Fire endurance of protected steel columns and beams: a compilation of published information on fire endurance of protected steel columns and beams by a number of test methods

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FIRE ENDURANCE OF PROTECTED STEEL COLUMNS AND BEAMS

(A COMPILATION OF PUBLISHED INFORMATION ON FIRE ENDURANCE OF PROTECTED STEEL COLUMNS AND BEAMS BY A NUMBER OF TEST METHODS)

BY

M. GALBREATH AND W. STANZAK

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FOREWORD

The sources of the information contained herein are the published reports of fire tests conducted in accordance with the standard methods of test ASTM E119 and BS 476 that are available to the Division of Building Research at present. No tests, so far as is known, have yet been conducted in accordance with CSA B54.3[8].

A number of countries have adopted methods of fire tests that differ in some respects from those recognized by the National Building Code [4]. Reports of these tests may be the subject of further investigation.

Tests of assemblies that contain materials identified by trade name only have been excluded from this paper because these assemblies are not adequately identified by description.

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LIST OF TABLES AND FIGURES

SPECIAL INTRODUCTION

THIS PUBLICATION HAS BEEN PREPARED TO BRING TOGETHER IN CONVENIENT FORM A LARGE AMOUNT OF INFORMATION SCATTERED THROUGHOUT THE PUBLISHED LITERATURE ON FIRE ENDURANCE OF STEEL AND CAST IRON COLUMNS AND BEAMS. IT IS INTENDED FOR INFORMATION PURPOSES ONLY AND IS NOT TO BE REGARDED AS AN OFFICIAL LISTING OR RATING. SUPPLEMENT NO. 2 TO THE NATIONAL BUILDING CODE PROVIDES SUCH RATINGS FOR COMMON MATERIALS AND SYSTEMS CAPABLE OF BEING IDENTIFIED ADEQUATELY BY DESCRIPTION, WHICH MAY BE USED IN THE ABSENCE OF SPECIFIC TEST INFORMATION OR OTHER CERTIFICATION. BUT THE DESIGNER, MANUFACTURER, OR BUILDING OFFICIAL MAY FIND IT NECESSARY TO EXERCISE JUDGEMENT ON MATERIALS OR SYSTEMS DIFFERING FROM THOSE FOR WHICH TEST OR RATING INFORMATION IS AVAILABLE, AND IN SUCH CASES THE INFORMATION NOW ASSEMBLED MAY BE USEFUL.

ALL THE TEST INFORMATION IN THIS PUBLICATION IS INCLUDED WITH THE PERMISSION OF THE ORIGINAL AUTHORS AND PUBLISHERS. IT HAS BEEN REARRANGED TO BRING TOGETHER CONVENIENTLY ALL THE RESULTS ON THE SAME OR SIMILAR MATERIALS WHEREVER THIS IS APPROPRIATE. IN MANY CASES THE DETAILED DESCRIPTIONS PROVIDED IN THE ORIGINAL PUBLICATIONS HAVE HAD TO BE ABBREVIATED OR OMITTED. REFERENCE SHOULD ALWAYS BE MADE TO THE ORIGINAL PUBLICATIONS FOR VERIFICATION OF THE DESCRIPTION AND METHOD OF TEST BEFORE PLACING GREAT WEIGHT ON INDIVIDUAL VALUES. THE VARIOUS ITEMS ARE CROSS-REFERENCED TO THE BIBLIOGRAPHY WHICH LISTS THE SOURCE PUBLICATIONS. NO REPRODUCTION SHOULD BE MADE OF ANY OF THIS MATERIAL

ACKNOWLEDGEMENT

THE PERMISSION GIVEN BY AUTHORS, AGENCIES, AND PUBLISHERS TO REPRODUCE THE MATERIAL ON WHICH THIS PUBLICATION IS BASED IS GREATLY APPRECIATED.

FIRE ENDURANCE OF PROTECTED STEEL COLUMNS AND BEAMS

(A compilation of published information on fire endurance of protected steel columns and beams by a number of test methods)

by

M. Galbreath* and W. Stanzak**

STANDARD METHODS OF TEST

The three methods of test relating to columns and beams that are accepted by the National Building Code are:

(i) ASTM E119, Standard Methods of Fire Test of Building Construction and Materials of the American Society for Testing and Materials, Philadelphia, Pa.

(ii) BS 476, Part 1, Fire Tests of Building Materials and Standards of the British Standards Institution, London, England.

(iii) CSA B54.3, Methods of Fire Tests of Walls, Partitions, Floors, Roofs, Ceilings, Columns, Beams and Girders of the Canadian Standards Association, Ottawa.

The time-temperature pattern followed in each of these tests is very similar though there are some differences in the details of the test methods. A number of changes have also been made in the British and American tests in the years since these were first developed.

ASTM E119

The ASTM E119 test method was first adopted in 1918. At that time it did not include any special provisions for testing columns or beams. The description of the method of test for columns was introduced in 1926. This requires that the column tested be of the length contemplated in the design and not less than 9 feet. The column must

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be loaded to develop theoretically the working stresses contemplated in the design. There is an optional provision that the column may be loaded to $1\frac{3}{4}$ times the working design load before the test is undertaken.

An alternative method of test for columns, introduced in 1947, was intended to evaluate steel column protections that are not required by design to carry any of the column load. In this test the column is not subjected to load. The temperature of the steel is measured by three thermocouples at each of four levels. The test is successful if the average temperature of the steel at any one of the four levels does not exceed 1000°F and if the temperature at any one of the thermocouples does not exceed 1200°F.

Beams and girders have been tested as part of a floor assembly since 1918. In 1953, an alternative test for protection of solid structural steel beams and girders was introduced. This is similar to the alternative test for columns and does not require loading. The temperature of the steel is measured at four points symmetrically disposed at each of four sections equally spaced along the beam. The test is successful if the average temperature at any one section does not exceed 1000°F and if the temperature at any one of the thermocouples does not exceed 1200°F.

A method of test for ceilings was introduced in 1947. Where there are no combustible materials above the ceiling the average temperature on the lower surface of main structural supporting members shall not exceed 1200°F and the average temperature of the top and bottom of the members shall not exceed 1000°F.

BS 476

The British Standard Method of Fire Test was first adopted in 1933. The time-temperature relationship is very close to that of ASTM E119. The test method adopted in 1933 required that a column or beam be subjected to $1\frac{1}{2}$ times the design load and that the test element be exposed to a hose stream test. The test method was revised in 1953 and the hose stream requirement was omitted and the applied load was reduced to the design load. The minimum length of column or beam in the British Test is 10 feet. The load is kept constant throughout the heating period and is re-applied 48 hours after the end of the heating period unless failure has already occurred.

CSA B54.3

The CSA B54.3 - Method of Test as it applies to tests of columns and beams is very similar to ASTM E119 but differs in the following respects:

(1) There is no provision for loading to $1\frac{3}{4}$ times the design load before the column test

(2) There is no special provision for testing a ceiling apart from the test of a floor and ceiling assembly.

(3) Temperature measurements in the alternate method of test are taken at 5 levels on columns and at 5 sections on beams, one level being at the centre of the member.

FIRE PERFORMANCE OF COLUMNS AND BEAMS

Columns and beams in a building on fire must perform a structural supporting function not a separating function. The limit on temperature rise on the unexposed surface that is required in the fire tests of walls and floors does not therefore apply to columns and beams. Failure of a column or beam occurs when it is no longer able to carry the load imposed on it.

To a degree the fire endurance of a column may be increased by reducing the superimposed load and reduced by increasing the superimposed load. In the case of structural steel columns protected by concrete, the concrete may perform two functions:

(1) it may provide an insulating barrier between the furnace and the steel, and

(2) it may carry part of the superimposed load.

Both of these functions contribute to the fire endurance of the column. If the loadbearing capacity of the concrete is not taken into account in the structural design the fire endurance of the column may be considerably extended. In a series of tests by Malhotra and Stevens[6] the fire endurance of combination columns (steel and concrete) has been studied.

The report of tests in Reference 1 makes it possible to compare the fire endurance performance of similar steel columns, unprotected, partially protected, and encased in concrete. These may be of assistance in understanding the contribution of the concrete cover to fire endurance. Protective covering materials that are weaker than concrete will generally contribute only to the insulation of the steel. For materials of this nature one of the major requirements is that the protective covering remain in place during these fire exposure periods. It may be noted that most of the masonry materials are either reinforced in the joints or tied around with wire.

The following Sections contain summaries of test reports referred to in this document.

TEST INFORMATION

SECTION 1

REFERENCE

Ingberg, S.H., H.K. Griffin, W.C. Robinson, and R.E. Wilson. Fire Tests of Building Columns. Technologic Papers of the Bureau of Standards No. 184, U.S. Department of Commerce, National Bureau of Standards, Washington, 1921.

NOTES

The 79 tests in this series were carried out during 1917-1918 before the specific provisions for testing building columns were introduced into ASTM E119. The test methods used were substantially the same as the present provisions for testing loadbearing columns. This is the largest number of tests in one series available at present and is notable for:

(1) the variety of shapes and sections included,

(2) the number of unprotected and partially protected columns tested,

(3) the variety of protective covering materials investigated.

Some of the more significant features of the tests are as follows. -

Firing
The furnace temperatures were controlled and came close to the now-standard time temperature curve. Fewer thermocouples were used and the furnace control may have been less exact than in present-day tests.

Loading
It may be assumed that the colums were loaded in accordance with the design procedures accepted at the time of the tests. A comparison has been made (Tables 1.8.A and 1.8.B) between the superimposed

loads applied in the tests and the design loads that would be applied using the design methods set forth in the National Building Code 1965 (4).

This shows that the loads applied during the tests were slightly higher than those calculated by the design methods applicable at the time. These applied loads were, in most cases, less than the design loads imposed by present National Building Code formulae.

Some of the columns in this series were exposed to the hose stream test. The results have not been reproduced here because none of the test methods now recognized by the National Building Code require a hose stream test for building columns or beams.

TABLE 1.1.A

RESULTS OF FIRE TESTS ON UNPROTECTED COLUMNS

Test No.	SECTION	Nominal Area, Sq. In.	l/r	Load Sustained During Test		Time to Failure, Hr—Min.	Furnace Exposure, Percent *
				Total Load, Lb.	Unit Load, Lb. per Sq. In.		
1	Rolled H........................	10.17	75.6	119500	11750	0—11¼	95.6
2	Plate and Angle................	13.00	111.8	116000	8900	0—19¼	97.0
3	Plate and Channel..............	8.76	64.7	111000	12650	0—14	101.4
4	Latticed Channel...............	7.78	44.0	111000	14250	0—11	101.1
5	Z-bar and Plate................	9.32	81.7	105000	11250	0—14¼	100.0
6	I-beam and Channel............	10.12	72.1	122000	12050	0—17	89.6
7	Latticed Angle.................	8.44	40.7	122500	14500	0—14	96.3
8	Starred Angle..................	13.27	108.5	124000	9350	0—21½	99.0
9	Round Cast Iron................	14.73	68.2	95500	6500	0—34¼	101.2
10	Round Cast Iron................	14.73	68.2	95500	6500	0—34½	101.7
10A	Round Cast Iron................	14.45	63.2	98500	6800	0—34¼	100.3
11	Round Cast Iron (Concrete filled).	14.73	68.2	95500	....	0—45¼	103.1
12	Steel Pipe (Concrete filled)......	Steel 6.93 Concrete 38.74	63.9	114500	....	0—36	101.9
3	Reinforced Steel Pipe (Starred angles imbedded in concrete filling)........................	Steel 18.36 Concrete 40.07	68.2	236000	....	1—11¾	99.3

NOTE: Details of the steel, cast-iron, and pipe columns listed in Tables 42*a* to 42*g* are given in Figs. 1 to 4 (p. 16–19), and Figs. 6 and 7 (p. 22 and 24). Further properties of the sections are given in Tables 3*a* to 3*h* (p. 33–47).

* This represents per cent of area under ASTM Standard Time-temperature curve

TABLE 1.1.B

DETAILS OF CONSTRUCTION OF UNPROTECTED STRUCTURAL STEEL COLUMNS 1-EFFECTIVE LENGTH, 12 FT. 8 IN.

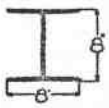
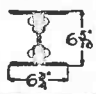
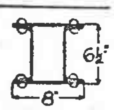
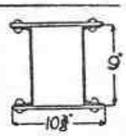
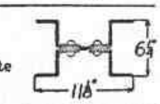
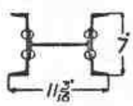
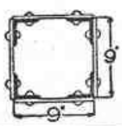
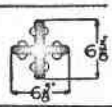
Test No.	SECTION		SECTION MEMBERS	Nominal Area, Sq. In.	Least Radius of Gyration, r, In.	$\frac{l}{r}$
1	Rolled H		Solid Rolled H, 8 in.—34½ lb..	10.17	2.01	75.6
2	Plate and Angle		1 Plate, ½ by 6 in............. 4 Angles, 3 by 2½ by ½ in......	13.00	1.36	111.8
3	Plate and Channel		2 Plates, ¼ by 8 in............ 2 Channels, 6 in.—8 lb.........	8.76	2.35	64.7
4	Latticed Channel		2 Channels, 9 in.—13¼ lb...... Single lattice, 5/16 by 2 in........	7.78	3.43	44.0
5	Z-bar and Plate		1 Plate, ¼ by 5¾ in........... 4 Z-bars, 3 by ¼ in............	9.32	1.86	81.7
6	I-beam and Channel		1 I-beam, 7 in.—15 lb.......... 2 Channels, 7 in.—9¾ lb.......	10.12	2.11	72.1
7	Latticed Angle		4 Angles, 3 by 3 by ⅜ in....... Single lattice, ¼ by 2¼ in......	8.44	3.73	40.7
8	Starred Angle		4 Angles, 3 by 3 by ⅜ in....... 1 Plate, ⅜ by 6⅝ in.......... 2 Plates, ⅛ by 3⅛ in..........	13.27	1.40	108.5

TABLE 1.1.C

DETAILS OF CONSTRUCTION OF UNPROTECTED CAST IRON AND PIPE COLUMNS

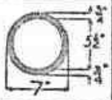
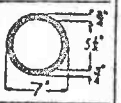
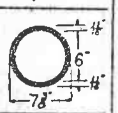
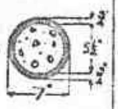
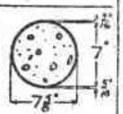
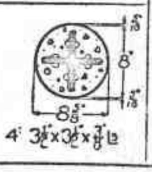
Test No.	SECTION	DETAILS	Nominal Area, Sq. In.	Effective Length, l, In.	Least Radius of Gyration, r, In.	$\frac{l}{r}$
9	Round Cast Iron, Horizontally cast 	Ends restrained	14.73	152	2.23	68.2
10	Round Cast Iron, Horizontally cast 	Ends not restrained	14.73	152	2.23	68.2
10-A	Round Cast Iron, Vertically cast 	Ends not restrained	14.45	150¼	2.38	63.2
11	Round Cast Iron, Horizontally cast, Concrete filled 	Ends not restrained Concrete, 1:2:4 Portland cement Joliet sand Joliet gravel	14.73	152	2.23	68.2
12	Steel Pipe, Concrete filled 	Ends not restrained Concrete, 1:1½:3 Portland cement Cambridge sand Westfield blue trap	Steel 6.93 Concrete 38.7	149	2.34	63.9
13	Reinforced Steel Pipe, Concrete filled 	Ends not restrained 4 angles inside pipe, 3½ in. 3½ in. ⅜ in. Concrete same as for No. 12	Steel 18.36 Concrete 40.1	152¾	2.24	68.2

TABLE 1.2.A

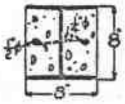
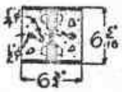
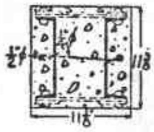
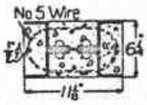
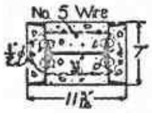
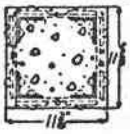
RESULTS OF FIRE TESTS ON COLUMNS PARTLY PROTECTED BY CONCRETE

Test No.	SECTION	*Protection		Age of Covering, Days	Load Sustained During Test, Lb.	Time to Failure, Hr.—Min.	Furnace Exposure, Percent
		Mixture	Kind of Concrete				
14	Rolled H..........	1:2:4	Joliet gravel.........	405	119500	1 — 04¼	85.1
15	Rolled H..........	1:2:4	Rockport granite....	407	119500	0 — 48¼	91.5
16	Plate and Angle...	1:2:4	New York trap......	416	116000	0 — 44½	94.8
17	Plate and Angle...	1:1½:4½	Hard coal cinders...	408	116000	0 — 41¾	99.6
18	Latticed Channel..	1:2:4	New York trap......	418	111000	2 — 53	98.1
19	Z-bar and Plate....	1:3:5	Chicago limestone...	414	105000	1 — 07¼	95.8
20	I-beam and Channel.........	1:3:5	New York trap......	415	122000	1 — 24½	100.2
21	I-beam and Channel.........	1:3:5	New York trap......	416	122000	1 — 21¾	99.6
22	Latticed Angle....	1:2:4	Chicago limestone...	408	119500	5 — 14	99.2

*Re-entrant portions and interior filled with concrete.

TABLE 1.2.B

DETAILS OF CONSTRUCTION OF COLUMNS PARTLY PROTECTED BY CONCRETE

Test No.	SECTION		PROTECTION	
			Mixture	Material
14	Rolled H		1:2:4	Portland cement Joliet sand Joliet gravel
15	Rolled H		1:2:4	Portland cement Plum Island sand Rockport granite
16	Plate and Angle		1:2:4	Portland cement Long Island sand New York trap
17	Plate and Angle		1:1½:4½	Portland cement Long Island sand Hard coal cinders
18	Latticed Channel		1:2:4	Portland cement Long Island sand New York trap
19	Z-bar and Plate		1:3:5	Portland cement Fox River sand Chicago limestone
20	I-beam and Channel		1:3:5	Portland cement Long Island sand New York trap
21	I-beam and Channel		1:3:5	Portland cement Long Island sand New York trap
22	Latticed Angle		1:2:4	Portland cement Fox River sand Chicago limestone

NOTE: The horizontal ties, consisting of ¼-inch bars or No. 5 wire, are bent around or wired to the vertical ½-inch bars, and are spaced 18 inches apart vertically.

TABLE 1.3.A

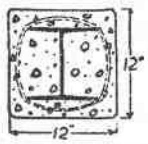
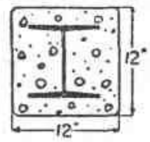
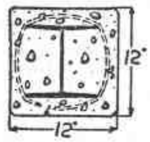
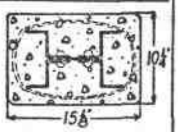
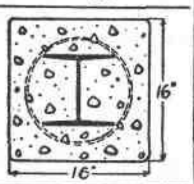
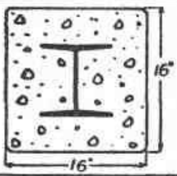
RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY CONCRETE

Test No.	SECTION	Protection			Age of Covering, Days	Load Sustained During Test, Lb.	Time to Failure, Hr.—Min.	Furnace Exposure, Percent
		Thickness, In.	Mixture	Kind of Concrete				
28	Rolled H..........	2	1:2:4	Chicago limestone	437	119500	6 — 33¾	96.9
28A	Rolled H..........	2	1:2:4	Chicago limestone	438	119500	7 — 09¼	95.2
29	Rolled H..........	2	1:2:4	New York trap	435	119500	4 — 38½	99.5
30	Rolled H..........	2	1:2:4	Joliet gravel	439	119500	7 — 16	99.2
31	Rolled H..........	2	1:2:4	Cleveland sandstone	500	119500	4 — 11½	90.4
32	Rolled H..........	2	1:2:5	Hard coal cinders	503	119500	3 — 44	101.3
32A	Z-bar and Plate	2	1:2:5	Hard coal cinders	497	105000	4 — 02	100.5
33	Rolled H..........	4	1:2:4	Chicago limestone	450	119500 ‡431000	8 — 08	99.2
33A	Rolled H..........	4	1:2:4	Chicago limestone	455	119500 ‡405000	8 — 07¼	98.8
34	Rolled H..........	4	1:2:4	Rockport granite	452	119500	7 — 58	98.6
34A	Rolled H..........	4	1:2:4	Rockport granite	454	119500	7 — 23	102.5
35	Rolled H..........	4	1:3:5	Chicago limestone	504	119500 ‡348000	8 — 07	101.3
36	Plate and Angle....	2	1:2:4	New York trap	445	116000	3 — 53¼	100.3
37	Plate and Angle....	4 round	1:2:4	New York trap	503	116000	7 — 34½	99.9
38	Plate and Channel..	2	1:2:4	Joliet gravel	449	*116500	5 — 28¾	100.2
39	Plate and Channel..	4	1:2:4	Meramec R. gravel	436	*116500	3 — 41¼	98.3
40	Latticed Channel ..	2 round	1:2:4	New York trap	501	111000	7 — 57	99.1
41	Z-bar and Plate....	4	1:3:5	Chicago limestone	451	105000 ‡332000	8 — 24½	99.6
42	Z-bar and Plate....	4	1:3:5	Chicago limestone	453	105000 ‡333000	8 — 11½	98.5
43	I-beam and Channel	2	1:2:4	Cleveland sandstone	456	122000	4 — 11	98.7
44	I-beam and Channel	2	1:3:5	Cleveland sandstone	458	122000	3 — 04¼	100.6
45	Starred Angle......	2 round	1:2:4	Meramec R. gravel	447	124000	1 — 47	99.7
46	Latticed Angle.....	†2	1:2:4	New York trap	451	122500	6 — 43½	99.0
47	Round Cast Iron...	2	1:2:5	Hard coal cinders	446	95500	2 — 48¾	99.6

* Heavier load used as plates have 1/32 in. greater thickness than nominal.
† 2-in. outside rivets, 3⅛-in. outside angles.
‡ Load necessary to cause failure of column. After 8 hr. the load was increased until failure occurred.

TABLE 1.3.B

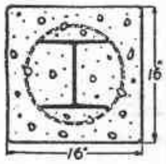
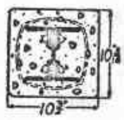
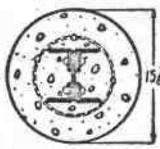
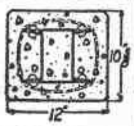
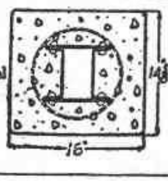
DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY CONCRETE

Test No.	SECTION		PROTECTION		
			Thickness, In.	Mixture	Material
28	Rolled H		2	1:2:4	Portlana cement Fox River sand Chicago limestone
28 A	Rolled H		2	1:2:4	Portland cement Fox River sand Chicago limestone
29	Rolled H		2	1:2:4	Portland cement Long Island sand New York trap
30	Rolled H		2	1:2:4	Portland cement Joliet sand Joliet gravel
31	Rolled H		2	1:2:4	Portland cement Pelee Island sand Cleveland sandstone
32	Rolled H		2	1:2:5	Portland cement Long Island sand Hard coal cinders
32 A	Z-bar and Plate		2	1:2:5	Portland cement Long Island sand Hard coal cinders
33	Rolled H		4	1:2:4	Portland cement Fox River sand Chicago limestone
33 A	Rolled H		4	1:2:4	Portland cement Fox River sand Chicago limestone

NOTE: Ties where used are of No. 5, B. & S. gage, steel wire, wound spirally on a pitch of 8 in.

TABLE 1. 3. B (Cont'd)

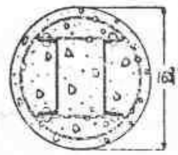
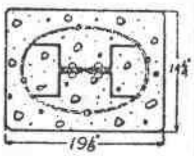
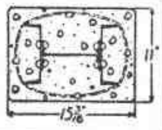
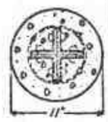
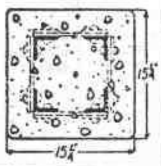
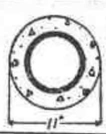
DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY CONCRETE

Test No.	SECTION		PROTECTION		
			Thickness, In.	Mixture	Material
34	Rolled H		4	1:2:4	Portland cement Plum Island sand Rockport granite
34A	Rolled H		4	1:2:4	Portland cement Plum Island sand Rockport granite
35	Rolled H		4	1:3:5	Portland cement Fox River sand Chicago limestone
36	Plate and Angle		2	1:2:4	Portland cement Long Island sand New York trap
37	Plate and Angle		4	1:2:4	Portland cement Long Island sand New York trap
38	Plate and Channel		2	1:2:4	Portland cement Joliet sand Joliet gravel
39	Plate and Channel		4	1:2:4	Portland cement Meramec River sand Meramec River gravel

NOTE: Wire ties are of No. 5, B. & S. gage, steel wire, wound spirally on a pitch of 8 in.

TABLE 1.3.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY CONCRETE

Test No.	SECTION	PROTECTION		
		Thickness, In.	Mixture	Material
40	Latticed Channel 	2	1:2:4	Portland cement Long Island sand New York trap
41	Z-bar and Plate 	4	1:3:5	Portland cement Fox River sand. Chicago limestone
42	Z-bar and Plate	4	1:3:5	Portland cement Fox River sand Chicago limestone
43	I-beam and Channel 	2	1:2:4	Portland cement Pelee Island sand Cleveland sandstone
44	I-beam and Channel	2	1:3:5	Portland cement Pelee Island sand Cleveland sandstone
45	Starred Angle 	2	1:2:4	Portland cement Meramec River sand Meramec River gravel
46	Latticed Angle 	2-in. outside rivets. 3⅛-in. outside angles.	1:2:4	Portland cement Long Island sand New York trap
47	Round Cast Iron 	2	1:2:5	Portland cement Long Island sand Hard coal cinders

NOTE: Wire ties where used are of No. 5, B. & S. gage, steel wire wound spirally on a pitch of 8 in.

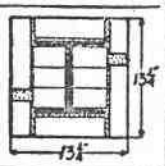
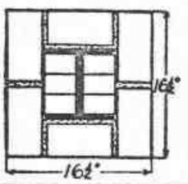
TABLE 1.4.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY BRICK

Test No.	SECTION	Thickness of Brick, In.	Kind of Brick and Filling	Age of Covering, Days	Load Sustained During Test, Lb.	Time to Failure, Hr.—Min.	Furnace Exposure, Percent
68	Rolled H..	2¼	Chicago common brick set on edge and end Brick fill	498	119500	1 — 40¾	104 0
69	Rolled H..	3¾	Chicago common brick laid flat Brick fill	502	119500	7 — 13¼	101 2

TABLE 1.4.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY BRICK

Test No.	SECTION	Thickness of Brick, In.	Kind of Brick	Filling
68	Rolled H 	2¼	Chicago common brick set on edge and end ⅜-in. mortar on flanges	Chicago common brick
69	Rolled H 	3¾	Chicago common brick laid flat ½-in. mortar on flanges	Chicago common brick

NOTE: The mortar consisted of 1 part Portland cement, 1 part lime putty and 4 parts bank sand.

TABLE 1.5.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY HOLLOW CLAY TILE

Test No.	SECTION	Protection		Age of Covering, Days	Load Sustained During Test, Lb.	Time to Failure, Hr.—Min.	Furnace Exposure Percent
		Thickness of Tile, In.	Kind of Tile, Filling, and Method of Tying				
48	Rolled H..........	2	New Jersey semi-fire clay................. No filling Outside wire ties	496	119500	1 — 50	100.9
49	Rolled H..........	4	Same as No. 48........	497	119500	1 — 40	99.9
50	Plate and Angle...	2	Surface clay, Boston.. Granite concrete fill No ties	494	116000	1 — 05¾	99.8
50A	Plate and Angle...	2	Same as No. 50........	505	*117500	1 — 59½	101.8
51	Plate and Angle...	4	Surface clay, Boston Granite concrete fill Outside wire ties	487	116000	2 — 17¼	101.8
51A	Plate and Angle...	4	Same as No. 51........	507	116000	2 — 55½	100.5
52	Plate and Channel.	2	Ohio shale............ Cinder concrete fill Outside wire ties	513	111000	1 — 40¾	100.2
53	Plate and Channel.	4	Same as No. 52........	495	111000	1 — 22¼	103.0
54	Latticed Channel..	2	Ohio semi-fire clay.... Trap concrete fill Outside wire ties	489	111000	3 — 17¼	101.1
55	Z-bar and Plate....	2	Ohio semi-fire clay.... Limestone concrete fill Outside wire ties	485	105000	3 — 46¾	99.5
56	Z-bar and Plate....	4	Ohio semi-fire clay.... Limestone concrete fill Wire mesh in joints	491	105000	3 — 33½	100.3
57	I-beam and Channel.........	4	Surface clay, Chicago.. Limestone concrete fill Outside wire ties	491	122000	3 — 23	100.0
58	I-beam and Channel.........	Two 2	Surface clay, Chicago.. Hollow tile fill Wire mesh in joints	502	122000	4 — 35¾	101.7
59	I-beam and Channel.........	Two 2	Surface clay, Chicago.. Hollow tile fill Outside wire ties	490	122000	1 — 33¾	101.2
60	Latticed Angle....	2	Ohio semi-fire clay.... Trap concrete fill, placed before tile was set Outside wire ties	487	122500	3 — 09½	100.4
61	Latticed Angle....	2	Ohio semi-fire clay.... No filling Outside wire ties	501	122500	0 — 50¼	100.3
62	Round Cast Iron..	2 round	Porous semi-fire clay, New Jersey......... No filling Outside wire ties	483	95500	4 — 11½	101.3
63	Round Cast Iron..	2 round	Same as No. 62........	493	95500	2 — 57½	100.6
76	Rolled H..........	2	Ohio shale; Ohio semi-fire clay; semi-fire clay, New Jersey.... Limestone concrete fill Wire mesh in joints Tile covered with ¾-in. layer of gypsum plaster	42	119500	4 — 25½	98.1
77	Plate and Angle	4	Semi-fire clay, N. J.; surface clay, Chicago; surface clay, Boston. Limestone concrete fill Wire mesh in joints Tile covered with ⅝-in. layer of lime plaster	45	116000	4 — 42¼	97.3

* Heavier load used as plate has 1/32 in. greater thickness than nominal.

TABLE 1.5.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY HOLLOW CLAY TILE

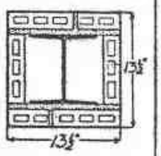
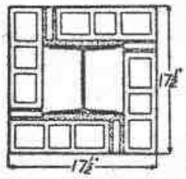
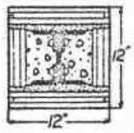
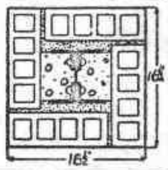
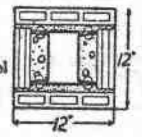
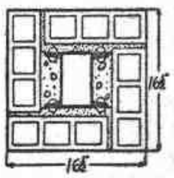
Test No.	SECTION		Thickness of Tile. In.	Kind of Tile and Method of Application	Filling
48	Rolled H		2	Semi-fire clay, New Jersey district ¾-in mortar on flanges Outside wire ties	No filling
49	Rolled H		4	Semi-fire clay, New Jersey district ¾-in. mortar on flanges	No filling
50	Plate and Angle		2	Surface clay, Boston district ½-in. mortar on flanges	1:3:5 concrete Portland cement Plum Island sand Rockport granite
50-A	Plate and Angle		2	Same as No. 50	Same as No. 50
51	Plate and Angle		4	Surface clay, Boston district 1½-in mortar on flanges Outside wire ties	1:3:5: concrete Portland cement Plum Island sand Rockport granite
51-A	Plate and Angle		4	Same as No. 51	Same as No. 51
52	Plate and Channel		2	Ohio shale ¾-in. mortar on flanges Outside wire ties	1:2:5 concrete Portland cement Long Island sand Hard coal cinders
53	Plate and Channel		4	Ohio shale 1-in. mortar on flanges Outside wire ties	1:2:5: concrete Portland cement Long Island sand Hard coal cinders

TABLE 1.5.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY HOLLOW CLAY TILE

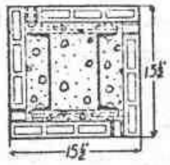
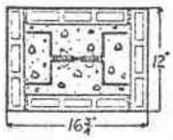
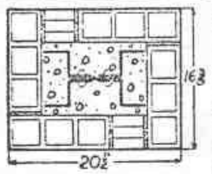
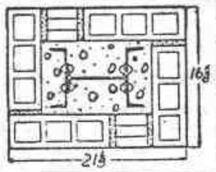
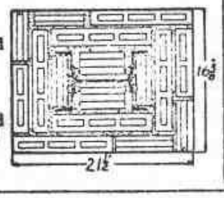
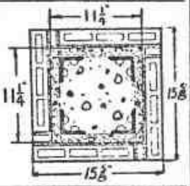
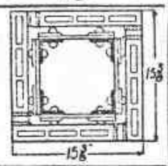
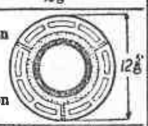
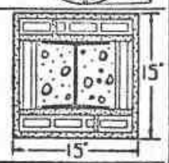
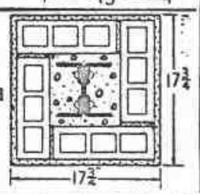
Test No.	SECTION	Thickness of Tile, In.	Kind of Tile and Method of Application	Filling
54	Latticed Channel 	2	Ohio semi-fire clay Outside wire ties	1:3:5 concrete, Portland cement Long Island sand New York trap
55	Z-bar and Plate 	2	Ohio semi-fire clay Outside wire ties	1:3:5: concrete, Portland cement Fox River sand Chicago limestone
56	Z-bar and Plate 	4	Ohio semi-fire clay ⅜-in. wire mesh in horizontal joints	1:3:5: concrete, Portland cement Fox River sand Chicago limestone
57	I-beam and Channel 	4	Surface clay, Chicago district Outside wire ties	1:3:5: concrete, Portland cement Fox River sand Chicago limestone
58	I-beam and Channel 	Two 2-in.	Surface clay, Chicago district ½-in. mortar on flanges ⅜-in. wire mesh in horizontal joints	Hollow clay tile, 2 by 12 by 6 in. at at ends 3 by 12 by 6 in. at sides
59	I-beam and Channel	Two 2-in.	Surface clay, Chicago district ½-in. mortar on flanges Outside wire ties	Hollow clay tile, 2 by 12 by 6 in. at ends 3 by 12 by 6 in. at sides

TABLE 1.5.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY HOLLOW CLAY TILE

Test No.	SECTION	Thickness of Tile, In.	Kind of Tile and Method of Application	Filling
60	Latticed Angle 	2	Ohio semi-fire clay ¼-in. mortar between fill and tile Outside wire ties	1:2:4: concrete Portland cement Long Island sand New York trap Fill placed before tile was set
61	Latticed Angle 	2	Ohio semi-fire clay Outside wire ties	No filling
62	Round Cast Iron 	2	Porous semi-fire clay, New Jersey district ¾-in. mortar Outside wire ties	No filling
63	Round Cast Iron	2	Same as No. 62	No filling
76	Rolled H 	2	Ohio shale: Ohio semi-fire clay; semi-fire clay, New Jersey district ¾-in. mortar on flanges ⅜-in. wire mesh in horizontal joints Tile covered with a 2-coat, ¾-in. layer of 1:3 gypsum plaster	1:3:5: concrete Portland cement Fox River sand Chicago limestone
77	Plate and Angle 	4	Semi-fire clay, New Jersey; surface clay, Chicago; surface clay, Boston district 1⅛-in. mortar on flanges ⅜-in. wire mesh in horizontal joints Tile covered with a 2-coat, ⅝-in. layer of 1:2½ lime plaster	1:3:5 concrete Portland cement Fox River sand Chicago limestone

NOTE: The mortar used in setting the tile consisted of 1 part Portland cement, 1 part lime putty and 4 parts fine beach or bank sand.

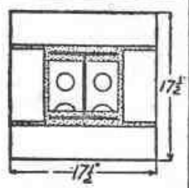
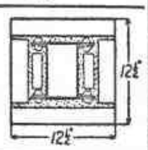
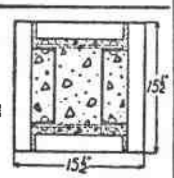
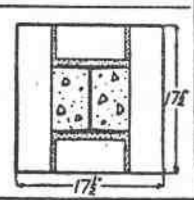
TABLE 1.6.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY GYPSUM BLOCK

Test No.	SECTION	Thickness of Block, In.	Protection Kind of Block, Filling and Method of Tying	Age of Cover-ing, Days	Load Sustained During Test, Lb.	Time to Failure, Hr.—Min.	Furnace Exposure, Percent
64	Rolled H..	4	Western gypsum (solid) Hollow gypsum block fill Wall ties in joints	502	119500	4 — 43¼	104.5
65	Plate and Channel	2	Western gypsum (solid) Solid gypsum block fill Wall ties in joints	505	111000	2 — 21½	104.5
66	Latticed Channel	2	Eastern gypsum (solid) Poured gypsum fill Wire mesh in joints	495	111000	2 — 36	101.0
67	Rolled H..	4	Same as No. 66	492	119500	5 — 31½	101.2
67A	Rolled H..	4	Same as No. 66	491	119500	6 — 24½	99.7

TABLE 1.6.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY GYPSUM BLOCK

Test No.	SECTION		Thick-ness of Block, In.	Kind of Gypsum and Method of Application	Filling
64	Rolled H		4	Western gypsum (solid) ¾-in. mortar on flanges Corrugated wall ties in horizontal joints	Hollow Western gypsum block
65	Plate and Channel		2	Western gypsum (solid) 1-in. mortar on flanges Corrugated wall ties in horizontal joints	Solid Western gypsum block
66	Latticed Channel		2	Eastern gypsum (solid) ¾-in. mortar on lattice ⅜-in. wire mesh in horizontal joints	1:1:4, Calcined gypsum Fine lake sand Broken gypsum block
67	Rolled H		4	Eastern gypsum (solid) ¾-in. mortar on flanges ⅜-in. wire mesh in horizontal joints	1:1:4, Calcined gypsum Fine lake sand Broken gypsum block
67-A	Rolled H		4	Same as No. 67	Same as No.67

NOTE: The gypsum blocks were set in mortar consisting of 1 part by volume of neat unfibered calcined gypsum and 3 parts fine lake sand.

TABLE 1.7.A

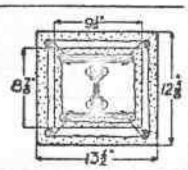
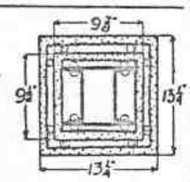
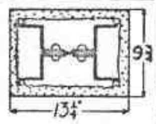
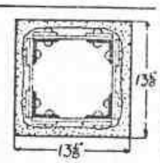
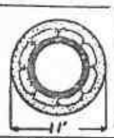
RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY PLASTER ON METAL LATH

Test No.	SECTION	Protection	Age of Cover-ing, Days	Load Sustained During Test, Lb.	Time to Failure, Hr.—Min.	Furnace Exposure, Percent
23	Plate and Angle...	Two 2-coat layers of Portland cement plaster on expanded metal lath, each layer 1 in. thick, with a ¾-in. air space between layers	508	*117500	2 — 52	103.1
24	Plate and Channel.	Two 2-coat layers of Portland cement plaster on woven wire lath, each layer ⅞ in. thick with a ¾-in. air space between layers	496	111000	2 — 24	101.5
25	Z-bar and Plate...	One 2-coat layer of Portland cement plaster, 1 in. thick, on expanded metal lath	484	105000	1 — 07¾	103.7
26	Latticed Angle....	One 2-coat layer of Portland cement plaster, 1⅛ in. thick, on expanded metal lath	497	122500	1 — 23½	104.2
27	Round Cast Iron..	One 2-coat layer of Portland cement plaster, 1½ in. thick on high ribbed expanded metal lath with a ½-in. broken air space	498	95500	2 — 58	98.2

*** Heavier load used as plate has 1/32 in. greater thickness than nominal.**

TABLE 1.7.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY PLASTER ON METAL LATH

Test No.	SECTION		*PROTECTION
23	Plate and Angle		Two 2-coat layers of Portland cement plaster on No. 24 expanded metal lath, each layer 1 in. thick, with a ¾-in. air space between layers
24	Plate and Channel		Two 2-coat layers of Portland cement plaster on woven wire lath, ⅜-in. mesh, each layer ⅞ in. thick, with a ¾-in. air space between layers
25	Z-bar and Plate		One 2-coat layer of Portland cement plaster, 1 in. thick, on No. 24 expanded metal lath
26	Latticed Angle		One 2-coat layer of Portland cement plaster, 1⅛ in. thick, on No. 24 expanded metal lath
27	Round Cast Iron Column Section same as No. 9		One 2-coat layer of Portland cement plaster, 1½ in. thick, on high ribbed expanded metal lath with ½-in. broken air space

*The plaster consisted of 1 part Portland cement, 1/10 part hydrated lime, 2½ parts coarse lake sand. Hair was used in the first coat; the second coat was trowelled smooth.

TABLE 1.8.A

ANALYSIS OF LOADS APPLIED TO STRUCTURAL STEEL COLUMNS IN TESTS RECORDED IN TABLE 1.1 TO 1.7

Reference No. (See Table 1.1.B)	Column Properties			Applied Load	Computed Load at Time of Test		Computed Load by NBC(1965) Formula		
								Computed Load	
	Section	Nominal Area Sq In.	Slenderness ℓ/r	lb	Formula	lb	NBC (1965) Formula *	lb	% of Applied Load
1	Rolled H	10.17	75.6	119,500	$16,000-70\ell/r$	108,900	$20,000-70\ell/r$	149,600	125
2	Plate and Angle	13.00	111.8	116,000	"	106,200	$\frac{145,000,000}{(k\ell/r)^2}$	151,000	136
3	Plate and Channel	8.76	64.7	111,000	"	100,500	$20,000-70\ell/r$	135,500	122
4	Latticed Channel	7.78	44.0	111,000	"	100,500	"	131,600	118
5	Bar and Plate	9.32	81.7	105,000	"	95,900	"	133,100	127
6	I - Beam and Channel	10.12	72.1	122,000	"	110,800	"	151,300	124
7	Latticed Angle	8.44	40.7	122,500	"	111,000	"	144,800	118
8	Starred Angle	13.27	108.5	124,000	"	111,900	"	164,600	133

* This complete formula is $[20,000 - 70\, k\ell/r] \left(\frac{f_y}{33,000}\right)$ but not to exceed $\frac{145,000,000}{(k\ell/r)^2}$

It is assumed that $k = 1$ and $f_y = 33,000$ psi

TABLE 1.8.B

ANALYSIS OF LOADS APPLIED TO CAST IRON AND PIPE COLUMNS IN TESTS RECORDED IN TABLES 1.1 TO 1.7

Reference No. (See Table 1.1.C)	Column Properties			Applied Load	Computed Load at Time of Test		Computed Load by NBC(1965) Formula		
								Computed Load	
	Section	Nominal Area Sq In.	Slenderness ℓ/r	lb	Formula	lb	NBC (1965) Formula	lb	% of Applied Load
9	Round Cast Iron (Horizontally Cast)	14.73	68.2	95,500	$10{,}000-60\,\ell/r$	87,100	$9{,}000-40\,\ell/r$	92,500	97
10	Round Cast Iron (Vertically Cast)	14.45	63.2	98,500	"	89,700	"	92,000	95
11	Round Cast Iron, Horizontally Cast (Concrete Filled)	14.73	68.2	95,500	"	87,100	"	92,500	97
12	Steel Pipe (Concrete Filled)	Steel 6.3 Concrete 38.74	ℓ/d = 19.6	114,500	$A_s(13{,}500-140\,\ell/d)$ $A_c(1{,}000-11\,\ell/d)$	104,900	$p=0.25\,f'_c(1-0.000025\,h^2/k_c^2)$ $A_c+f'_r\,A_s$	105,650	92
13	Reinforced Steel Pipe (Starred Angles Embedded in Concrete Filling)	Steel 18.36 Concrete 40.07	ℓ/d = 17.7	236,000	"	234,700	"	288,540	122

SECTION 2

REFERENCE

Mitchell, N.D., Fire Tests of Columns Protected with Gypsum. Research Paper RP 563, Bureau of Standards. Journal of Research, Vol. 10, June 1933.

NOTES

This includes results of 6 tests on steel columns protected by gypsum block masonry. Time to failure by collapse and temperature of the steel at the time of failure are both recorded.

TABLE 2.1.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY GYPSUM BLOCK

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	2⅛	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.

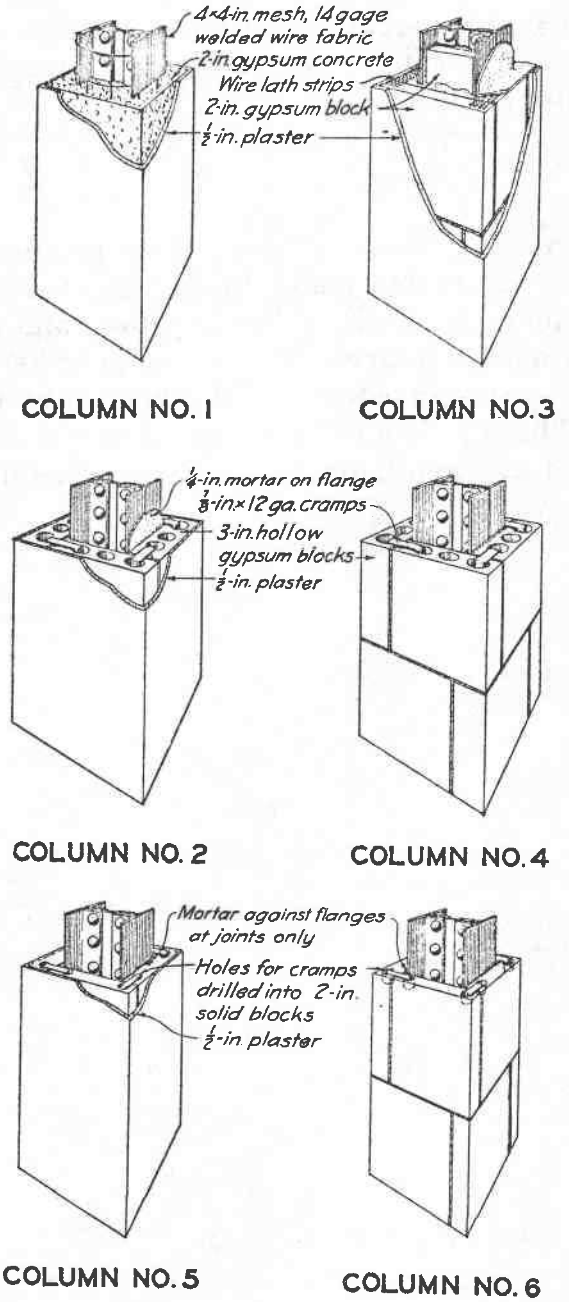
[3] The gross thickness of covering of column no. 2 was 3¾ inches.

[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.

FIGURE 2.1.B

DETAILS OF CONSTRUCTION OF
COLUMNS PROTECTED BY GYPSUM BLOCK



SECTION 3

REFERENCE

Mitchell, N.D., Fire Tests of Steel Columns Protected with Siliceous Aggregate Concrete. Building Materials and Structures Report, BMS 124. U.S. Dept. of Commerce, National Bureau of Standards, Washington, 1951.

NOTES

This relates to 4 tests on steel columns with siliceous aggregate concrete cover tested under load. The tests were conducted at the National Bureau of Standards, Washington, and reported in 1951. The clear and milky quartz aggregate was selected as an example of almost 100 per cent quartz crystals and did not resemble regular concrete aggregates. The mix had to be adjusted to make the concrete workable. Details of the construction and fire endurance periods are shown in Table 3. 1. A.

TABLE 3.1.A

REPORT OF FIRE ENDURANCE TESTS OF STEEL COLUMNS WITH CONCRETE PROTECTION

Test No.	Steel Section	Applied Load(2) lb	Concrete Cover				Temperatures at Failure		Fire Endurance(3)	
			Thickness of cover(4) (in.)	Aggregate	Mix(1)	Comp Strength lb/in^2	Average °F	Max at One Point °F	Hr	Min
1	6 in. 20 lb H	81,700	2	Potomac River Gravel	1 $2\frac{1}{2}$ $3\frac{1}{2}$	2580	1346	1427	3	34
2	6 in. 20 lb H	81,700 (double load applied until steel temp. reached 883°F)	2	Potomac River Gravel	1 $2\frac{1}{2}$ $3\frac{1}{2}$	2580	1337	1400	3	32
3	6 in. 20 lb H	81,700	2	Milky Quartz	1 3 2	1930	1157	1346	3	10
4	6 in. 20 lb H	81,700	2	Clear Quartz	1 3 2	2600	1148	1391	2	50

(1) Properties (by volume): portland cement:sand:coarse aggregate

(2) Formula: $P = (17{,}000 - 0.485 \frac{\ell^2}{r^2})A$ Steel stress = 13,700 lb/sq in.

$A = 5.97$ sq in. $\ell = 124$ in. $r = 1.50$ in.

Allowable load by design requirements of National Building Code

1965 = 85,400 lb. $P = (20{,}000 - 70 \frac{k\ell}{r})A$

$f_y = 33{,}000$ psi

(3) Failure was assumed to be time for column to yield 0.16 in. from the point of maximum expansion

(4) No. 8 SWG wire (0.16 in. diam) wound around the column spirally 1 in. from column face

SECTION 4

REFERENCE

Mitchell, N.D., and J.V. Ryan. Fire Tests of Steel Columns Encased with Gypsum Lath and Plaster. Building Materials and Structures, Report BMS 135, U.S. Dept. of Commerce, National Bureau of Standards, Washington, 1953.

NOTES

This includes results of 16 tests on steel columns protected by plaster on gypsum lath. The columns, with two exceptions, were tested without load using the alternative method of test of ASTM E119 (1947). Two of the columns were tested under load providing a means of comparing the two test conditions.

TABLE 4.1.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY PLASTER ON GYPSUM LATH

Test number	Steel column: Exposed length	Steel column: Section	Steel column: Load	Gypsum lath: Type	Gypsum lath: Length	Gypsum lath: Thickness	Gypsum lath: Number of layers	Wire fabric reinforcement	Plaster: Aggregate	Plaster: Mix [1]	Plaster: Strength, Scratch	Plaster: Strength, Brown	Plaster: Number of basic coats [2]	Plaster: Thickness all coats	Total protective thickness, lath and plaster	Age at test	Test results: End-point criterion *	Test results: End-point time	Test results: Intensity of fire exposure	Test results: Fire-endurance limit
	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	28	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
306	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 7/8	2 1/4	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.

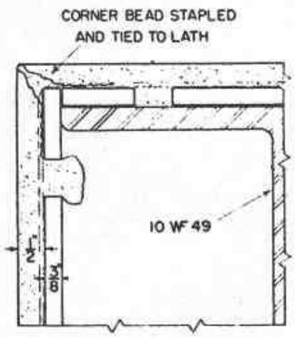
[3] The wire-fabric reinforcement and corner beads were applied outside of the scratch-coat plaster.

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

* Tests in accordance with ASTM E119-47

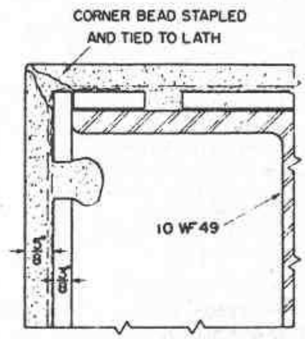
FIGURE 4.1.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY PLASTER ON GYPSUM LATH



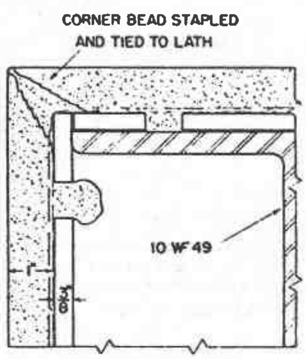
TEST NO. 273

1:2½ SANDED GYPSUM PLASTER DOUBLED BACK ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



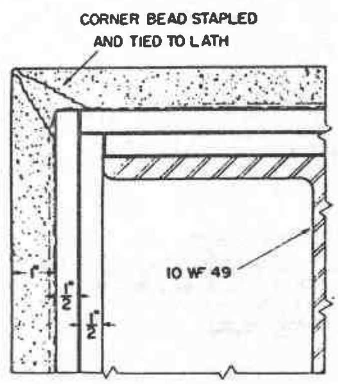
TEST NO. 274

1:2½ SANDED GYPSUM PLASTER DOUBLED BACK ON PERFORATED GYPSUM LATH TIED TO COLUMN WITH DOUBLED 18 GA. WIRE 15" O.C.



TEST NO. 275

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

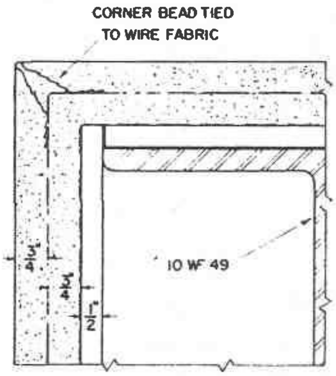


TEST NO. 276

2½ 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.

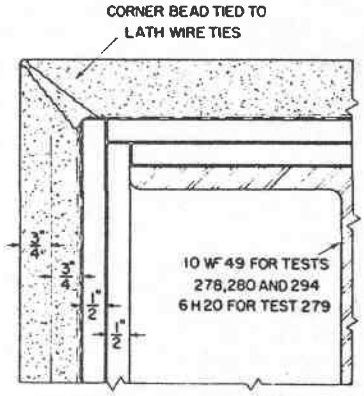
FIGURE 4. 1. B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY PLASTER ON GYPSUM LATH



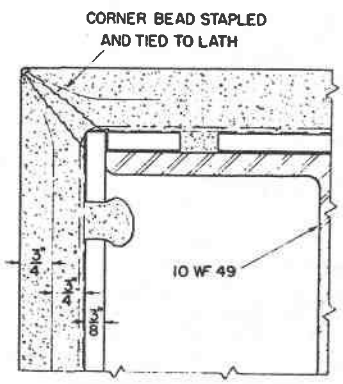
TEST NO. 277

$2\frac{1}{2}$ 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.



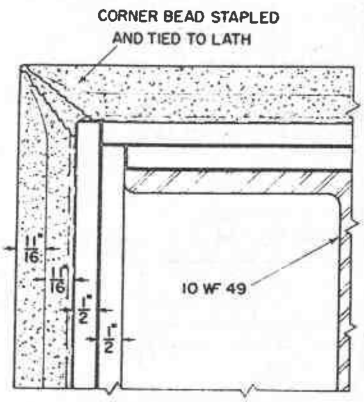
TESTS NO. 278, 279, 280, 294

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.



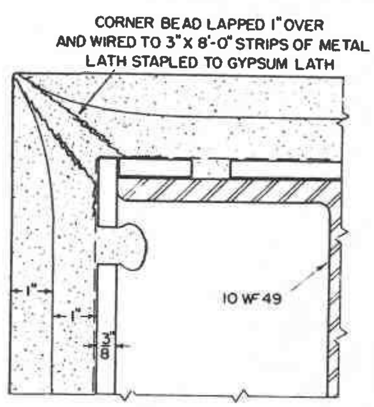
TESTS NO. 288, 292, 302

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.



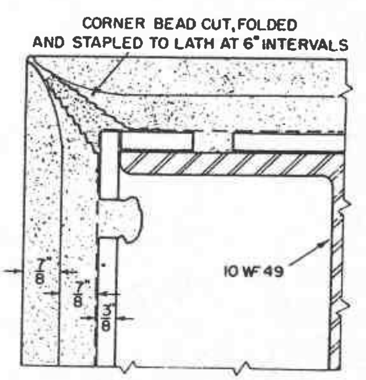
TESTS NO. 289, 293

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.

SECTION 5

REFERENCE

Ashton, L. A., and N. Davey. Fire Tests of Steel Columns from "Investigation of Building Fires, Part V. Fire Tests on Structural Elements". National Building Studies, Research Paper No. 12, H. M. Stationery Office, London, 1953.

NOTES

This includes results of 61 fire tests on steel columns conducted at the British Fire Research Station. The tests were made between 1936 and 1946 in substantial accord with BS 476 (1933). Some deviations appear to have been made in the loading conditions in certain cases where special features were being investigated. In order to assist the designer in relating these fire tests to present construction practices, a comparison has been made between the load applied at the time of test and the load that would be required by structural design in accordance with the National Building Code 1965.

TABLE 5.1.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY CONCRETE

Test No. (See Fig. 5.1.B)	Steel Column			Wire Mesh	Encasement			Concrete Data						Max. Expansion (in.)	Fire Endurance	
	Section BSB #	Applied Load on Steel Area (psi)	Computed Load by NBC 1965 Formula (See Table 5.6.A) (psi)	in. in. SWG	Gross Area $(in.)^2$	Total Cover (in.)	Mesh Cover (in.)	Nominal Mix	Aggregate	Age at Test (days)	Strength (psi) 28 days	Strength (psi) test	Moist. % wt		Collapse hr	Collapse min
1	104	9,140	4,360	6 x 4 x 13	30	1	1/2	1:2:4	Gravel (3/8" max)	47	4,260	4,900	3.9	0.81	1	29
2	104	9,140	4,360	6 x 4 x 13	56	2	1	1:2:4	Gravel (3/4" max)	-	4,070	5,140	3.9	0.91	3	01
3	104	9,140	4,360	6 x 4 x 13	132	4	1	1:2:4	Gravel (3/4" max)	62	4,310	4,550	4.6	0.91	6	00
4	104	9,140	4,360	6 x 4 x 13	56	2	1	1:2:4	Crushed Whinstone (3/4" max)	53	4,050	4,540	3.4	0.69	3	09
5	104	9,140	4,360	6 x 4 x 13	56	2	1	1:2:4	Crushed Brick (3/4" max)	60	4,850	6,220	5.0	0.75	2	46
6	104	9,140	4,360	4 x 4 x 16	56	2	1	1:2:4	Gravel (3/4" max)	284	3,500	5,520	-	0.83	2	50
7	104	12,200	4,360	4 x 4 x 16	132	4	1	1:2:4	Gravel (3/4" max)	387	3,830	-	3.0	0.89	5	32
8	109	14,820	8,960	6 x 4 x 13	85	2	1	1:2:4	Gravel (3/4" max)	85	4,520	5,140	4.3	0.77	3	08
9	109	19,750	8,960	4 x 4 x 16	175	4	1	1:2:4	Gravel (3/4" max)	452	3,750	-	2.2	0.56	4	29
10	114	19,600	14,000	6 x 4 x 13	80	1	1/2	1:2:4	Gravel (3/4" max)	37	4,050	4,240	4.3	0.52	2	01

11	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Gravel (3/4" max)	147	5,100	5,570	5.3	0.47	3	39
12	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Crushed Whinstone (3/4" max)	39	4,150	4,350	5.2	0.24	3	22
13	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Crushed Whinstone (3/4" max)	55	3,750	3,930	4.8	0.25	3	17
14	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:3	Crushed Brick (3/4" max)	53	3,350	3,630	14.1	0.23	4	06
15	114	19,600	14,000	6 x 4 x 13	160	2 & 4	1	1:2:4	Gravel (3/4" max)	48	4,600	4,950	6.6	0.41	4	32
16	114	19,600 min*	14,000	6 x 4 x 13	120	2	1	1:2:4	Gravel (3/4" max)	45	3,640	-	4.7	-	3	07
17	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Crushed Brick (3/4" max)	187	4,260	-	6.6	0.41	3	54
18	114	19,600	14,000	See Ill. 4	120	2	1/2	1:2:4	Gravel (3/4" max)	78	5,070	-	4.5	0.49	3	59
19	114	19,600	14,000	See Ill. 5	120	2	See Ill. 5	1:2:4	Gravel (3/4" max)	57	3,610	4,480	6.6	0.56	3	26
20	114	19,600	14,000	6 x 4 x 13	120	2	1	1:12**	Gravel (3/4" max)	157	342	-	2.1	0.26	1	02
21	114	19,600	14,000	6 x 4 x13	140	2 & 3	1	1:2:4	Crushed Brick (3/4" max)	87	5,310	-	7.2	0.40	4	28
22	114	18,700	14,000	None	120	2	-	1:6	Gravel (3/4" max)	43	3,100	3,290	7.0	0.26	2	08
23	114	18,700	14,000	13 SWG iron wire wound at 6" pitch	120	2	See Ill. 8	1:6	Gravel (3/4" max)	75	3,600	4,000	6.0	0.46	3	56

* Tested under "Total Restraint". Load increased to prevent expansion. Minimum load 19,600 psi.

** Open texture

TABLE 5.1.A (Cont'd)

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY CONCRETE

Test No. (See Fig. 5.1.B)	Steel Column			Wire Mesh	Encasement			Concrete Data						Max. Expansion (in.)	Fire Endurance	
	Section BSB #	Applied Load on Steel Area (psi)	Computed Load by NBC 1965 Formula (See Table 5.6.A) (psi)	in. in. SWG	Gross Area (in.)^2	Total Cover (in.)	Mesh Cover (in.)	Nominal Mix	Aggregate	Age at Test (days)	Strength (psi)		Moist. % wt		Collapse	
											28 days	test			hr	min
24	114	19,600	14,000	6 x 4 x 13	120	2	1	1:8	Gravel (3/4" max)	86	1,370	-	3.8	0.40	2	00 Test Dis-continued
25	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Cheddar Limestone (3/4" max)	117	4,350	-	5.4	0.54	3	54
26	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Matlock Limestone (3/4" max)	127	5,300	-	-	0.54	3	00 Test Dis-continued
27	114	19,600	14,000	6 x 4 x 13	120	2	1	1:2:4	Clitherue Limestone (3/4" max)	334	4,010	4,800	4.8	0.56	3	00 Test Dis-continued
28	114	26,100	14,000	4 x 4 x 16	168	3	1	1:2:4	Gravel (3/4" max)	459	4,150	-	-	0.41	3	24
29	114	19,600	14,000	4 x 4 x 16	224	4	1	1:2:4	Gravel (3/4" max)	500	4,240	-	2.4	0.29	3	40
30	114	19,600	14,000	4 x 4 x 16	160	2 & 4	1	1:2:4	Gravel (3/4" max)	264	4,300	-	1.7	0.48	2	52
31	114	19,600	14,000	4 x 4 x 16	80	1	1/2	1:2:4	Gravel (3/4" max)	340	3,750	-	-	0.55	1	58
32	124	20,700	15,380	4 x 4 x 16	140	1	1/2	1:2:4	Gravel (3/4" max)	319	3,750	4,930	-	0.39	2	08

33	124	13,820	15,380	4 x 4 x 16	140	1	1/2	1:2:4	Gravel (3/4" max)	382	3,900	-	1.7	0.58	2	42
34	124	20,700	15,380	4 x 4 x 16	192	2	1	1:2:4	Gravel (3/4" max)	403	3,550	-	2.1	0.29	2	31
35	124	13,820	15,380	4 x 4 x 16	192	2	1	1:2:4	Gravel (3/4" max)	410	3,450	-	2.4	0.59	4	04
36	124	20,700	15,380	4 x 4 x 16	252	3	1	1:2:4	Gravel (3/4" max)	518	4,000	-	2.5	0.25	3	26

FIGURE 5.1.B

DETAILS OF CONSTRUCTION OF COLUMNS
PROTECTED BY CONCRETE

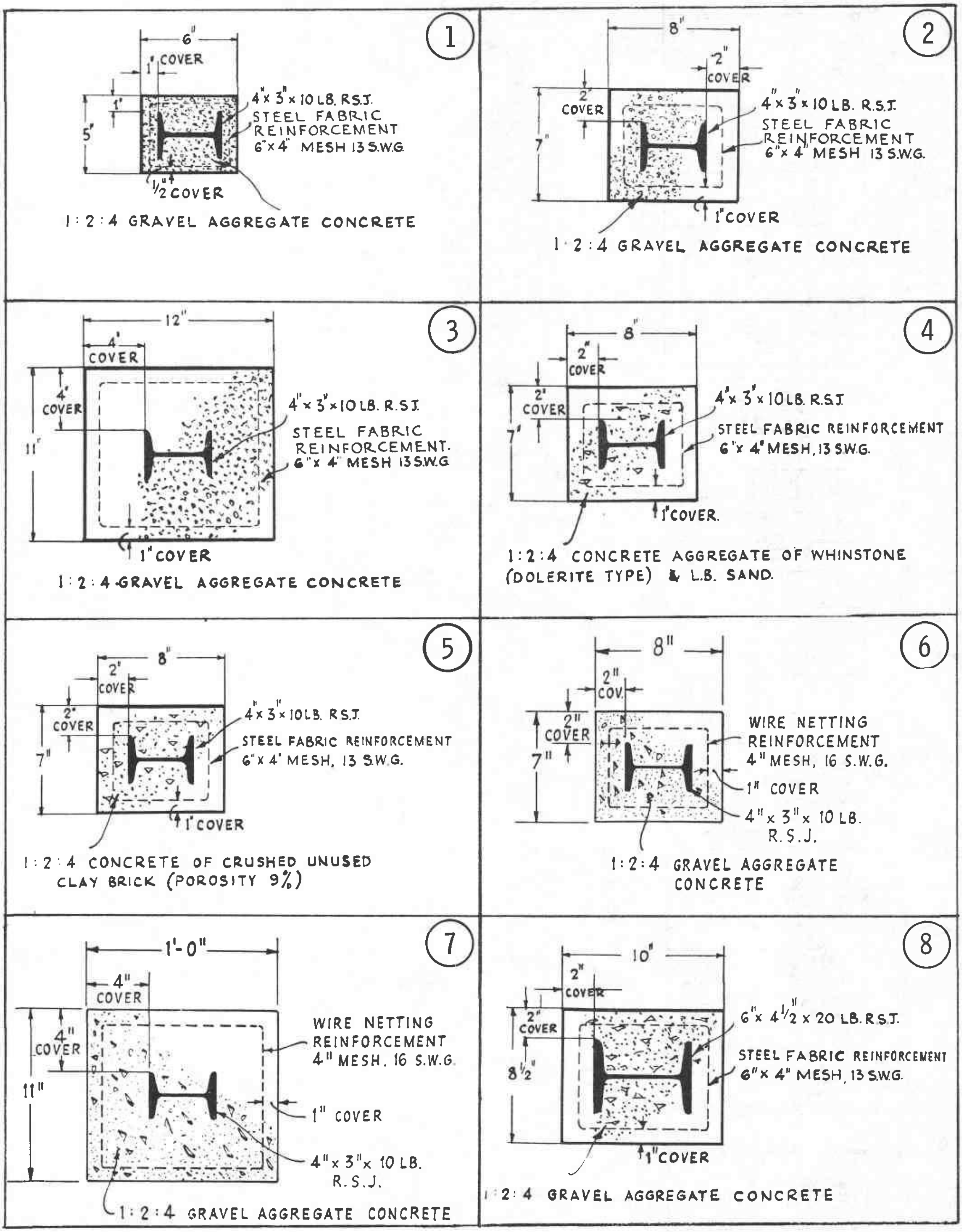


FIGURE 5.1.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY CONCRETE

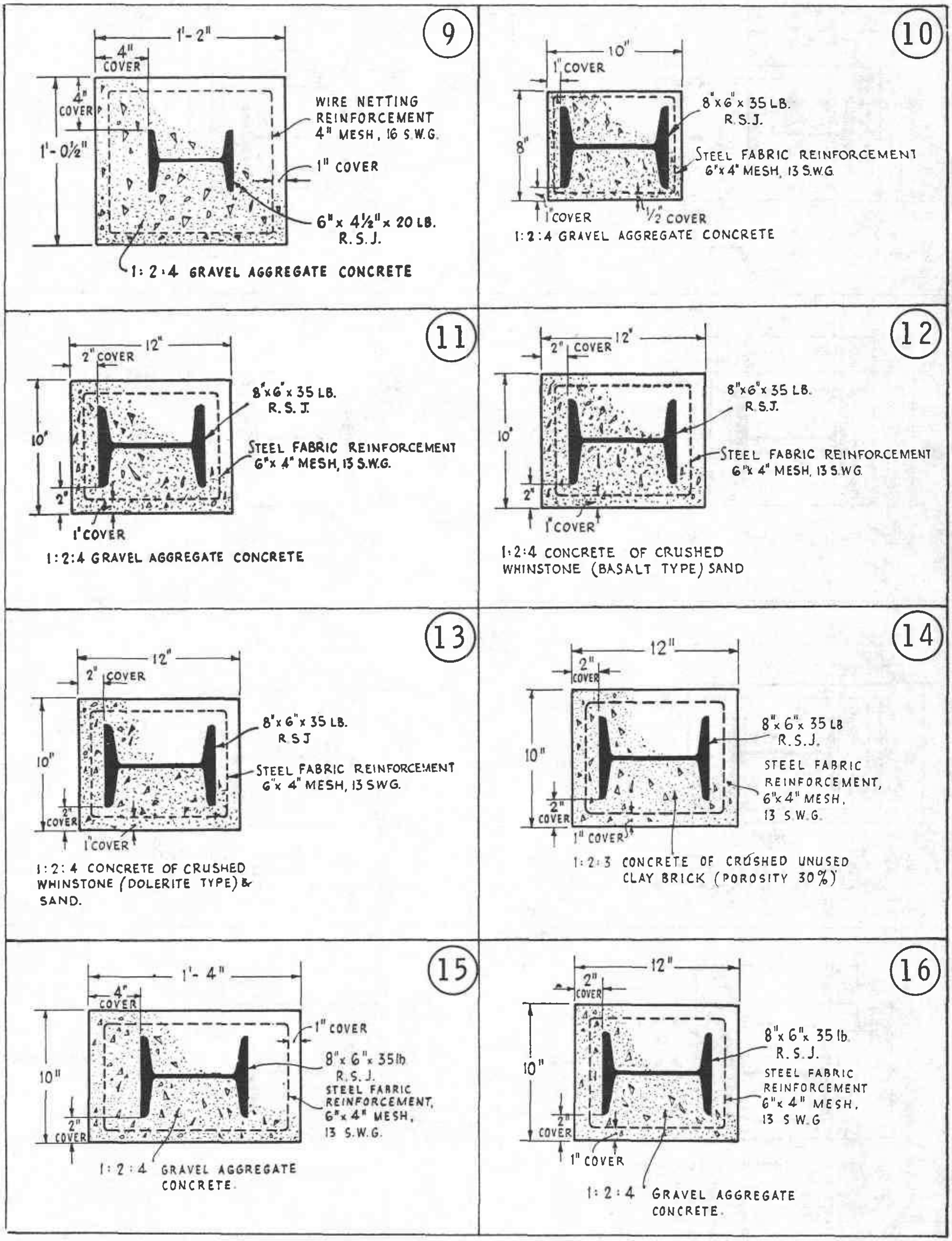


FIGURE 5.1.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS
PROTECTED BY CONCRETE

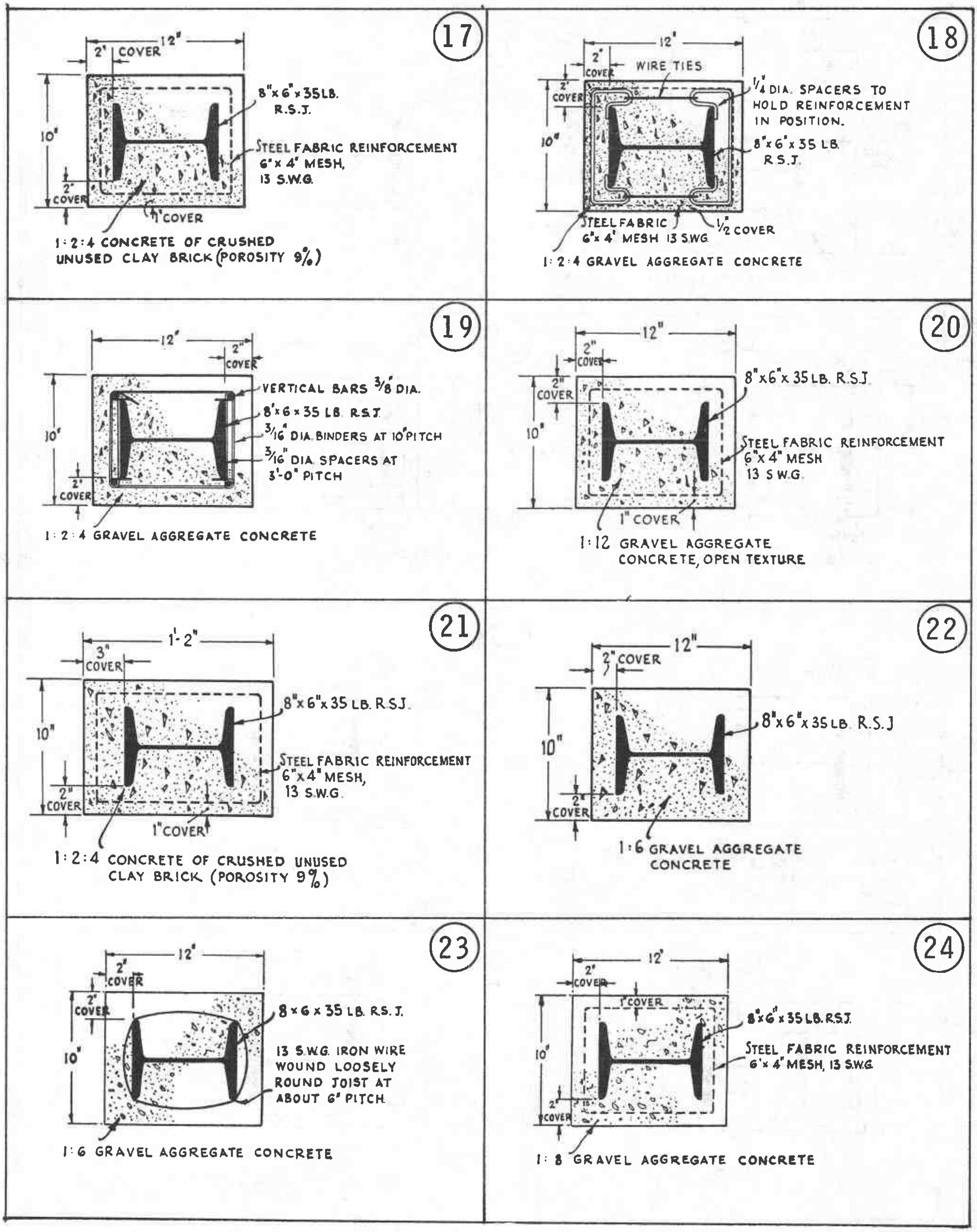


FIGURE 5.1.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS
PROTECTED BY CONCRETE

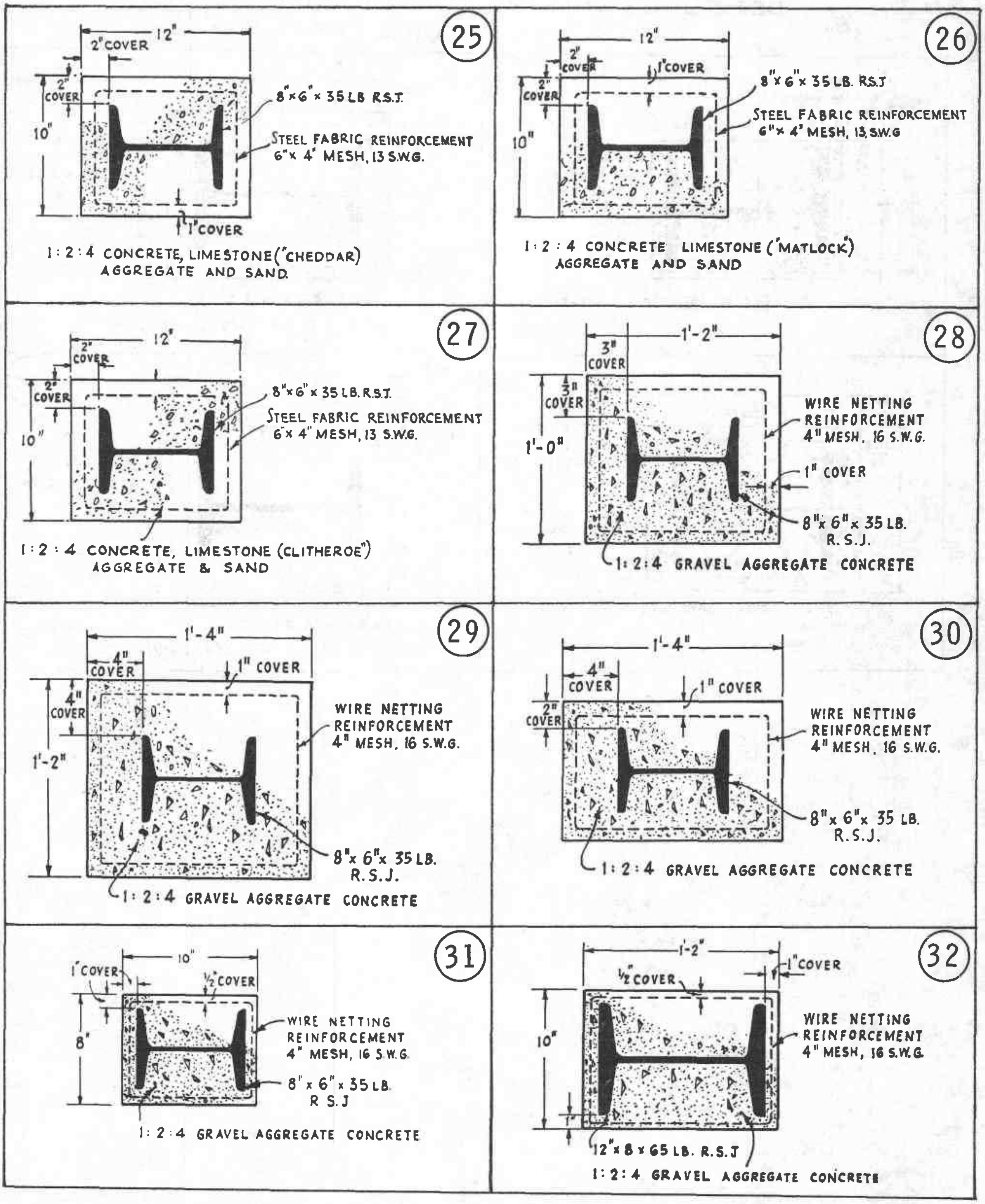


FIGURE 5.1.B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS
PROTECTED BY CONCRETE

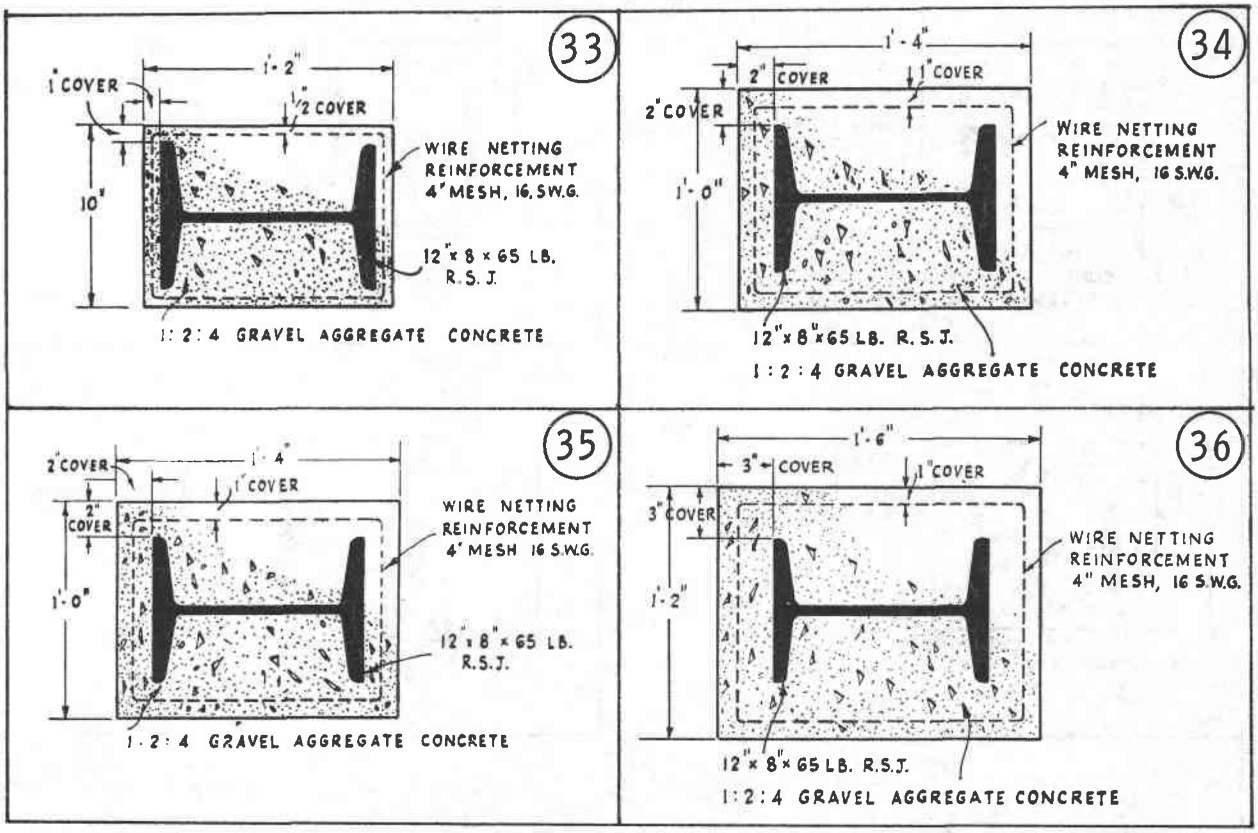


TABLE 5.2.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY CONCRETE AND PLASTER

Test No. (See Fig. 4.2.B)	Steel Column			Wire Mesh	Encasement			Concrete Data						Max. Expansion (in.)	Fire Endurance	
	Section BSB #	Applied Load on Steel Area (psi)	Computed Load by NBC 1965 Formula (See Table 5.6.A) (psi)	in. in. SWG	Gross Area (in.)[2]	Total Cover (in.)	Mesh Cover (in.)	Nominal Mix	Aggregate	Age at Test (days)	Strength (psi) 28 days	Strength (psi) test	Moist. % wt		hr	min
1	114	19,600	14,000	6 x 4 x 13	120	1-1/2 Concrete 1/2 Plaster[1]	3/4	1:2:4	Gravel (3/4" max)	97	4,410	-	5.4	0.52	2	50
2	114	19,600	14,000	6 x 4 x 13	128	2 Concrete 3/16 Plaster[2]	1	1:12	Gravel (3/4" max)	92	835	-	3.5	0.42	2 Test Dis-	00 continued
3	114	19,600	14,000	6 x 4 x 13	143	3 Concrete 1/2 Plaster[3]	2	1:12	Crushed Brick (1/2" - 1/4")	50	890	-	5.9	0.33	3	00

[1] 3/8 in. lime/cement plaster + 1/8 in. neat hemihydrate gypsum plaster

[2] 3/16 in. neat hemihydrate gypsum plaster

[3] 3/8 in. cement/lime/sand (1:2:9) + 1/8 in. neat hemihydrate gypsum plaster

FIGURE 5.2.B

DETAILS OF CONSTRUCTION OF COLUMNS
PROTECTED BY CONCRETE AND PLASTER

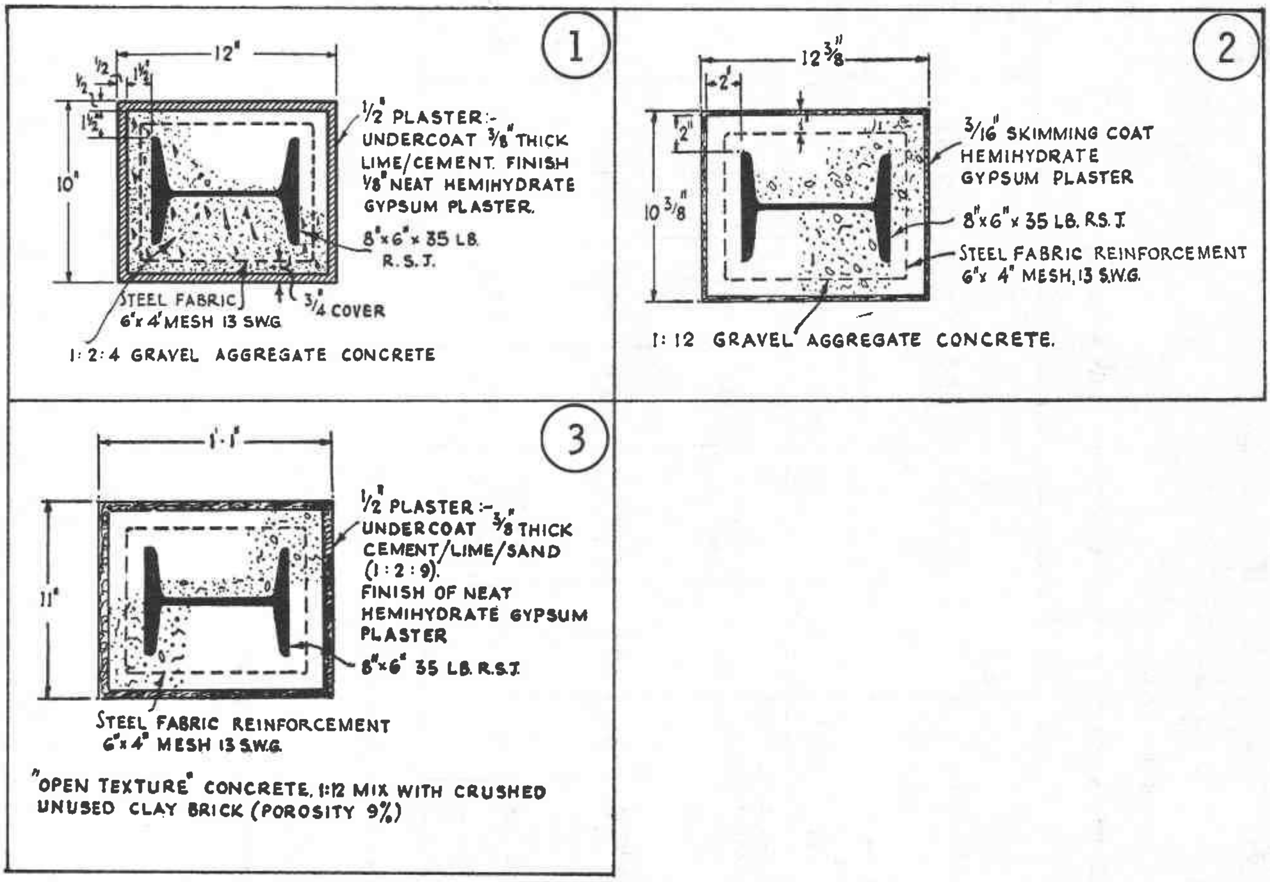


TABLE 5.3.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY MASONRY

Test No. (See Fig. 5.3.B)	Steel Column			Details of Encasement								Maximum Expansion (in.)	Duration of Fire Test	
				Brick or Block						Mortar				
	Section BSB #	Applied Load on Steel Area (psi)	Computed Load by NBC 1965 Formula (See Table 5.6.A) (psi)	Thickness of Cover (in.)	Type	Strength (psi)	Density (pcf)	Porosity %	Moisture Content % by wt	Moisture Content % by wt	Age at Test (days)		hr	min
1	114	19,600	14,000	2-1/4, 2-1/2	Fletton Brick	2,095	100	33.0	4.1	9.0	43	0.25	3	06 Collapse
2	114	19,600	14,000	2-1/4, 2-1/2	Fletton Brick	2,095	100	33.0	2.5	5.9	78	0.42	2	00 Test Discontinued
3	114	19,600	14,000	3, 3-1/2	Fletton Brick	2,980	102	33.9	6.7	8.3	90	0.16	1	49 Collapse
4	114	18,700	14,000	4-1/2	Fletton Brick	2,430	98	-	6.9	5.3	24	0.32	6	00 Test Discontinued
5	114	9,800 (Nom. Load)	14,000	4-1/2	Fletton Brick	2,430	98	-	1.0	4.1	192	0.43	6	00 Test Discontinued
6	114	19,600	14,000	4-1/2, 5	Fletton Brick	-	102	37.3	7.7	7.3	55	0.51	4	00 Collapse
7	114	19,600	14,000	2	Foamed Slag Concrete (1/2" max)	440 (28 days)	93	-	3.2	2.5	84	0.27	2	00 Collapse
8	114	19,600	14,000	4	Foamed Slag Concrete (1/2" max)	-	-	-	5.2	-	478	0.44	5	52 Collapse
9	114	18,700	14,000	2-1/4	Hollow Clay Tile	700	-	43.8	0.6	4.1	40	0.08	0	22 Collapse
10	114	18,700	14,000	2-1/4	Hollow Clay Tile	700	-	43.8	0.3	5.8	47	0.11	0	56 Collapse

FIGURE 5.3.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY MASONRY

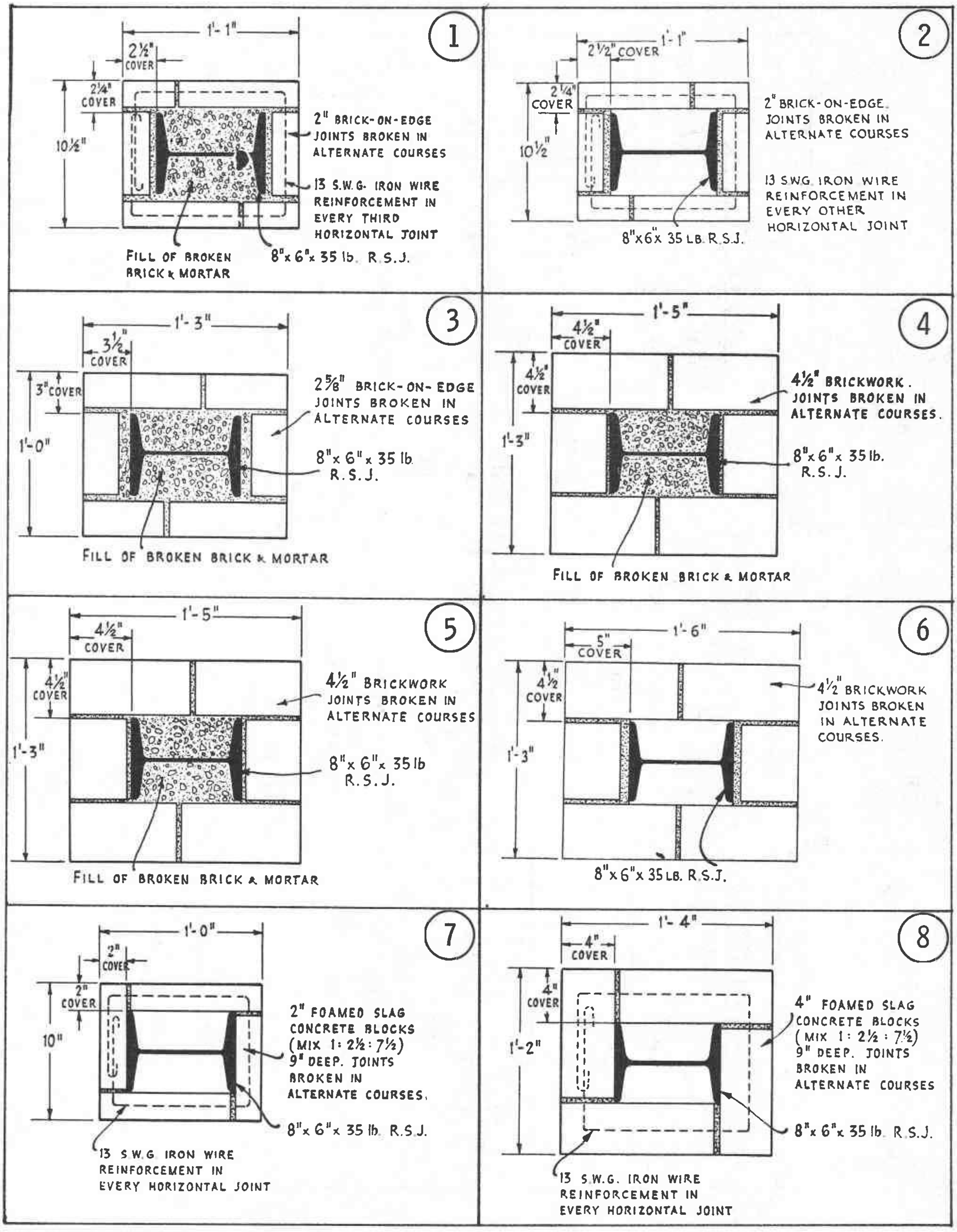


FIGURE 5. 3. B (Cont'd)

DETAILS OF CONSTRUCTION OF COLUMNS
PROTECTED BY MASONRY

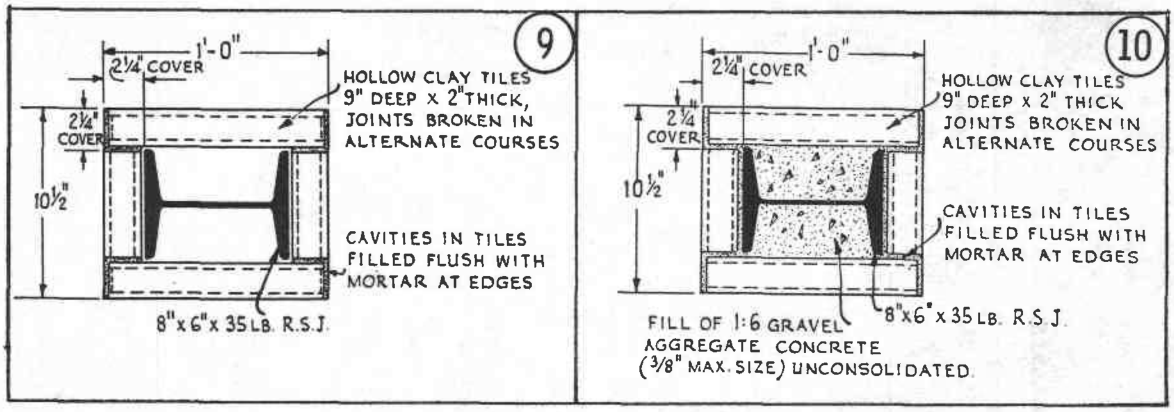


TABLE 5.4.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY PLASTER

Test No. (See Fig. 5.4.B)	Steel Column			Details of Encasement					Maximum Expansion (in.)	Duration Fire Test	
	Section BSB #	Applied Load on Steel Area (psi)	Computed Load by NBC1965 Formula (See Table 5.6.A) (psi)	Plaster Base	Thickness of Plaster (in.)	Plaster Mix (by vol)	Age at Test (days)	Moisture Content % by wt		hr	min
1	114	19,600	14,000	Metal lath:- 24 SWG, 3/8" short way of mesh	3/4	Undercoat:- 1:1:4 Cement/Lime/Sand, with hair Finish coat:- as undercoat without hair	50	4.4	0.56	0 Collapse	57
2	114	18,700	14,000	"	1	Neat retarded hemihydrate gypsum plaster, with hair in rendering and floating coats	72	-	0.30	1 Collapse	23
3	114	19,600	14,000	Metal lath:- 24 SWG, 3/8" short way of mesh. Wire netting:- 1-1/2" x 22 SWG between rendering and floating coats	1-1/4	Rendering and floating coats:- 1-1/2 hemihydrate gypsum plaster (haired) to sand by wt (equivalent to 1:1 approx by vol). Finish coat:- neat hemihydrate gypsum plaster	72	-	0.49	1 Collapse	36
4	114	19,600	14,000	"	1-1/2	"	86	-	0.22	1 Collapse	33
5	114	19,600	14,000	Gypsum plaster board, 3/8" thick	1/2	Rendering coat (3/8" thick), 1:2 hemihydrate gypsum plaster to sand by wt (equiv. to 1:1-1/2 approx by vol). Finish coat:- neat hemihydrate gypsum plaster, 1/8" thick	59	-	0.31	1 Collapse	13

6	114	19,600	14,000	Gypsum plaster board, 3/4" thick	1/2	Rendering coat (3/8" thick), 1:2 hemihydrate gypsum plaster to sand by wt (equiv. to 1:1-1/2 approx by vol). Finish coat: neat hemihydrate gypsum plaster 1/8" thick	308	-	0.56	2	00 Test Discontinued
7	114	19,600	14,000	Gypsum plaster board, 3/8" thick	1/4	Neat hemihydrate gypsum plaster	20	-	0.46	1	14 Collapse

FIGURE 5.4.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY PLASTER

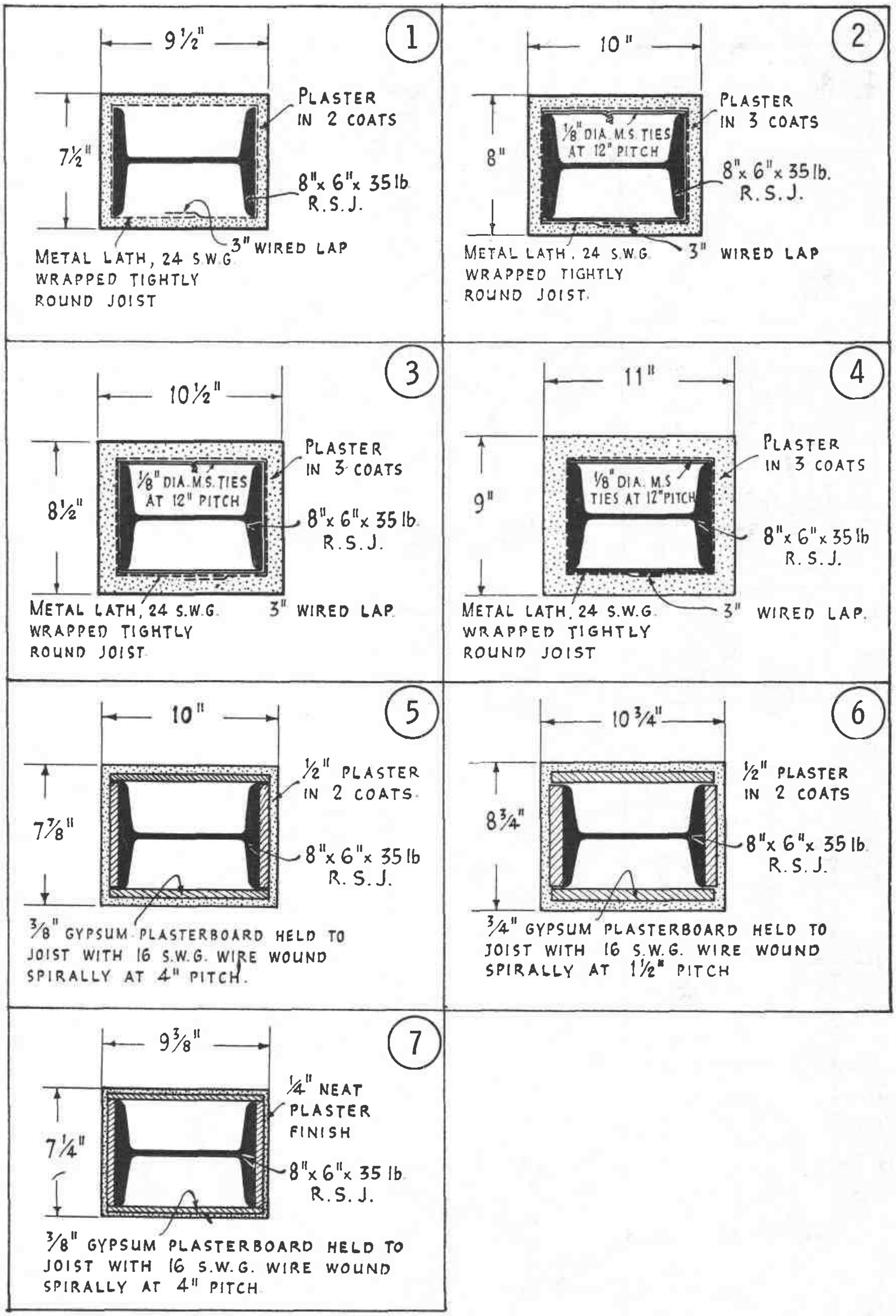


TABLE 5.5.A

RESULTS OF FIRE TESTS ON COLUMNS PROTECTED BY MISCELLANEOUS MATERIALS

Test No. (See Fig. 5.5.B)	Steel Column			Details of Encasement				Maximum Expansion (in.)	Duration of Fire Test	
	Section BSB #	Applied Load on Steel Area (psi)	Computed Load by NBC 1965 Formula (See Table 5.6.A) (psi)	Thickness of Cover (in.)	Description	Age at Test (days)	Moisture Content % by wt		hr	min
1	114	19,600	14,000	2	Sprayed asbestos Density 44.5 lb/ft^3	79	10.7	0.20	4	00 Test Discontinued
2	114	19,600	14,000	3/4" plaster on 2" wood wool blocks	Blocks made from wood-wool and cement binder Plaster: 5/8" undercoat; 1:1-1/2 hemihydrate gypsum plaster and sand (by volume); 1/8" finish coat neat hemihydrate gypsum plaster	165	-	0.15	2	00 Test Discontinued
3	114	18,700	14,000	3	1-in. moulded asbestos held in position by nichrome wire over 2-in. moulded asbestos. Density: Inner Section - 23.5 lb/ft^3 Outer Section - 35.0 lb/ft^3 Both 3 ft long	13	-	0.42	4	43 Test Discontinued
4	114	19,600	14,000	5/8" plaster on asbestos slabs	Plaster 1:1:6 Cement:Lime:Sand Asbestos fibre slabs	35	2.5 (Asbestos + Plaster)	0.28	2	00 Collapse
5	114	19,600	14,000	1	Blue asbestos plaster made from asbestos fibre and cement binder	84	38	0.43	1	52 Collapse

FIGURE 5.5.B

DETAILS OF CONSTRUCTION OF COLUMNS PROTECTED BY MISCELLANEOUS MATERIALS

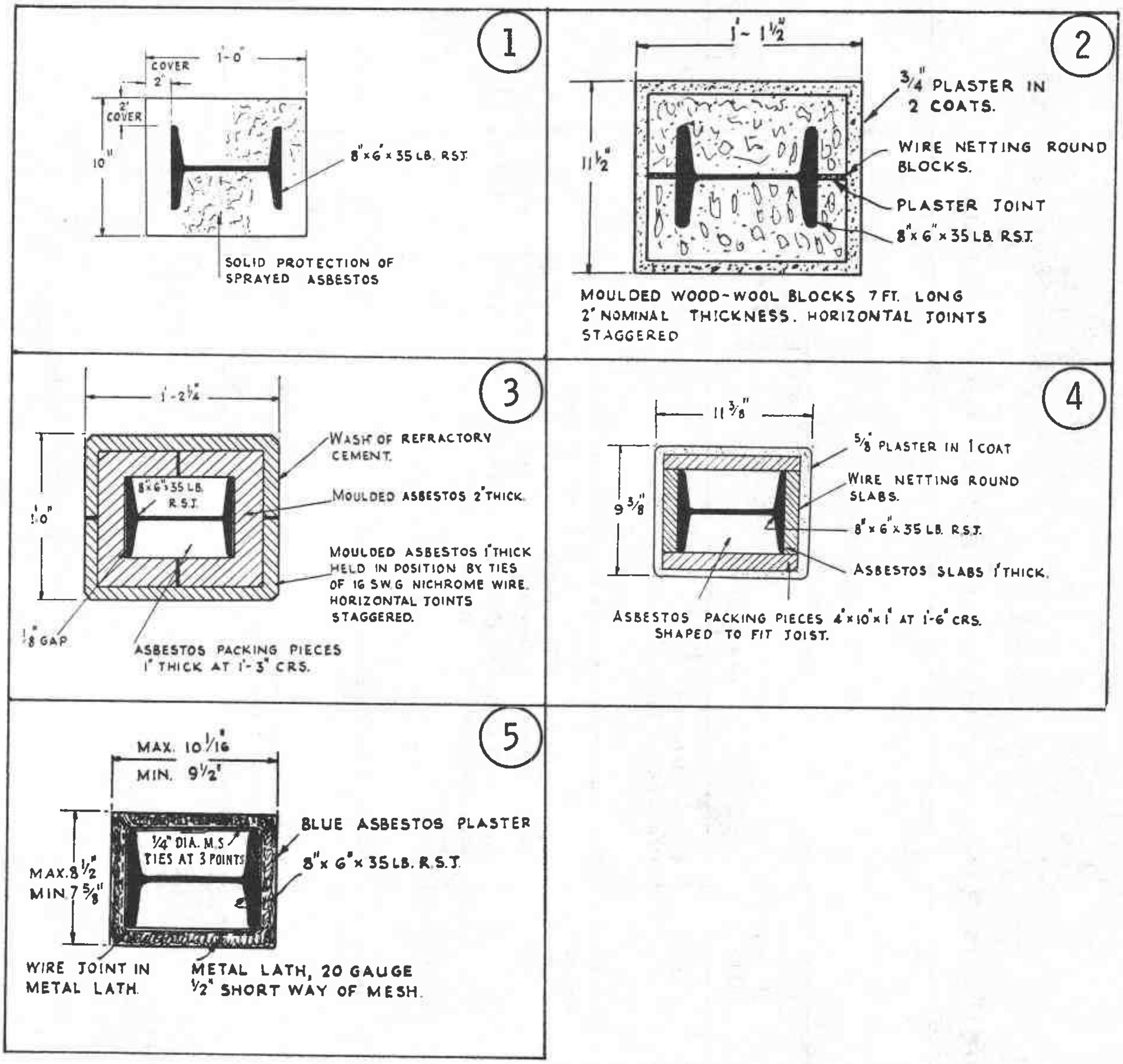


TABLE 5.6.A

ANALYSIS OF LOADS APPLIED TO STRUCTURAL STEEL COLUMNS RECORDED IN SECTION 5

Section BSB #	Description	Area ($in.^2$)	r_{yy} ** (in.)	Slenderness ℓ/r	Allowable Stress*	
					NBC(1965)(5), CISC(1962)(6)	AISC(1961)(7)
104	4" x 3" x 10 lb	2.94	0.67	182	4,360(1)	4,370(3)
109	6" x 4-1/2" x 20 lb	5.89	0.96	127	8,960(1)	9,150(3)
114	8" x 6" x 35 lb	10.30	1.38	88.5	14,000(2)	13,200(4)
124	12" x 8" x 65 lb	19.12	1.85	66	15,380(2)	14,885(4)

* Strength of encasement not considered in calculations

** Radius of gyration about the minor axis

End Conditions: unrestrained Effective Length: 10 ft - 2 in. Loading: concentric

(1) $f = \dfrac{145,000,000}{\left(\frac{k\ell}{r}\right)^2}$ NBC (1965), CISC (1962)

(2) $f = \left[20,000 - 70\frac{k\ell}{r}\right]\left(\dfrac{f_y}{33,000}\right)$, f_y taken at 33,000 psi (NBC 1965)(CISC 1962)

(3) $f = \dfrac{18,000}{1 + \dfrac{\ell^2}{18,000\, r^2}} \times \left(1.6 - \dfrac{\ell/r}{200}\right)$, $\ell/r > 120$, AISC (1961)

(4) $f = 17,000 - 0.485 \dfrac{\ell^2}{r^2}$ $\ell/r \leq 120$, AISC (1961)

(5) NBC - National Building Code

(6) CISC - Canadian Institute of Steel Construction

(7) AISC - American Institute of Steel Construction

SECTION 6

REFERENCE

Harmathy, T. Z. and J. A. C. Blanchard. Fire Test of a Steel Column of 8-in. H Section Protected with 4-in. Solid Haydite Blocks. National Research Council, Division of Building Research, Fire Study No. 6. Ottawa 1962.

NOTES

This relates to one test conducted at the Division of Building Research of a steel column protected by lightweight concrete masonry. The test was made in accordance with the alternate method of test of ASTM E119 without superimposed load.

TABLE 6.1.A

RESULTS OF FIRE TEST ON COLUMN PROTECTED BY CONCRETE BLOCK

Size of Steel Column	Height of Column	Protective Cover	Thickness of Cover	Fire Endurance		Manner of Failure(1)
				hr	min	
8"x8"x31 lb/ft H	8' 2-1/2"	Expanded Shale Concrete Block(2)	4" (+1-1/2" airspace)	4	40	1000°F av. temp

(1) Failure by average temperature rise in steel of 1000°F in accordance with the alternative method of test of ASTM E119. No load applied to column.

(2) Density of Concrete block = 70 lb/cu ft. Compressive strength of Concrete blocks - 1297 lb/in^2.

SECTION 7

REFERENCE

Malhotra, H. L. and R. F. Stevens. Fire Resistance of Encased Steel Stanchions. Proceedings, Institution of Civil Engineers, London, 1964.

NOTES

This includes 11 tests on combination columns, structural steel columns with concrete encasement, in which the load-carrying capacity of the concrete is taken into account in the design. The columns were tested under load in accordance with BS 476. The report includes results of loading tests on columns similar to those that were fire tested, in order to compare the structural behaviour under normal conditions with that in fire. Combination columns with only a 1-in. cover were tested although the British Standard B449 (1959) and the National Building Code 1965 require at least a 2-in. cover in combination columns.

TABLE 7.1.A

RESULTS OF FIRE TESTS ON STRUCTURAL STEEL AND CONCRETE COMBINATION COLUMNS

Column* Number	Load † (lb)	Encasement: Gross Area (in.^{2})	Encasement: Cover (in.)	Encasement: Aggregate	Encasement: Nominal Mix (vol)	Encasement: Cube Strength at 28 Days (psi)	Encasement: Maximum Expansion (in.)	Structural Tests ** on Similar Columns: Working Load (lb)	Structural Tests ** on Similar Columns: Ultimate Load (lb)	Structural Tests ** on Similar Columns: Load Factor Against Failure	Fire Resistance: Collapse hr	Fire Resistance: Collapse min	Fire Resistance: Mean Temp at Failure °F
1	195,000	80	1	Gravel (3/8" max)	1:2.7:4.5	2710	0.58	195,000	537,000	2.76	2	15	1148
2	195,000	80	1	Expanded Clay (3/8" max)	1:3:3	4310	-	195,000	630,000	3.23	2	15	1065
3	195,000	80	1	Foamed Slag (1/2" max)	$1:1\frac{1}{4}:1\frac{1}{4}:2\frac{1}{2}$	3350	-	195,000	577,000	2.97	2	35	1102
4	233,000	120	2	Gravel	1:2.7:4.5	3060	-	233,000	650,000	2.78	3	20	1112
5	233,000	120	2	Expanded Clay	1:3:3	4600	-	233,000	850,000	3.65	4	05	1083
6	233,000	120	2	Foamed Slag	$1:1\frac{1}{4}:1\frac{1}{4}:2\frac{1}{2}$	3780	-	233,000	717,000	3.08	4	12	1044
7	274,000	168	3	Gravel	1:2.7:4.5	3420	-	274,000	815,000	2.99	4	12	1024
8	274,000	168	3	Expanded Clay	1:3:3	4360	-	274,000	850,000	3.12	5	50	1064
9•	274,000	168	3	Foamed Slag	$1:1\frac{1}{4}:1\frac{1}{4}:2\frac{1}{2}$	4260	0.44	274,000	947,000	3.48	6	01	1004
10•	146,000	120	2	Gravel	1:2.7:4.5	3060	-	-	-	-	4	04	1245
11••	56,000	120	2	Gravel	1:2.7:4.5	3060	-	56,000	307,000	5.47	5	03	1479

* All Columns BSB # 114 Joist Section

† Columns designed according to BS 449-1959

** Structural tests on columns similar to those fire tested

• Concrete nominally reinforced with light mesh

•• Eccentric loading

SECTION 8

REFERENCE

Ashton, L. A. , and N. Davey. Fire Tests of Steel Beams from "Investigation of Building Fires, Part V. Fire Tests on Structural Elements". National Building Studies, Research Paper No. 12, H. M. Stationery Office, London, 1953.

NOTES

This includes 11 fire tests on steel beams unprotected, partially protected and encased in concrete. The tests were carried out at the British Fire Research Station in accordance with BS 476.

TABLE 8.1.A

RESULTS OF FIRE TESTS ON STEEL BEAMS PROTECTED BY CONCRETE

Test No. (See Fig. 7.1.B)	Section BSB #	Section Modulus (in. ^{3})	Load (Concentrated at Mid-Span) (lb)	End Condition	Concrete				Strength			Maximum Deflection (at Mid-Span) (in.)	Fire Endurance	
					Thickness of Cover (in.)	Aggregate	Nominal Mix	Age at Test (days)	28 Days (psi)	At Test (psi)	Moisture % by wt		hr	min
1	111	11.29	12,300	Restrained	2	River Gravel 3/4" max	1:6	45	-	3630	6.6	3.0 5 hr - 25 min	5	26
2	111	11.29	8,740	Simply Supported	2	River Gravel 3/4" max	1:6	42	-	4170	6.1	3.0 3 hr - 45 min	3	46
3	111	11.29	8,740	Simply Supported	2	River Gravel 3/4" max	Precast Blocks $1:1\frac{3}{4}:3\frac{1}{2}$	-	-	-	Concrete 4.0 Tile 6.0	2.2	4	00*
4	117	24.47	22,400	Restrained	2,4	River Gravel 3/4" max	1:2:4	45	-	3290	4.5	3.2	6	00**
5	117	24.47	22,400	Restrained	2,3	River Gravel 3/4" max	1:2:4	46	-	3825	4.9	3.3	6	00
6	117	24.47	22,400	Restrained	2	River Gravel 3/4" max	1:2:4	42	-	3720	4.6	1.2	6	00**
7	117	24.47	22,400	Restrained	1	River Gravel 3/4" max	1:2:4	49	-	4895	4.5	7.9	6	00
8	117	24.47	22,400	Restrained	2,4	River Gravel 3/4" max	1:2:4	40	-	4820	4.6	0.8	6	00**
9	117	24.47	22,400	Simply Supported	1	River Gravel 3/4" max	1:2:4	35	-	3045	4.4	6.1	4	00

* Tested for Grade B Fire Resistance

** Tested for Grade A Fire Resistance

FIGURE 8. 1. B

DETAILS OF CONSTRUCTION OF STEEL BEAMS
PROTECTED BY CONCRETE

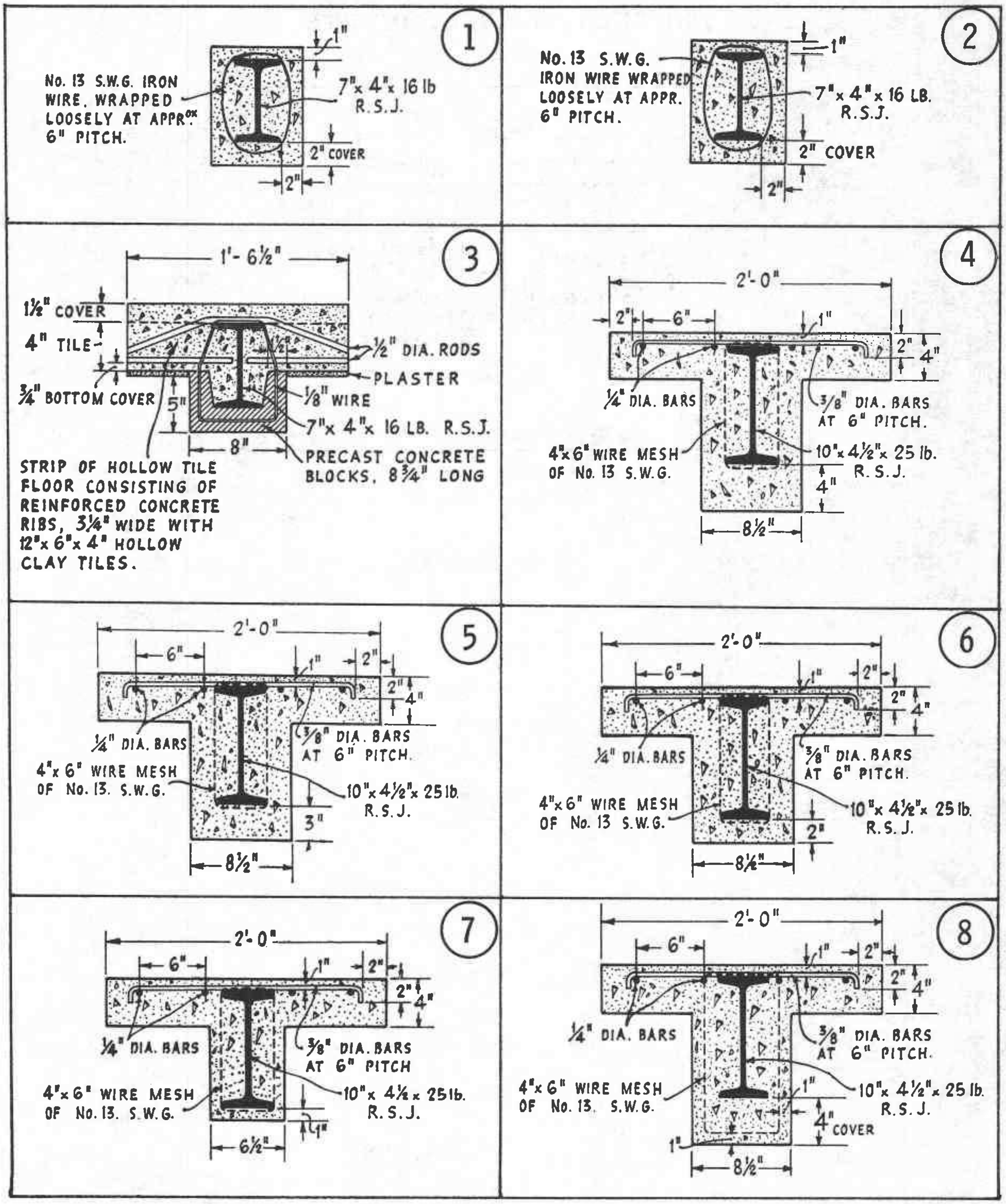


FIGURE 8. 1. B (Cont'd)

DETAILS OF CONSTRUCTION OF STEEL BEAMS
PROTECTED BY CONCRETE

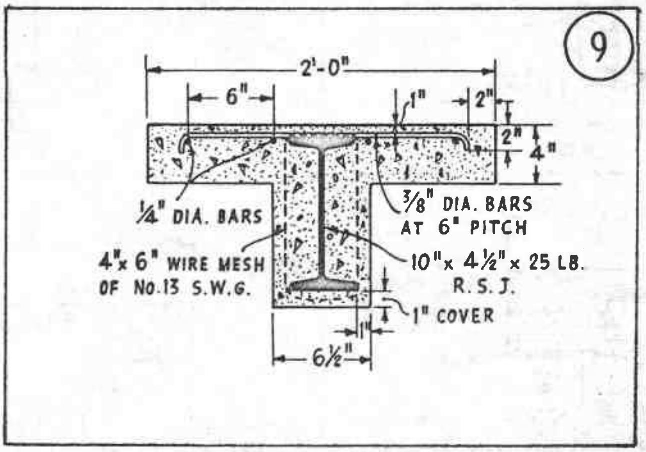


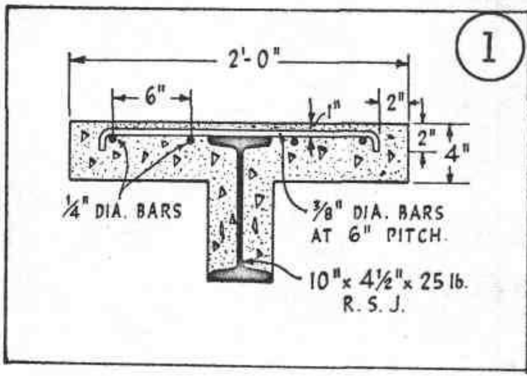
TABLE 8.2.A

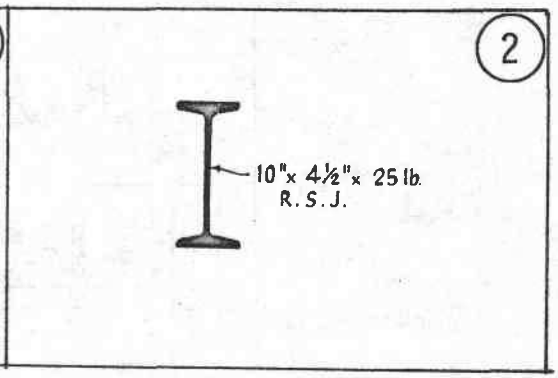
RESULTS OF FIRE TESTS ON STEEL BEAMS PARTIALLY PROTECTED OR UNPROTECTED

Test No. (See Table 7.2. B)	Section BSB #	Section Modulus (in. ^{3})	Load (Concentrated at Mid-Span) (lb)	End Condition	Concrete							Maximum Deflection (at Mid-Span) (in.)	Fire Endurance	
					Thickness of Cover (in.)	Aggregate	Nominal Mix	Age at Test (days)	Strength 28 Days (psi)	Strength At Test (psi)	Moisture % by wt		hr	min
1	117	24.47	22,400	Restrained	0	River Gravel 3/4" max	1:2:4	45	-	3525	4.0	7.3	4	00
2	117	24.47	22,400	Restrained	0	None	-	-	-	-	-	3.1	0	39

FIGURE 8. 2. B

DETAILS OF CONSTRUCTION OF STEEL BEAMS PARTIALLY PROTECTED OR UNPROTECTED





ADDITIONAL SOURCES OF TEST INFORMATION

There are a number of additional sources of test information that for one reason or another it has not been possible to include in this paper.

Unpublished Test Reports

The majority of fire testing agencies have conducted many fire tests that have not resulted in published test reports. Copies of unpublished test reports are often given to the sponsor of the test who is, in most cases, the producer of one of the components in the test assembly. It may be possible to obtain information of this kind from the product manufacturers.

Underwriters Laboratories

Underwriters Laboratories follow generally the same practice. Confidential test reports are made available in limited numbers to the test sponsor. A brief description of the test assembly is then included in the Building Materials List(1) if the proponent is prepared to pay for continued listing and if U. L. are satisfied that the product manufactured is the same as that in the test assembly.

Proprietary Materials

Underwriters Laboratories listing and labelling service is a useful means for making available fire test information on proprietary products, where the proponent does not wish, for commercial reasons, to publish detailed specifications. Fire test information relating to proprietary products has however been published by the British Fire Research Station in "Sponsored Fire Resistance Tests on Structural Elements"(2) and by the corresponding authority in France in "Cahiers du Centre Scientifique et Technique du Bâtiment"(3).

Lists of Fire Tests

It should be noted that lists of ratings put out by various agencies such as Code authorities, technical societies, and trade associations, although generally based on actual tests, may contain many entries which have been arrived at by calculation or by the exercise of judgement by the authors. In one well known and widely quoted source of rating information, less than half of the entries are directly supported by published test reports. In such cases the value of the information as evidence in support of a particular rating must depend on the confidence placed in the judgement of the issuing agency. On occasion some agencies have accepted and reproduced ratings published by others so that the appearance of a particular rating in a number of lists does not necessarily mean that the original was directly supported by test.

It is not intended to condemn this practice which has been brought about by the urgent necessity to provide information on the fire performance of building assemblies in common use. In order to clarify this situation in Canadian practice an attempt has now been made to separate these kinds of information. The new Supplement No. 2, "Fire Performance Ratings," to the National Building Code 1965 is devoted almost entirely to ratings based on judgement, exercised after careful study of the published test information. The information in the preceding pages of this publication on the other hand has been confined to detailed published fire test reports, and no reference has been made to lists of fire resistance ratings based on the judgement of others.

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