Fire Tests of Steel Columns Encased With Gypsum Lath and Plaster

United States Department of Commerce
National Bureau of Standards
Building Materials and Structures Report 135

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Fire Tests of Steel Columns Encased With Gypsum Lath and Plaster

Nolan D. Mitchell and James V. Ryan

Building Materials and Structures Report 135

Issued April 3, 1953

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Foreword

This report, one of a series issued by the National Bureau of Standards on building materials and structures, presents the results of fire tests of steel building columns protected by gypsum lath and gypsum plaster, the latter incorporating three different aggregates. Such materials are generally available and are in common use in standard building practice.

The fire-endurance limits of protected columns described in this report may serve as a guide for the selection of constructions to meet building-code requirements and as a measure of the extent of compliance of building practice with existing codes.

A. V. Astin, *Director.*

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The results presented are those derived from fire-endurance tests of 16 steel columns encased with gypsum lath and gypsum plasters. The laths were wired into place; those on eight columns were of the ⅜-in. thick perforated type in a single layer, those on seven of the other eight columns were of two layers of the ½-in. thick plain type, and on the other a single layer. Six of the latter eight also had a layer of wire fabric to reinforce the plaster. Expanded perlite was used as the plaster aggregate for 13 columns, sand for two, and vermiculite for one. The thickness of the plasters ranged from ½ in. to 2 in. and those of the encasements from ⅞ in. to 2½ in.

The fire-resistance values indicated by the tests varied with the composition, reinforcement, and thickness of the protective coverings, and to some degree with the size of the column. The fire-endurance limits, as determined from the tests, ranged from 1 hr 23 min for a 10-in. steel H-section column protected with ⅜-in. perforated lath and ½ in. of sanded gypsum plaster to 4 hr 42 min for one protected with two layers of ½-in. lath, and a 1½-in. thickness of perlite-gypsum plaster reinforced with wire fabric.

1. Introduction

The fire resistance of columns is considered of prime importance in buildings. Building regulations usually require fire-resistive columns, whether they support roof or floors. Columns are also frequently used in conjunction with partitions or walls in the subdivision of large buildings into fire areas. The number of these areas is determined by the required fire resistance which, in turn, is governed by the type of construction and the amount of combustible material involved in the occupancy of the building. The fire-resistance ratings of columns or other building members are based upon the results of standard fire tests on representative constructions.

Inasmuch as gypsum laths and lightweight plasters are extensively used as protective coverings for steel structures, a series of fire tests of columns so protected was undertaken as a part of the program of research on building materials and structures at the National Bureau of Standards. Sixteen steel H-section columns encased with various combinations of gypsum laths and plasters comprised this series. Two of the 16 columns were subjected to fire tests while under load.

2. Materials

The materials used in the test columns were of commercial quality typical of those normally used in building construction.

2.1. Steel Columns

The steel columns were fabricated to the designs shown in figure 1. Those to be subjected to test without load are shown as A, and those for test under load as designs B and C. They were fabricated under contract by a local plant and the workmanship was of good quality.

2.2. Laths

The thicknesses and breaking loads for the three brands of long length ½-in. laths and five brands of 16- by 48- by ⅜-in. perforated gypsum laths received, as well as the ASTM specification requirements for these characteristics, are given in table 1. Two or more brands of laths were used as the plaster bases on each of 13 of the columns, for the other three columns, 273, 294, and 314, a separate brand was applied on each.

TABLE 1. *Characteristics of gypsum laths*

Lot [2]	Thickness		Load on bearing edge [1]			
	Nominal	Measured	Across fiber		Parallel to fiber	
			Average	Minimum	Average	Minimum
	in.	*in.*	*lb*	*lb*	*lb*	*lb*
A_1	½	0.532	162	161	47	47
A_2	½	.495	162	148	57	52
A_3	½	.500	155	154	43	42
B_1	½	.484	148	142	43	42
B_2	½	.475	142	129	40	37
C	½	.507	122	117	42	39
D_1	⅜	.360	78	75	22	22
D_2	⅜	.380	74	71	37	35
D_3	⅜	------------	69	64	21	------
E_1	⅜	.359	78	75	24	22
E_2	⅜	.362	71	68	20	18
E_3	⅜	------------	71	61	19	18
F_1	⅜	.357	81	80	24	22
F_2	⅜	------------	80	77	25	24
G	⅜	.390	85	82	[3] 22	21
H	⅜	.376	66	62	(4)	------
S[5]	½	.500 ±0.031	100	100	40	40
S[5]	⅜	.375 ±0.031	60	60	27	27

[1] The samples were tested under the methods specified in ASTM Designation: C37-50, except that in some cases the supply of lath was insufficient to provide the five specimens required.
[2] Lots A, B, and C were ½-in. unperforated laths, all others were of the ⅜-in. perforated type. All lots having the same letter designation were from the same manufacturer.
[3] The results of strength tests of two of the five specimens of lot G, as tested parallel to the fiber, were discarded because they differed by more than 15 percent from the average, as required by the test method.
[4] There were no specimens of the sample from lot H available for the test for strength with load applied parallel to the fiber.
[5] Specification requirements of ASTM Designation: C37-50.

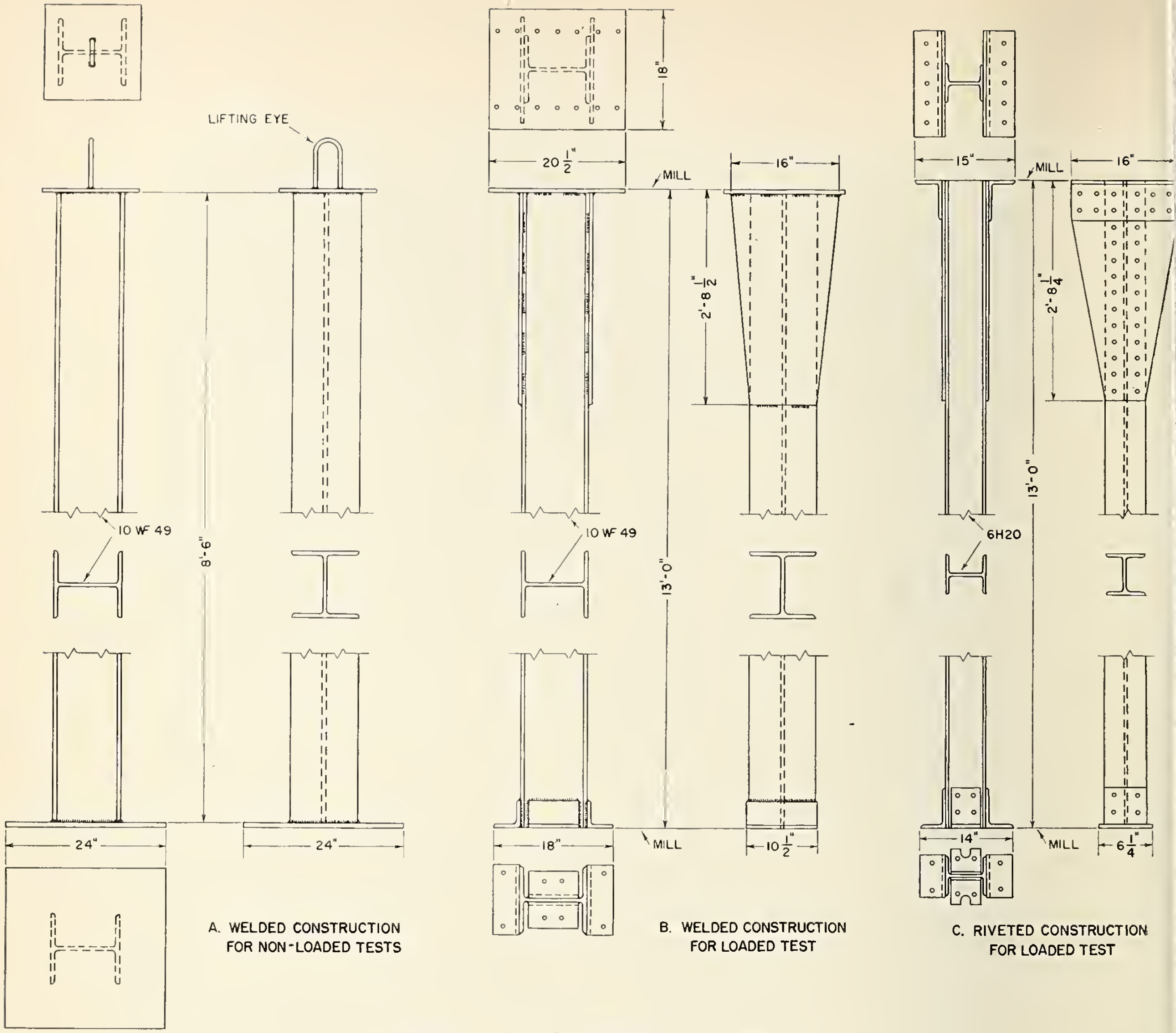


FIGURE 1. *Details of steel test columns.*

2.3. Lathing Accessories

The lathing accessories used included: woven wire fabric, tie wire, expanded metal angles (cornerite), corner beads, and staples.

The plaster encasements of six columns had 1-in. hexagonal mesh, 20-gage (0.036-in. diameter), galvanized wire fabric weighing 0.6 lb/yd^2 as reinforcement. The galvanized tie wire used by the lathers was standard 18-gage, 0.042-in. diameter.

The expanded metal angles were a commercial product known as cornerite, fabricated from 6 in. wide strips of 2.5-lb/yd^2 expanded metal lath bent 90 degrees along the centerline. The corner beads were a solid nose type made from 26-gage galvanized steel with 2½-in. wide expanded metal flanges. They weighed 190 lb/1,000 lin ft.

2.4. Plaster

Several lots of each of two brands of fibered gypsum plaster were used. Each lot complied with the requirements of Federal Specification SS–P–402 for fibered neat gypsum plaster. The physical and chemical properties of these two plasters, as determined by the methods prescribed in the specification and compressive strengths of 2-in. cubes prepared in the laboratory, are given in table 2.

2.5. Aggregates

The three types of aggregates used, sand, perlite, and vermiculite as shoveled into a 1-ft^3 measure, weighed, respectively, 100, 8.6, and 7.3 lb/ft^3. Typical sieve analyses of the three are given in table 3.

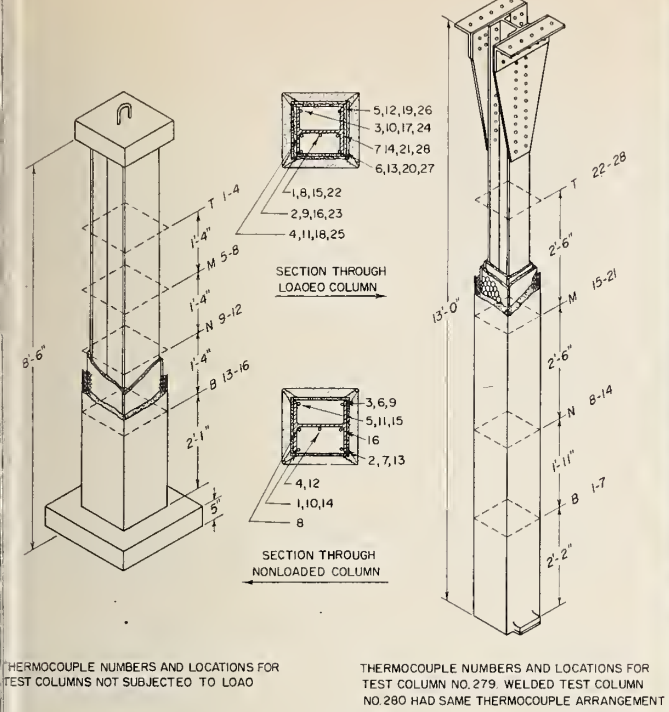


FIGURE 2. *Locations of thermocouples on columns.*

FIGURE 3. *Columns in various stages of lathing and application of corner bead.*

3. Construction Details

3.1. Thermocouple Mounting

Thermocouples were mounted on the flanges and webs of the steel columns at each of four levels, four at each level on those tested without load, and seven at each level on those tested under load, as shown in figure 2. The thermocouple wires were laid along the column web, thence through a 1-in. pipe at the top to the instrument indicating temperatures.

3.2. Column End Protection

The columns for test without load were provided with steel plates to restrain the protective coverings of the column shafts from longitudinal expansions greater than that of the steel column, as required by the standard method of test. These plates were, in turn, protected from the furnace fires by 5-in. thicknesses of pumice concrete. The ends of the columns subjected to load were not subjected to intense heat and therefore did not require such protection.

3.3. Assembly of Plaster Bases

The 3/8-in. laths, cut to width from 16- by 48-in. pieces, were bound to the column shafts by four ties of doubled wires to each 4 ft of column length, as shown in figures 3 and 4. The 1/2-in. laths, cut to width and length from 24- by 120-in. pieces, were applied to seven of the column shafts in two

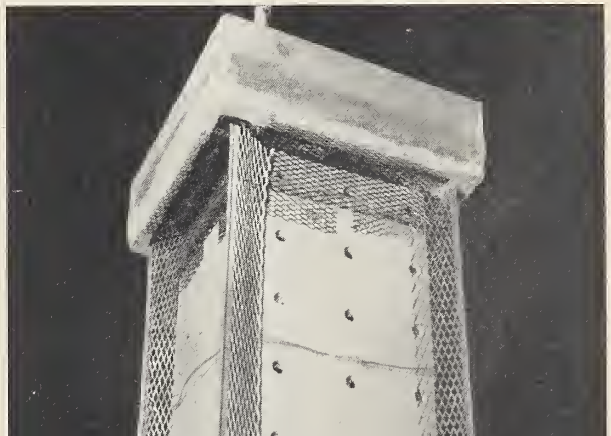


FIGURE 4. *Column top showing perforated lath, ties, corner bead with metal lath extensions, and cornerite at junction between lath and cap.*

Table 2. *Characteristics of gypsum plasters*

Chemical analysis	Lot											
	1	2	3	4	5	6	7	8	9	10	11	12
$CaSO_4 \cdot \frac{1}{2} H_2O$ (computed from loss at 220° C) ---------- %	83.1	80.1	83.8	87.2	84.2	93.0	93.6	94.7	88.2	94.7	94.9	91.7
$CaSO_4 \cdot \frac{1}{2} H_2O$ (from ammonium acetate insoluble) ---------- %	86.8	89.8	83.9	83.2	81.8	92.7	93.7	94.3	92.8	93.3	94.6	89.3
$CaSO_4 \frac{1}{2} H_2O$ (computed from SO_3) ---------- %	85.7	88.6	----------	84.5	79.8	92.4	-----	----------	93.1	93.3	93.6	89.6
$CaSO_4 \cdot \frac{1}{2} H_2O$ (average) ---------- %	85.2	86.1	83.8	85.0	81.9	92.7	93.6	94.5	91.3	93.8	94.4	90.2
Physical tests												
Consistency for time of set ml/100 g	17	16	18⅔	18⅔	16⅓	16	19⅔	18	19	18	-----	18
Time of set ---------- hr	8	12	>8, <16	>9, <16	23	19	5	>8, <15¾	7	>9, <16	3½	>9, <16
Consistency for strength ml/100 g	18⅔	18	22	21⅓	18	18	22	20½	21⅓	20⅓	-----	20⅔
Tensile strength [1] ---------- lb/in.^{2}	200	230	[2] 175	185	220	230	215	230	250	255	[2] 260	220
Compressive strength ---------- lb/in.^{2}	1,080	1,320	980	1,070	1,170	1,310	1,340	1,410	1,320	1,450	1,600	1,210

[1] Average of 6, except as noted.

[2] Average of 5.

Table 3. *Sieve analyses of aggregates*

Sieve designation	Sieve analyses—percentage passing		
	Sand	Perlite	Vermiculite
4	100	--------	--------
6	--------	--------	98
8	99	100	--------
12	--------	--------	69
14	93	--------	--------
20	--------	--------	30
28	72	--------	--------
30	--------	37	--------
50	--------	21	7
100	3	12	3
200	--------	5	--------

thicknesses, and to one in one thickness, and bound with doubled wires spaced about 23 in. on centers.

The wire-fabric reinforcement for the plaster was wrapped horizontally outside of the gypsum lath as applied to five of the columns and outside the scratch coat of plaster as applied on a sixth column, test 277. The longitudinal edges of the fabric were fastened together with wire ties. Details of the assembly of plaster bases and plaster are shown in figure 5.

All the columns were provided with corner beads set as grounds to give the required thickness of plaster. With one exception, the corner beads were fastened directly to the gypsum lath or to strips of expanded metal lath if the flanges of the corner bead were not wide enough to fasten to the lath. At least ¼-in. clearance was provided at each end of the corner beads to allow for expansion. In addition to staples or nails fastening the corner beads or extension strips to the gypsum lath, wire ties threaded through the flanges of the corner beads and surrounding the column secured the four corner beads at seven levels on each assembly. See details in figure 4.

In attempting to prevent the development of openings between the protective coverings and the caps of the columns, such as had occurred during previous tests due to shrinkage of the gypsum during calcination, 3- by 2-in. angles of expanded metal lath were stapled to the gypsum lath and attached by nails through the outstanding leg to caps of columns 294, 302, and 308.

3.4. Plastering

The basic plaster of 1 in. or less thickness was applied in a single rendering by the double-back method. That of greater thickness was applied as two distinct renderings with sufficient time between for the first or scratch coat to set thoroughly, before the second or brown coat was applied. A white-coat finish about $\frac{1}{16}$-in. thick was applied to each column to bring the surfaces even with the corner beads.

The proportions of the plaster mixes, the number of coats applied, the total thicknesses and the strengths of 2-in. cubes made from the various batches of the plasters as they were ready for application to the individual columns are given in table 4.

3.5. Aging

To condition the specimens for test, the plastered columns were allowed to stand for periods of 26 to 67 days in a large, well-ventilated room heated from 70° to 85° F. Each specimen was weighed periodically until the rate of loss of weight resulting from the drying of the plaster became less than 1 lb a day. The 2-in. cubes prepared during the application of the plaster were conditioned by placing them at the bases of the columns and were tested on the same day as the column.

4. Test Method and Equipment

4.1. Specifications and End-Point Criteria

The tests were conducted in accordance with the Standard Methods of Fire Tests of Building Construction and Materials of the American Society for Testing Materials, ASTM Designation: E119–47.

TABLE 4. *Summary of construction details and test results*

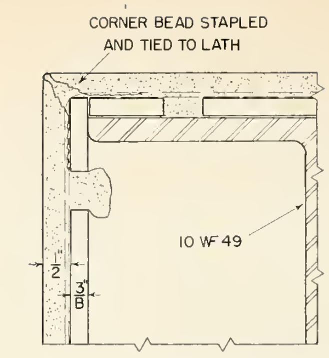
Test number	Steel column			Gypsum lath				Wire fabric reinforcement	Plaster						Total protective thickness, lath and plaster	Age at test	Test results			
	Exposed length	Section	Load	Type	Length	Thickness	Number of layers		Aggregate	Mix [1]	Strength		Number of basic coats [2]	Thickness all coats			End-point criterion	End-point time	Intensity of fire exposure	Fire-endurance limit
											Scratch	Brown								
	ft in.		*lb*		*ft in.*	*in.*					*lb/in.²*	*lb/in.²*		*in.*	*in.*	*Days*		*hr min*	*Percent*	*hr min*
273	8 1	10WF49	None	Perforated	4 0	3/8	1	No	Sand	A	740	740	1	1/2	7/8	26	1,000° F	1 30	92.3	1 23
274	8 1	10WF49	None	do	4 0	3/8	1	No	do	A	740	740	1	5/8	1	28	1,000° F	1 32	97.9	1 30
275	8 1	10WF49	None	do	4 0	3/8	1	No	Perlite	B	400	400	1	1	1 3/8	35	1,000° F	2 16	101.4	2 17
276	8 1	10WF49	None	Plain	8 1	1/2	2	Yes	do	B	600	600	1	1	2	31	1,000° F	3 56	97.5	3 50
277	8 1	10WF49	None	do	8 1	1/2	1	Yes [3]	do	B	520	180	2	1 1/2	2	37	1,000° F	3 38	100.3	3 39
278	8 1	10WF49	None	do	8 1	1/2	2	Yes	do	C	340	400	2	1 1/2	2 1/2	41	1,000° F	4 40	100.8	4 42
279	10 4	6H20	80,500	do	10 0	1/2	2	Yes	do	C	560	330	2	1 1/2	2 1/2	44	Load [4]	4 20	100.1	4 20
280	10 4	10WF49	228,300	do	10 0	1/2	2	Yes	do	C	560	380	2	1 1/2	2 1/2	49	Load	4 37	100.5	4 38
288	8 1	10WF49	None	Perforated	4 0	3/8	1	No	do	C	1,080	890	2	1 1/2	1 7/8	34	1,000° F	2 39	100.0	2 39
289	8 1	10WF49	None	Plain	8 1	1/2	2	No	do	C	1,030	890	2	1 3/8	2 3/8	37	1,000° F	3 32	100.2	3 32
292	8 1	10WF49	None	Perforated	4 0	3/8	1	No	do	C	1,370	730	2	1 1/2	1 7/8	39	1,000° F	2 48	99.8	2 48
293	8 1	10WF49	None	Plain	8 1	1/2	2	No	do	C	1,370	730	2	1 3/8	2 3/8	41	1,000° F	3 40	100.6	3 41
294	8 1	10WF49	None	do	8 1	1/2	2	Yes	Vermiculite	C	630	390	2	1 1/2	2 1/2	52	1,000° F	4 16	100.0	4 16
302	8 1	10WF49	None	Perforated	4 0	3/8	1	No	Perlite	C	730	440	2	1 1/2	1 7/8	42	1,000° F	2 39	100.2	2 39
308	8 1	10WF49	None	do	4 0	3/8	1	No	do	C	1,330	800	2	2	2 3/8	67	1,000° F	2 28	100.0	2 28
314	8 1	10WF49	None	do	4 0	3/8	1	No	do	C	1,280	690	2	1 3/4	2 1/8	60	1,000° F	3 42	100.6	3 43

[1] Mix A: 1 part of gysum plaster to 2½ parts of aggregate (sand) by weight applied doubled back to thickness. Mix B: 1½ ft³ (one 100-lb bag) of gypsum plaster to 2½ ft³ of aggregate. Mix C: Scratch coat of 1½ ft³ of gypsum plaster to 2 ft³ of aggregate: brown coat of 1½ ft³ of gypsum plaster to 3 ft³ of aggregate.

[2] All columns were finished with 1/16 in. of whitecoat plaster, mixed 3 parts of lime putty to 1 part of gaging plaster by volume.

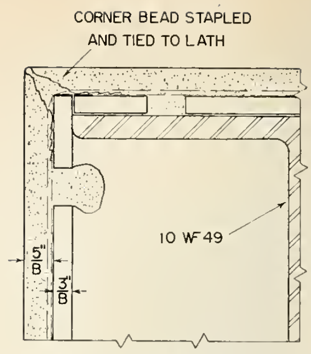
[3] The wire-fabric reinforcement and corner beads were applied outside of the scratch-coat plaster.

[4] The average temperature of 1,000° F at one level was observed at the same time that failure under load occurred.



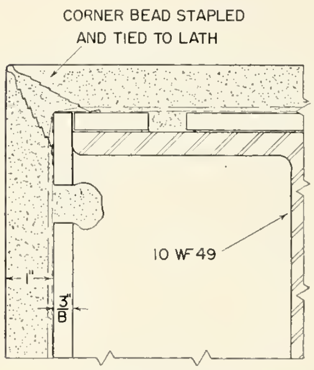
TEST NO. 273

1:2 1/2 SANDED GYPSUM PLASTER DOUBLED BACK ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



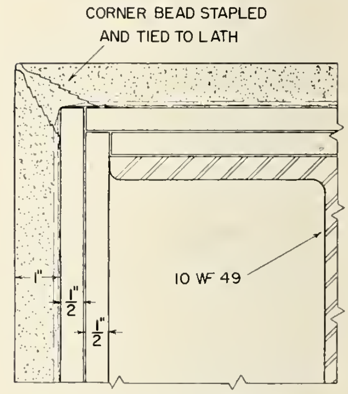
TEST NO. 274

1:2 1/2 SANDED GYPSUM PLASTER DOUBLED BACK ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



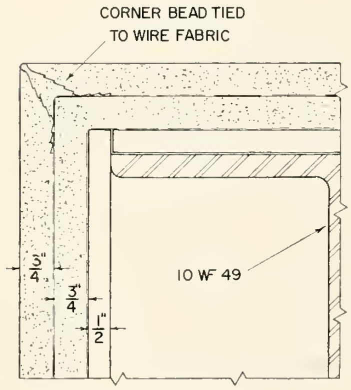
TEST NO. 275

2 1/2 CU. FT. PERLITE TO 1 BAG GYPSUM DOUBLED BACK ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



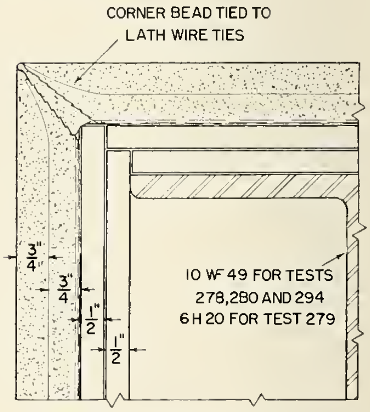
TEST NO. 276

2 1/2 CU. FT. PERLITE TO 1 BAG GYPSUM DOUBLED BACK ON 2 LAYERS OF GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 23" O.C. AND WRAPPED WITH 1" HEX MESH 20 GA. GALV. WIRE FABRIC.



TEST NO. 277

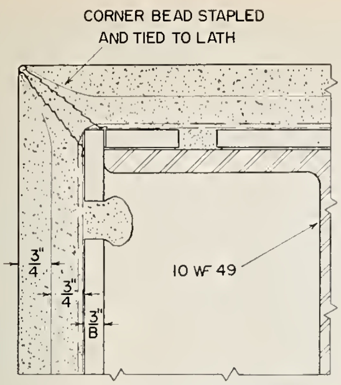
2 1/2 CU. FT. PERLITE TO 1 BAG GYPSUM FOR SCRATCH AND BROWN COATS ON GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 23" O.C. WRAPPED WITH 1" HEX MESH 20 GA. GALV. WIRE FABRIC OVER SCRATCH COAT.



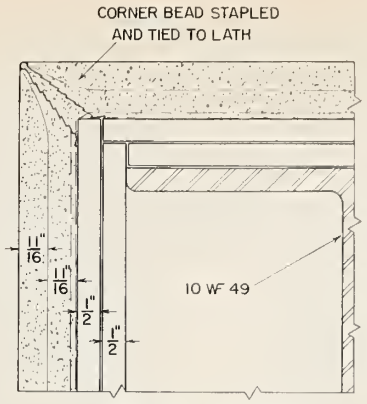
TESTS NO. 278, 279, 280, 294

2 CU. FT. PERLITE TO 1 BAG GYPSUM FOR SCRATCH AND 3 CU. FT. PERLITE TO 1 BAG GYPSUM FOR BROWN COAT ON 2 LAYERS OF GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 23" O.C. AND WRAPPED WITH 1" HEX MESH 20 GA. GALV. WIRE FABRIC. TEST 294 USED VERMICULITE.

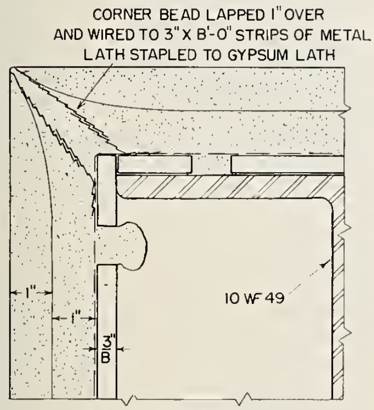
FIGURE 5. *Cross sections of protective coverings for test columns.*



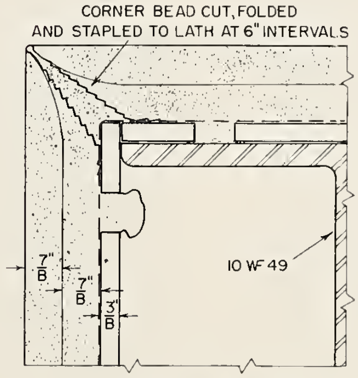
TESTS NO. 288,292,302
2 CU. FT. PERLITE TO 1 BAG GYPSUM FOR SCRATCH AND 3 CU. FT. PERLITE TO 1 BAG GYPSUM FOR BROWN COAT ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



TESTS NO. 289,293
2 CU. FT. PERLITE TO 1 BAG GYPSUM FOR SCRATCH AND 3 CU. FT. PERLITE TO 1 BAG GYPSUM FOR BROWN COAT ON 2 LAYERS OF GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 23" O.C.



TEST NO. 308
2 CU. FT PERLITE TO 1 BAG GYPSUM FOR SCRATCH AND 3 CU. FT. TO 1 BAG GYPSUM FOR BROWN COATS ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



TEST NO. 314
2 CU. FT. PERLITE TO 1 BAG GYPSUM FOR SCRATCH AND 3 CU. FT. TO 1 BAG GYPSUM FOR BROWN COATS ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.

FIGURE 5. *Cross sections of protective coverings for test columns*—Continued

These methods require that the columns be exposed on all sides to furnace fires controlled to have average temperatures of approximately 1,000° F at 5 min; 1,300° F at 10 min; 1,550° F at 30 min; 1,700° F at 1 hr; 1,850° F at 2 hr; 2,000° F at 4 hr; 2,300° F at 8 hr or over.

Fourteen of the columns were tested without load, in which the conditions of acceptance require that the average temperature of the steel at any one of the four levels shall not exceed 1,000° F (538° C), and that at any one measured point shall not exceed 1,200° F (649° C), during the period for which classification is desired. The fire-exposed length of the column is specified to be at least 8 ft. The other two columns were tested under load, a method which requires that the exposed length be not less than 9 ft and that the column sustain the applied load during the fire-endurance test for a period equal to that for which classification is desired.

4.2. Column-Testing Furnace

The tests were made in a gas-fired furnace which was equipped with a hydraulic jack for applying loads, as shown in figure 6. The hydraulic pressure was controlled by a motor-driven rotary pump and a spring-loaded pressure-regulating valve, thus raising or lowering the movable furnace floor, which rested on a spherical bearing block on top of the jack. The fluid pressures used were determined by the loads required to be imposed on the columns.

To accommodate the 10-ft 4-in. effective length of the loaded column, a brick chamber was built above the furnace roof slab. A framework of steel beams provided a fixed bearing for the upper end of the column. The bases of the columns and the furnace floor were covered with loose perlite.

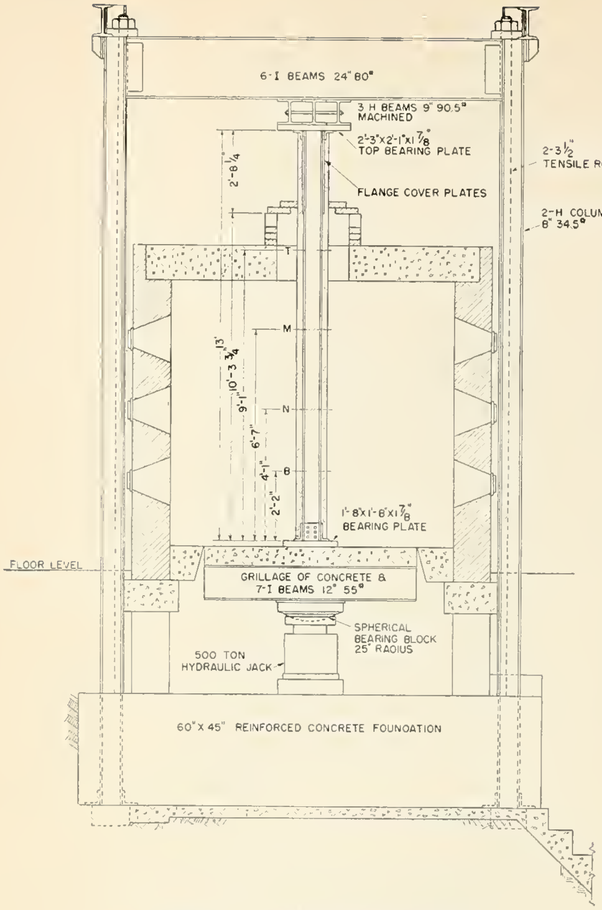


Figure 6. *Column-test furnace.*

A column representative of those tested without load is shown as installed in the furnace for test in figure 7.

4.3. Temperatures

Twelve thermocouples were located in the furnace—four suspended from the ceiling and two protruding from each of the four walls. The thermocouples were provided with porcelain insulators and enclosed in iron tubes with the junctions about 24 in. from the test column. The pyrometer arrangements were completed by connecting the thermocouples to an indicating potentiometer. The furnace temperatures were recorded at 5-min intervals during the first 2 hr of the tests and at 10-min intervals thereafter.

The temperatures at selected locations in the column shafts were determined at regular intervals throughout the test by means of thermocouples, previously described, and a potentiometer.

4.4. Deformations

Movement of the piston of the hydraulic jack as observed on a dial indicator was taken as a measure of the longitudinal deformation of the column under load. Measurements made during previ-

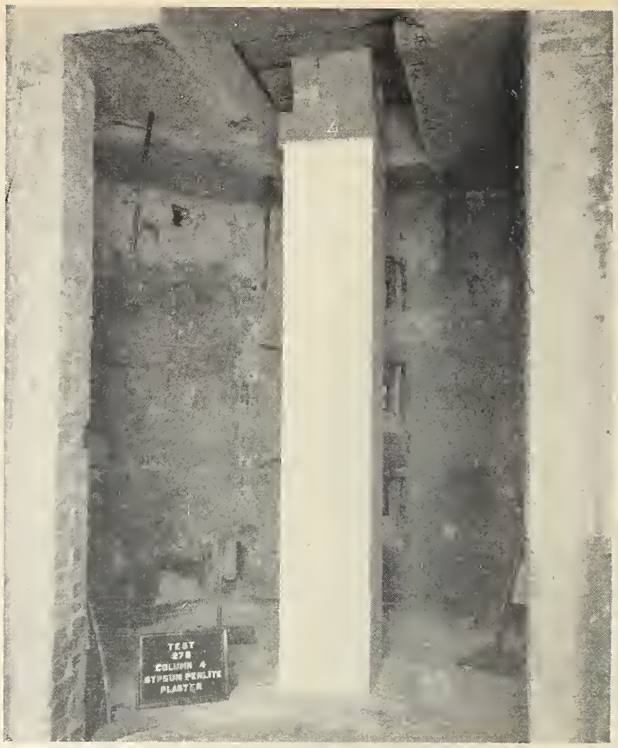


Figure 7. *Representative nonloaded column in furnace before test.*

ous tests indicated that the thermal expansion of the vertical framework was closely compensated by the expansion of the unexposed section of the column and the thermal deflections of the overhead beams supporting the upper bearing plate. No measurements of lateral deflections of the columns were made during or after test.

5. Results of Tests

Table 4 summarizes the characteristics of the test specimens and results of the tests.

A general pattern of behavior was observed in all the tests. A network of fine craze cracks covering the plaster surface and thin cracks parallel to and about 1 or 2 in. away from the corner beads developed early in the tests. The latter extended over the full exposed length of the protective covering and by midtest had grown to widths ranging from 1/8 to 1/2 in., with evidence of curling of the whitecoat finish along the edges of the plaster. Usually, too, by midtest shrinkage of the column covering caused it to begin separating from the column cap, thus creating an opening all around the column. In comparison with the other cracks, these openings widened more rapidly during the rest of the test and are considered to have contributed to hastening the failure of the coverings protecting the steel. The widths of these openings at the times the column-shaft temperatures reached the allowable limits were esti-

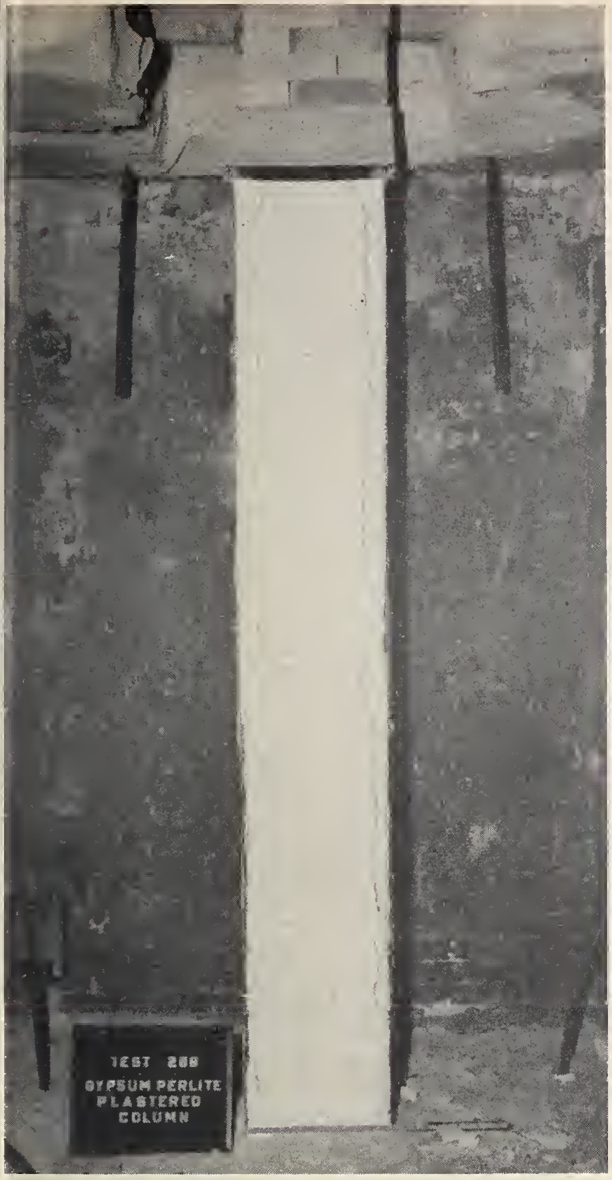


Figure 8. *Representative column without cornerite at top, after test.*

Figure 9. *Representative column with cornerite at top, after test.*

Other than the cornerite, the construction of the column was the same as that of the column shown in figure 8. Fire exposures were of the same length.

mated to range from ½ to 2 in., not excepting those columns having cornerite and plaster intended to cover the opening. See figures 8 and 9. Because of the narrowness of these openings and their position on the column, they were probably a minor factor in the failure of the columns tested under load. Shrinkage of the type mentioned above is characteristic of gypsum exposed to fire [1, 2, 3, 4].[1] Graphs of the furnace and column temperatures observed in a representative selection of tests are given in figures 10, 11, 12, and 13.

In no test did any significant amount of plaster covering fall before the limit of temperature had been reached, notwithstanding the large cracks parallel to the corner and the bulging of the plaster and plaster bases, as shown in figure 14. In three instances, however, soon after the permissible temperature limit of the steel had been reached, the coverings fell, exposing a large part of the steel column shaft to the fire, as shown in figure 15 [2, 4].

In test 280, because of undue heating of oil in the hydraulic system, difficulty was encountered in maintaining the load. Consequently, the load was reduced to about half value when the average temperature of the steel was 212° F (100° C).

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

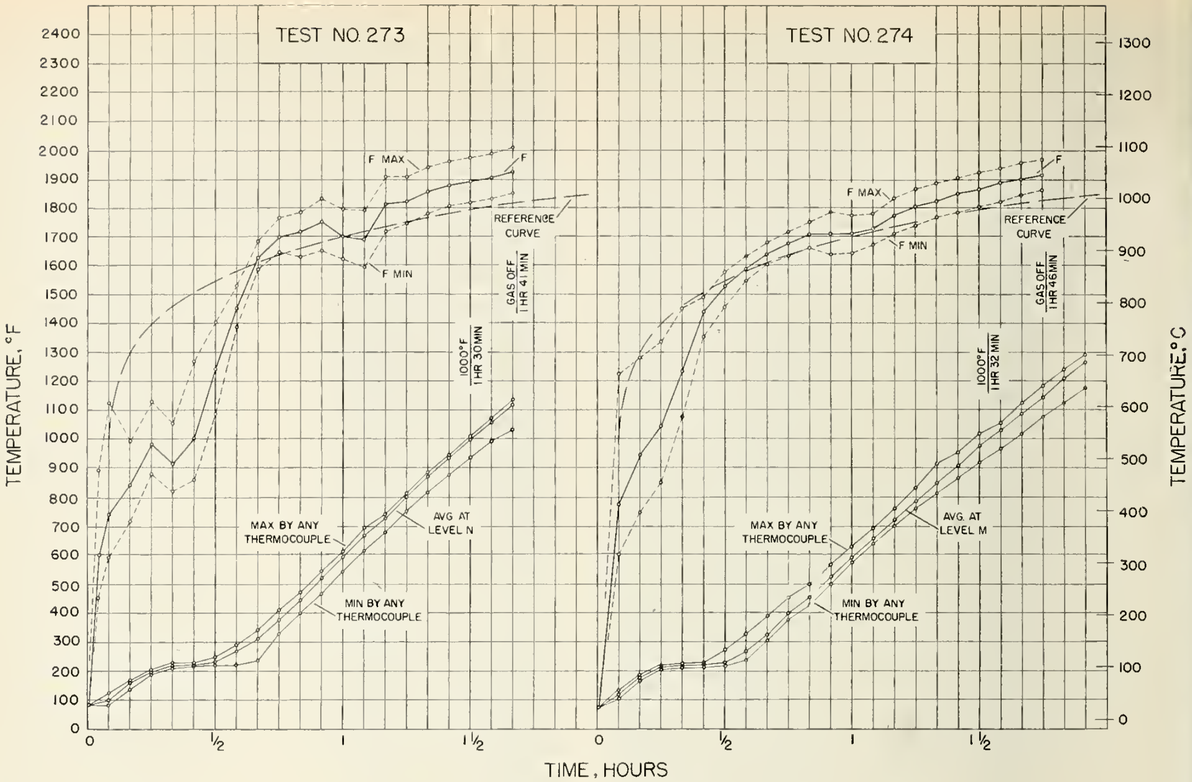


FIGURE 10. *Temperatures observed in column tests 273 and 274.*
Columns with sanded gypsum plaster.

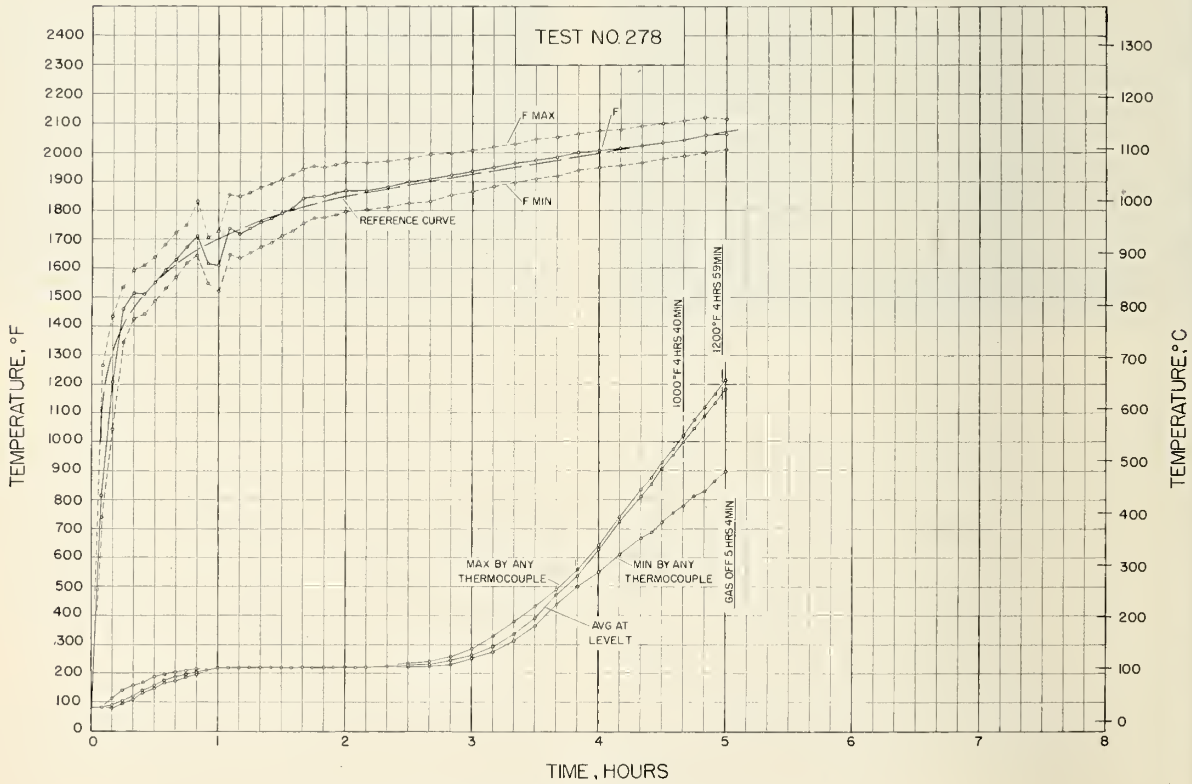


FIGURE 11. *Temperatures observed in column test 278.*
Perlite gypsum plaster and wire fabric reinforcing.

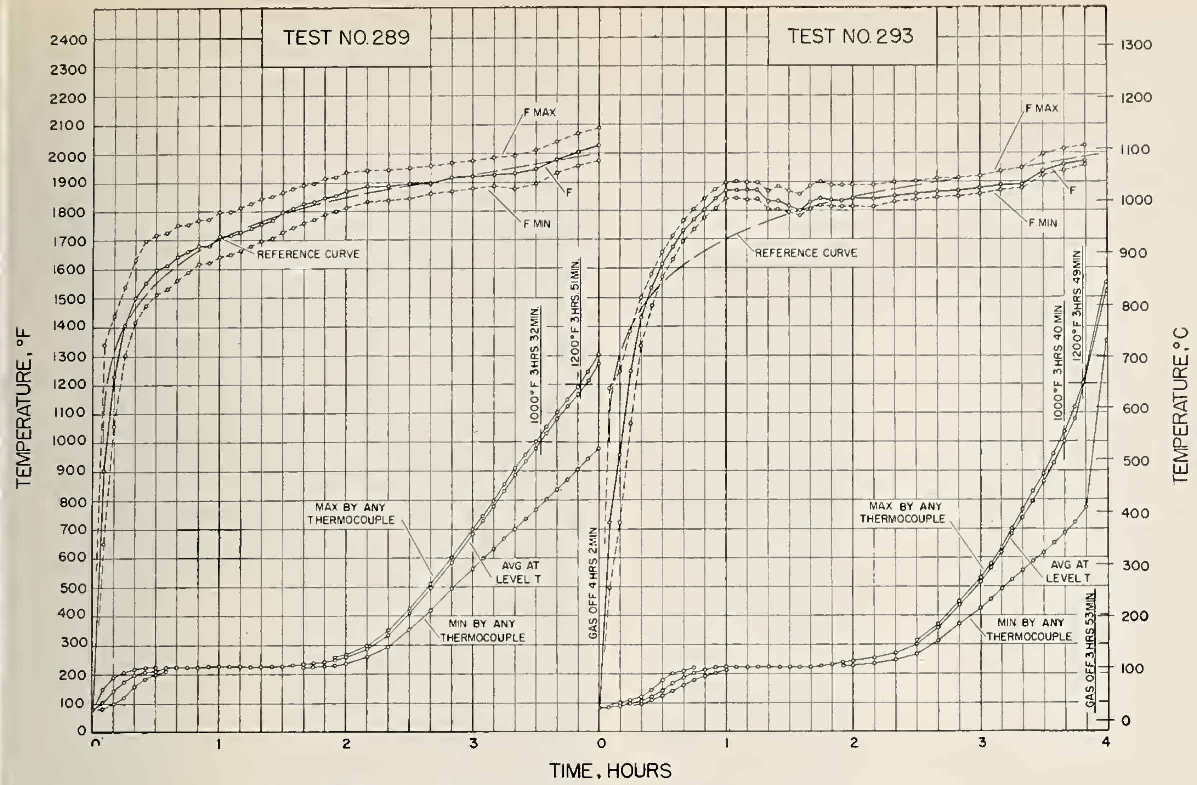


FIGURE 12. *Temperatures observed in column tests 289 and 293.*
Perlite gypsum plaster without reinforcing. Both constructions were the same.

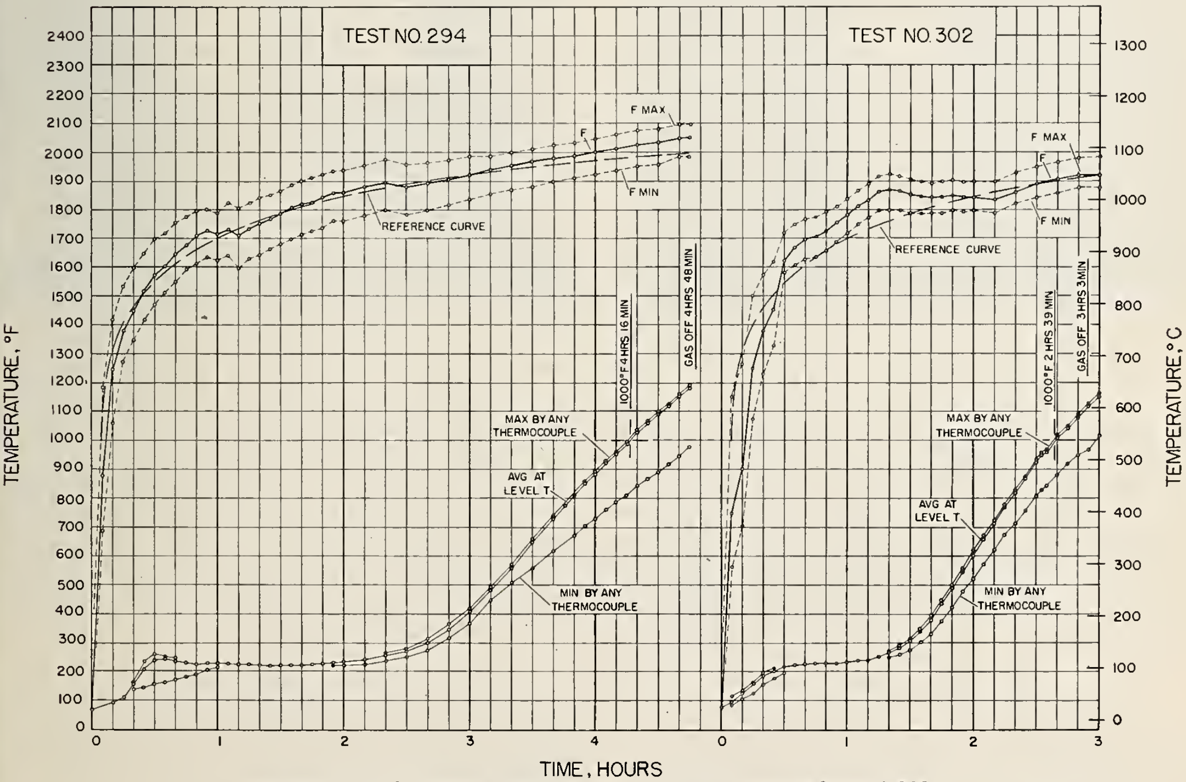


FIGURE 13. *Temperatures observed in column tests 294 and 302.*
The former was vermiculite gypsum plaster with wire fabric and cornerite; the latter was perlite gypsum plaster with cornerite but no wire fabric.

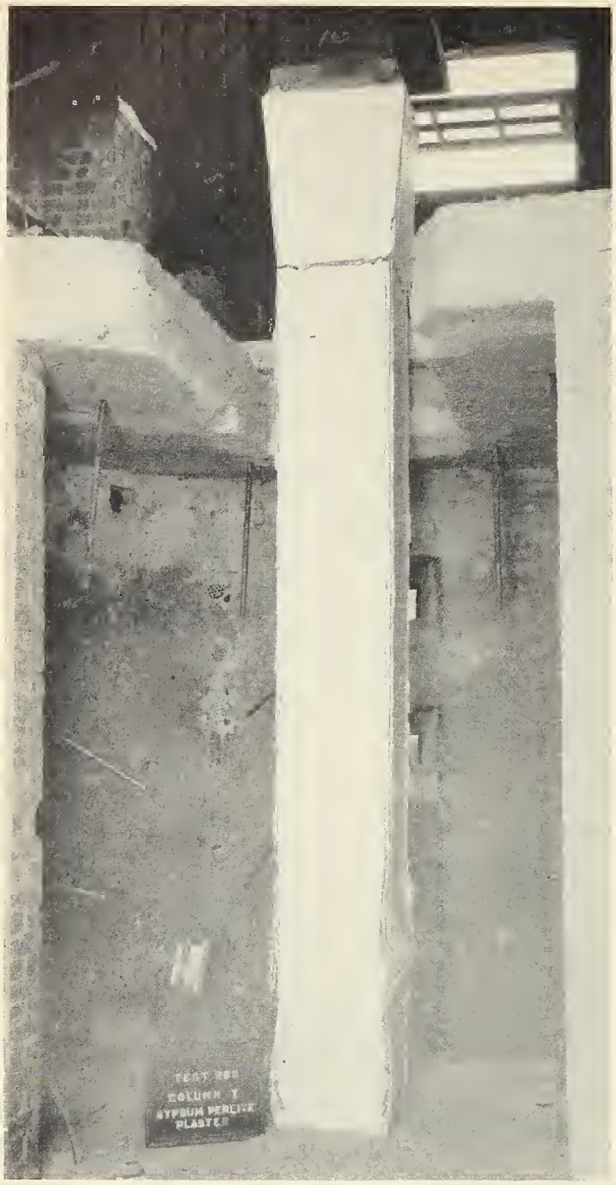


FIGURE 14. *Loaded, 10-in. column in furnace after test.* The bulging in the plaster near the bottom was observed in a few of the nonloaded columns.

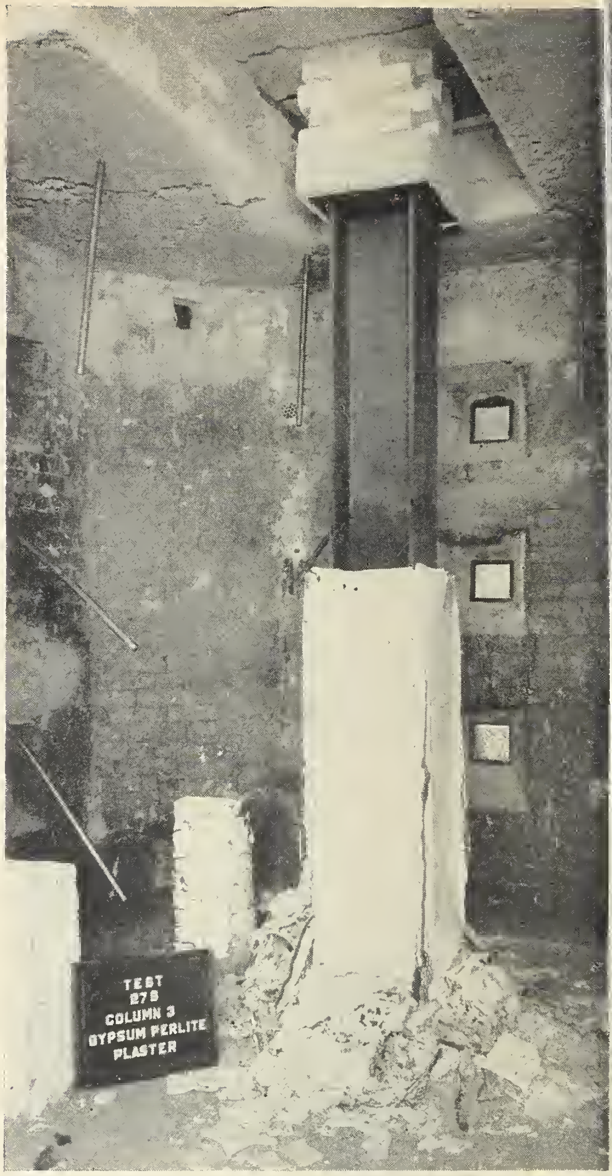


FIGURE 15. *One of three columns from which lath and plaster fell after reaching limiting conditions.*

resulting in the behavior shown in figure 16. The full load was reapplied at 4 hr 27 min when buckling of the column covering indicated the approach of the fire-endurance limit, at which time the temperatures of the steel averaged slightly over 716° F (380° C). Failure under load occurred soon thereafter, at which time the highest temperature at any thermocouple was 1,058° F (570° C).

6. Discussion

6.1. Variations Among Test Specimens

The variations included among the test specimens, which should be considered with respect to their influence on the test results, are those in such items as plaster bases, gypsum-cement plasters, plaster aggregates, plaster thicknesses, plaster reinforcement, size of columns, and workmanship. Evaluation of the effects of certain of these items can be made by comparing the results obtained from specimens differing in one major respect, whereas others can be evaluated only indirectly [5].

6.2. Plaster Bases

Only gypsum laths were used as plaster bases on the columns for the series of tests covered in this report. Those on eight columns were single thicknesses of ⅜-in. perforated laths. Those on

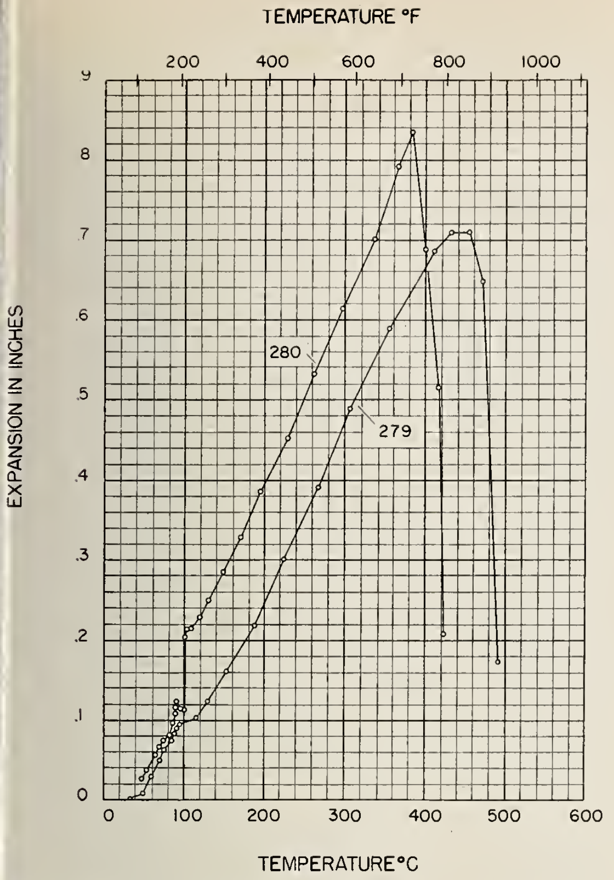


FIGURE 16. *Deformations of loaded columns with increase of temperature.*

The sudden jump in the curve from test 280 resulted when mechanical difficulties made it necessary to reduce the load to about half value. The load was restored to full intensity after the temperature of the steel had risen to 716° F at the hottest section.

seven columns were double thicknesses of the ½-in. plain lath, and that on the other column was a single thickness. Two thicknesses of ½-in. thick lath were used on the column for test 276 and a single thickness on that for test 277. These columns had protections of the same total thickness, 2 in. The first had a fire-endurance limit of 3 hr 50 min, whereas the limit in test 277 was reached at 3 hr 39 min. This difference is in agreement with previous findings that the gypsum board, on the basis of a given thickness, affords slightly greater resistance to heat penetration than an equal thickness of perlite plaster. From the derived data, no comparison can be made on the relative effectiveness of ⅜-in. perforated lath and the ½-in. plain lath.

6.3. Plasters

The plaster was composed of gypsum-cement plasters, produced by two manufacturers, mixed with selected plaster aggregates. Distinct differences in the hemihydrate content of the plasters produced by these manufacturers did not usually enter into the results, inasmuch as the two plasters were mixed together, bringing the hemihydrate content to about 90 percent in all specimens except that of test 314, in which only plaster from lot 11 (table 2), having a hemihydrate content of 94 percent, was used. It is probable that a part of the 1-hr increase in the protection afforded by the covering of test 314 over that of 308 resulted from the differences in the plasters used. The random manner of cracking of the protective coverings, as influenced by the plasters, may also have played a part in the differences observed among the results.

6.4. Plaster Aggregates

The three aggregates differed slightly in effectiveness as components of fire protective coverings. On the basis of the results obtained from tests 273 and 274 in comparison with tests 288, 292, and 302, it was found by plotting the thickness of covering versus time to failure on log log paper that the plaster made with perlite aggregate and applied on ⅜-in. gypsum lath gave protection of the steel one-fourth longer for a given thickness than did the plaster made with sand aggregate [4]. However, an exception must be noted for the results from test 308, in which the effectiveness of the perlite gypsum mixture approximated that of the sanded plaster, tests 273 and 274, if compared on the basis of a common thickness.

The slight difference in the results obtained with plaster having vermiculite aggregate (test 294) and those obtained with perlite (tests 278 and 280) can possibly be attributed to the quality of workmanship of the column encasement for test 294 rather than to the plaster aggregate. This is discussed later under "workmanship."

6.5. Plaster Thicknesses

The tests were not well adapted to making determinations of the relative effectiveness of the coverings with relation to total thicknesses. The difference in the thickness of the sanded gypsum plaster plus lath (tests 273 and 274) was only ⅛ in. The coverings appeared to slump as the result of shrinkage due to calcination of the gypsum and to expose the steel before they had served to their full capacity as protections. It is probable that the opening of the relatively large cracks at the top of the protective coverings brought about a more rapid rise in the temperature of the column than would otherwise have been observed. This effect was more noticeable in the tests of columns without wire-fabric reinforcement in the coverings.

6.6. Plaster Reinforcement

The effectiveness of reinforcement for the plaster can be seen by comparing the average of the results obtained in tests 289 and 293 with the average of results obtained in tests 278 and 280. By extrapolating graphically on the basis of the effectiveness of the reinforced plaster, an increase of 54 min, or 24 percent, in time to failure was found from the use of wire-netting reinforcement in 2½-in. thick coverings. Properly designed reinforcement increases the reliability and efficacy of gypsum protective coverings by insuring that they remain in place [2, 4].

If the results of test 302 or 288 are compared with those obtained in test 276, by extrapolating from the 1⅞-in. thickness of 302 to 2 in., the thickness of the covering for test 276, it is found that the increased protection attributable to the reinforcement is 67 min, or 40 percent.

All the reinforcement used in the tests was wrapped around the column. In view of the difference in resistance to compression in the transverse and longitudinal directions of the wire fabric, it is probable that better results could have been obtained with the fabric applied as continuous strips from top to bottom of the column, thus providing less opportunity for the sag of the plaster to open wide cracks at the top cap, such as are illustrated in figures 8 and 9.

6.7. Size of Column

The only opportunity to study the effect of size of column is by comparison of the results obtained in tests of columns under load, namely, 279 and 280. It has been found in fire tests of columns with monolithic protections, that the smaller the column the less resistant a given thickness of covering [2]. In this instance, the 6H20 column with 2½-in. thickness of covering failed 18 min, or 10 percent, sooner than did the 10WF49 column of the same length having the same thickness of protective covering.

6.8. Workmanship

The quality of workmanship found in the plastering of the column for test 294 was somewhat inferior to that in the plastering of the similar column, test 278. At least one of the corner beads of the former had little plaster between the expanded metal flanges, and the earlier failure of this column by 26 min, or 9 percent, in time might be attributable, in large measure, to this apparent defect. Continuous strips of expanded metal lath were attached to the wings of the corner beads for column 308 to extend their width to allow for a 2-in. thickness of plaster. Because of the double thickness of these wings, it is suspected that the expansion of the metal produced wider than usual cracks through the plaster and in consequence the covering afforded less protection than should have been expected. The other test constructions had the spaces between the flanges of the corner beads well filled.

6.9. Effectiveness of Combined and Free Water

A characteristic of hydrated gypsum plaster is the relatively large amount of chemically combined water in the crystallized gypsum. This water can be driven off by heating the plaster. The dehydration process begins at temperatures about that of boiling water. The effectiveness of the process of driving off water in retarding the heating of the columns under test can be seen in figures 10, 11, 12, and 13, wherein it is observed that the temperature of the steel column shafts remained at or near steam temperatures, ranging from about 10 min for the column with ⅞-in. thick gypsum protective covering to 100 min for some of the columns having 2½-in. thickness of covering. The heat-retarding effect up to this point varied approximately as the square of the thicknesses of the protective coverings. The proportion of the amount of this effect that resulted from chemically combined water to the amount resulting from free water remaining in the plaster and the lath was not determined by the tests. This dehydration characteristic is found in few other building materials to such a large degree as in gypsum.

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WASHINGTON, October 13, 1952.

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