Fire Research Note No.934

A RELATIONSHIP BETWEEN THE FIRE RESISTANCE OF COLUMNS AND THE COST OF CONSTRUCTION

by

D V MASKELL and R BALDWIN

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FIRE RESEARCH STATION

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SUMMARY

The "deemed to satisfy" provision of the building regulations have been priced in order to investigate the relationship between the cost of protecting a column and the degree of protection (fire resistance). A straight line relationship is found, accurate to within 5% for steel columns and to within 10% for concrete columns. This formula will be used in subsequent cost - benefit analyses.

KEYWORDS: Column, economics, fire resistance.

DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE

JOINT FIRE RESEARCH ORGANIZATION

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INTRODUCTION

The Fire Research Station is currently analysing the cost and benefits of fire protection with a view to determining the optimum level of fire protection and to identify the costs associated with life safety requirements. The feasibility of this research programme is determined largely by the availability of suitable information for assessing the benefits of a particular fire protection system, by a combination of statistical and experimental data.

The other ingredient, perhaps more readily identified, is the construction costs associated with fire protection, and in this note we study the costs of a simple fire protection system, i.e. the provision of fire resistance to columns. Because of the complex mathematical nature of the proposed cost-benefit studies, it is convenient to deal with costs by means of a simple mathematical formula; the aim of this present paper therefore is to identify the form of the relationship between the fire resistance of the column and its cost. This note deals only with the cost of a single building element, and therefore the conclusions must be viewed with this in mind. More complex forms of construction e.g. frameworks, which have several elements, mayushow some degree of variation. Similarly certain systems of construction such as Industrialised buildings, employ a consistent degree of fire resistance for all elements within the system in order to obtain economies of mass production. Both these aspects would require separate investigations. It should be realised that although in this note costs of treatments have been attributed to fire protection, in practice a particular treatment may be chosen for quite different reasons e.g. aesthetic grounds, unsuitability for the environment, etc. In that case the costs would be attributed to the function having the highest priority.

FIRE RESISTANCE OF COLUMNS

The basis of this report is Part E of the Building Regulations[1] and in particular regulations E5 and E6. The first deals with the fire resistance of "elements" of construction - the elements being the walls, floors, frameworks, etc., and the second, in the form of its accompanying schedule, provides various methods of forming these elements which are "deemed to satisfy" the requirements of the previous regulations.

The various degrees or periods of fire resistance required for an element will depend upon:-

1. The building occupancy.
2. The height of the building.
3. The internal floor area, and
4. The cubic capacity of the building.

There are five recognised degrees of fire resistance, (if it is assumed that a nil fire resistance will be anything less than the minimum period) and they are:

1. ½ hour (30 minutes or more up to 1 hour.
2. 1 hour (60 minutes or more up to 1 ½ hours.
3. 1 ½ hours.
4. 2 hours.
5. 4 hours.

The table accompanying regulation E5 state the fire resistance periods required for elements of construction depending on the four varying factors listed previously.

Schedule 8, entitled "Notional Periods of Fire Resistance", lists in some detail, the various methods of construction which satisfy particular fire resistance requirements. These methods are divided into categories depending on the type of building element, and since this report considers only the column element, our attention need be focused only on Parts II and VA of the schedule.

COSTS OF CONSTRUCTION

The "deemed to satisfy" provisions of Parts II and VA of schedule 8 have been priced and are contained in this note as Appendix A. Much of these data have been extracted from a previous report[2] which dealt with the fire resistance of steel and concrete frameworks, using the column element as the basis. The sizes of columns used were as follows:

For steel - 200 mm (8 inches) x 200 mm (8 in) x 47.5 Kg/m (32 lbs/ft) and 3.66 m (12 ft) in height and

For concrete - from 150 mm (6 in) x 150 mm (6 in) to 450 mm (18 in) x 450 mm (18 in) in cross-section, also with heights of 3.66 m (12 ft)

Several techniques have been omitted which have no similar construction in at least four out of the six possible categories (i.e. including nil fire resistance) because there would be insufficient data to define the trend.

Tables 1 and 2 which follow have been extracted from Appendix A.

Table 1. Costs of construction of concrete columns (£)

Concrete column Ref. No. (see Appendix A)		Fire resistance category				
	Nil	½ hour	1 hour	1½ hours	2 hours	4 hours
1a	*	11.35	15.72	22.13	27.26	42.33
1b	*	13.99	15.87	21.99	28.07	47.89
1c	*	10½82	13.61	18.34	21.40	30.80
1d	*	12.20	16.80	16.80	19.90	28.73

*Concrete has a natural fire resistance and it would be unlikely that a size of column would be used less than 150 mm x 150 mm (6 in x 6 in)

For dimensions of column see text and Appendix A

Table 2. Costs of construction of protected steel columns (£)

Encased steel stanchion Ref. No. (see Appendix A)	Fire resistance category					
	Nil	½ hour	1 hour	1½ hour	2 hours	4 hours
Solid A4	†18.70	*	24.98	25.93	27.68	34.60
Hollow B3	18.70	24.35	24.88	26.07	28.58	–
B4a	18.70	*	24.78	25.19	25.60	33.06
B5b	18.70	*	24.37	24.86	25.05	–
B6a	18.70	23.22	23.76	24.01	24.26	–
B6b	18.70	*	24.46	*	25.05	28.49
B7	18.70	*	24.95	26.35	26.91	32.09

*No casing provided for these periods.

†The cost of a steel stanchion unprotected.

For dimension of column see text and Appendix A

ANALYSIS OF DATA

The data on costs (Tables 1 and 2) are plotted in Figs. 1 and 2 as a function of the fire resistance. The cost of the unprotected steel columns has also been included on the graphs for protected steel. Although these columns are deemed to have zero fire resistance, this simply means that their fire resistance is less than half an hour: for this reason unprotected steel columns has been represented by a range of fire resistance from 0 – 30 mins.

It can be seen from the graphs that the relationship between cost and fire resistance is approximately linear, provided the unprotected steel column is excluded, and so a straight line of the form

$$\text{Cost} = A + BR$$

has been fitted to the data, where A and B are constants and R is the fire resistance in hours. The constants A and B and the maximum deviation of the data from the line are given in Tables 3 and 4. For steel, the fit is very good, with a maximum error of 5%, and most treatments with an error of 1–2%. For concrete the fit is still very good, but the maximum error is 10%. In view of the uncertainties inherent in estimation and in business practice this degree of approximation is acceptable.

The constant A measures the cost of a column with zero fire resistance, but the cost of unprotected steel is considerably lower than that predicted by the equation. The difference between the two figures measures the cost of applying the treatment, irrespective of its fire resistance. The additional cost per hour of fire resistance (measured by B) is relatively small in most cases. The equation for steel only applies for fire resistances in excess of half an hour.

For concrete, the equation again applies only to columns with a fire resistance in excess of half an hour, but the cost per hour of fire resistance is considerably greater than for steel. However, the two sets of data are not comparable because whilst the steel data is based on a column with given fixed load-bearing capacity, fire resistance in the concrete columns is achieved by varying the dimension and hence the load-bearing properties of the column. A concrete column with the same load-bearing properties as the steel column considered has a fire resistance of one and a half hours. In practice it may be found that the load-bearing requirements for a concrete column are more onerous than the fire resistance requirements; the additional fire resistance is thus a bonus.

CONCLUSIONS

There is a straight line relationship between the cost of construction of a column and its fire resistance, of the form

$$\text{Cost} = A + BR$$

for columns with a fire resistance greater than half an hour.

For columns considered this formula is accurate to within a maximum error of 5% for protected steel columns and to within 10% for concrete columns.

Although these costs have been attributed to fire protection, in practice a particular treatment may be chosen for quite different reasons, e.g. load-bearing properties of concrete columns. The design of fire protection cannot be divorced from the design of other building functions.

REFERENCES

1. The Building Regulations 1965: Statutory Instrument 1965, No. 1373 HMSO.

2. A cost study of concrete and steel frameworks: A single column by D. V. Maskell. Department of the Environment and Fire Offices' Committee Joint Fire Research Organization. Fire Research Note No. 905, March 1972.

3. The Building Regulations 1965. Metric values Consultative proposals. H.M.S.O. 1969.

Table 3. Constants of straight line fitted to cost data - steel

Ref.	A £	B £/hr	Max error %	Range hrs.
A4	22	3.1	2	1-4
B3	22.8	2.6	2	½-2
Bua	20.6	3.0	5	1-4
B5b	23.6	0.7	1	1-2
B6a	22.8	0.9	1	½-2
B6b	22.8	1.4	2.5	1-4
B7	22.4	2.4	1.5	1-4

£ cost = A + BR

Table 4. Constants of straight line fitted to cost data - concrete

Ref.	A	B	Max error %
1a	7.2	9.1	6
1b	7.2	10.2	10
1c	9.2	5.4	10
1d	9.8	4.8	3

£ cost = A + BR

APPENDIX A

Detailed costs of construction using techniques from Schedule 8

Part 1

Ref. No.	Reinforced concrete column description	Size of member (mm)*	Fire resistance (hour)	Cost (£)
1a	Without plaster	150 x 150	½	11.35
		200 x 200	1	15.72
		250 x 250	1½	22.13
		300 x 300	2	27.26
		450 x 450	4	42.33
1b	With 13 mm gypsum plaster on mesh reinforcement fixed around columns	150 x 150	½	13.99
		175 x 175	1	15.87
		225 x 225	1½	21.99
		275 x 275	2	28.07
		425 x 425	4	47.89
1c	Finished with 13 mm encasement of vermiculite-gypsum plaster	125 x 125	½	10.82
		150 x 150	1	13.61
		200 x 200	1½	18.34
		225 x 225	2	21.40
		300 x 300	4	30.80
1d	With hard drawn steel wire fabric 2.5 mm of maximum 150 mm pitch in each direction placed in concrete cover to main reinforcement	150 x 150	½	12.20
		200 x 200	1	16.80
		200 x 200	1½	16.80
		225 x 225	2	19.90
		300 x 300	4	28.73

*The imperial dimensions of the present Building Regulation have been corrected to metric using the approximate conversion factor of 25 mm to 1 inch. The Consultative Proposals[3] of the metric values are somewhat lower particularly for 1b and 1c.

Part 2

Ref. No.	Description of casing to structural steel column	Dimensions* (mm)	Fire resistance (hours)	Cost (£)
	Solid			
A4	Sprayed asbestos – (140–240 Kg/m^3 (9–15 lb/ft^3) of thickness of	10	½	24.98
		10	1	24.98
		16	1½	26.93
		19	2	27.68
		45	4	34.60
	Hollow			
B3	Metal lath with gypsum plaster of thickness of	13	½	24.35
		19	1	24.88
		25	1½	26.07
	(Also requiring light mesh reinforcement)–	38	2	28.58
B4a	Metal lath with vermiculite–gypsum of thickness of	13	½	24.78
		13	1	24.78
		16	1½	25.19
		19	2	25.60
	(Also including a light mesh reinforment)–	50	4	33.06
B5b	19 mm plasterboard, including wire binding, with gypsum plaster of thickness of	7	½	24.37
		7	1	24.37
		10	1½	24.86
		13	2	25.05
B6a	9.5 mm plasterboard, including wire binding, with vermiculite–gypsum plaster of thickness of	7	½	23.22
		10	1	23.76
		13	1½	24.01
		16	2	24.26
B6b	19 mm plasterboard, including wire binding, with vermiculite gypsum plaster of thickness of	7	½	24.46
		7	1	24.46
		10	1½	25.05
		10	2	25.05
	(Also including light mesh reinforcement)–	32	4	28.49
B7	Metal lath with sprayed asbestos of thickness of	10	½	24.95
		10	1	24.95
		16	1½	26.35
		19	2	26.91
		45	4	32.09

*The metric equivalents for the existing imperial dimensions have been taken from the consultative proposals of metric values[3]. They are a direct conversion with little rationalisation.

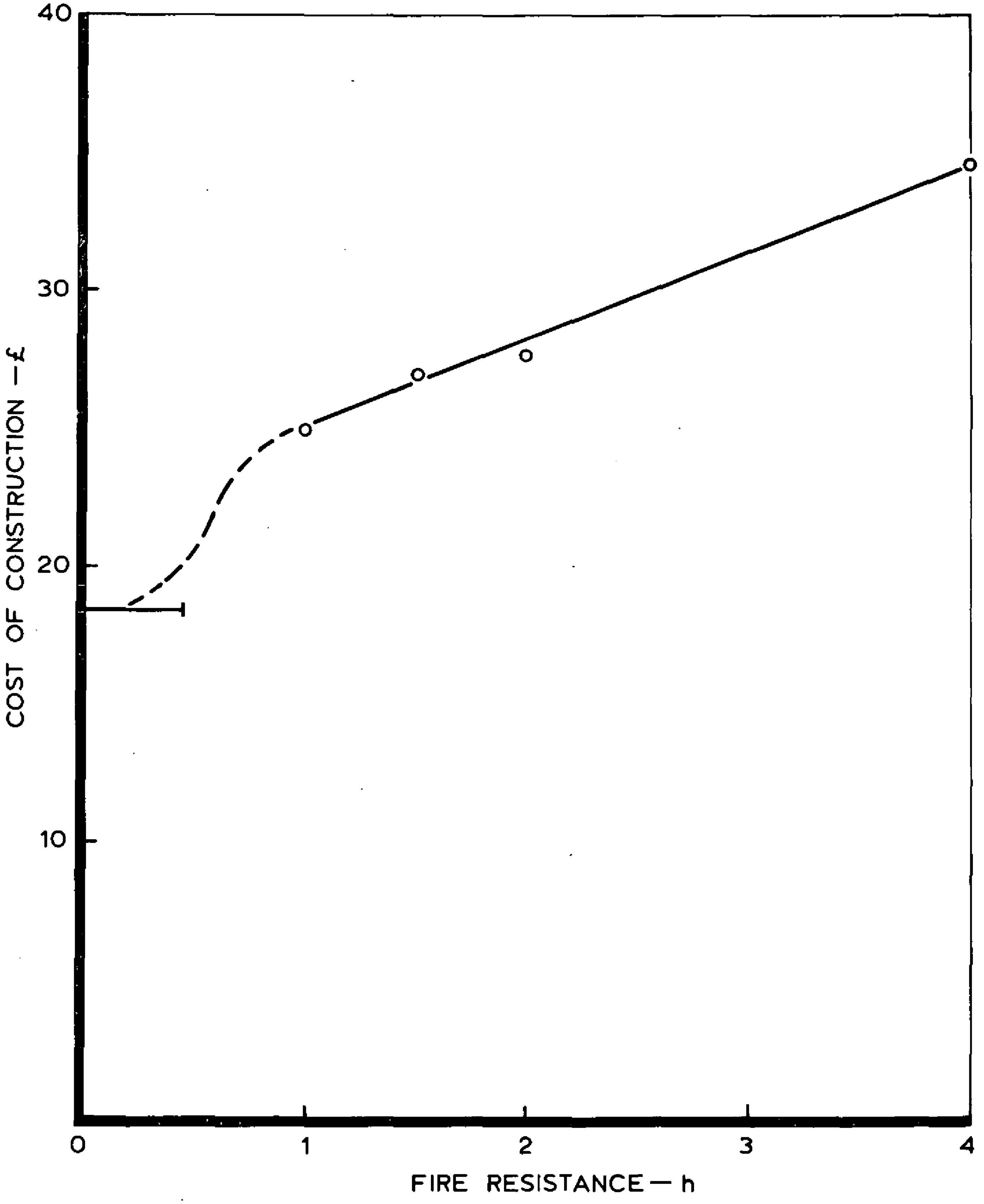

FIG. 1 COST OF CONSTRUCTION PLOTTED AGAINST FIRE RESISTANCE (a) TREATMENT A4 — STEEL

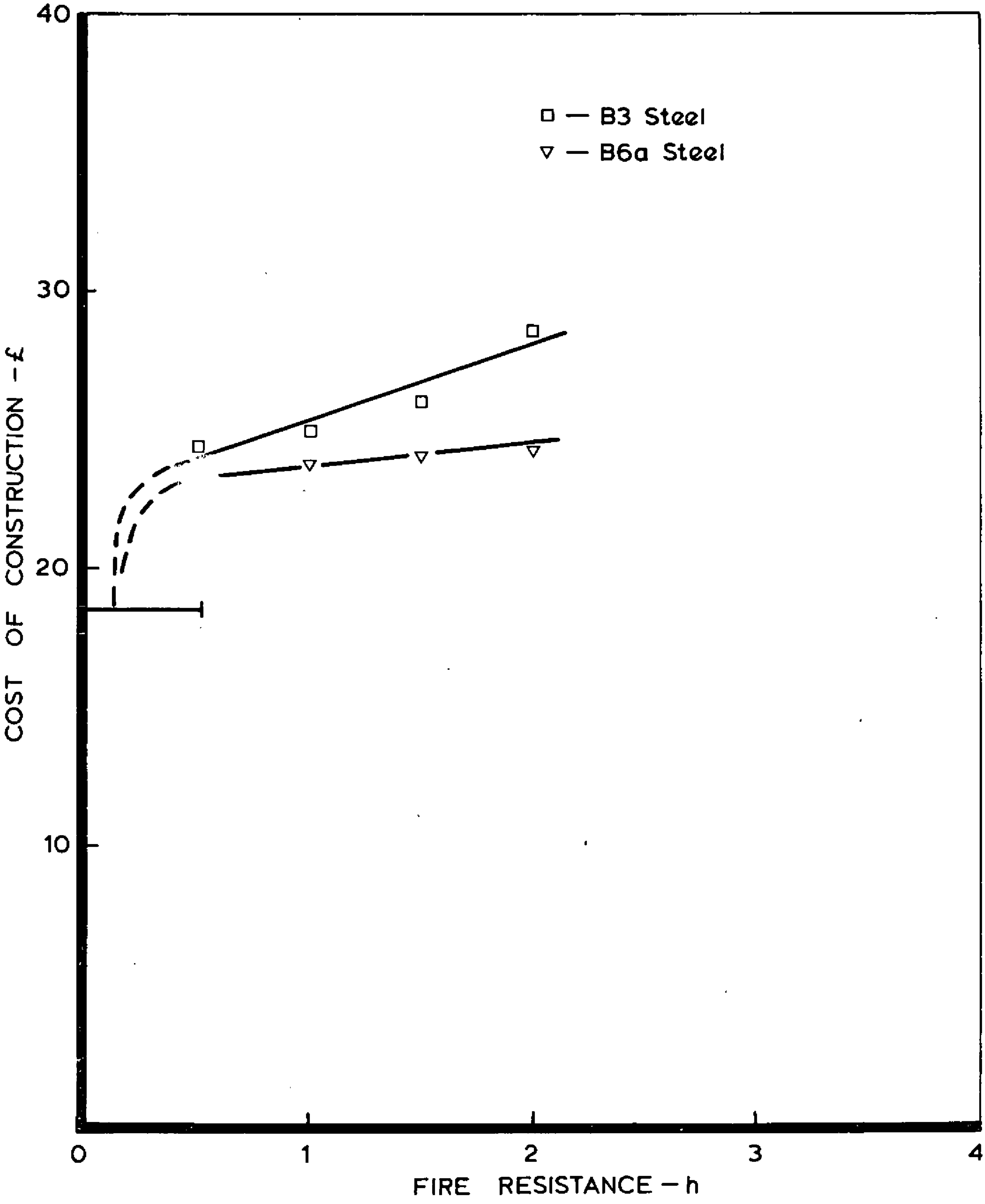

FIG.1(b) TREATMENTS B3 AND B6a - STEEL

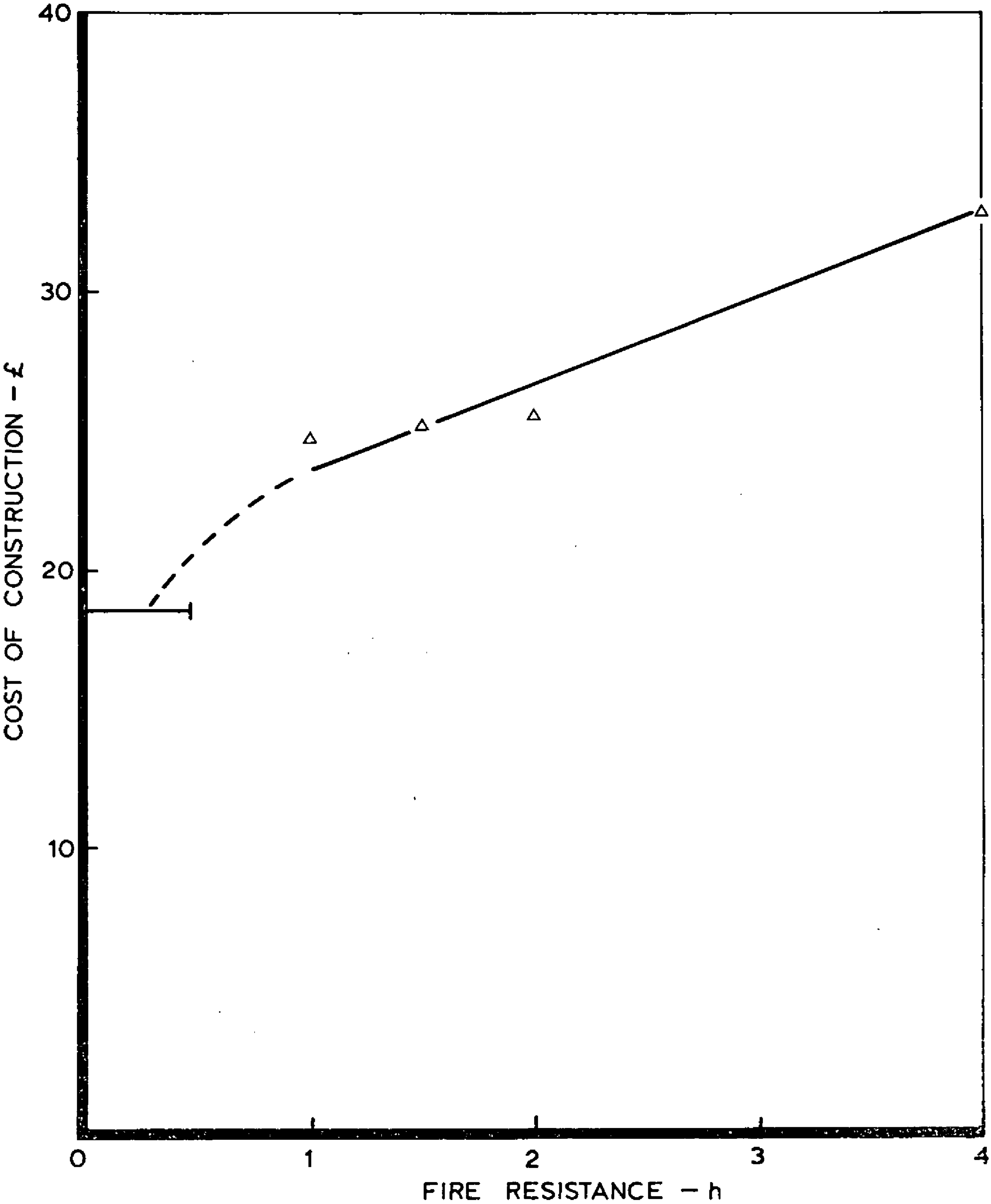

FIG. 1(c) TREATMENT B4a – STEEL

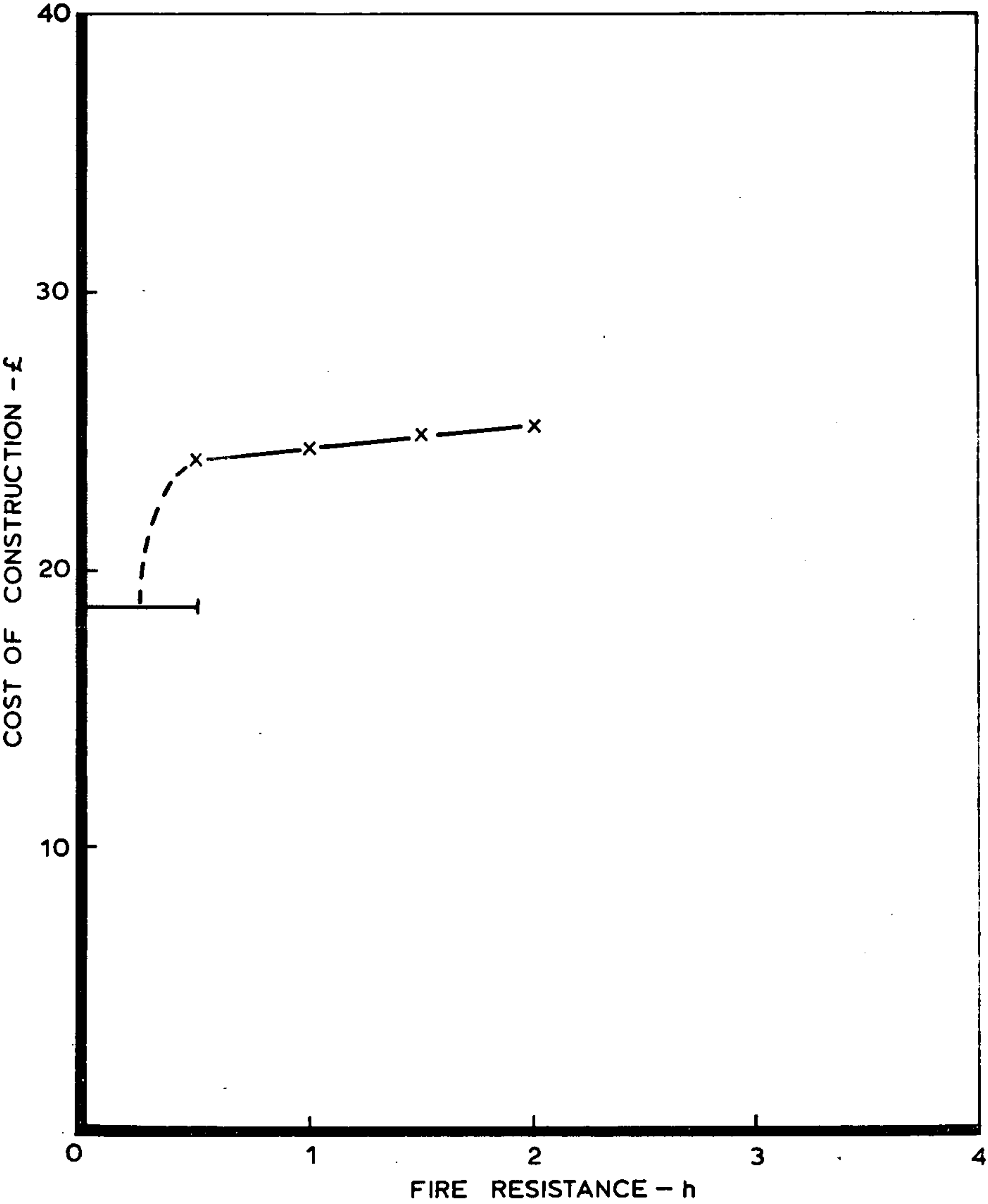

FIG. 1(d) TREATMENT B5b – STEEL

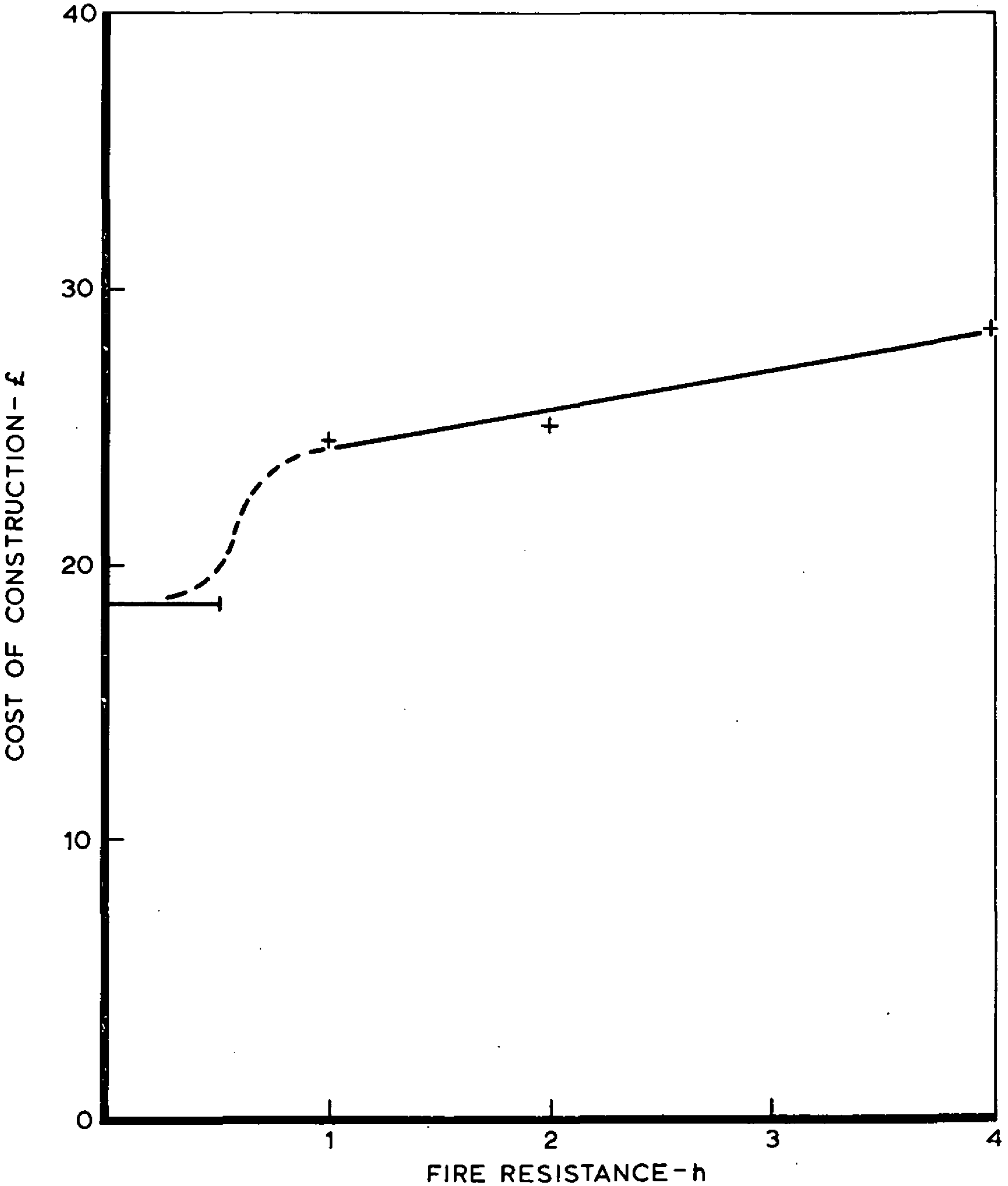

FIG 1(e) TREATMENT B6b - STEEL

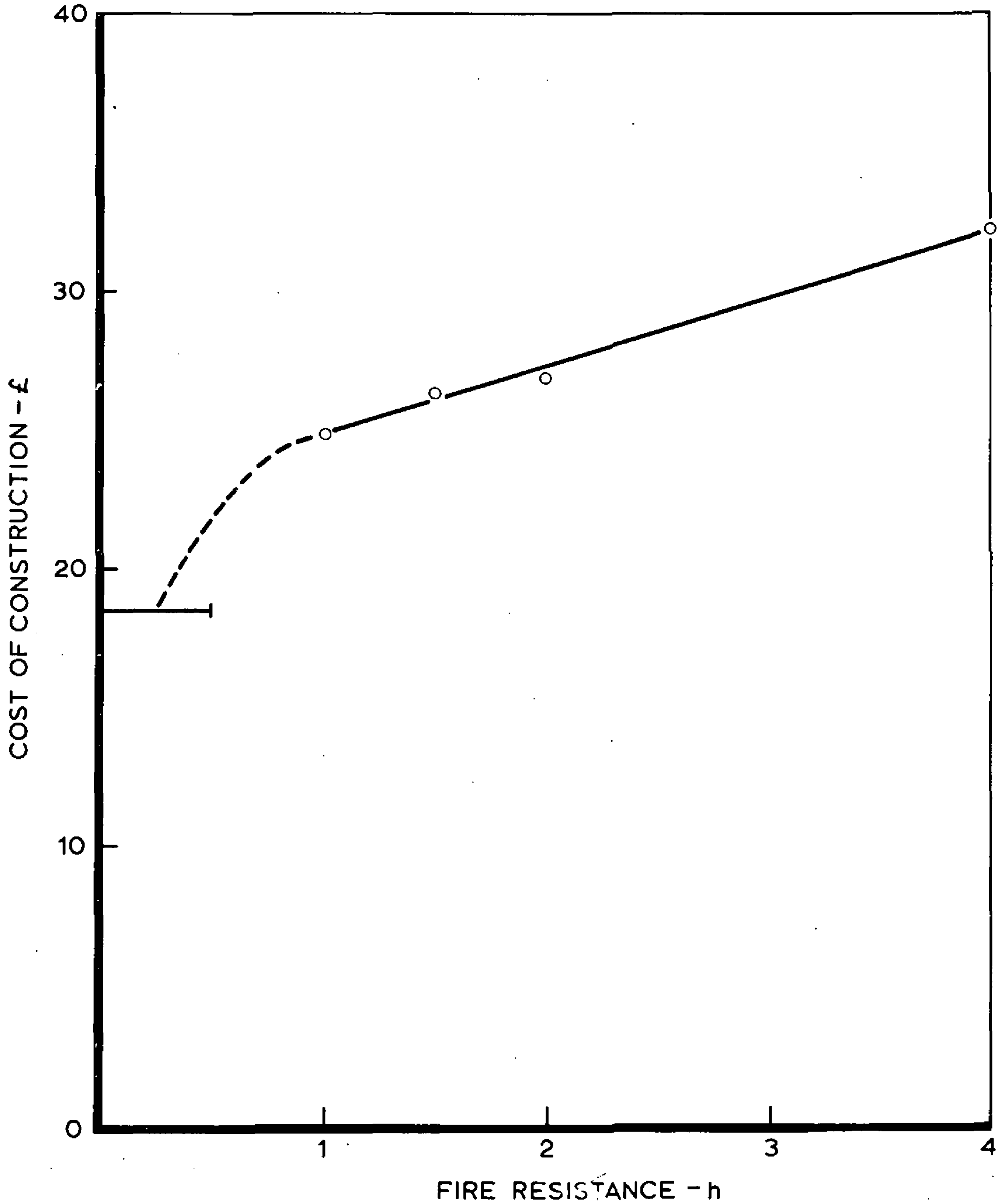

FIG 1 (f) TREATMENT B7 – STEEL

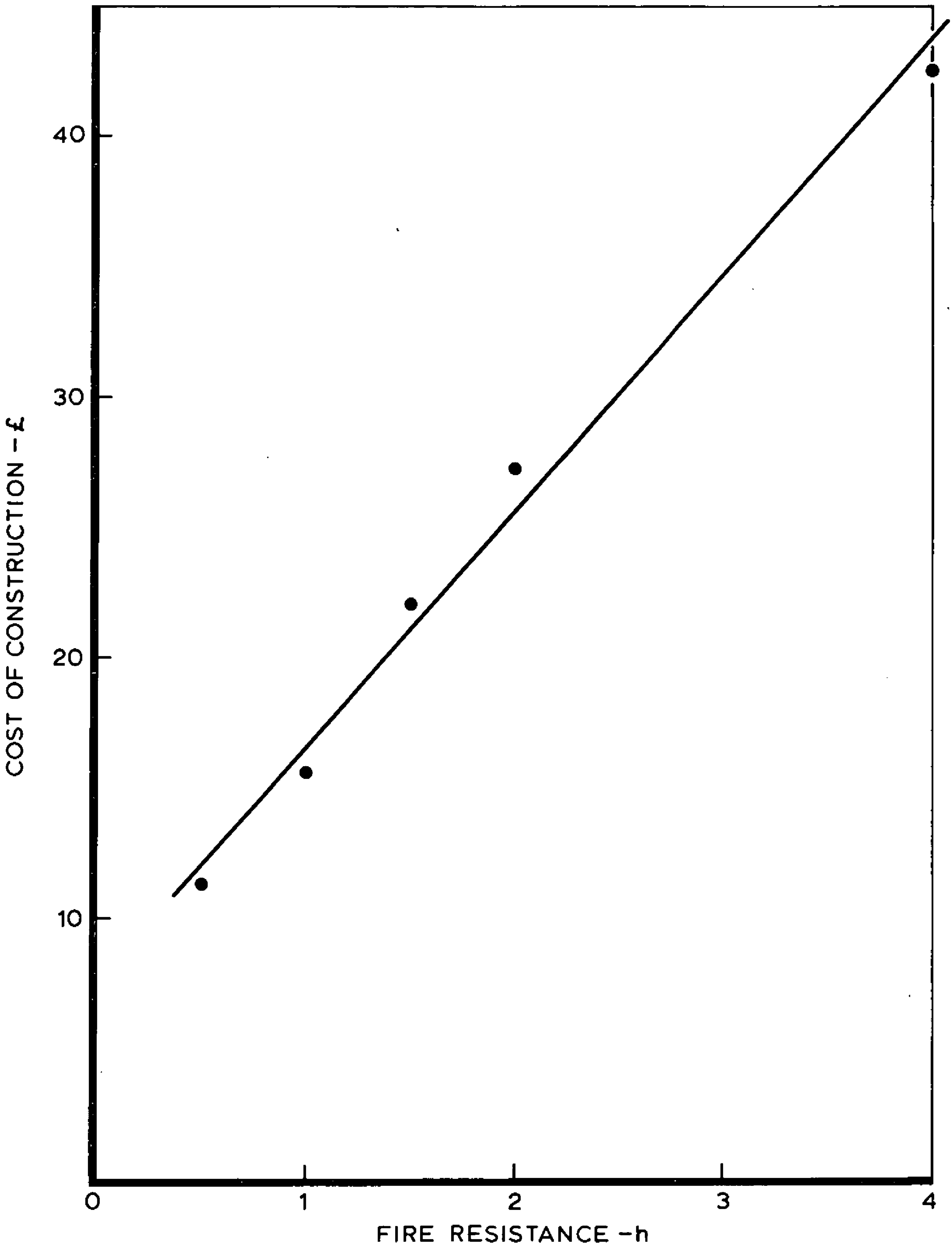

FIG. 2 COST OF CONSTRUCTION PLOTTED AGAINST FIRE RESISTANCE
(a) TREATMENT 1a – CONCRETE

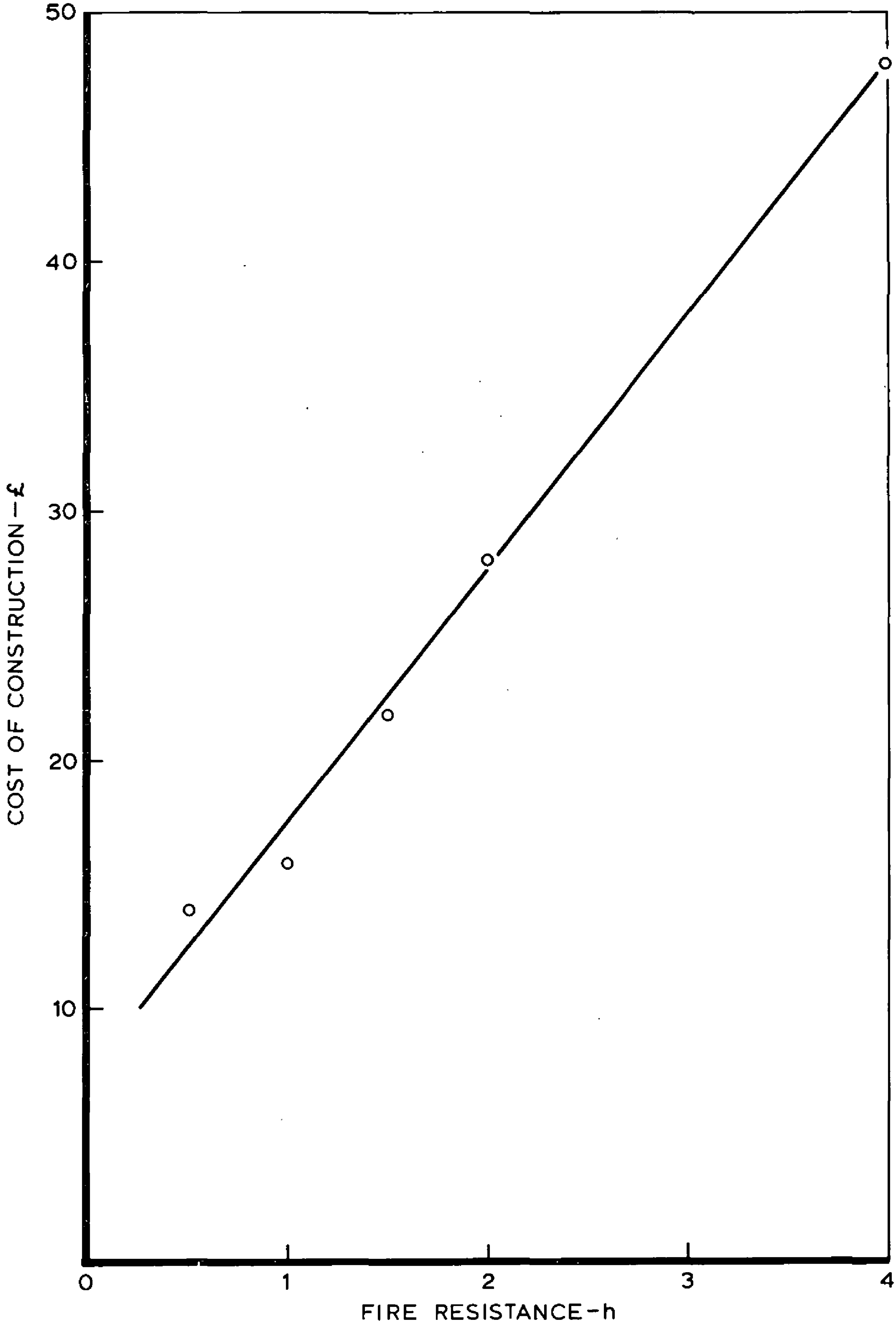

FIG 2(b) TREATMENT 1b – CONCRETE

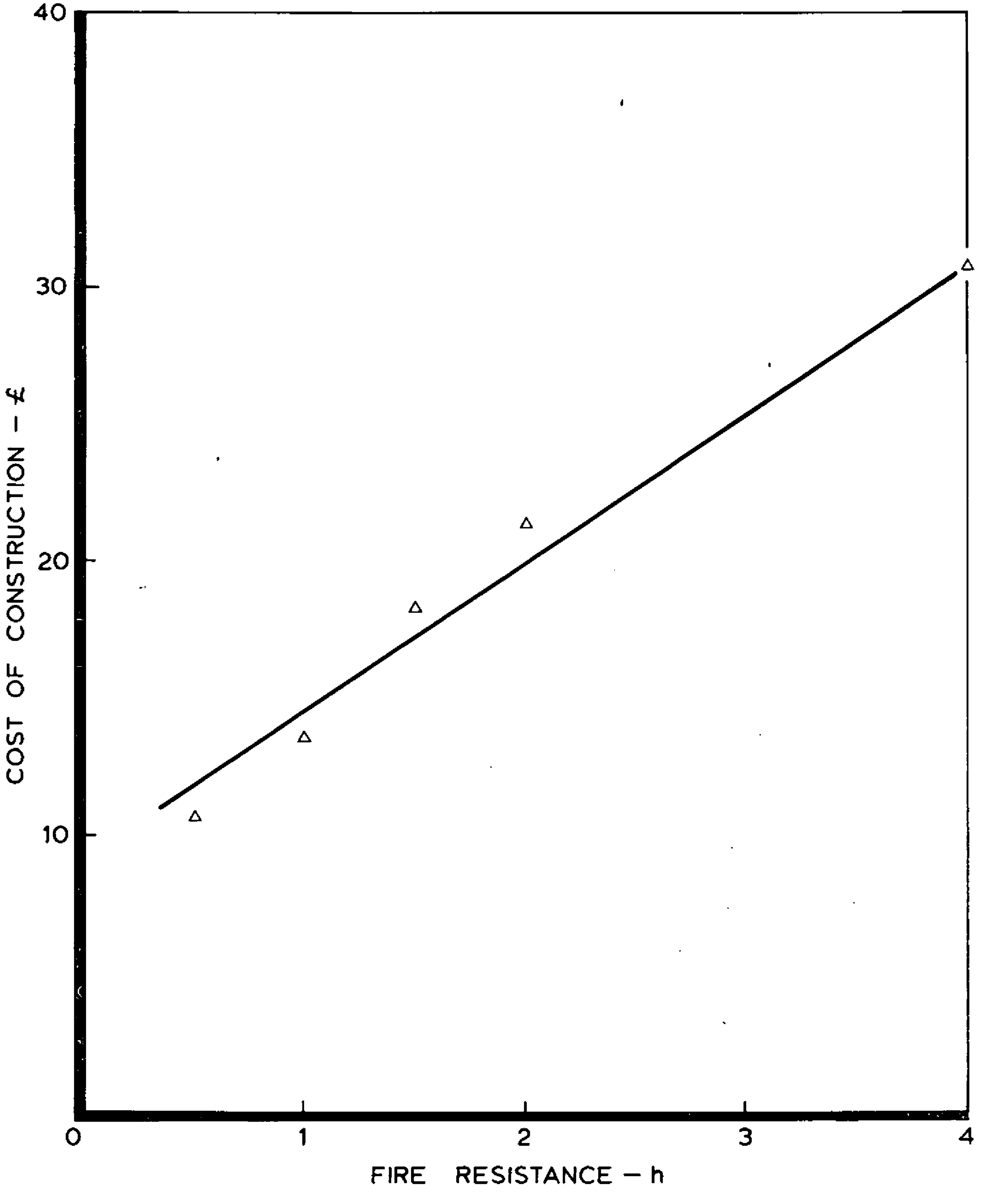

FIG. 2(c) TREATMENT 1c – CONCRETE

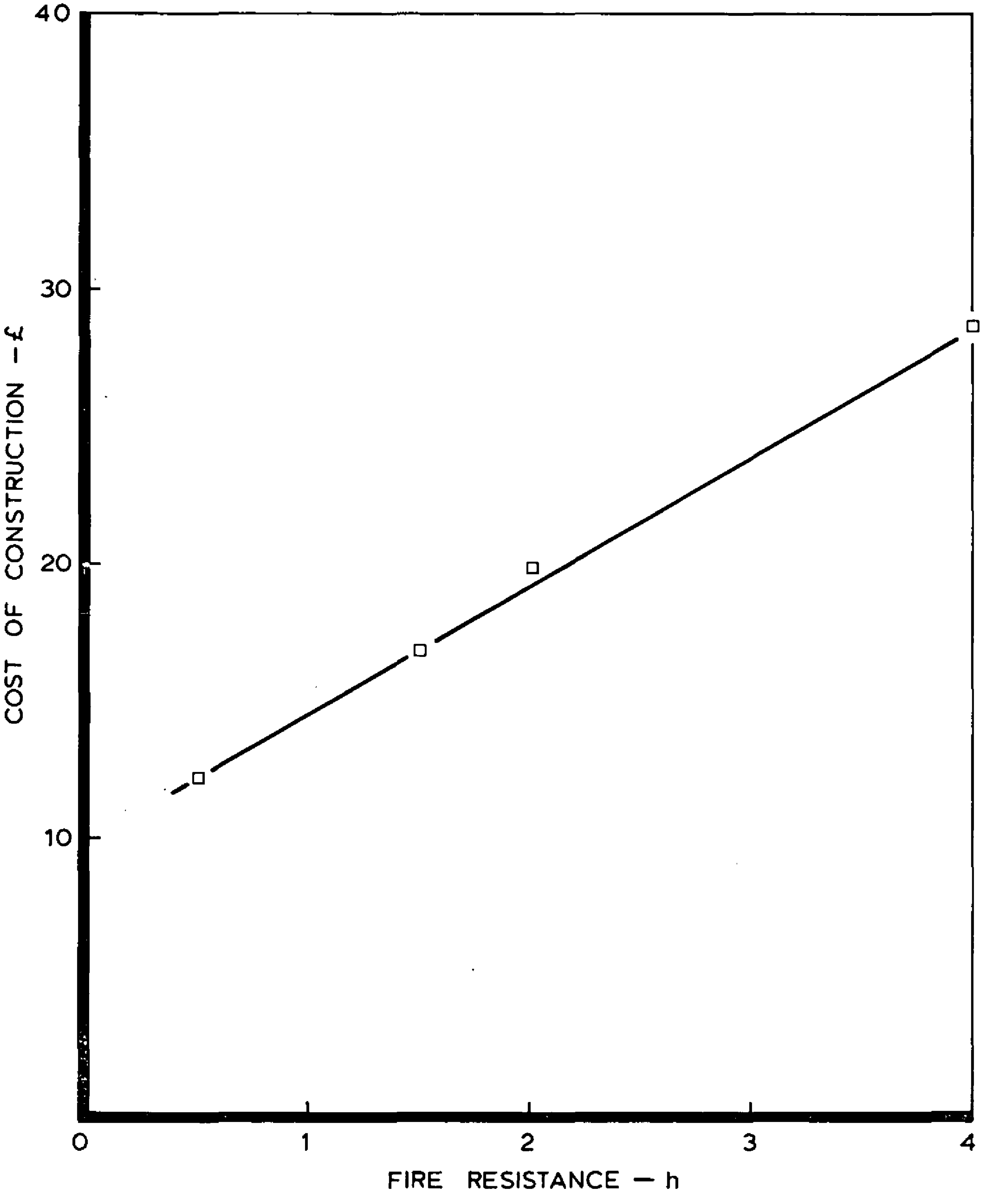

FIG. 2(d) TREATMENT 1d — CONCRETE