RP563

FIRE TESTS OF COLUMNS PROTECTED WITH GYPSUM

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ABSTRACT

Fire tests of six building columns protected with gypsum have been made to supplement previous fire tests of columns similarly protected. These tests demonstrate the importance of some form of positive bond, such as steel cramps or ties, to hold unplastered block coverings in place. Block coverings with sanded gypsum plaster finish shrank less than the unplastered blocks and remained in place during the fire until the columns had failed. The plaster applied to block coverings increased the fire resistance in greater proportion than the ratio of the squares of resulting net thicknesses of covering outside of the steel.

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I. INTRODUCTION

The results of fire tests of six steel columns which had fire protective coverings of gypsum products are presented. One of the coverings was of monolithic construction, the others were built of blocks cut from gypsum partition tiles.

The information obtained supplements that derived from the tests of columns with gypsum block coverings included in the series of tests conducted jointly by the Associated Factory Mutual Fire Insurance Companies, the National Board of Fire Underwriters, and the Bureau of Standards, at Underwriters' Laboratories, Chicago, Ill., during the years 1917–18.[1] In those tests it was observed that

[1] Fire Tests of Building Columns, Underwriters' Laboratories, 1920, also published as B.S. Tech. Paper no. 184, 1921.

shrinkage of the unplastered blocks loosened the mortar until the metal ties imbedded in the horizontal mortar joints were no longer effective. As the fire progressed the blocks fell, exposing the steel, usually before its temperature exceeded 100° C. (212° F.).

In the present tests it was aimed to obtain more positive anchorage for the blocks and to determine the effect of plaster in decreasing the shrinkage from fire exposure and increasing the fire resistance of the protected column.

II. COLUMNS AND PROTECTIVE COVERINGS

1. MATERIALS

The six steel columns were fabricated from plates and angles in accordance with the details shown in figure 1. The tensile tests of the steel gave, yield point, 37,700 lb./in.^{2}; ultimate strength, 58,000 lbs./in.^{2}; and elongation, 32 percent in 8 inches.

The fibered gypsum concrete used in one test had a compressive strength of 760 lb./in.^{2} as tested in a 6 by 12 inch cylinder, the average of four 2-inch cubes was 790 lb./in.^{2}, and the average tensile strength of 3 standard briquettes was 180 lb./in.^{2}

The gypsum blocks used for the protective coverings in the other tests were cut from ordinary 2-inch solid and 3-inch hollow gypsum partition tiles having approximately 3 percent of wood fiber in the form of fine excelsior. These when tested for transverse breaking strength with a concentrated load at the center of a 28-inch span gave breaking loads of 230 and 420 pounds or moduli of rupture of 200 and 185 lb./in.^{2}, respectively, for the solid and hollow blocks. The modulus of rupture of the hollow blocks was computed on the gross section. Compressive strengths were determined on half-length blocks remaining from the transverse tests. The results for edge and end bearings, respectively, were for solid blocks, 920 and 810 lb./in.^{2}, and for hollow blocks, 760 and 770 lb./in.^{2} of net area.

The mortar used for setting the gypsum blocks had tensile and compressive strengths of 70 and 300 lb./in.^{2}, respectively. The sanded plaster as sampled during construction of the columns had tensile and compressive strengths of 50 and 670 lb./in.^{2}, respectively.

The gypsum plaster and the hydrated lime conformed with Federal specifications for the corresponding class of products and the hydrated lime also, except that 16 percent of the lime was retained on the no. 200 sieve where as 15 percent was the allowable limit.

2. WORKMANSHIP

The workmanship in the fabrication of the columns was in accordance with commercial practice. The construction of the coverings was superintended by a man having long experience in this class of work and the workmanship was of good commercial grade.

3. DETAILS OF COVERINGS

Details of the six coverings are given in table 1 and figures 2 and 3.

The gypsum concrete covering for column no. 1, composed of 7 parts gypsum cement, 1 part wood chips, and approximately 7 parts water, by weight, mixed to a semifluid consistency, was poured and puddled into the wooden form so as to flow through the wire mesh surrounding the column.

The mortar and plaster were proportioned by weight of dry materials in the ratio 1:3 gypsum plaster and sand. The amount of water used was varied slightly from batch to batch to compensate for conditions which cause variations in consistency or setting time, or both. The

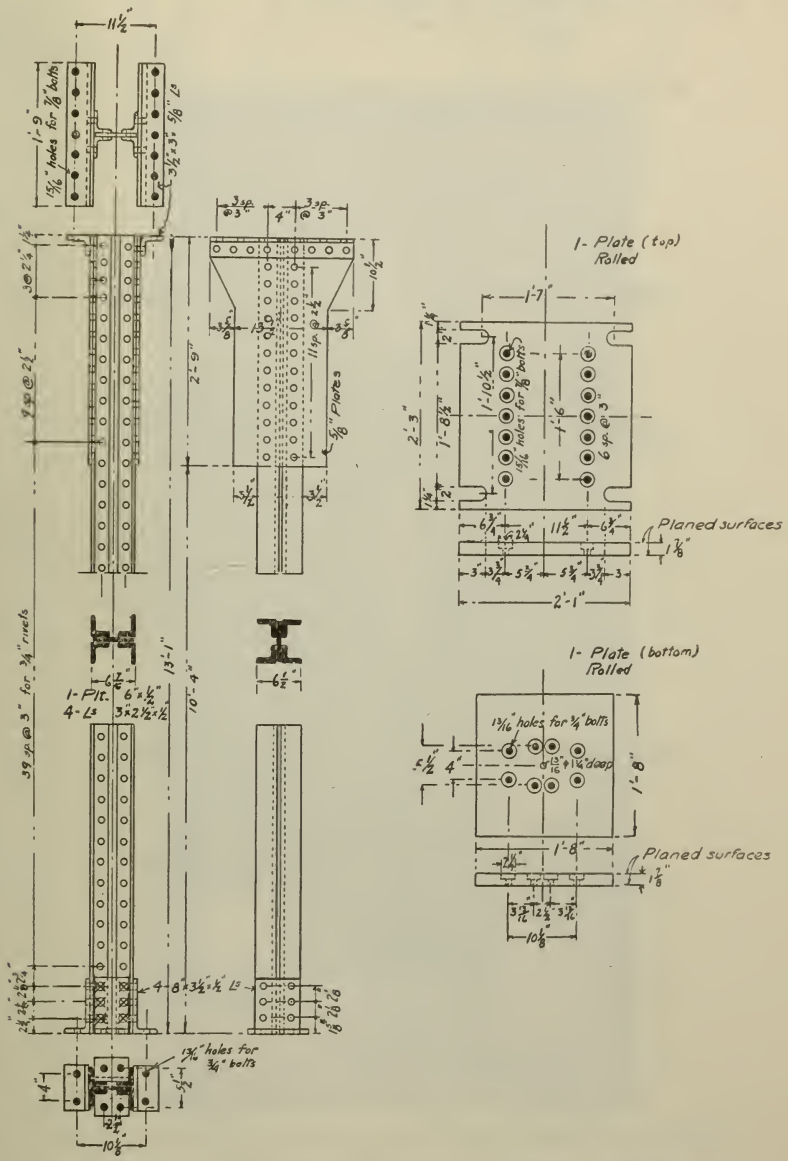

FIGURE 1.—*Details of test columns and bearing plates.*

plaster was applied by the double-up method and finished with lime and plaster of paris white coat.

The block coverings were dried from 1 to 2 weeks and the gypsum concrete for 1 month in the blast of a unit heater, with

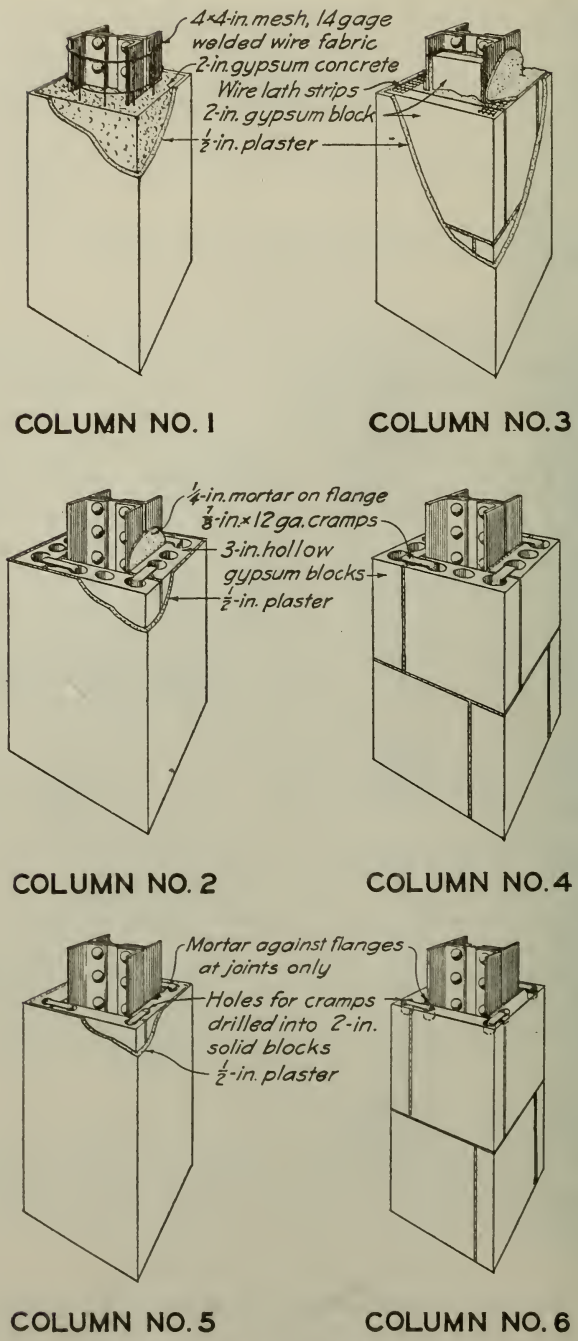

FIGURE 2.—*Details of column coverings.*

FIGURE 3.—*Columns nos. 3, 4, and 5 with block coverings started.*

temperatures ranging from 38° to 54° C. (100° to 130° F.) before the plaster was applied. Column no. 2. had the white-coat finish applied two days after the brown and scratch coats, but nos. 3 and 5 were dried for 2 weeks between the plastering and the application of the finish. The finished plaster on columns nos. 1, 2, 3, and 5 had seasoned 25, 25, 29, and 27 days, respectively, before being subjected to the fire test.

III. METHOD OF TESTING

1. TESTING EQUIPMENT

The tests were made in a gas-fired furnace which was equipped with a hydraulic jack for applying loads as shown in figure 4. The jack piston was raised by a hand pump and lowered by opening a needle valve, thus raising or lowering the movable furnace floor which rested on the spherical bearing block. Loads on the test columns corresponding to measured fluid pressures were determined by calibration of the system, including jack and connected fluid pressure scale.

The furnace was not designed for column tests and to accommodate a column of 10 feet 4 inches effective length an extension was built above the furnace roof slab. The temperatures at 12 locations in the furnace were indicated by chromel-alumel thermocouples, some protected by iron tubes and some by porcelain tubes. The temperature of the column at 10 points was indicated by iron-constantan thermocouples inserted into the steel column shaft.

The changes in length of the columns were obtained approximately by measuring the movements of the jack piston with micrometers and by observing the changes in elevation of the column heads through a telescope. As the furnace floor system was massive and had a protective covering of 5 inches of sand, gypsum, and fire bricks above the concrete, it can be assumed that the changes in length between the two observation points, which were 15 feet 6 inches apart, were mainly those of the steel column. No measurement of the lateral deflections of the columns was made.

2. WORKING LOADS, BEARINGS, AND RESTRAINT

The loadings (lb./in.^{2}) causing failure of the columns are shown in table 1. That for columns nos. 1 and 2 was about 14 percent in excess of allowable loads computed by the formula [2]

$$f = \frac{18{,}000}{1 + \frac{l^2}{18{,}000\, r^2}}$$

recommended by the American Institute of Steel Construction, and for columns nos. 3 to 6, inclusive, the excess was about 4 percent.

The average stresses imposed in these tests at the time of failure were for the first two columns 33 percent, and for the last four, 21 percent, more than would have been applied in the Chicago tests to columns of corresponding slenderness ratio.

The column was mounted in the furnace as shown in figure 4 with the top bolted and the bottom bearing plate bedded in quick-hardening

[2] In the formula f is the allowable stress, lb./in.^{2}, l^2, the effective length of the column, and r the least radius of gyration of the column section.

cement mortar. The condition of restraint of the columns during test was designed to be that of having the upper end fixed and the lower

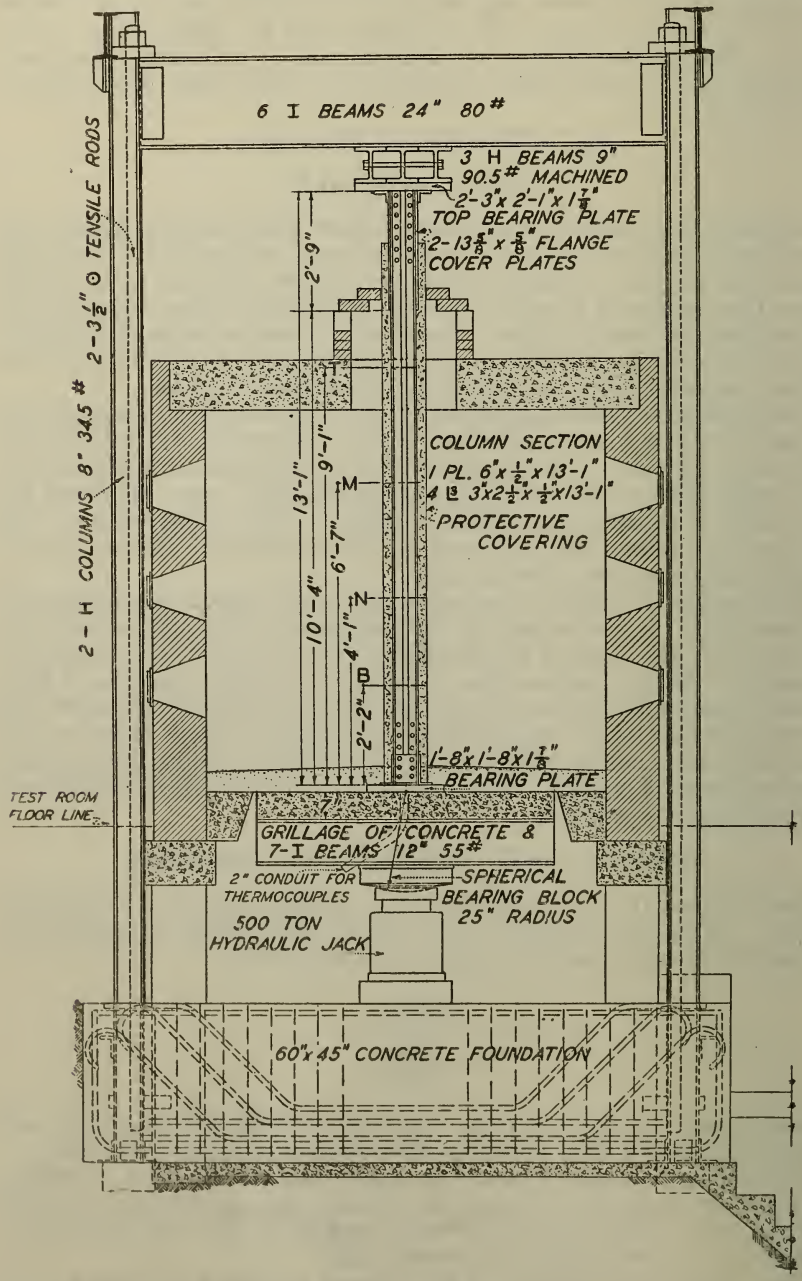

FIGURE 4.—*Furnace and loading equipment with column in place.*

end free except for friction at the spherical bearing and possible minor restraint at the edges of the movable floor section.

IV. RESULTS OF FIRE TESTS

1. GENERAL RESULTS

The results of the fire tests are summarized in table 1 and in table 2 results from the earlier series of fire tests of columns protected with

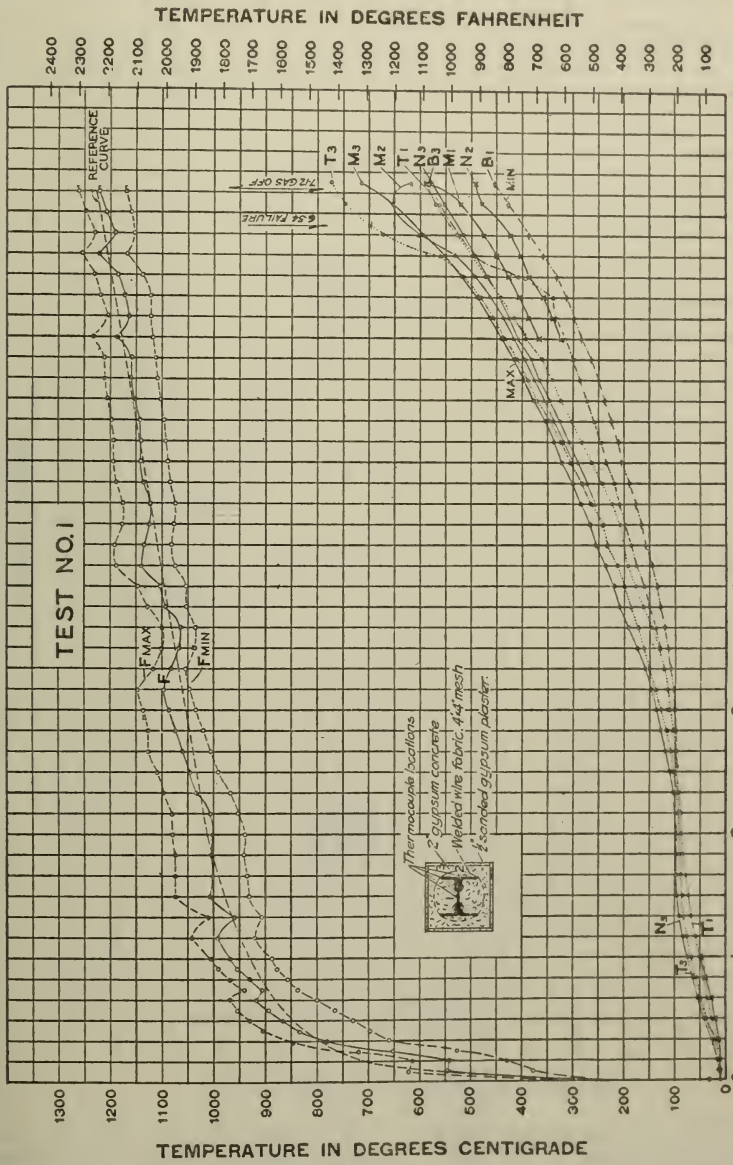

FIGURE 5.—*Temperature chart, test no. 1, column protected with 2-inch gypsum concrete and one half inch plaster.*

gypsum block coverings are given for comparison. The temperature charts, figures 5 to 8, inclusive, show temperatures of the furnace and at several points in the column steel. The locations of these points are shown in elevation in figure 4 by the letters *B*, *N*, *M*, and *T*, and

in plan by the numerals *1*, *2*, and *3*, on the detail sections (figs. 5 to 8). The temperature averages given in table 1 for the cross section were computed from the indications of the thermocouples weighted in

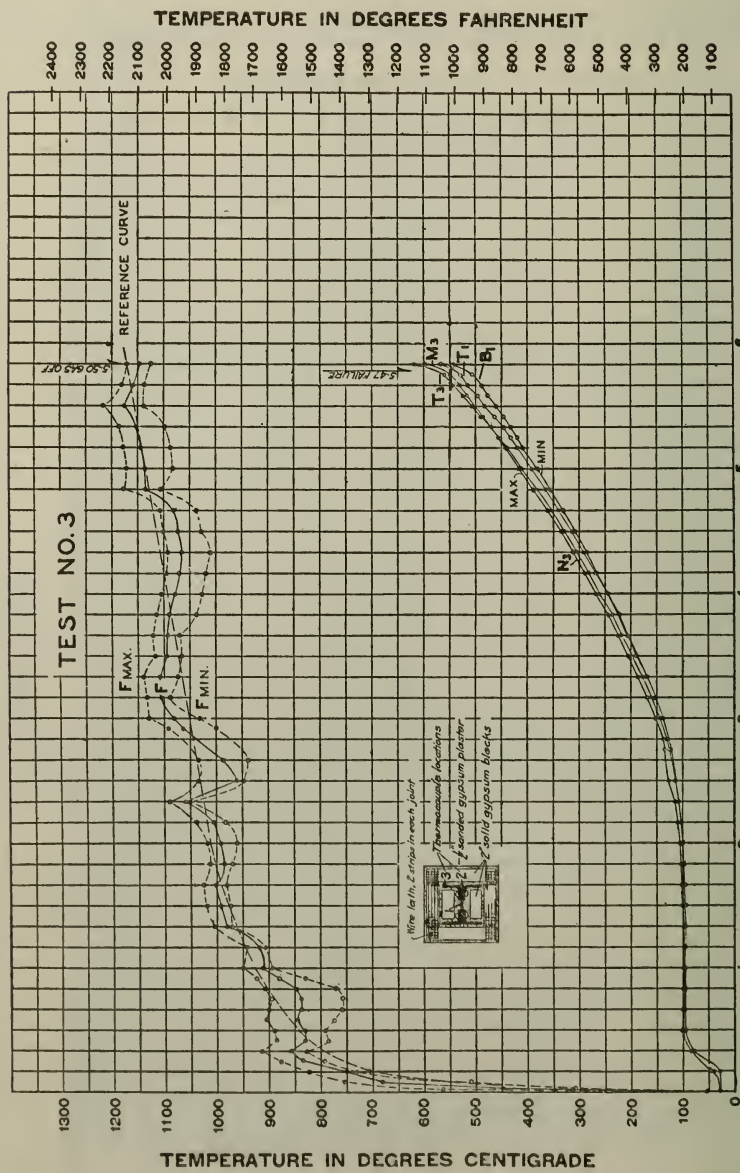

FIGURE 6.—*Temperature chart, test no. 3, column protected with 2-inch solid gypsum partition tile, filled solidly and plastered.*

proportion to the areas involved. The region of the column represented by sections *N*, *M*, and *T*, covers three fourths of the exposed length and comprises in each case the portion involved in the failure.

TABLE 1.—*Fire resistance of columns with gypsum protective coverings*

[Tests conducted at the Bureau of Standards]

Column no.	Load [1]	Protective covering			Exposure, percent of standard	Period of expansion	Time to failure	Temperature at time of failure		
		Kind [2]	Thickness over flange of column, average	Net area of column and covering				Maximum indicated temperature in column flanges	Average at the hottest of 4 sections	Average for sections *N*, *M*, and *T*
	Lb./in.[2]		*Inches*	*Sq. inches*		*Hr. min.*	*Hr. min.*	*° C.*	*° C.*	*° C.*
1	14,100	Monolithic wood-fibered gypsum concrete, plastered	2½	130	100	6 30	6 54	700	620	554
2	14,100	Hollow gypsum block, plastered; no fill	[3] 2.9	123	100	5 00	5 10	([4])	----------	----------
3	12,800	Solid gypsum block, plastered; filled	2.9	153	100	5 30	5 47	575	558	554
4	12,800	Hollow gypsum block; no fill; no plaster	[5] 2.2	94	101	2 52	2 52	558	546	514
5	12,800	Solid gypsum block, plastered; no fill	2½	107	100	4 05	4 21	574	565	543
6	12,800	Solid gypsum block; no fill; no plaster	2	84	103	2 32	2 33	587	559	508

[1] The allowable load computed by the American Institute of Steel Construction formula, based on an effective length of 124 inches and least radius of gyration of 1.36 inches ($l/r=91.2$) is 12,300 lbs./in.[2]

[2] See fig. 2 for details of construction.

[3] The gross thickness of covering of column no. 2 was 3¾ inches.

[4] The measurements of temperatures of column no. 2 were not reliable.

[5] The gross thickness of covering of column no. 4 was 3 inches.

TABLE 2.—*Fire resistance of columns with unplastered gypsum protective coverings*

[Tests conducted at Underwriters' Laboratories]

Column no.	Load [1]	Protective coverings			Exposure, percent of standard	Period of expansion	Time to failure
		Kind	Thickness over flange of column, average	Net area of column and covering			
	Lb./in.²		*Inches*	*Sq. inches*		*Hr. min.*	*Hr. min.*
64 [2]	11,750 (13,662)	4-inch solid gypsum block, corrugated wall ties in horizontal joints; fill of gypsum block and mortar.	4¾	303	104	4 32	4 43¼
65 [3]	12,670 (14,604)	2-inch solid gypsum block, corrugated wall ties in joints; fill of gypsum block and mortar	3	135	104	2 20	2 21½
66 [4]	14,270 (15,000)	2-inch solid gypsum block, wire lath strips in joints; fill of gypsum concrete [5]	3¼	240	101	2 32	2 36
67 [2]	11,750 (13,662)	4-inch solid gypsum block, wire lath strips in joints; fill of gypsum concrete [5]	4¾	303	101	5 01	5 31½
67A [2]	11,750 (13,662)	Same as no. 67	4¾	303	100	5 45	6 24½

[1] The allowable loads (lb./in.²) computed by American Institute of Steel Construction formula are given in parentheses.
[2] Steel column, 8-inch H, 34.5 pounds; area 10.17 square inches; $l/r=75.6$.
[3] Steel column, two 6-inch channels, 8 pounds; two 8 by ¼ inch plates; area, 8.76 square inches; $l/r=64.7$.
[4] Steel column, two 9-inch channels, 13¼ pounds; area, 7.78 square inches; $l/r=44.0$.
[5] Concrete composed of 1 part gypsum cement, 1 part sand, and 4 parts broken gypsum block.

2. DEFORMATIONS

The average compressive deformation of three columns, including column, base plate, furnace floor, and bearing block, on applying the

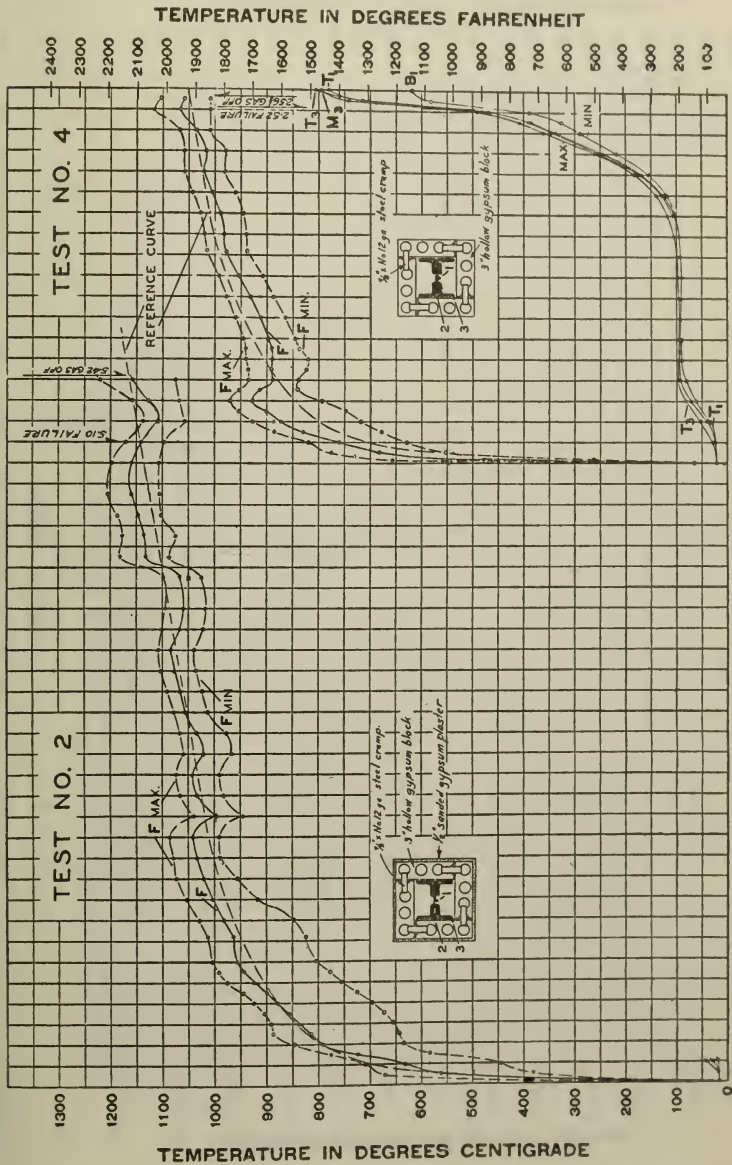

FIGURE 7.—*Temperature charts, tests nos. 2 and 4, columns protected with 3-inch gypsum partition tiles, no fill.*

load before test was 0.073 inch, approximately 60 percent of which was in the 124-inch effective length of the column, to judge from known stress-strain relations of steel. Changes in length of columns nos. 1, 2, and 3 during fire test, as determined by observation of movements

at the two gage points, located one on the lower bearing block and the other 6 inches from the upper bearing surface of the column, are shown by the curves in figure 9. A comparison of the expansion of column

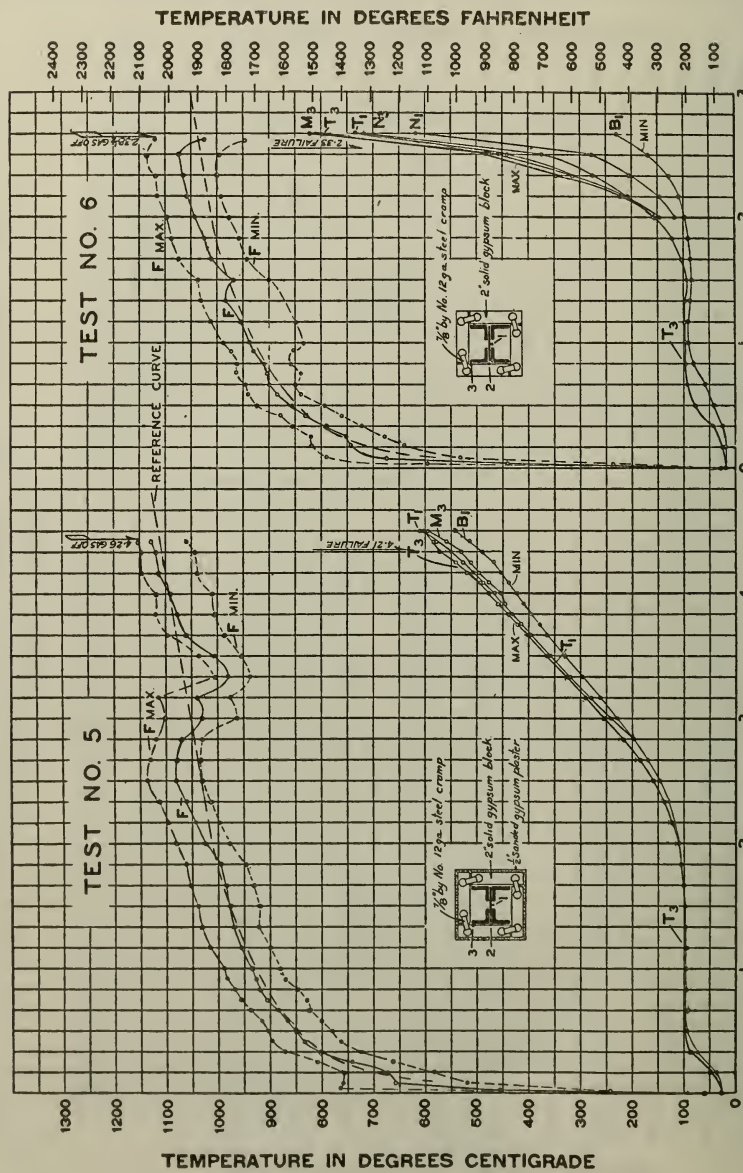

FIGURE 8.—*Temperature charts, tests nos. 5 and 6, columns protected with 2-inch solid gypsum partition tiles, no fill.*

no. 3 with steel of approximately the same quality expanding under load with rise of temperature is given by the curves in figure 10, in which the temperatures for the column are the averages computed

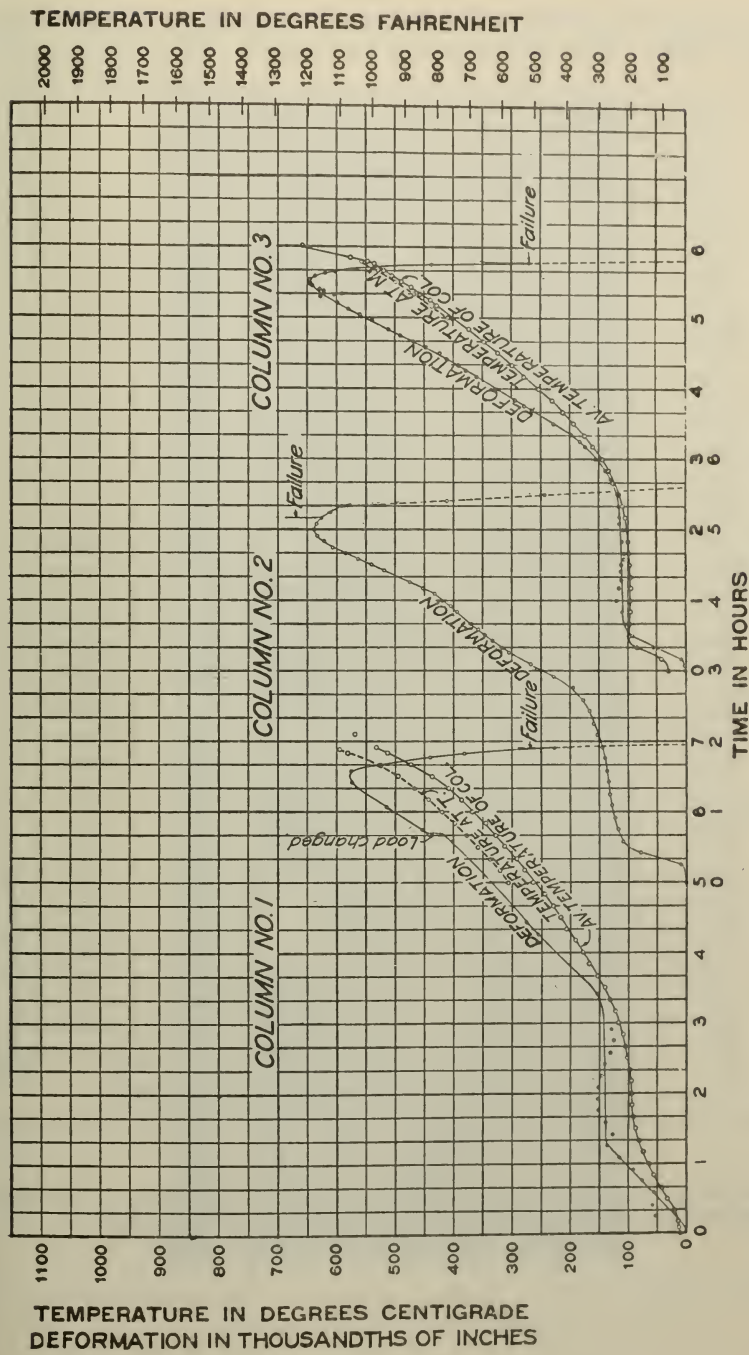

FIGURE 9.—*Average temperatures and measured deformations, tests nos. 1, 2, and 3.*

from weighted indications of the thermocouples at the 10 points in the column shaft. The expansion was equivalent to that which would be

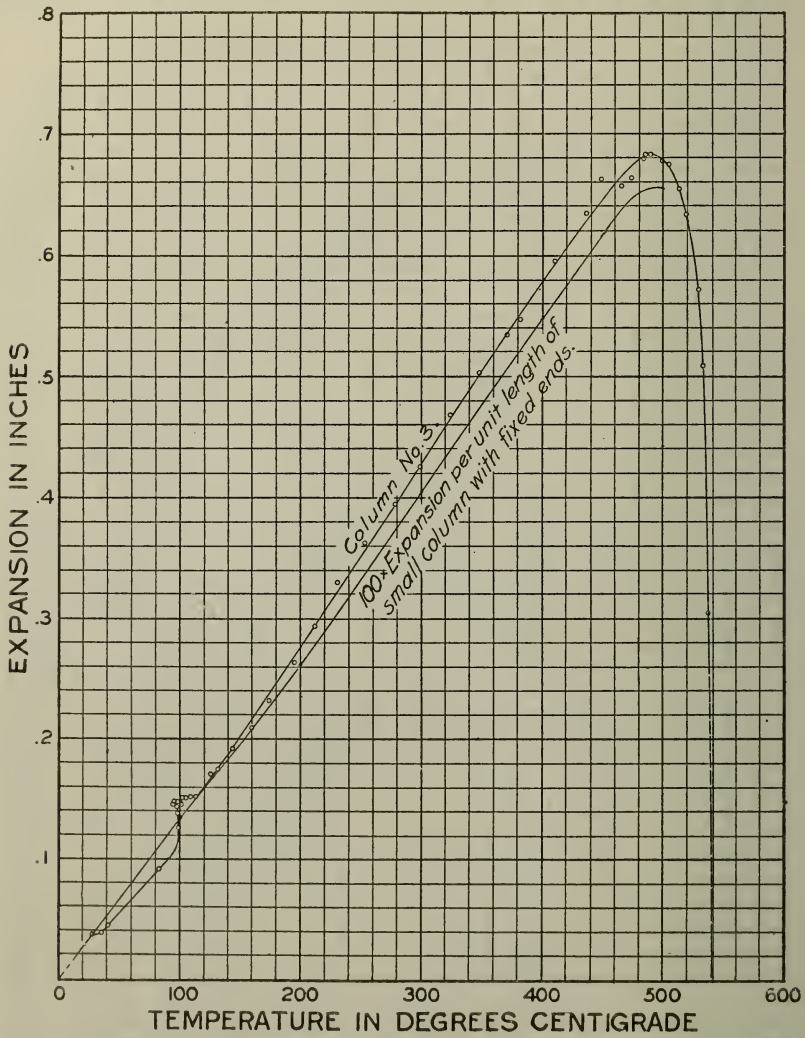

FIGURE 10.—*Measured expansion of column no. 3 compared with expansion of small loaded steel column.*

obtained by heating to the average measured temperature 105 inches of the column, the exposed length of which was 120 inches.

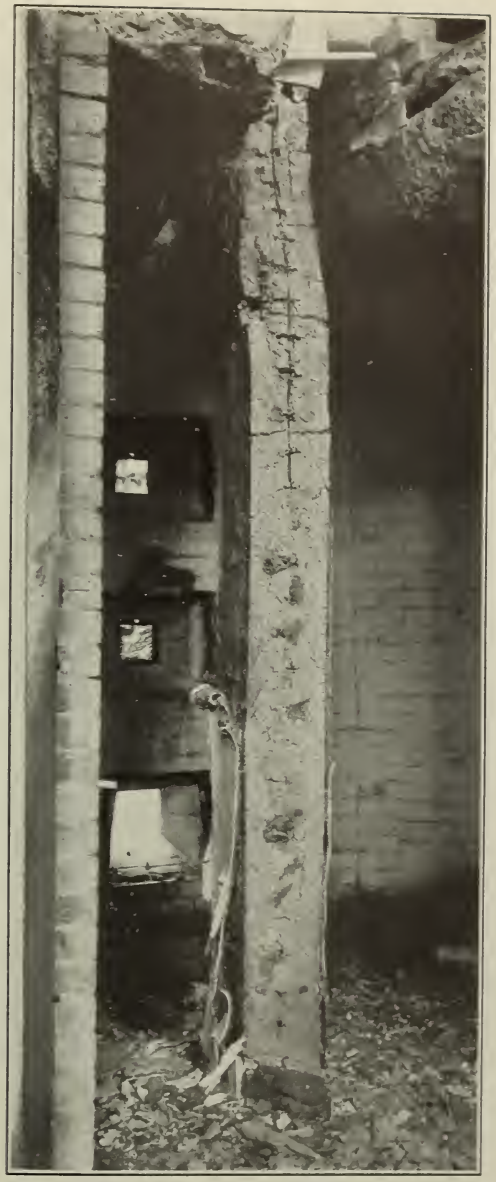

FIGURE 11.—*Column no. 1 after failure in fire test showing condition of fibered gypsum concrete after fire exposure.*

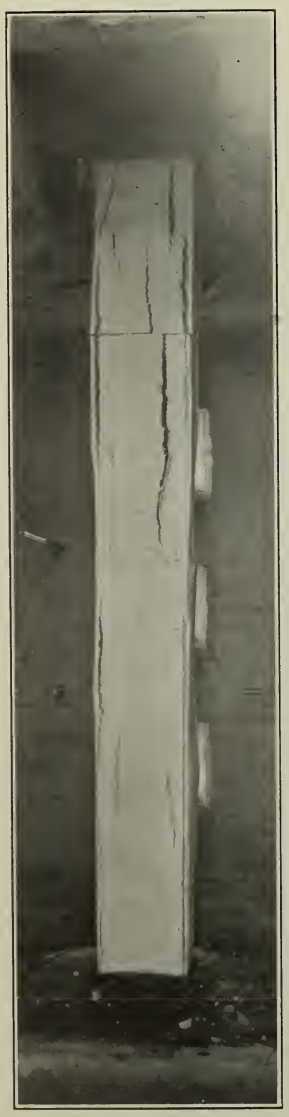

FIGURE 12.—*Column no. 5 after failure in fire test showing condition of covering after fire exposure.*

FIGURE 13.—*Column no. 6 after failure in fire test.*

3. FIRE EFFECTS ON COVERINGS

The photographs (figs. 11, 12, and 13) show columns nos. 1, 5, and 6 after completion of the fire tests, and are typical of all the tests. The plaster, it will be observed, has fallen from a large part of the exposed surface of column no. 1 but remained in place on the block covering of column no. 5.

Plaster began to fall from column no. 1 a few minutes after the fire was started. About two thirds of the plaster fell during the fire test, almost all of which took place during the first one and one half hours. The surface of the gypsum concrete, where exposed to the fire, was traversed by small cracks at intervals of 2 to 3 inches. One of these cracks, near where failure later occurred, had increased to five eighths inch in width at six and one half hours. The gypsum concrete shrank from 2 inches thickness to 1⅝ inches, but remained in place even after severe distortion of the column shaft.

Although cracks up to one half inch wide were observed in the covering of column no. 2 before failure, all plaster and blocks remained in place until removed after failure of the column. The plaster appeared to have prevented all serious cracking of the covering except opposite mortar joints. The other two plastered block-covered columns behaved in much the same manner as no. 2 except that the outside covering fell from column no. 3 after failure of the steel.

The block coverings of columns nos. 4 and 6, without plaster finish, began to crack early in the tests and before two hours had passed parts of the corners of some of the blocks had fallen, exposing ends of cramps. At 2 hours, 31 minutes, and 2 hours, 23 minutes, the steel of the respective columns was visible through cracks and from this time the cracks widened rapidly until at 2 hours, 49 minutes for no. 4 and 2 hours, 30 minutes for no. 6 some blocks fell. The column shafts, thus exposed, failed about 3 minutes later.

V. SUMMARY AND DISCUSSION

1. COMPARISON WITH RESULTS OF PREVIOUS TESTS

The fire tests of five steel columns with unplastered gypsum block coverings conducted in 1917–18,[3] give fire endurance limits from 2 hours 21½ minutes for a 2-inch block covering to 6 hours 24½ minutes maximum, for 4-inch block coverings. Failure in each test was hastened by exposure of the steel by falling of the blocks generally before the temperature of the steel exceeded 100° C. (212° F.). These columns had, in addition to the block coverings, layers of mortar three fourths inch or more in thickness between the steel and the blocks and all accessible reentrant parts were filled with gypsum blocks and mortar or a concrete made of gypsum cement and broken gypsum blocks.

The average stress from applied loads at failure in the recent tests, for columns having a slenderness ratio of 91.2, was 4 percent greater than for the columns of the previous tests, the slenderness ratios of which were 44.0, 64.7, and 75.6 for the three types employed. The degrees to which the performance was affected by the greater slenderness, greater stress, and different end restraint in the present tests

[3] See footnote 1, p. 737.

was not determined, but the effect of stress may be judged, at least qualitatively, from available information.[4]

2. FIRE EFFECTS ON PROTECTIVE COVERINGS

About two thirds of the plaster fell from column no. 1 during the test. This was the only column from which any considerable amount of plaster fell. The character of the concrete surface left by the oiled wooden form may have been a contributing cause.

The effect of fire on the block coverings without plaster was such as that described in the reports of previous tests [5] [6] [7]. Notwithstanding the iron cramps in the joints of these coverings, the blocks broke and fell before the temperature of the steel columns had reached a point high enough to cause failure of the steel. Even so, they remained in place relatively longer than the block coverings in the previous tests in which the metallic bond consisted of strips of wire lath or corrugated wall ties in the mortar of the horizontal joints. The plastered block coverings, on the other hand, remained in place throughout the test. The shrinkage and cracking of the sanded gypsum plaster was not as decided as that of the exposed surfaces of the unplastered gypsum blocks. Only a few cracks opened enough to be considered as particularly serious and there was no noticeable warping of the blocks during the test. After the failure of column no. 3, the covering fell, but neither of the other plastered coverings fell.

3. ANCHORAGE OF COVERINGS

The tests have clearly indicated that gypsum block coverings without plaster must have some means of positive anchorage to hold the units in place if they are to develop the full protection that can be given by the material. The cramps made of band iron and pushed down into holes to link adjacent blocks of the same course together served to hold the blocks in place for two and one-half hours or more, but did not enable the covering to develop its full fire protective properties. None of the block coverings with plaster finish fell from place before the fire endurance limit of the column had been reached irrespective of method of anchorage used. The collapse of the covering of column no. 3 when the column bent indicates that the anchorage of wire cloth strips in the horizontal joints was less effective than the cramps which held the coverings of columns nos. 2 and 5 in place through the period of failure of the column and the subsequent cooling.

4. EFFECTIVENESS OF PLASTER

Sanded gypsum plaster with the usual lime and plaster of paris white coat when applied over gypsum block coverings is apparently at least as effective as an equal thickness of block. Although the heat conductivity of the plaster may be greater than that of the block, its shrinkage under fire is less, and cracks do not open up to the same extent as when the blocks are exposed directly to the fire. The plaster also prevented the decided shrinkage and warping of the blocks

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[4] S. H. Ingberg and P. D. Sale, Compressive Strength and Deformation of Structural Steel and Cast Iron Shapes at Temperatures up to 950° C. (1,742° F.) Proc.Am.Soc.Test. Materials, vol. 26, pt. 2, 1926.

[5] See footnote 1, p. 737.

[6] Hull, W. A., A Comparison of the Heat Insulating Properties of Some of the Materials used in Fire Resistive Construction. B.S. Tech. Paper No. 130, 1919.

[7] Hull, W. A., and Ingberg, S. H., Fire Resistance of Concrete Columns. B.S. Tech. Paper No. 272, 1925.

such as was experienced in fire tests of columns with unplastered block coverings.

5. TEMPERATURE AT FAILURE

The temperatures given in table 1, although the highest observed or the greatest average, were not necessarily the highest prevailing at the time of failure. However, for those columns on which the coverings remained in place it is improbable that the temperatures greatly exceeded those given.

Column no. 1 failed at higher local temperature than those tested later in spite of a greater applied load. The gypsum concrete covering may have augmented its load-carrying capacity by increasing its stability as a column and carrying at failure a minor portion of the load.

Columns nos. 3 to 6, inclusive, failed when the temperature of the cross section giving the highest average reached 546° to 565° C. (1,015° to 1,049° F.), or an average of 557° C. (1,035° F.) for the four. While the temperature at this section was, no doubt, a large factor in the cause of failure, it is believed that the maximum temperature and the general temperature over the region of failure were also significant.

6. FIRE RESISTANCE OF COLUMNS

Among the factors affecting the fire resistance of steel building columns are the size and slenderness of the columns, the intensity of loading, and the kind and thickness of protective covering. The slenderness ratio of all the columns in the recent tests was the same, but greater loads were applied to columns nos. 1 and 2 than the others. The principal variations in protection for the columns were in the manner of applying and anchoring the covering materials and in the thickness of the covering.

The tests were too few for the determination of the values of the various factors, but a consistent relation has been found for the fire tests on the basis of the thickness of covering and the method of its application and bonding. This relation is expressed by the formula, $t=c(d^2+b)$, in which t is the time to failure, c, a factor varying with the units of measurement employed and with the form and composition of the covering material and its method of application, d, the average net thickness of the covering material outside of the flange of the column shaft and b, a quantity depending on the size and properties of the column and its loading, also upon the effects of air spaces surrounding the steel or of fill in the reentrant spaces in the column shaft, and possibly other factors.

The test results have been plotted in figure 14 with average net thickness of covering on column flange and time to failure as coordinates. The relation for columns covered with gypsum blocks held in place by cramps or wire mesh ties, and plastered with one-half inch of sanded gypsum plaster is given by the formula, $t=35(d^2+1)$, where t is the time to failure in minutes and d is the average net thickness of covering over the column flange in inches. It is shown by curve A. This formula applies to results found in the tests with this type of covering for thicknesses from 2½ to 3 inches.

The time to failure in the tests of columns similarly protected, but without plaster finish, was 85 percent of that computed by the formula and is shown as curve B.

Similarly the time to failure in the earlier tests (table 2) as shown by curve *C*, was 40 percent of that computed by the formula. The time to failure for the 4¾-inch thickness of covering has been taken as the average of the three tests.

Only one test (no. 1) was made with gypsum concrete protection which contained about 35 percent by volume of wood shavings, or

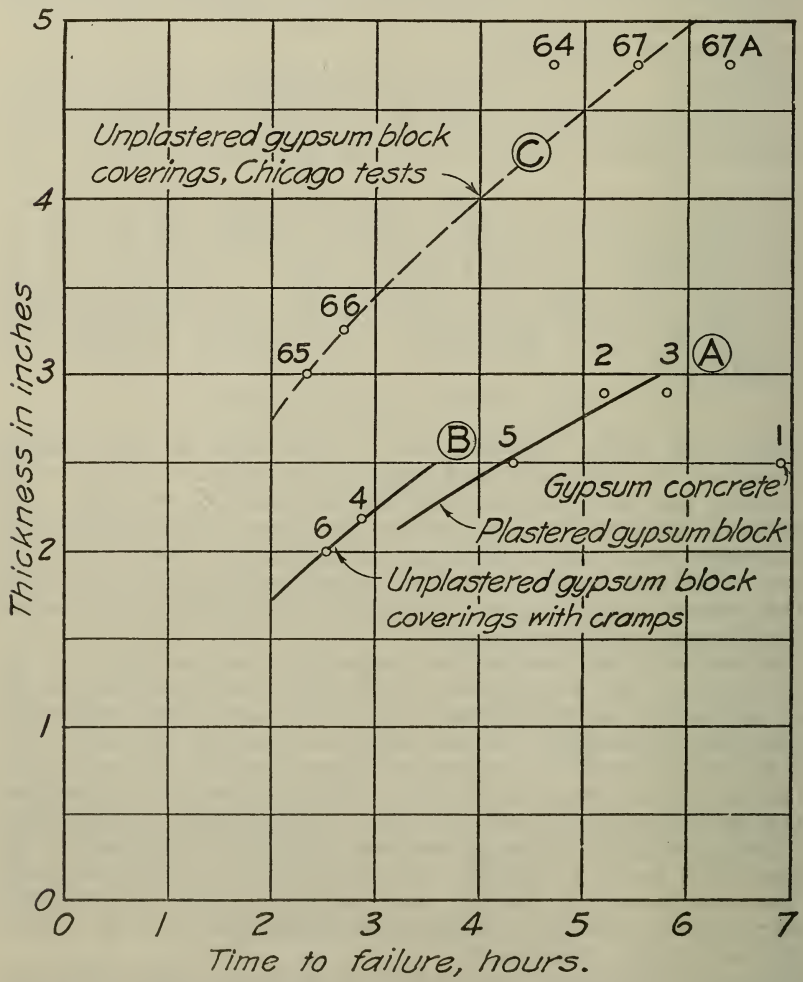

FIGURE 14.—*Relation of thickness of covering to time of failure of columns in fire tests.*

12½ percent of the dry mixture by weight. A considerable portion of the plaster finish fell off the 2-inch covering during the first part of the test, but, even so, a fire resistance of nearly 7 hours was developed. The principal differences between the covering of this column and those with solidly filled block coverings were its greater proportion of wood shavings, monolithic construction, and a well distributed reinforcement, but which of these or other factors contributed to its greater fire resistance is not known.

A summary of fire-resistance periods for small columns, unprotected and protected with gypsum coverings as derived from tests, together with data suitable for reference in designing fire-resistive buildings is given in table 3. A study of this summary will show striking advantages to be derived from the use of cramps or plaster with block coverings and still greater advantage from the use of the gypsum materials in reinforced monolithic coverings.

TABLE 3.—*Summary of ultimate fire resistance periods of steel columns with gypsum coverings*

Kind of covering	Surface finish	Thickness outside of column flange	Metal bond in horizontal joints	Internal construction	Minimum net area of column and covering	Ultimate-fire resistance period
		Inches			*Square inches*	*Hours*
None		0		Bare column	13	¼
2-inch solid block	None	3	Corrugated wall ties.	Solid fill of gypsum block and mortar.	130	2¼
Do	do	3¼	Strips of wire lath.	Solid fill of gypsum concrete.	130	2½
4-inch solid block	do	4¾	Corrugated wall ties.	Filled with hollow block and mortar.	240	4½
Do	do	4¾	Strips of wire lath.	Filled with concrete of broken block and mortar.	240	6
2-inch solid block	do	2	Cramps	Air space surrounding steel. No fill.	85	2½
3-inch hollow block	do	[1] 2.2	do	do	95	2¾
2-inch solid block	Plaster	2½	do	do	105	4¼
3-inch hollow block	do	[1] 2.9	do	¼-inch of mortar on flange. No fill.	120	5
2-inch solid block	do	3	Strips of wire lath.	Solid fill of gypsum block and mortar.	150	5¾
			Reinforcement			
2-inch fibered gypsum concrete.	do	2½	4 by 4 inch mesh wire fabric.	Monolithic poured covering.	130	7

[1] Net average thickness outside column flange.

VI. ACKNOWLEDGMENTS

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