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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

EFFECT OF RESTRAINT IN FIRE RESISTANCE TESTS

by

L. A. Ashton

Summary

The paper describes how restraint is applied to different types of specimen at the Fire Research Station, and the reasons for adopting these methods are given. Data showing the effect of varying the restraint for a given type of specimen are scarce, but the evidence available is examined, and suggestions are made for specifying the procedure which should be adopted in Standards for fire resistance testing.

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Fire Research Station,
Boreham Wood,
Herts.

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INTRODUCTION

Fire tests must necessarily be made under standardized conditions. There is no question that a great variety of conditions will be met with in actual fires, both with regard to the fire itself and to the loading and restraint to which an element of structure is subjected. It is generally agreed that the standard fire shall be a constant factor in all tests and that the loads applied to the specimen in the test shall produce stresses of the same magnitude as those which the element is designed to support in service. With regard to restraint, however, there may be an argument for attempting to reproduce more closely than is the practice at present the actual conditions in a building when a fire occurs.

The conditions at the edges or ends of a given type of structural element vary widely in different buildings and in different parts of the same building. Any attempt to alter from test to test the restraint applied to a given type of specimen is difficult to apply, even if the appropriate conditions of restraint can be determined. In the United Kingdom restraint is applied to floors, beams and walls in a standard manner. For example, concrete floors are constructed for test purposes in a frame of steel beams encased in concrete to simulate the effect produced in a building by the beams surrounding a floor panel. The degree of restraint obtained in practice may be greater than this, as when one or two panels of a large floor are exposed to fire; or less, as when the complete floor is heated at the same time. A similar argument applies to non-loadbearing walls which are constructed for test in a heavy steel frame protected with concrete which applies a high degree of restraint at all edges.

The conditions at the edges of a specimen in the fire test may have a significant influence on its fire resistance, since they will in general affect the deformation produced during fire exposure. The following notes describe the conditions adopted at the United Kingdom Fire Research Station for floors, beams and walls, and cite test data showing the effect on fire resistance of varying the restraint applied to given types of structure.

Effect of edge conditions on fire resistance

(1) Floors

A type of floor which may be simply supported in service is tested in this condition. Timber floors are always tested simply supported, and generally floors constructed of factory-made units are most appropriately tested in this way. An exception is made where a floor construction of this type is designed for a particular purpose which involves a given degree of restraint. Then for this application the intended method of restraint, may, if practicable, be adopted for the test. Floors which are restrained in the test are those containing reinforced concrete slabs and these are all treated alike, being constructed in a standard "restraint" frame which gives a reasonable degree of resistance to the expansion of the specimen and to angular movement at the edges.

The standard restraint frame shown in Figure 1 consists of rolled steel beams of I-section, 12 in. x 8 in. x 65 lb/ft, forming a rectangle with inside dimensions of 12 ft 5 in. x 10 ft 5 in. At their junctions the members are connected by angle cleats and gusset plates. When the floor specimen is cast, concrete, monolithic with the slab, is placed round the frame members, and the continuity reinforcement is bent round them and embedded in the concrete. Originally the frame was made of 12 in. x 5 in. members (two 6 in. x 5 in. beams placed one on top of the other), but the heavier frame was substituted after experience had shown that thick reinforced concrete slabs caused considerable distortion of the lighter frame. Heavy frames have now been in use for about 18 years, and when encased in concrete are sufficiently rigid to withstand, without significant distortion, the stresses imposed by the largest specimens, as shown by the relative ease with which the frame assemblies can be unbolted and taken apart when required to be stored. The support moments appear from the behaviour of specimens to simulate reasonably well those which would be provided under normal loading conditions by continuity of a construction over supporting beams. Information is lacking at present, however, of the effect on a continuous structure of exposure to fire of one portion of it, but an investigation is being planned to provide data on this aspect, and these will enable also an appraisal to be made of the validity of certain of the assumptions made in restraint.

The effect of restraint, of the degree described above, on the fire resistance of three types of floor has been obtained by testing both restrained and simply supported specimens of similar construction as follows:-

(a) Filler joist floor 6 in. thick; joists 4 in. deep with 1 in. concrete cover top and bottom; gravel aggregate concrete; no plaster.

Test data

	Restrained floor	Simply supported floor
Imposed load	60 lb/ft^2	25 lb/ft^2
Duration of test	2 hours	3 hours 35 minutes
Mode of failure	Did not fail	Local temperature rise on unexposed face
Maximum deflection	1·5 in.	10·4 in. (5·5 in. at 2 hours)

(b) Reinforced concrete slab floor $4\frac{1}{2}$ in. thick; main reinforcement $\frac{3}{8}$ in. diameter with $\frac{1}{2}$ in. concrete cover; gravel aggregate concrete; no plaster.

Test data

	Restrained floor	Simply supported floor
Imposed load	150 lb/ft^2	75 lb/ft^2
Duration of test	42 minutes	1 hour 22 minutes
Mode of failure	Formation of hole	Collapse
Maximum deflection	3.4 in.	6 in. at 50 minutes

(c) Hollow clay tile floor $5\frac{1}{2}$ in. thick with $\frac{1}{2}$ in. plaster on soffit; clay tiles 4 in. thick; concrete $1\frac{1}{2}$ in. thick over tiles; $\frac{3}{4}$ in. cover to reinforcement in concrete ribs; gravel aggregate concrete; soffit plastered.

Test data

	Restrained floor	Simply supported floor
Imposed load	115 lb/ft^2	75 lb/ft^2
Duration of test	2 hours 23 minutes	2 hours 46 minutes
Mode of failure	Local temperature rise on unexposed face	Collapse
Maximum deflection	5.0 in. at 2 hours 20 minutes	22.6 in. at 2 hours 40 minutes

It will be noted that as far as complying with the "insulation" requirement for fire resistance is concerned, there may be little difference between restrained and simply supported floors, as in (c), but that restraint is more favourable to the occurrence of spalling of concrete and may lead to earlier "integrity" failure of a restrained floor as in (b). At present British Standard 476 (1) defines "load" failure of an element of structure as collapse, and since there is no limit on deformation a restrained floor may not be superior to a simply supported floor since "insulation" failure of a simply supported floor may occur before collapse (a).

(2) Beams

Comparative tests have been made on two typesof steel beam under conditions of simple support and of a high degree of longitudinal and angular restraint. In addition some evidence is available of the effect on fire resistance of applying longitudinal restraint to prestressed concrete beams. The frame in which the beams are mounted for test is shown in Figure 2. It is in the form of an inverted "U" of heavy steel beams, the joints between the vertical legs and the horizontal member being designed to develop the full moment of resistance of the section. Protection of concrete was cast round each leg, and this concrete was monolithic with that of the restrained beams. Under these conditions the connexion of a steel beam to the restraint frame by means of cleats behaves very nearly as a perfectly rigid joint (2).

(a) Steel beam of I-section 10 in. x $4\frac{1}{2}$ in. carrying reinforced concrete slab 4 in. thick and encased in concrete giving cover of 1 in. at sides and bottom.

Test data

	Restrained beam	Simply supported beam
Imposed load (central)	10 tons	10 tons
Duration of test	6 hours	4 hours
Mode of failure	Did not fail	Did not fail
Maximum deflection	7.9 in. at 6 hours (0.5 in. at 4 hours)	6.1 in. at 4 hours

(b) Steel beam of I-section 7 in. x 4 in. encased with concrete giving side and bottom cover of 2 in.

Test data

	Restrained beam	Simply supported beam
Imposed load (central)	5.5 tons	3.9 tons
Duration of test	5 hours 26 minutes	3 hours 46 minutes
Mode of failure	Did not fail	Did not fail
Maximum deflection	3.0 in. at 5 hours 25 minutes (0.6 in. at 3 hours 45 minutes)	3.0 in. at 3 hours 45 minutes

(c) Prestressed concrete beams with post-tensioned cable, consisting of <u>in situ</u> concrete slab on precast beam 9 in. deep x 5 in. wide; gravel aggregate concrete.

Test data

	Restrained beam	Simply supported beam
Imposed load	10.9 tons	10.9 tons
Duration of test	1 hour 29 minutes	1 hour 38 minutes
Mode of failure	Fracture of concrete and yield of cable	Fracture of concrete and yield of cable
Maximum deflection	0.66 in. at 1 hour 25 minutes	3.0 in. at 1 hour 30 minutes

Since for beams the only criterion of failure in the test of B.S.476 is collapse, no clearly defined end point can be determined in testing restrained steel beams with concrete encasements. The test data show that the degree of restraint is unlikely to be critical unless failure is also defined in terms of deformation. With prestressed concrete beams of the dimensions given, a high degree of longitudinal restraint did not significantly affect the fire resistance, but the influence of restraint on mode of failure is worthy of note. Collapse occurred with little warning, without the gradual increase in deflection as in the simply supported beam. The liability to fail in this manner is an undesirable property in structural elements of any type, and other things being equal, a form of construction which yields gradually is to be preferred. Therefore, for prestressed concrete beams which may be restrained in service, it may be necessary to introduce in the test a high degree of restraint in order to show the effect of possible end conditions on their fire behaviour.

(3) Walls and partitions

(a) Loadbearing walls

Tests on loadbearing walls are made on elements which have their vertical edges free, and no data are available on the effect of introducing lateral restraint on the fire resistance of a given type of wall. The method adopted was similar to that used in normal structural testing, and there do not appear to be sufficient grounds for altering this practice, especially as a complication of the test equipment would be involved.

This could hardly be justified in view of the relative unimportance at present of loadbearing walls of such a small thickness that their fire resistance is in doubt. In general the thickness necessary for structural purposes ensures that the fire requirements will be amply met.

(b) Non-loadbearing walls

All non-loadbearing walls are tested in the same manner and no attempt is made to change the edge conditions according to the type of construction being tested. Comparative tests are lacking, therefore, which would enable an appraisal to be made of the effect of restraint on fire resistance. Specimen walls are built for test in the 10 ft square opening of a restraint frame constructed, as shown in Figure 3, of heavy steel beams of 24 in. x $7\frac{1}{2}$ in. x 90 lb/ft section encased in refractory concrete. Observations of the behaviour of walls during a fire test lead to the conclusion that a frame of this construction imposes a high degree of restraint on the specimen, and that consequently a test made in this way represents the extreme conditions which might be encountered in service. Although such a test can be regarded as the most severe, experience has shown that with the greater proportion of walls this is not of prime significance, for while the deformation of a given type of specimen is greater than would be obtained with less restraint, this is rarely likely to lead to earlier collapse or integrity failure.

REFERENCES :

(1) British Standard 476 : Part 1 : 1953, Fire tests on building materials and structures.

(2) Pippard, A. J. S. and Baker, J. F. The analysis of engineering structures p. 436. London, 1957. Edward Arnold Ltd.

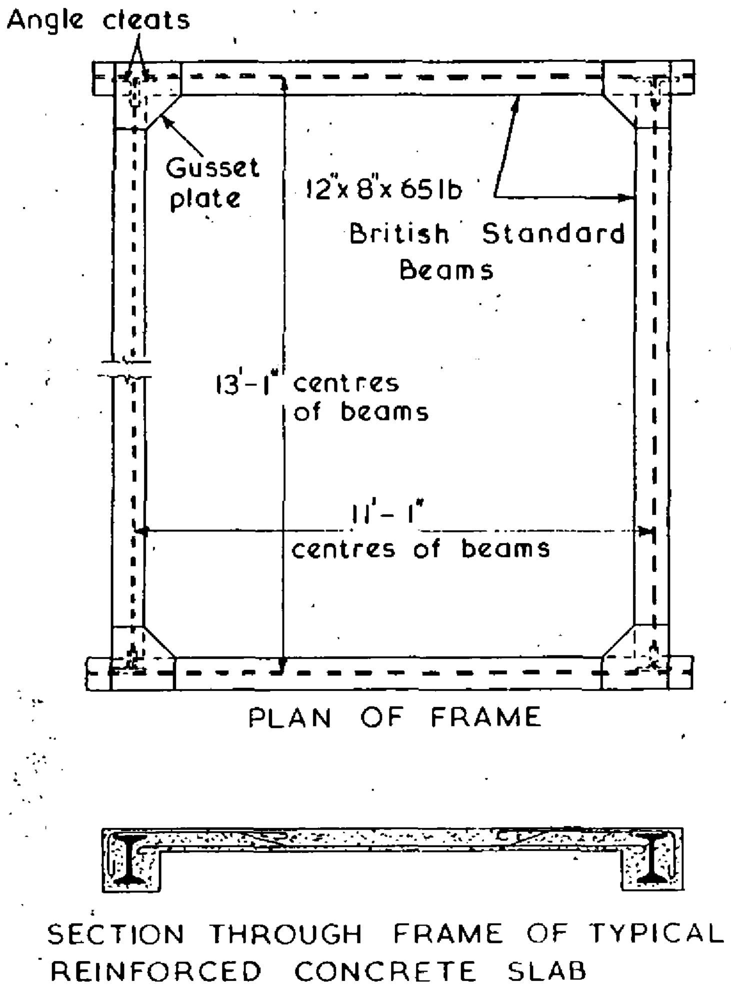

FIG.1. STEEL FRAME FOR RESTRAINED FLOORS

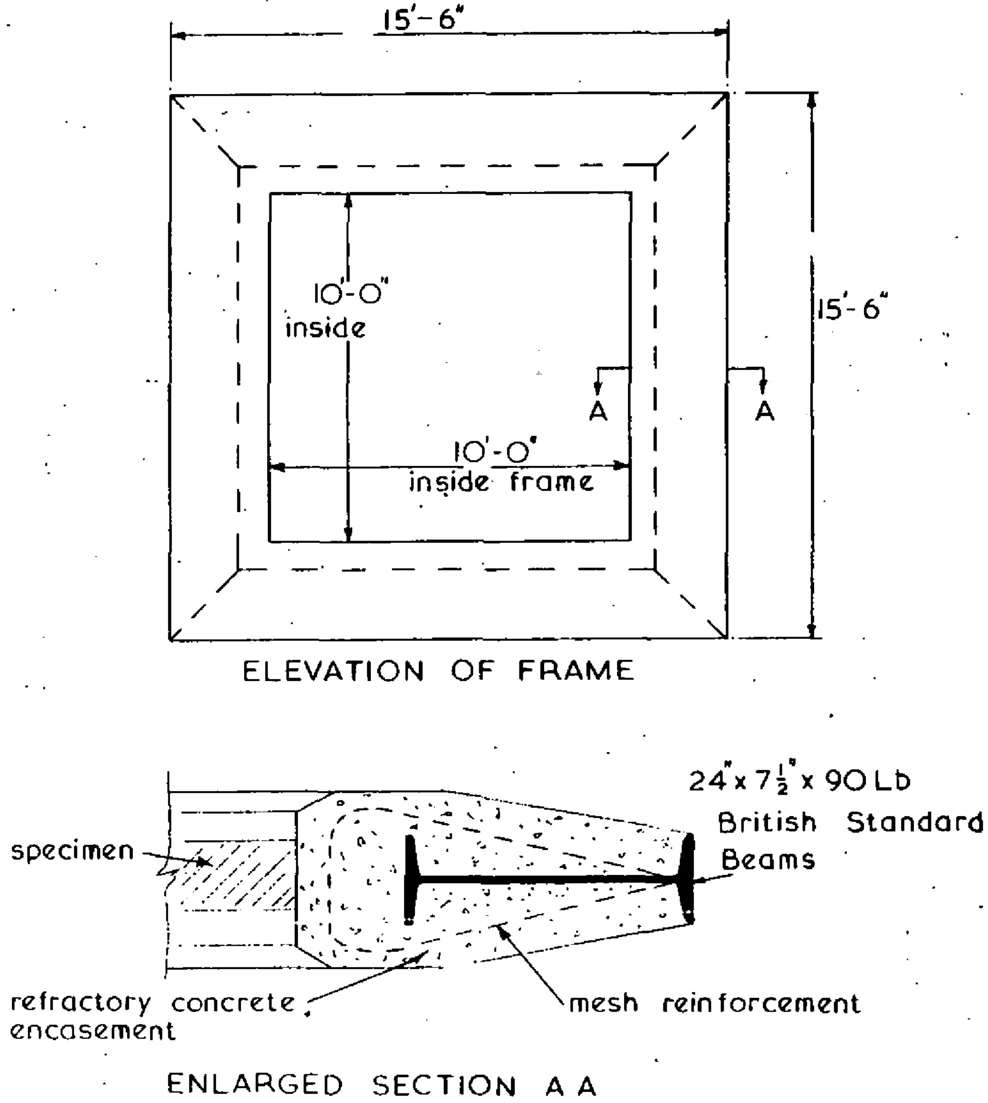

FIG. 3. RESTRAINT FRAME FOR WALLS

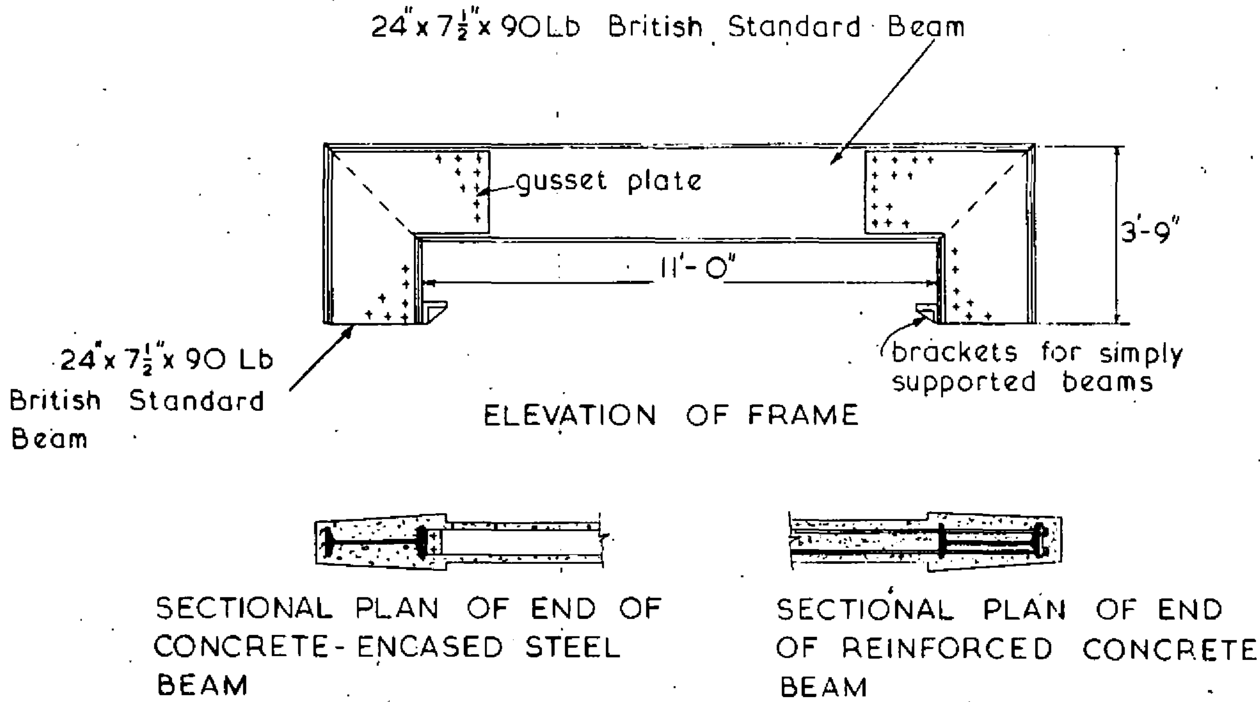

FIG. 2. STEEL FRAME FOR BEAMS