capacity [%]	Wood moisture content ² [%]	Wood moisture content ² [%]	Soil moisture content [%]
1	5	0.0031	0.0093	0.0008	0.0241	0.7161	0.0728
2	10	0.0006	0.1164	0.0359	0.2334	0.0078	0.2478
3	20	0.0783	0.5686	0.3443	0.0792	0.0033	0.1497
4	30	0.5802	0.3546	0.3481	0.6151	0.6927	0.8032
5	60+x ¹	0.1008	0.0057	0.0027	0.4509	0.5494	0.6688

¹the posts have been in service for at least 60 years.

²Wood moisture content measured in the interior fifth of the posts.

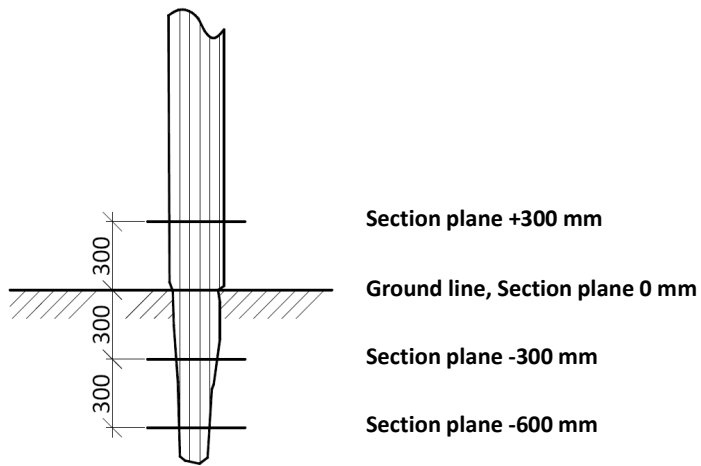
1 **Table 9. Decay rating for in-ground field tests according to EN 252 (CEN 1990) and corresponding**
2 **remaining cross sections of specimens.**

3 **Tabelle 9. Abbaubewertung für Eingrabeversuche nach EN 252 (CEN 1990) und entsprechende**
4 **Restquerschnitte der Prüfkörper.**

5

Decay rating after EN 252 (CEN 1990)	Description	Remaining cross section of specimen x [%]
0	No attack	$x = 100$
1	Slight attack	$100 > x \geq 88$
2	Moderate attack	$88 > x \geq 67$
3	Severe attack	$67 > x \geq 48$
4	failure	$48 > x$

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17 **Fig. 1. Cutting schedule of fence posts for determination of remaining cross sections and wood moisture**
18 **content (all dimensions in mm).**

19
20 **Abb. 1. Schnittplan zur Entnahme von Pfahlscheiben für die Bestimmung von Restquerschnitt und**
21 **Holzfeuchte (alle Angaben in mm).**



Fig. 2. Determination of remaining cross section. Grey line: Reconstructed original heartwood cross section. Black line: Remaining undecayed heartwood cross section.

Abb. 2. Bestimmung des verbliebenen Restquerschnitts. Graue Linie: Rekonstruierter ursprünglich vorhandener Kernholzquerschnitt. Schwarze Linie: Querschnitt des verbliebenen, nicht verfauten Kernholzes.

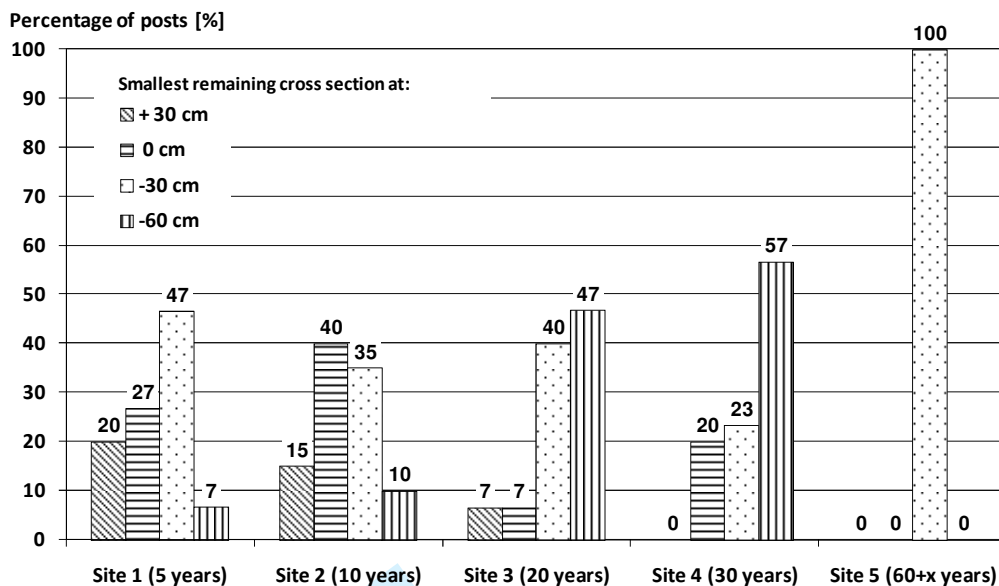


Fig. 3. Percentage of posts with the smallest remaining cross section in different section planes for the different sites.

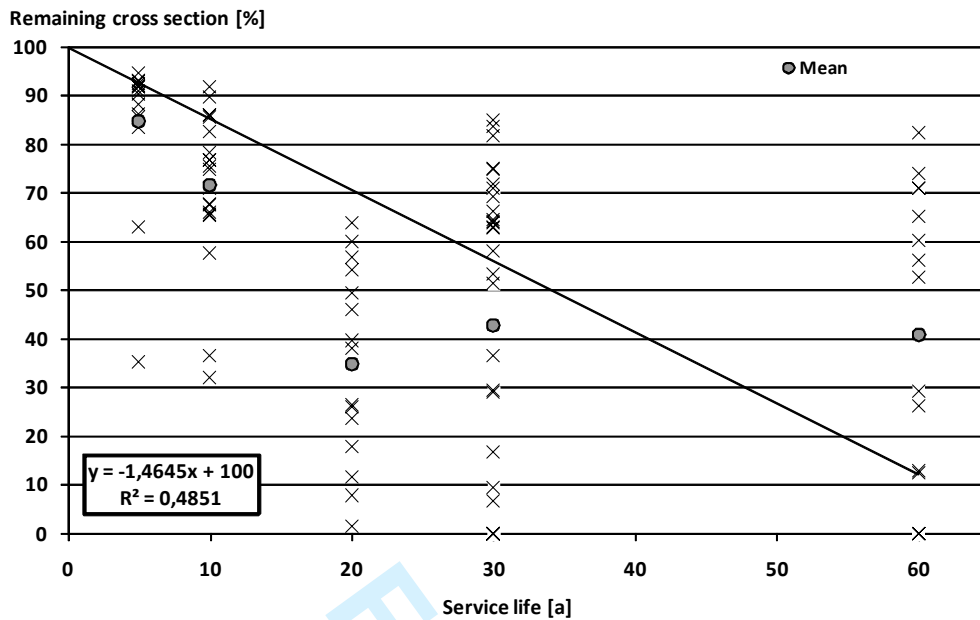
Abb. 3. Anteil von Pfählen mit dem geringsten verbliebenen Restquerschnitt in den jeweiligen Schnittebenen an den unterschiedlichen Standorten.



Fig. 4. Examples for different types of distribution and dissemination of decay in round posts. Left: Decay starting from the sapwood. Centre: Decay starting from the central heartwood. Right: Decay starting mainly from radial cracks.

Abb. 4. Beispiele für die Verteilung und Ausbreitung von Fäulnis in Rundpfählen. Links: Fäulnis vom Splintholz ausgehend. Mitte: Fäulnis vom inneren Kernholz ausgehend. Rechts: Fäulnis überwiegend von radialen Rissen ausgehend.

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22 Fig. 5. Interrelationship between remaining cross section and the previous service life of the posts (refers
23 to the section plane with the least remaining cross section of each post).

24 Abb. 5. Zusammenhang zwischen Restquerschnitt und bisheriger Gebrauchsdauer der Pfähle
25 (berücksichtigt wurde jeweils der minimale Restquerschnitt des Pfahls).