Fire Resistance of Concrete Floors

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[List continued on cover page III]

Errata to accompany National Bureau of Standards Building Materials and Structures Report BMS 134 "Fire Resistance of Concrete Floors."

Page 4, right column, section 4.6. Formula (1) should read:

$$t_f = \beta\rho L^{1.7} 10^{-\frac{\rho}{a}}$$

Page 5, the sentence immediately above table 2 should read:

The difference between the β values for siliceous- and calcareous-aggregate concretes was considered to be real and may be attributed to endothermic changes that take place in calcareous-aggregate concretes when heated, which would tend to increase the fire endurance.

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UNITED STATES DEPARTMENT OF COMMERCE • Charles Sawyer, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

Fire Resistance of Concrete Floors

Daniel S. Goalwin

Building Materials and Structures Report 134

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Foreword

This report is one of a series issued by the National Bureau of Standards dealing with the fire resistance of building materials and constructions. It indicates the results in a series of tests of concrete floors.

The information is intended to aid building authorities and regulatory groups in evaluating the fire-resistance characteristics of concrete floor constructions and to give designers and builders a basis for the selection of constructions that will meet given requirements with respect to fire resistance.

A. V. Astin, *Director.*

Contents

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Daniel S. Goalwin

The results of eleven exploratory and four full-scale fire-endurance tests on reinforced concrete floors are given. All the slabs were monolithic and were made with gravel aggregates; six consisted of slabs cast to engage the tops of precast lightweight concrete joists. The effects of moisture content, aggregate type, and soffit protection are discussed. A general equation for the relation between slab thickness and fire resistance for different aggregates is proposed.

1. Introduction

The increasing use of concrete slab floors in industrial and commercial building and multiple residential dwellings emphasizes the need for adequate fire-resistance ratings of these components. The proper selection of fire-resistant floor material, together with a closure of vertical openings, can restrict fires in large buildings to one floor for a considerable length of time, allowing proper abatement measures to be taken in the rest of the building.

This report covers the result of 11 exploratory fire-endurance tests and 4 full-scale tests on monolithic concrete floors made with siliceous-gravel aggregates. It includes a series of tests on reinforced slabs of 4- to 8-in. thickness tested to determine the relationship between floor thickness and fire resistance, as well as on a series of six 2½- and 3-in.-thick floors tested primarily to investigate the fire resistance of concrete floors made with prefabricated concrete joists. Several of the tests were made to determine the fire-endurance limits of a particular construction without regard to other constructions; therefore, some of the data are lacking that are essential to an over-all evaluation of the relationships between the fire endurance and such variables as the slab thickness, type of aggregate; strength and density of the concrete, and method and time of curing the concrete. The specific results presented should be of interest to laboratory workers, designers, builders, and the writers and administrators of building codes.

2. Test Methods

The full-scale tests were made in accordance with the American Society for Testing Materials Specification E119–47, and the American Standards Association Standard Specifications for Fire Tests of Building Construction and Materials, No. A21–1942, which require that a fire exposure with standard time-temperature relation shall be applied to the under side of a test floor having no dimension less than 12 ft and an area of at least 180 sq ft. The specifications require that the floor must carry a continuously applied load sufficient to cause the maximum allowable working stress in the structural members. The criterion of failure may be either (a) structural (load failure), (b) the passage of direct flame or hot gases through the floor, or (c) a rise of the average temperature on the upper surface of the floor of 250° F or of the temperature at a single point on the upper surface of 325° F.

An average temperature rise of 1,000 deg F on the reinforcing steel or of 1,200 deg F at a single point on the reinforcing steel is considered critical in these tests, inasmuch as the yield strength of carbon steel at 1,000° F is only about half its value at 70° F, and it decreases even more markedly as the temperature rises above 1,000° F. The standard fire-exposure temperatures specified are shown in the various curves of test results, together with the actual temperatures achieved. While the tests of the small floors, those suffixed with the letter A, may be considered exploratory, every effort was made to use the standard time-temperature curve. Loadings were in accordance with the ASA test specifications except for floors 70A, 71A, and 72A, which were tested primarily to study the effects of moisture content and were tested without load.

The floors were tested in gas furnaces. The furnace temperatures were achieved by means of gas burners in the furnace below the test floor. Temperature measurements were obtained with 12 chromel-alumel thermocouples in the large furnace and 6 in the small furnace, symmetrically arranged and encased in iron protection tubes. The temperature of the upper surface of the floors was measured by means of thermocouples placed on top of the floor and protected against radiation and convection effects by 6- by 6-in. dry felted-asbestos pads 0.4 in. thick. In some of the tests thermocouples were also embedded at various points within the floor construction.

The loads on the floors were selected to cause the maximum allowable stress in the test members and varied from about 40 to 80 lb/ft^2.

The floor deflections were measured during the tests to obtain a quantitative measure of load failure or an indication of approaching load failure. Deflection measurements when made were by means of weighted wires running over a pulley system to the outside of the test structure, where pointers were read against graduated scales.

Curing of the floors was in two stages: during the first stage, the floors were covered with burlap and kept wetted; during the second stage, the floors were heated from underneath, the furnace temperature varying in different tests from 100°

Table 1. *Summary of fire-endurance tests of reinforced-concrete floor constructions* [1]

Floor or slab	Construction [2]								Test data[1]				
				Concrete			Reinforcement					Failure [4]	
	Thickness	Figure number	Type	Mix cement:sand: aggregate, by volume	Compressive strength	Thickness protecting reinforcement	Size	Spacing	Figure number	Age	Fire intensity	Criterion	Time
	in.				*psi*	*in.*	*in.*	*in.*		*Days*	*Percent*		*hr min*
25A	4	1	Monolithic slab	1:2:4	2,370	⅜	⅜	7	------	30	88	Steel temperature Surface temperature Load	1 27 1 34 1 46
23A	4	1 (25A)	do	1:2¼:4½	3,000	1	⅜	7	------	30	95	Temperature Load	1 13 1 15
27A	3¼	1	Monolithic slab plus ¾-in. gypsum plaster on lath on underface.	1:2:4	2,810	¾ (bars laid on lath).	⅜	7	6	28	103	Steel temperature Surface temperature Load	1 10 1 21 1 41
29A	4	--------	Monolithic slab	1:2:4	2,830	1 1/16	½	7¾	------	38	96	Temperature Load	1 25 1 28
30A	5	1	do	1:2:4	1,790	1	½	6	6	32	98	Steel temperature Load Surface temperature	1 44 1 52 2 00
31A	6	--------	do	1:2:4	2,020	1	½	4½	------	39	103	Load Temperature	1 55 2 35
35A	6	2	do	1:2:4	---------	1	½	5½	6	33	95	Steel temperature Load Surface temperature	2 05 2 07 2 47
38A	8	2	do	1:2:4	---------	1½	½	4½	7	------	100	Steel temperature Load Surface temperature	2 30 3 38 4 40
70A	3	2 (71A)	Slab on precast concrete joists: embedment 1-in., spacing 36 in.[5]	1:3½:4¼	2,500	½	(6-gage wire fabric)	------	------	33	96	Temperature	0 38
71A	3	2	do	1:3½:4¼	2,500	½	do	------	10	30 41	93 100	do do	1 00 0 43
72A	3	2 (71A)	do	1:3½:4¼	2,500	½	do	------	------	150	------	do	0 50
37	6	3	Slab cast monolithic with beams and girders.	-----------	2,100	1	½	8	5	26	100	Steel temperature Surface temperature [6] Average surface temperature. Spalling	2 38 3 08 3 27 6 00 [7]
47	2½ 3	-------- --------	Slab on precast concrete joists: thin portion, embedment ½ in., spacing 2 ft 5 in.; thick portion, embedment 1 in., spacing 2 ft 10 in.[5]	1:2¾:3¼	4,750	½ (thin portion). 1 (thick portion).	¼	9	------	21	83	Spalling	0 34
48	3	4	Slab on precast concrete joists with ceiling of ½-in. gypsum wallboard: 1-in. embedment, spacing 3 ft.[5]	1:3½:4	2,700	½	6-gage wire fabric.	------	------	28	93	Load	0 57 [8]
49	3	--------	Slab on precast concrete joists (same as 48 but no soffit protection and reinforcement placed higher in joists).[5]	1:3½:4	2,740	½	do	------	10	28	90	Steel temperature Surface temperature Load	0 44 0 48 0 57

[1] Floors 37, 47, 48, and 49 were 13½ by 17 ft in horizontal area; all the others were 4½ by 9 ft.
[2] All slabs were of gravel aggregate. Potomac River gravel mineral content: vein quartz 21%, quartzite 38%, sandstone 23%, chert 12%. Potomac River sand mineral content: vein quartz 90%, mica 4%.
[3] All floors, except 70A, 71A, and 72A, were loaded to 20,000-psi nominal stress. These three were not loaded.
[4] All failures by temperature rise were by average rise on unexposed surface, unless otherwise indicated.
[5] The tensile reinforcement in the joists consisted of 0.5-in.-diam deformed bars, the compressive and web reinforcement of 0.265-in.-diam rods. The strength of concrete in joists was 2,290 psi; deflection 0.42 in. at 162 lb/linear ft; yield load, 415 lb/linear ft.
[6] At one point only.
[7] No failure of beams at 6.0 hr.
[8] Temperature rise limit not reached at 1 hr 10 min.

to almost 250° F. The total curing time ranged from 21 to 41 days, with one exception.

The monolithic constructions were made with siliceous aggregates from ½ to 1¼ in. maximum size. Proportions of the mixes are given in table 1.

The full-scale floors, 37, 47, 48, and 49, were about 13½ ft wide by 17 ft long. Smaller floors about 4½ ft wide by 9 ft long were also tested to provide data on other variables. Construction details of some of the floors are shown in figures 1, 2, 3, and 4; loading data and details of the mixes and curing are tabulated in table 1.

3. Test Results

The compressive strengths of control cylinders were measured at the end of the curing period for each of the floor slabs; the data are given in table 1. Compressive strengths of the prefabricated joists used in floors 47 through 49 and 70A through 72A are also given in table 1. Time-temperature curves for some of the slabs are given in figures 5, 6, 7, and 10. Each of the graphs shows the standard, maximum, and average furnace temperatures, the average and maximum temperatures of the slab top, and, in some cases, the average and maximum temperatures in the principal reinforcement. Figures 8, 9, 11, and 12 show the condition of some of the specimens before and after test. The fire intensity, defined as the ratio of actual temperatures to standard temperatures integrated over the period of the test, is also given in table 1.

4. Discussion

4.1. Type of Aggregate

Deflection of a slab due to differential thermal expansion in the material takes place in the direction of the heated surface and is, with certain simplifying assumptions, proportional to the temperature gradient through the slab, the square of a linear slab dimension, and the coefficient of thermal expansion [1].[1] As concretes made with limestone or blast-furnace slag (calcareous aggregates) in general have lower coefficients of thermal expansion than do concretes made with gravel or quartz (siliceous) aggregates [2, 3, 4] smaller deflections may in general be expected for slabs of the former than for the latter. Menzel's data [5] on concrete walls give qualitative confirmation.

In addition, the temperature rise within siliceous-aggregate concrete slabs will be greater than for calcareous-aggregate concrete slabs under similar test conditions due to the higher thermal conductivity [6, 7]. Data on the thermal conductivities of concretes are scarce, but, as with most solid materials, such conductivities are found to increase with temperature. For clay brick, for instance, the thermal conductivity doubles between 100° and 2,000° F.

Chemical changes also take place as the concrete is heated. Large volume changes take place as a result of chemical action in chert and quartz at relatively low temperatures; these tend to aggravate strains due to differential expansion in the structure. Chemical changes in concretes made of calcareous aggregates are endothermic, thus tending to retard temperature rise in the structure.

Entrapment of water or water vapor in the more impervious concretes may have a deleterious effect on their fire resistance. While the moisture has a high heat capacity and consequently retards the temperature rise, the pressures developed on heating and the resultant expansion of the water cause additional strains in the structure and may cause flaking or spalling. This effect has been observed not only with quartz and chert gravel aggregates but also with high-strength concretes in which the aggregates were limestone or crushed firebrick [8].

The tests reported herein were made only on concretes of siliceous aggregates, and, with one exception, Potomac River gravel of ½- to ¾-in. size was used. The fire resistance on corresponding units made of calcareous or high-grade cinder aggregate concretes may be assumed to be higher [9, 5].

There is some evidence that the fire endurance of concrete containing siliceous aggregate alone increases slightly as the strength or impermeability of the concrete decreases. The data are not sufficient to draw quantitative conclusions. However, it is interesting to note that for the series of 4-in.-thick slabs of similar construction and aging, the failure by temperature rise varied from 1.22 hr with 3,000-psi concrete to 1.57 hr with 2,375-psi concrete, and the time of load failure varied from 1.25 hr with the 3,000-psi concrete to 1.77 hr for the 2,375-psi concrete.

4.2. Effect of Restraining Forces

Load failure of concrete slabs subjected to the fire test may be influenced by the type of restraint against lateral expansion. If the floor is restrained at the edges, the resulting stresses will accelerate spalling; in an unrestrained floor, the only expansion stresses are those due to thermal gradients in the slab. The large slabs of this series may be considered to be partially restrained because of light framing at the edges and the lower temperatures toward the edges of the slab. The 4½- by 9-ft floors tested in the small furnace may be considered to have been entirely unrestrained except for the negligible bearing friction at the ends and the temperature gradient toward the edges. Ingberg [1] discusses the effect of restraint on fire endurance in some detail.

4.3. Moisture Content

For most of the tests of this series, data on moisture content of the concrete at the time of test are not available. A relationship may be expected to exist between moisture content of the concrete and the fire endurance, higher moisture content at the start of the fire exposure resulting in greater resistance to the fire. In the case of some dense concretes, however, excess moisture content may result in spalling as pressure is built up within the concrete.

As the method of curing was fairly similar for all the slabs tested, the indications are that the differences in fire resistance were probably not due entirely to the variation in moisture content of the slabs. The control slab of one of the floors, cured in a manner typical of the entire group of floors, decreased in weight by 3.1 percent in a drying period of 21 days, during 14 of which it was being heated. Another control slab showed a residual moisture content of 4 percent at the time of the test.

Most of the floors were aged for 30 days and, while they were oven-heated for part of this time, they may not have been as dry as construction that had been in place for several years; it is generally

[1] Numbers in brackets indicate the literature references at the end of this report.

considered that a concrete slab in place in a heated building will lose most of its free moisture in from 1.5 to 2 years. In this respect, it may be interesting to compare the results of tests made on floors of identical construction, 70A and 71A. Floor 70A, which had been heated at 100° F for 1 week and at 150° F for an additional week, took 38 min to reach the limiting temperature on the upper surface at an age of 28 days. Floor 71A, which was not oven-heated, took 60 min at an age of 39 days to reach the same limiting temperature. Floor 71A was retested 11 days after the first test, at which time it may be considered to have been representative of a condition of extreme dryness. In the retest, the limiting temperature was reached in 43 min.

Menzel's data [5] on concrete wall slabs includes a retest of each slab after the initial nonload-bearing fire test. The reductions in time to reach limiting temperature in the retest as compared to the original test ranged from 7 to 48 percent. Menzel's floors had been cured for 1 year without auxiliary heating before the first tests.

4.4. Soffit Protection

The data in this series of tests are, with one or two exceptions, for floors without plaster. It is recognized, of course, that the addition of a properly designed ceiling below a floor can increase the fire resistance of a reinforced concrete slab.

In floor 48, the joists were protected by a ceiling of ½-in. gypsum wallboard that had been painted with one coat of cold-water paint. Parts of the wallboard began to fall after 15 min of exposure to fire, and the entire wallboard had fallen by 30 min. The duration of the applied fire was 1 hr 10 min, at which time the temperature limit had not been reached, the floor having failed under load. Floor 49, consisting of a slab similar to that of floor 48 but without soffit protection, failed by temperature rise at 48 min. The ceiling thus gave at least 20 min of additional fire protection to the slab.

Floor 27A was protected by ¾-in. gypsum plaster on lath on the underface of the slab. This 3¼-in. slab failed by temperature rise at 1 hr 21 min as compared to an average failure time of 1 hr 30 min for three 4-in. slabs of the same general construction but with no plaster protection. Load failure occurred at 1 hr 54 min compared with an average of 1 hr 30 min for the 4-in.-thick floors.

Other tests have shown more conclusively the effectiveness of plaster as a fire retardant whether applied on metal lath or directly to the concrete. The Canadian code, for instance, allows a reduction of up to 1 in. in slab thickness if a ceiling of ¾-in. gypsum plaster is used.

4.5. Joists

The precast joists of floors 47, 48, 49, 70A, 71A, and 72A (figs. 2 and 4, and table 1, footnote 5) contained haydite, a burned-clay aggregate (lightweight). The performance of the unprotected joists of floor 47 could not be determined because of early failure of the slab by spalling. In the cases of both floors 47 and 48, the bond between the joists and the slab was found to be broken. The encasement of the upper part of the joists in the slab was 0.5 to 1.0 in.

To prevent bond failure in floor 49, the ¼-in. compression bars were moved 1 in. upward so as to be adjacent to and just inside the top of the joist, and the joists were embedded 1 in. into the slab; the joist web rods thus served as reinforcement against shear of the joists at the level of the bottom of the slab. This also gave additional concrete protection below the steel of the joists. The tension steel in this floor reached 1,000° F in 44 min, the upper surface of the floor reached limiting temperature in 48 min, and the floor failed under load at 57 min. The joists spalled only slightly, and the bond between the joists and floor did not fail. The unprotected joists thus have a fire endurance of approximately ¾ hr, the load-carrying ability of the joists under fire being dependent upon the thickness of the concrete protecting the steel.

4.6. Effect of Slab Thickness and Density

The fire endurance of a concrete slab, as determined by temperature rise only, is plotted in figure 13 against the slab thickness. Although the scatter of the points is large, the fire endurance may be best represented as varying with the 1.7 power of the slab thickness. This relation of thickness to fire resistance is also given in BMS92 [10][2] for other types of construction.

An empirical relation has been developed giving the time for failure of a concrete slab due to 250 deg F temperature rise as a function of the density of the concrete and the thickness of the slab. This formula is

$$t_f = \beta \rho L^{1.7} 10^{-\frac{\rho}{2}}, \qquad (1)$$

where t_f is the time to failure by 250 deg F temperature rise, L is the slab thickness, ρ is the specific gravity of the concrete (water=1), and β is a proportionality constant.

The validity of equation 1 for predicting the results of fire-endurance tests has been evaluated by calculating β for fire tests conducted at the National Bureau of Standards and in the Portland

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[2] The thermal conductivity of concrete is obtainable from data given in reference [7] and unpublished NBS data as

$$k = a.10^{\frac{\rho}{2}}, \qquad (2)$$

where k is the thermal conductivity, a is the constant, ρ is the specific gravity of the concrete.

Cement Association Laboratories in Chicago [5] on 28 concrete slabs of various aggregates and thicknesses. Some of the slabs were tested vertically, some horizontally. The data and calculated values are listed in table 2. In this table t_f is in hours, ρ is dimensionless (specific gravity), L is in inches, and β is a constant of mixed units that includes specific heat and the heat-transfer coefficient.

The average value of β for siliceous-aggregate concrete slabs was found to be 0.74; for slabs of calcareous aggregates, 0.96; for haydite, 1.00; and for a mixture of siliceous and haydite aggregates, 0.87. The difference between the β values for siliceous- and calcareous-aggregate concretes was considered to be real and may be attributed to exothermic changes that take place in siliceous-aggregate concretes when heated, which would tend to decrease the fire endurance. It may be noted that the specific gravities of the siliceous- and calcareous-aggregate concretes were very similar.

The above β values were obtained from data on typical medium-dry slabs. In accordance with data obtained by retesting slabs after the initial fire tests, the "bone-dry" condition may be reasonably represented by a decrease in fire endurance of from 10 to 35 percent. Very wet slabs may be expected to have fire endurances not exceeding 30 percent greater than those calculated from equation 1.

TABLE 2. *Validity of generalized fire-resistance formula*

Aggregate [1]	Source of data [2]	Thickness, L	Specific gravity [3] ρ	Time to failure, t_f	Proportionality constant, [4] β	Deviation from average
		in.		*hr*		
S	M	4	2.26	1.10	0.65	0.09
S	M	6	2.24	2.50	.72	.02
S	M	8	2.20	4.55	.75	.01
S	NBS	4	2.2	1.28	.72	.02
S	NBS	4	2.2	1.35	.76	.02
S	NBS	4	2.2	1.42	.80	.06
S	NBS	5	2.2	2.00	.76	.02
S	NBS	6	2.2	2.58	.70	.04
S	NBS	6	2.2	2.82	.76	.02
S	NBS	8	2.2	4.67	.78	.04
S	M	6	2.25	2.63	.75	.01
S	M	6	2.24	2.50	.70	.04
S	M	6	2.26	2.38	.68	.06
S	NBS	3	2.2	1.00	.82	.08
S	NBS	3	2.2	0.83	.70	.04
Average					0.74	0.04
C	M	4	2.35	1.37	0.82	0.14
C	M	6	2.37	3.27	.98	.02
C	M	8	2.35	5.52	1.00	.04
C	M	6	2.45	3.02	.98	.02
C	M	6	2.40	3.27	1.00	.04
Average					0.96	0.05
H	M	4	1.39	2.33	0.82	0.17
H	M	6	1.38	6.38	1.02	.02
H	M	8	1.47	10.0	1.02	.02
H	M	6	1.46	8.12	1.09	.09
H	M	6	1.38	6.38	1.02	.02
Average					1.00	0.07
SH	M	6	1.80	3.98	0.83	0.04
SH	M	6	1.88	4.20	.89	.02
SH	M	6	1.84	4.23	.88	.01
Average					0.87	0.02

[1] S=siliceous; C=calcareous; H=haydite; SH=equal quantities siliceous and haydite aggregates.
[2] M=Menzel (slabs tested vertically); NBS=National Bureau of Standards (slabs tested horizontally).
[3] Specific gravity (ρ) values for the NBS slabs are average values based upon measurements of representative slabs.
[4] $\beta=\frac{t_f}{\rho}L^{-1.7}10^{\frac{\rho}{2}}$.

4.7. General

In all the tests described in this report, the fire was applied to the underside of the floor in accordance with ASA specifications for fire tests. It is to be expected that fire conditions on the upper side of the floor will not be as severe as on the bottom of the slab because of convection effects, and that the fire endurance of concrete floors will be as great or greater when exposed to fire from the top as when exposed from the bottom.

The effect of reinforcement has not been investigated thoroughly. It is apparent that if the protection for the reinforcing bars is not adequate, the temperature rise in the bars may be such as to cause failure due to decrease in yield strength, even though the temperature on top of the floor has not risen the necessary amount to cause failure by temperature rise. (The yield strength of carbon steel drops rapidly as the temperature approaches 1,000° F.) Menzel [5] presents some interesting data on the temperatures within the slab, indicating the concrete covering required under the reinforcement for a given protection for the steel. For siliceous sand and gravel, a concrete covering of 1 in. under the reinforcement in a 6-in. slab keeps the steel temperature below 1,000° F for 1½ hours.

The results of tests of essentially identical floors were found to differ considerably, due in part to uncontrolled or unreproducible variables, such as differences in the moisture content, workmanship, size of aggregates, density of concrete, and details of curing and framing. The tests provide qualitative information as to the ranges of fire endurance to be expected and the character of failure to be encountered.

Acknowledgement is made to the various manufacturers who supplied materials and assisted in the erection of some of the full-scale floors, to S. H. Ingberg, N. D. Mitchell, H. D. Foster, and other members of the Fire Protection Section who planned, supervised, and conducted the tests.

5. References

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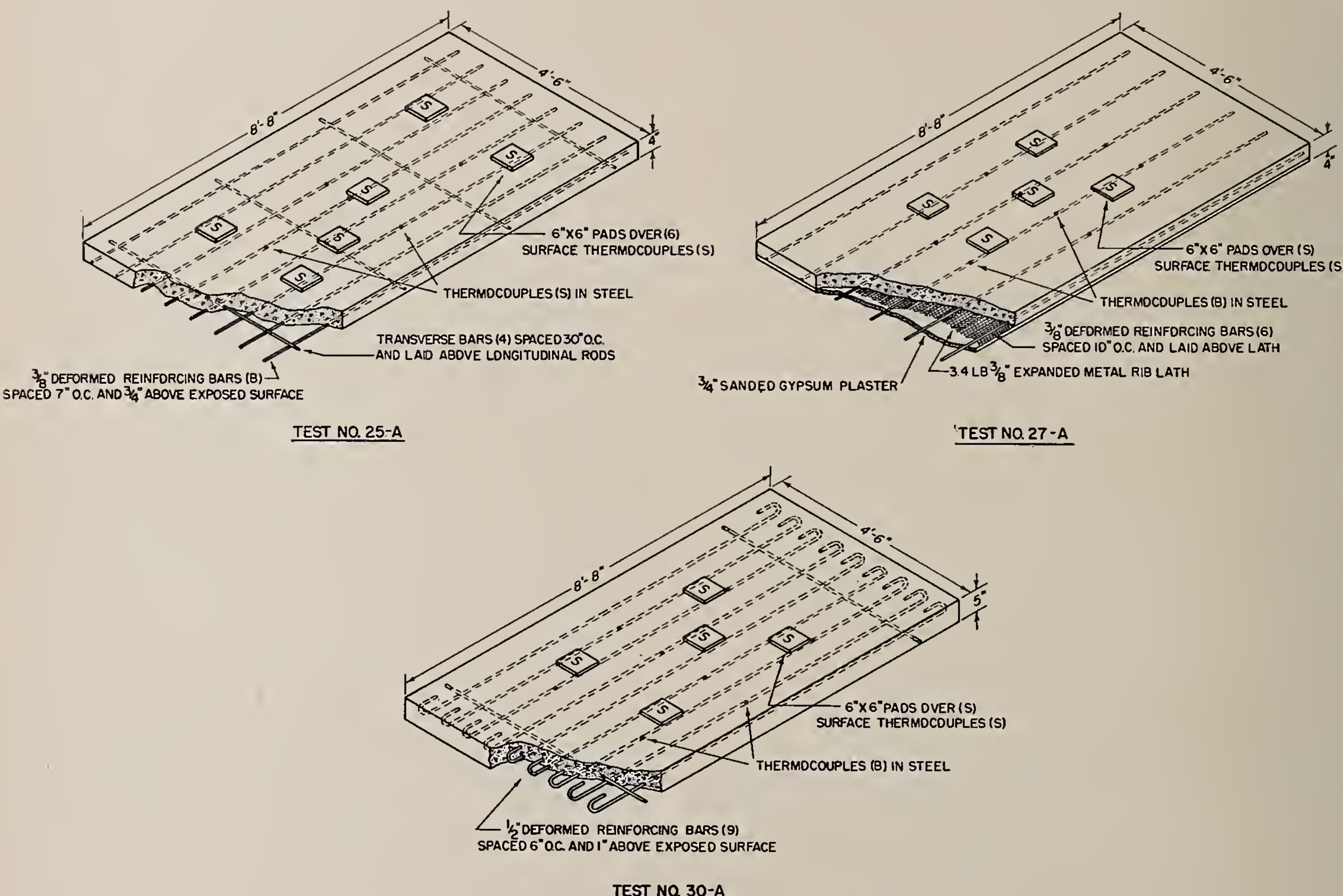
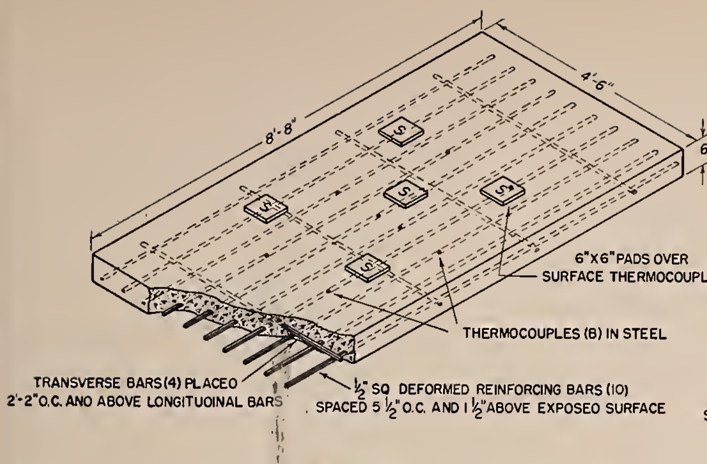
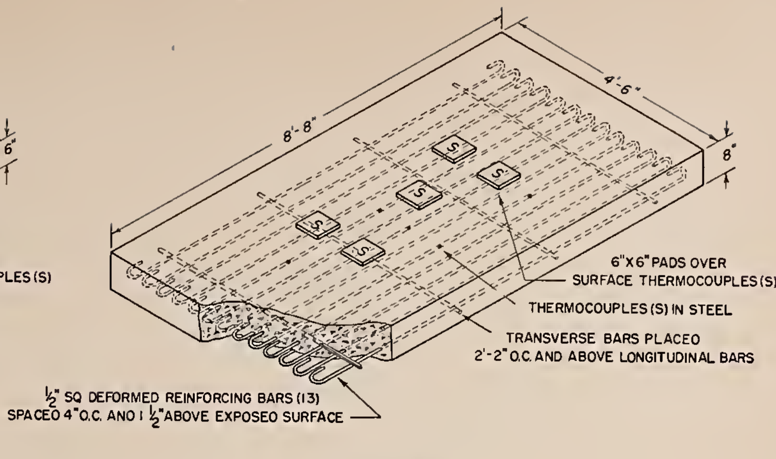


Figure 1. *Construction of floors 25A, 27A, and 30A.*





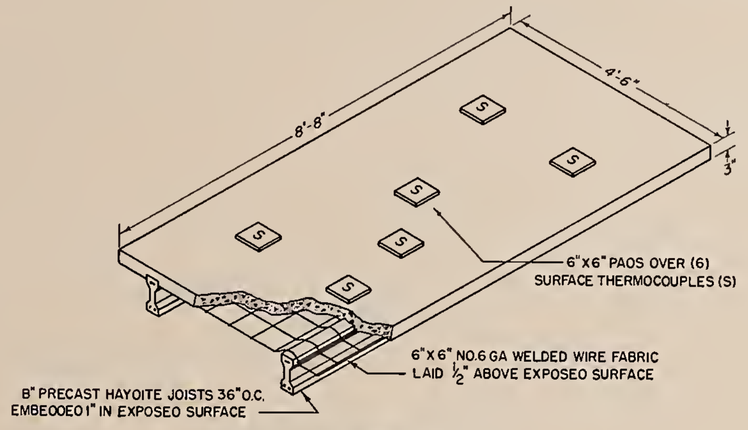


FIGURE 2. *Construction of floors 35A, 38A, and 71A.*

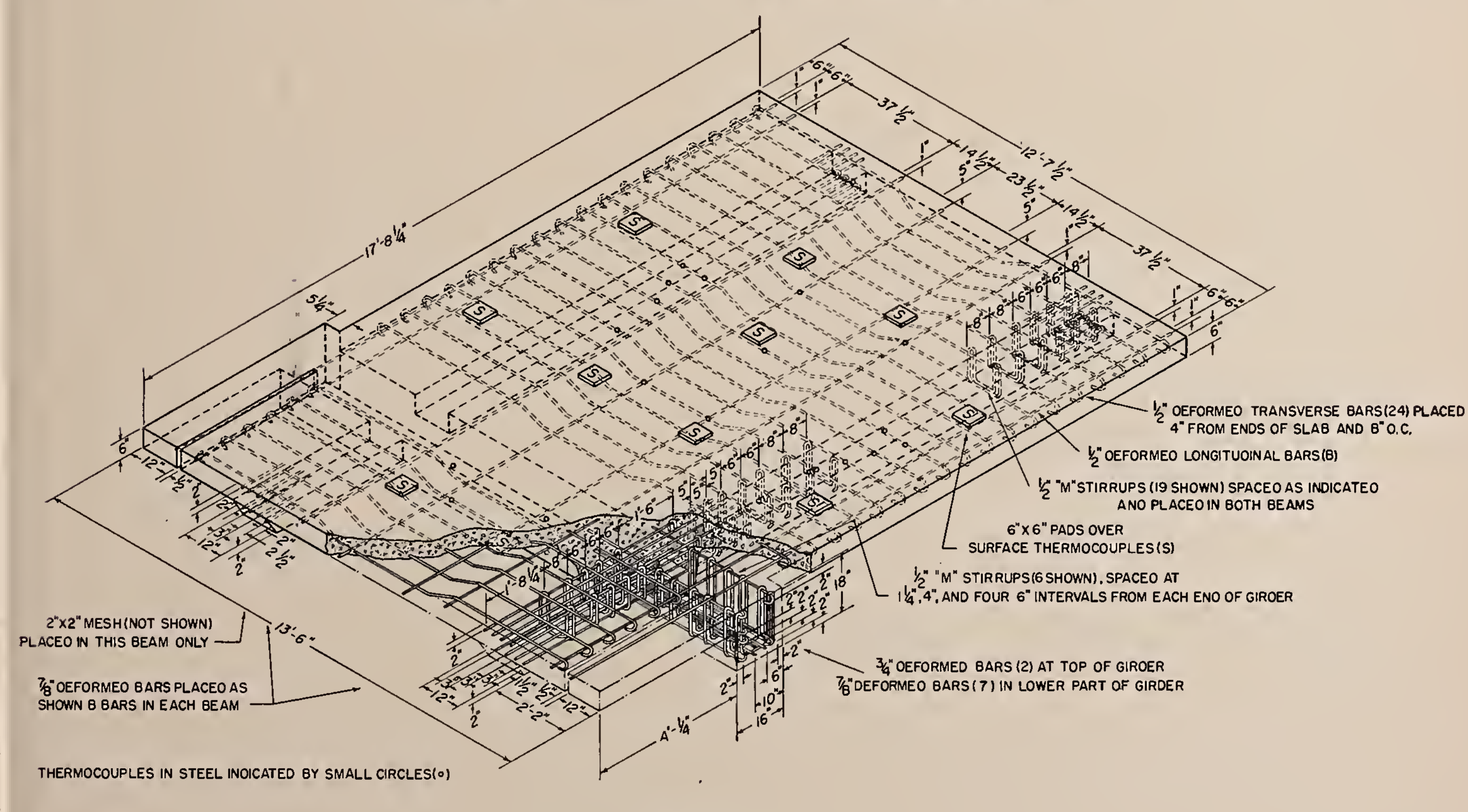


FIGURE 3. *Construction of floor 37.*

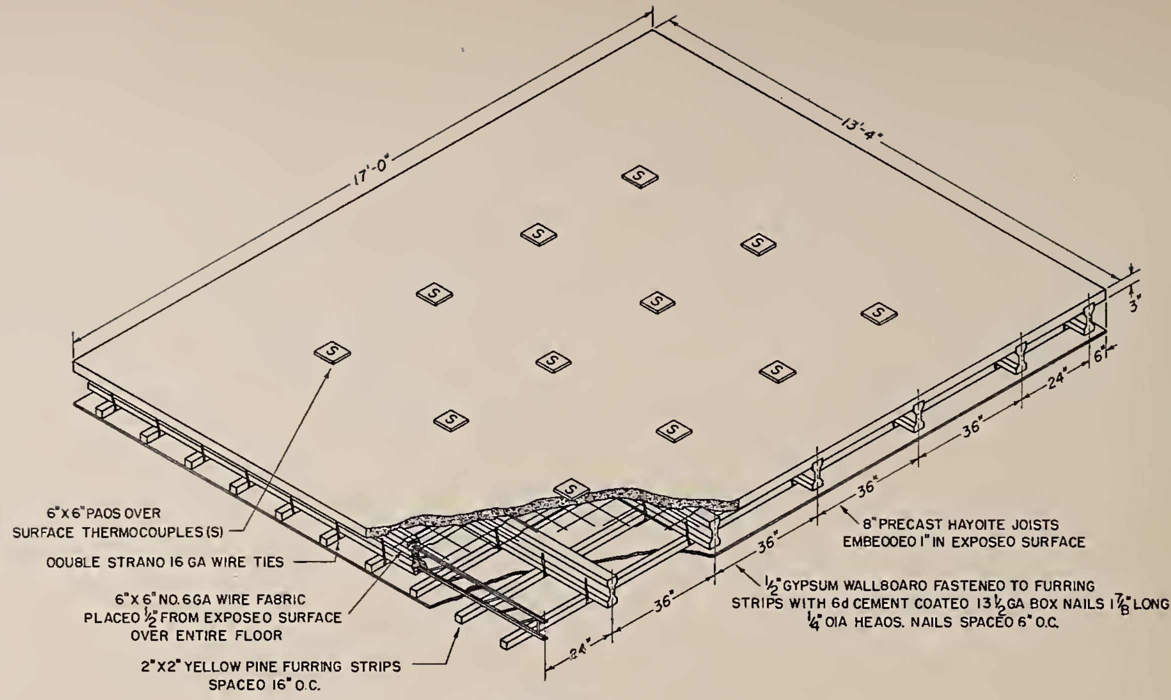


FIGURE 4. *Construction of floor 48.*

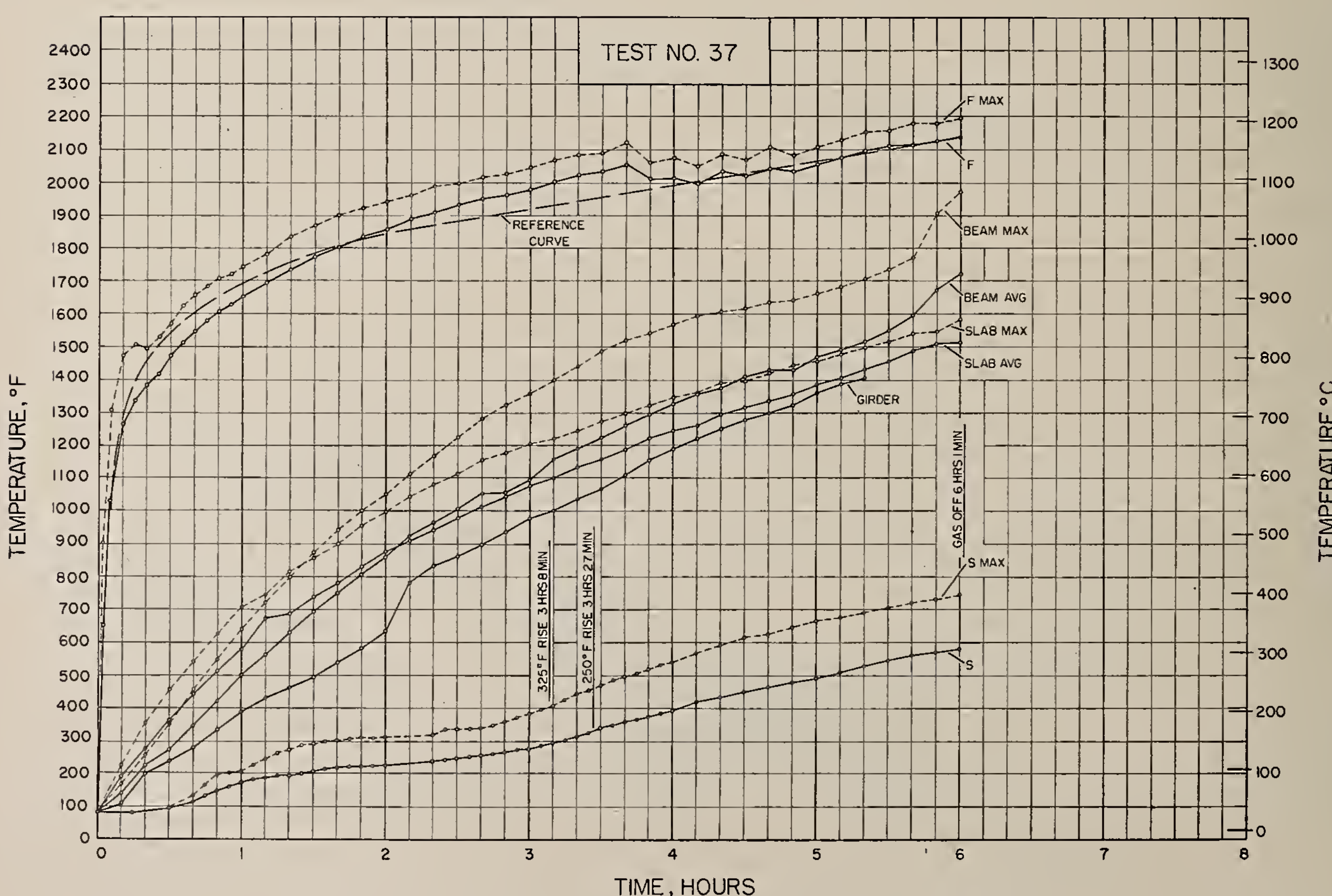


FIGURE 5. *Surface, steel, and furnace temperatures for floor 37.*

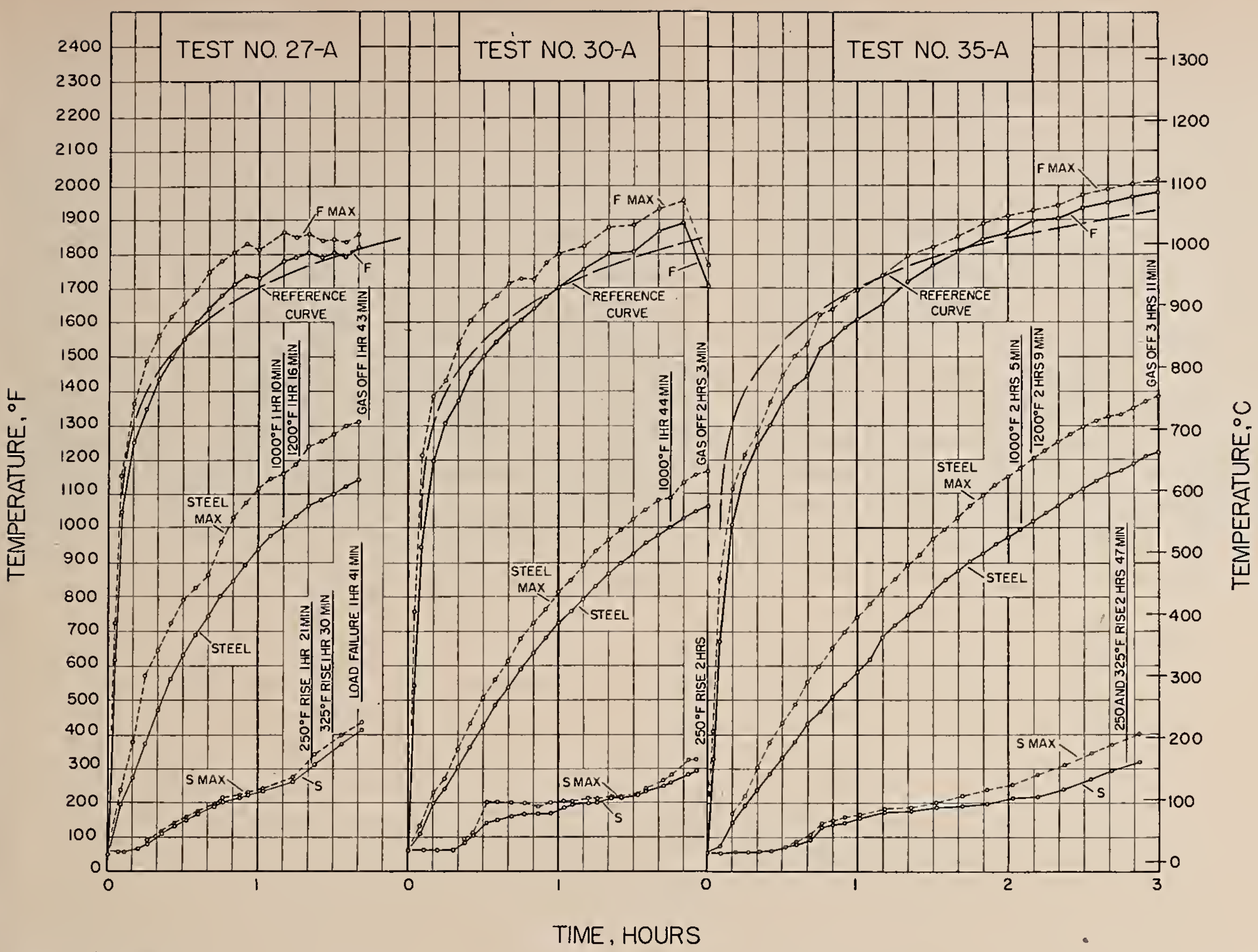


Figure 6. *Surface, steel, and furnace temperatures for floors 27A, 30A, and 35A.*

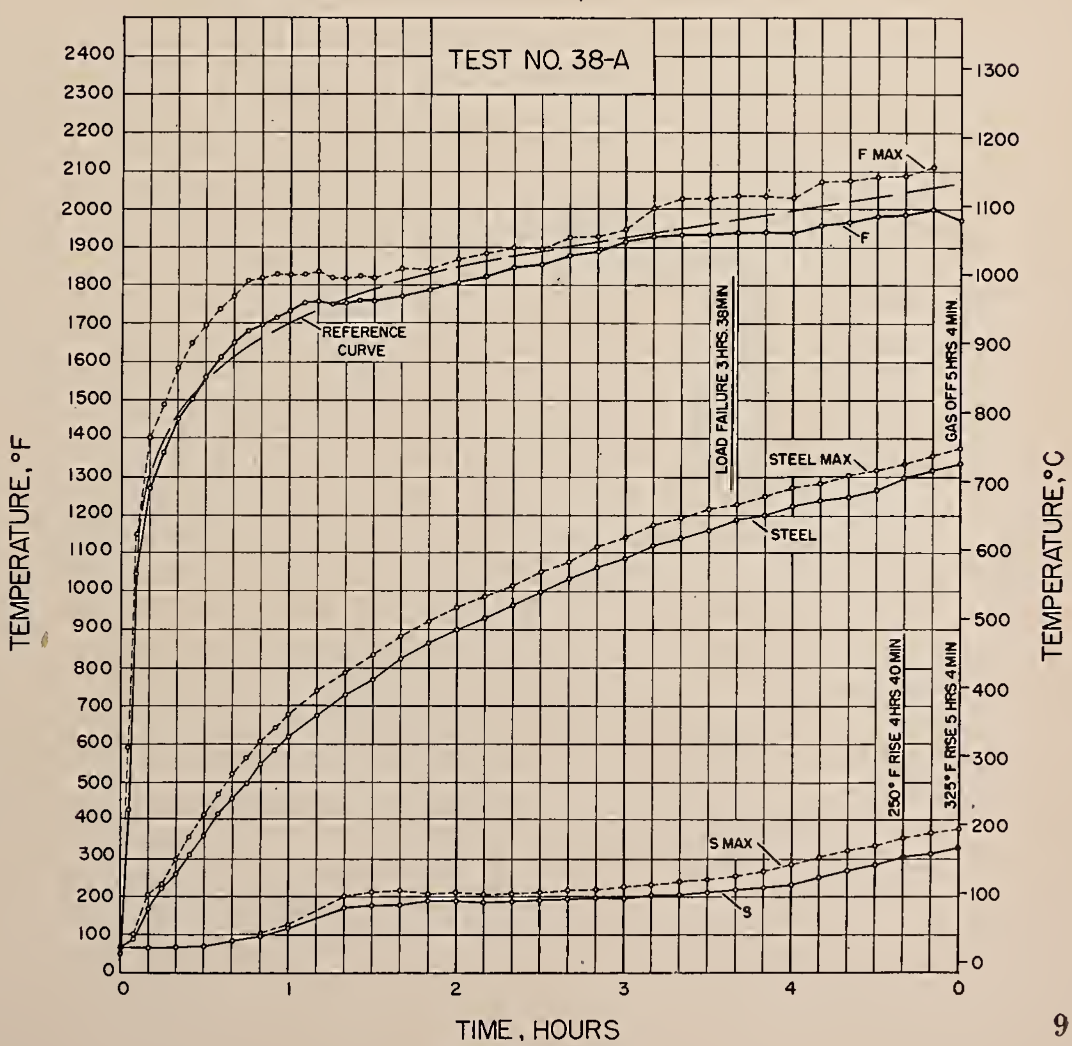


Figure 7. *Surface, steel, and furnace temperatures for floor 38A.*

FIGURE 8. *Floor 47 after test showing holes in 2½-in. slab formed by spalling.*

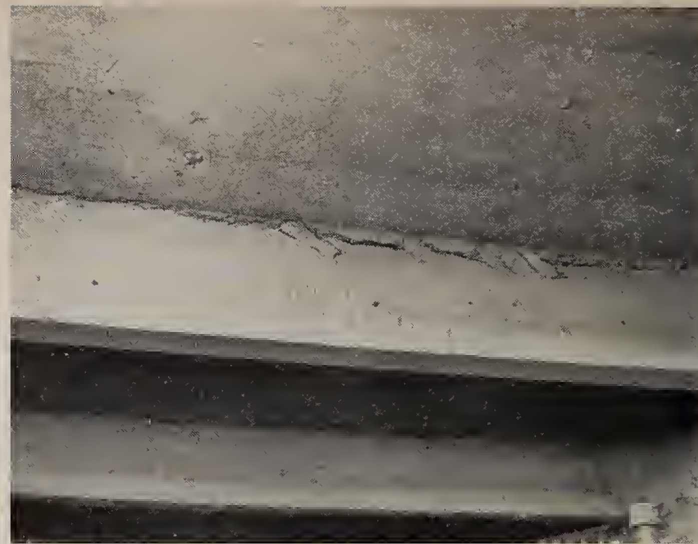


FIGURE 9. *Detail showing shear failure between joist and 3-in. slab of floor 47.*

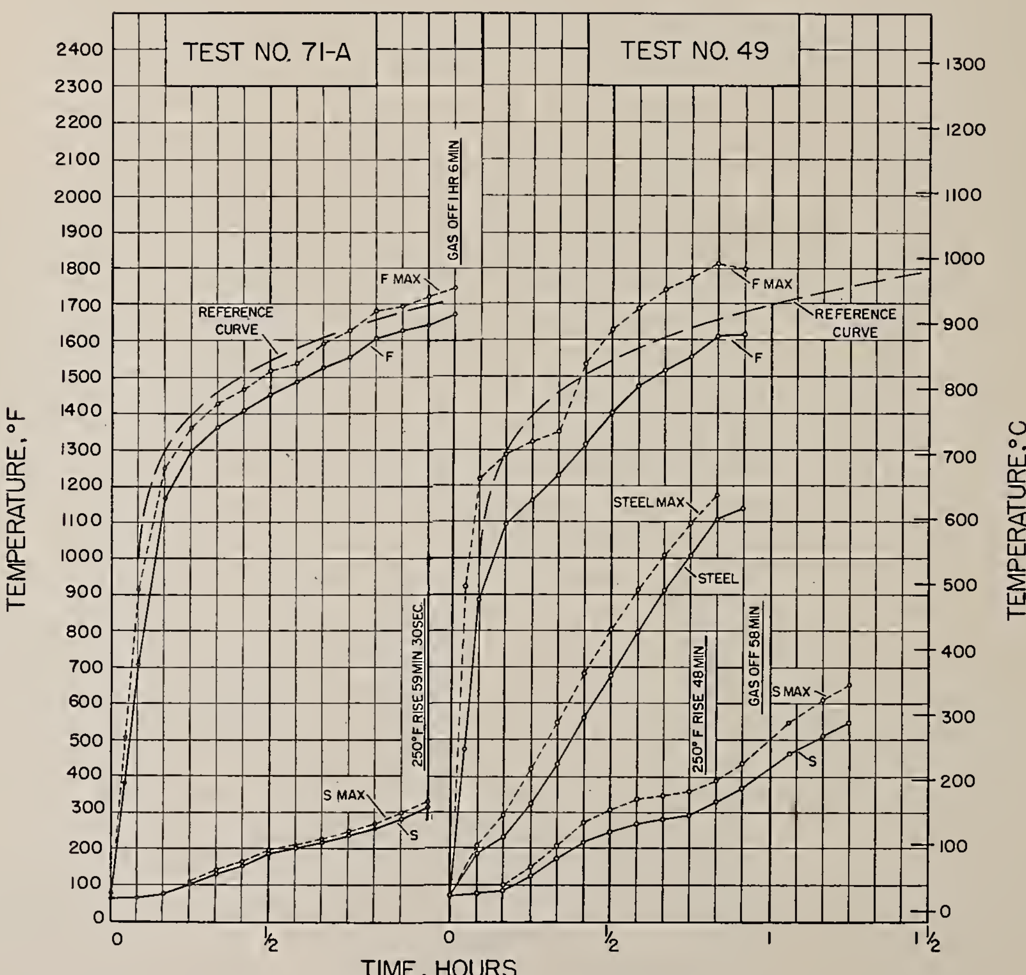


FIGURE 10. *Surface, steel, and furnace temperatures for floors 71A and 49.*

Figure 11. *Exposed side of floor 48 after fire-endurance test.*

Figure 12. *Unexposed surface of floor 49 after fire-endurance test.*

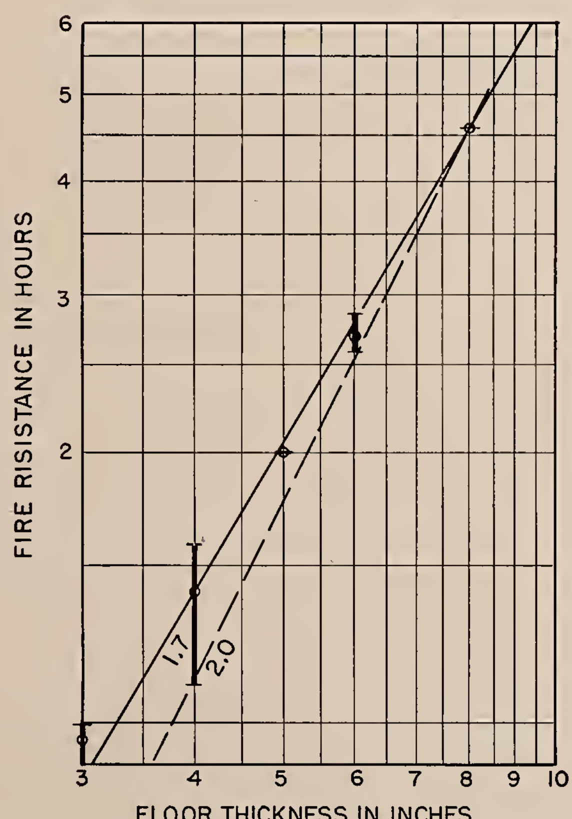


Figure 13. *Fire resistance, t_f, as a function of slab thickness, L (log-log plot).*

Vertical lines show range of data; circles show average fire endurance for a given thickness. The solid line, 1.7 power, gives the best linear fit; the dashed line shows that a 2.0 power might also conceivably fit the data.

Washington, October 6, 1952.

U. S. GOVERNMENT PRINTING OFFICE: 1952

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[Continued from cover page II]

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