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DEFLECTION AS A CRITERION OF FAILURE FOR BEAMS AND FLOORS

by

H.L. Malhotra

Summary

The results of a number of fire resistance tests have been analysed and show how the application of a criterion for limiting deflection of either $\ell/30$ or $\ell^2/800d$ would affect the fire resistance rating of beams and floors.

ℓ is the span of the beam

and d is its thickness

Fire Research Station,
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INTRODUCTION

Certain criteria for defining failure of beams and floors during fire tests on account of excessive deflection were reported to the third Conference of C.I.B./C.T.F.[(1), (2)]. In the report by Robertson and Ryan data for fifty tests were analysed and the effect of applying their proposed criteria studied. A similar analysis has been made of some tests performed at Boreham Wood and the deflection criterion proposed by United Kingdom applied to the results.

PROPOSED DEFLECTION CRITERION

It was suggested that when the central deflection of a beam or floor undergoing the fire test exceeds $1/30$ of the span, it should be presumed to have failed although it may still be successfully supporting the applied load and satisfying other fire resistance requirements. Deflections up to the limiting values are expected to ensure the stability of the structure after a fire and to give prospects of repairability. Compliance with this criterion may also be regarded as a proof of the ability of the structure to withstand the reapplication of the load two days after the fire test as currently required by British Standard 476.

The limiting deflection for a floor specimen having a span of 12 ft would be 4.8 in. and that for a beam with a span of 10 ft would be 4.0 in.

TEST RESULTS

Table 1 gives the details of the fifty-three tests selected for this study which represent a wide variety of constructions, with the exception of timber floors which do not show appreciable deflection until approaching collapse. Under the column giving deflection readings for a number of constructions showing unduly large deflections, an earlier reading with the corresponding time has also been included. Values of limiting deflection are followed by the times when such values were reached. Where tests were terminated before the limiting deflection occurred it has not been considered advisable to extrapolate. The time and the cause of failure reported are followed by the change, if any, in the fire resistance periods entailed by the application of the deflection criterion. Where failure had occurred by under either the integrity or temperature rise requirement of B.S. 476 before the occurrence of critical deflection no change has been reported. Any reduction in fire resistance is indicated with the amount of the reduction. On the other hand, the actual amount of an increase is not given.

In the final column of Table 1 are given the limiting deflections in accordance with the formula proposed by Robertson and Ryan. This formula takes into account the thickness of the construction (d), in addition to the span (ℓ). It should be observed that under this method for constructions of less than 6 in. in thickness and with the spans commonly used for tests at Boreham Wood, larger deflections are permitted than under the criterion proposed by the United Kingdom.

DISCUSSION OF TEST RESULTS

The analysis of the results in Table 2 shows that out of the fifty-three tests reported, the application of the proposed deflection criterion would result in a decrease in the fire resistance periods for nearly half the constructions (49 per cent). In nearly a third of the tests (30 per cent) there would be no change as failure due to other causes would take place before the occurrence of the limiting deflection. The decrease in fire resistance varies from 1 minute to 256 minutes and a further study of Table 1 shows that in only seven tests a downgrading (i.e. the next lower grade) of fire resistance would be entailed by using this criterion. In a further four tests the grading would have been affected had collapse not taken place at or just after the end of the test.

The results also show that with the exclusion of the hollow clay tile floors where only two instances have been cited, the constructions liable to excessive deflections are the simply supported floors and beams of any type and hence more likely to be affected by the application of the deflection criteria than restrained elements. It is also obvious from the tabulated results that the application of the alternative formulation ($\ell^2/800d$) would not give significantly different results from the proposed deflection limit of 1/30 of the span. The rate of deflection criteria[1] had not been considered in this study for two reasons, first the deflection is likely to be increasing more rapidly when the specimen has attained higher net deflection and is nearing collapse and the two are therefore interrelated, and secondly it is not considered as easily applicable during a test as a net deflection limit criterion.

CONCLUSION

This analysis of the results of a number of fire tests shows the effect of applying a limiting deflection value as a test criterion. It appears that the proposed limit of 1/30 of span would enable test specimens to comply with the requirement for stability of the structure after a fire exposure, and thus to satisfy the reload requirement of B.S. 476.

References

1. CIB/CTF No. 35/UK/4 - Load Failure in Fire Resistance Tests (Department of Scientific and Industrial Research and Fire Offices' Committee, Joint Fire Research Organization).

2. CIB/CTF No. 35/USA/1 - Proposed Criterion for defining Load Failure of Beams, Floors and Roof Constructions during Fire Tests, by A. F. Robertson and J. V. Ryan (N.B.S.).

T A B L E 2

ANALYSIS OF RESULTS SHOWING EFFECT OF APPLYING PROPOSED DEFLECTION CRITERION

	Type of Construction	No. of tests	No Change		Increase		Decrease	
			No.	Per cent	No.	Per cent	No.	Per cent
A	Reinforced concrete slab floor	12	5	42	2	16	5	42
B	Filler joist floor	7	3	42	2	29	2	29
C	Hollow clay tile floor	2	-	-	-	-	2	100
D	Precast reinforced concrete units	4	-	-	2	50	2	50
E	Prestressed concrete floors	14	4	28	2	15	8	57
F	Cellular steel decks	6	-	-	3	50	3	50
G	Beams	8	4	50	1	13	3	37
	Total number of test	53	16	30	11	21	26	49

[redacted]

TABLE 1

DETAILS OF THE FLOOR AND BEAM TESTS

Ref. Ref.	Construction	Thickness (d)	Span (l)	End conditions	Duration of fire test	Central deflection	Permissible deflection l/30	Time deflection criterion reached	Time of failure reported	Cause of failure reported	Change in fire resistance by applying deflection criterion	Deflection with criterion $l^2/800d$
	A. Reinforced concrete slab floors	in.	ft in.		hr. min.	in.	in.	hr. min.	hr. min.			in.
F34	Gravel aggregate - no ceiling	3¼	13 1	R	0 31	4.4	5.2	-	0 31	integrity due to spalling	no change	9.6
F45	Crushed brick aggregate - no ceiling	3¼	13 1	R	2 00	8.1	5.2	1 20	no failure	-	decrease 40 min	9.6
F48	Whinstone aggregate - no ceiling	3¼	13 1	R	1 05	2.4	5.2	-	1 05	local temp. rise due to spalling	no change	9.6
F49	" " " "	3¼	13 1	R	0 41	1.5	5.2	-	0 41	integrity due to spalling	no change	9.6
F71	Limestone aggregate - no ceiling	4	13 1	R	1 23	1.3	5.2	-	1 23	temp rise due to spalling	no change	7.7
F25	Gravel aggregate - no ceiling	4½	12 0	S.S.	1 32	6.0 (0-31) 17.4	4.8	0 22	1 32	collapse	decrease 1-10	5.8
F18	" " " "	4½	12 0	S.S.	2 00	6.0 (0-33) 29.0	4.8	0 22	2 00	collapse	decrease 1-38	5.8
F33	" " " "	4½	13 1	R	0 42	3.4	5.2	0 - 42	[illegible] 42	integrity due to spalling	no change	6.8
F17	" " " "	5	12 0	S.S.	2 00	6 (0-57) 15.3	4.8	0 39	2 00	collapse 10 hr after test	decrease 1-21	5.2
F22	Gravel aggregate - plaster ceiling	5	12 0	S.S.	2 00	6 (1-19) 14.6	4.8	1 07	no failure	-	decrease 0-53	5.2

NOTE: In the column giving end conditions

S.S. means simply supported

R " restrained

Ref.	Construction	Thickness (d)	Span (l)	End conditions	Duration of fire test	Central deflection	Permissible deflection 1/30	Time deflection criterion reached	Time of failure reported	Cause of failure reported	Change in fire resistance by applying deflection criterion	Deflection with criterion $l^2/800d$
		in.	ft in.		hr. min.	in.	in.	hr. min.	hr. min.			in.
F76	Limestone aggregate - no ceiling	6	13 1	R	4 00	2.9	5.2	-	no failure	-	increase	5.1
F63	Brick aggregate - no ceiling	7	13 1	R	6 00	1.3	5.2	-	no failure	-	increase	4.4
	<u>B. Filler Joist Floors</u>											
F30	4" x 3" R.S.J. sections - gravel aggregate concrete no-ceiling	6	12 0	S.S.	3 00	7.0	4.8	-	[illegible] 29 due to spalling	integrity due to spalling	no change	4.3
FR 1	" " " " "	6	13 1	R	3 48	4.3	5.2	-	3 48	temp rise	no change	5.1
FB 2	" " " " "	7	13 1	R	6 00	0.4	5.2	-	no failure	-	increase	4.4
F8	4" x 3" R.S.J. sections - gravel aggregate concrete plaster ceiling	5.75	12 0	S.S.	4 00	9.0	4.8	1 50	no failure	-	decrease 2-10	4.5
F28	4" x 1¾" R.S.J. sections - gravel aggregate concrete - no ceiling	6	12 0	S.S.	5 44	16.0	4.8	1 28	4 30	temp rise	decrease 4-16	4.3
F31	" " " " "	6	13 1	R	2 00	1.5	5.2	-	no failure	-	increase	5.1
F57	3"x 1½" R.S.J. sections - gravel aggregate concrete - no ceiling	5	8 0	R	2 00	1.7	3.2	-	1 24	temp rise	no change	2.3
	<u>C. Hollow Clay Tile Floors</u>											
F26	4" clay tiles with concrete topping	5.5	12 0	S.S.	3 23	14.5	4.8	2 16	3 23	collapse	decrease 1-07	4.7
F27	" " " "	5.5	12 0	S.S.	2 46	22.6	4.8	1 11	-	no failure	decrease 1-35	4.7

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Ref.	Construction	Thickness (d)	Span (l)	End conditions	Duration of fire test	Central deflection	Permissible deflection l/30	Time deflection criterion reached	Time of failure reported	Cause of failure reported	Change in fire resistance by applying deflection criterion	Deflection with criterion $l^2/800d$
		in.	ft in.		hr. min.	in.	in.	hr. min.	hr. min.			in.
F32	4in. claytiles with concrete topping	5.5	13 1	v	2 23	5.0	5.2	-	2 23	temp.rise	no change	5.6
	D. Precast Reinforced Concrete Units											
482	U-shaped sections plaster finish on ceiling	7	12 0	SS	1 15	2.9	4.8	-	no failure	-	increase	3.7
548	Inverted U sections - no ceiling finish	6	12 10	SS	1 22	4.8 (1 - 20)	4.8	1 20	no failure	-	decrease 2 min.	4.3
571	Inverted U sections - mortar screed combustible ceiling lining	6	12 0	SS	1 00	3.8	4.8	-	no failure	-	increase	4.3
662	Hollow foamed slag units with $1\frac{1}{2}$ in. concrete topping - no ceiling finish	5.5	12 00	one end restrained	4 09	4.83	4.8	4 00	no failure	-	decrease 9 min.	4.7
	E. Prestressed Concrete Floors											
140	'Stahlton' floor	7	12 0	SS	1 50	2.4	4.8	-	collapse	1 - 50	no change	3.7
73	Prestressed joists with filler blocks and concrete screed	6.5	12 0	SS	2 09	5.5	4.8	1 59	collapse	2 09	decrease 10 min.	3.9
271	do.	8	12 0	SS	2 00	2.45	4.8	-	no failure	-	increase	3.25
139	Prestressed joists with timber flooring	5.5	12 0	SS	0 45	10.0 (0-40)	4.8	0 36	0 - 39	temp.rise	decrease 3 min.	4.7
210	Prestressed joists with concrete topping	6.0	12 00	SS	1 18	7.5	4.8	1 02	1 - 18	collapse	decrease 16 min.	4.3
44	Hollow prestressed units	5.0	12 00	SS	0 29	3.75	4.8	-	0 - 29	collapse	no change	5.2

Ref	Construction	Thickness (d)	Span (l)	End conditions	Duration of fire test	Central deflection	Permissible deflection l/30	Time deflection criterion reached	Time of failure reported	Cause of failure reported	Change in fire resistance by applying deflection criterion	Deflection with criterion $l^2/800d$
		in.	ft in.		hr. min.	in.	in.	hr. min.	hr. min.			in.
94	Hollow units with concrete screed (1¼")	6.25	12 00	SS	1 28	4.1 (1 - 20)	4.8	1 20	1 28	collapse	decrease 8 min.	4.15
384	2 in. planks with 1 in. topping	3	12 00	SS	1 00	2.3	4.8	-	0 54	Integrity due to spalling	no change	8.6
448	do with ⅞ in. topping	5	12 00	SS	1 47	6.0	4.8	1 30	1 47	collapse	decrease 17 min.	5.2
428	Inverted U units	8	12 00	SS	0 37	1.0	4.8	-	0 37	Integrity due to spalling	no change	3.25
483	Inverted U units with mortar screed and ceilings of plaster or metal lath	7	12 00	SS	4 00	2.65	4.8	-	no failure	-	increase	3.7
630	2 in. planks with topping and plaster finish in ceiling	4	12 00	SS	1 49	12. 0	4.8	1 33	no failure	-	decrease 16 min.	6.5
786	do without finish on ceiling	4	12 00	SS	1 00	7.6	4.8	0 - 47	no failure	-	decrease 13 min.	6.5
627	Prestressed lattice beams with 1¼ in. screed	16	12 00	SS	0 - 47 47	0.5 (0 - 30) 6.0 (0 - 47)	4.8	0 45	0 47	Local temp. rise due to spalling	decrease 2 min.	1.62
	F. Cellular Steel Decks											
431	Deck with 2½ in. topping and ceiling finish	5.5	12 00	SS	0 16	6.0 (0 - 12)	4.8	0 10	0 16	collapse	decrease 6 min.	4.7
645	Steel troughing with concrete topping and lightweight plaster ceiling	6	12 00	SS	4 17	2.63	4.8	-	no failure	-	increase	4.3
612	Steel troughing with concrete topping and plasterboard ceiling	4.75	12 00	SS	0 32	1.6 (0 - 30)	4.8	-	no failure	-	increase	5.55
613	Steel troughing with concrete topping without a ceiling finish	5.5	12 00	one end restrained	1 03	6.3 (1 - 00)	4.8	0 52	no failure	-	decrease 11 min.	4.7

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Ref.	Construction	Thickness (d)	Span (l)	End conditions	Duration of fire test	•Central deflection	Permissible deflection 1/30	Time deflection criterion reached	Time of failure reported	Cause of failure reported	Change in fire resistance by applying deflection criterion	Deflection with criterion L²/800 d
F996	Cell	in.	ft in		hr. min.	in.	in.	hr. min.	hr. min.			in.
998	Cellular steel deck with concrete topping and sprayed asbestos on soffit	5.5	12 00	S.S.	5 30	2.4	4.8	-	no failure	[illegible]	increase	4.7
1041	Cellular steel deck with concrete topping and no ceiling	6.0	12 00	S.S.	0 38	6.0	4.8	0 37	no failure	-	decrease 1 min.	4.3
	G. Beams											
F47	Steel joist encased in a T-shaped concrete beam	12	10 3	S.S.	4 00	6.1	4.1	3 40	no failure	-	decrease 20 min.	1.6
F39	" " " "	12	11 00	R	6 00	7.9	4.4	4 58	no failure	-	decrease	1.8
F41	Reinforced concrete T-beam	11.5	10 3	R	3 24	1.2	4.1	-	3 24	collapse	no change	1.55
F42	" " "	11	10 3	R	3 03	1.5	4.1	-	3 03	collapse	no change	1.5
F51	" [illegible] "	11	10 3	R	4 02	4.6	4.1	-	no failure	-	decrease 2 min.	1.5
F52	(brick aggregate)	11	10 3	R	3 32	2.4	4.1	-	3 32	collapse	no change	1.5
R/16/59	" "	12	10 3	R	2 00	0.18	4.1	-	no failure	-	increase	1.6
202	Prestressed concrete beam	8	12 00	S.S.	2 00	6.8	4.8	-	1 17	temp rise	no change	3.25