1970

VTT RESEARCH NOTES

VTT TIEDOTTEITA

Tuuli Oksanen & Jorma Kangas

Strength and fire resistance of connections based on glued-in rods

TECHNICAL RESEARCH CENTRE OF FINLAND

ESPOO 1999

VTT TIEDOTTEITA – MEDDELANDEN – RESEARCH NOTES 1970

Strength and fire resistance of connections based on glued-in rods

Tuuli Oksanen & Jorma Kangas
Building Technology

TECHNICAL RESEARCH CENTRE OF FINLAND
ESPOO 1999

ISBN 951–38–5753–0 (nid.)
ISSN 1235–0605 (nid.)

ISBN 951–38–5754–9 (URL: http://www.inf.vtt.fi/pdf/)
ISSN 1455–0865 (URL: http://www.inf.vtt.fi/pdf/)

JULKAISIJA – UTGIVARE – PUBLISHER

Valtion teknillinen tutkimuskeskus (VTT), Vuorimiehentie 5, PL 2000, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 4374

Statens tekniska forskningscentral (VTT), Bergsmansvägen 5, PB 2000, 02044 VTT
tel. växel (09) 4561, fax (09) 456 4374

Technical Research Centre of Finland (VTT), Vuorimiehentie 5, P.O.Box 2000, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 4374

VTT Rakennustekniikka, Rakennusfysiikka, talo- ja palotekniikka, Kivimiehentie 4, PL 1803, 02044 VTT
puh. vaihde (09) 4561, faksi (09) 456 4815

VTT Byggnadsteknik, Byggnadsfysik, fastighets- och brandteknik, Stenkarlsvägen 4, PB 1803, 02044 VTT
tel. växel (09) 4561, fax (09) 456 4815

VTT Building Technology, Building Physics, Building Services and Fire Technology,
Kivimiehentie 4, P.O.Box 1803, FIN–02044 VTT, Finland
phone internat. + 358 9 4561, fax + 358 9 456 4815

Otamedia Oy, Espoo 2000

Oksanen, Tuuli & Kangas, Jorma. Strength and fire resistance of connections based on glued-in rods. Espoo 1999, Technical Research Centre of Finland, VTT Tiedotteita – Meddelanden – Research Notes 1970. 28 p. + app. 31 p.

Keywords steel structures, joints, glulam structures, glueing, ribbed steel rods, strength, dimensioning, fire resistance, fire safety, glulam beams, wooden structures

Abstract

A short summary of extensive research on joints of glulam structures based on glued-in ribbed steel rods has been reported. On the basis of research work a calculation method of structures with these connections has been developed and presented. The main concern is on ease of manufacturing and construction as well as fire safety.

This paper presents also results of fire resistance tests performed on loaded glulam beams connected together with the joints based on glued-in ribbed steel rods. The tests were carried out at VTT Building Technology, Fire Technology. The structure of the connections was the same in all tests but the thickness of the fire protection and the wood covering of the steel rods were varied in order to achieve fire resistance classes R30, R60 and R90. Rock wool (density 140 kg/m^3) covered by steel sheet was used as the fire protection on the bare steel parts of the joint. The test load corresponded 40 % of the design load at the normal temperature design. The furnace temperature was controlled according to the standard ISO 834.

The deflection of the beams began to increase remarkably about ten minutes before the failure of the joint. Fire resistance classes of R30, R60 and R90 were achieved with 20 mm, 40 mm and 60 mm thick rock wool fire protection and wood coverings of the steel rods respectively.

Preface

This study is a part of a reseach project concerning wood construction (Product systems of wood construction - multitechnological development work / Wooden halls and connection technique of the halls) which is associated with the internal research programme of VTT, Building technology. The participants of the project come from the following research groups of Building technology: Air Handling Technology and Acoustics, Fire Research, Construction Management and Production Technology, Timber structures, Concrete Production and Structural Technology and Steel and Composite Structures.

Anstar Oy is gratefully acknowledged for the manufacturing and delivering of the steel connections and Vierumäen Teollisuus Oy for the delivering the glulam beams.

The authors wish to thank Mr Rauno Vinttala for manufactoring the test specimens and Mr Arto Hätelä, Mr Hemmo Juutilainen, Mr Timo Jyry, Mr Ville Kaasinen, Mr Arto Nieminen for carrying out the tests.

Contents

1. Introduction

Fastening method is based on ribbed steel rods, which have been glued at skew angles into the glulam (V-joint). The rods convey forces effectively in their direction up to the tensile capacity of the steel. By welding the rods on to steel members, the forces can be carried forward to next member by the method known in steel structures**.** This report presents results of the experimental research carried out in VTT (Technical Research Centre of Finland) by ramp loading [1] developed design method and comparison of the test results and the calculated values. The connection is effective to carry bending moments up to the capacity of glulam and not vulnerable for splitting of wood in the joint area.

Fire resistance of the connection described above has been studied in the research project of "Product systems of wood construction - multitechnological development work / Wooden halls and connection technique of the halls" which is a part of the internal research programme of VTT. The results of the tests are presented in this report.

The fire resistance requirement of a joint is equal to the requirement of the structures connected together. If e.g. the fire resistance requirement of a beam and a column is 60 minutes the requirement of the connection is also R60 (R = loadbearing capacity). The steel strength decreases at the elevated temperatures and according to EUROCODE 3 [2] this decrease begins at temperature of 400 ^{o}C. That is why almost all steel members have to be fire protected if fire resistance is required.

Steel members on the surface of a beam can easily be mortised and covered by boards or other materials for fire protection and for architectural reasons. The other parts of the connection are invisible and protected inside the glulam. In this study three fire resistance tests were carried out in order to achieve R30, R60 and R90 fire resistance classes for a fire protected V-joint.

2. Strength experiments in the background

2.1 Tests with one rod

The anchorage strength in the glueline was tested with joints of one rod. The rods with a diameter (*d*) of 20 mm were glued both with the epoxy and polyurethane adhesives into spacious holes drilled in the glulam beams. Their direction angles α with the grain direction were 30°, 45°, 60° and 90°. The rods were loaded in tension or in compression, see Figure 1.

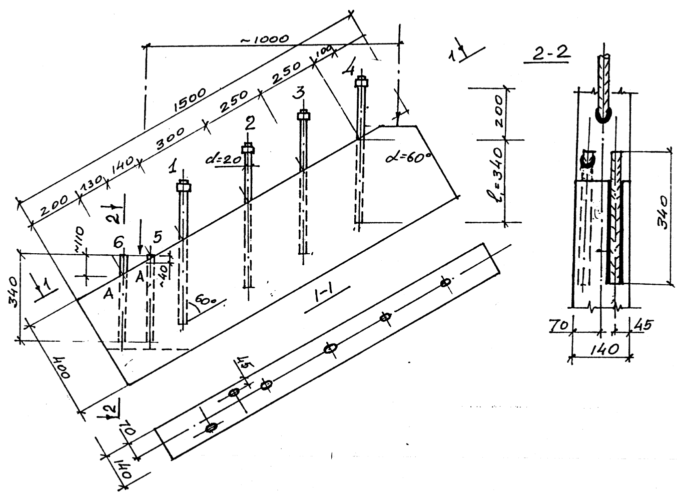


Figure 1. Specimen of tensile test series with α = 60° [1].

All adhesives gave equal strength values in short term loading in normal indoor climate.

The mean of 96 rods was m{f_a} = 6.4 N/mm^2 and variation coefficient v{f_a} = 0.088, when the anchorage length was 340 mm (17*d*) and hole diameter *D* = 25 mm was used in calculation. Variation in strength values in different grain and load directions was small.

2.2 Tests with V-joints

Different V-anchor joints of two or four rods were loaded in centric tension at skew angles into beam or in shear in the direction of the beam, see Figure 2. The lengths of the rods were chosen so that the anchorage and tensile capacities were close to each other. Thickness of the rods was 20 mm or 16 mm. Several combinations of rod directions were used. The failure with the anchorage length of 25 *d*, was often caused by breaking of the steel rods. Tensile strength of the rods was more than 600 N/mm^2. Mean anchorage strength of 32 specimens with anchorage length of 25*d* was $m\{f_a\} = 5.44$ N/mm^2 and variation coefficient $v\{f_a\} = 0.076$, when the dowel effect was subtracted.

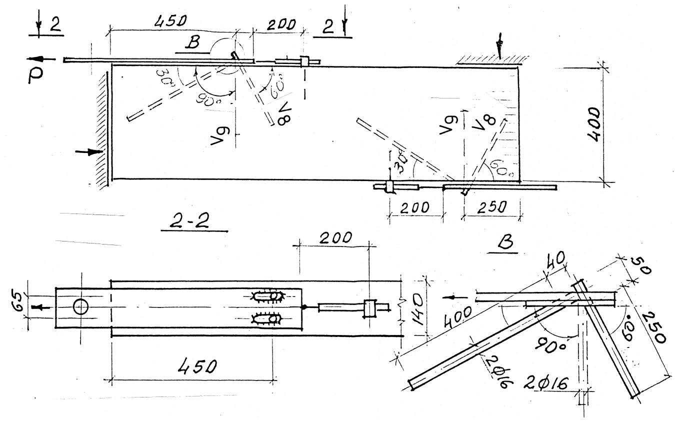


Figure 2. Plans of small joint test series with four 16 mm rods [1].

2.3 Tests with moment bearing connections

Four connections of 1.2 *m* deep beams were tested. The capacities of the timber members and the joints were designed to be equal. Densities (Picea abies) of all small and big beams were about 450 kg/m^3. Two connections of the beams were symmetric, see Figure 3. They broke in a similar way in the tensile joint of the connection: A piece of timber broke off the beam. Height of this piece was the same as was hold by the anchoring rods. In two unsymmetric connections only the tensile force was taken by V-joints, see Figure 4. In the first connection the shear failure of timber member happened in the mid depth of the beam. In the loading of the second connection two furthermost rods broke in tension. Calculated stresses of the rods were equal to the material strength.

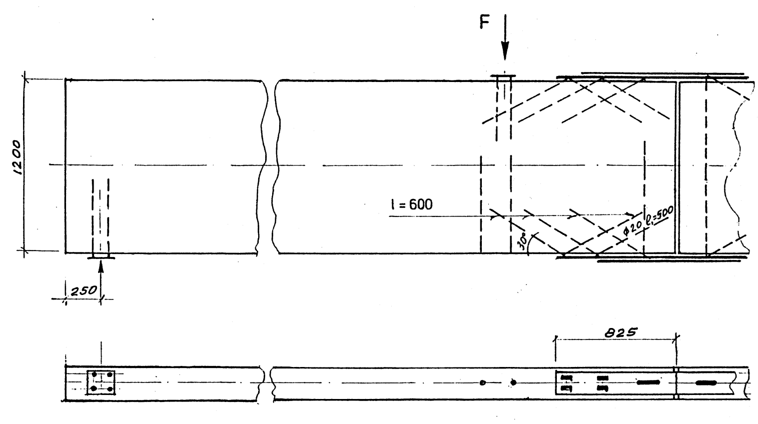


Figure 3. A symmetric connection of 1.2 m high beam [1].

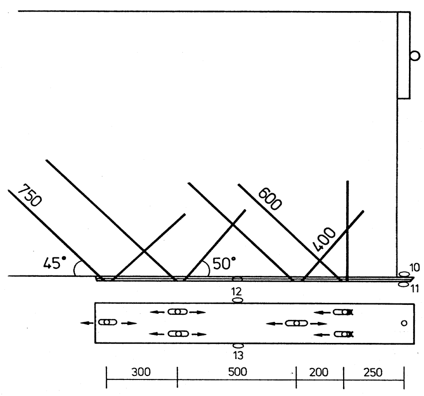


Figure 4. Spacing of the rods in the connections of 1,2 m high asymmetric beam [1].

Calculated tensile strength valves for the effective cross section A_{ef} and calculated bending strength values for the total cross section coincide with the characteristic strength values of their density class. Rods seem not to reduce the bending capacity of the beam in the connection of V-joints, when the direction angle γ of the rods in tension is not more than 40°. Strain gauges were glued on the steel plates, to which the rods were welded. Relative strains proved with sufficient accuracy that the load is divided evenly between the rods.

3. Design of the connection

3.1 Anchorage capacity

Mean anchorage strength f_a of the rods depends on the effective anchorage length l_{ef}, which is the glued length of the rod reduced by 1,5d. Its characteristic value both in compression and tension and in all grain directions can be given by

$$f_{ak} = 6.5(1\text{-}l_{ef}\ /100d)\ [\text{N/mm}^2]. \quad (1)$$

Anchorage capacity $R_{a,k}$ of the rod is calculated on the outer surface of glued joint, when the diameter of the drilled hole is $D \leq 1.25d$:

$$R_{a,k} = \pi D\ l_{ef}\ f_{a,k} \quad (2)$$

3.2 Dowel effect

Tensile rods in V-joint can have maximum capacity by anchorage strength and they are supposed to yield while the rods in compression with steep direction angle ($\alpha_2 \geq 50°$ or $\gamma_2 \leq 130°$) are not fully utilised. They will then work also as a dowel when the load is in grain direction and that capacity can be added to the calculated capacity of V-joint. The load-bearing capacity of dowel in single shear steel-to-timber joints can be calculated in accordance with Eurocode 5 [3]:

$$R_D = 1.5(2M_y f_h d^{1/2}, \quad (3)$$

The fastener yield moment is calculated from the formula $M_{y,k} = 0.8 f_{u,k}\ d^3/6$, where $f_{u,k}$ is the characteristic tensile strength of the rod. Embedding strength in timber can be taken as f_h= 0.082(1-0,01D)ρ.

3.3 Modelling of V-joint

Relation of the load F and axial forces in rods S_1 and S_2 is illustrated in Figure 5. Design model is based on the capacity of the tensile rod. In general case the capacity of V-joint is

$$F_{max} = S_1 \sin(\gamma_2\text{-}\gamma_1)/\sin\gamma_2\ (+R_D), \quad (4)$$

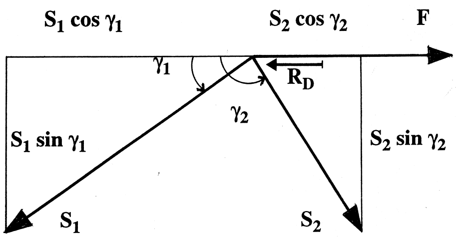


Figure. 5. Modelling of V- joint.

where R_{D} is a dowel effect. The capacities of different V-anchors can be summed on the condition that anchorage length allows yielding of the rods.

3.4 Timber capacity

Effective cross section of the timber member, which is loaded in tension in the connection is calculated by reducing the width b of the member by the drilled portion: $b_{\mathrm{ef}} = b - nD$, where n is the number of parallel drilled holes in the farthest cross section. The tensile capacity of the portion of the cross section ($b_{\mathrm{ef}}\ l\sin\alpha$), which is joined by rods, shall be calculated for the tensile force N in the joint, see Figure 6.

$$b_{\mathrm{ef}}\ l \sin\alpha f_{\mathrm{t}} \geq N \qquad (5)$$

Bending capacity of the beam will be calculated in the farthest section of the joint. No reduction of effective cross section is needed when the angle between the rods in tension and grain direction is $\alpha \leq 40°$. Moment bearing connections of gluelam can then be made without reducing its bending capacity. V- shaped joint is quite rigid. Long rods have, however, like mechanical joints, some deformation capacity because of yielding of the rod which is to be seen in Figure 7. This lowers otherwise possible stress concentrations.

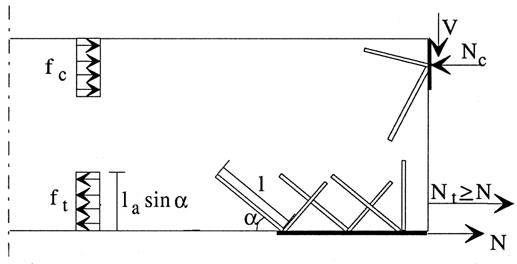


Figure 6. Diagram about the design of moment resisting connections of timber beams [1].

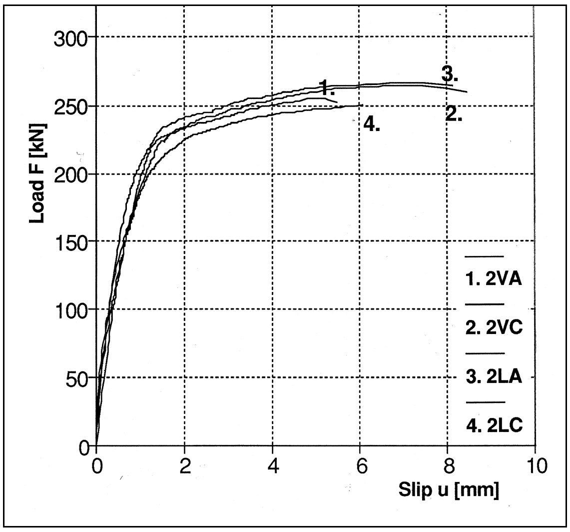


Figure 7. Load- deformation curves of V-joints loaded in tension perpendicular to the beam with the angle of 30° between the rods. They are linear up to the yield limit 200 kN of rod material [1].

4. Fire resistance tests

The aim of the fire resistance tests was to investigate how to reach fire resistance classes R30, R60 and R90 for a connection based on glued-in rods with different fire protection thickness of rock wool and wood. Fire resistance of a joint depends on the structure and materials of the joint, fire protection of the joint and loading as well as fire exposure.

4.1 Test specimens

In Figure 8 is shown a connection of a timber column to a concrete foundation of a hall with the span of 22 m. It was designed for full bending capacity of glulam. The connection was on the column side similar to the symmetric connection of the test beams. The test specimens had the same V-joint in their tensile side and hinged contact joint in compression side. The capacity of the joint was designed and checked by formulae (1)..(5).

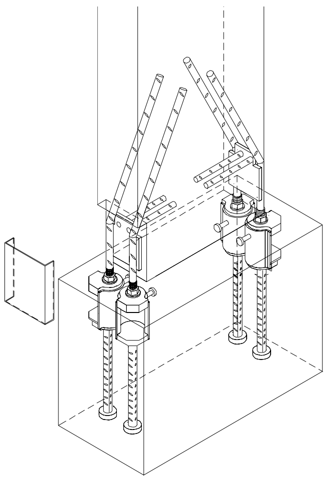


Figure 8. Schema of the moment resisting connection between column and foundation. Steel parts are fastened beforehand into the foundation, where the column would be fixed to.

The speciments were three glued laminated timber beams 450 x 160 mm^2 and length of 2 500 m with a connection in the middle of the span (see Figure 9). The beams had the same cross section as designed for the structure in Figure 8. Each beam consisted of two 1250 mm long members connected together with a steel V-joint. The grade of the beams was L40 which corresponds GL32 of Eurocode 5 [3]. Density of timber beams was about 440 kg/m^3 and moisture content 9.7 %.

The V-joint connector consisted of two steel elements, which were glued into the glulam and connected together with a muffle in beam 1 or welded in beams 2 and 3. The elements were partially prefabricated and they consisted of two ribbed steel rods (∅ 20 mm, A500HW, l = 595 mm), two screw taps (M20 8.8, l = 182 mm) and a steel plate (Fe52). The steel rods, which were welded on to the steel plate beforehand were glued at the angle of 30° into the glulam with epoxy adhesive EΔ 20. The screw taps were screwed through the steel plates and glued also with epoxy adhesive EΔ 20. The steel elements of the whole connection were made by Anstar Oy and the adhesive was purchased from Russia.

The fire exposed steel parts of the connection at the bottom of the beam were fire protected with rock wool PV-PAL (density 140 kg/m^3, Paroc Oy) and covered with steel sheet fixed by nails with elongated holes to allow the slip in the connection. In order to achieve the required fire resistance class (R30, R60 or R90), thickness of the rock wool at the bottom edge of the beam was varied as well as the distance of the steel rod from the vertical edge of the beam. Distance variation was carried out by extra timber which was glued by RF30 on the beam faces. Information concerning fire protection of the V-joint are summarised in Table 1 and the detailed drawing of the beam structures and the connection are shown in Appendix A.

The beams were assembled in the testing hall of VTT Building Technology and transported after that to the laboratory of Fire Technology where the fire resistance tests were performed in the model furnace.

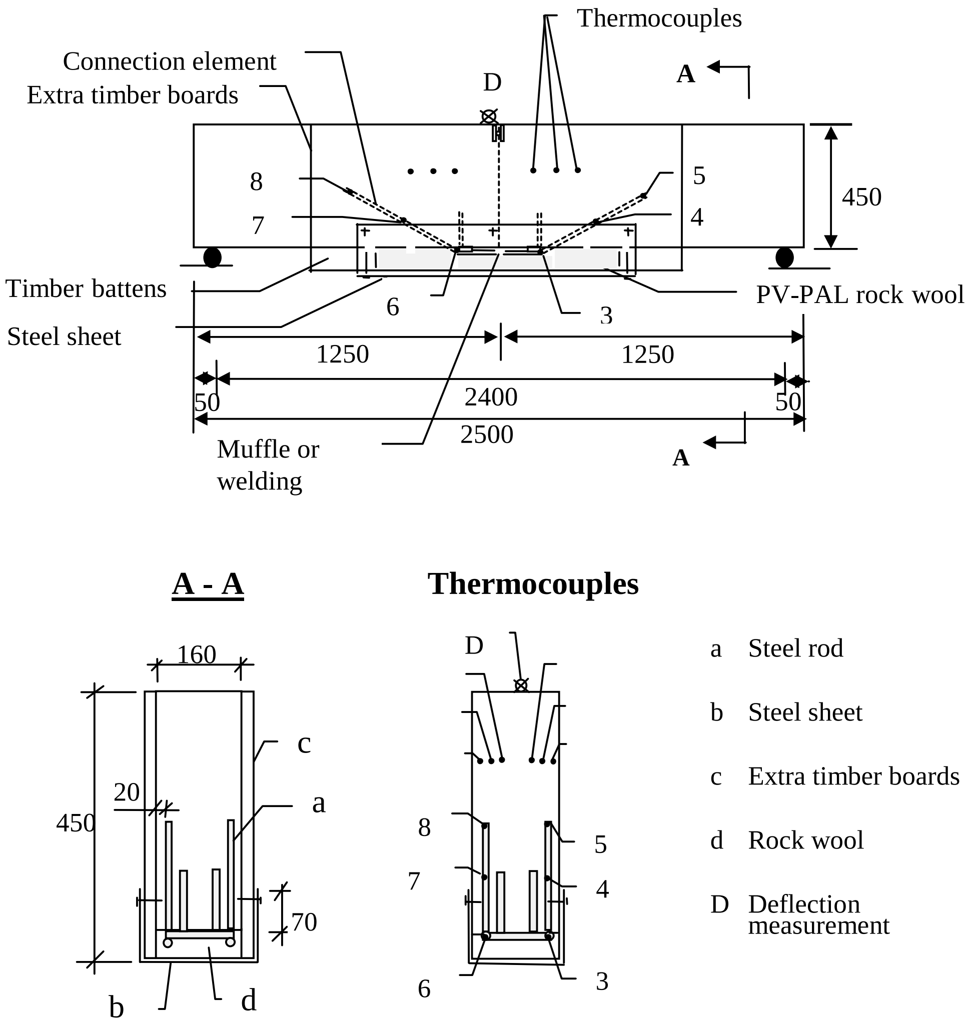


Figure 9. The structure of the test specimens in principle and some measuring points of temperature and deflection.

Table 1. Fire protection of V-joint of the test specimens.

Test specimen	Thickness of rock wool on the steel muffle / rod at the bottom (mm)	Thickness of timber covering of the steel rods on the vertical faces (mm)	Test date
Beam 1	60 (muffle)	62	8.12.1998
Beam 2	20 (rod)*	20	16.12.1998
Beam 3	40 (rod)*	40	18.12.1998

* A muffle was not used in beam 2 and 3; the rods were welded together.

4.2 Test

The fire resistance tests were performed in the model furnace. The test specimens were simply supported with a point load of 34.5 kN applied at the middle of the span 2400 mm. The load corresponds 40% of the design load in normal temperature design [3]. The test load of the beams was applied 15 min - 30 min before the commencement of the test by a hydraulic jack located above the furnace. The resulting deflection was measured (see Appendix D). The test load was kept constant during the test. Test arrangements are presented in Figure 10.

The fire exposed area of the beam was about 1500 mm long. Furnace temperature was raised according to the standard ISO 834 (T = 345 lg (8t + 1) + 20 [K], where t is time in minutes) [4]. The temperatures of the V-joint and the timber in several points were measured using Chromel-Alumel thermocouples of K-Type 2 x 0.5 mm. Furnace gas temperatures were measured 100 mm from the beam face with 4 Chromel-Alumel thermocouples of K-type ∅ 3 mm stainless steel sheathed. The location and numbering of the thermocouples in the specimens and in the furnace are shown in Figure 9 and detailed in Appendix B. The deflection of the beams at midspan was also recorded.

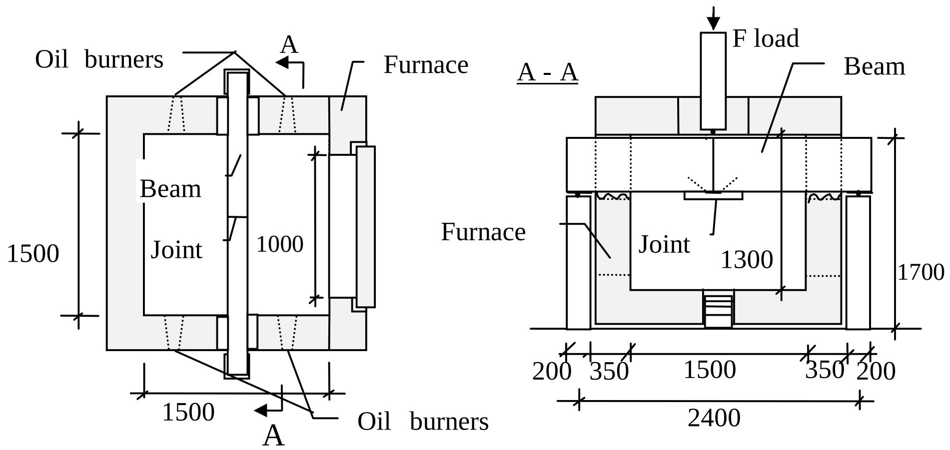


Figure 10. Test arrangements in the model furnace.

Temperatures and deformations were measured automatically at intervals of 10 s. During the test observations were made and photographs taken of the specimens. The photograph of the test arrangement in the furnace is shown in Figure 11.

Figure 11. Furnace test set-up.

4.3 Test results

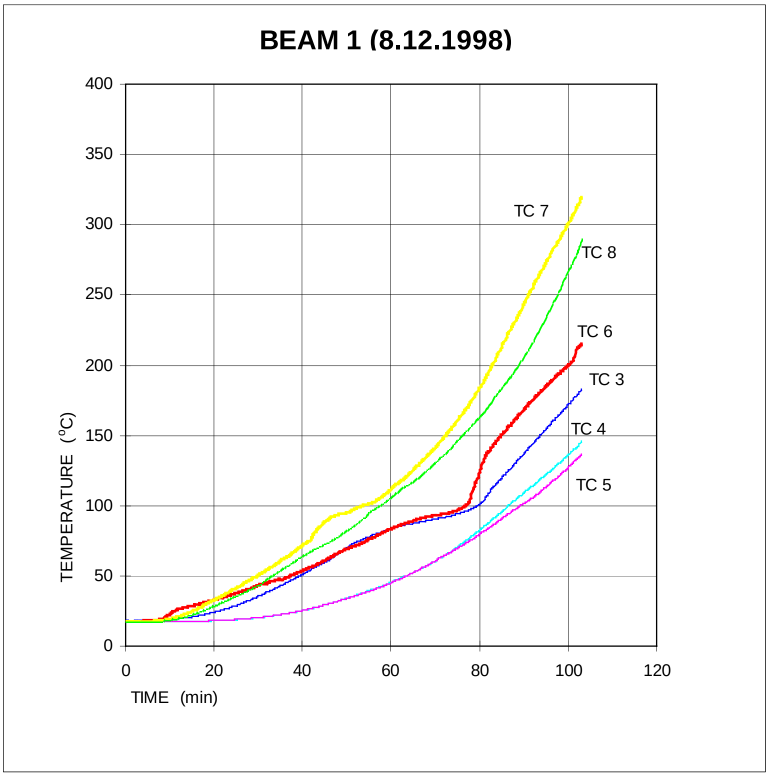
The fire resistance test of the beam 1 was terminated when the specimen was no longer capable to carry the load and the test of the beams 2 and 3 some minutes after removal of the load. Beam 1 collapsed because of failure of the beam outside the joint whereas beam 2 and beam 3 lost their capacity because failure of the joint. Summary of the main results; test time, the time when loading was removed and slip of the joint as well as failure type, are presented in Table 2. The deflection of the beam can be considered to be caused due to the slip in the joints and the thermal elongation of the steel parts at the lower edge. That “slip” in the chosen fire class is calculated as an upper limit and given in the table.

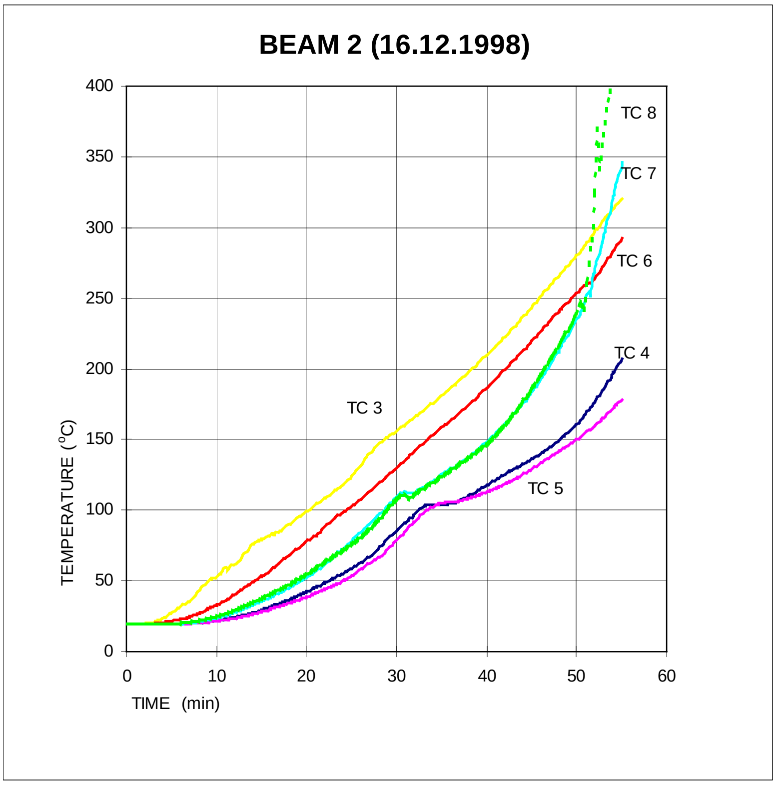
Table 2. Summary of the results.

	Beam 1	**Beam 2**	**Beam3**
Fire protection of rock wool / timber	60 mm / 62 mm	20 mm / 20 mm	40 mm / 40 mm
Test time	103 min	55 min	80 min
Loading removed	103 min	52 min	78 min
"Slip" in the joint	< 7 mm	< 2,5 mm	< 4 mm
Type of failure	Beam failure	Joint failure	Joint failure

Measured temperatures of the steel rods are presented in Figure 12. Measuring points 3 and 6 were in the steel rods at the bottom of the beam protected with rock wool whereas measuring points 4 and 5 as well as points 7 and 8 were in the rods inside the beam. Measured temperatures of each rod inside the beam are very close to each other whereas temperatures in different rods of the same beam can diverge strongly. For instance the temperature difference between the rods was 174 ^{o}C, 139 ^{o}C and 72 ^{o}C in the middle of the rods and 154 ^{o}C, 310^{o}C and 105 ^{o}C in the end of the rods, in beams 1, 2 and 3 respectively at the end of the test. The reoson could be that the position of the rods is not exact the same because of long, drilled holes. Additionally a gap round the rod allowes some difference in its position.

The maximum temperature of the rod at the time of failure was about 300 ^{o}C in beam 1 and beam 2 and 250 ^{o}C in beam 3. These temperatures are much higher than the temperature when the glue is workable. In consequence at the end of the test the glued steel rods did not act any longer but the forces were conveyed by the screw taps. This can be seen in Figure 13 and 14. The screw taps have slipped about 10 mm after the failure of timber.


BEAM 1 (8.12.1998)
TEMPERATURE (°C)
TIME (min)
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
120
TC 7
TC 8
TC 6
TC 3
TC 4
TC 5


BEAM 2 (16.12.1998)
TEMPERATURE (°C)
TIME (min)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
TC 8
TC 7
TC 6
TC 4
TC 3
TC 5

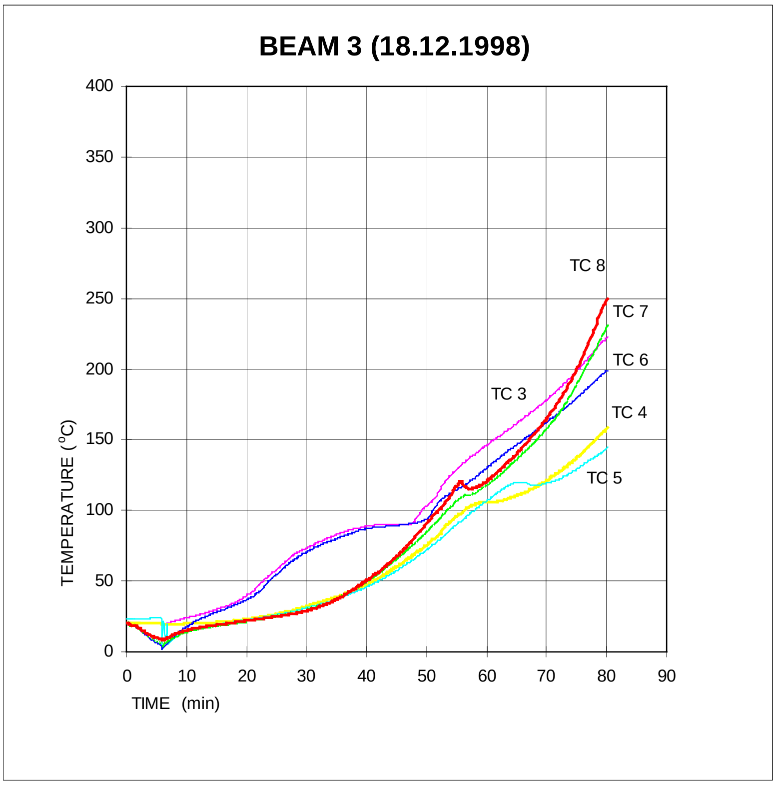


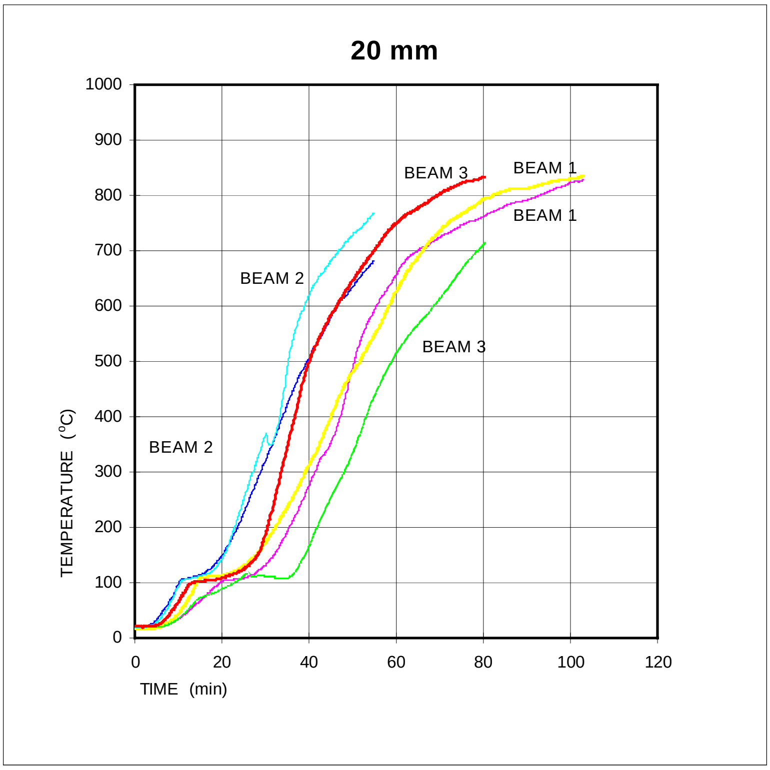
Figure 12. The temperatures of the rods.

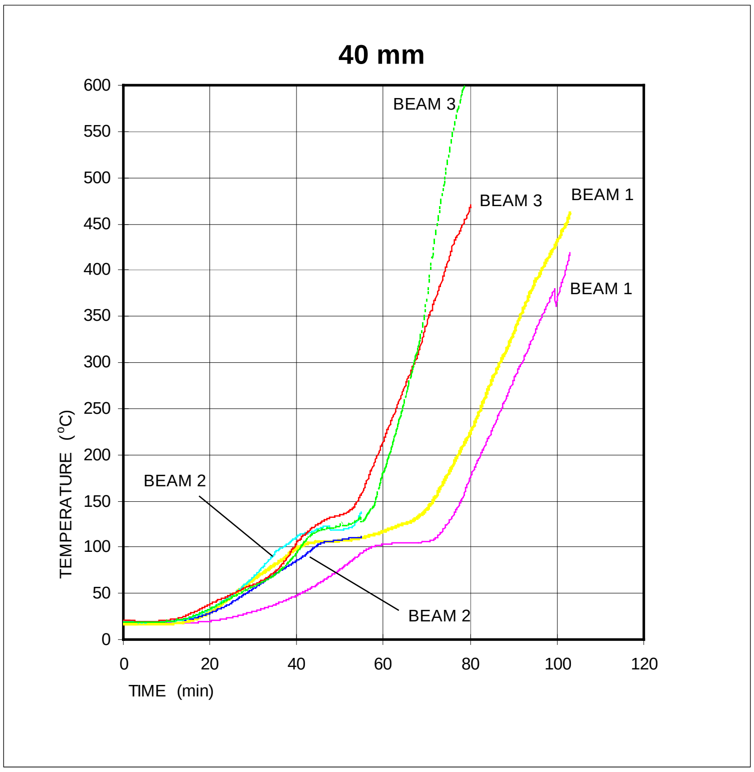
Figure 13. The slip of the steel rod in beam 2 after the test.

Figure 14. Failure of timber in beam 2 after the test.

Temperatures in the timber measured at the distances of 20 mm (21 mm beam 1), 40 mm (42 mm beam 1) and 60 mm (62 mm beam 1) from the vertical beam faces are presented in Figure 15. Each curve has a plateau at the temperature of about 100 ^oC because of evaporation of moisture. The curves have quite a lot of variation. The temperature rise of beam 1 and beam 3 in the beginning of the test is slower and the evaporation plateau is longer than with beam 2. After the temperature of about 100 ^oC temperature rise is quite equal, see Figure 15a. These phenomena indicate higher moisture content of the timber boards in the beam faces than in the beam itself (moisture content of timber boards was not defined). Some variation can also result from the different position of the thermocouples (beam 1) as well as the glue between the beam and the timber boards (beams 1 and 3).

Charring depth of 20 mm was achieved in time of about 28 min (beam 2), if 300^oC is considered the temperature of charring [3]. Charring rates calculated on the basis of temperature measurements of 300 ^oC at the distances of 20 mm and 40 mm from the vertical beam faces are presented in Table 3.


20 mm
1000
900
800
700
600
500
400
300
200
100
0
TEMPERATURE (°C)
0
20
40
60
80
100
120
TIME (min)
BEAM 3
BEAM 1
BEAM 1
BEAM 2
BEAM 3
BEAM 2


40 mm
600
550
500
450
400
350
300
250
200
150
100
50
0
TEMPERATURE (°C)
0
20
40
60
80
100
120
TIME (min)
BEAM 3
BEAM 3
BEAM 1
BEAM 1
BEAM 2
BEAM 2

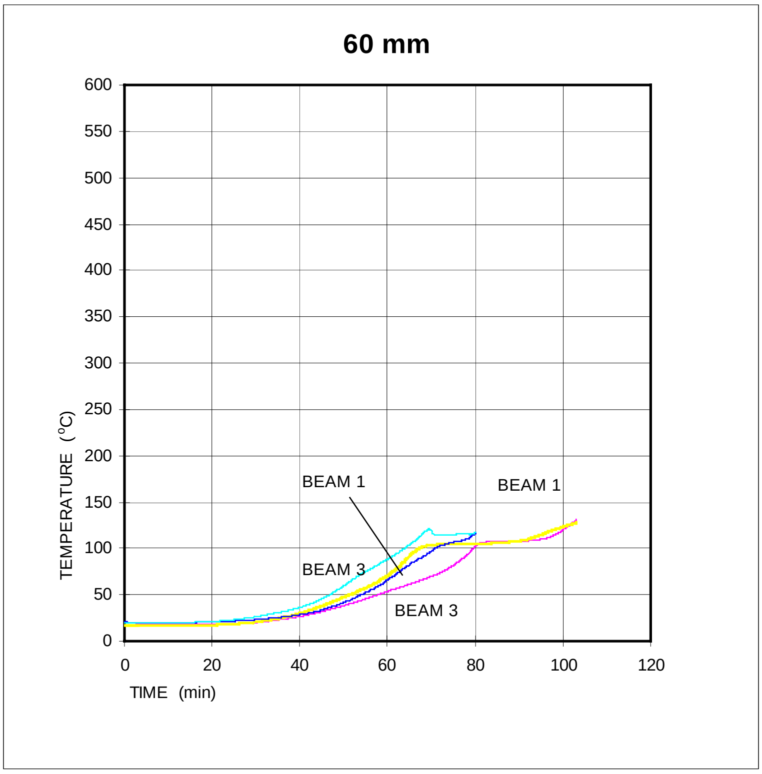


Figure 15. Temperatures measured at the distances of 20 mm, 40 mm and 60 mm from the vertical beam faces.

Table 3. Charring rates calculated on the basis of temperature measurements of 300 °C at the distances of 20 mm and 40 mm from the vertical beam faces.

	Distance from the beam face			
	20 mm		**40 mm**	
	Time (min) / thermocouple	**Charring rate (mm/min)**	**Time (min) / thermocouple**	**Charring rate (mm/min)**
Beam 1	41.3 / tc13	0.51[1]	92.0 / tc14	0.46[1,2]
	39.2 / tc17	0.54[1]	86.8 / tc18	0.48[1,2]
Beam 2	28.9 / tc13	**0.69**	-	-
	27.2 / tc16	**0.74**	-	-
Beam 3	47.9 / tc13	0.42[2]	67.2 / tc14	0.60[2]
	33.6 / tc16	0.60[2]	67.0 / tc17	0.60[2]

[1] Measuring point at the distance of 21 mm or 42 mm.
[2] Glue could have some effect on charring rate.

Measured deflections, deflection rates and the time points when deflection rate has changed are presented in Figure 16. Deflection rate of beams 2 and 3 (joint failure) has increased considerably after 40 min and 70 min. After this increasing of deflection rate the beams failed in about 10 minutes. The reason was the exceeding of the dowel capacity (half of the design load in fire) after the total loss of the anchorage capacity due to softening of the adhesive. The change of deflection rate in beam 1 is not so rapid. It failed outside fire protected area.

The criteria of loadbearing capacity according to the test standard ISO 834-1 (1999) "Fire resistance tests - Part 1: General requirements" [4] are as follows

Limiting deflection, $D = \frac{L^2}{400d}\left[mm\right]$ and

Limiting rate of deflection, $\frac{dD}{dt} = \frac{L^2}{9000d}\left[mm/\min\right]$,

where L is the clear span of the test specimen, in millimetres
d is the distance from the extreme fibre of the design compression zone to the extreme fibre of the design tensile zone of the structural section, in millimetres.

The failure of a loadbearing structure is deemed to have occured when both of the criteria have been exceeded. It is also stated in the standard that the rate of deflection criteria is not applied until a deflection of L/30 has been exceeded. This cannot be applied on wood structures which have not an ability to deflect as high e.g. in this case L/30 = 80 mm. The limiting deflection D = 32 mm and the limiting rate of deflection dD/dt = 1.4 mm/min seem to be reasonable values when comparing the test results. Times when the limiting deflection D and the limiting rate of deflection dD/dt were achieved are presented in Table 4.

Table 4. Times when the limiting deflection D and the limiting rate of deflection dD/dt were achieved.

	Beam 1	Beam 2	Beam 3
D=32 mm	101 min 15 s	45 min 17 s	76 min 10 s
dD/dt=1.4 mm/min	99 min 20 s	40 min 45 s	70 min 25 s

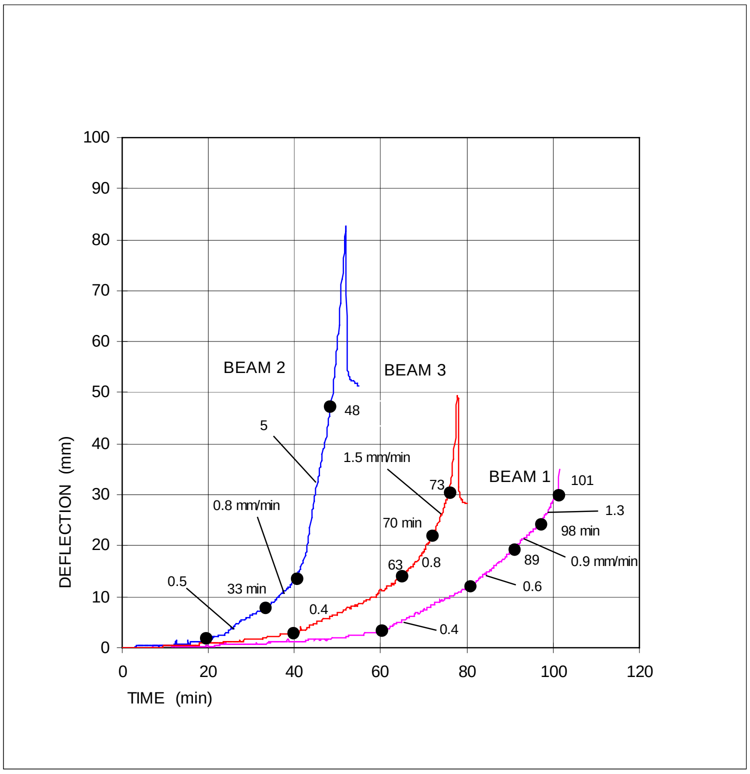


Figure 16. Deflection of the beams.

The main results concerning deflections are presented in Table 5: time when deflection rate changes, deflection rate and temperatures of the steel rods (thermoccouples 4, 5 and 7, 8) at the corresponding time. When comparing beam 2 and 3 it can be seen that the first turning point is achieved when the temperature of the steel rods is about 50 ^{o}C, the next point when temperature is between 100 ^{o}C - 130 ^{o}C and after the temperature of about 150 ^{o}C deflection rate begin to increase rapidly. The temperatures of the steel rods measured in beam 1 differ from each other considerably; the temperature of one rod is more than twice as high as the temperature of the other rod. This was the reason for the different fire behaviour. After the total loss of the anchorage capacity of one steel rod the other one could still carry load.

Table 5. Time (t) when deflection rate (dD/dt) begins to increase, deflection rate and temperatures (T = mean value of thermocouples 4 and 5 or thermocouples 7 and 8) of the steel rods at the corresponding time.

Beam 1			**Beam 2**			**Beam 3**		
t / dD/dt (min / mm/min)	T of tc 4 and 5	T of tc 7 and 8	t / dD/dt (min / mm/min)	T of tc 4 and 5	T of tc 7 and 8	t / dD/dt (min / mm/min)	T of tc 4 and 5	T of tc 7 and 8
60 / 0.4	45	109	20 / 0.5	40	53	40 / 0.4	47	50
80 / 0.6	80	173	33 / 0.8	100	116	63 / 0.8	112	130
89 /0.9	103	219	40 / < 5.0	115	148	70 / 1.5	120	162
98 / 1.3	125	271	48 / rapid increase			73 / rapid increase	127	180
101 / rapid increase	135	290						

Photographs of the test specimen and performance of the test are presented in Appendix E.

The test results relate to the behaviour of the test specimen under the particular conditions of the test. At other conditions the behaviour of the construction may differ from the presented test results. However, V-joint connection can achieve fire resistance classes of R30, R60 and R90, if fire exposed connection is protected with 20 mm, 40 mm and 60 mm thick rock wool (140 kg/m^3) and the edge distance of the steel rods of the connection are 20 mm, 40 mm and 60 mm thick respectively.

5. Summary

Design method for the connections based on steel rods glued at skew angles into the glulam (V-joint) is presented. It is effective and reliable means to construct economic timber structures with high capacity.

Fire resistance of a joint depends on the structure and materials of the joint, fire protection of the joint and loading as well as the fire exposure. In order to determine the fire resistance of the connection based on steel rods glued at skew angles into the glulam three fire resistance tests were performed.

The specimens were glulam beams (h x b = 450 x 160 mm^2 and the length of 2 500 mm) which consisted of two glulam members connected together with V-joint in the middle of the span = 2400 mm. The structure of the joint was the same in all tests but the thickness of the fire protection and the wood covering of the steel rods at the vertical faces were varied. Rock wool PV-PAL (density 140 kg/m^3, manufactured by Paroc Oy) covered by steel sheet was used as the fire protection at the bottom of the beam. The beams were tested simply supported with a point load of 34.5 kN applied at the mid span. The load corresponds 40 % of the design loading in normal temperature design. Furnace temperature was raised according to the standard ISO 834.

One of the beams collapsed because of the failure of the beam and the other two because of the failure of the joint. On the basis of temperature measurements it can be noted that at the end of the test the glued steel rods did not act any longer but the forces were conveyed by the screw taps. The deflection began to increase remarkably about ten minutes before the failure of the joint. The following fire resistance classes of the V-joint were achieved with the different thicknesses of fire protection and wood covering:

Fire resistance class	**R30**	**R60**	**R90**
Fire protection of rock wool (140 kg/m^3) and the distance of the rods from the vertical face of the beam.	20 mm	40 mm	60 mm

The test results relate to the behaviour of the test specimen under the particular conditions of the test. At other conditions e.g. with other dimensions of the joint or the angle of the rods, under different degree of loading or fire exposure the behaviour of the construction may differ from the presented test results.

References

1. Kangas, J. 1994. Joints of glulam structures based on glued-in ribbed steel rods. Espoo: Technical Research Centre of Finland. 61 p. + app. 20 p. (VTT Publication 196)

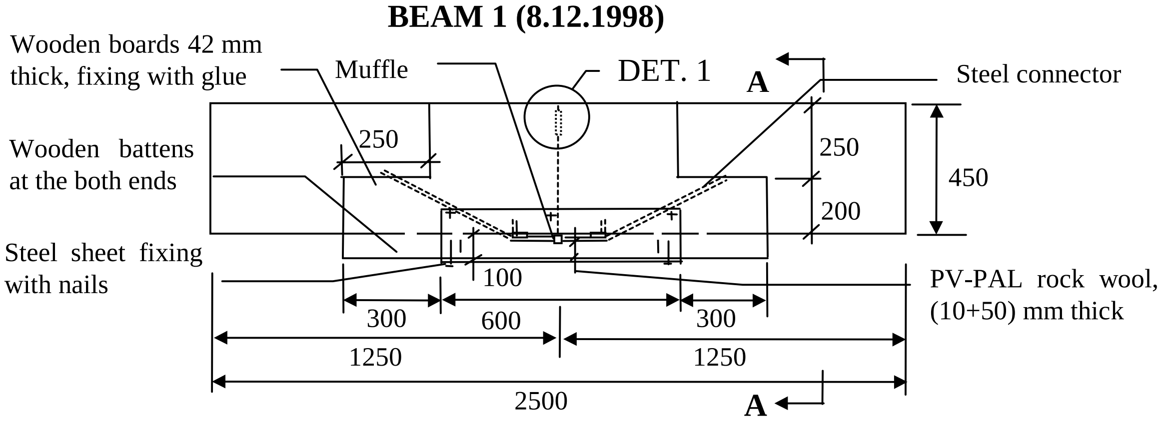
2. Eurocode 3, Design of steel structures - Part 1-2: General rules - Structural fire design, European Committee for Standardisation, ENV 1993-1-2:1995, Brussels, Belgium.

3. Eurocode 5, Design of timber structures - Part 1-1: General rules and rules for buildings and Part 1-2: General rules - Structural fire design, ENV 1995-1-1:1993 and ENV 1995-1-2:1994, European Committee for Standardisation. Brussels, Belgium.

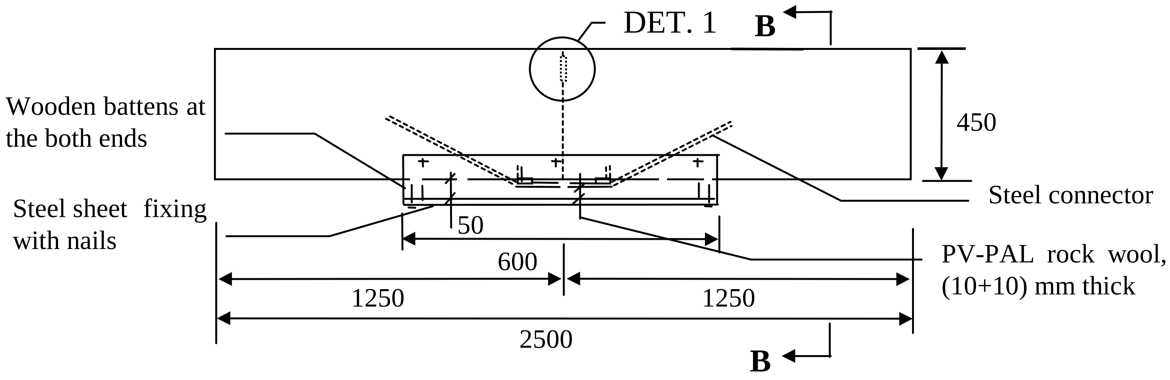
4. ISO 834-1. 1999. Fire resistance tests - Elements of building construction – Part 1: General requirements. Switzerland: Internal Organization of standardization ISO.

Appendix A: The drawings of the test specimens

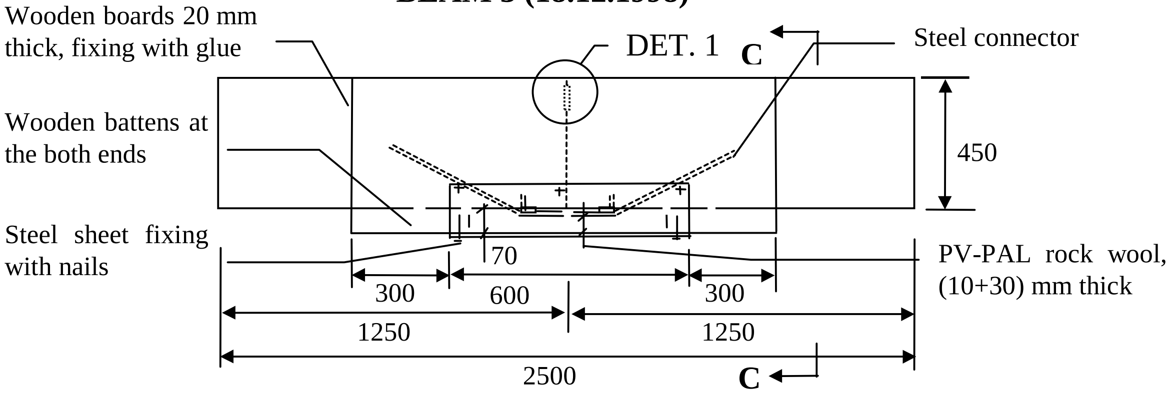
BEAM 1 (8.12.1998)



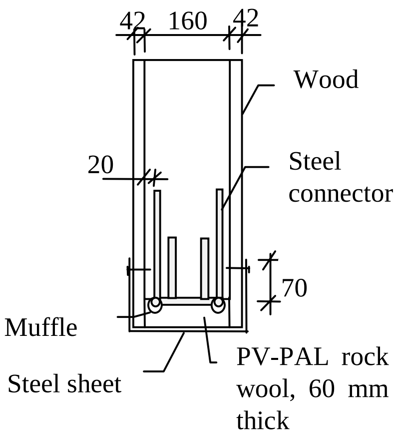
BEAM 2 (16.12.1998)



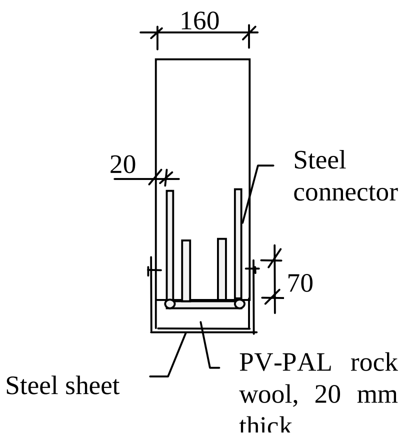
BEAM 3 (18.12.1998)



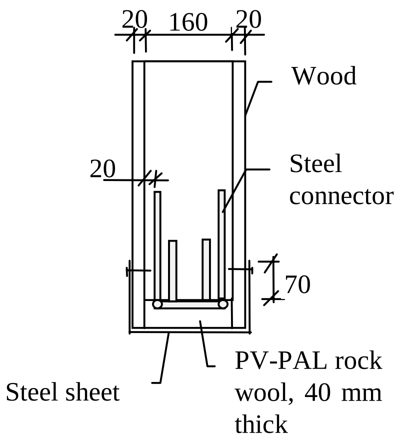
A - A


42
160
42
Wood
20
Steel connector
70
Muffle
Steel sheet
PV-PAL rock wool, 60 mm thick

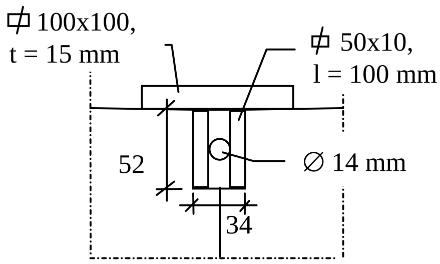
B - B


160
20
Steel connector
70
Steel sheet
PV-PAL rock wool, 20 mm thick

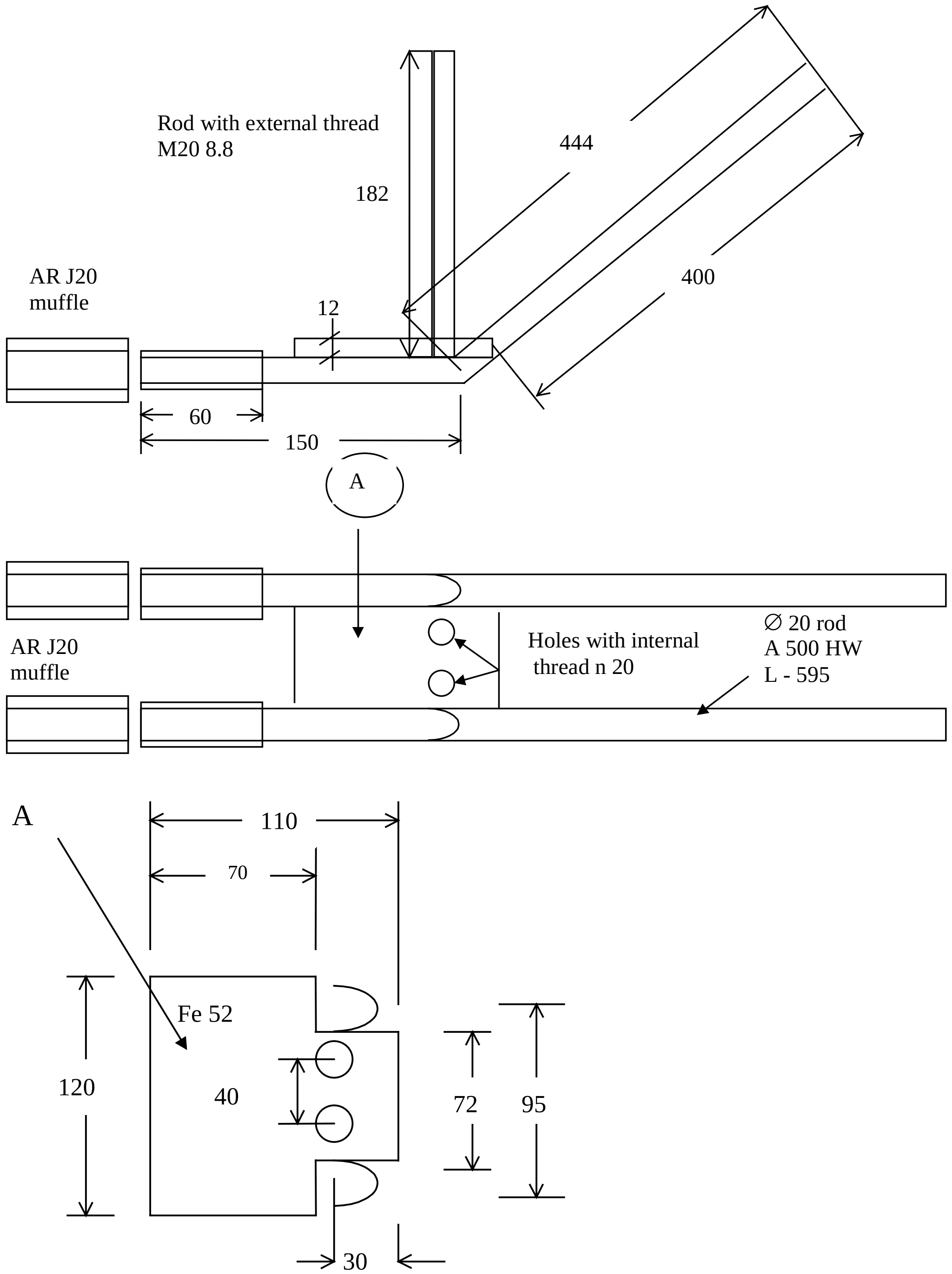
C - C


20
160
20
Wood
20
Steel connector
70
Steel sheet
PV-PAL rock wool, 40 mm thick

DET. 1

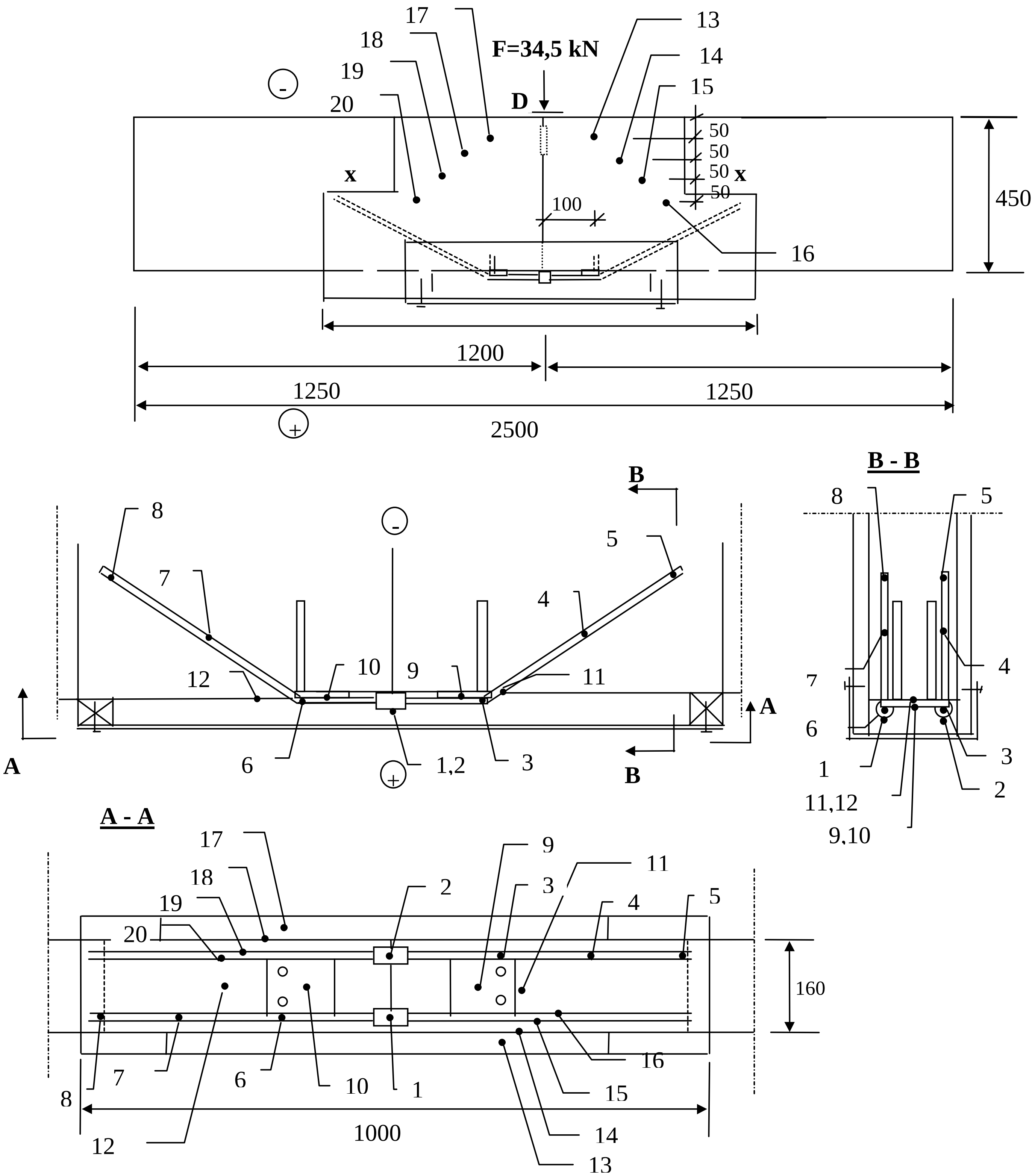

中 100x100, t = 15 mm
中 50x10, l = 100 mm
52
∅ 14 mm
34

Detail of steel connector.

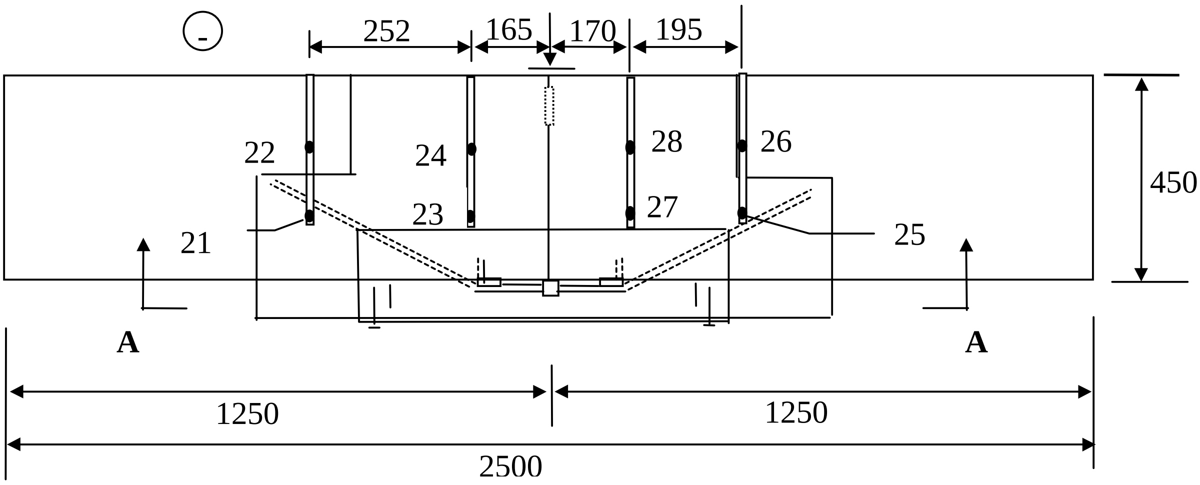


Appendix B: Position of temperature and deflection measurements

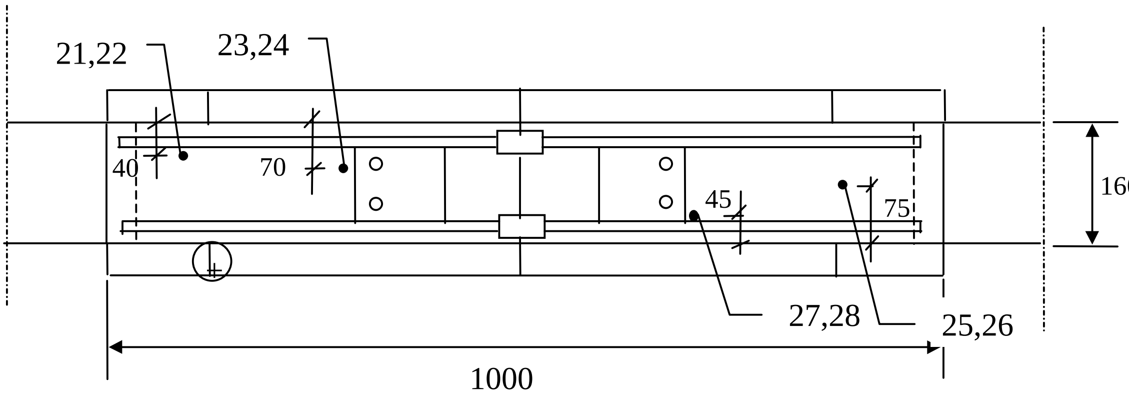
BEAM 1 (8.12.1998)



Extra measurements were performed with steel rods (∅ 20 mm) glued in wood. The length of the rods was 330 mm.



A - A



Temperature mesuring points

1-2	at the lower surface of the muffle
3-8	in the steel rod
9,10	at the lower surface of the steel plate
11,12	at the lower surface of the beam
13,17	at the distance of 21 mm from the outer surface
14,18	at the distance of 42 mm from the outer surface
15,19	at the distance of 62 mm from the outer surface
16,20	at the distance of 82 mm from the outer surface

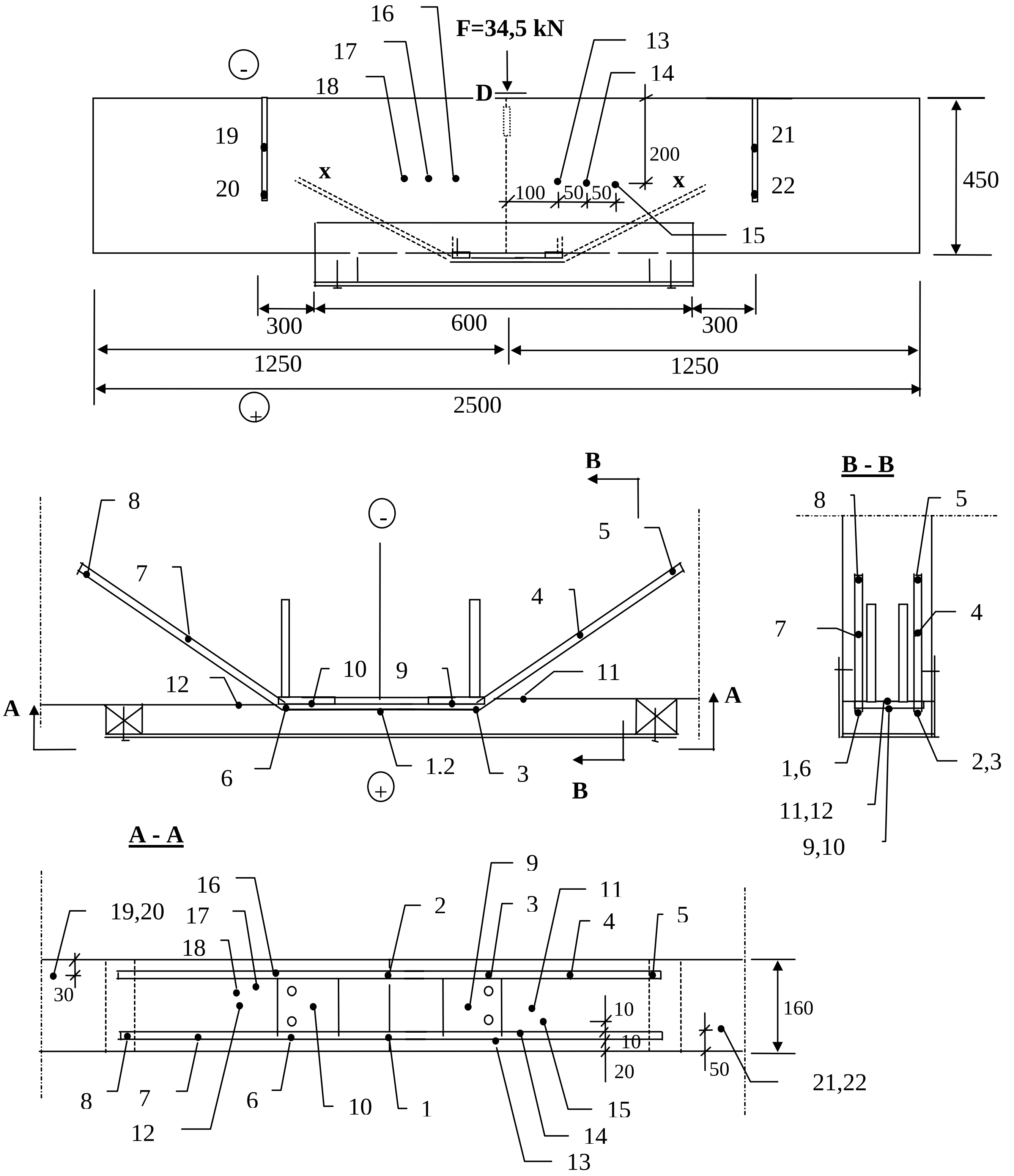
21,23,25,27 at the end of the steel rod

22,24,26,28 in the middle of the steel rod

x	temperature mesuring point of the furnace 100 mm from the beam face

Deflection measuring point D

BEAM 2 (16.12.1998)

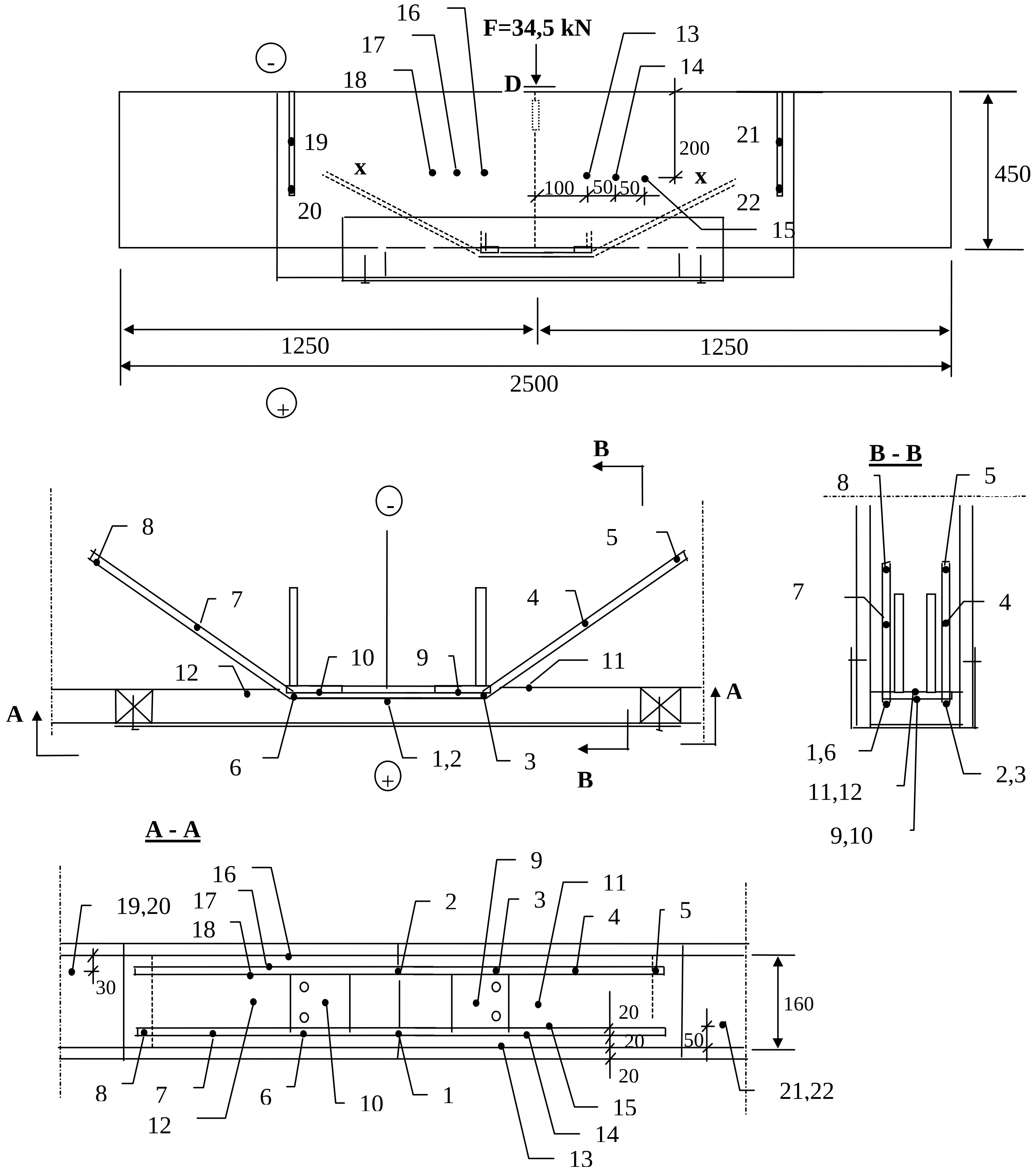


Temperature mesuring points

1-2	at the lower surface of the muffle
3-8	in the steel rod
9,10	at the lower surface of the steel plate
11,12	at the lower surface of the beam
13,16	at the distance of 20 mm from the outer surface
14,17	at the distance of 30 mm from the outer surface
15,18	at the distance of 40 mm from the outer surface
19,21	in the middle of the steel rod
20,22	at the end of the steel rod
x	temperature mesuring point of the furnace 100 mm from the beam face

Deflection measuring point D

BEAM 3 (18.12.1998)

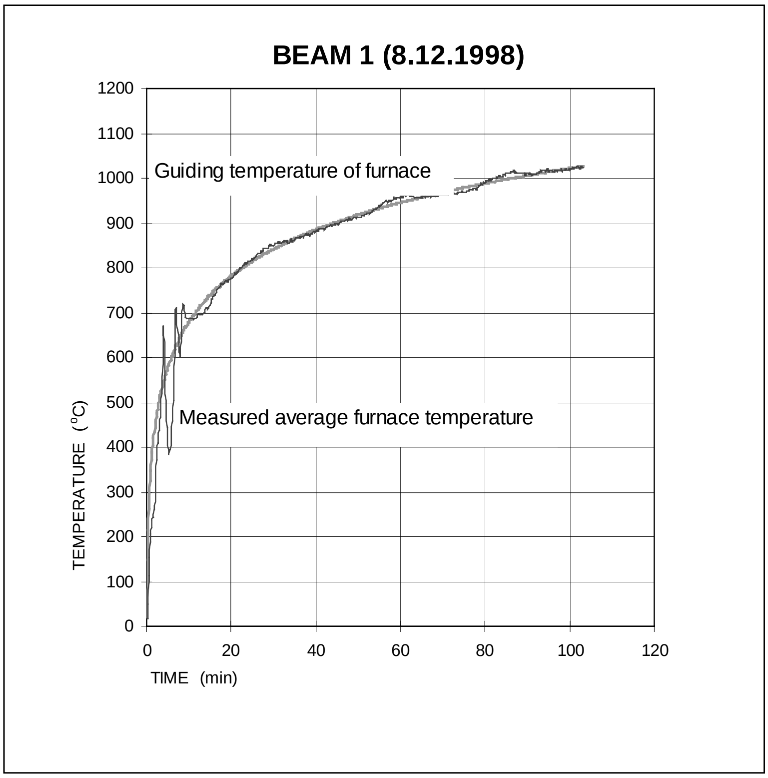


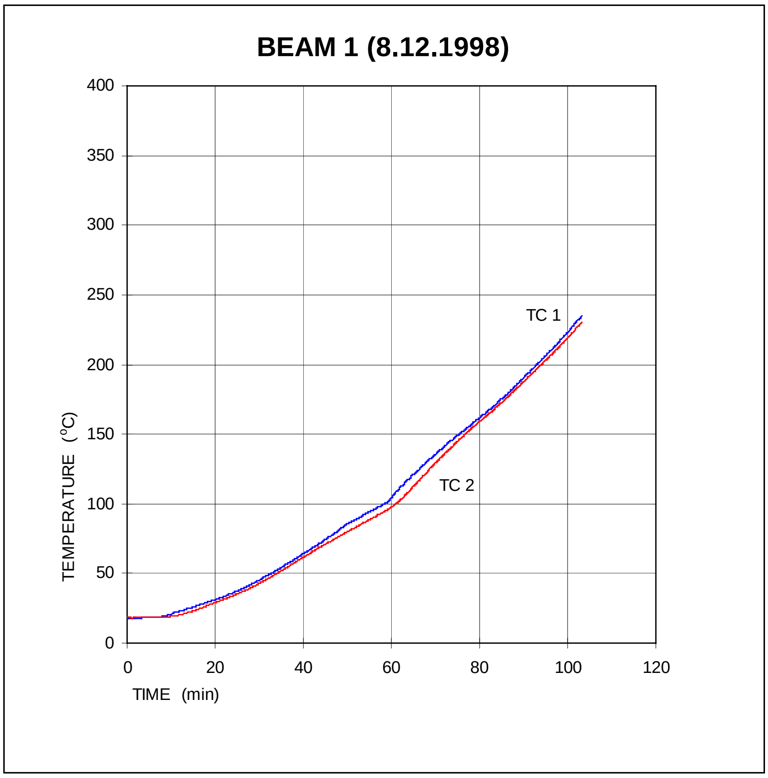
Temperature mesuring points

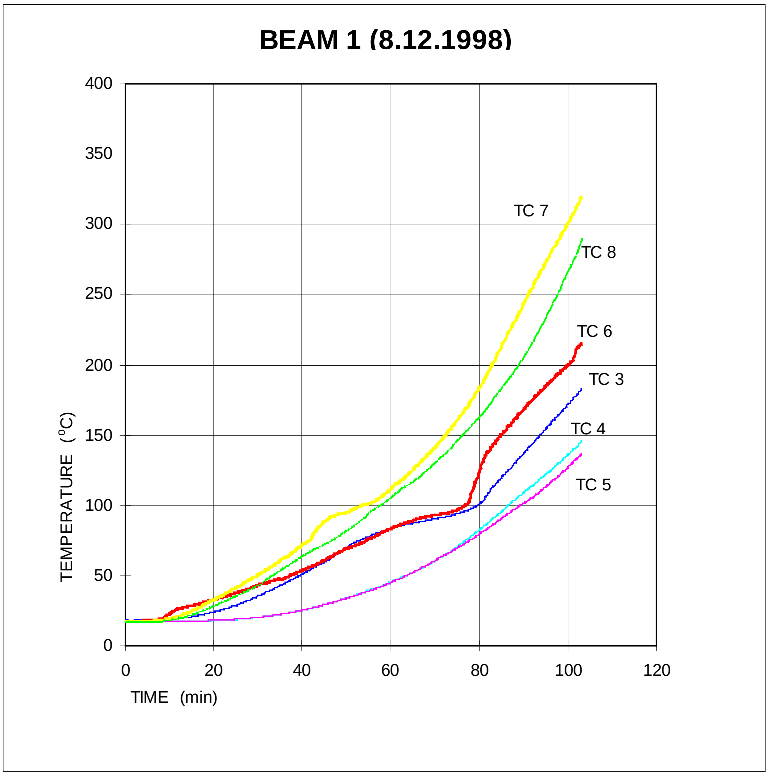
1-2	at the lower surface of the muffle
3-8	in the steel rod
9,10	at the lower surface of the steel plate
11,12	at the lower surface of the beam
13,16	at the distance of 20 mm from the outer surface
14,17	at the distance of 40 mm from the outer surface
15,18	at the distance of 60 mm from the outer surface
19,21	in the middle of the steel rod
20,22	at the end of the steel rod
x	temperature mesuring point of the furnace 100 mm from the beam face

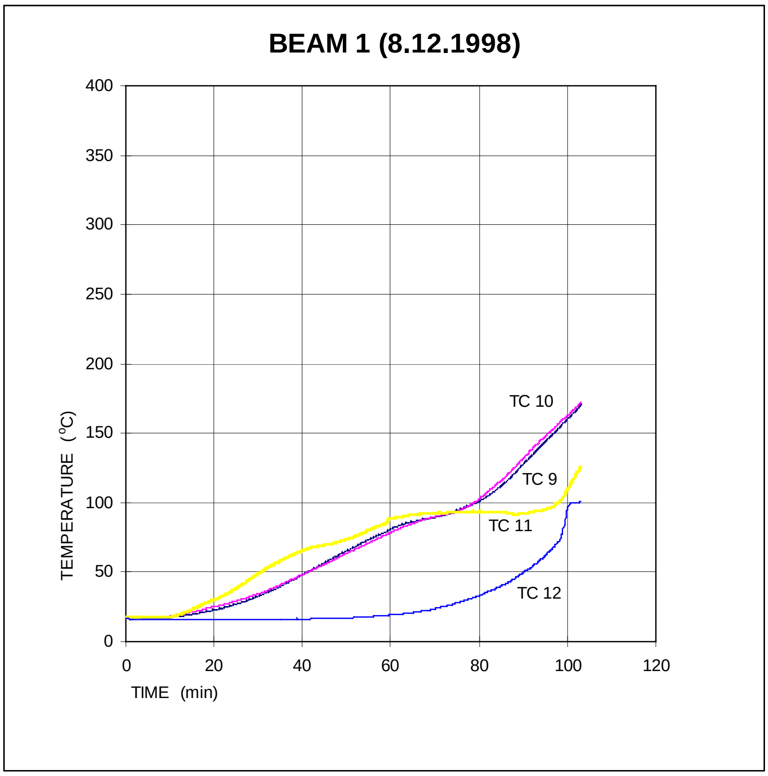
Deflection measuring point D

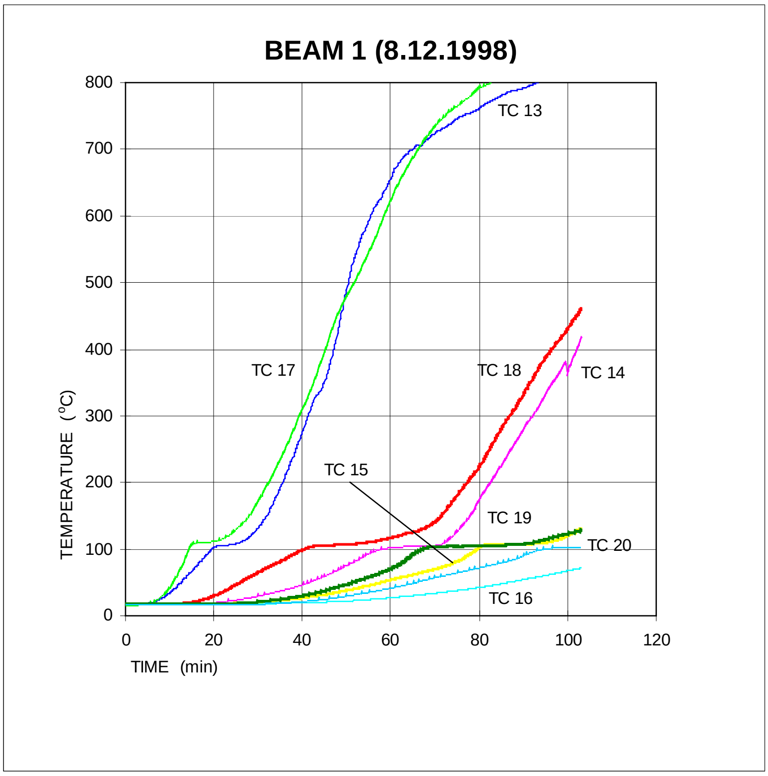
Appendix C: Furnace temperature and temperatures of the test specimens

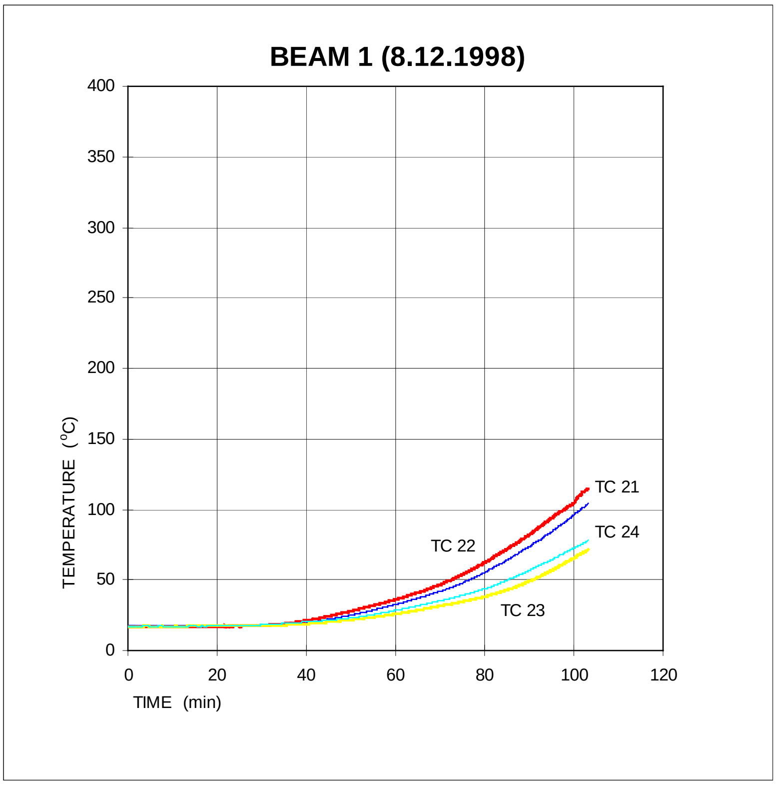


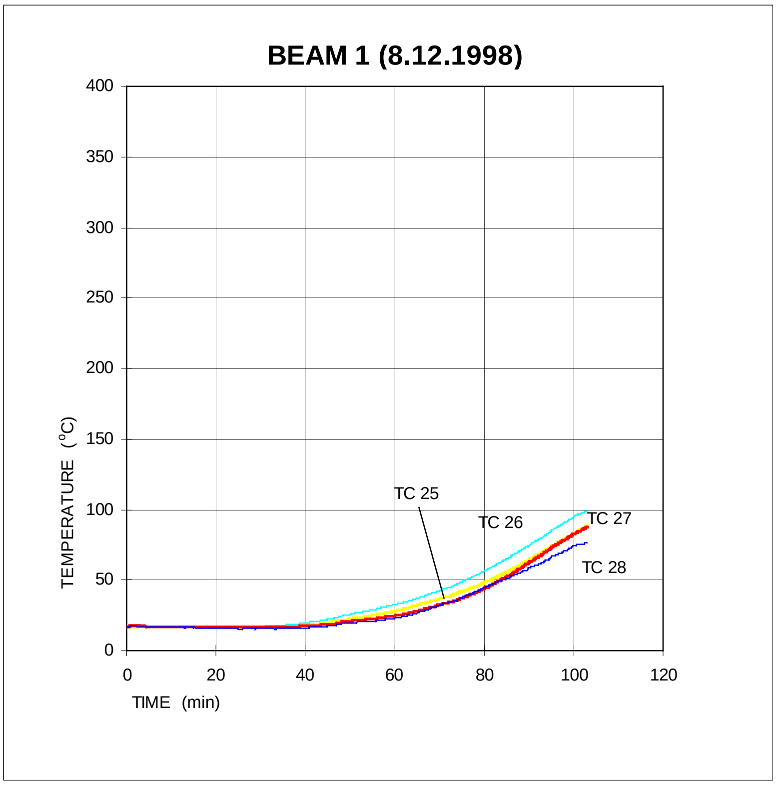


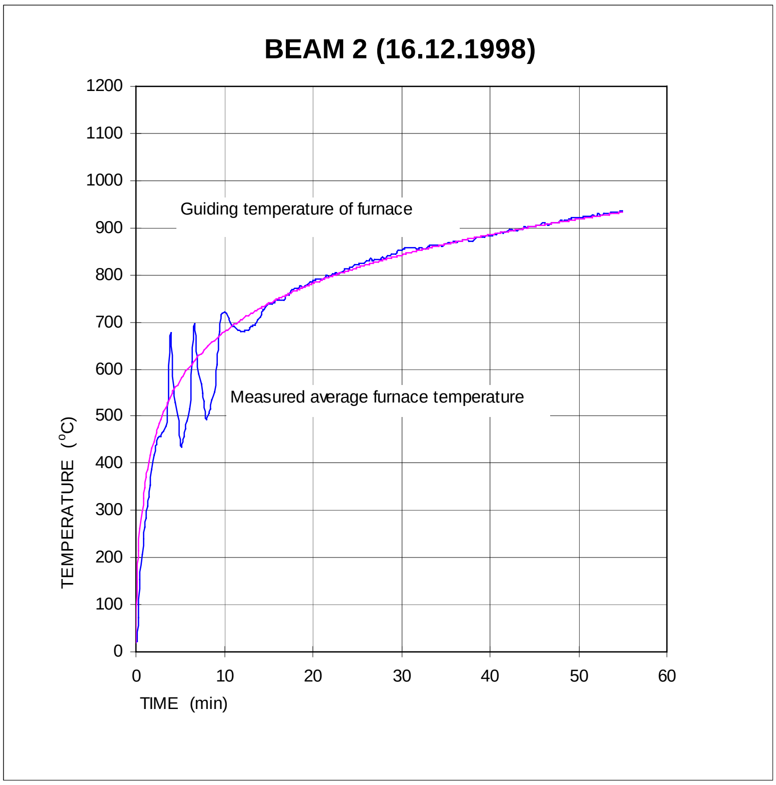

BEAM 1 (8.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 7
TC 8
TC 6
TC 3
TC 4
TC 5
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
120

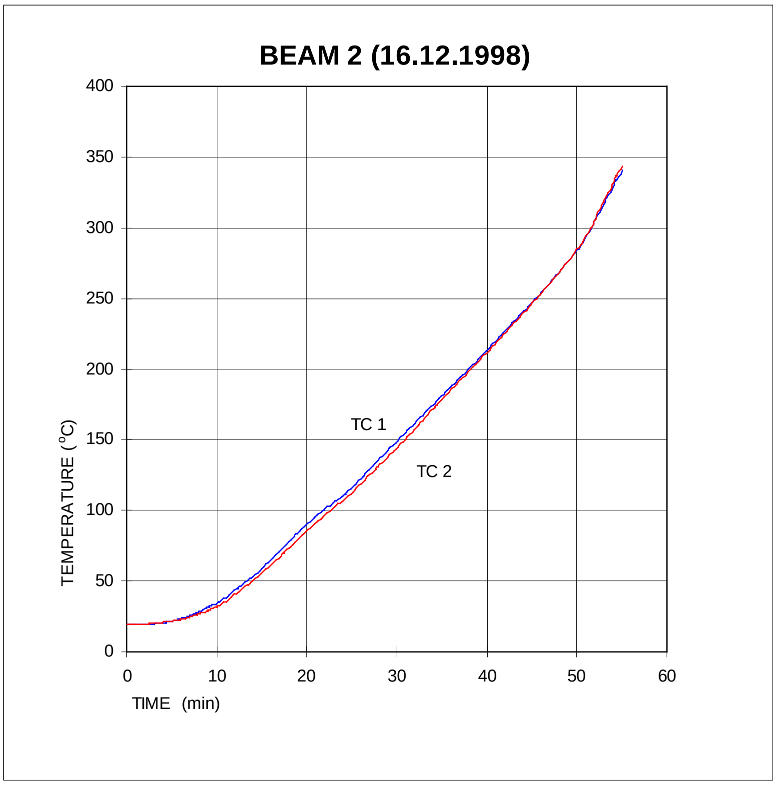

BEAM 1 (8.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 10
TC 9
TC 11
TC 12
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
120

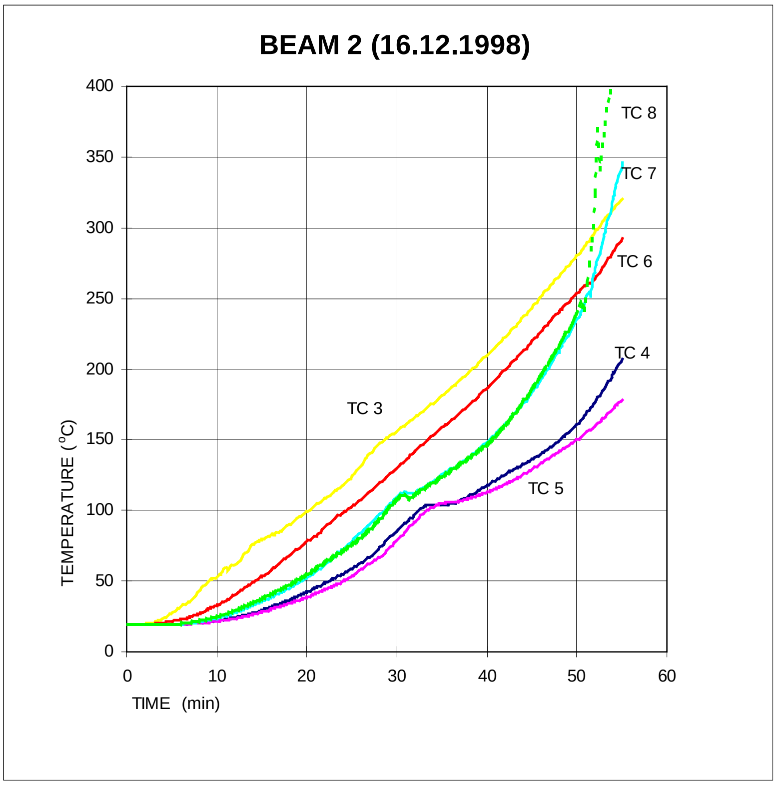

BEAM 1 (8.12.1998)
TEMPERATURE (°C)
TIME (min)
0
100
200
300
400
500
600
700
800
0
20
40
60
80
100
120
TC 13
TC 17
TC 18
TC 14
TC 15
TC 19
TC 20
TC 16

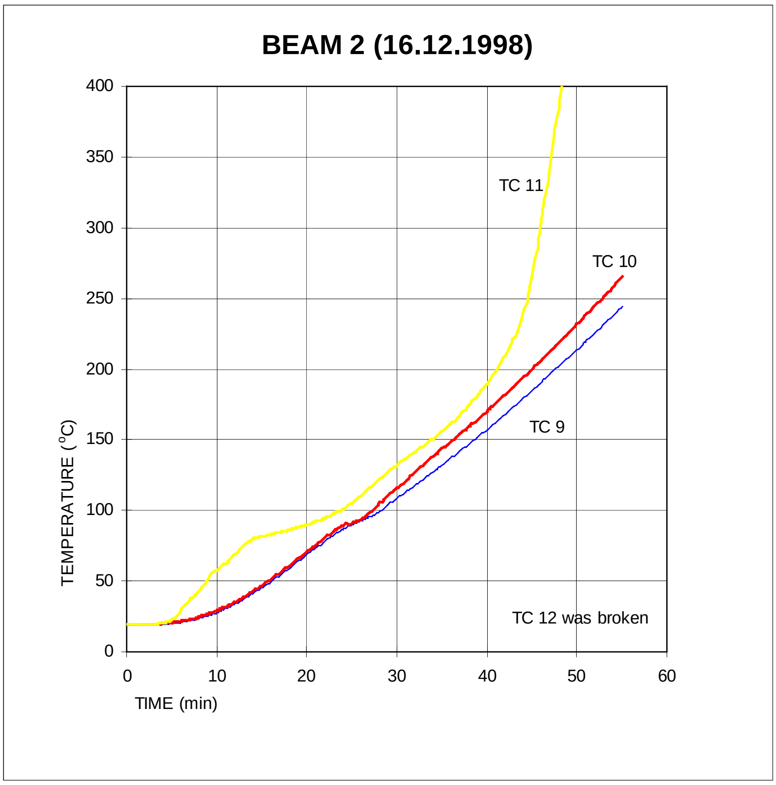

BEAM 1 (8.12.1998)
TEMPERATURE (°C)
TIME (min)
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100
120
TC 21
TC 24
TC 22
TC 23

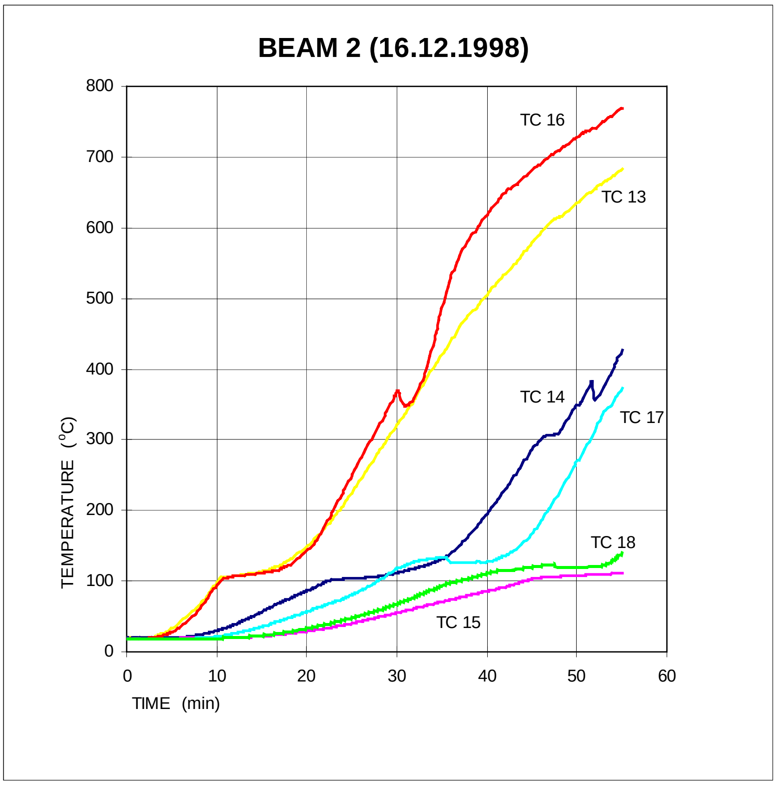

BEAM 1 (8.12.1998)
TEMPERATURE (°C)
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
TIME (min)
TC 25
TC 26
TC 27
TC 28

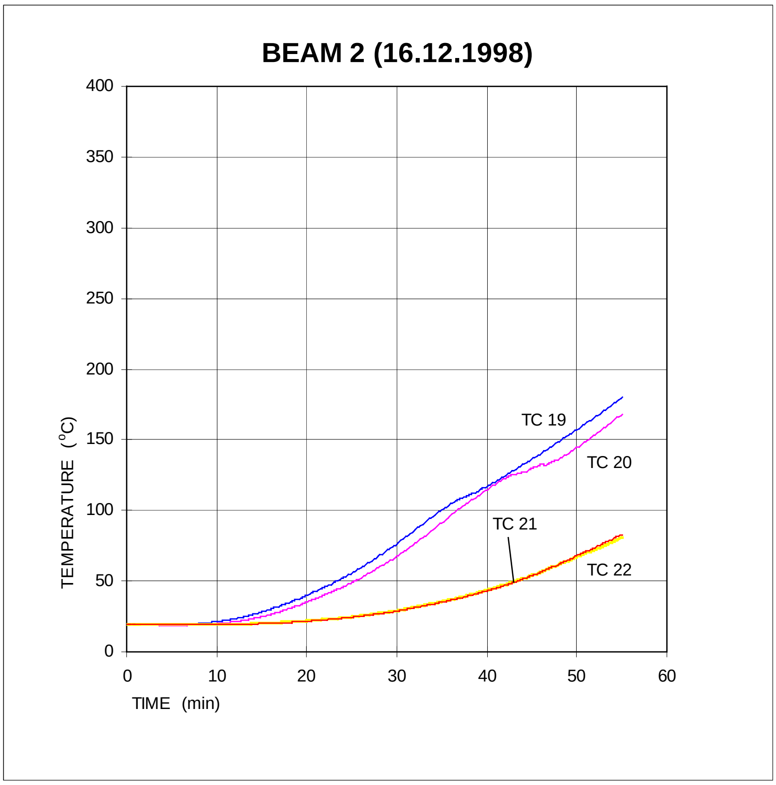

BEAM 2 (16.12.1998)
Guiding temperature of furnace
Measured average furnace temperature
TEMPERATURE (°C)
TIME (min)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0
10
20
30
40
50
60

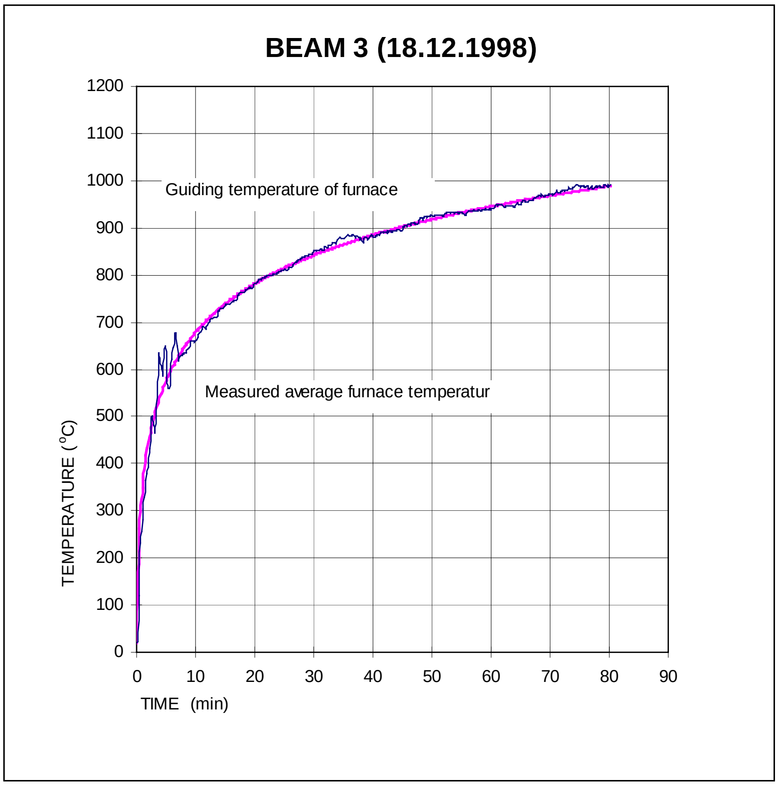

BEAM 2 (16.12.1998)
TC 1
TC 2
TEMPERATURE (°C)
TIME (min)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60

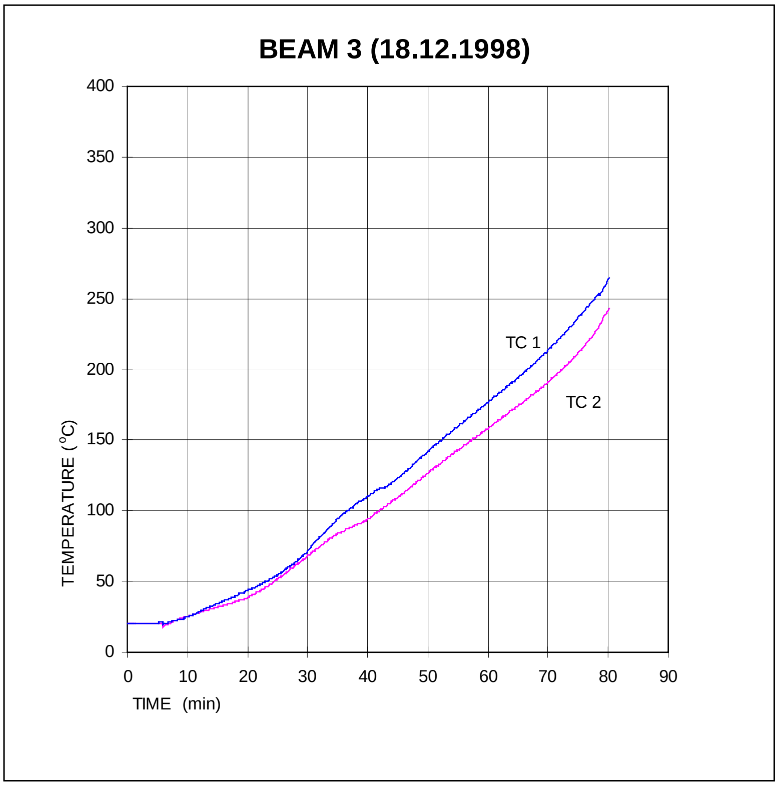

BEAM 2 (16.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 8
TC 7
TC 6
TC 4
TC 3
TC 5

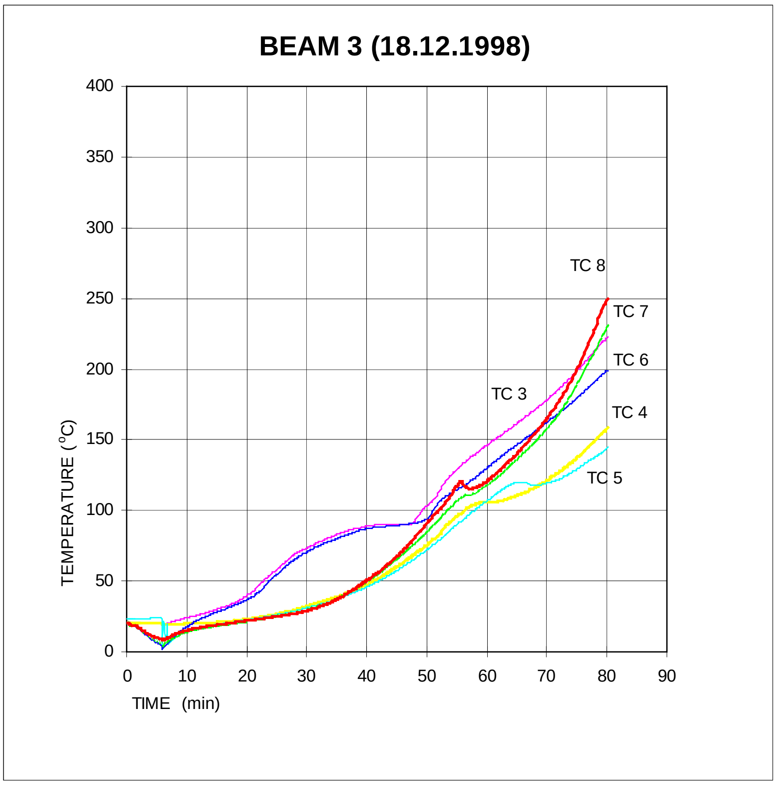

BEAM 2 (16.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 11
TC 10
TC 9
TC 12 was broken


BEAM 2 (16.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 16
TC 13
TC 14
TC 17
TC 18
TC 15
0
100
200
300
400
500
600
700
800
0
10
20
30
40
50
60

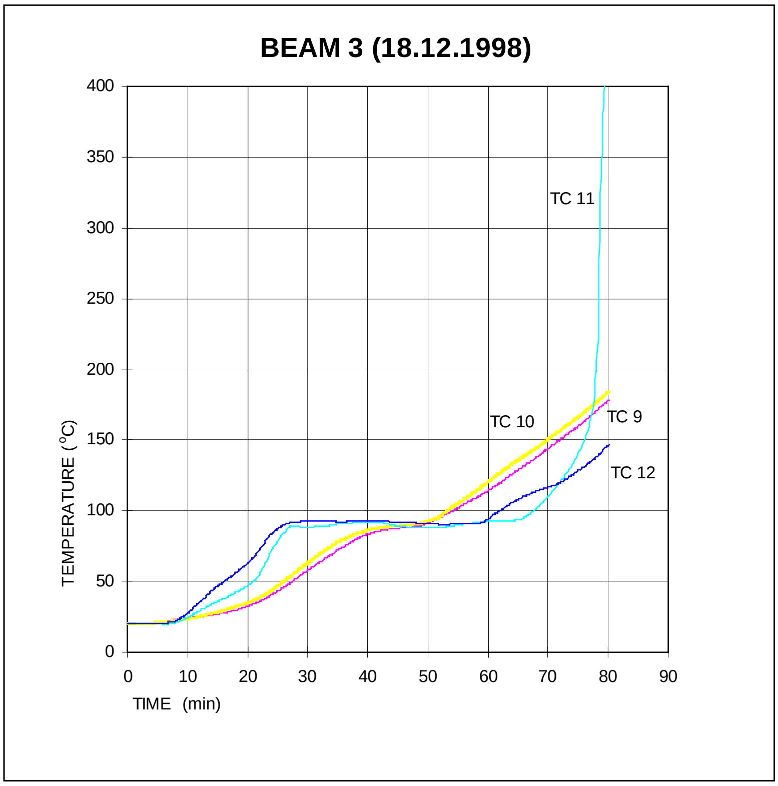

BEAM 2 (16.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 19
TC 20
TC 21
TC 22
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60


BEAM 3 (18.12.1998)
Guiding temperature of furnace
Measured average furnace temperatur
TEMPERATURE (°C)
TIME (min)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0
10
20
30
40
50
60
70
80
90

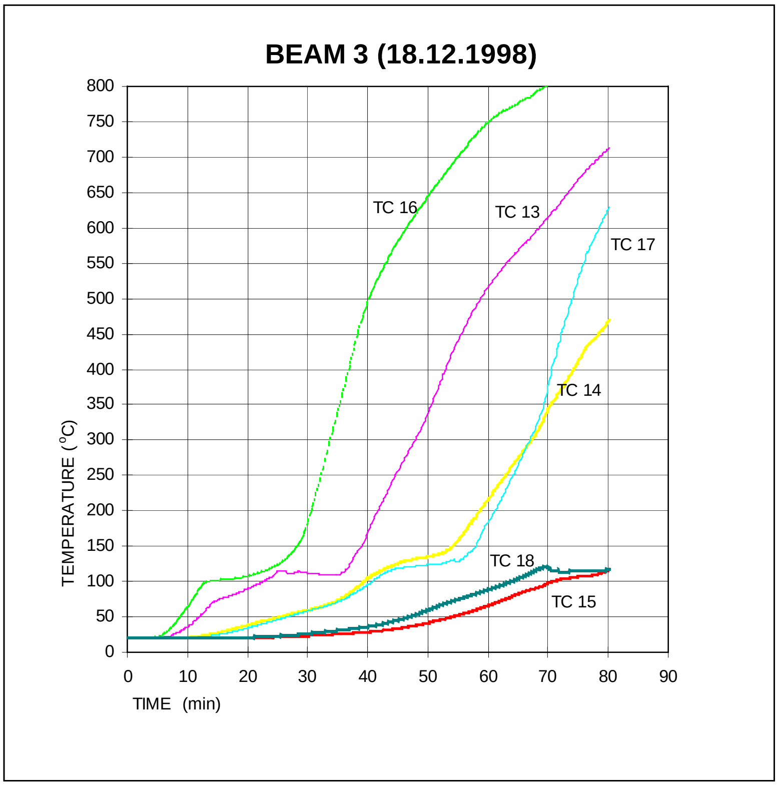

BEAM 3 (18.12.1998)
TC 1
TC 2
TEMPERATURE (°C)
TIME (min)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
80
90

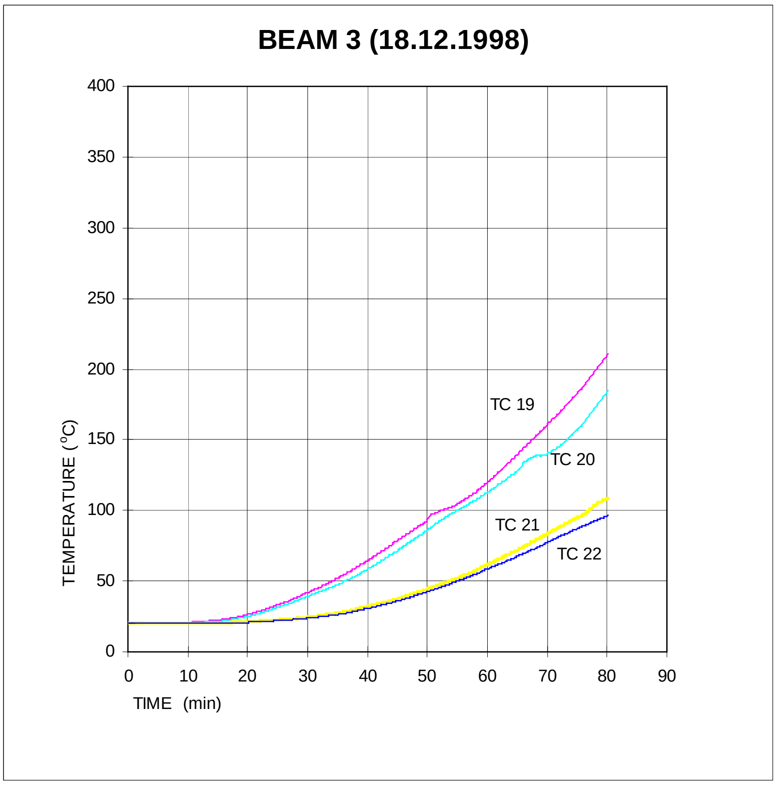


BEAM 3 (18.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 8
TC 7
TC 6
TC 3
TC 4
TC 5



BEAM 3 (18.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 11
TC 10
TC 9
TC 12


BEAM 3 (18.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 16
TC 13
TC 17
TC 14
TC 18
TC 15


BEAM 3 (18.12.1998)
TEMPERATURE (°C)
TIME (min)
TC 19
TC 20
TC 21
TC 22

Appendix D: Delections of the test specimens

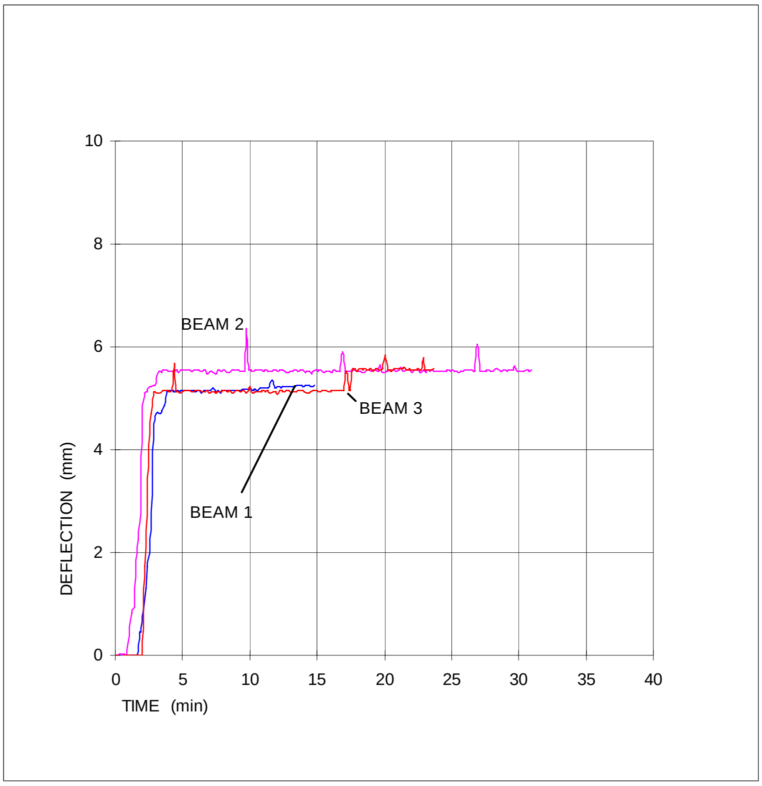


Figure 1. Deflection of the beams resulting from the loading before the commencement of the test.

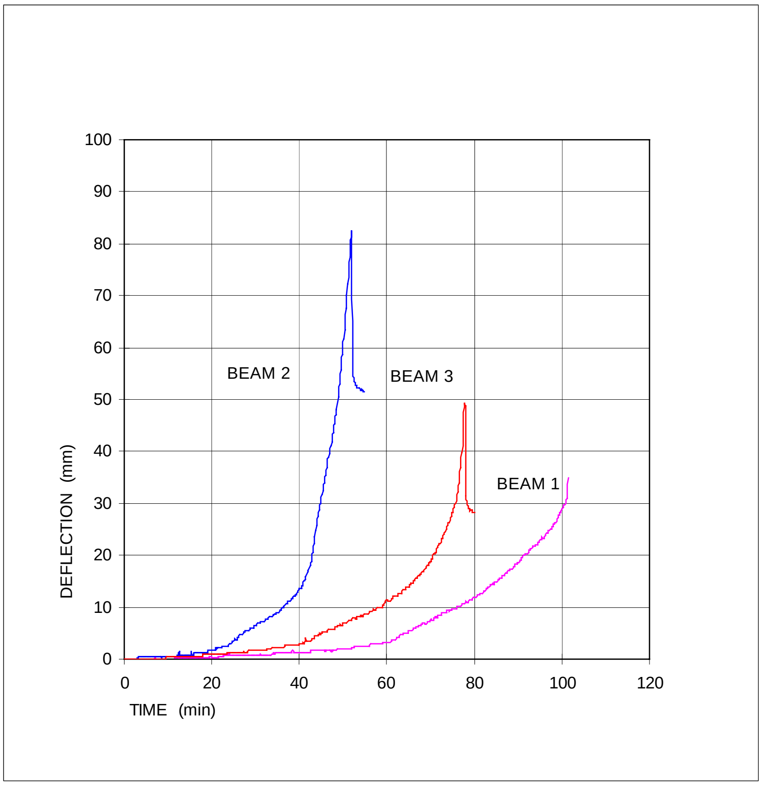


Figure 2. Deflection of the beams during the test.

Appendix E: Photographs

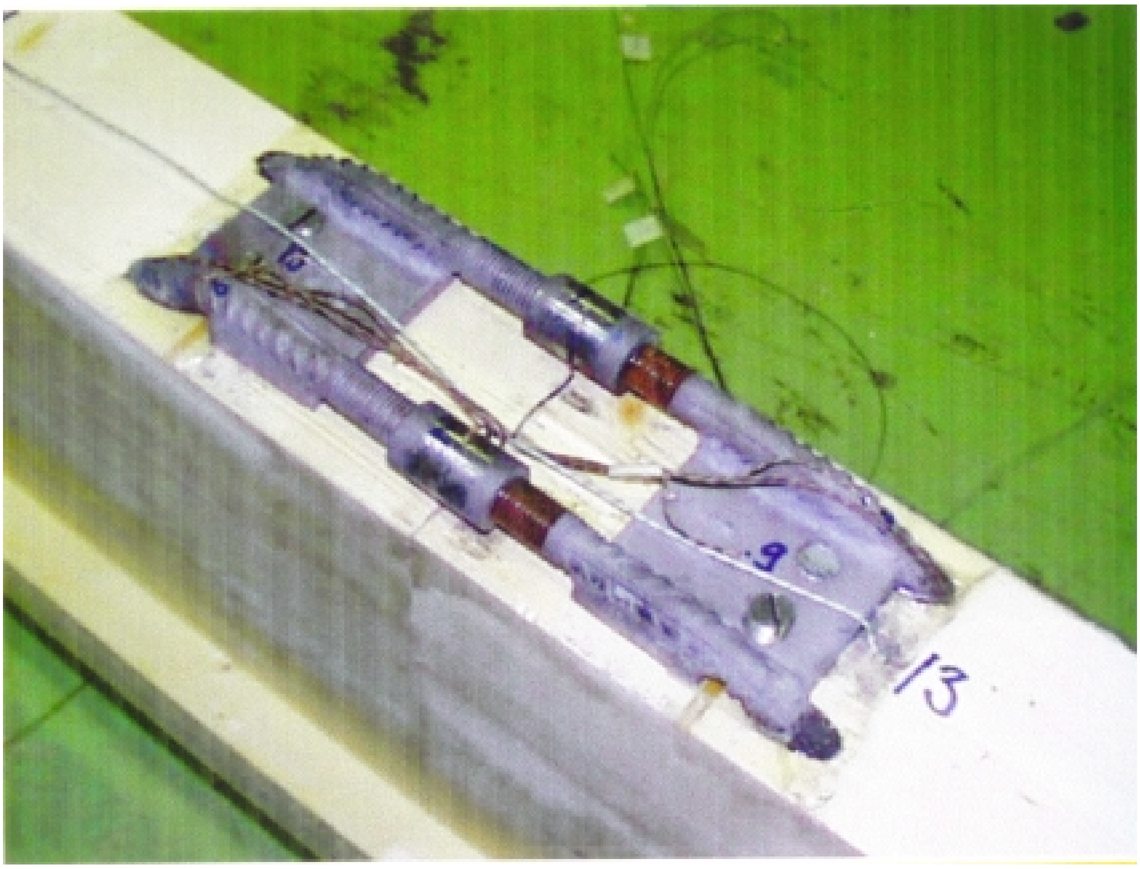


Figure 1. The connection after gluing the ribbed steel rods into the glulam beam (the beam is up side down.

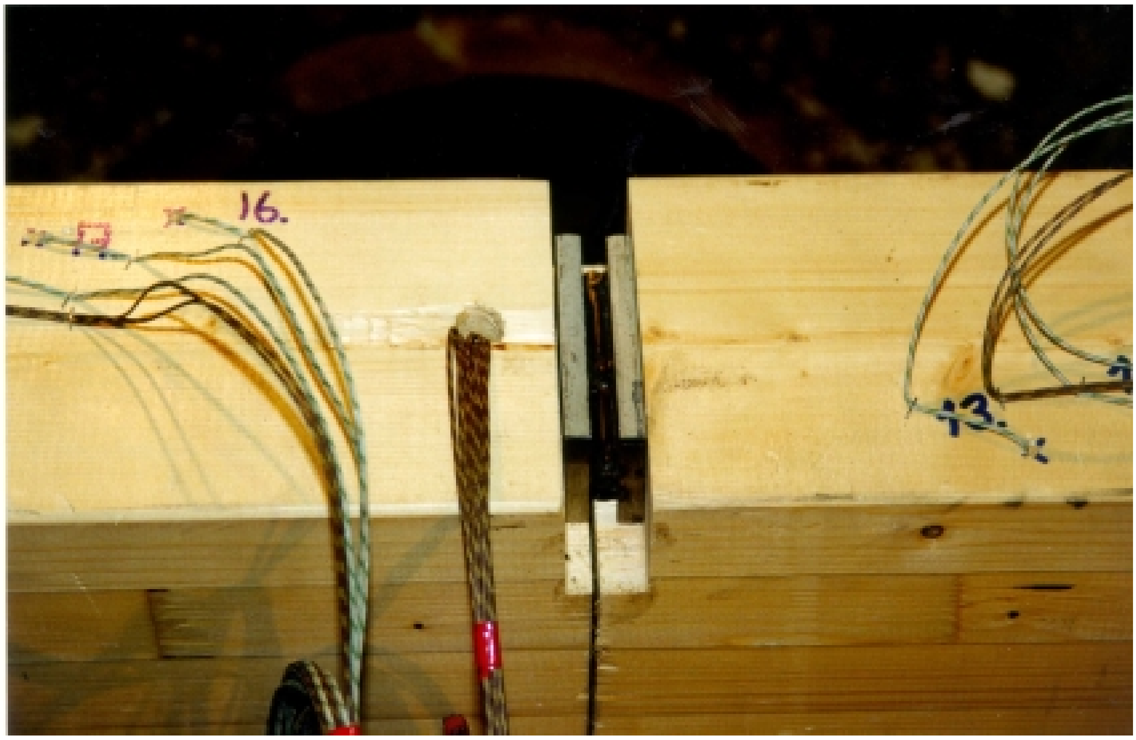


Figure 2. The hinged contact joint of the beam in the compression side.

Figure 3. Test arrangements in the furnace.

Figure 4. Beam 1 prior the test (8.12.1998).

Figure 5. Beam 2 prior the test (16.12.1998).

Figure 6. Beam 3 prior the test (18.12.1998).

Figure 7. Test time 3 min 36 s Beam 2.

Figure 8. Test time 14 min 58 s Beam 2.

Figure 9. Test time 26 min 46 s Beam 2.

Figure 10. Test time 44 min 20 s Beam 2.

Figure 11. Test time 55 min Beam 2.

Figure 12. Beam 2 after the test.

Figure 13. Beam 1 behind and beam 2 in front.

Figure 14. The connection of Beam 1 after removal of the fire protection.

Figure 15. The connection of Beam 2 after removal of the fire protection and the char.

Figure 16. The steel plate of Beam 2 moved about 10 mm when the failure occured.

Figure 17. Failure of wood in Beam 2.

Figure 18. Slide of the rod in Beam 2.

Figure 19. Bare rod in Beam 2.

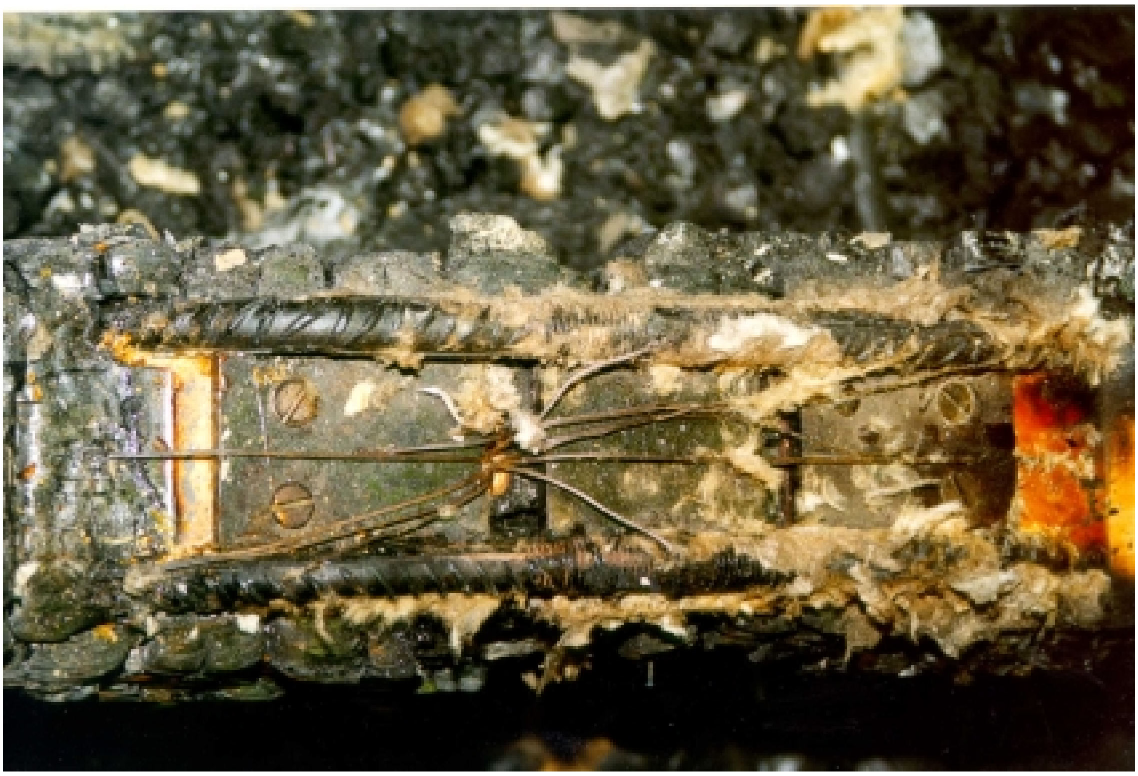


Figure 20. The connection of Beam 3 after removal of the fire protection.The steel plate moved about 10 mm when the failure occured. The type of failure was like in Beam 2.

Published by

Vuorimiehentie 5, P.O.Box 2000, FIN-02044 VTT, Finland
Phone internat. +358 9 4561
Fax +358 9 456 4374

Series title, number and report code of publication

VTT Research Notes 1970
VTT–TIED–1970

Author(s)

Oksanen, Tuuli & Kangas, Jorma

Title

Strength and fire resistance of connections based on glued-in rods

Abstract

A short summary of extensive research on joints of glulam structures based on glued-in ribbed steel rods has been reported. On the basis of research work a calculation method of structures with these connections has been developed and presented. The main concern is on ease of manufacturing and construction as well as fire safety.

This paper presents also results of fire resistance tests performed on loaded glulam beams connected together with the joints based on glued-in ribbed steel rods. The tests were carried out at VTT Building Technology, Fire Technology. The structure of the connections was the same in all tests but the thickness of the fire protection and the wood covering of the steel rods were varied in order to achieve fire resistance classes R30, R60 and R90. Rock wool (density 140 kg/m^3) covered by steel sheet was used as the fire protection on the bare steel parts of the joint. The test load corresponded 40 % of the design load at the normal temperature design. The furnace temperature was controlled according to the standard ISO 834.

The deflection of the beams began to increase remarkably about ten minutes before the failure of the joint. Fire resistance classes of R30, R60 and R90 were achieved with 20 mm, 40 mm and 60 mm thick rock wool fire protection and wood coverings of the steel rods respectively.

Keywords

steel structures, joints, glulam structures, glueing, ribbed steel rods, strength, dimensioning, fire resistance, fire safety, glulam beams, wooden structures

Activity unit

VTT Building Technology, Building Physics, Building Services and Fire Technology, Kivimiehentie 4, P.O.Box 1803, FIN–02044 VTT, Finland

ISBN			Project number
951–38–5753–0 (soft back edition) 951–38–5754–9 (URL: http://www.inf.vtt.fi/pdf/)			R8SU00113
Date December 1999	Language English	Pages 28 p. + app. 31 p.	Price B
Name of project		Commissioned by	
Series title and ISSN VTT Tiedotteita – Meddelanden – Research Notes 1235–0605 (soft back edition) 1455–0865 (URL: http://www.inf.vtt.fi/pdf/)		Sold by VTT Information Service P.O.Box 2000, FIN-02044 VTT, Finland Phone internat. +358 9 456 4404 Fax +358 9 456 4374	

VTT TIEDOTTEITA – MEDDELANDEN – RESEARCH NOTES

VTT RAKENNUSTEKNIIKKA – VTT BYGGNADSTEKNIK – VTT BUILDING TECHNOLOGY

1970 Oksanen, Tuuli & Kangas, Jorma. Strength and fire resistance of connections based on glued-in rods. 1999. 28 p. + app. 31 p.

1979 Nieminen, Jyri & Kouhia, Ilpo. Hyvin eristetyn loivan katon toimivuus ja vaatimukset. 1999. 38 s. + liitt. 3 s.

1981 Hakkarainen, Tuula (ed.) Smoke gas analysis by Fourier transform infrared spectroscopy. The SAFIR project. 1999. 81 p.

1988 Lahdenperä, Pertti. Ajatuksia ST-urakasta. Suomalaisen suunnittelu ja toteutus -menettelyn kehittäminen amerikkalaisten oppien pohjalta. 1999. 40 s. + liitt. 2 s.

1990 Keski-Rahkonen, Olavi & Björkman, Jouni. Palotilastoja Suomesta ja ulkomailta toiminnallisten palosäädösten perusteiksi. 1999. 56 s.

1991 Kokko, Erkki, Ojanen, Tuomo, Salonvaara, Mikael, Hukka, Antti & Viitanen, Hannu. Puurakenteiden kosteustekninen toiminta. 1999. 160 s.

1994 Leppänen, Pekka, Pulakka, Sakari, Saari, Mikko & Viitanen, Hannu. Life-cycle-cost optimised wooden multi-storey apartment building. Nordic Wood, Phase 2, Project P-2. Final report. 1999. 73 p.

1997 Jokinen, Petri, Lahtinen, Reima & Lehmus, Eila. Teräsrakenteiden suojaus kaariruiskutetulla sinkkipinnoitteella. 1999. 50 s. + liitt. 14 s.

2001 Haakana, Maarit & Soitinaho, Ulla. Kiinteistönhoitohenkilöstön motivointi energiansäästöön. Kokemukset koulukohteista. 1999. 43 s. + liitt. 14 s.

2002 Andstén, Tauno, Juutilainen, Hemmo, Vaari, Jukka & Weckman, Henry. Test method for actuating and safety devices of portable fire extinguishers. Nordtest Project No. 1435–99. 1999. 40 p. + app. 25 p.

2003 Vainio, Terttu, Riihimäki, Markku & Mäkelä, Pekka. Rakennuskustannusindeksi 2000. 1999. 70 s. + liitt. 2 s.

2005 Baroudi, Djebar, Kokkala, Matti & Weckman, Henry. Savuilmaisimien toiminta-aikojen laskentaohjelma PALDET 2.1S. 1999. 37 s. + liitt. 1 s.

2013 Tillander, Kati & Keski-Rahkonen, Olavi. Palokunnan saatavuuden merkitys rakennuksen paloriskitarkastelussa. 2000. 213 s. + liitt. 55 s.

2025 Riihimäki, Markku & Lehtinen, Erkki. Talopaketit asuinrakentamisessa. Valmisosien yleisyys toimituksissa. 2000. 44 p.

2027 Hietaniemi, Jukka, Hostikka, Simo, Lindberg, Liisa & Kokkala, Matti. Vyöhykemalliohjelman CFAST-kelpoisuuden arviointi. 2000. 51 s. + liitt. 14 s.

2028 Kokkala, Matti. Rakennusten paloturvallisuussuunnittelu. Toiminnallinen lähestymistapa. 2000. 63 s. + liitt. 15 s.

2029 Helenius, Antti. Shear strength of clinched connections in light gauge steel. 2000. 40 p. + app. 13 p.

2030 Rantamäki, Jouko, Kääriäinen, Hannu, Tulla, Kauko, Viitanen, Hannu, Kalliokoski, Pentti, Keskikuru, Timo, Kokotti Helmi & Pasanen, Anna-Liisa. Rakennusten ja rakennusmateriaalien homeet. 2000. 40 s. + liitt. 6 s.

2047 Leivo, Markku. Betonin pakkasenkestävyyden varmistaminen. Osa 2. Laadunvalvonta ja -varmistus. 2000. 13 s. + liitt. 25 s.

2048 Kuosa, Hannele. Älykkäät betonit ja betonirakenteet. 2000. 35 s. + liitt. 9 s.

2049 Lehtinen, Jari. Rakennushankkeen turvallisuusjohtaminen. Korkea rakennuskohde. 2000. 77 s. + liitt. 16 s.

2051 Karhu, Vesa & Loikkanen, Kaisu. Japanese and Chinese construction and facilities management software markets. Preliminary study. 2000. 58 p. + app. 4 p.

2053 Luoma, Marianna & Pasanen, Pertti. Ilmanvaihtojärjestelmien puhdistus 15 toimistorakennuksessa. Puhdistuksen ja säädön vaikutus toimistotilojen kanavien puhtauteen, ilmanvaihtuvuuteen, tuloilman laatuun ja työntekijöiden työoloihin. 2000. 43 s. + liitt. 6 s.

2054 Riihimäki, Markku & Lehtinen, Erkki. Luonnonkiviteollisuuden markkinat. 2000. 57 s. + liitt. 19 s.