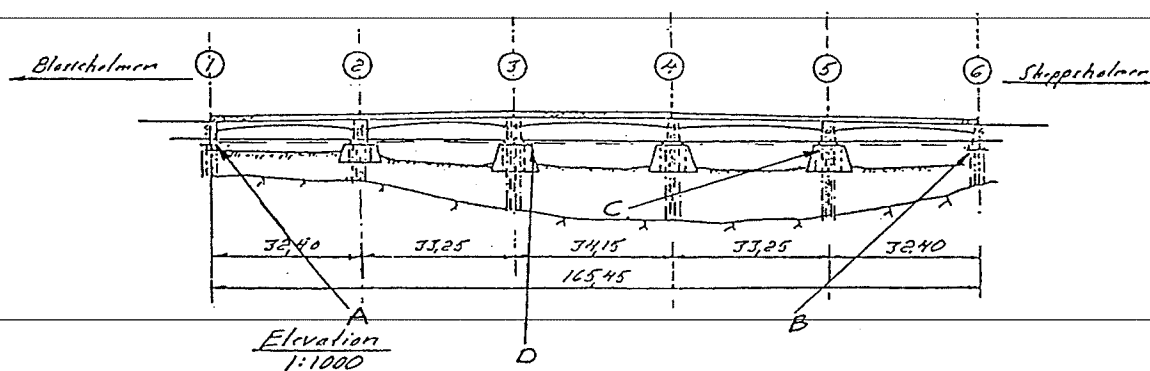


Skeppsholmsbron

The condition of timber
from foundation no. 3

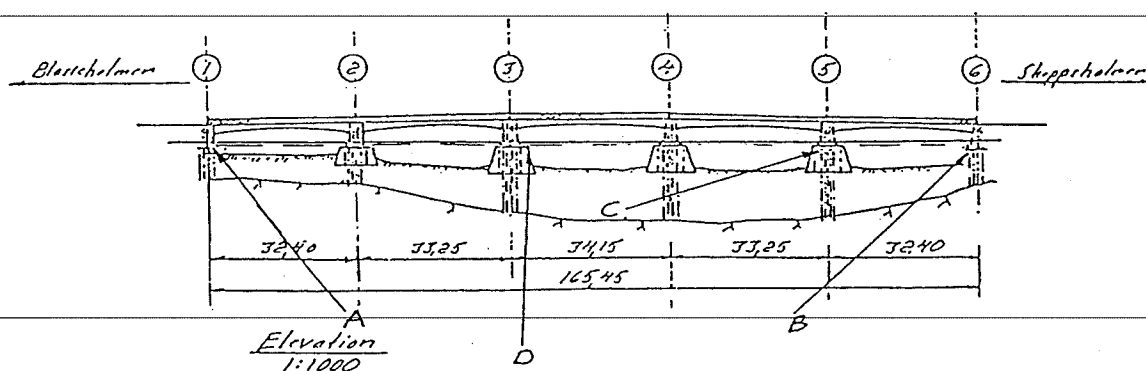
Preben Hoffmeyer
Ulla Gjøl Jacobsen



Skeppsholmsbron

The condition of timber
from foundation no. 3

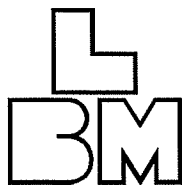
Preben Hoffmeyer
Ulla Gjøl Jacobsen



LABORATORIET FOR BYGNINGSMATERIALER
Danmarks Tekniske Højskole

BUILDING MATERIALS LABORATORY
Technical University of Denmark





Skeppsholmbron

An assessment of the condition of timber from foundation no.3

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Technical University of Denmark
1994.05.07

Introduction

The present report summarizes the results of a laboratory investigation of the condition of marine timber removed from foundation no. 3 of "Skeppsholmbron" in Stockholm. The work is a result of an investigation carried out in a cooperation between KFS AnlægningsKonstruktörer AB and LBM/DTU.

The draft programme for the investigation is outlined in KFS letter of 94.02.14, section 2.2 "Laboratorieundersökning av träprover". A number of additional tests were later included to form the final programme (see Appendix A).

A series of light microscope investigations of decay were also included in the programme. Although that investigation is reported separately by Hussvamlaboratoriet, some of the results are included here.

The report comprises a listing of test results and does not attempt to draw any conclusions concerning possible consequences with respect to the bridge foundation.

Material

10 samples from foundation no. 3 were delivered to LBM on April 1, 1994. They were received in water filled bags and kept submerged in tap water until further processing. The samples comprise the eight samples included in the project programme plus an additional two samples.

Methods

Specimen preparation

From each of the 10 samples two 100 mm thick cross section discs were cut at approximately 20 mm from each end. From most of these discs a number of small prisms (approximately 25x25x100 mm) were cut. Two small specimens were immediately removed from each prism. One was weighed for later oven-drying and moisture content assessment. The other was sealed in a plastic bag and kept in refrigerator for a possible later decay assessment. The remaining part was shaped to give a 20x20x60 mm prism for strength testing. Discs and prisms were kept in water except during processing.

Marking

Upon arrival at LBM, the samples had been marked with a brass plate informing about number and orientation relative to up/down. Also included in the marking was an arrow identifying the direction north (Appendix C).

The discs were marked in accordance with the guidelines of Appendix A.

The prisms were marked in accordance with the discs from which they were cut. When only two prisms were cut from a disc, the outermost prism was marked S (sapwood) and the innermost was marked H (heartwood). In cases where more than two prisms were cut from a single disc, capital letters were added for identification (Appendix E). Some discs showed no clear signs of sapwood. An "S"-prism removed from such discs merely represents a prism removed from the youngest part of the wood

Visual assessment of discs

Each of the 20 discs were visually examined for decay or other anomalies. In addition, an assessment of the amount of sapwood/heartwood was carried out where possible.

Species identification

Species identification on the basis of macroscopic features was possible only for one of the ten samples. A light microscopical identification was therefore carried out for all ten samples.

Density

Density was measured as basic density i.e. oven-dry weight over green volume.

Moisture content (MC)

Moisture content is defined as the ratio of the weight of removable water to the dry weight of the wood. The dry weight is obtained by oven-drying at 103 ± 2 °C until the weight loss is less than 0,1% over a period of 24 hours. Moisture content is most often expressed in percentage terms as

$$MC = \frac{w_w - w_0}{w_0} 100$$

where w_w is the weight of the sample at the actual moisture content and w_0 is the weight of the sample at oven-dry condition.

MC was calculated both for the small specimens removed from the prisms during specimen preparation and from the compression test specimens tested later after one week's soaking in water. The former MC represents an estimate of the actual moisture "as received" at LBM. The latter moisture content was included only to make sure that all prisms were strength tested at a MC above the so-called fibre saturation point.

Strength test

The compression strength testing was carried out in accordance with the test standard described in SKANORM 5 and 6 [1]. Time to failure was approximately 3 minutes. A total of 67 compression tests were carried out. 11 of these were across-the-grain-tests while 56 were along-the-grain-tests.

An extra set of 12 compression tests were included to assess the influence of MC on compression strength. Six specimens were tested at approximately 10% MC and six matched specimens were tested at a moisture content above fibre saturation (30%). 2x3 specimens were tested along the grain and 2x3 specimens were tested across the grain.

Additional tests

A Pilodyn instrument was used to assess the strength of the outer parts of some of the discs. The instrument works by shooting a blunt pin into the wood and measuring the depth of penetration. The penetration depth of the instrument is limited to 40 mm and usually amounts to about 14-16 mm in sound, moisture saturated wood. The Pilodyn was shot into the wood perpendicular to the original surfaces of the discs. Four readings were taken for each disc. The Pilodyn instrument was the standard version i.e. an energy of 6J and a pin diameter of 2.5 mm.

Results

Visual assessment of discs

The results of the visual assessment are summarized in Table 2. Many of the discs developed a dark blue discoloration shortly after exposing the freshly cut surface to the atmosphere. This added to the general difficulties of identifying the true sapwood/heartwood border. Often this border was assessed only on the basis of an apparent contrast in moisture content.

Whereas the poles appear to have lost only a limited amount of their original sapwood, the other wood members seem to have lost most of their sapwood. A few of these specimens had decayed in a manner which suggested that the cross sectional area was originally significantly larger.

A summary of length of samples and species identification is presented in Table 1. Also shown is the sapwood percentages of the cross sections calculated as sapwood area divided by total area.

Table 1 Length of sample, sapwood percentage and species

Specimen identification	Length of sample as delivered (mm)	Species	Sapwood area/total area %
P1	490	Pine	57
P2	260	Pine	38
P3	420	Pine	56
RU1	515	Spruce	presumably 0
RU2	495	Spruce	presumably 0
RÖ1	555	Pine	presumably 0
RÖ2	480	Pine	presumably 0
TK	510	Pine	10-15
1	480	Pine	presumably 0
3	510	Spruce	presumably 0

Table 2 Results of visual assessment of discs

Specimen identification	Description
P1.1	Distinct heartwood appearance. Average pole diameter: 215 mm. Average diameter of heartwood: 145 mm. Heartwood without visible decay. Sapwood with incipient decay and slight discoloration.
P1.2	Distinct heartwood appearance. Average pole diameter: 220 mm. Average diameter of heartwood: 145 mm. Heartwood without visible decay. Sapwood with incipient decay. No discoloration.
P2.1	Vague heartwood appearance. Irregular shape of cross section due to wound which stopped the growth locally 40-50 years prior to felling. Average pole diameter: 235 mm. Average diameter of heartwood: 185 mm. Heartwood sound except locally around wound. Sapwood decayed with grey-colouring of latewood bands.
P2.2	Same as P2.1.
P3.1	No distinct heartwood appearance. Sapwood/hardwood borderline taken as line of distinct moisture contrast. Average pole diameter: 265 mm. Average diameter of heartwood: 180 mm. Heartwood predominantly sound. Sapwood decayed with grey-colouring of latewood bands.
P3.2	No distinct heartwood appearance. Sapwood/hardwood borderline taken as line of distinct moisture contrast. Average pole diameter: 270 mm. Average diameter of heartwood: 180 mm. Heartwood sound. Sapwood decayed with grey-colouring of latewood bands.
RU1.1	Sound wood (probably heartwood). Cross section dimensions 115x175 mm
RU1.2	Sound wood (probably heartwood). Cross section dimensions 115x175 mm
RU2.1	Sound wood (probably heartwood). Cross section dimensions 115x160 mm
RU2.2	Sound wood (probably heartwood). Cross section dimensions 115x175 mm
RÖ1.1	Predominantly sound wood but some incipient decay. Cross section dimensions 50x180 mm.
RÖ1.2	Incipient decay. Cross section dimensions 45x170 mm
RÖ2.1	Sound wood with small pockets of incipient decay on the pith side of the board. Dimensions 35x165 mm
RÖ2.2	Sound wood with small pockets of incipient decay on the pith side of the board. Dimensions 55x165 mm
TK.1	15 % of cross section is sapwood. Sapwood decayed. Heartwood sound. Cross section dimensions 205x240 mm. An ø35 mm increment core has been removed from this sample at an earlier occasion.
TK.2	10 % of cross section is sapwood. Sapwood decayed. Heartwood sound. Cross section dimensions 205x240 mm.
1.1	Sound wood. Cross section dimensions 33x160 mm
1.2	Sound wood. Cross section dimensions 50x180 mm
3.1	Some incipient decay. Cross section dimensions 33x160 mm
3.2	Predominantly sound wood. Cross section dimensions 100x135 mm

Strength tests

The results of the comparative test concerned with the influence of moisture on strength properties are presented in Table 3. The "dry" condition corresponds to MC \approx 10%. The ratio wet strength/dry strength is in agreement with other such values found in literature.

Strength values for all prisms are given in Appendix B. The strength values are superimposed the cross section photos (Appendix E) to better visualize the strength variation e.g. across a pole cross section. The average strength values for sapwood and heartwood of 14 discs are presented in Table 4.

By allocating the relevant strength values to sapwood and heartwood areas of the poles, their average compression strength along the grain is estimated to be 19 MPa, 15 MPa and 14MPa for poles nos. P1, P2 and P3 respectively. These values are all referring to the low level discs marked (2).

A rough estimate of the average compression strength values for sound, water saturated spruce and pine of the relevant average density are of the order 20 MPa along the grain and 2 MPa across the grain.

Pilodyn penetration

The Pilodyn penetration results are given in Table 4 above and the relationship to compression strength along the grain is illustrated in Figure 1 (page 7). The results suggest that the Pilodyn may be used as a non-destructive tester of marine timber strength. It can not be used underwater in its standard configuration. However, a modified version is known to have been used under such conditions.

Microscopical assessment of degree of decay

The main results of Hussvamlaboratoriet's decay assessment are listed in Appendix B. In order to illustrate the relationship between strength and decay as assessed by microscopy, a rating was introduced. "No decay" was given the value 0, "incipient decay" was given the value 1 and "decay" was given the value 2. The relationship is depicted in Figure 2 (page 7), which illustrates that the identification of "decay" does not automatically mean that the particular prism has lost its load capacity. Although the weak prisms are indeed all identified as having decay, there are even prisms (spruce) with decay which retain their original strength.

Figure 3 (page 7) illustrates that the relationship between compression strength and basic density is very weak for wood prisms which shows various degrees of decay.

Literature

- [1] Kucera, B.: Skandinaviske normer for testing av små feilfrie prøver av heltre. Institut for Treteknologi. Norges Landbrukshøgskole

Table3 *Comparison of wet and dry compression strength (MPa)*

Load orientation	Perpendicular to grain		Parallel to grain	
Condition	wet	dry	wet	dry
P1.1 - sapwood	1.6	6.0	12.0	34.3
P1.2 - heartwood	1.9	8.1	17.3	57.4
P1.2 sapwood	1.6	9.4	20.6	63.4
Mean value	1.7	7.8	16.6	50.7
wet/dry	22 %		33%	

Table 4 *Average values of properties of 20x20x60 mm prisms taken from heartwood and sapwood of 14 discs*

Specimen no.	Sapwood Heartwood	Number of prisms	Basic density kg/m ³	MC arrival %	MC at test %	Compression strength Mpa		Pilodyn penetration mean (mm)
						parallel	perpend.	
P1.1	H	1	428	87	95	18.6		
P1.1	S	2	406	184	173	11.5		27
P1.2	H	5	420	80	75	20.4		
P1.2	S	4	430	191	165	17.8		24
P2.1	H	2	391	139	137	16.5		
P2.1	S	1	285	363	249	7.5		31
P2.2	H	7	356	92	147	19.1		17
P2.2	S	3	430	370	152	8.7		34
P3.1	H	1	376	141	122	15.1		
P3.1	S	2	394	212	186	8.0		32
P3.2	H	6	401	92	96	16.0		
P3.2	S	3	387	216	191	13.1		26
RU1.2	H	1	416	174	174	17.5		
RU1.2	S	1	408	147	183	20.5		14
RU2.2	H	1	623	63	90	26.6		
RU2.2	S	1	595	120	98	24.8		13
RØ1.2	H	1	390	150	190	12.9	0.8	19
RØ1.2	S	1	409	138	179	13.7	1.2	19
RØ2.2	H	1	432	170	164	15.2	1.7	18
RØ2.2	S	1	479	143	139	18.6	2.3	14
TK.1	H	2	411	75	62	18.9	2.1	17
TK.1	S	2	312	230	259	11.5	1.2	33
TK.2	H	2	410	577	62	20.0		18
TK.2	S	2	318	349	250	10.6		36
1.2	H	1	456	158	151	19.8		16
1.2	S	1	478	141	139	19.5		16
3.2	H	1	369	89	97	16.5		18
3.2	S	1	386	206	149	17.3		17
RU1.2	H	1	416	188	119		1.9	
RU1.2	S	1	461	162	148		2.6	
RU2.2	H	1	556	109	115		1.5	
RU2.2	S	1	552	96	120		2	

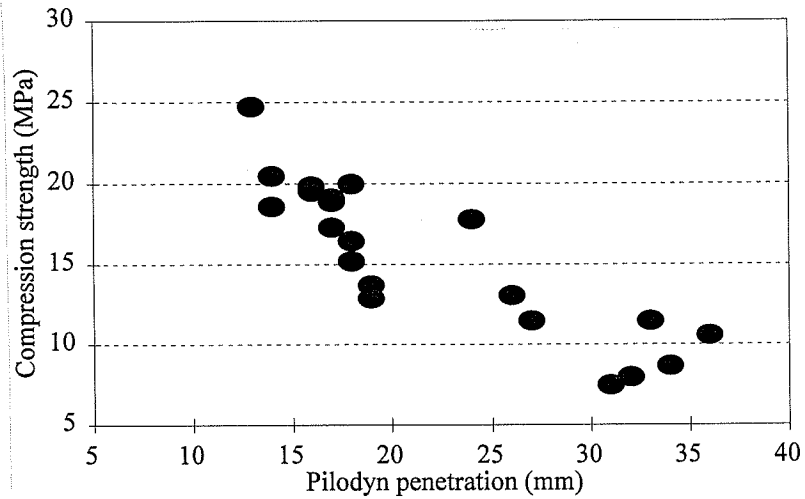


Figure 1 *Compression strength along the grain against Pilodyn penetration*

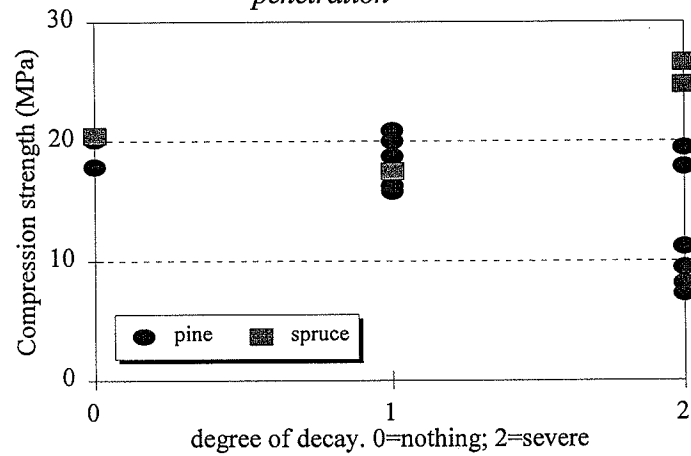


Figure 2 *Compression strength against degree of decay. 0="no decay"; 1="incipient decay"; 2="decay"*

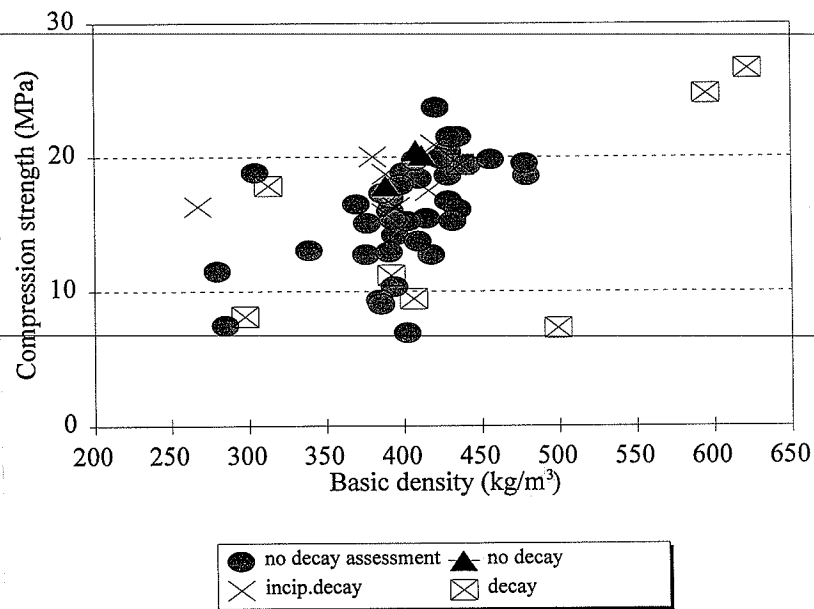


Figure 3 *Compression strength against basic density.*



APPENDIX A

Definition of programme
(Bilaga till KFS PROGRAM, 1993-02-14)

Additional tests not included in agreed programme.

Prov Märkning Splint=S, Käma=K	Träslag	Splintved bredd mm	Läge i provstycke	Vät- vikt g	Torr- vikt g	Fukt- kvot %	Densitet kg/m³	Tryckhållfasthet i belastningsriktningen Mpa	Övrigt Okulärbedömning etc
()=prov nr Träkista=I									
T1(1) <i>(TK)</i>	x	x	x	x	x	x	x	x	x
T1(2)	x	x	x	x	x	x	x	x	x
Pålar=P									
P1(1)	x	x	x	x	x	x	x	x	Prov (1) nära pålopp
P1(2)	x	x	x	x	x	x	x	x	Prov (2) nära underyta
P2(1)	x	x	x	x	x	x	x	x	Prov (1) nära pålopp
P2(2)	x	x	x	x	x	x	x	x	Prov (2) nära underyta

across the grain
x x x
x x x
along the grain
x x x

// fiberriktningen

*(+3)
(+6)*

*(+3)
(+6)*

Prov Märkning Splint=S, Kärra=K	Träslag	Splintved		Läge i provstycke	Våt- vikt g	Torr- vikt g	Fukt- kvot %	Densitet kg/m ³	Tryckhållfasthet i belastningsriktningen Mpa	Övrigt Okulärbedömning etc
P3(1)	x	x	x	x	x	x	x	x	x	x Prov (1) nära pålopp
P3(2)	x	x	x	x	x	x	x	x	x	x Prov (2) nära underyta
Rustbädd=R U=undre lagret Ö=övre lagret										
RU1(1)	x	x	x	x	x	x	x	x	x	x Prov (1) nära plankände
RU1(2)	x	x	x	x	x	x	x	x	x	x Prov (2) nära stenmur <i>fristat snit</i>
RU2(1)	x	x	x	x	x	x	x	x	x	x Prov (1) nära plankände
RU2(2)	x	x	x	x	x	x	x	x	x	x Prov (2) nära stenmur <i>fristat snit</i>

↓ fiberriktningen
// fiberriktning

across + along the grain

additional

Prov Märkning Splint=S, Kärna=K	Träslag	Splintved bredd mm	Läge i provstycke	Våt- vikt g	Torr- vikt g	Fukt- kvot %	Densitet kg/m ³	Tryckhållfasthet i belastningsriktningen Mpa	Övrigt Okulärbedömning etc
RÖ1(1)	x	x	x						x Prov (1) nära plankände
RÖ1(2)	x	x	x	x x	x x	x x	x x	<i>across the grain</i> x x	x Prov (2) nära stenmur <i>frist</i> <i>suit</i>
RÖ2(1)	x	x	x						x Prov (1) nära plankände
RÖ2(2)	x	x	x	x x	x x	x x	x x	<i>along the grain</i> x x	x Prov (2) nära stenmur <i>frist</i> <i>suit</i>
Σ undersökn.	16	16	16	24 49	24 49	24 49	24 49	24 49	16

*Total agreed**Additional sets of specimens nos 1 & 3.*

1(1)	x	x	x	x	x	x	x	x	x
1(2)	x	x	x	x	x	x	x	x	x
3(1)	x	x	x	x	x	x	x	x	x
3(2)	x	x	x	x	x	x	x	x	x

*Additional**Total, extra*

4

4

4

4

4

4

4

4

4

4

4

4

4



APPENDIX B

Results from tests of 20x20x60 mm prisms

Specimen identification

Sapwood/heartwood

Species identification

Basic density

Moisture content "as received"

Moisture content at test

Compression strength along the grain

Compression strength across the grain

Degree of decay

Project : "Skeppsholmsbron"

Data sheet no. A Data for 20x20x60 mm prisms

Results from individual specimens

File A.sk1.wb1

1994.05.05

PAGE 1

Specimen marking	Specimen no.	Additional marking	Sapwood Heartwood	Species Pine or Spruce	Basic density kg/m ³	MC arrival %	MC at test %	Compression strength		Decay assessment "Husvamlab."
								parallel	perpend.	
3P1 1kerne B	P1.1	B	H	P	428	87	95	18.6		no test
3P1 1splint A	P1.1	A	S	P	418	171	166	12.7		no test
3P1 1splint C	P1.1	C	S	P	394	198	180	10.4		no test
3P1 2kerne B	P1.2	B	H	P	420	75	70	20.9		incipient decay
3P1 2kerne C	P1.2	C	H	P	389	102	75	17.9		no decay
3P1 2kerneE	P1.2	E	H	P	429	73	72	20.4		no test
3P1 2kerne G	P1.2	G	H	P	435	76	83	21.5		no test
3P1 2kerne I	P1.2	I	H	P	430	74	73	21.5		no test
3P1 2splint A	P1.2	A	S	P	437	211	164	19.5		decay
3P1 2splint D	P1.2	D	S	P	429	no test	164	16.7		no test
3P1 2splint F	P1.2	F	S	P	441	177	160	19.4		no test
3P1 2splint H	P1.2	H	S	P	415	184	170	15.4		no test
3P2 1kerne B	P2.1	B	H	P	391	92	113	16.0		no test
3P2 1kerne C	P2.1	C	H	P	391	187	161	16.9		no test
3P2 1splint A	P2.1	A	S	P	285	363	249	7.5		no test
3P2 2kerne B	P2.2	B	H	P	421	91	163	23.7		no test
3P2 2kerne C	P2.2	C	H	P	400	83	116	18.9		no test
3P2 2kerne D	P2.2	D	H	P	313	108	211	17.9		decay
3P2 2kerne F	P2.2	F	H	P	380	82	83	20.0		incipient decay
3P2 2kerne G	P2.2	G	H	P	267	78	175	16.3		incipient decay
3P2 2kerne I	P2.2	I	H	P	304	101	171	18.9		no test
3P2 2kerne J	P2.2	J	H	P	410	99	110	18.4		no test
3P2 2splint A	P2.2	A	S	P	499	420	105	7.3		decay
3P2 2splint E	P2.2	E	S	P	406	324	171	9.5		decay
3P2 2splint H	P2.2	H	S	P	384	365	181	9.4		no test
3P3 1kerne C	P3.1	C	H	P	376	141	122	15.1		no test
3P3 1splint A	P3.1	A	S	P	402	224	179	7.0		no test
3P3 1splint B	P3.1	B	S	P	386	200	193	9.1		no test

Specimen marking	Specimen no.	Additional marking	Sapwood Heartwood	Species Pine or Spruce	Basic density kg/m	MC arrival %	MC at test %	Compression strength Mpa parallel	perpend.	Decay assessment "Husvamlab."
3P3 2kerne D	P3.2	D	H	P	388	59	103	18.7		incipient decay
3P3 2kerne E	P3.2	E	H	P	435	69	47	16.1		no test
3P3 2kerne F	P3.2	F	H	P	388	160	190	15.8		incipient decay
3P3 2kerne G	P3.2	G	H	P	395	62	80	16.2		incipient decay
3P3 2kerne H	P3.2	H	H	P	394	88	62	14.2		no test
3P3 2kerne I	P3.2	I	H	P	402	117	96	15.2		no test
3P3 2splint A	P3.2	A	S	P	393	243	189	15.4		no test
3P3 2splint B	P3.2	B	S	P	392	224	184	11.2		decay
3P3 2splint C	P3.2	C	S	P	375	181	201	12.7		no test
3RU1 2kerne	RU1.2		H	S	416	174	174	17.5		incipient decay
3RU1 2splint	RU1.2		S	S	408	147	183	20.5		no decay
3RU2 2kerne	RU2.2		H	S	623	63	90	26.6		decay
3RU2 2splint	RU2.2		S	S	595	120	98	24.8		decay
3RØ1 2kerne	RØ1.2		H	P	390	150	190	12.9	0.8	no test
3RØ1 2splint	RØ1.2		S	P	409	138	179	13.7	1.2	no test
3RØ2 2kerne	RØ2.2		H	P	432	170	164	15.2	1.7	no test
3RØ2 2splint	RØ2.2		S	P	479	143	139	18.6	2.3	no test
3TK 1kerne	TK.1		H	P	424	76	55	19.9	2.1	no test
3TK 1kerne	TK.1	blue	H	P	398	74	70	17.9	2.0	no test
3TK 1splint	TK.1		S	P	280	188	297	11.5	1.2	no test
3TK 1splint	TK.1	blue	S	P	344	271	222	no test		no test
3TK 2kerne	TK.2		H	P	408	56	64	19.8		no test
3TK 2kerne	TK.2	blue	H	P	412	57	61	20.1		no decay
3TK 2splint	TK.2		S	P	339	322	228	13.0		no test
3TK 2splint	TK.2	blue	S	P	297	375	271	8.2		decay
1.2 kerne	1.2		H	P	456	158	151	19.8		no test
1.2 splint	1.2		S	P	478	141	139	19.5		no test
3.2 kerne	3.2		H	S	369	89	97	16.5		no test
3.2 splint	3.2		S	S	386	206	149	17.3		no test
3RU1 2kerne	RU1.2		H	S	416	188	119		1.9	no test
3RU1 2splint	RU1.2		S	S	461	162	148		2.6	no test
3RU2 2kerne	RU2.2		H	S	556	109	115		1.5	no test
3RU2 2splint	RU2.2		S	S	552	96	120		2.0	no test

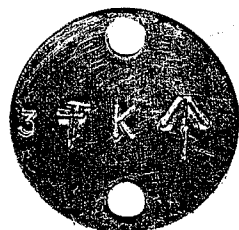


APPENDIX C

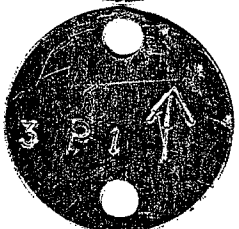
Picture of brass plates from samples

Skeppsholmsbron pelare 3.

Märkning av träprover från botten fundament



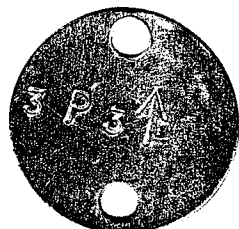
3 T K ↑ = Pelare 3 trä kista Norrpil



3 P 1 ↑ = Pelare 3 påle nr 1 norrpil



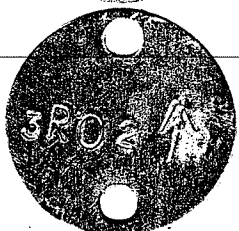
3 P 2 ↑ = Pelare 3 påle nr 2 norrpil



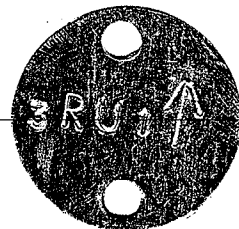
3 P 3 ↑ = Pelare 3 påle nr 3 norrpil



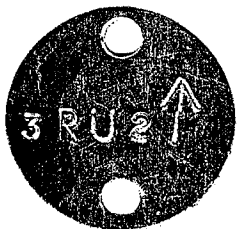
3 RÖ 1 ↑ = Pelare 3 Rustbädd övre plank nr 1 norrpil



3 RÖ 2 ↑ = Pelare 3 Rustbädd övre plank nr 2 norrpil



3 RU 1 ↑ = Pelare 3 Rustbädd undre plank nr 1 norrpil

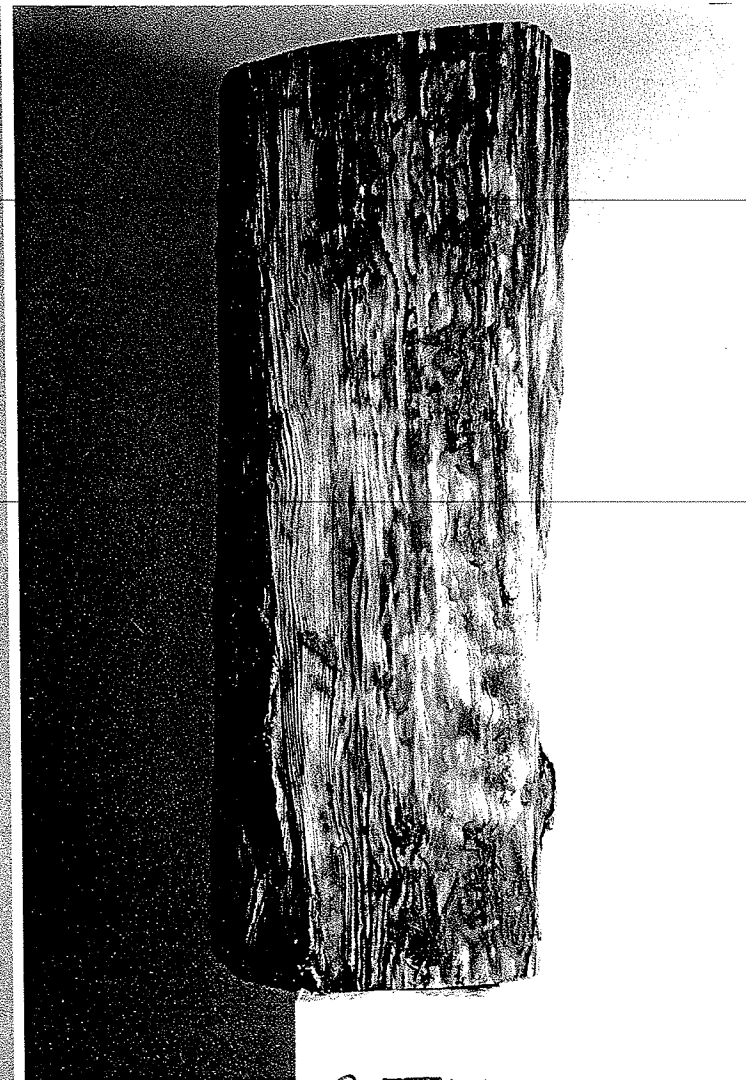
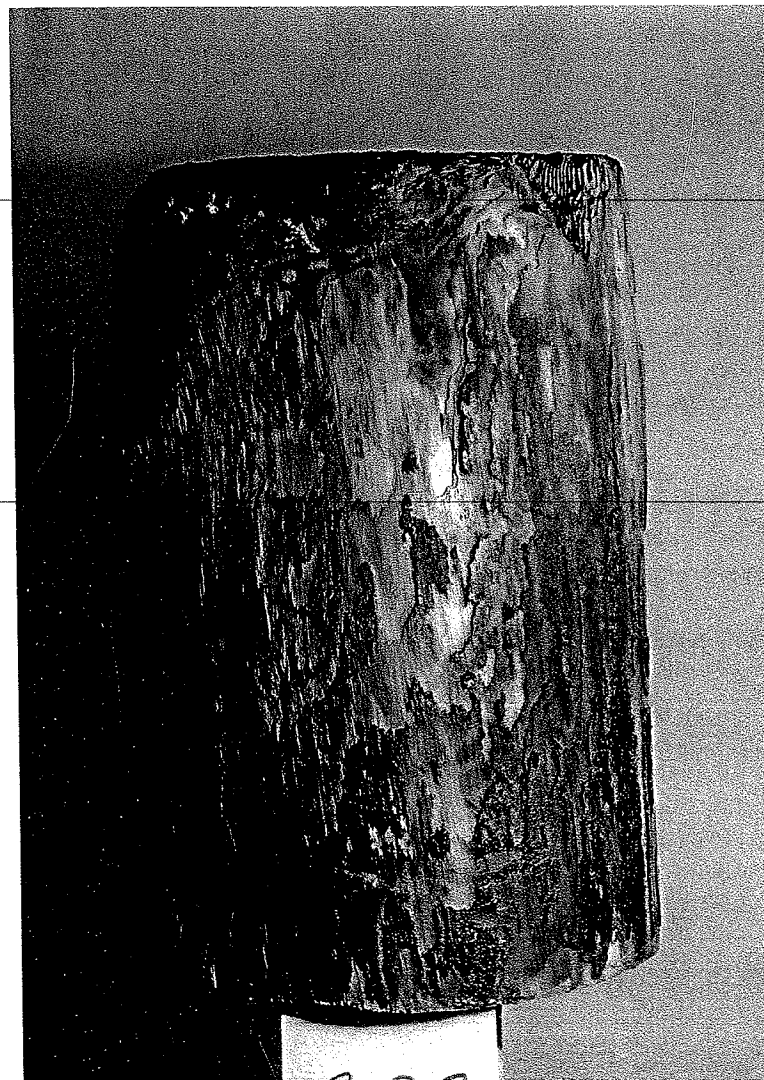
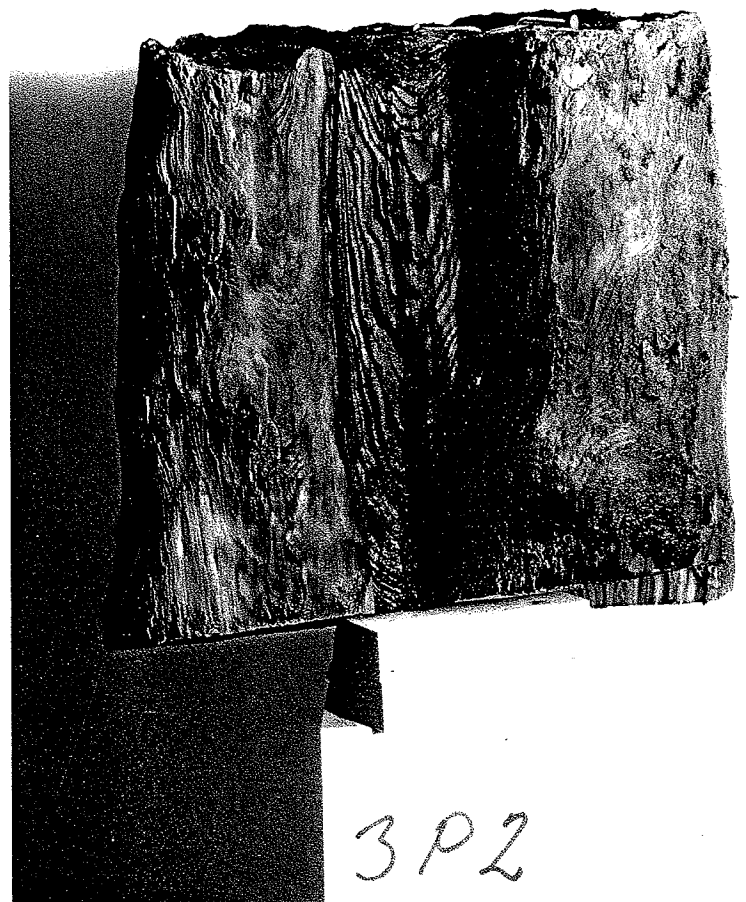


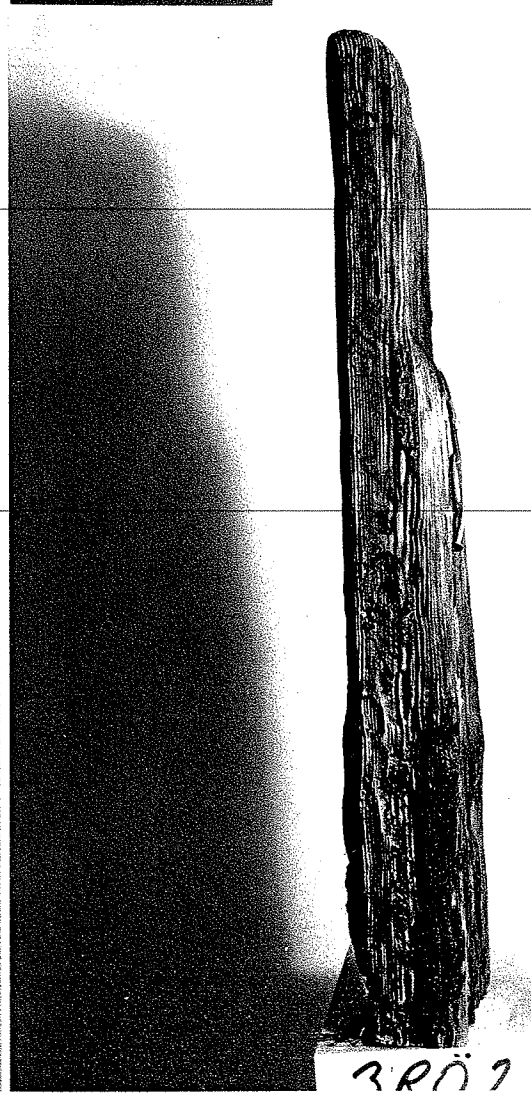
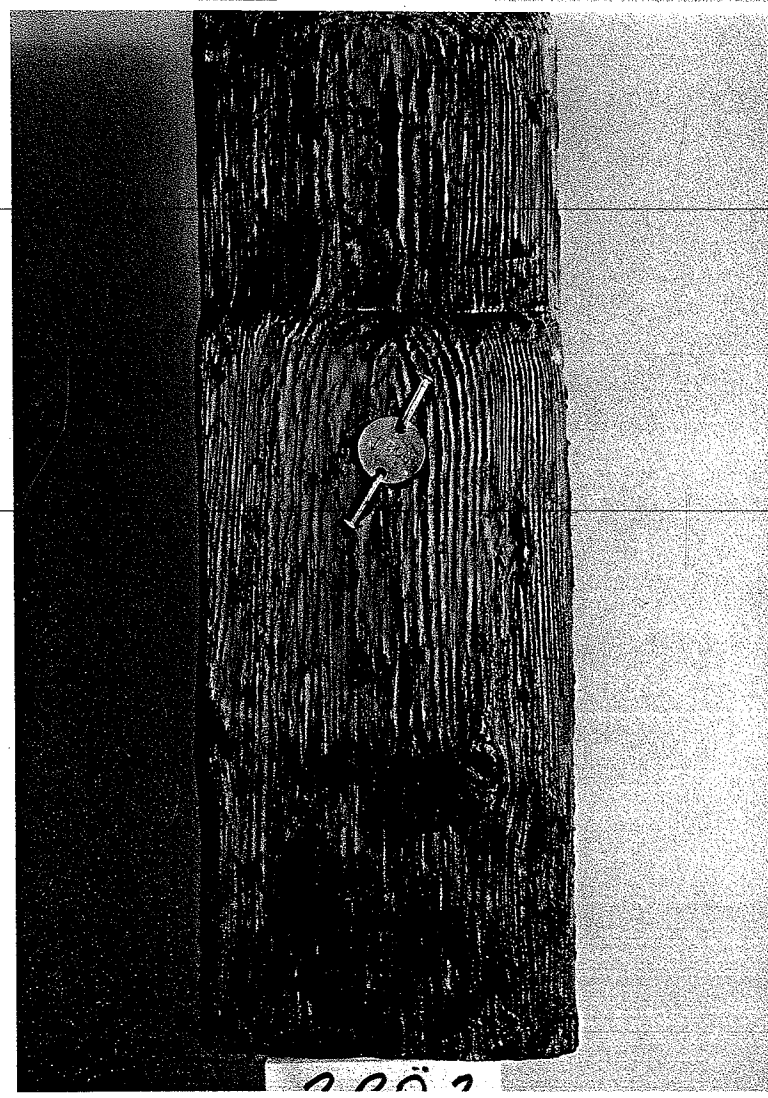
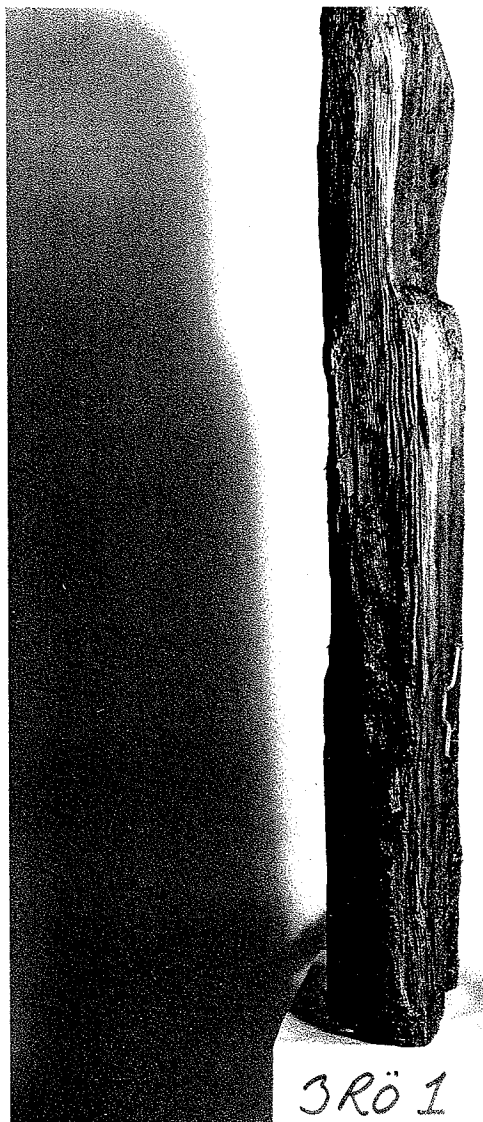
3 RU 2 ↑ = Pelare 3 Rustbädd undre plank nr 2 norrpil



APPENDIX D

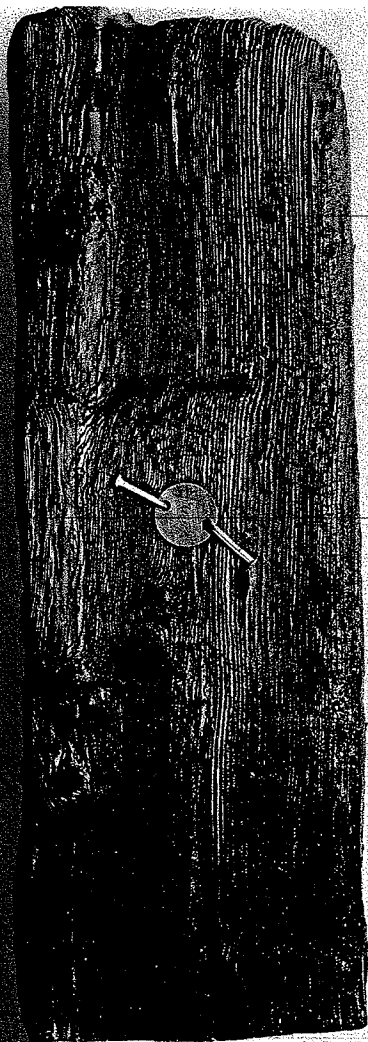
Photos of the ten samples after cleaning







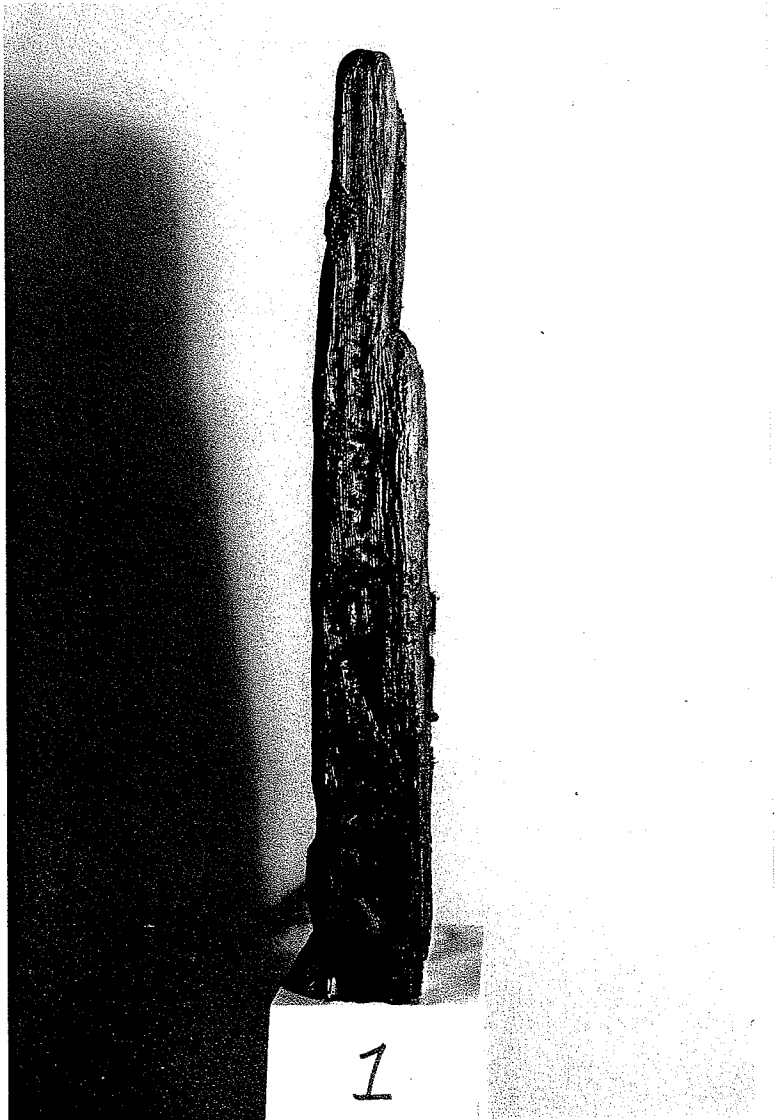
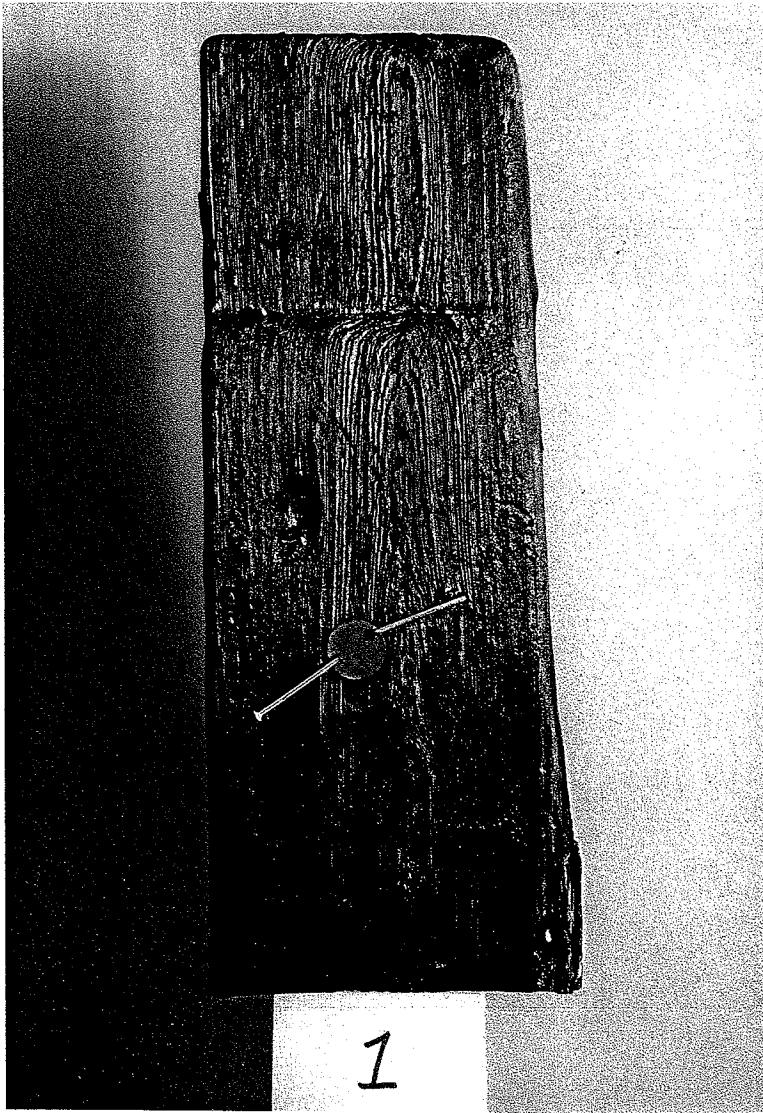
3RU1



3RU2



3RU2

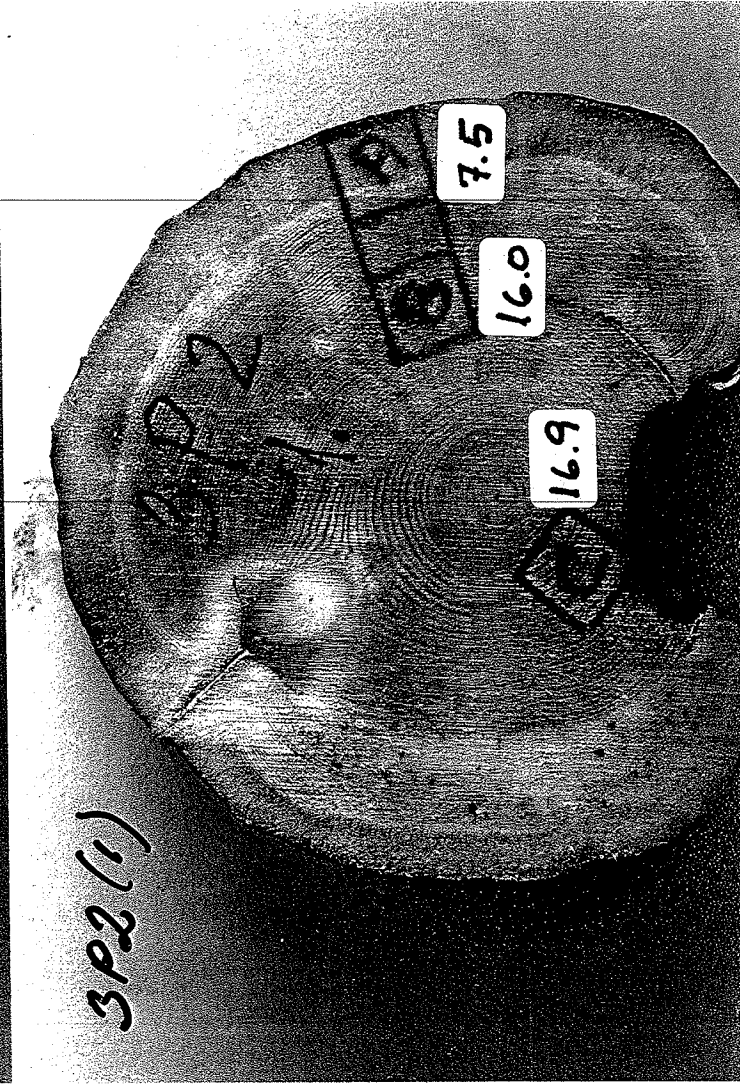
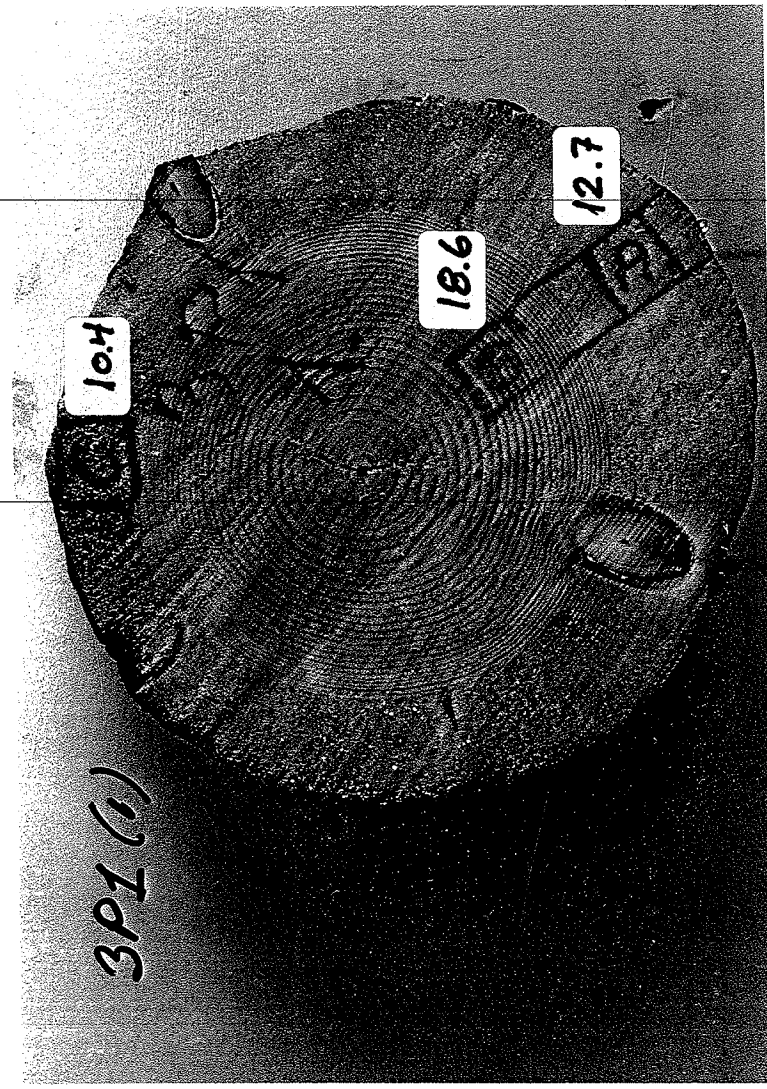
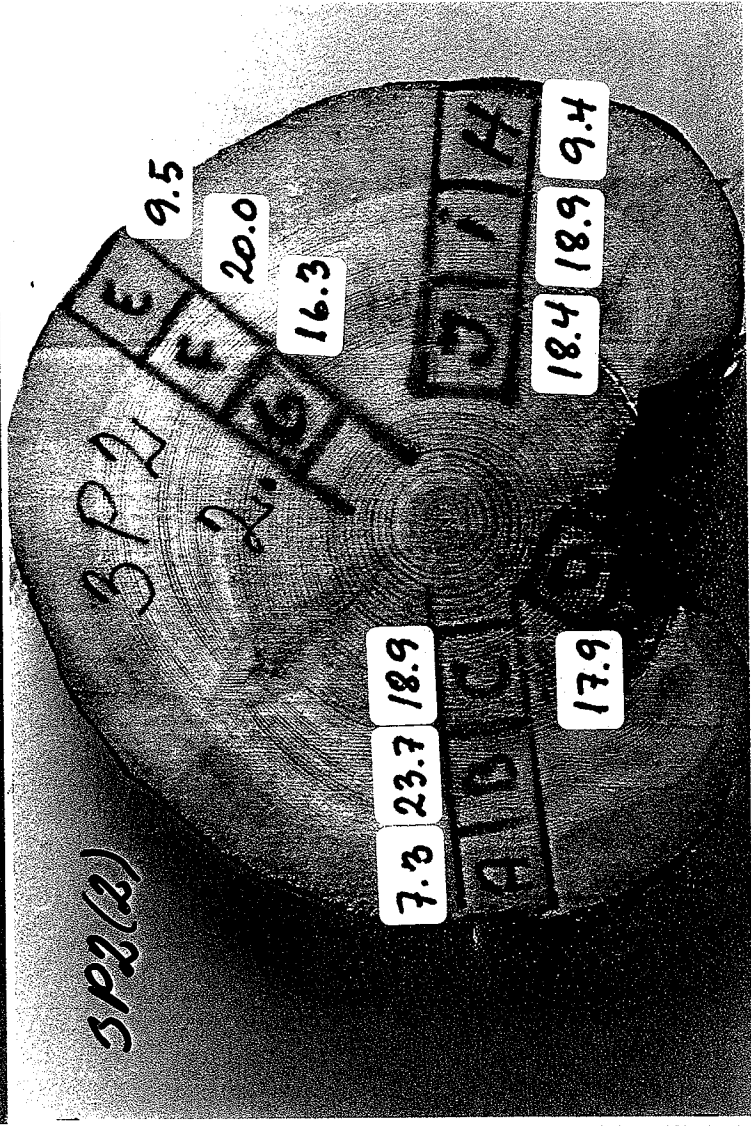
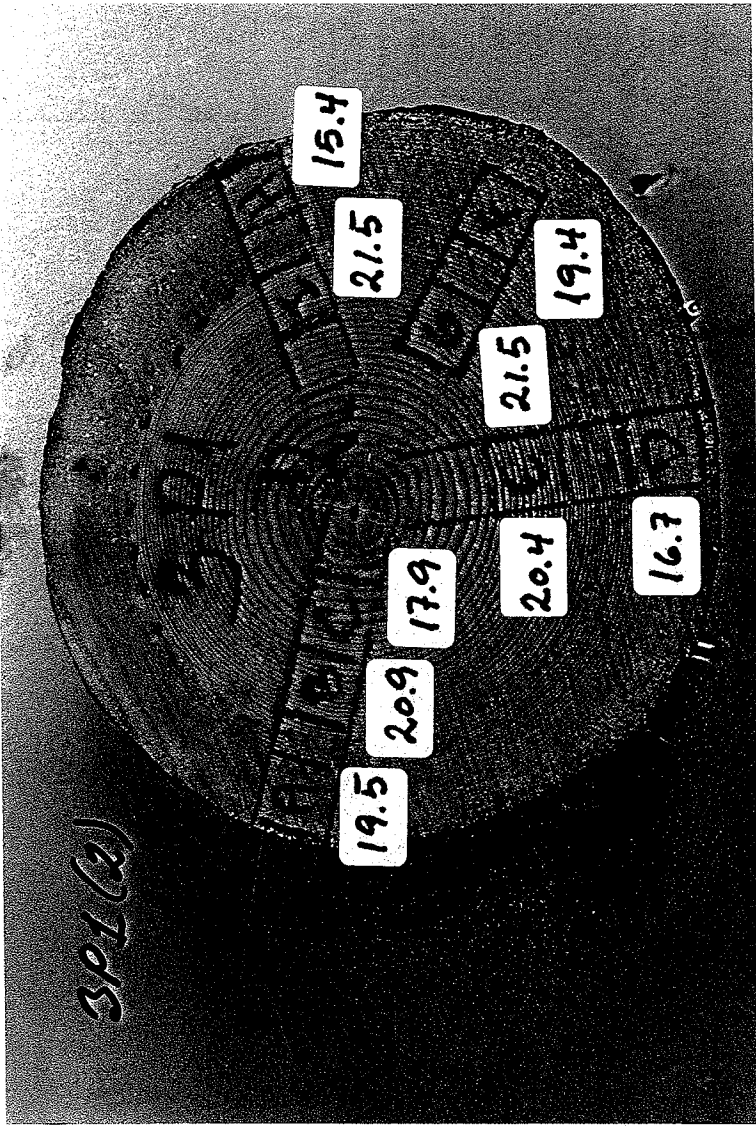


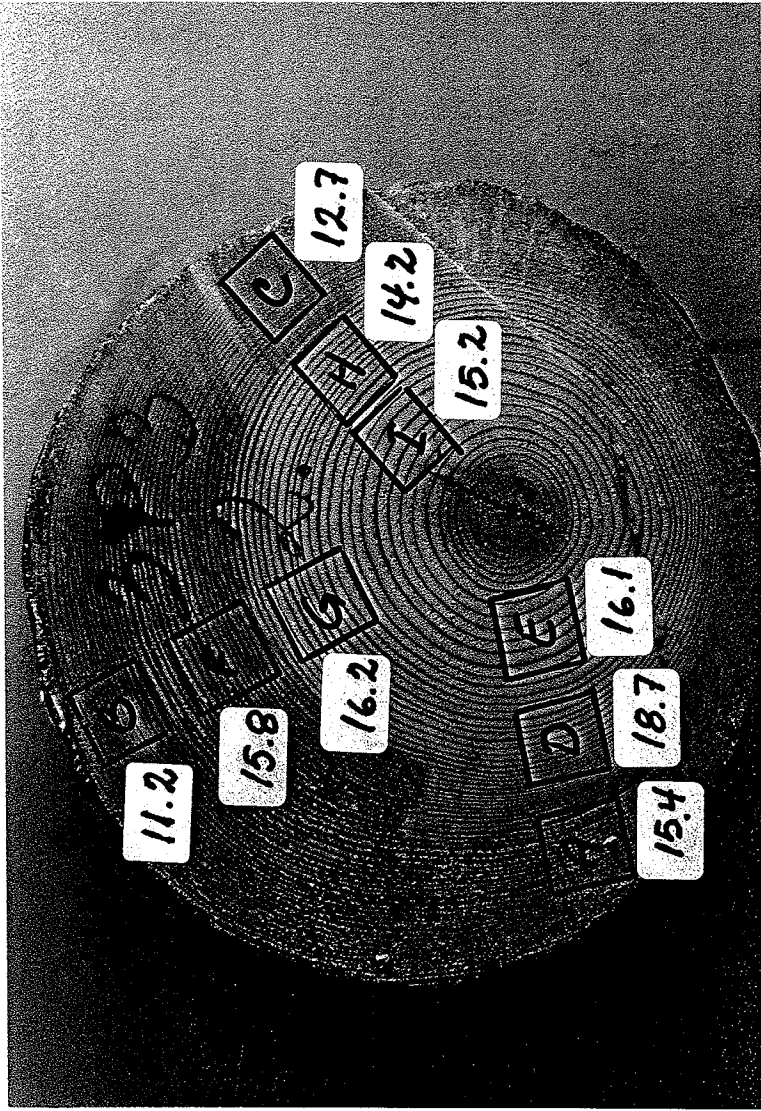


APPENDIX E

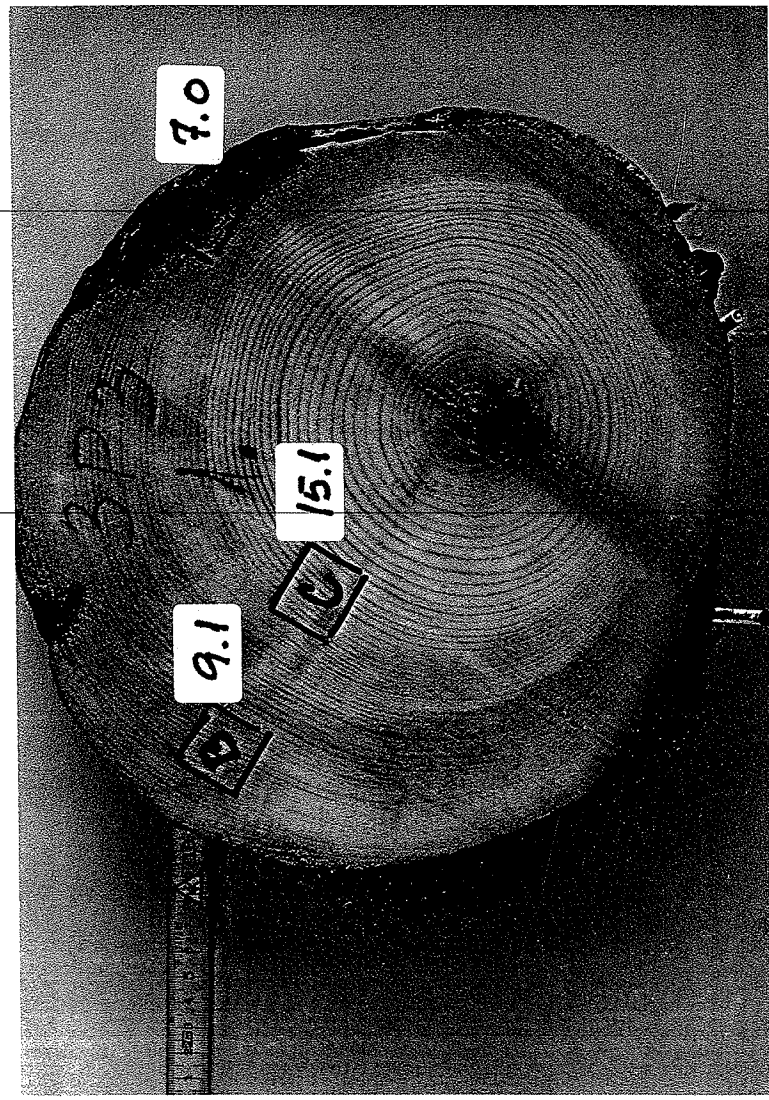
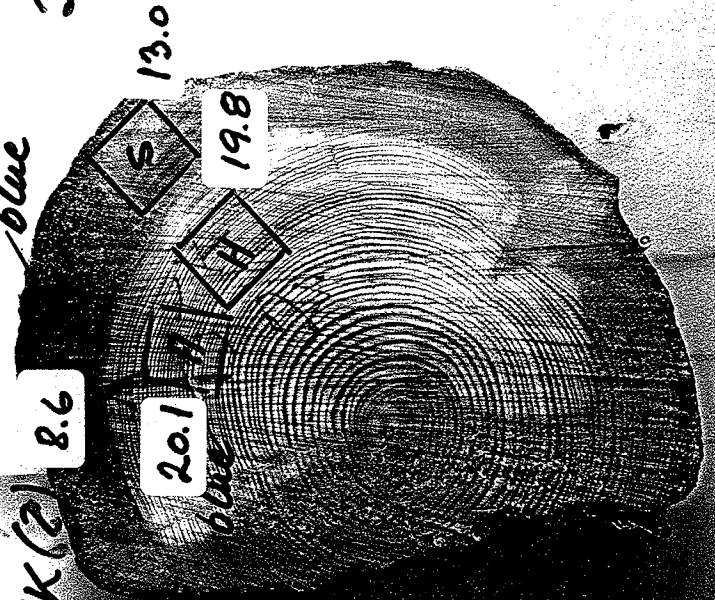
Photos of the 14 discs from which prisms were prepared

Location of prisms in the cross section
Superimposed values of compression strength along the grain

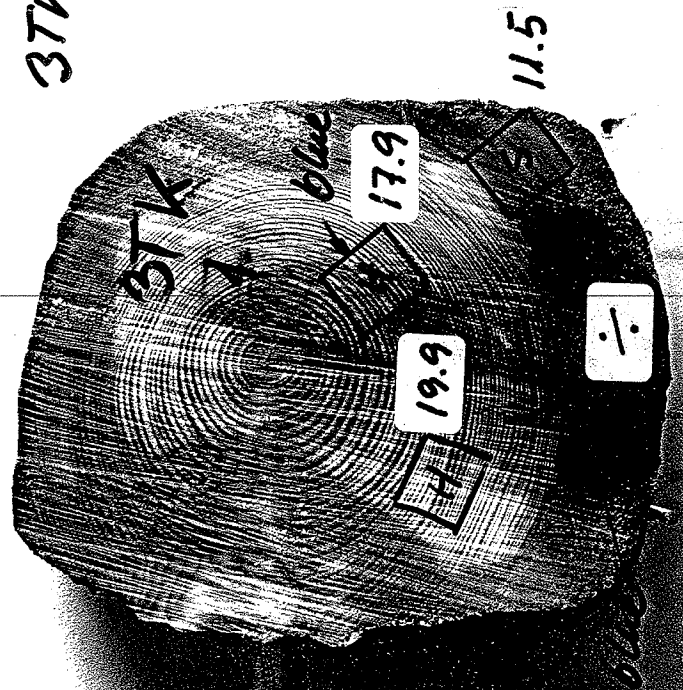




3TK(2) 8.6 blue 3TK2



3TK1



3R01(2)

13.7

12.9



3R02(2)

18.6

15.2



3RU1(2)

L

17.5

20.5

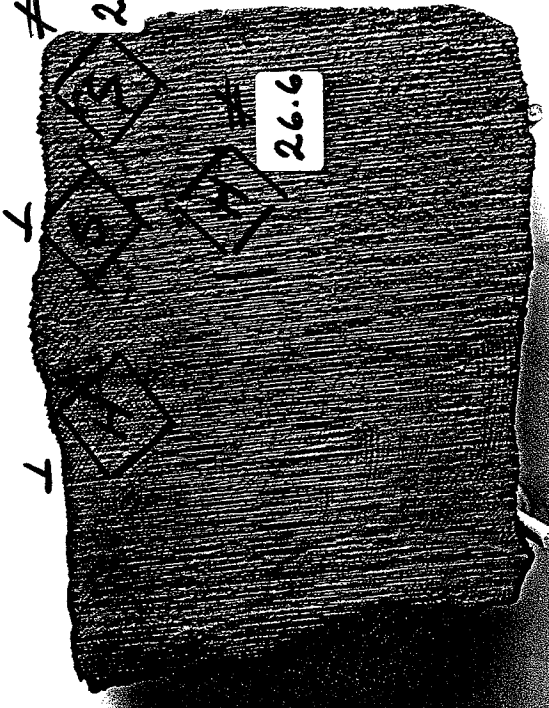


3RU2(2)

L

26.6

24.8





1 (2)

