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New tool for choosing micropile type

Decay modeling of wood pile foundations in Turku, Finland

Abstract

Wood piles have been used in Turku mainly as supporting or cohesive piles. Cohesive piles were popular in the 19th century and at the beginning of the 20th century under foundations, where clay layers are more than 15 m thick. End bearing piles became more popular in the 1950´s and use of end bearing wood piles continued up to the 1970´s until pre-cast concrete piles came into common use.

Decay of wood piles has been observed in several cases due to lowering or contaminated ground water. The buildings may settle either due to decaying wood piles or due to settling of cohesive piles, sometimes as a combination of these factors.

A decay model has been developed to classify the phenomena in Turku for wood pile foundations, based on observations in the DATU database. The classification model can be utilized when designing micropile types or load transfer structures for underpinning. The type of micropiles and load transfer structures has influence on the costs and duration of underpinning. In addition, earlier stages of the wood pile life-cycle cause less settlements during underpinning when compared with later stages.

In underpinning in Turku, there is a versatile collection of micropiling and load transfer structure methods in use contributing e.g. variance in the settlement of superstructures during underpinning or after the construction stage. The proposed decay model provides a preliminary link to the impacts of designed type of micropiles and load transfer structures.

Background

Wood piles have been common foundation structures for thousands of years (Ulitskii 1995, Kretschmar et al 2007). A large number of historical monuments and old buildings are founded on wood piles, and, for example in the Netherlands, over 30 million wood piles are in place, sometimes with lowered bearing capacity (Klaassen 2008a, Klaassen 2008b). Many outstanding monuments, such as the Swedish parliament house in Stockholm and the German parliament house in Berlin, and nearly all the buildings of the city centres of Amsterdam or Venice rest on wood piles (Huisman et al 2008). Saint Petersburg's city centre has been founded on weak soil, either on shallow foundations or using wood piles (Sotnikov et al 1999, Bronin and Povyshev 2004). Use of wood piles continued typically until the 1960´s (Klaassen 2008b), in Finland even until the 1970´s. Untreated wood piles have been seen to be virtually immune to biological degradation and the decay of wood has often been considered only when wood structures come in contact with air and oxygen (e.g. Reynolds 2004). There are several reasons to assess the potential decay of wood piles, e.g. damage to the façade, change of use of the superstructure or underground building activities (e.g. van de Kuilen 2007). Normally, wood decays due to fungi in aerobic conditions (e.g. Kretschmar et al 2008, Huisman et al 2008).

In the 1980´s, many observations of cracks or settlements were made in Dutch houses where the groundwater was kept at a high level in order to protect wood foundation structures. Decay of wood under waterlogged conditions has been later reported as bacterial degradation. Earlier, bacterial decay was considered to progress very slowly, but recent observations have shown that bacterial wood decay can cause significant losses of strength within one hundred years. Water movement through the wood has been proposed to be the driving process for bacterial degradation. Today, bacterial decay can be considered causing significant problems to foundations together with fungi. Mean velocity for severe bacterial decay is 0.10 mm/year at the pile top, and a velocity of 0.04 mm/year at the pile tip has been observed. (Klaassen 2008a, Klaassen 2009)

Decay of wood piles causes either uniform or differential settlement to superstructures. For floating cohesive piles, the uneven settlement can be observed as tilting of the building. A traditional limit of disturbing inclination is 1:100, and beyond this limit visual problems start to appear. Sometimes, large inclination causes demolition of the building. In Turku, a 7-storey building was demolished when the inclination of the house was at rate of 2:100. The demolished building was supported with end-bearing piles, but probably due to poor end-blows, the building was tilting. (Perälä 2008)

The ideal timing for the underpinning of wood pile foundations has traditionally been a key issue for the owners. In Amsterdam, a procedure has been established to ensure sustainable results of renovation of the superstructures, Table 1. Typically, the assessment of wood piles is based on observations using methods such as visual inspection, ultrasound and stress waves, Pilodyn hammering, drilling bore cores (Fig. 1), measuring drilling resistance or full scale pile testing (van de Kuilen 2007). On the other hand, overall observations have been made on cracks (Lizzi 1982, Thorburn 1993) or settlement speed of the superstructure (e.g. Heikinheimo 2009), and an impact vibration test has been proposed to evaluate the soundness of wood pile foundations, especially in railway bridges (Haya et al 2005).

Table 1. Classification of wood pile foundations in Amsterdam (de Vries after Pitkänen et al 1999). Class 1 is reflects new structures and Class 4 indicates immediate need to underpin.

	Predicted service life (years)
Class I	50
Class II	25
Class III	15
Class IV	1

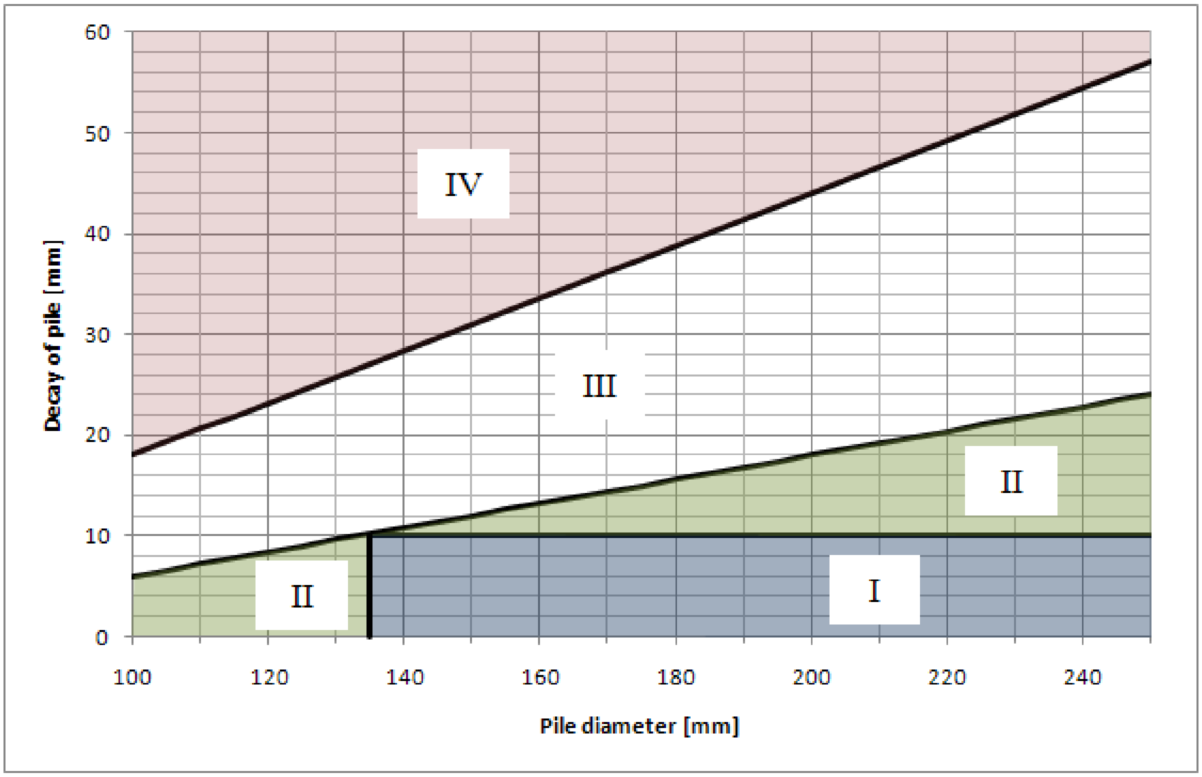

Figure 1. Decay of wood pile material, the pile diameter and respective classification of wood piles (see Table 1). (Stichting Platform Fundering 2007)

Underpinning in Turku

Wood piles have been used in Turku mainly as end-bearing (supporting) or cohesive piles. Cohesive piles were popular in the 19th century and at the beginning of the 20th century under foundations where clay layers are more than 15 m thick. End bearing piles became more popular in the 1950´s and use of end bearing wood piles continued up to the 1970´s until pre-cast concrete piles became to common use. Wood piles were driven either with or without lengthening joints, typically one coupler per each pile.

Underpinning is particularly common in Turku, Finland. At the moment, the total number and extent of projects in Turku is exceptionally high even relative to international standards. A database, containing about 200 different parameters from some 100 underpinning projects, has been compiled (DATU 2008). This database, called DATU, is one of the most extensive of its kind in the world. The data have been gathered from the property owners, project planners, and from the building supervision authority in Turku. The user interface can be accessed by a web browser and it is possible to work in the database over the Internet. Both Finnish and English versions of the user interface are available.

For underpinning in Turku, if the soft soil is over 15m thick, micropiles are normally used; if the thickness of soft soil is less than 15m, micropiles or jet grouting is used. The costs of the underpinning projects included in the DATU database vary from 150-450 €/net m^2 (Lehtonen 2008). An alternative estimate of 170-675 €/net m^2 has also been used (Pitkänen et al. 1999).

Settlement classification of wood pile foundations

The objective of this paper is to develop a method of defining the status of a wood pile foundation to contribute a preliminary link to design the type of the micropiles and, in the addition, costs and duration of underpinning. The new method is based on the modelling of settlement behavior on wood piles structures.

The pre-underpinning settlement observations of wood pile foundations can be defined according to the geotechnical behavior of the wood piles and considering the speed of settlement, Table 2. Speed of settlement is greater when wood piles are floating or cohesive. End-bearing piles have less settlement in the same decay phase of wood piles. Sometimes cohesive pile structures have uneven settlement - one corner is settling more than another corner and the building is tilting - but only the mean value of settlement has been considered in the developed models. A new end-bearing wood pile has practically no settlement until the decay process has caused enough loss of strength in the cross-section of the wood pile. On the other hand, single settlement observations have been made when end-bearing piles with solid pile head have penetrated to the bearing stratum, due to poor end-blows during embedding.

A proposal for modeling the total settlement behavior of the wood pile foundations is shown in Fig. 2 and Fig. 3. The proposed models include the decay process as a function of bearing capacity, the probable load changes in the superstructures and the settlement curve. The first stage (C1 and E1) covers the starting part of the life-cycle, without observed losses in bearing capacity. The final stage (C3 and E3) is the last chance to underpin the structure, before the final failure of the wood piles.

Discussion

The proposal for modeling wood pile foundations is a new approach to assess the status of wood pile foundations giving opportunity to explain e.g. the differences in costs or duration of underpinning. The differences in costs and duration can be caused by micropile type or the load transfer method which has to be chosen considering the sensitivity of the underpinned foundation. An example to compare costs between the stages 1 and 3 is given in Table 3. Duration of underpinning can vary based on pile type or load transfer category as discussed in IWM2009 (Lehtonen&Hattara 2009).

Table 2. Pre-underpinning settlement observations on wood pile foundations in Turku (DATU 2010).

	Settlement *s* in average, mm/year	Number of sites (N = 22)
C1, cohesive wood piles	$s < 4$	2
C2, cohesive wood piles	$4 \leq s \leq 6$	-
C3, cohesive wood piles	$s > 6$	4
E1, end bearing wood piles	$s < 2$	6
E2, end bearing wood piles	$2 \leq s \leq 4$	5
E3, end bearing wood piles	$s > 4$	4

Settlement during underpinning has a link to the decay phase of the wood piles. Typically, wood piles in good condition have better tolerance to stresses during underpinning where very weak wood piles lose their bearing capacity when the vibrations of underpinning cause additional stresses on them. Some preliminary observations on the sensitiveness of wood pile foundations are shown in Fig. 4 and Fig. 5. However, there are limitations in the research data: (i) commonly observed uneven settlement and occasional non-settlement behavior of seriously decayed wood piles (Fig. 6) have been ignored, (ii) only some observations are available, (iii) samples of decayed wood piles have not compared with the settlement data and (iv) the effect of underpinning method (especially type of micropile or type of load transfer structure, see Table 4) has not been considered in the analysis.

Data used in this research supports the presumption that the proposed decay model of the wood piles contributes information on the sensitiveness of existing foundations. For end-bearing wood piles (Fig. 4) in stage E1, the mean value for settlement during underpinning is at level of 5 mm where as settlement at stage E2 approaches a level of 10 mm. The stage E3 covers the highest observed rate, 30 mm. The respective difference for cohesive piles can be seen in Fig. 5. Range of settlement of jacked micropiles in the research data is 3.7 to 10.6 mm. The range for driven micropiles is 4.7 to 48.9 mm and for drilled micropiles 3.1 to 48.7 mm. For jet grouting, the range of settlement is 2.2 to 12.3 mm. Mainly used pile types and load transfer categories have been introduced in Table 4.

Conclusions

The developed model is a new proposal for describing the overall behavior of the wood pile foundations. It covers the total life-cycle of the wood foundations corresponding the earlier published Dutch practices and classifications.

Table 3. Cost comparison based on an underpinning cost model (Lehtonen&Kiiras 2010). The case includes 328 micropiles, length 20 m. The impact driven RR140 (steel pipe pile 139.7x10, S440) piles are typically applicable to stage E1 or C1 in the decay of wood piles, respectively the drilled piles RD140 (steel pipe pile 139.7x10, S440) for E3 or C3.

Cost classification based on the Finnish Talo 2000 standard	Micropile type		
		Stage E1 or C1 RR140, impact driven	Stage E3 or C3 RD140, drilled micropile
1.1.2.1 Piles	€/pc	300	400
	€/m	150	200
1.1.2.2 Supports	€/m^2	20	20
1.1.2.3 Reinforcement	€/pc	1100	1600
2 HVAC	€/m^2	5	5
3 Project management	€/m^2	20	20
Totally	€/m^2	165	208
		cost increase	26 %

Table 4. Mainly used pile type and load transfer category in the observed sites (DATU 2010)

ID	pile type	load transfer category
15	jacked micropile	C/D
16	jacked micropile	B
24	jacked micropile	D
25	drilled micropile	B
27	impact driven micropile	A
29	jet grouting	A
31	drilled micropile	B
34	impact driven micropile	B
35	impact driven micropile	B
37	jet grouting	A
38	jet grouting	A
42	jet grouting	A
44	jet grouting	A
51	jacked micropile	D
56	jacked micropile	B
58	drilled micropile	B
68	drilled micropile	B
70	drilled micropile	B

The new model of wood pile decay is based on the observations of the settlements of the superstructures and it is easy to utilize if only the monitoring process has been started early enough for long-term conclusions.

The analysis based on the developed model supports the thumb-rule on the differences of settlements between various micropile methods. Traditionally, the driven micropiles have been considered causing more vibrations and settlements to the superstructures while the drilled and the jacked micropiles have been assumed to be applicable in very sensitive conditions. In future research, a special model for choosing a micropile type could be further developed.

The developed model gives preliminary tools for the timing of underpinning. According to settlement analysis, later underpinning timing causes bigger additional settlements and greater costs during underpinning than an earlier started renovation activity. The owner can use the model in order to compare the effects of various timing alternatives. The analysis typically covers settlement and cost prediction including comparison between different micropiles and load transfer structures.

The developed model offers a warning system to the owners. Stable foundation with no or minor settlement can be explained either non-decay of wood piles or non-settlement behavior of severely decayed wood piles. However, when monitoring of foundations gives information on transfer from stage C1 or E1 to respective 2 or 3 stages, the owner can be convinced in the need of short-term underpinning.

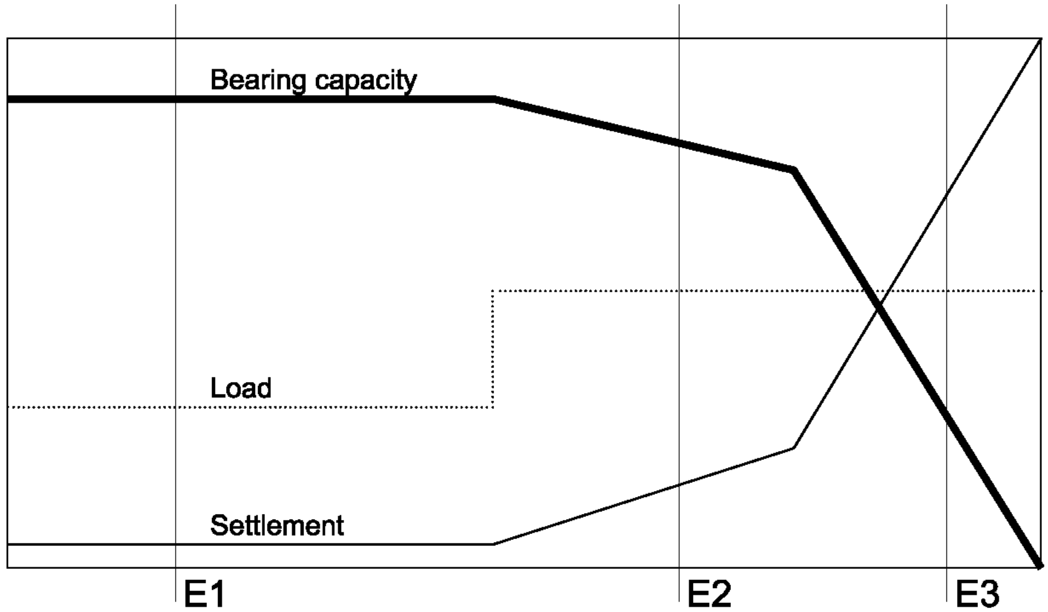

Figure 2. Decay of end-bearing wood piles. The supporting piles have no settlement in earlier stages of the life-cycle, E1. The load bearing capacity of wood piles decreases when wood decay goes forward; foundations start to settle, E2. In addition, the load of superstructures may increase, e.g. due to the re-use of the building. Finally, wood piles lose their capacity and settlement of foundations increases in speed, E3.

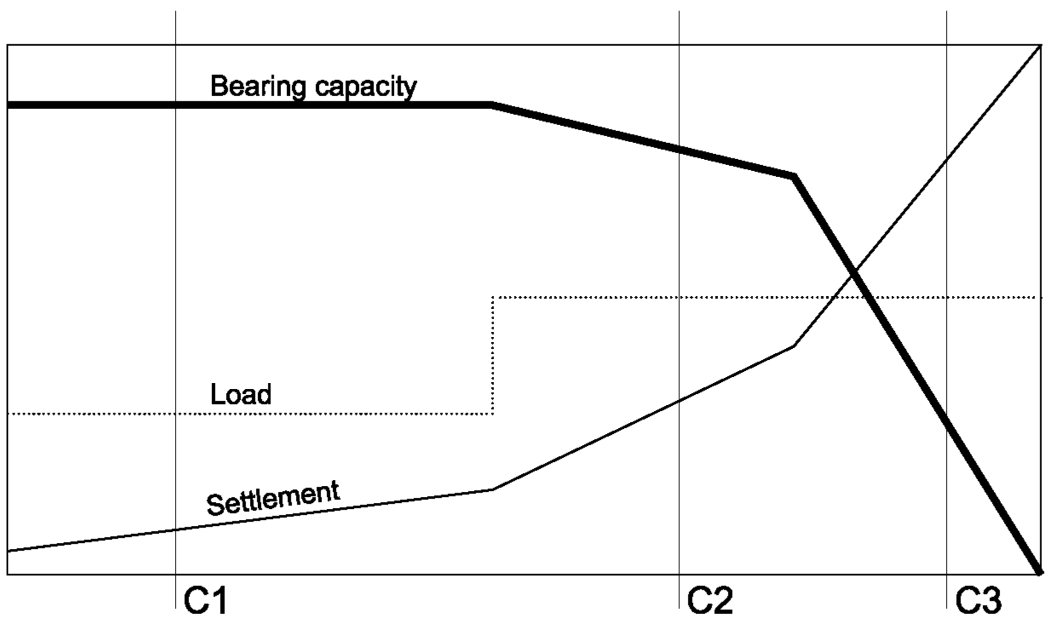

Figure 3. Decay of cohesive wood piles. The floating piles have some settlement in earlier stages of the life-cycle, C1. The load bearing capacity of wood piles decreases when wood decay goes forward; foundations settle more than earlier, C2. In addition, the load of superstructures may increase, e.g. due to the re-use of the building. Finally, wood piles lose their capacity and settlement of foundations accelerates, C3.

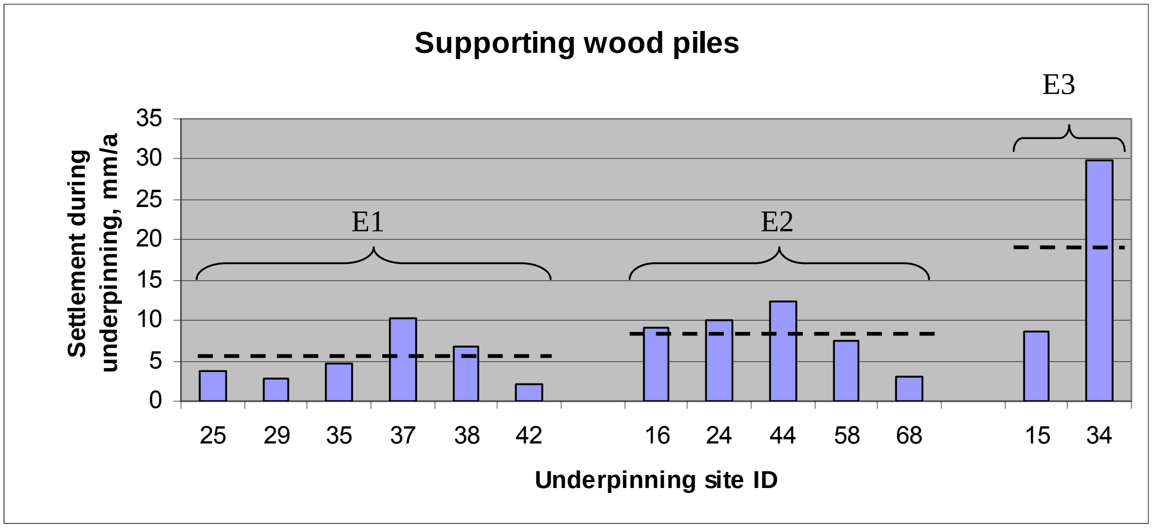

Figure 4. Observations from Turku: settlement during underpinning to existing end bearing wood pile foundations (the dotted lines indicate mean values). The sites on the left (ID25 to 42) have been classified to stage E1 (pre-underpinning settlement s < 2 mm/year), the sites in the middle (ID16 to 68) have been classified to stage E2 and the sites on right (ID15 and 34) have been classified to stage E3 (pre-underpinning settlement s > 4 mm/year). (DATU 2010)

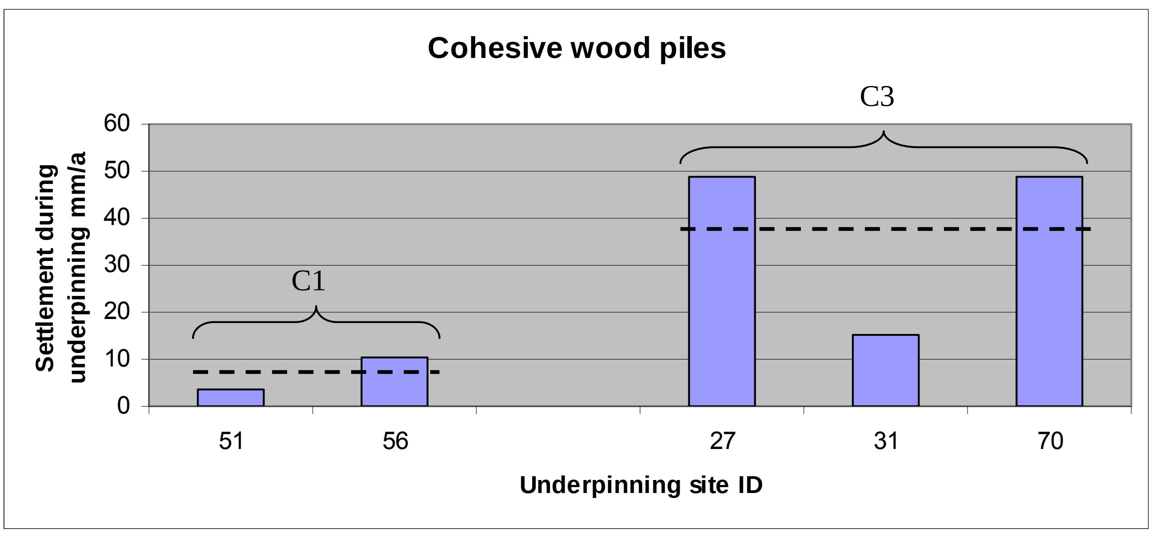

Figure 5. Observations from Turku: settlement during underpinning to existing cohesive wood pile foundations (the dotted lines indicate mean values). The sites on the left (ID51 and 56) have been classified to stage C1 (pre-underpinning settlement s < 4 mm/year), and the sites on right (ID27, 31 and 70) have been classified to stage C3 (pre-underpinning settlement s > 6 mm/year). (DATU 2010)

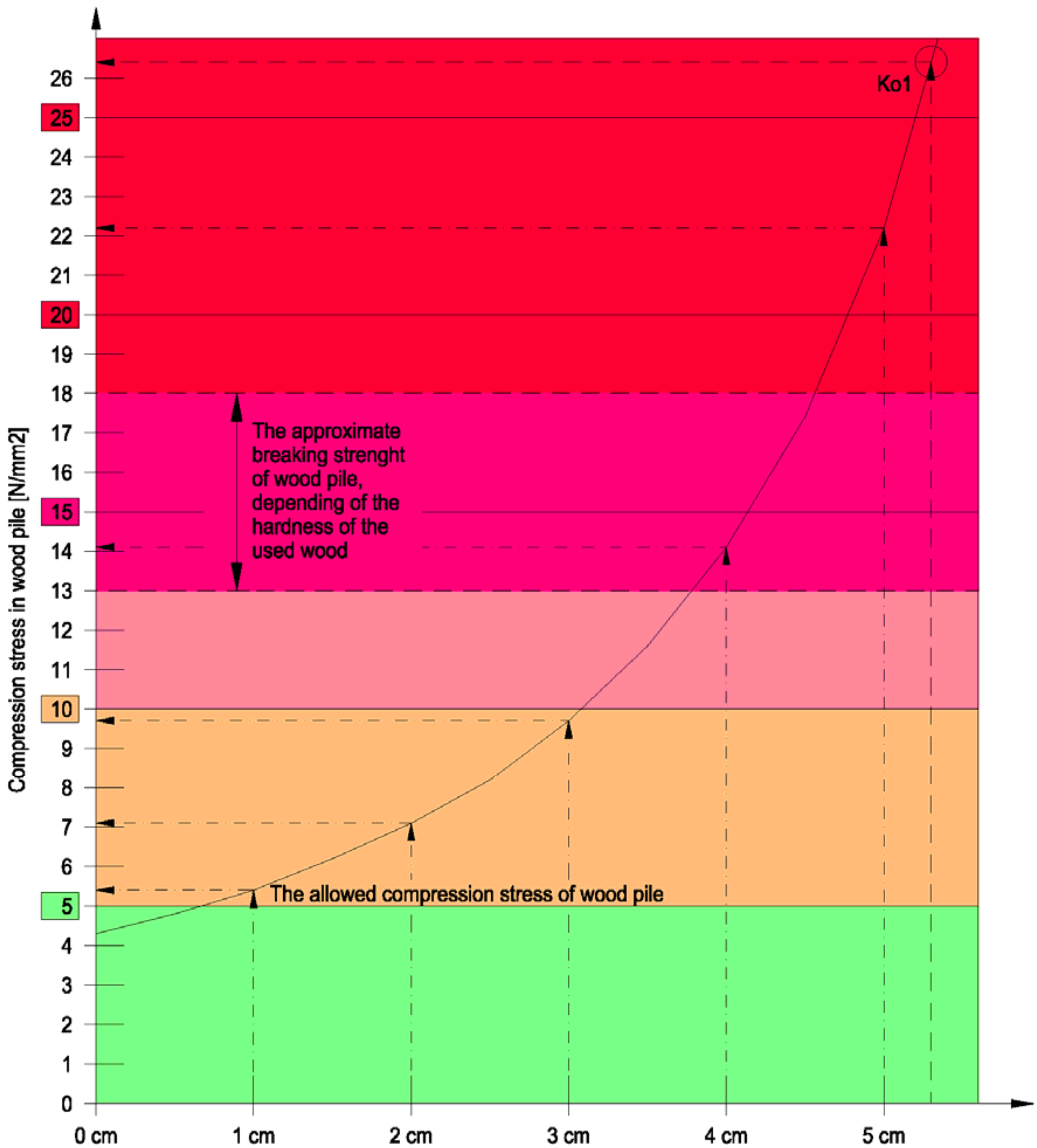

Figure 6. Exceptional high stresses in wood material when occasional non-settlement behavior of seriously decayed wood piles (Ko1: decay of wood material over 5 cm) has been observed (Perälä 2008).

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