



# STUDY REPORT

NO. 43 (1992)

## DESIGN OF LOADBEARING LIGHT TIMBER FRAMED WALLS FOR FIRE RESISTANCE: PART 2

**P.C.R. Collier**

The work reported here was jointly funded by the Building Research Levy, and the Foundation for Research, Science and Technology from the Public Good Science Fund

## **PREFACE**

This report covers the second part of a research programme undertaken by the Building Research Association of New Zealand (BRANZ) to develop a design method for loadbearing light timber framed walls for fire resistance.

The first part of this programme resulted in BRANZ Study Report SR 36, entitled "Design of light timber framed walls for fire resistance" (Collier, 1991a), and BRANZ Technical Recommendation TR 9, "Design of light timber framed walls and floors for fire resistance" (Collier, 1991b).

The second part of the programme, involved a series of loaded fire tests - two pilot sized and two full-sized. The primary objective was to establish if there is a relationship between results generated using the two sizes of test specimen. If a relationship did exist, pilot scale tests could be used to model the likely performance of a full-sized fire resistance test. The new data generated along with data from the first part of the programme were analysed. This has resulted in an improved and more versatile method of designing and predicting the performance of loadbearing light timber framed walls.

## **ACKNOWLEDGEMENTS**

The author thanks his BRANZ colleagues for their work. Also, Kevin Golding and Hans Gerlich (Winstone Wallboards) gave valuable advice on how the design methods could be applied.

## **INTENDED AUDIENCE**

This report will interest engineers and architects involved in the design of fire resisting loadbearing structures using light timber framing, and manufacturers of products used in such constructions.

# DESIGN OF LOADBEARING LIGHT TIMBER FRAMED WALLS FOR FIRE RESISTANCE: Part 2

BRANZ Study Report SR 43

P.C.R. Collier

## REFERENCE

Collier, P.C.R. 1992. Design of Loadbearing Light Timber Framed Walls for Fire Resistance: Part 2. Building Research Association of New Zealand Study Report SR 43. Judgeford, New Zealand.

## KEYWORDS

From Construction Industry Thesaurus - BRANZ Edition:

Charring; Design; Eccentricity; Failure; Fire Endurance; Fire Resistance; Fire Testing; Failure; Gypsum Plasterboard; Insulation; Linings; Loading; Model; Structural; Studs; Test; Timber.

## ABSTRACT

Fire performance of loadbearing light timber framed walls can be predicted within certain limitations, provided some base line information on the performance of similar walls is available.

Four loadbearing tests were conducted to determine if there is a relationship between results generated using small scale pilot tests and full-sized fire resistance tests. Results from previous testing programmes were analysed further to determine the relationship between time to structural failure and the applied load level.

This report proposes a design procedure whereby results from pilot fire testing can be used to establish a starting point for design of a new wall system, and hence to design a prototype for a full-sized fire resistance test.

This report also describes a new procedure whereby a previously tested wall may be subjected to a greater applied load, reducing the structural resistance time to a figure closer to but still greater than the minimum fire resistance requirement. This will enable more efficient use of materials in meeting fire resistance requirements.

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## 1. INTRODUCTION

This research programme continues work undertaken in Collier (1991a), where a method for designing fire resisting, loadbearing, light timber framed walls was developed. The method was developed from six loadbearing tests, in which the remaining stud section at failure was compared with the applied load to determine if a relationship existed between these parameters. Remaining stud sections were measured to determine the second moment of area; from this, the notional depth of char which would have resulted in the same second moment of area was found. This notional char depth or charfactor was then used as a measure of the fire damage which would cause structural failure, thereby providing the relationship between a prototype wall design and all wall designs extrapolated from it. The new wall designs were required to use the same lining configuration, but different loads and/or heights were catered for by variations in stud size. This method then required a single full-sized loadbearing fire resistance test of a prototype wall. Using the results of this test, other feasible wall designs could be extrapolated (Collier, 1991b).

The experimental phase of this programme aimed to demonstrate that results from a loaded pilot scale test could be used to establish the performance expected in a full-sized fire test. A pilot sized specimen frame was modified so that a load could be applied; and two tests were conducted. The results from these tests were then compared with those from two full-sized tests. To enable extrapolation between results from pilot and full-sized tests, the load applied was scaled according to the height of the wall. This was done by equivalence of charfactors at structural collapse for 2.2 (pilot) and 3 m (full-sized) high walls. All four test walls used the same lining configuration; similar times for structural and insulation failure of each wall were found.

To further refine the extrapolation method (which was limited to the structural fire resistance time established by the test) data from the earlier phase of the research programme were analysed further. This analysis established a relationship between charfactor and time, whereby the charfactor and hence fire resistance time could be reduced to the minimum actually required for the rating period. This minimum charfactor is then used to establish the structural load level, height and stud size required to achieve the minimum structural performance required of the extrapolated wall design. This will enable more efficient use of materials in meeting fire resistance requirements.

## 2. EXPERIMENTAL

### Fire Resistance Tests

The experimental programme which this report covers involved four fire resistance tests. Two loadbearing fire resistance tests on light timber framed walls (2.2 and 3 m high) were conducted in each of the BRANZ pilot and full-sized furnaces. A pilot furnace specimen frame was modified, as shown in Figure 1, to enable application of structural load. Two hydraulic jacks and load cells were fitted to the frame, so that each of the two studs was loaded independently. Figure 2 shows a full-sized fire resistance test specimen under construction.

All tests were conducted according to AS 1530.4 (SA, 1990). Each specimen was loaded at least 1 hour before the test started to complete the required conditioning of the wall. Tests were stopped when the specimens were judged no longer able to support the applied load.

## Similarity of Loading

To ensure that specimens in both pilot and full-sized tests were subjected to equivalent loads, the method detailed in Collier (1991b) was used. There was already a charfactor table for a 3 m wall (TR 9 table 1.1); a similar table for a 2.2 m wall was therefore required. Rather than use a pair of tables where interpolation would be required for intermediate values, results from both pilot and full sized tests are plotted in Figure 3. This graph enables a load on a 3 m specimen to be converted to an equivalent load on a 2.2 m specimen and vice versa. The method used to generate the charfactors for 2.2 m high walls was similar to that used in Appendix B in Collier (1991a). It is reprinted in this report as Appendix 1; lines 10 to 280 of the programme being used, and the wall height is entered as 2.2 m. For two similar walls, which have the same linings, but different heights and studs - equivalent structural loads which will result in structural failure at the same time under fire test conditions can be determined on the basis of equivalency of charfactors at failure (which will be the same for both walls). A charfactor of 14 was selected as the failure point for the four tests conducted, loads expected to result in failure at the same time under fire test conditions were determined for nominal stud sizes of 75 x 50 mm and 100 x 50 mm. It was expected that the time to structural failure would be greater than 30 minutes, yet not exceed the time to insulation failure.

## Construction of Specimens

Test specimens were constructed using kiln-dried Radiata pine timber of nominal sizes 75 x 50 mm and 100 x 50 mm for studs, dwangs, and top and bottom plates. Spacing between members was 600 mm and 800 mm between centres for studs and dwangs, respectively. The timber was selected visually for each specimen, discarding lengths with excessive curvature or knots. The dry density and moisture content of the timber ranged from 390 to 500 kg/m<sup>3</sup> and 13 to 14%, respectively. The values of other physical properties were assumed to be Modulus of Elasticity 8 GPa and Modulus of Rupture 24 MPa. Specimens were lined each side with 9.5 mm fire-rated plasterboard lining, fixed and stopped in accordance with the manufacturer's instructions.

Of the four specimens constructed, two were pilot-sized (2.2 m high) and two full-size (3 m high), one of each size used timber of nominal size 75 x 50 mm and the other used timber of nominal size 100 x 50 mm.

## Test Instrumentation

The specimen temperatures were monitored with disc thermocouples in the following locations (see also Figure 4).

- 1) On the cavity (cooler) side of the exposed face lining.
- 2) In the air space (cavity) between the two linings, but not in contact with the studs.
- 3) On the cavity (hotter) side on the non-exposed face lining.
- 4) On the outside (cooler) side of the non-exposed face lining.
- 5) Between the lining and stud, on the cavity (cooler) side of exposed face lining.

Additionally, twelve sheath thermocouples were mounted internally in dummy studs to monitor progression of charring over the cross-section (see Figure 5).

## **Additional Measurements**

A relative humidity sensor was used to measure the relative humidity in the cavity between linings.

The load was monitored using load cells incorporating strain gauges, which were mounted on the hydraulic jacks. Movements of a specimen in the direction of loading were monitored using dial gauges, which were used to predict impending structural collapse.

Lateral wall deflection was monitored at points indicated in Figures 6a and 6b, at 10 minute intervals.

## **3. RESULTS**

Test results for the four tests are presented in Table 1.

### **Typical Observations of Exposed Lining**

At 0 to 10 minutes, the exposed paper face of the plasterboard lining had charred to ash, and plaster stopping the joints had cracked and started to flake and drop off.

At 10 to 20 minutes, cracking of the exposed board began, and continued to progress. Cracks occurred each side of the studs. They were up to a maximum of 5 mm wide and extended over the entire frame of vision (approximately 500 mm). Cracking was generally in a vertical direction.

At 30 to 40 minutes, the cracks in the lining continued to open up to 10 to 15 mm, allowing flames to issue from inside the cavity into the furnace. However, joints in the lining over the studs remained intact with no sign of tearing.

When each test finished, the furnace was opened and the burning wall extinguished with water. In all four tests the exposed lining was still attached to the studs in spite of large cracks, but was easily removed with the jets of water.

### **Typical Observations of Non-exposed Lining**

At 29 minutes onwards, a crackling sound could be heard from inside the wall cavity.

At 37 to 38 minutes, scorching of the paper on the outer surface of the lining was increasing, followed by a rapid temperature rise and cracking.

### **Temperatures**

The temperatures recorded within and on the wall cavity at the thermocouple locations (Figure 4) are shown in Figures 7a, b, c and d, for each of the four tests, respectively.

### **Deflections**

Lateral wall deflections measured for the four test specimens, at locations shown in Figure 6a and b, are recorded in Figures 8a, b, c and d, for each of the four tests, respectively.

## 4. DISCUSSION

### Pilot vs Full-Sized Tests

Results of the four tests are compared in Table 1. Time to structural failure ranged from 39 to 44 minutes. Time for insulation failure ranged from 38 to 44 minutes. The variation in failure times for different specimens can be accounted for by the greater severity in the first 15 minutes of test FP 1583A. This is due to the furnace being driven above the time-temperature curve for this test and appears to be the most likely cause of the earlier than expected failure of this specimen.

It was expected that for the remaining specimens, based on experience at BRANZ and the advice of test standards (AS 1530.4)(BS 476.20: 1987), that there would be a trend towards a marginally longer time to failure for pilot tests. This was the case for FP 1583B and FR 1582B where the margin observed between a pilot and full-sized test was approximately 2-3 minutes. The reversal of this trend for FP 1583A and FR 1582A is attributed to the greater severity in the early stages of FP 1583A.

One of the considerations in determining the applied loads in each test was that times to structural and insulation failure would be similar for specimens with equivalent charfactors. This was observed to be true. The hypothesis was that if the loads applied to each test specimen were based on the same charfactor, then failure times would be very close between pilot and full-sized tests. A close relationship between results from the pilot and full-sized tests is evident.

Thus, a pilot test, which is less expensive to conduct, can yield valuable data on the likely fire performance of a new wall system. Such data can be refined in further pilot testing. Then a full-sized fire resistance test can be conducted for confirmation of performance to meet the requirements of AS 1530.4 and BS 476.20. The following is an analysis of the other parameters which influence the performance of the specimen.

### Charfactors

In Collier (1991a) the term "charfactor" was introduced. Simply stated, charfactor is a means of measuring the damage by fire to a wall. It is based on a notional depth of charring in the studs, and is used as the basis for comparison between a tested prototype wall and an extrapolated design.

Each of the four tests in this study were instrumented using dummy studs (see Figure 5). Data obtained were used to determine char progression in the dummy studs in the wall cavity. Data at 5 minute intervals (from 25 minutes exposure to failure) were analysed to determine the charfactors, plotted in Figure 9a. Points plotted fall on a narrow band, also, results for pilot tests lag behind (i.e., fall to the right of) the full-sized tests by about 2-4 minutes. The charfactors at failure were about 14 for each of the four tests as expected, because the applied load was based on a structural failure at a charfactor of 14.

Using data plotted for the tested lining-stud combination, plus the time that the back of the exposed lining exceeded a temperature of 300°C (temperature that stud charring commences), - 14 minutes for test FP 1583A - a generalised "charfactor line" can be drawn between the time that studs may be expected to commence charring (Figures 7a-d where t/c 1 exceeds 300°C) and the charfactor (char depth) at failure (see Figure 9a).

It was shown in earlier research (Collier, 1991a) that a plot of charfactor against time has an increasing gradient. Therefore if a straight line is drawn from the point representing where charring of the studs is expected to begin to the point representing charfactor at failure, the actual charfactors for the time interval in between fall below this straight line. Thus, a degree of conservatism in the estimation of intermediate charfactors is inherent. This will be particularly useful for designing new walls, based on a tested specimen, which may be required for different fire resistance times or loads, as described at the end of this report.

### **Temperatures within Walls**

Internal temperatures within the walls for each test specimen are plotted in Figures 7a to 7d; thermocouples locations are shown in Figure 4. It can be seen from the temperature rise rates that pilot and full-sized tests would be expected to yield similar results. The peaks observed in Figure 7a for test FP1583A can be attributed to a deviation in furnace temperature from the standard time-temperature curve, as explained above.

Further analysis of these results was not attempted, as it was beyond the scope of this study. However, the data collected would provide valuable input for a heat flow model describing the behaviour of plasterboard lined, light timber framed walls.

### **Deflections**

Lateral wall deflections recorded in the four tests are plotted in Figures 8a to 8d. All walls deflected outwards, away from the furnace, shown as positive values in the figures.

The deflection points in the legend correspond to the points marked on Figures 6a and b. Initial deflection measurements were taken before the application of load. After the load was applied, some slight movement was noted between unloaded and loaded conditions (indicated at the origin of the graphs). Deflection measurements were taken throughout the test until it was considered the wall could collapse and it was thought unsafe to continue.

An attempt to establish a relationship between deflections at failure in a pilot test and full-sized test was not successful. Uncertainties caused by initial eccentricity of loading, timber properties and the lining stiffness produced a wide scatter of results.

### **Extension of Extrapolation Procedure**

Examination of the margins by which some of tested specimens exceeded required fire resistance rating periods, suggested the possibility of increasing stud load to make more efficient use of materials.

Using the charfactor lines drawn in Figure 9a it is possible to determine a set of reduced charfactors corresponding to a set of reduced exposure times. Reduction of the charfactor will permit an increase in the wall load and/or height, still enabling the production of wall designs which comply with minimum fire resistance requirements.

This is likely to result in more flexibility in application of fire test results, especially if results of a fire test exceed the required resistance time by a wide margin. In this instance, a reduction in charfactor could mean that a higher load can be applied without altering the required loadbearing wall fire resistance time.

Using results of tests 1, 2 and 3 in Table 2 of the previous test programme (Collier, 1991a) the above procedure can be demonstrated (see Table 2).

Using data from test 2 (structural failure at 70 minutes, charfactor of 14, temperature of non-exposed side of exposed lining exceeded 300°C after 25 minutes), it is possible to draw a charfactor line for the 14.5 mm lining (Figure 9b, charfactor line for 9.5 mm board is also shown). It can then be used to predict fire resistance times for this wall design if the wall load and height vary.

The following examples using test 2 as the prototype test illustrate this procedure. In each example, load = 8 kN/stud, charfactor = 14, resistance time = 70 min (structural).

**Example 1.** The predicted failure time if the load is increased to 10 kN/stud is calculated by;

Charfactor at failure = 10

Time to failure = 57 minutes

See steps 1a, 1b, 1c on Figure 10.

The actual time to failure in test 3 where the load was 10 kN/stud was actually 60 minutes.

**Example 2.** If the load is increased to 16 kN/stud as in test 1 then;

Charfactor at failure = 3.7

Time to failure = 37.5 minutes

See steps 2a, 2b, 2c on Figure 10.

The actual time to failure was 46 minutes.

The above method gives a conservative estimate of the likely time to failure. This is for two reasons:

1. The slope of the charfactor line increases, but has been drawn as a straight line for simplicity.
2. Technical Recommendation TR 9 (Collier, 1991b) has a design factor built into it, accounting for differences between the controlled laboratory conditions under which a prototype wall is constructed and tested, compared with the on-site conditions where an extrapolated design will be built. This design factor is based on the assumption that eccentricity of loading in the prototype test is  $\pm 5\%$  and that for an extrapolated wall this is increased to  $\pm 10\%$  to account for the variation in conditions described above.

### **Design Optimisation using Test Results**

A design can be optimised by reducing the margin by which a tested wall achieves its fire resistance rating.

**Example 3.** Test 2 above, could have its load increased if the resistance time is reduced from 70 to 60 minutes.

At 60 minutes the charfactor = 10.9

New load at this charfactor = 9.5 kN/stud

See steps 3a, 3b, 3c, 3d on Figure 11.

The wall tested in test 3 above at a load of 10 kN/stud actually failed at 60 minutes also. However, because of the design factor incorporated into the method, some reduction in the applied load occurs.

Similarly, test results from this part of the experimental programme, using the 9.5 mm plasterboard, could provide an optimised design with structural fire resistance of 30 minutes.

**Example 4.** Test FR 1582B with the 9.5 mm lining, loaded at 8 kN/stud, 3 m high with studs 100 x 50 mm, the resistance time can be reduced from 40 down to 30 minutes.

The charfactor correspondingly reduces from 14 to 8.5 for that time reduction. New load at this charfactor = 11.3 kN/stud.

See steps 4a, 4b, 4c, 4d on Figure 11.

### **Future Work**

The two parts of this study have developed and extended a method whereby results of a single loaded fire resistance test can be used to predict fire performance of a wall design for a wide range of wall loadings and heights. Also some freedom has been introduced, so that resistance times can be varied. The use of pilot sized loaded tests to predict performance characteristics of new products is also a valuable research tool.

At this stage, no further work developing methods of predicting fire wall performance is required. Subsequently, this project will extend the practical application of this method into the design of fire rated timber buildings, thus encouraging use of timber as a viable construction material in fire rated applications.

## **5. CONCLUSIONS**

- 1) A loaded pilot test gives an indication of the likely behaviour of a full-sized test. The load per stud in the pilot test can be adjusted by using the model as shown in Figure 3, where the load on a 3 m high wall is scaled for a 2.2 metre high wall. Pilot test results agreed with full-sized tests within 2 minutes. Provided care is exercised in establishing a similarity of loading and test conditions, a pilot result is suitable as a means of establishing probable performance of a wall, or as a research tool.
- 2) Optimisation of wall design based on prototype test results, which established the performance of a particular wall/lining system, can be performed. The establishment of a linear relationship between the charfactor and time shows that a reduction in the required fire resistance time is linked to a commensurate reduction in charfactor at failure. With a reduced charfactor, more

freedom is permitted with the design of the extrapolated wall, resulting in the more efficient use of materials. Similarly, using the same basic method, one can make predictions on the time to structural failure of a wall.

## **REFERENCES**

British Standards Institution. 1987. Fire tests on building materials and structures. Methods for determination of the fire resistance of elements of construction (general principles). BS 476 Part 20. London, England.

Collier, P.C.R. 1991a. Design of loadbearing light timber framed walls for fire resistance. Building Research Association of New Zealand Study Report SR 36. Judgeford, New Zealand.

Collier, P.C.R. 1991b. Design of loadbearing light timber framed walls for fire resistance. Building Research Association of New Zealand Technical Recommendation TR 9. Judgeford, New Zealand.

Standards Australia, 1990. Methods for fire tests on building materials, components and structures. Fire resistance tests of elements of building construction AS 1530 Part 4. North Sydney, Australia.

### **Further Reading, not specifically referenced in this report**

Shigley, J.E. 1972. Mechanical Engineering Design. McGraw-Hill Kogakusha, Tokyo, Japan.

Standards Association of New Zealand. 1990. Code of practice for timber design. NZS 3603, Wellington, New Zealand. pp. 136-143.

Standards Association of New Zealand. 1989. Fire properties of building materials and elements of structure. MP9. Wellington, New Zealand.

## APPENDIX A:

### The Extrapolation Method

The following is a BASIC programme listing, similar versions of which were used to analyse the test data and generate the tables and graphs which form the basis of Technical Recommendation No.9. Two worked examples are included to demonstrate how a new design can be extrapolated from a prototype test result.

A design factor is included in this procedure. This involves increasing the assumed eccentricity of loading from 5% for the prototype wall to 10% for the extrapolated wall. This takes account of the difference between the controlled conditions under which a prototype will be constructed in a test laboratory, and the on-site conditions under which the extrapolated wall will be built.

The term "charfactor", which appears in the programme listing and Technical Recommendation No.9 is equivalent to the char depth in mm as defined by Figure 1 (Collier, 1991a). It is intended to be the linkage between the prototype and extrapolated walls, by providing an arbitrary measure of the fire damage at the time of failure.

```
10 PRINT "DESIGN OF LIGHT TIMBER FRAMED WALLS FOR FIRE
RESISTANCE"
20 PRINT "Determination of charfactor"
30 'Timber properties assumed for both prototype and extrapolated walls
40 E=8E+09'Modulus of elasticity Pa
50 S(0)=2.4E+07'Max permissible stress Pa
60 EX=5'Assumed eccentricity %
70 PF=10 'Pressure in furnace Pa
80 ST=.6 'Stud spacing m
90 PRINT "Enter Test Data From Prototype Test:"
100 INPUT "Actual Stud Depth mm ";DA
110 DA=DA/1000
120 INPUT "Actual Stud Breadth mm ";BA
130 BA=BA/1000
140 INPUT "Wall Height m";L1
150 INPUT "Test Load per Stud kN";P1
160 L=L1-2*BA 'Stud height allowing for top and bottom plates
170 'Iteration to find "Charfactor" or char depth mm at failure (max
    permissible stress)
180 C(1)=0:C(2)=BA
190 IF ABS(C(1)-C(2))<=.00001 THEN 270
200 C=(C(1)+C(2))/2
210 X=EX/100*DA 'Eccentricity
220 GOSUB 2000
230 IF Y>3.1416 THEN 250
240 IF S<S(0) THEN 260
250 C(2)=C:GOTO 190
260 C(1)=C:GOTO 190
270 CF=C*1000
280 PRINT "Charfactor of test specimen =";CF
1000 PRINT
```

```

1010 PRINT "Design of Extrapolated Wall"
1020 EX=10 'Assumed eccentricity of loading for extrapolated wall.
1030 PRINT "Determine max allowable stud load"
1040 INPUT "Nominal Stud Depth mm";D
1050 INPUT "Nominal Stud Breath mm";B
1060 INPUT "Wall Height m";L2
1070 INPUT "Charfactor or char depth in mm";C
1080 C=C/1000
1090 BA=(B-5)/1000 'Approximate actual stud depth.
1100 DA=(D-10)/1000 ' Approximate actual stud breadth.
1110 L=L2-2*BA 'Stud height allowing for top and bottom plates.
1120 X=EX/100*DA 'Actual eccentricity of loading in stud.
1130 I=(BA-C)*(DA-C)^3/12 'Second moment of area of stud.
1140 'Iteration to determine max load.
1150 P(1)=0
1160 P(2)=3.1^2*E*I/L1^2/1000!-50*L1*DA*BA 'Upper limit of load.
1170 IF ABS (P(1)-P(2))<=.0001 THEN 1230
1180 P1=(P(1)+P(2))/2
1190 GOSUB 2000
1200 IF S<S(0) THEN 1220
1210 P(2)=P1:GOTO 1170
1220 P(1)=P1:GOTO 1170
1230 PRINT "Maximum Allowable Stud Load =";P1;"kN"
1240 PRINT "Try another stud y/n ? "
1250 A$=INKEY$
1260 IF A$='y'OR A$='Y' THEN 1030
1270 IF A$='n'OR A$='N' THEN END
1280 GOTO 1250
2000 'Subroutine
2010 P=(P1+50*L*DA*BA)*1000'Total load on wall including approx self
      weight
2020 M=PF*L/2*ST*L^2/8 'Moment generated by pressure.
2030 I=(BA-C)*(DA-C)^3/12 'Second moment of area.
2040 A=SQR(P/(E*I)) 'Alpha as in secant formula.
2050 R=.289*(DA-C) ' Radius of gyration.
2060 S=P/((BA-C)*(DA-C))*(1+(C/2+X)*(DA-C)/2/R^2*1/COS((A*L)/2))+M*
      (DA-C)/2/I 'Secant formula
2070 Y=A*L
2080 RETURN

```

### Example 1

#### DESIGN OF LIGHT TIMBER FRAMED WALLS FOR FIRE RESISTANCE

Determination of charfactor

Enter Test Data From Prototype Test:

Actual Stud Depth mm ? 90

Actual Stud Breadth mm ? 45

Wall Height m? 3

Test Load per Stud kN? 8

Charfactor of test specimen = 13.84827

Design of Extrapolated Wall

Determine max allowable stud load

Nominal Stud Depth mm? 150

Nominal Stud Breadth mm? 50

Wall Height m? 4

Charfactor or char depth in mm? 14

Maximum Allowable Stud Load = 17.48686 kN

### Example 2

#### DESIGN OF LIGHT TIMBER FRAMED WALLS FOR FIRE RESISTANCE

Determination of charfactor

Enter Test Data From Prototype Test:

Actual Stud Depth mm ? 150

Actual Stud Breadth mm ? 50

Wall Height m? 4

Test Load per Stud kN? 16

Charfactor of test specimen = 22.69898

Design of Extrapolated Wall

Determine max allowable stud load

Nominal Stud Depth mm? 150

Nominal Stud Breadth mm? 75

Wall Height m? 5

Charfactor or char depth in mm? 23

Maximum Allowable Stud Load = 13.87126 kN

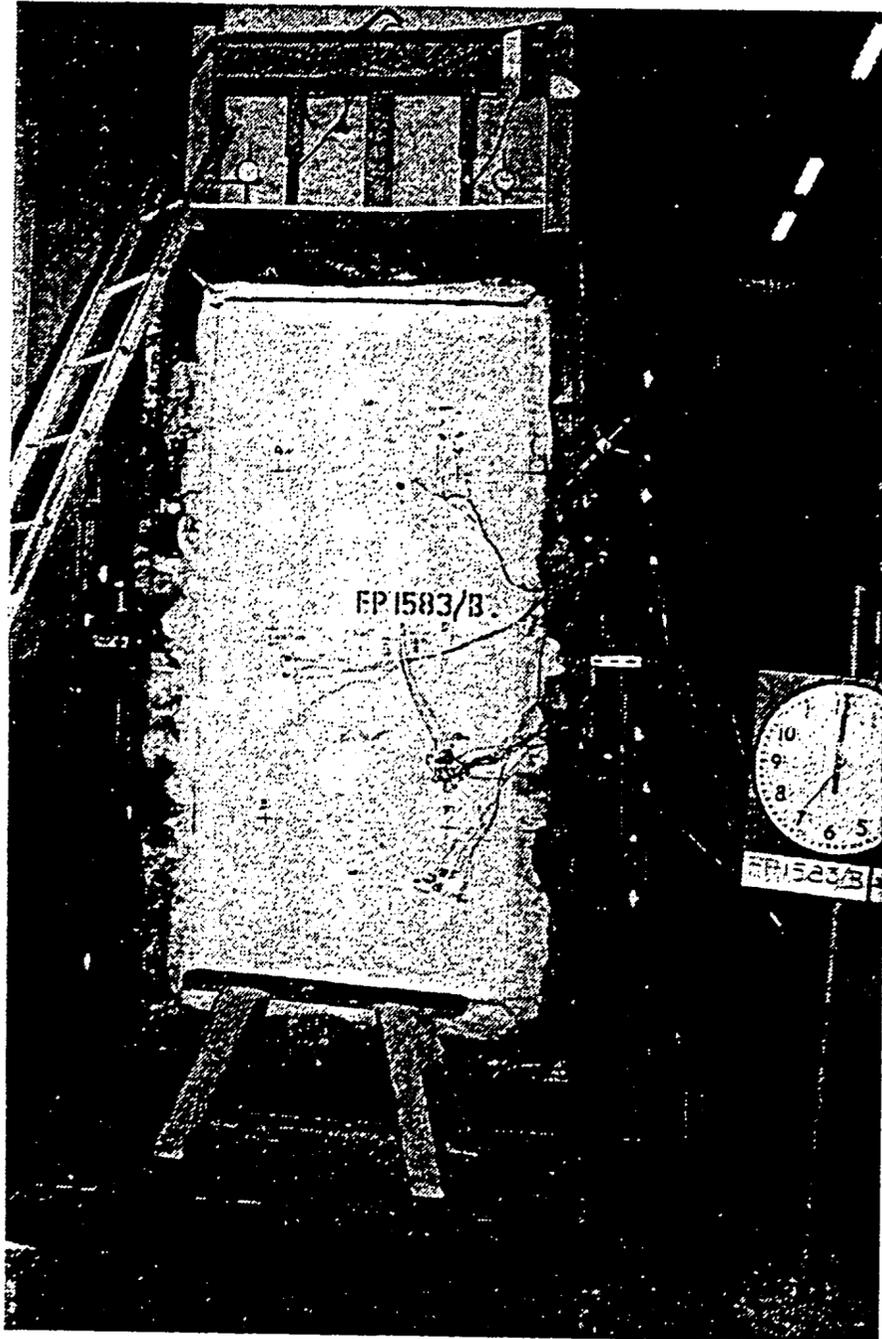


Figure 1 Loadbearing pilot test.



Figure 2 Loadbearing full-size test, specimen under construction.

### Full size test versus Pilot

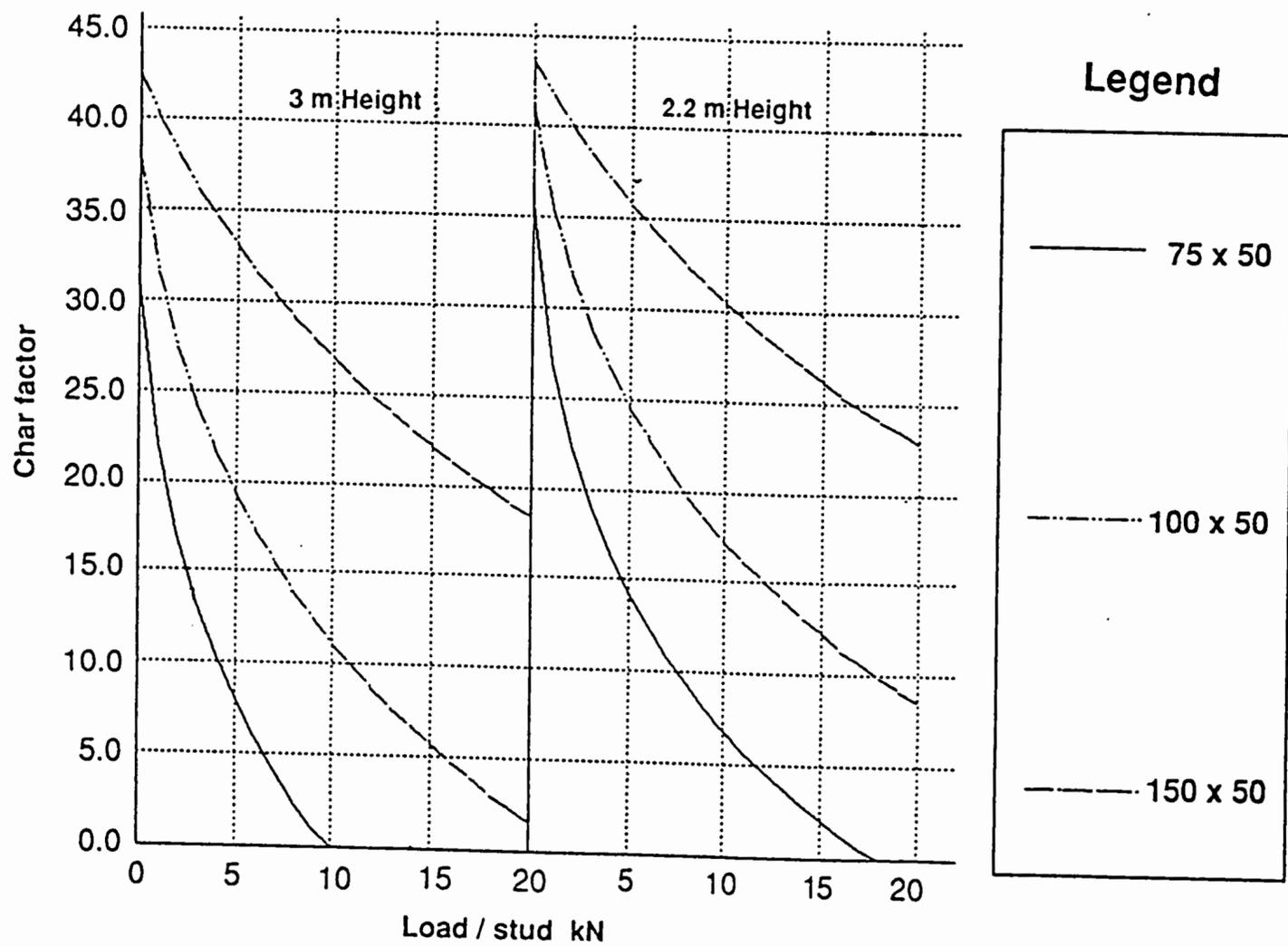


Figure 3 Similarity of loading for resistance and pilot tests.

# Fire Exposed Side

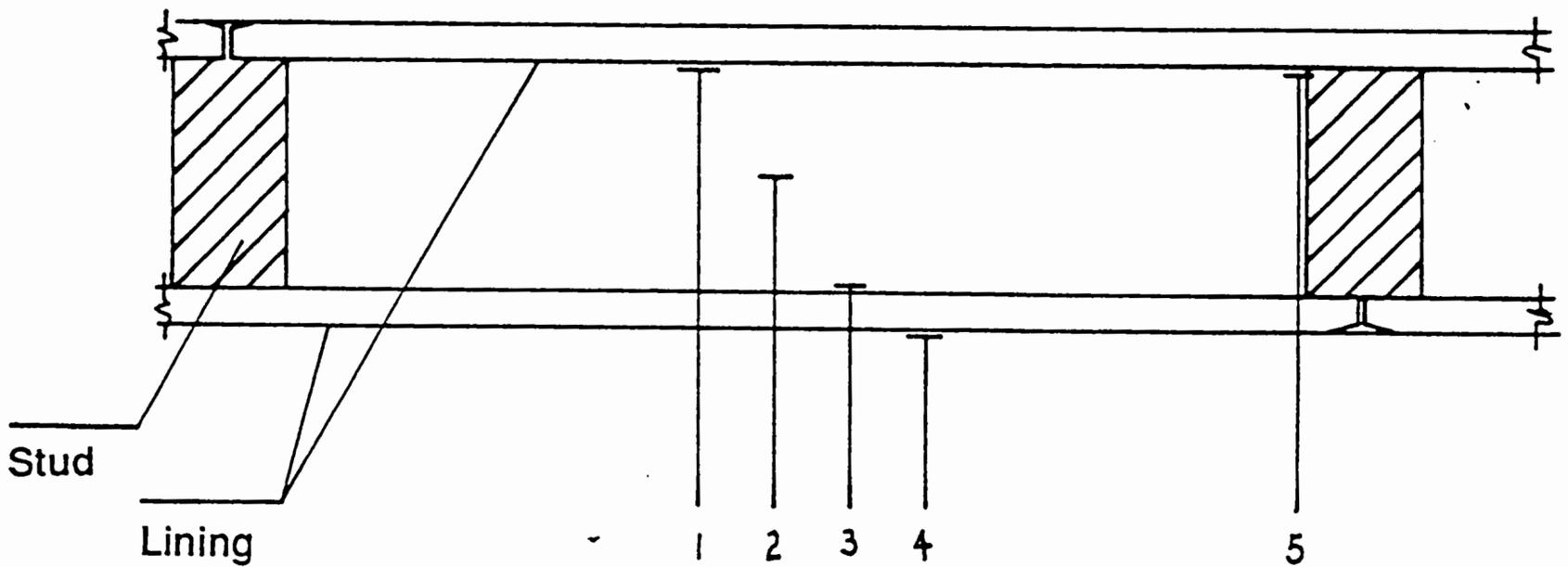


Figure 4 Thermocouples in wall cavities.

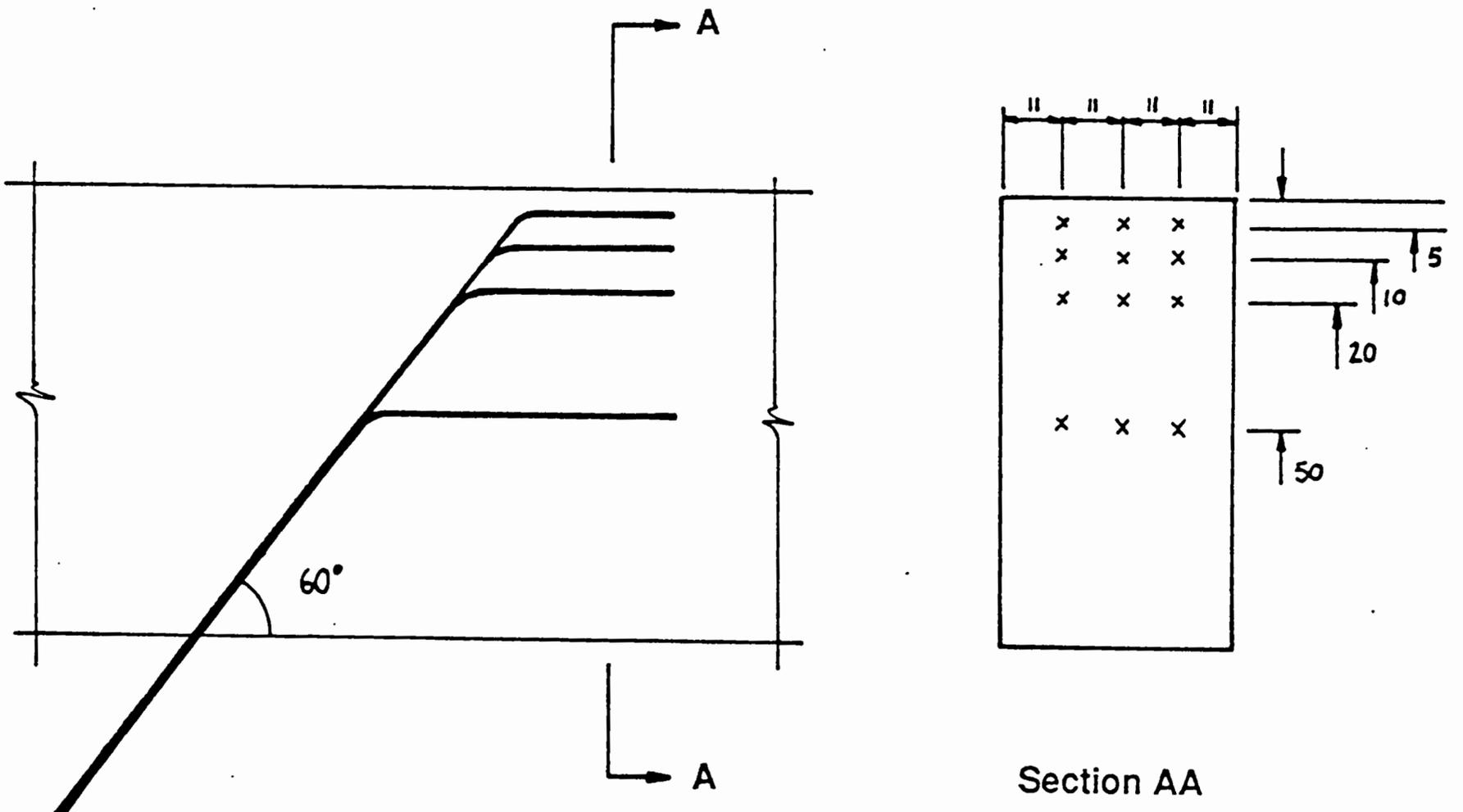
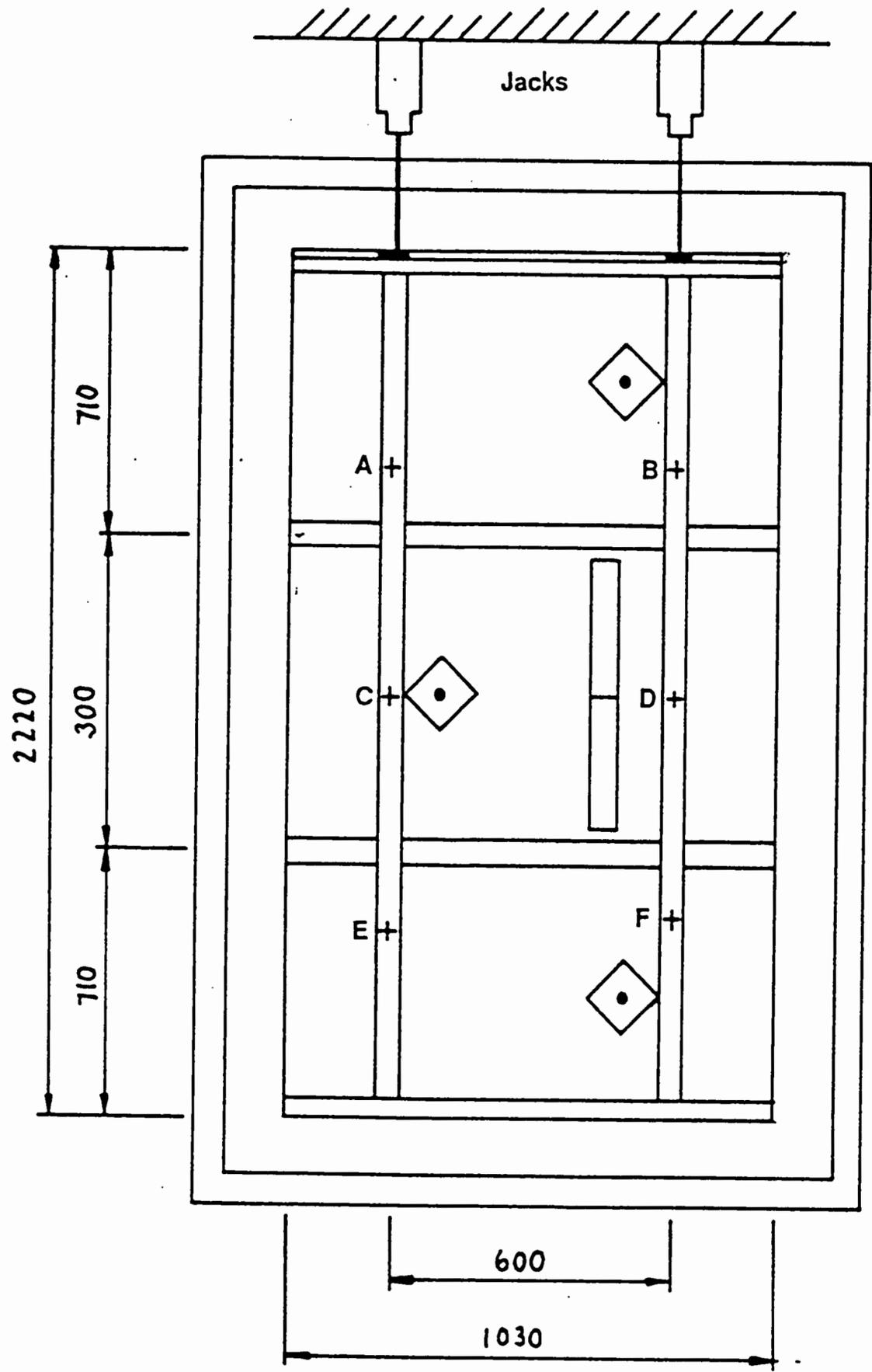


Figure 5 Thermocouples in dummy studs.

12 sheath thermocouples marked "x" were embedded into a sectioned stud (dummy) as shown at the depths indicated and the stud was then glued back together and installed in wall as shown in figure 6a and b.



Key:



Dummy Stud

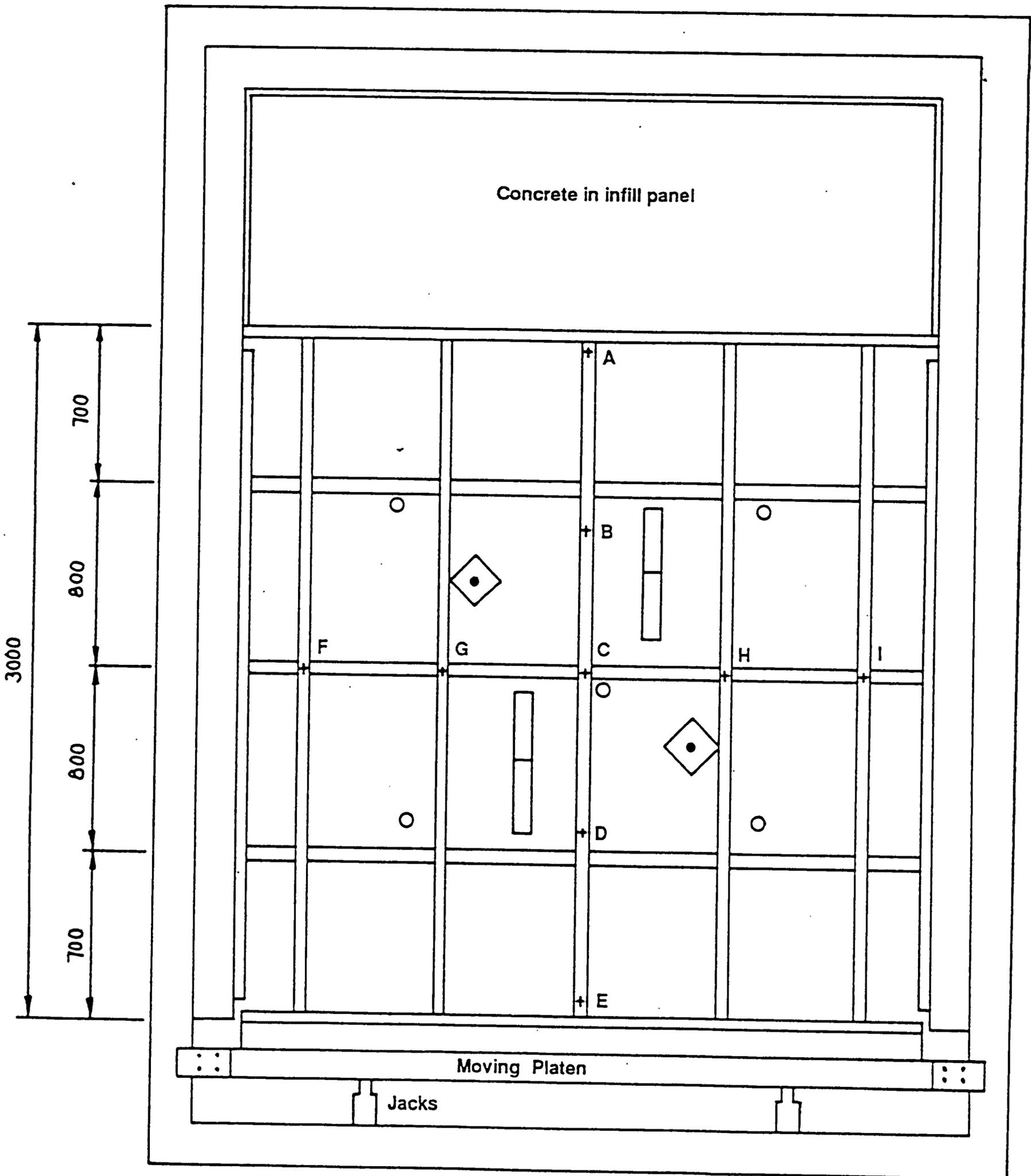


Deflection Points A to F.



Disc thermocouples, groups of 5 as per figure 4

Figure 6a Deflection points, pilot tests.



Key:



Dummy Stud

+

Deflection Points A to I.



Disc thermocouples, groups of 5 as per figure 4

○

Disc thermocouples at wall centre and centre of 4 quadrants

Figure 6b Deflection points, resistance tests.

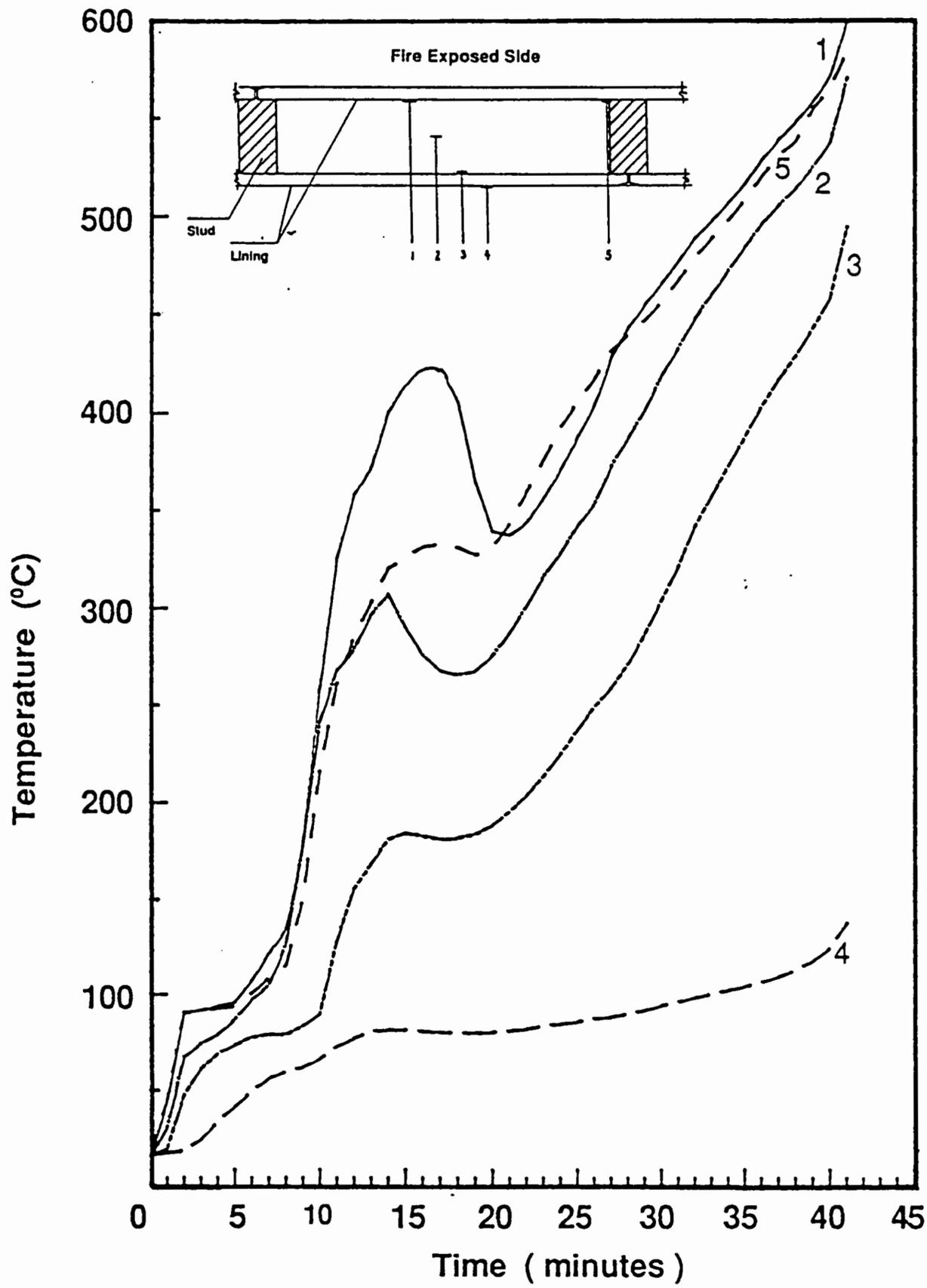


Figure 7a Temperature in wall cavity test FP1583A.

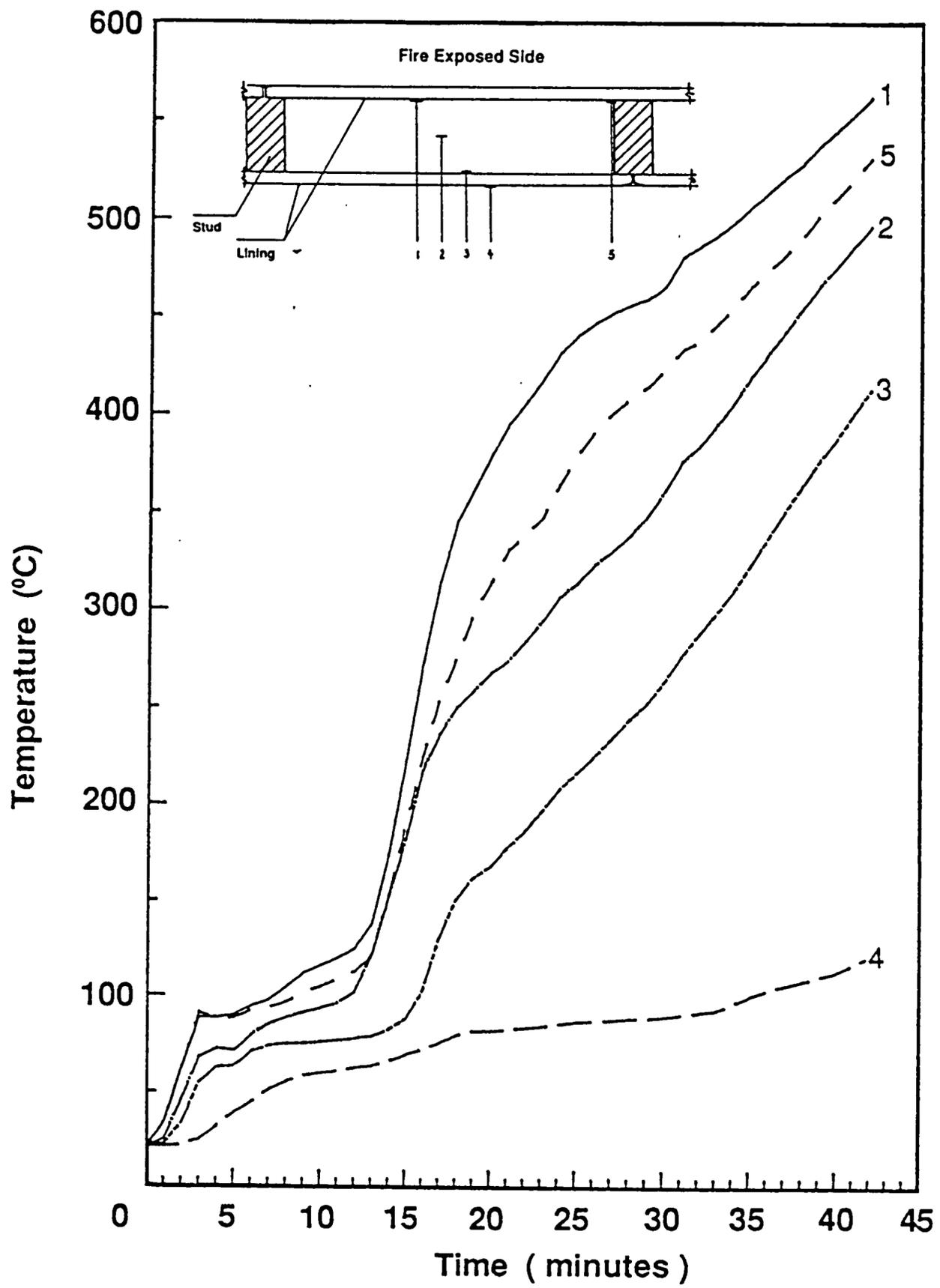


Figure 7b Temperature in wall cavity test FP1583B.

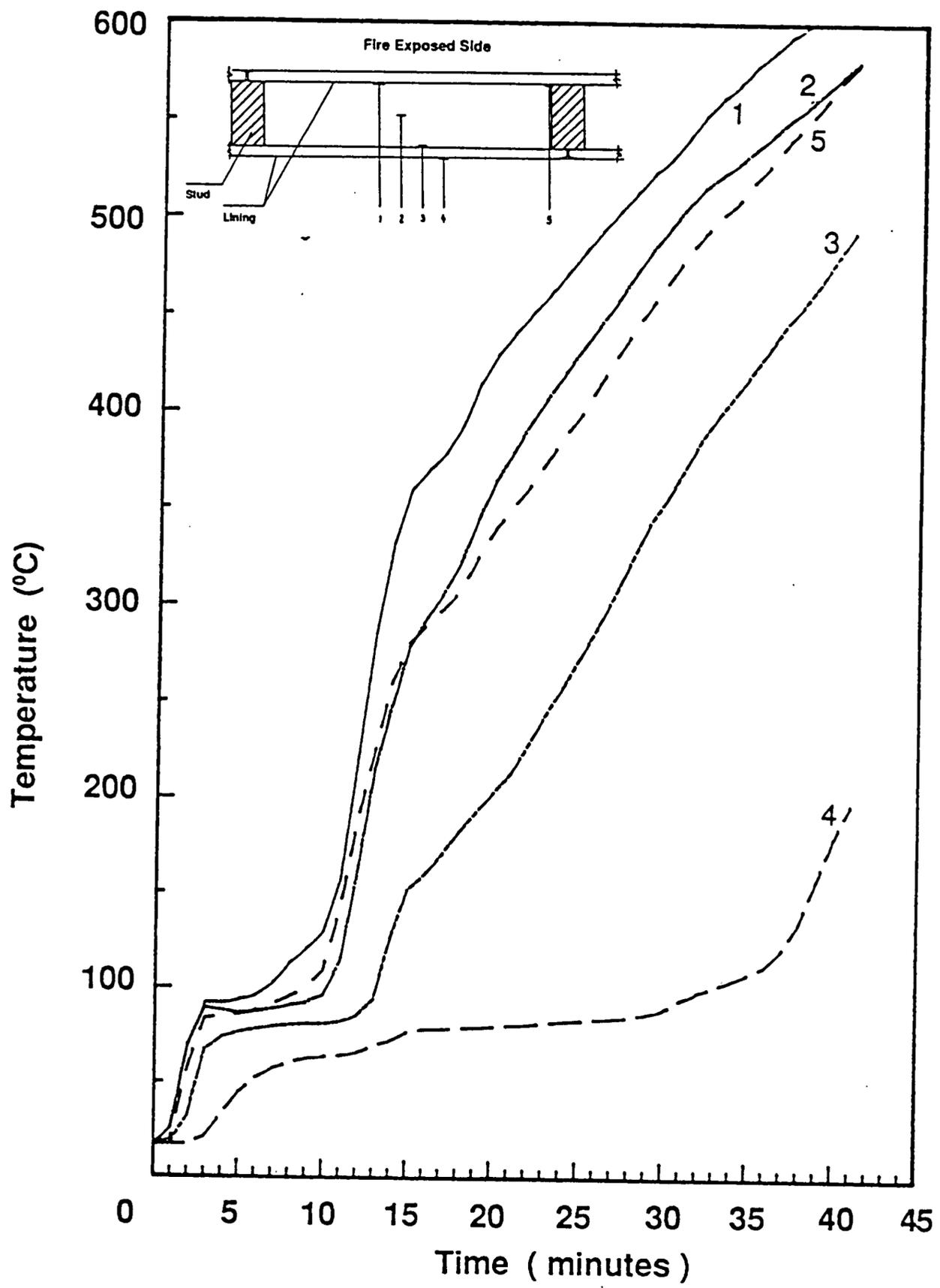


Figure 7c Temperature in wall cavity test FP1582A.

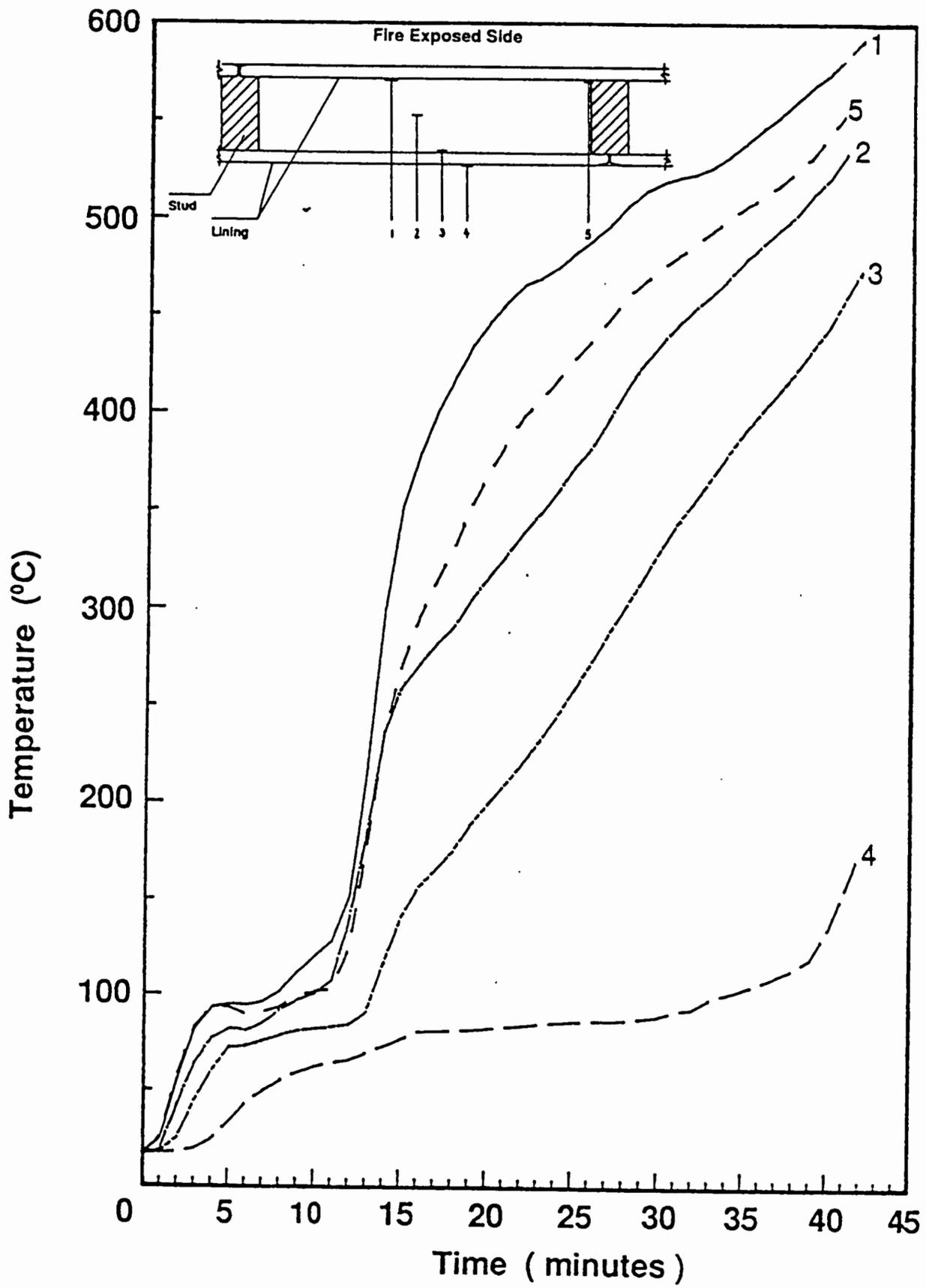


Figure 7d Temperature in wall cavity test FP1582B.

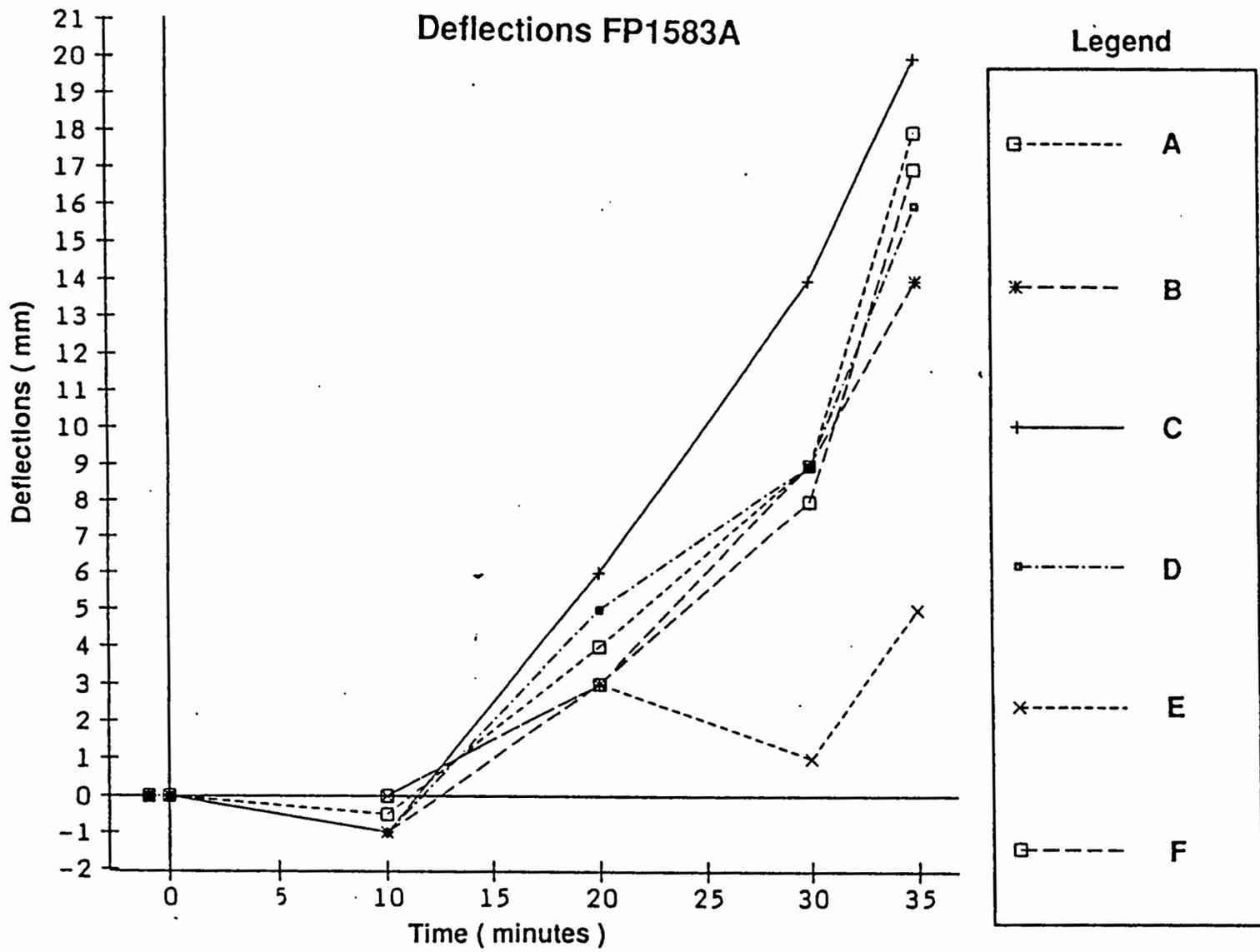


Figure 8a Deflections test Fp 1583A.

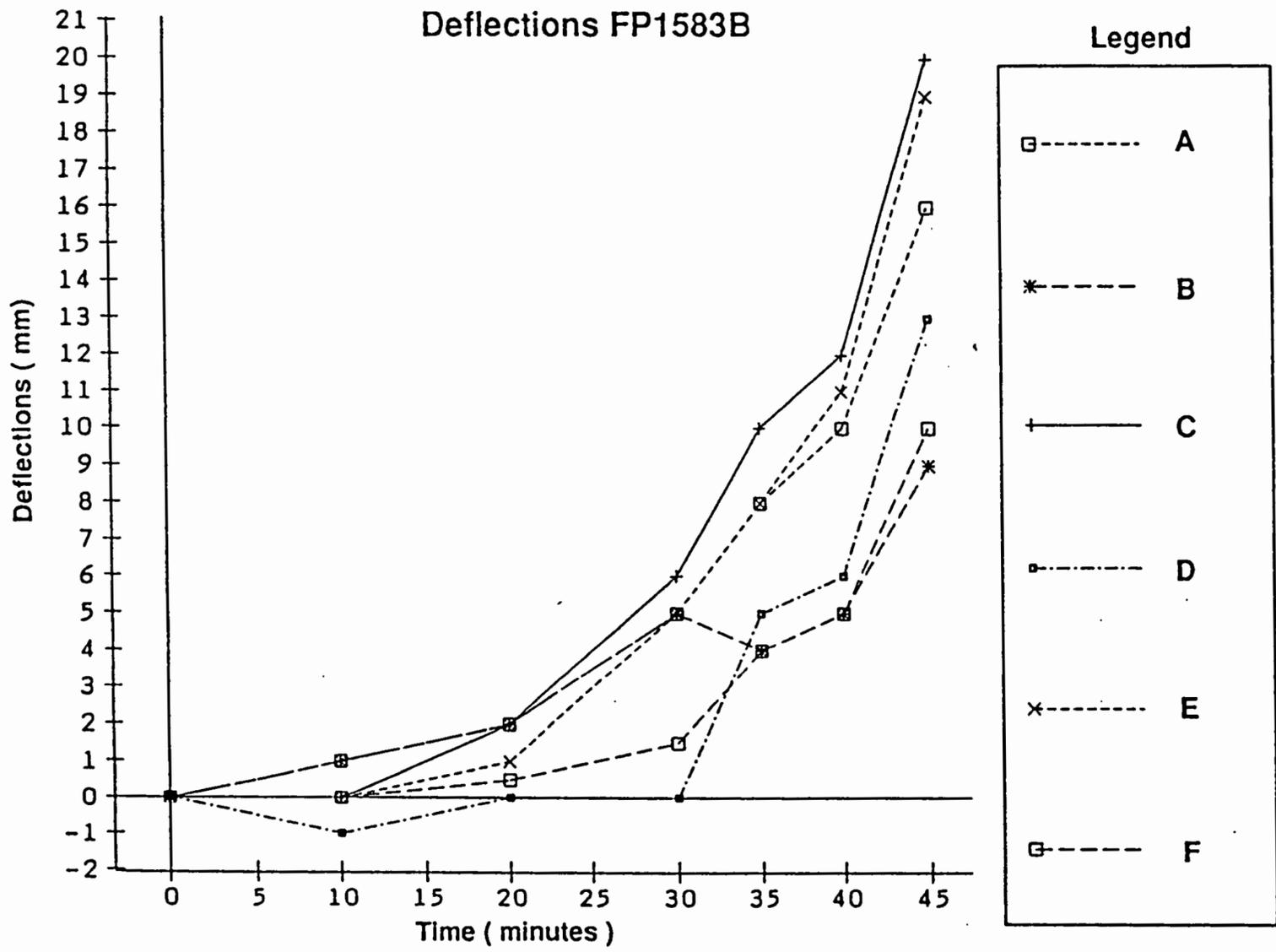


Figure 8b Deflections test Fp 1583B.

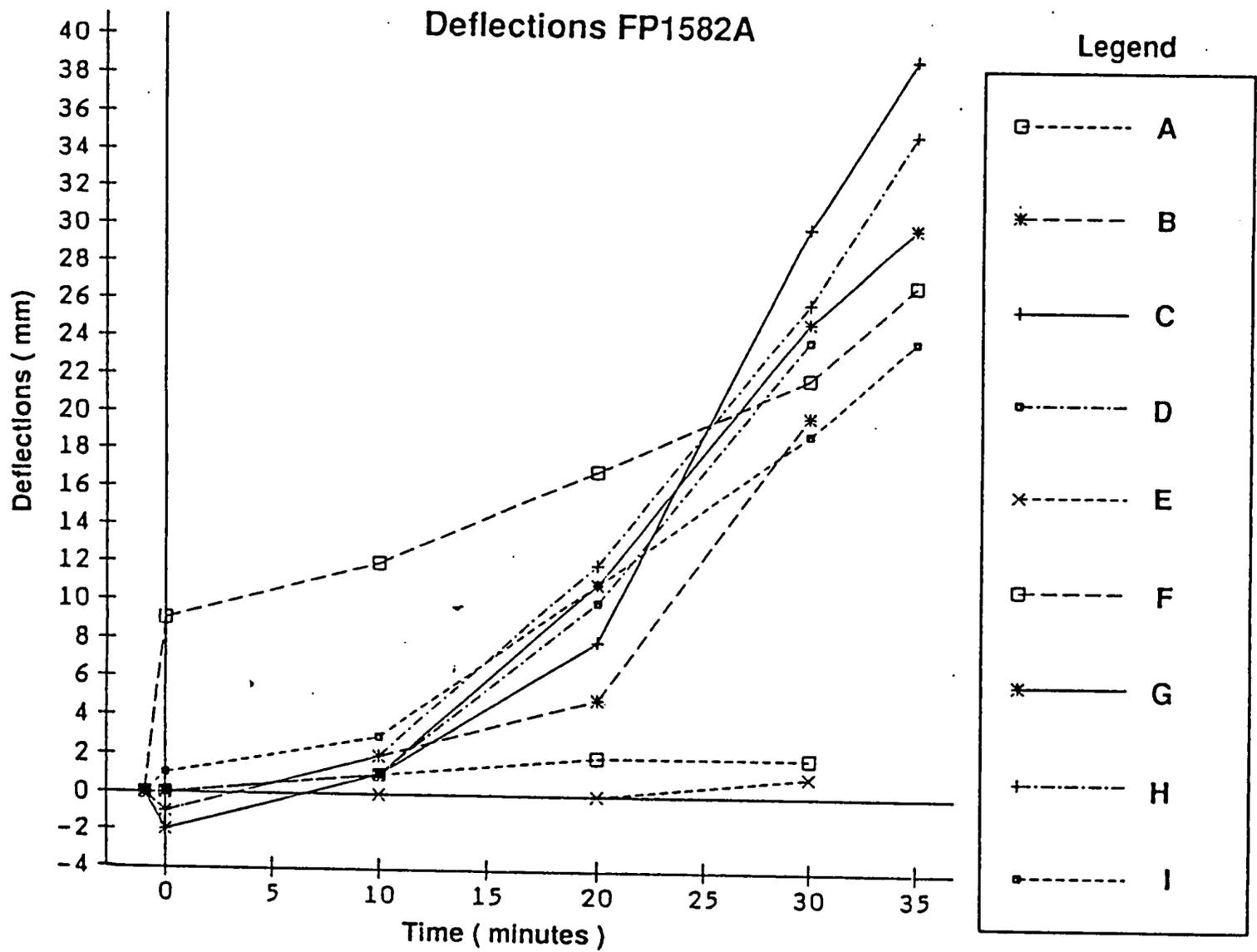


Figure 8c Deflections test Fp 1582A.

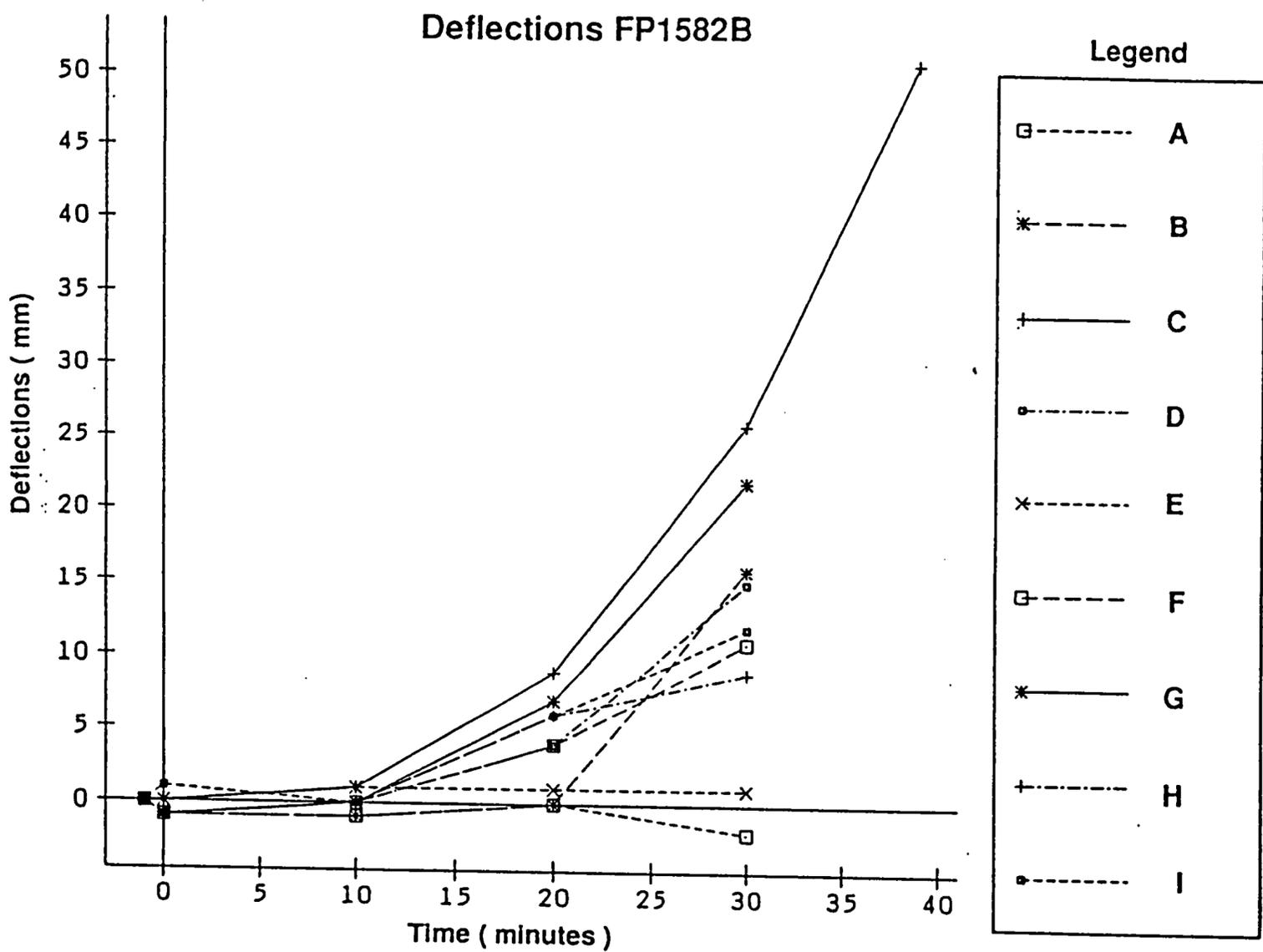


Figure 8d Deflections test Fp 1582B.

### Deflections FP1582B

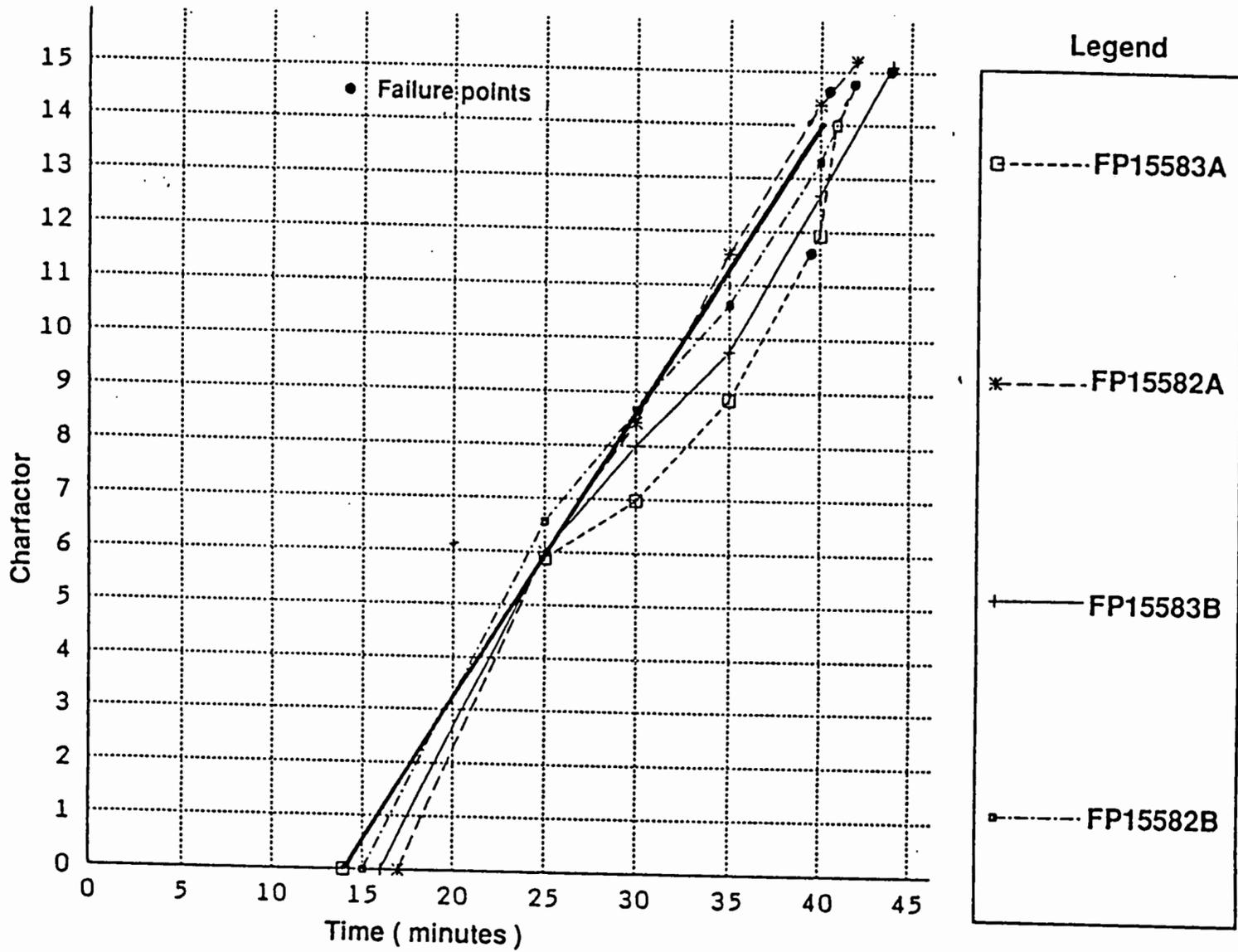


Figure 9A Charfactors, 9.5 mm plasterboard tests.

### Charfactors

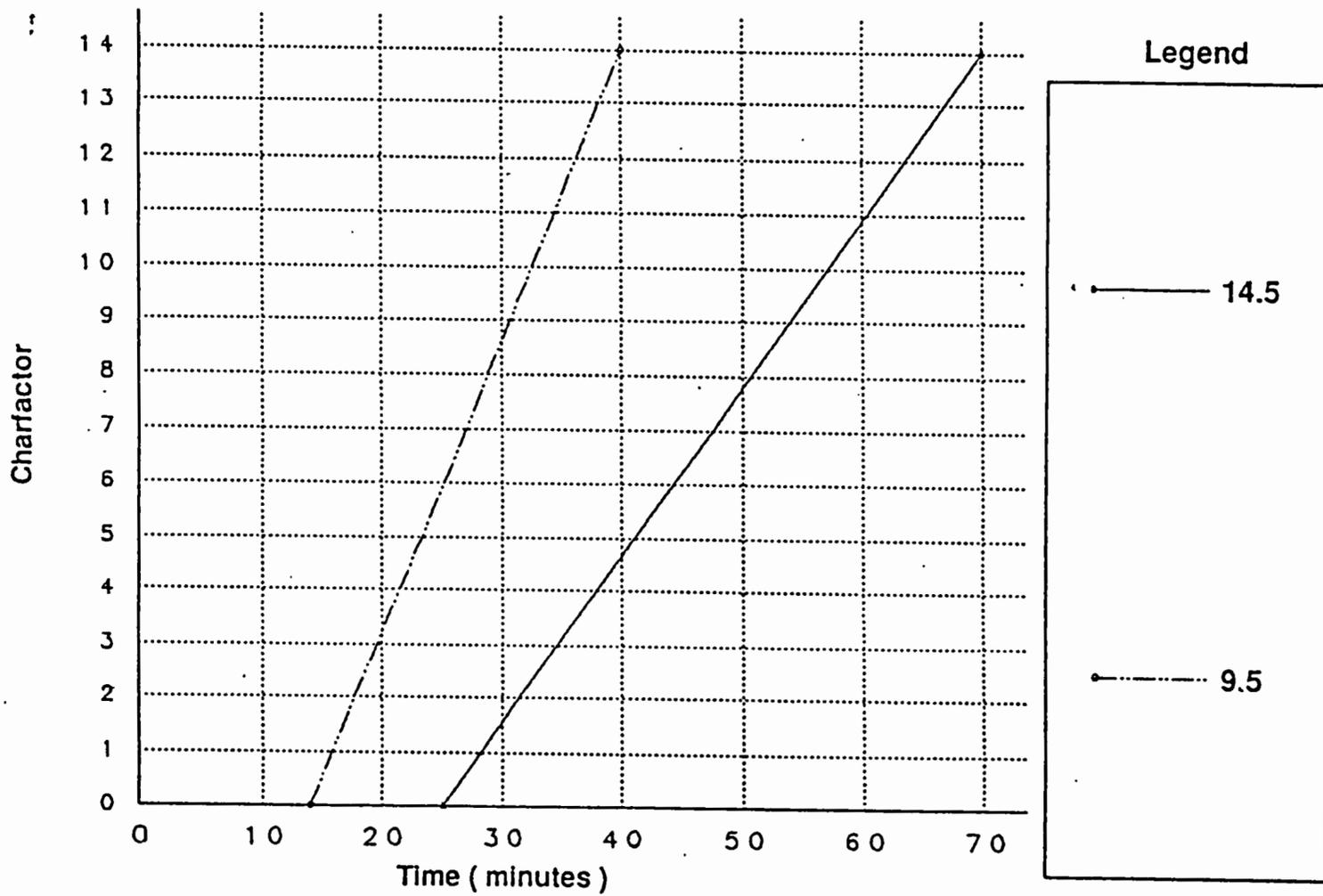


Figure 9b Charfactors, 9.5 mm and 14.5 mm plasterboard.

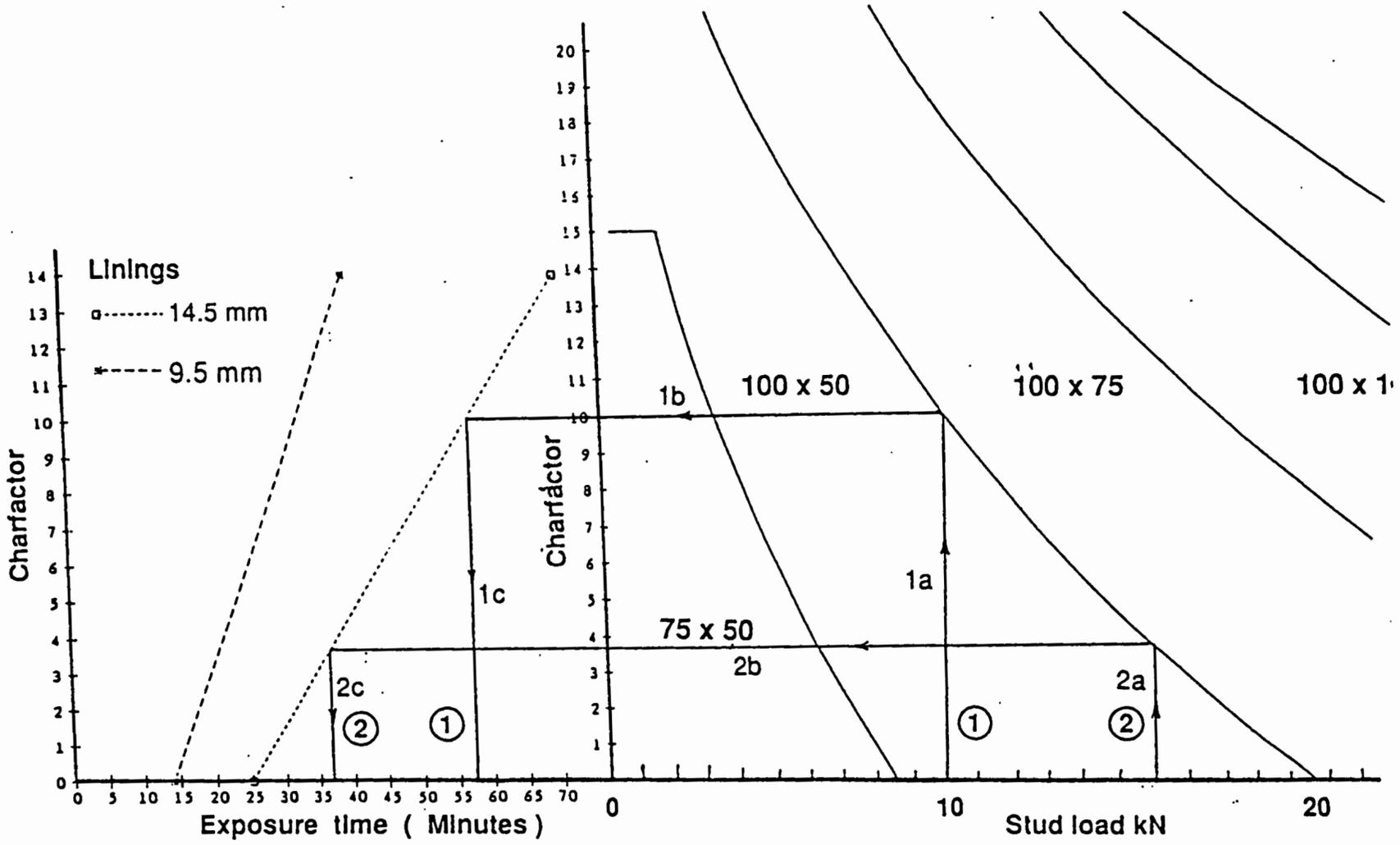


Figure 10 Extension of extrapolation procedure, examples 1 and 2.

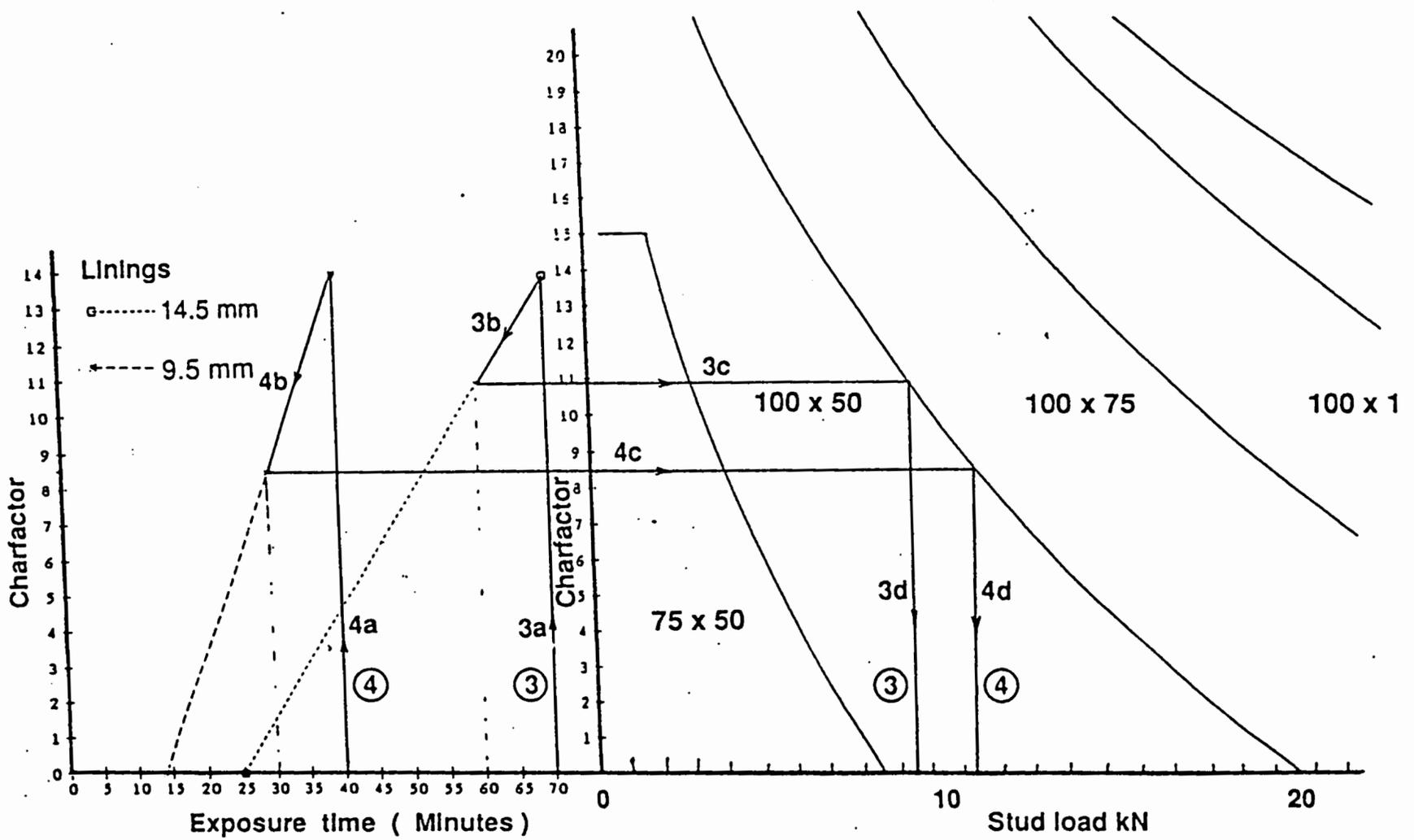


Figure 11 Optimisation of a test result, examples 3 and 4.

**Table 1: Test Results**

Test #	FP 1583A	FP 1583B	FR 1582A	FR 1582B
Size	Pilot	Pilot	Resistance	Resistance
Wall height (m)	2.2	2.2	3.0	3.0
Wall length (m)	1.03	1.03	3.0	3.0
Stud Size (mm x mm) (Nominal) (Actual)	75 x 50 66 x 45	100 x 50 90 x 45	75 x 50 66 x 45	100 x 50 90 x 45
Stud spacing (mm)	600	600	600	600
No. of studs	2	2	5	5
Lining (mm)	9.5	9.5	9.5	9.5
Load/stud (kN)	5.0	13.1	2.8	8.0
Failure (mins):				
Structural adequacy	39	44	42	42
Insulation	38	44	41	42
Integrity	-	-	-	-
Deflections (mm) (+ve outwards)				
@ 30 mins (actual)	14	6	30	26
@ failure (estimated)	12	18	51	58
Time @ 300 C, mins:				
lining t/c 1.	14	16	17	15
stud t/c 5. (see Figure 4)	12	18	18	18
% Fire severity, cf. standard Time-Temperature curve (AS 1530) @ char time lining t/c 1 above)	124	100	104	100
* Loads based on a charfactor of 14, refer to Figure 3				
The relative humidity in the wall cavity in test FP 1583A exceeded 100% at 3 minutes.				

**Table 2: Tests 1, 2 and 3 from previous programme  
(Collier, 1991a)**

Test #	1	2	3
Height (m)	3	3	3
Length (m)	3	3	3
Stud size (mm x mm)	100 x 50	100 x 50	100 x 50
Stud spacing (mm)	600	600	600
No. of studs	5	5	5
Stud load (kN)	16	8	10
Lining (mm) plasterboard	14.5	14.5	14.5
Failure time:			
- Structural	46	70	60
- Insulation	-	-	-
- Integrity	-	-	-
Deflections (mm)			
@ 45 mins	-100	+16	+21
@ failure	-100	+42	+40*
(+ve outwards)			
Time @ 300 C (mins) (exposed lining)	25	25	25
Fire severity %			
- @ char time (300 C) for lining (25 min)	100	100	100
Charfactor at failure - (see Figure 3 of TR 9 table 1.1)	5	14	12
* estimate			



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## HEAD OFFICE AND RESEARCH CENTRE

Moonshine Road, Judgeford  
Postal Address - Private Bag 50908, Porirua  
Telephone - (04) 235-7600, FAX - (04) 235-6070

## REGIONAL ADVISORY OFFICES

### AUCKLAND

Telephone - (09) 524-7018  
FAX - (09) 524-7069  
290 Great South Road  
PO Box 17-214  
Greenlane

### WELLINGTON

Telephone - (04) 235-7600  
FAX - (04) 235-6070  
Moonshine Road, Judgeford

### CHRISTCHURCH

Telephone - (03) 663-435  
FAX - (03) 668-552  
GRE Building  
79-83 Hereford Street  
PO Box 496