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INTERNATIONAL COUNCIL FOR BUILDING RESEARCH STUDIES AND DOCUMENTATION

WORKING COMMISSION W18A - TIMBER STRUCTURES

DETERMINATION OF THE FRACTURE ENERGIE OF WOOD FOR TENSION PERPENDICULAR TO THE GRAIN

by

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MEETING TWENTY - THREE

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Contents

1. Introduction

The fracture energy of timber being exposed to tension acting across the grain is a parameter which is required for the calculation of the shear stress of girders with notchings at the supports (see the reference /1/).

Since hitherto only a few test results and findings concerning the fracture energy have been available, in 1989 the CIB W 18 A working commission has agreed to perform further tests and experiments with the participation of interested institutions.

2. Test procedure

2.1. Objectives

The objectives of the tests are the investigation into the crack development parallel to the grain and the determination of the corresponding fracture energy with a view to enabling a drawing of conclusions therefrom to the behaviour in practice of notched beams or connections (joints/fasteners) being exposed to stresses and strains acting perpendicularly to the grain.

Considering the dependence of the results and findings on the test method being adopted, a standardized (i.e. uniform) method has been taken as the basis for all tests /6/.

The tests and investigations performed in the GDR referred to a determination of the influence of the timber moisture on the fracture energy of mechanically sorted high-strength timber, of the influence of a visual grade-related sorting on the fracture energy with an equal degree of timber moisture and of the fracture energy of glued laminated timber as compared with that of structural timber.

2.2. Test arrangement and test material

The test arrangement of the test material used is being shown by Table 1 (see page 4). The test arrangement demonstrating in detail the example of testing a timber square with a glue-inserted middle piece of glued laminated timber is being illustrated by the Figures 1, 2 and 3 (see the pages 5, 6 and 7, respectively).

2.3. Test procedure

2.3.1. Preparation of the test specimens

- Storage of the glued test specimens in the climatic test cabinet until reaching the equilibrium moisture rate ω.
  Variant: A with ω = 12 %;
  B with ω = 18 %;
  C with ω = 24 %;
  D to F with ω = 12 %.
- After having reached the equilibrium moisture rate ω, the weighing of the total sample is being carried out.
- Immediately prior to beginning the test, the slot in the middle piece is being provided.
- Measurement and recording of all geometrical parameters of the test specimens.

2.3.2. Execution of the testing

Testing machine:	"TIRATEST 2300"-type universal testing machine, manufactured by the machine tool builders' trust Werkzeugmaschinenkombinat "Fritz Heckert" of Karl-Marx-Stadt (Chemnitz), factory at Rauenstein
Testing speed:	0.6 mm per minute
Load application:	constant until the complete failure of the test specimen concerned

(to be continued on page 8)

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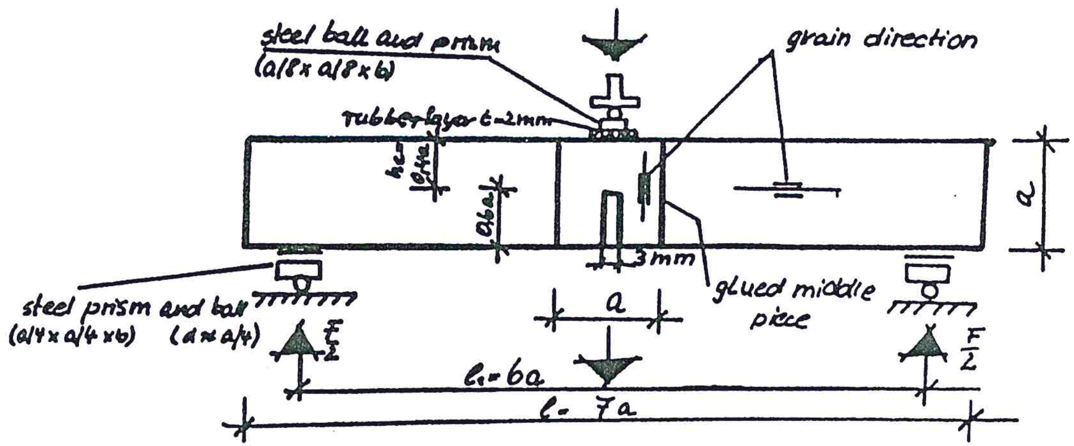
Table 1: Test procedure for tests to determine the fracture energy

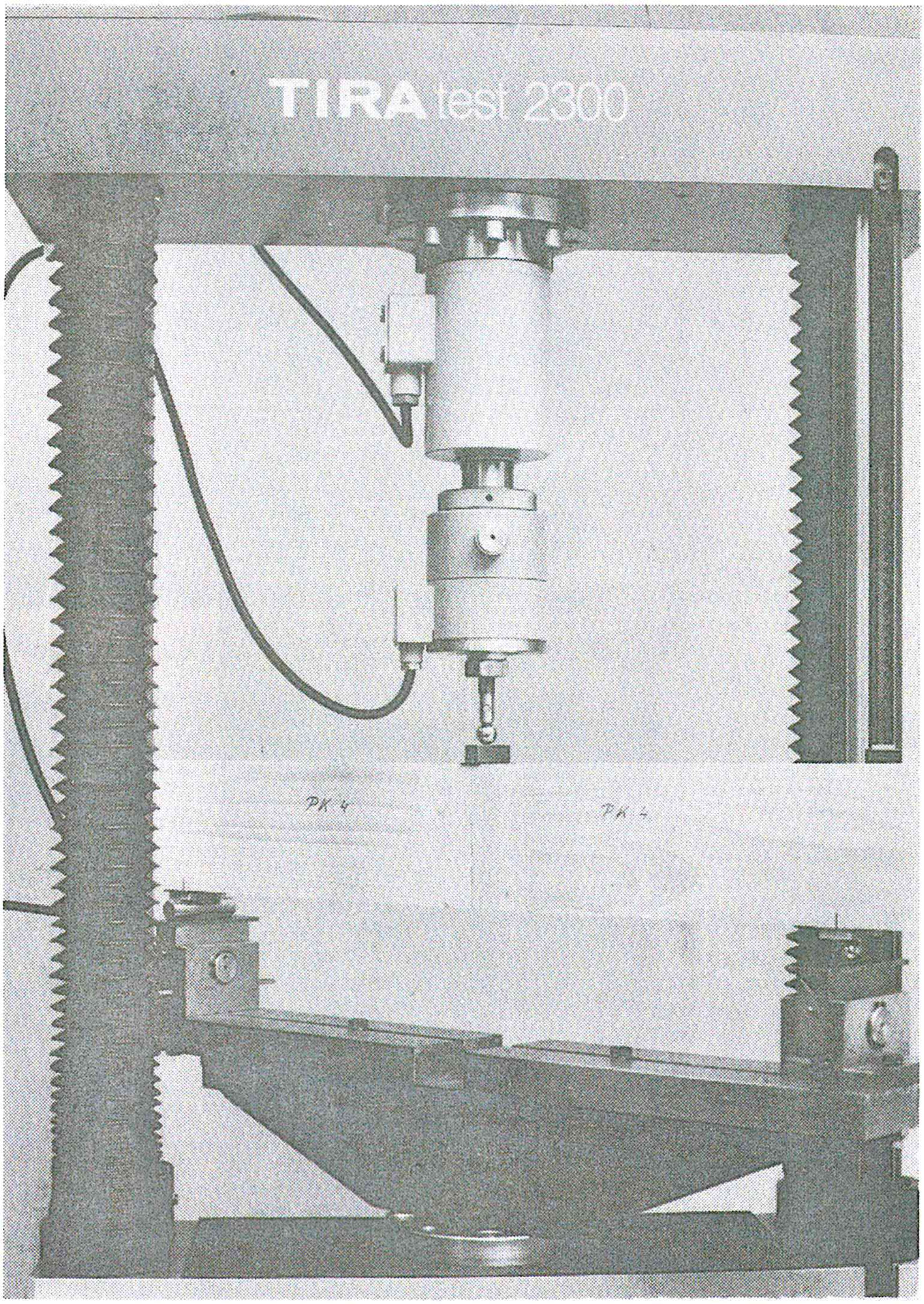


solid wood	glued laminated timber
b = 45 mm	b = 45 mm
a = 90 mm	a = 128 mm
he= 36 mm	he = 51,2 mm
l = 630 mm	l = 896 mm
l = 540 mm	l = 768 mm

layer thickness T = 32 mm
(= 4 Layers)
slotted area being free from knots

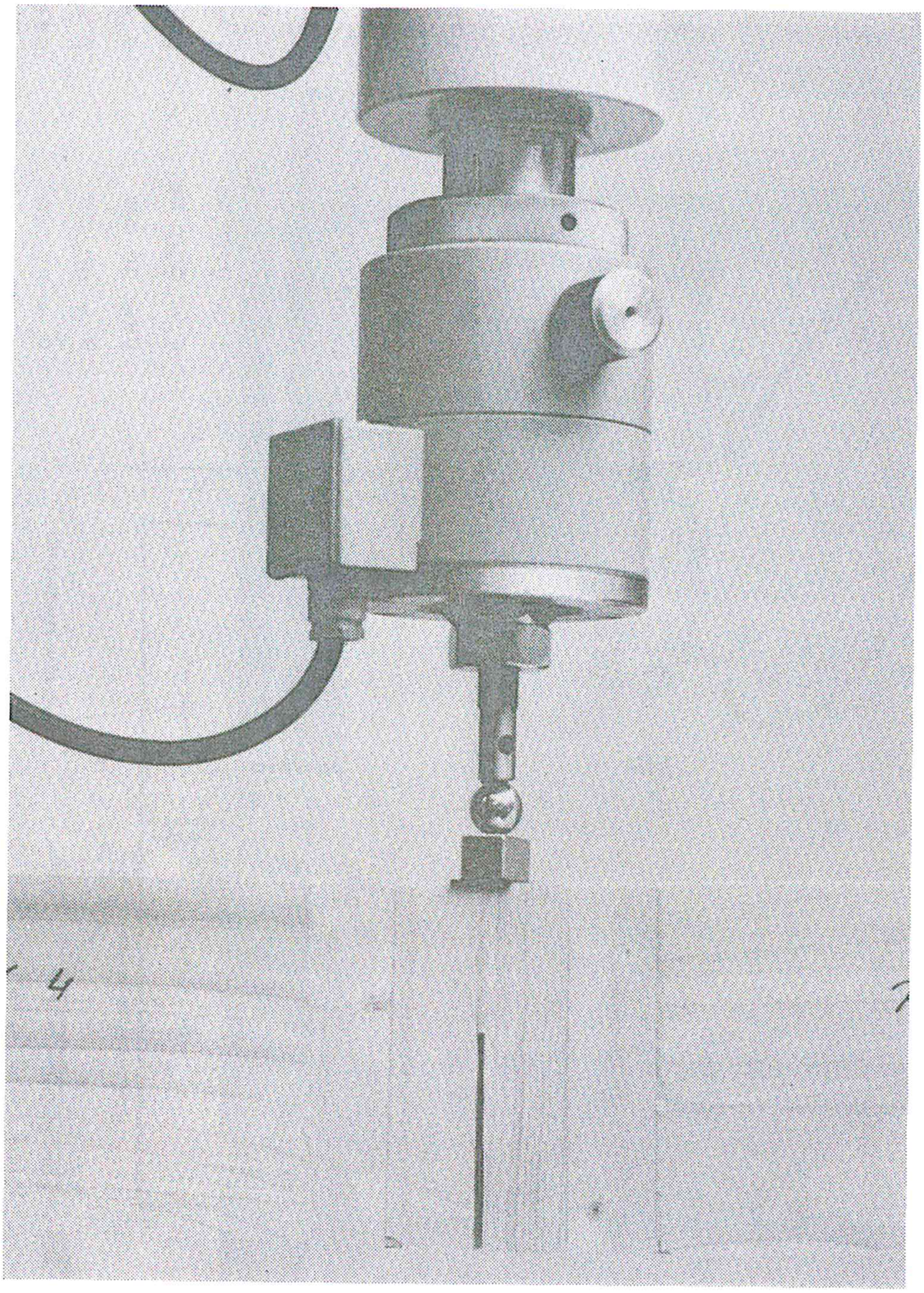
Test series	grad according to	grad according to Eurocode 5	species	Number of tests	moisture content ω
A	GDR-Code /2/ Em = 12000 N/mm^2	C 7	red pine	12	12
B B	GDR-Code /2/ Em = 12000 N/mm^2	C 7	red pine	12	18
C	GDR-Code /2/ Em = 1200 N/mm^2	C 7	red pine	12	24
D	FRG-Code /3/	C 5	red pine	12	12
E	FRG-Code /3/	C 3	red pine	12	12
F	GDR-Code /4/		white wood	12	12

Gesamtübersicht am Beispiel der Prüfung einer Holzkantel mit eingeleimtem BSH-Stück.
Total view with the example of testing a timber square with a glue-inserted piece of glued laminated timber.



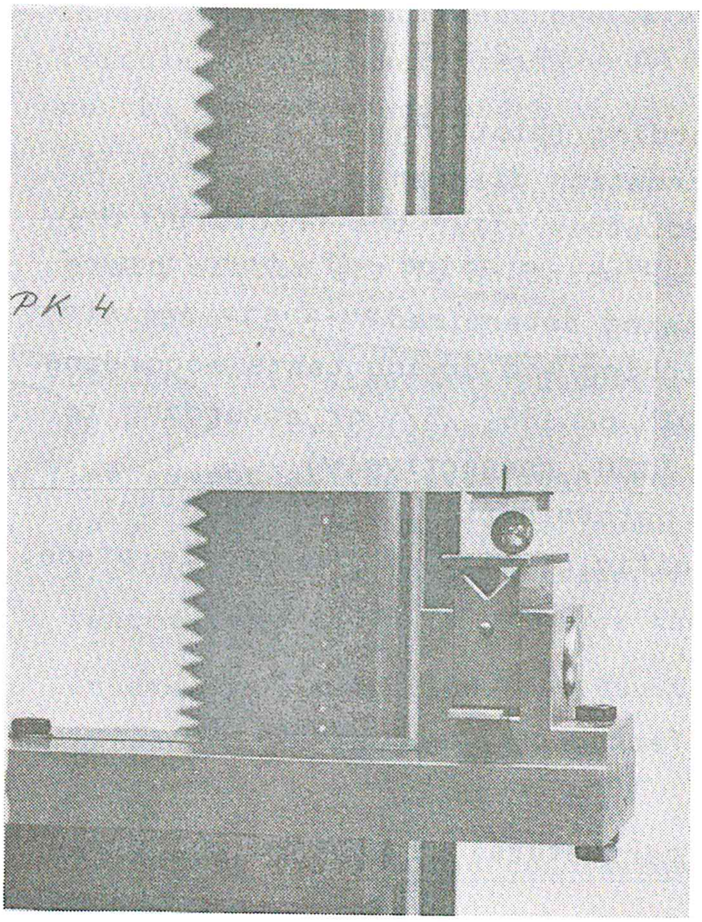
Prüfkörper Variante F
Variant F test specimen

Punkt der Lasteintragung über Kraftmeßwandler, Stahlkugel (d=a/8), Stahlprisma (a/8x a/8 x b) und Gummilage (t~2mm);
Point of load application by means of force transmitter, steel ball (d=a/8), steel prism (a/8 x a/8 x b) and rubber layer (t~2mm);



Prüfkörper Variante F
Variant F test specimen

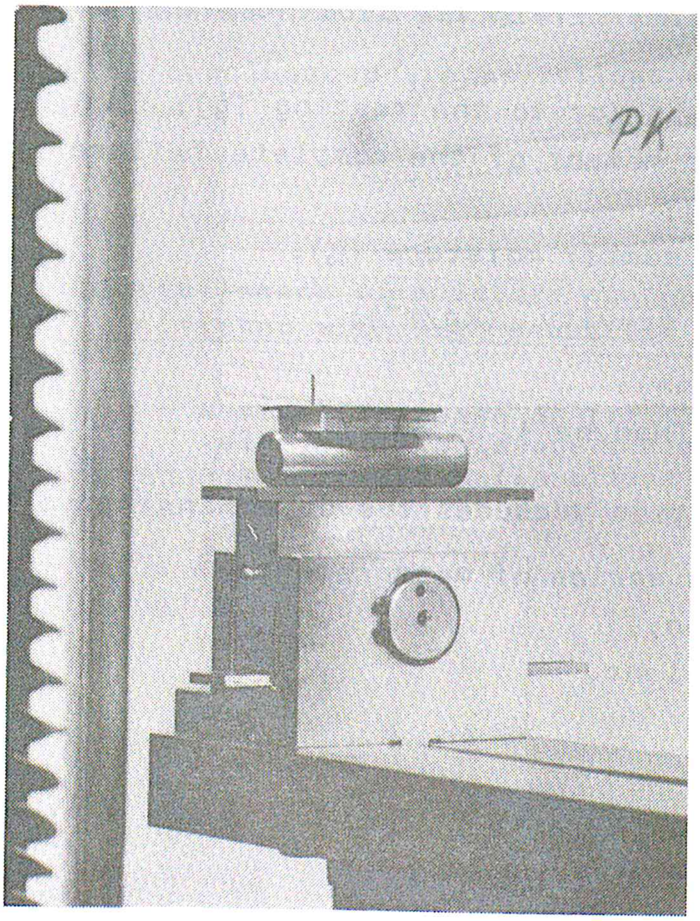
Ansicht des rechten Auflagers/View of the right-hand support



Prüfkörper
Gummilage (t~2mm)
Stahlprisma (a/4 x 5mm x b)
Stahlkugel (d~a/4)

Test specimen
rubber layer (t~2mm)
steel prism (a/4 x 5mm x b)
steel ball (d~a/4)

Ansicht des linken Auflagers/View of the left-hand support



Prüfkörper
Gummilage (t~2mm)
Stahlprisma (a/4 x 5mm x b)
Stahlzylinder (d~a/4 x b)

Test specimen
rubber layer (t~2mm)
steel prism (a/4 x 5mm x b)
steel cylinder (d~a/4 x b)

(Continuation from page 3 as to item 2.3.2.)

Measurement data:

- Recording (plotting) of a load-deformation diagram
- Immediately after the fracture, the timber moisture of the middle piece is being determined (weighing and drying tests according to DIN 52 183 /5/ or according to ISO 3130, respectively) and determination of the apparent specific gravity of the middle piece.

2.4. Evaluation

The evaluation was being effected by analogy with the reference /6/.

The characteristic values (parameters) determined and evaluated were as follows:

b - width of the test specimen (mm);
h_e - timber height (depth) within the slotted area (mm);
F_{max} - maximum force (N);
m - weight immediately prior to the testing (g);
u_o - deformation at the moment of the complete failure of the sample (mm);
ω_{real} - really determined timber moisture (%);
ρ - apparent specific gravity (kg/m^3);
W - measured work (Nmm);
G - fracture energy (Nmm/mm^2).

The statistical interpretation includes the determination of

x_{mean} - mean value of one series of measurements;
s - standard deviation;
v - variation coefficient.

In addition, measurement photographs of all test specimens (middle pieces) were being provided from which all data as to the location and width of the annual rings may be inferred.

One force-deformation diagram for each test specimen has been ploted. The point x_1 is marking the beginning of the visible cracking.

The acoustic attendant phenomena of the crack development have been investigated into by means of a sound emission instrument at two additional test specimes. With a view to providing an initial orientation, two of the diagrams are including a lotting (recording) of the sound occurrences (expressed in mV) over the deformation u.

In order to safeguard the results and findings, further tests and investigations will be required.

3. Test results and conclusions

A summary of the results and findings of all tests and determination is being provided in the report /7/.

The conclusions are as follows (see table 2 and figure 4):

a) influence of moisture content
(timber with high density)

- a small degrease of fracture energy related to mean value up to moisture content of 18 %
- a more continually effect of moisture content of fracture energy related to the 5 % - fractil

b) influence of sorting

- no difference between viusal sorted timber (grouped in grade II according to DIN 4074) and machine sorted timber.
  The reason is the accidental high density of visual sorted timber.
- the fracture energy of visual sorted timber (grouped in grade III according to DIN 4074(differ essential (approximately 15 % related to mean value and 25 % related to 5 % fractil)

c) fracture energy of glue

- glue has the lowest value fracture energy (approximately 30 % related to the mean value and 40 % related to the 5 % fractil)

Table 2: Summary of the results of all Test series

series	density $w[kg/m^3]$	fracture energy $G [Nmm/mm^2]$	compared to series A	compared to series D
A	509...547...573 v = 4,5 %	$\bar{x}$ = 0,350 v = 9,40 % $G_{5\%}$ = 0,296	100 – 100	–
B	539...574...616 v = 4,4 %	$\bar{x}$ = 0,326 v = 10,40 % $G_{5\%}$ = 0,256	93,0 – 91,2	– – –
C	438...478...548 v = 9,5 %	$\bar{x}$ = 0,328 v = 13,30 % $G_{5\%}$ = 0,256	93,7 – 86,5	– – –
D	491...515...536 v = 3,2 %	$\bar{x}$ = 0,358 v = 12,80 % $G_{5\%}$ = 0,282	102 – 95,3	100 – 100
E	412...453...521 v = 8,7 %	$\bar{x}$ = 0,307 v = 17,80 % $G_{5\%}$ = 0,217	87,7 – 73,31	85,60 – 76,95
F	545...580...607 v = 4,5 %	$\bar{x}$ = 0,255 v = 17,40 % $G_{5\%}$ = 0,182	72,85 – 61,42	71,12 – 64,47

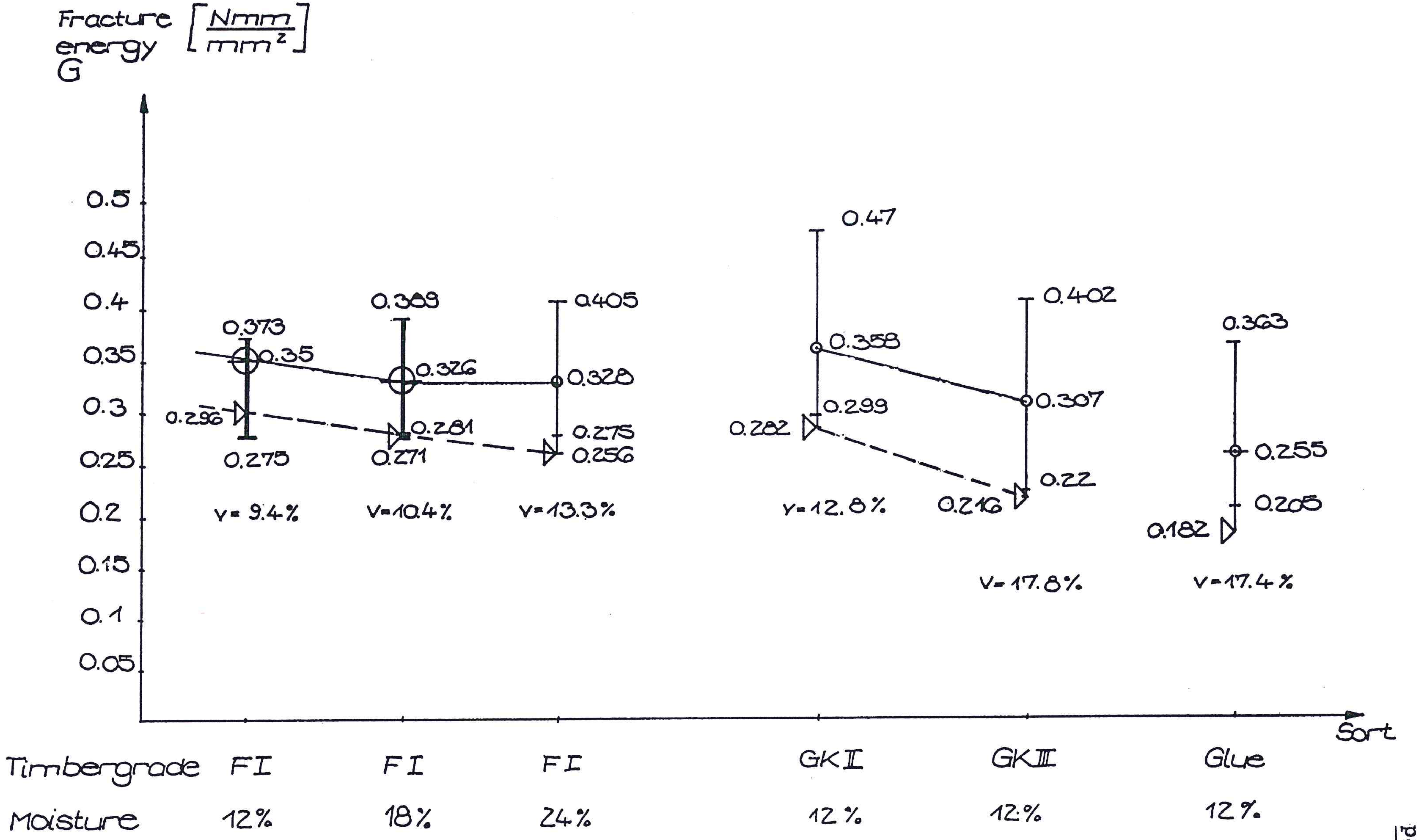


Figure 4: Fracture Energy of all tests

4. Literature (references)

/1/ Per Johan Gustafsson and Hans Jörgen Larsen:
DESIGN OF END-NOTCHED BEAMS; CIB Paper
W 18 A / 22-10-1, Berlin, GDR; September 1989

/2/ TGL 33 135/03 - E 89: Holzbau; Tragwerke; Berechnung nach Grenzzuständen
(Timber construction; Loadbearing structures; Limit states design)

/3/ DIN 4074, Teil 1. Sortierung von Nadelholz nach der Tragfähigkeit; Nadelschnittholz. - September 1989
(DIN..., Part 1. Sorting of softwood by the load-bearing capacity; Mill run softwood.)

/4/ TGL 33 136/01: Holzbau; Bauteile aus Brettschichten, geklebt. Technische Bedingungen. - Januar 1987
(TGL...: Timber construction; Structural components made of glued laminated timber. Technical conditions. January 1987)

/5/ DIN 52 183: Prüfung von Holz; Bestimmung des Feuchtegehaltes. - November 1977
(DIN...: Testing of timber; Determination of the moisture content)

/6/ Determination of the Fracture Energy of Wood for Tension Perpendicular to the Grain
CIB - W 18 A Group, Draft Standard, November 1989

/7/ Rug, W.; Badstube, M.; Schöne, W.:
Determination of the Fracture Energy of Wood for Tension Perpendicular to the Grain
Report, Berlin/Leipzig 1990

A N N E X 1

Tables of all test results

Tabellarische Zusammenstellung der Einzelergebnisse
"Bruchenergie von Holz bei Zug rechtwinklig zur Faser"

(Tabular compilation of test results)

Variante A: NSH F 1, ω = 12 %
(series A)

PK-Nr.	b (mm)	h_e (mm)	F_{max} (N)	m (g)	u_o (mm)	ω_{real} (%)	ρ (kg/m^3)	W (Nmm)	G ($\frac{Nmm}{mm^2}$)
1	44,0	35,8	175	1126,0	8,6	12,2	509	434,00	0,306
2	44,0	36,0	169	1210,0	10,7	12,2	538	489,79	0,349
3	44,0	36,3	206	1173,0	10,7	12,4	526	534,03	0,373
4	44,0	36,3	201	1210,0	10,4	12,5	568	501,83	0,353
5	44,0	36,1	182	1198,0	10,6	12,4	550	486,15	0,345
6	44,0	36,0	210	1169,0	9,6	12,4	570	516,32	0,361
7	43,9	36,0	188	1189,0	10,7	12,7	516	547,26	0,386
8	43,8	36,0	214	1162,0	9,5	13,0	573	525,84	0,368
9	44,0	36,4	230	1118,0	10,5	12,4	516	569,31	0,391
10	43,7	36,0	209	1283,0	10,6	12,6	562	493,43	0,356
11	43,8	36,1	216	1207,0	7,9	12,6	560	388,78	0,275
12	44,0	36,0	190	1071,0	9,5	12,8	572	475,79	0,332
X_{mean}			199		9,9	12,5	547		0,350
s			18,4		0,9	0,24	24,4		0,033
v			9,2		9,4	1,9	4,5		9,4

$x_{5\%}=0,2957$

Tabellarische Zusammenstellung der Einzelergebnisse
"Bruchenergie von Holz bei Zug rechtwinklig zur Faser"

(Tabular compilation of test results)

Variante B: (series B) NSH F I, ω = 18 %

PK-Nr.	b (mm)	h_e (mm)	F_{max} (N)	m (g)	u_0 (mm)	ω_{real} (%)	ρ (kg/m³)	W (Nmm)	G ($\frac{Nmm}{mm^2}$)
1	44,6	36,1	164	1390,8	10,0	16,8	539	476,35	0,338
2	44,8	35,7	163	1272,7	9,2	17,8	581	413,91	0,295
3	44,8	36,1	196	1221,1	11,2	17,2	548	488,04	0,343
4	44,7	35,7	149	1331,8	9,6	16,6	548	514,01	0,361
5	44,6	36,2	159	1255,1	10,3	16,8	547	456,19	0,322
6	44,7	36,0	182	1310,1	11,1	16,8	590	555,66	0,389
7	44,7	35,7	150	1205,1	5,7	17,7	576	399,49	0,271
8	44,8	36,3	139	1391,0	9,9	17,8	616	458,01	0,324
9	45,0	35,9	123	1402,4	9,8	17,8	612	373,73	0,273
10	44,6	36,4	125	1366,2	11,3	17,8	561	471,17	0,337
11	44,5	35,9	161	1212,9	11,8	17,3	585	470,82	0,339
12	44,8	36,2	160	1235,1	11,3	17,6	581	449,40	0,319
X_{mean}			156		10,1	17,3	574		0,326
s			21,0		1,6	0,48	25,5		0,034
v			13,5		16,0	2,7	4,4		10,4

$x_{5\%}$=0,2700

Tabellarische Zusammenstellung der Einzelergebnisse
"Bruchenergie von Holz bei Zug rechtwinklig zur Faser"
(Tabular compilation of test results)

Variante C: NSH F I. ω = 24 %
(series C)

PK-Nr.	b (mm)	h_e (mm)	F_{max} (N)	m (g)	u_o (mm)	ω_{real} (%)	ρ (kg/m^3)	W (Nmm)	G ($\frac{Nmm}{mm^2}$)
1	44,7	35,9	204	1284,0	9,6	23,0	548	432,88	0,307
2	44,9	36,0	225	1318,0	12,0	24,1	482	563,64	0,397
3	44,8	35,9	202	1320,0	11,7	23,2	482	512,12	0,365
4	45,0	36,0	180	1277,0	8,9	23,3	438	428,61	0,299
5	44,9	36,1	193	1242,0	11,2	23,6	494	500,08	0,351
6	45,0	36,1	157	1359,0	9,3	23,1	466	410,55	0,291
7	45,0	36,0	156	1462,0	9,2	23,4	499	401,03	0,288
8	45,0	36,1	162	1454,0	10,4	23,2	486	423,92	0,306
9	44,8	35,8	196	1411,0	10,6	22,8	464	426,16	0,311
10	45,0	36,2	156	1405,0	11,9	24,1	463	485,59	0,348
11	45,0	36,2	192	1437,0	8,8	23,2	452	385,77	0,275
12	45,0	36,1	158	1260,0	12,2	23,5	464	582,89	0,405
x_{mean}			182		10,5	23,4	478		0,328
s			23,6		1,3	0,49	45,5		0,044
v			12,9		12,3	2,1	9,5		13,3

$x_{5\%}$=0,256

Tabellarische Zusammenstellung der Einzelergebnisse
"Bruchenergie von Holz bei Zug rechtwinklig zur Faser"
(Tabular compilation of test results)

Variante D: BSH GK II, ω = 12 %
(series D)

PK-Nr.	b (mm)	h_e (mm)	F_{max} (N)	m (g)	u_o (mm)	ω_{real} (%)	ρ (kg/m³)	W (Nmm)	G ($\frac{Nmm}{mm^2}$)
1	44,7	36,0	214	1138	10,7	12,1	520	444,36	0,313
2	44,5	36,2	224	1117	10,3	12,2	508	519,96	0,358
3	44,4	36,2	219	1230	11,2	12,4	491	495,46	0,350
4	44,9	35,7	219	1326	12,5	12,4	536	672,84	0,470
5	44,5	36,2	225	1294	10,2	12,3	513	502,39	0,352
6	44,4	36,0	225	1075	9,4	12,2	497	428,82	0,299
7	44,5	36,0	215	1140	10,7	12,0	507	461,65	0,325
8	44,5	36,8	218	1154	11,0	12,4	521	488,11	0,336
9	44,6	35,6	232	1083	11,2	12,3	508	498,33	0,351
10	44,7	35,8	223	1128	11,4	12,5	516	489,23	0,345
11	44,7	35,8	243	1125	11,8	11,8	552	592,06	0,411
12	44,5	36,0	221	1113	11,7	12,4	514	546,91	0,381
x_{mean}			224		11,0	12,2	515		0,358
s			9,2		0,8	0,20	16,3		0,046
v			4,1		7,5	1,6	3,2		12,8

$x_{5\%}$=0,2824

Tabellarische Zusammenstellung der Einzelergebnisse
"Bruchenergie von Holz bei Zug rechtwinklig zur Faser"

(Tabular compilation of test results)

Variante E: NSH GK III, ω = 12 %
(series E)

PK-Nr.	b (mm)	h_e (mm)	F_{max} (N)	m (g)	u_o (mm)	ω_{real} (%)	ρ (kg/m³)	W (Nmm)	G ($\frac{Nmm}{mm^2}$)
1	44,4	35,8	222	1268	9,2	13,2	430	486,78	0,342
2	45,0	35,8	204	1033	9,6	14,2	516	449,89	0,309
3	44,3	35,8	210	1246	7,0	13,6	412	368,83	0,260
4	44,9	36,0	194	1105	8,5	13,5	465	360,85	0,252
5	44,7	36,0	194	1290	8,3	13,9	521	384,72	0,272
6	44,4	36,0	224	968	10,4	13,6	431	520,94	0,357
7	44,4	35,7	184	1268	6,9	11,8	501	303,63	0,222
8	44,8	35,9	162	1158	9,8	12,2	416	419,37	0,295
9	44,4	35,7	210	1186	7,1	12,8	442	385,56	0,269
10	44,8	35,9	180	1182	11,3	12,9	428	487,69	0,344
11	44,5	35,8	192	1138	11,1	12,6	458	519,75	0,365
12	44,4	35,9	214	1070	11,4	12,5	418	581,91	0,402
$\bar{x}_{mean}$			199		9,2	13,0	453		0,307
s			18,3		1,7	0,74	39,4		0,054
v			9,2		18,1	5,7	8,7		17,8

$x_{5\%}$=0,2168

Tabellarische Zusammenstellung der Einzelergebnisse

"Bruchenergie von Holz bei Zug rechtwinklig zur Faser"

(Tabular compilation of test results)

Variante F: **BSH - Sorte 3,** = 12 %
(series F)

PK-Nr.	b (mm)	h_e (mm)	F_{max} (N)	m (g)	u_0 (mm)	ω real (%)	ρ (kg/m³)	W (Nmm)	G ($\frac{Nmm}{mm^2}$)
1	45,0	51,3	241	2271	8,2	10,5	584	539,63	0,273
2	45,0	51,5	223	2361	7,4	10,5	557	501,76	0,253
3	45,2	51,3	254	2294	14,2	10,9	550	680,89	0,363
4	45,2	51,5	209	2057	6,7	10,2	596	434,49	0,216
5	45,2	51,5	240	2254	6,0	10,7	594	420,63	0,209
6	45,3	51,3	285	2243	6,8	9,7	603	474,60	0,236
7	45,3	51,7	258	2237	6,2	10,1	559	413,21	0,205
8	45,0	51,4	235	2604	7,5	10,8	606	607,04	0,304
9	45,0	51,6	261	2102	6,1	10,7	607	465,45	0,236
10	45,1	51,4	251	2511	6,8	10,8	545	464,73	0,236
11	45,0	51,3	257	2154	8,5	10,2	604	508,90	0,267
12	45,0	51,4	258	2356	7,4	10,4	565	514,50	0,259
x_{mean}			250		7,6	10,4	580		0,255
s			21,6		2,2	0,64	26,2		0,044
v			8,6		29,2	6,1	4,5		17,4

$x_{5\%}$=0,1818

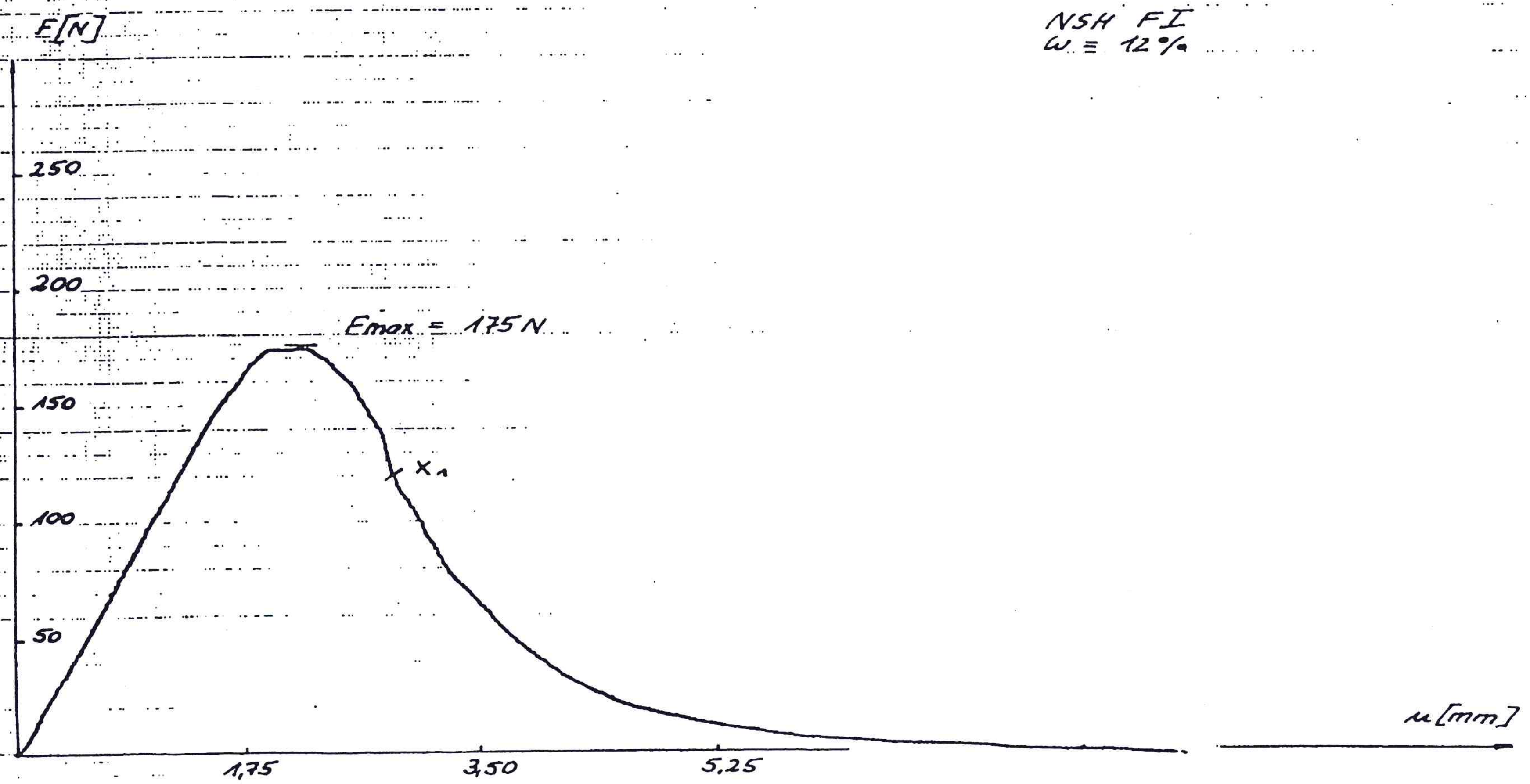
A N N E X 2

Force-deformation diagram (series A, test-no 1)

Variante A

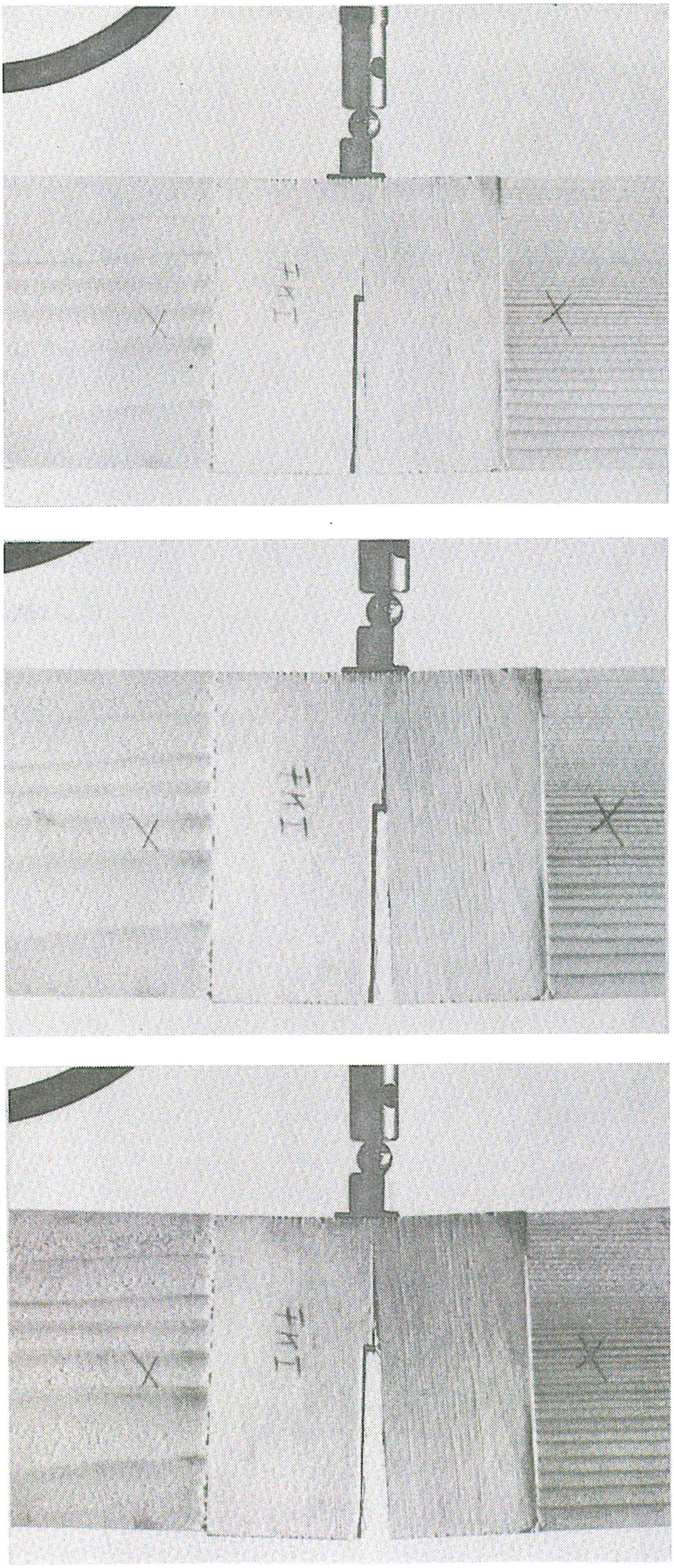
PRÜFKÖRPER NR. 1

NSH FI
ω = 12 %

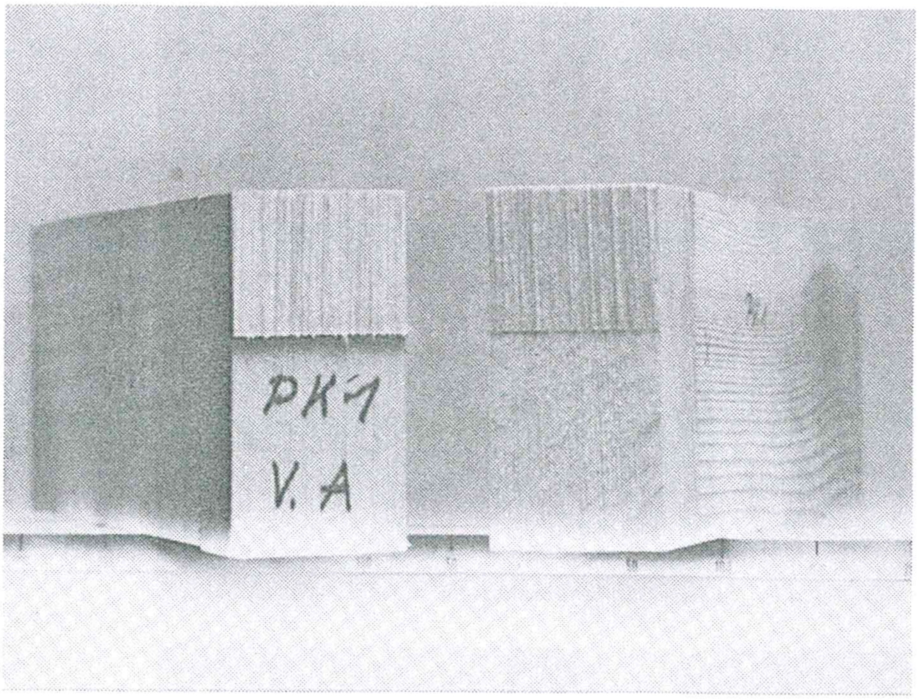


A N N E X 3

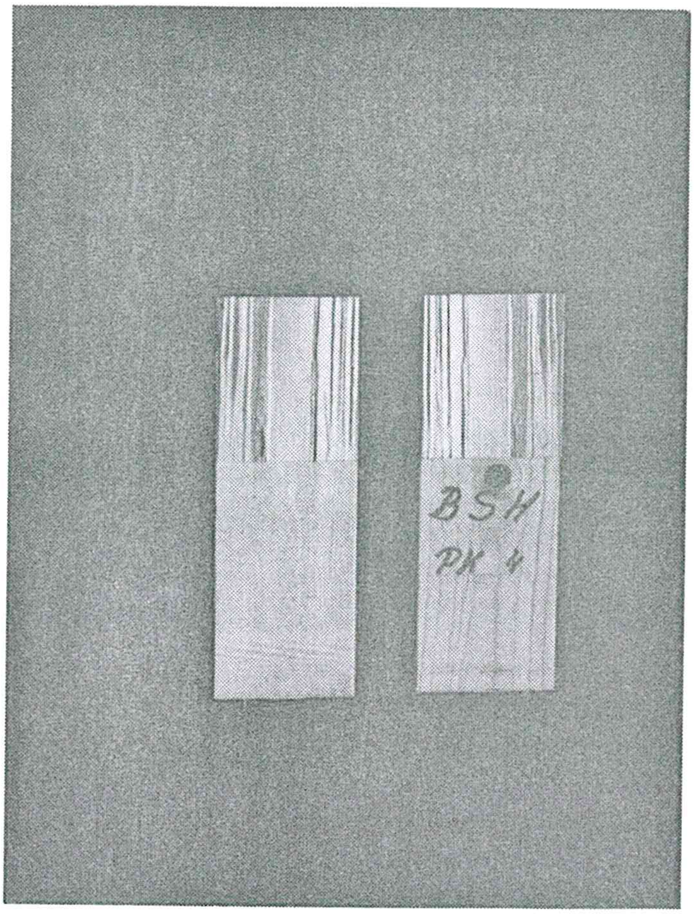
Photographic representation of the crack development by means of an example and repesentation of the fracture surface (series A)



Darstellung der Rißentwicklung am Prüfkörper der Variante A (NSH F I, ω =12%)



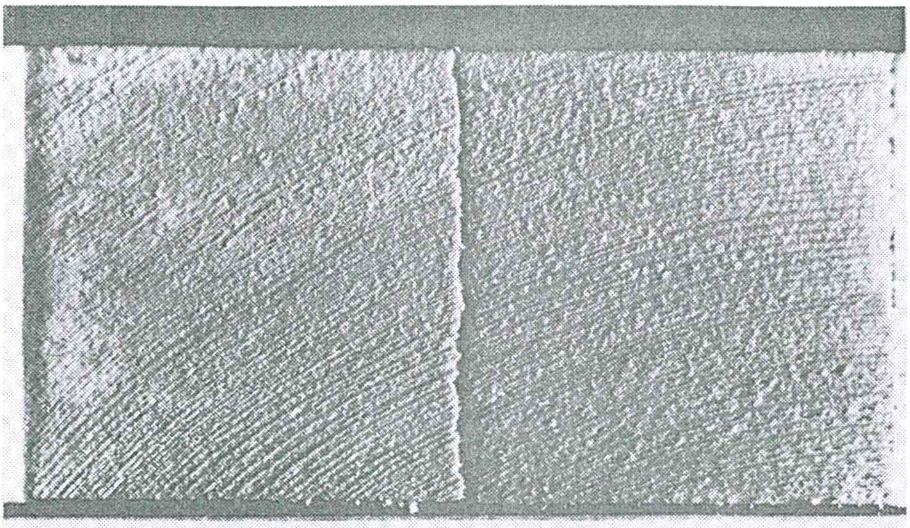
Darstellung der Bruchfläche am Prüfkörper 1 der Variante A (NSH F I, ω =12%)



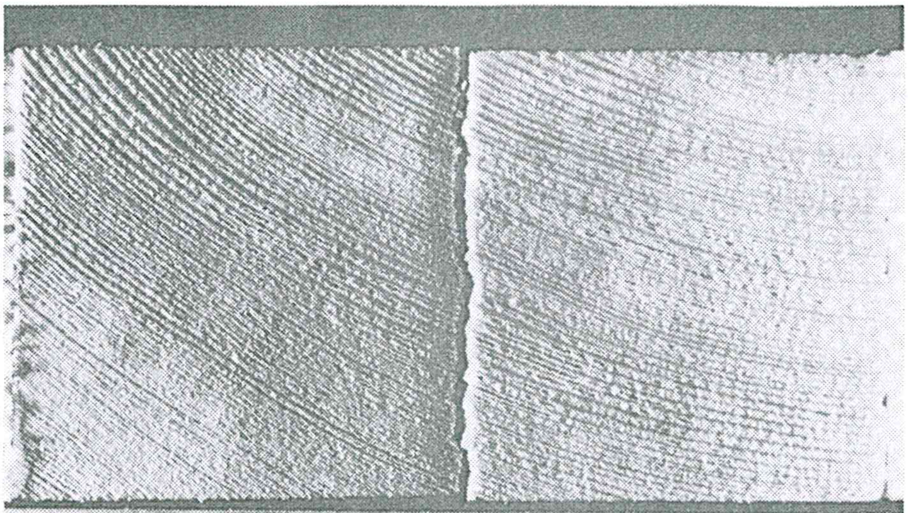
Darstellung der Bruchfläche am Prüfkörper 4 der Variante F (BSH - Sorte 3, ω =12%) Bruch neben der Leimfuge

A N N E X 4

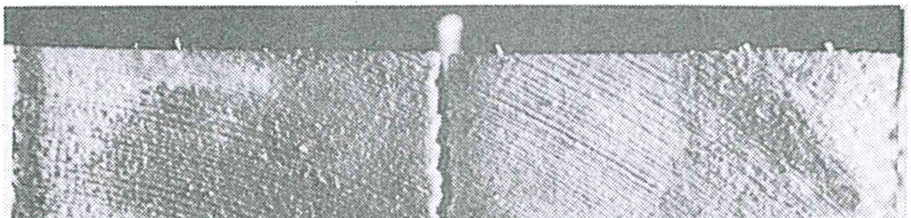
Measurement photographs as to location and with of the annual rings (series A, test-no 1...3)



F I, 12 %, PK 1



F I, 12 %, PK 2



F I, 12 %, PK 3

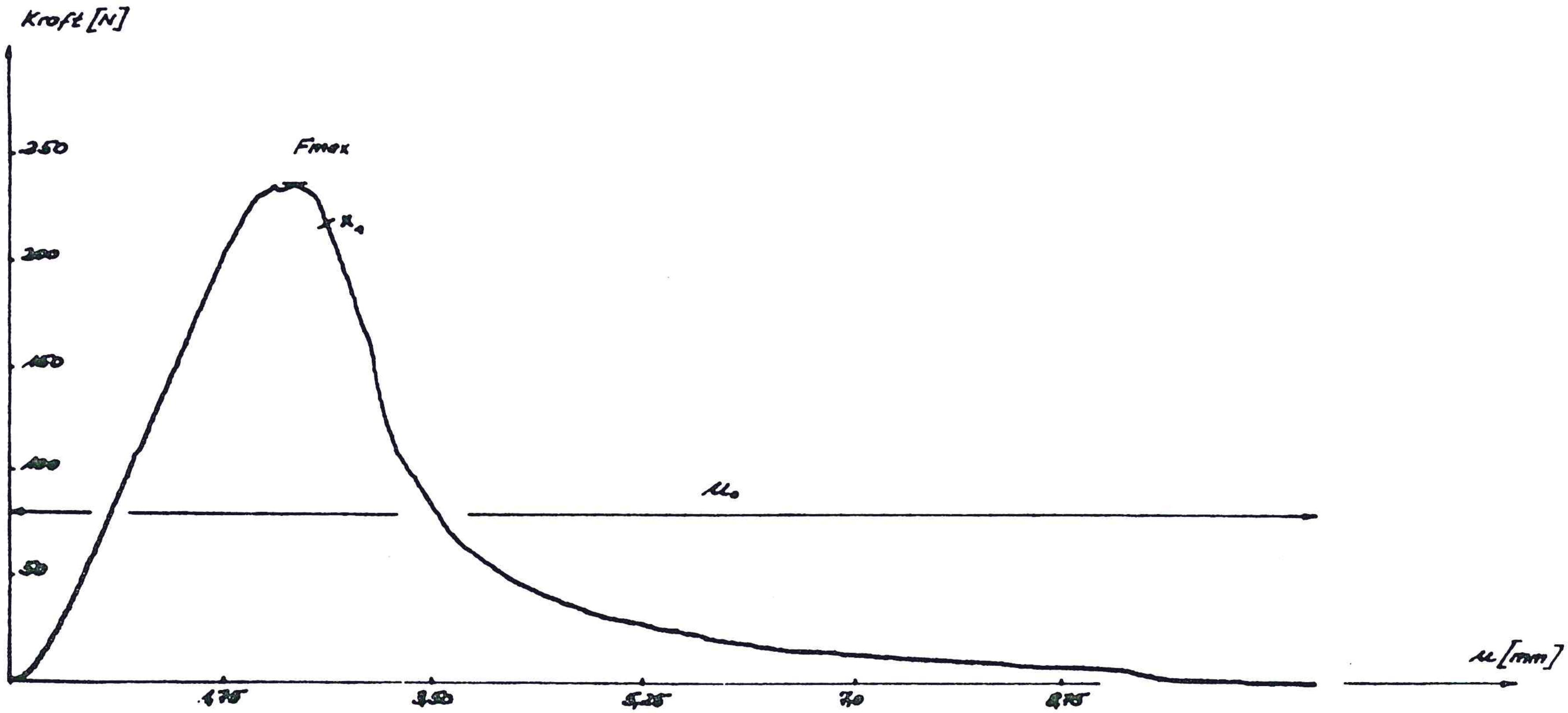
A N N E X 5

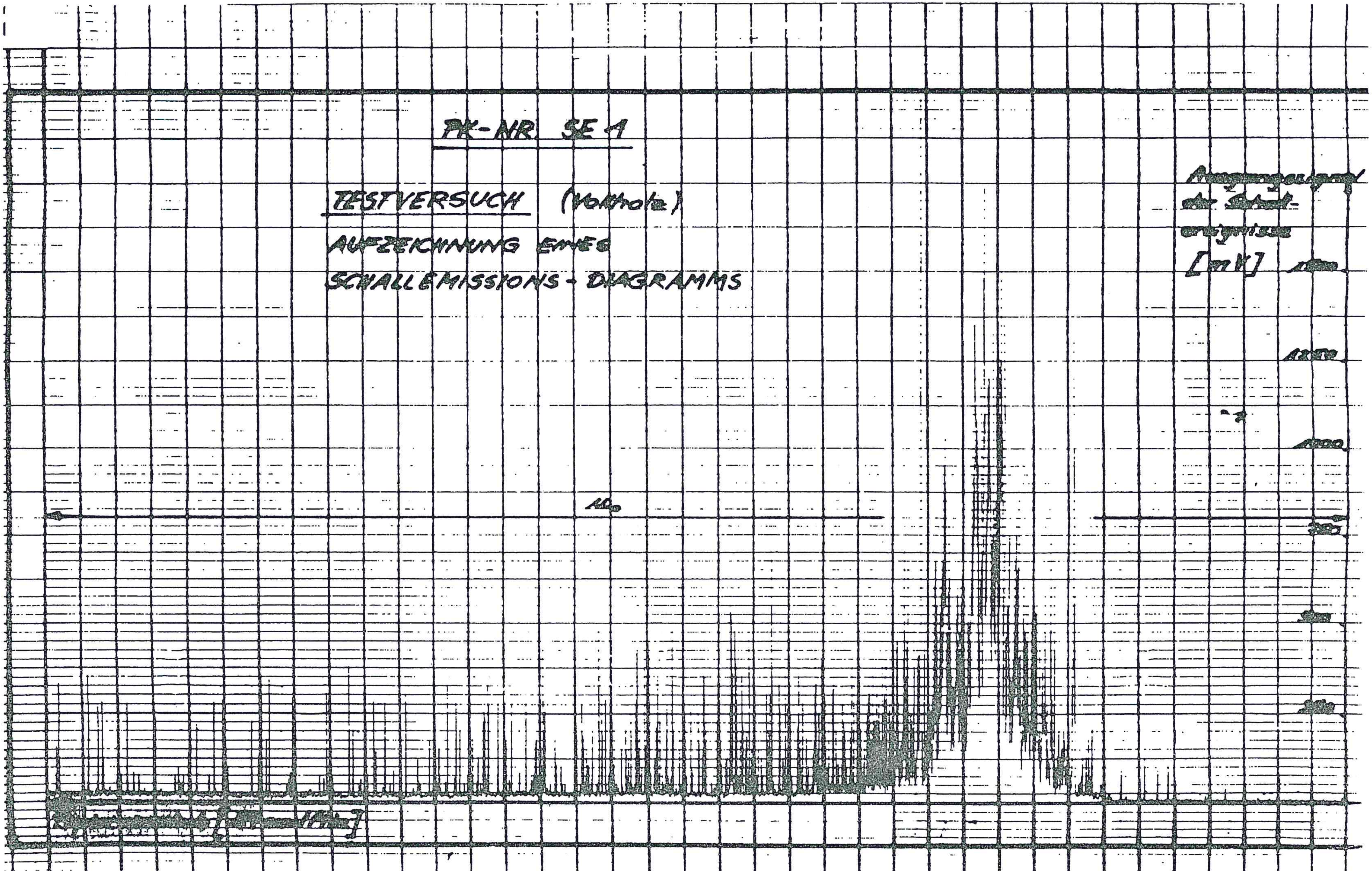
Test experiments as to the problems of sound emission

PK-NR. SE1

TESTVERSUCH (VOLLHOLZ)

Kraft-Weg-Diagramm




PK-NR. SE 1
TESTVERSUCH (Vollholz)
AUFZEICHNUNG EINES
SCHALLEMISSIONS-DIAGRAMMS

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