Column covers: a practical application of sheet steel as a protective membrane

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ABSTRACT

Two fire tests on structural steel columns protected by standard gypsum wallboard held in place with sheet steel column covers are described. The tests showed that sheet steel column covers are able to retain the gypsum board for much longer periods of fire exposure than other mechanical fastening methods. The fire endurance classifications developed were $1\frac{1}{2}$ hr and 2 hr, for two layers of $\frac{1}{2}$-in. and two layers of 5/8-in. standard wallboard, respectively.

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W. W. Stanzak*

An earlier study by the author demonstrated the ability of sheet steel protective membranes to hold weak and dimensionally unstable materials in place during fire exposure (1). It pointed out that most materials possessing the desirable thermal properties of low conductivity and high heat storage capacity lack the most vital characteristic required for a protective membrane, the ability to remain in place. While some materials are readily damaged or removed even at normal service temperatures, thin sheet steel was shown to remain in place and retain its backup insulation for periods of over two hours under standard fire exposure. No attempt was made in the previous study to develop a prototype system, but the results indicated that a practical sheet steel column cover with back-up insulation could be developed.

The present report describes fire tests on two steel wide-flange column sections protected with a sheet steel membrane backed by standard gypsum wallboard**. The covers were designed to be adaptable to a variety of applications, joinery methods, and finishing. The particular covers, joinery methods and finishing used in the fire tests should be regarded only as examples of the general design concept.

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** Standard gypsum wallboard is manufactured by several firms in Canada. The individual products of each firm are sufficiently similar to yield almost identical fire performance, i. e. they generally remain in place for a very short time (twenty minutes or less). To improve the performance, most manufacturers provide a variety of "Type X" wallboards, whose ability to remain in place during fire exposure is improved by certain additives, including fibre reinforcement. No satisfactory test (other than the standard fire test) has been developed, however, to assess the quality of these special products (2). Use of standard wallboard, made possible by combination with the sheet steel, eliminates the difficult material identification problem involved with the proprietary products.

A number of backup insulations can be used. In the earlier feasibility studies (1) mineral wool was used alone and in combination with gypsum wallboard to provide fire ratings in steel columns and beams ranging from 3/4 hr to 2 hr. One application of such a combination (fire-tested in Holland by the Instituut T. N. O. voor Bouwmaterialen en Bouwconstructies) was reported recently (3) in which rock wool batts and 1 mm (0.0254-in.) sheet steel were used to provide beams and columns with 1- and 2-hr fire resistance ratings (see Figure 1).

The main function of a sheet steel membrane should be to retain insulating materials that would fall away under fire exposure if unenclosed. (In comparison with the backup material, sheet steel is not a good insulator and, from a heat transfer point of view, its use on the exposed surface contravenes a basic rule of fire endurance rating (4) — that materials with relatively high conductivity should be placed away from the fire exposed surface). To be effective, the sheet steel cover must be adequately mechanically joined and backed by sufficient insulation to provide the desired fire endurance. In addition, it must be thick enough so that it will not oxidize excessively during the anticipated fire exposure. Provided that these requirements are met, details can be allowed to vary from one design to another as is demonstrated in References 1 and 3 and in this paper. A satisfactory column protection does, however, have the following general requirements:

(1) the protection should be difficult to remove after construction and during normal service,

(2) the protection should be amenable to various degrees of prefabrication,

(3) the system should be capable of rapid and simple assembly by semi-skilled or unskilled personnel,

(4) the system should fit in readily with the protective systems of other key structural components,

(5) the system should preferably comprise only generic materials.

(6) the system should be economical in comparison with other systems offering similar quality and protection,

(7) the finished protection should be aesthetically pleasing or at least unobtrusive.

Cognisance of these general requirements was taken in the design of the test specimens.

DESCRIPTION OF TEST SPECIMENS

Two identical column sections were similarly protected with a sheet steel membrane backed by a double layer of gypsum wallboard. Two thicknesses of board were used and the steel seam details differed in the two specimens. The general design is illustrated in Figure 2. A gypsum insulating backup material, a sheet steel cover with a mechanically fastened seam and a seam cover are the essential design features.

A description of the individual test specimens follows. The item numbers correspond with the part numbers in Figure 2.

Specimen No. 1

1. Wide-flange steel column section: 10 WF 49, 8 ft 1 in. long, steel specification CSA G40.12, supplied with welded end plates, $\frac{3}{4}$ in. thick by 12 in. square.

2. Regular gypsum wallboard, nominally $\frac{1}{2}$ in. thick (measured 0.510 in.), 8 ft long, conforming to CSA A82.27, density approx. 50 lb/ft^3.

3. 0.023 in. thick cold rolled steel, 8 ft 1 in. long, prepainted semi-gloss white, brake formed into top-hat section.

4. 1 in. by 2 in. (nominal) wood strip (measured $\frac{3}{4}$ x 1 5/8 in.) joint cover, painted semi-gloss black.

5. Self-threading steel screw (8-32, $\frac{1}{4}$ in. long), attached 24 in. o.c.

Specimen No. 2

1. Wide-flange steel column section: 10 WF 49, 8 ft 1 in. long, steel specification CSA G40.12, supplied with welded end plates, $\frac{3}{4}$ in. thick by 12 in. square.

2. Regular gypsum wallboard, nominally 5/8 in. thick (measured 0.650 in.), 8 ft long, conforming to CSA A82.27, density approx. 50 lb/ft^3.

3. 0.032 in. thick cold rolled, wiped zinc coated (galvanized) steel, 8 ft 1 in. long, brake formed into top-hat section.

(On specimen no. 2 the joint was crimped with a standard crimping tool, 12 in. o.c. The wood trim or joint cover was omitted.)

CONSTRUCTION OF TEST SPECIMENS

All construction was carried out by members of the staff of the Division of Building Research. The basic procedure was similar for the two specimens, and the illustrative photographs were taken during the assembly of specimen no. 1.

Gypsum wallboard, supplied in 4 ft by 8 ft sheets was pre-cut to size with a standard cutting knife. Two pieces, sized to fit over the flanges, were placed and each was temporarily held with two strips of masking tape (Figure 3). Figure 4 shows completion of the first layer, with two pieces of masking tape holding each board temporarily in position. The second layer was applied in a similar manner and the sheet steel column cover was positioned (Figure 5), closed, 1/8-in. holes punched with a Whitney punch, and the seams fastened with sheet metal screws, approximately 2 ft o.c., with one screw being about 1 ft on either side of the mid-height of the column. The self-nailing wood strip was centre-grooved to a depth of about ½ in. and pressed onto the seam. The completed specimen is shown in Figure 6.

For specimen 2, the procedure was identical up to the stage illustrated by Figure 5. Then the seam was crimped at approximately 1 ft o.c. with a mechanical crimping tool commonly employed in the drywall trade for fastening steel studs to floor and ceiling runners. Figure 7 shows a close-up of the type of joint produced. The wood finish was omitted as it is merely decorative and does not contribute to the fire performance of the specimen.

It should be noted that the covers on both specimens were left free to expand on heating, thus anticipating a floor to underfloor clearance of ½ to 1 in. in practical applications (5).

TEST METHOD

The fire endurance tests were carried out in accordance with CSA Standard B54.3-1964 (6): Alternate test of protection for steel columns.

The upper and lower ends of the specimen were insulated with ceramic fibre to prevent appreciable longitudinal heat transfer. Temperatures on the steel cross-section were measured by fifteen chromel-alumel thermocouples peened into the steel at five levels (Figure 8). To demonstrate the degree of protection afforded by the sheet steel cover, two thermocouples were located at mid-height between the steel and outer layer of wallboard (specimen no. 2 only).

The furnace temperature was measured by nine thermocouples positioned symmetrically about the column (Figure 9). All thermocouples were enclosed in $\frac{1}{2}$-in. black iron pipe with a carbon steel cap at the tip. The junction of the thermocouples was placed 12 in. away from the surface of the specimen. Both the individual temperatures at the nine points and the average of the nine thermocouples were recorded during the test. Fuel input to the furnace was controlled automatically to make the average temperature follow the course specified by CSA B54.3.

Figure 10 shows column no. 2 installed in the furnace immediately before the fire test.

OBSERVATIONS DURING FIRE TESTS

Test No. 1

At 1 min the wood trim ignited, flaming brightly in the dark furnace. Thirty seconds later the steel began to bulge slightly near mid-height and the white paint on the steel cover was blackening. The wood trim continued flaming until about 8 min, when its charred remains began to fall from the column. The vertical seam was observed to have opened about $\frac{1}{2}$ in. near the centre at 35 min. By 45 min this opening had increased to 2 in. or more, however, the wallboard behind was still intact. No further significant change was observed until 110 min, when the bulging of the steel at mid-height began increasing at a noticeable rate. At 113 min the cover split open and much of the protective material fell away. The test was terminated at 1 hr, 55 min.

Figure 11 shows the condition of the specimen in the furnace after it had cooled. Note the bulging on the right side of the seam; it is similar to the appearance of the left side, just before the cover split.

Test No. 2

Flames began to issue from the seam joint at about 3 min and continued for about 2 min before dying down. At 25 min some buckling was observed along the lower half of one seam but the seam was not open. By this time the zinc coating had begun to blister off the steel in large bubbles. No significant changes were observed during the remainder of the test with the cover and seam joint being relatively intact at 143 min, when the test was terminated.

Figure 12, showing the specimen in the furnace after cooling, indicates the condition of the seam joints and the cover. The opening on one of the joints shown in the photograph was not observed during the fire test. It should be noted that the wallboard behind is still in place.

RESULTS

The average furnace temperature during the fire tests was always within the allowable limits, and a computation indicated that no time correction needed to be applied to the results. Figures 13 and 14 are plots showing the average furnace temperatures and the temperature rise of the columns at the cross-section causing thermal failure. Specimen No. 1 failed at level 1 (top, Figure 8) at 110 min. Specimen No. 2 exceeded the 1000°F allowable average temperature at level 1 at 139 min.

Accordingly the column specimens would receive fire endurance classifications of $1\frac{1}{2}$ hr and 2 hr respectively.

COMMENTS

1. The fact that both failures occurred at level 1 is interesting. In most steel column tests conducted in the DBR/NRC floor furnace the failure has occurred at level 5, which coincides approximately with the level of the propane burners (7). The exceptions have normally involved protective materials containing considerable quantities of free or combined moisture. *

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* The gypsum used in fire protective materials is calcium sulphate dihydrate, of which about 20 per cent by weight is water of crystallization. When the product is exposed to fire this water is released and finally driven off as steam.

Harmathy (8) has found that moisture migrates away from the fire exposed surface towards the coolest part of the construction. Because of the effect of gravity on migrating water the opportunity for re-condensation of moisture is obviously greater in the lower cooler portions, and this in part explains the temperature differences between the three cross-sections plotted in Figure 15.

Also, except at the burner level, furnace temperatures tend to be higher near the top of the furnace, and it is more difficult to insulate the top of the specimen against longitudinal heat transfer than it is the bottom.

2. The ability of the sheet steel membrane to remain in place and the result of a protective membrane suddenly failing has again been clearly demonstrated. For specimen 1 the membrane burst about 3 min after thermal failure had occurred at level 1. Note the rapid rise of temperature at 113 min (Figure 13), after the column suddenly became unprotected.

It should be recognized that while steel is not a good insulator, it does afford some protection from the exposing fire as may be seen from Figure 16. The interface between the back of the sheet steel and the first layer of insulating material was about 150°F cooler than the furnace and 80-100° cooler than the calculated surface temperature of the steel throughout most of the fire test.

3. In these and many other tests, steel has been observed to oxidize quite rapidly when at or near the furnace temperatures, and the oxide has a similar appearance to the "mill scale" found on hot rolled plate. The thickness of steel required depends to some extent on the pressure the deteriorating insulating materials exert on it, but to a greater extent on the temperature it attains and at which it must function.

In a previous test (1) the 0.022 in. thick steel cover burst at 120 min; in the current test no. 1 the 0.023 in. thick cover burst at 113 min. The residual thickness (i.e. thickness of steel not oxidized) in the latter test was approximately 0.018 in., and thinner in local areas; in the former, it was about 0.012 in. Greater pressure exerted by the weight of a double layer of gypsum board (as opposed to a single layer) explains the earlier failure of the second cover.

4. The seams opened considerably during the first test, but the wallboard remained in place. This indicates that local distortions and openings in the cover are unimportant, as long as it remains in place on the column.

CONCLUSIONS

1. The sheet steel membrane column cover was shown to hold standard gypsum wallboard in place for much longer periods than other fastening methods, and to provide:
   (a) a fire endurance classification of $1\frac{1}{2}$-hr using two layers of $\frac{1}{2}$-in. board;
   (b) a fire endurance classification of 2 hr using two layers of 5/8-in. board.

2. A sheet steel column cover for a 2-hr design should have a minimum gauge of 0.025 in.

3. A sheet steel cover will remain in place provided the seams or joints are fastened by some positive mechanical method.

4. Small local distortions or openings in the cover do not significantly impair its effectiveness.

5. A sheet steel membrane is effective in reducing the severity of the furnace exposure, even though it is not a good insulating material.

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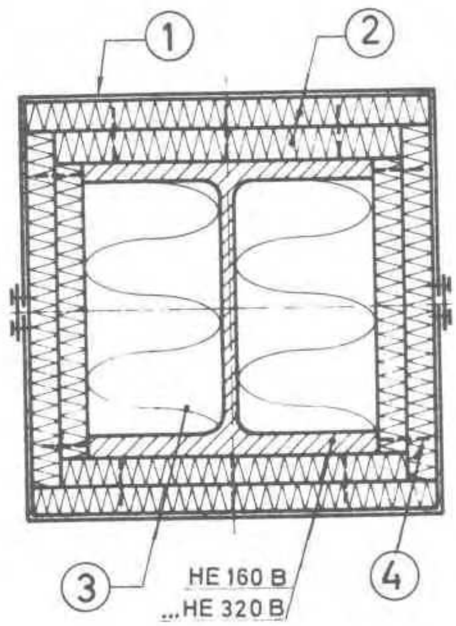

Fig. 1a: Fire Protection of Column.

1. 2 mm cold bent steel sheet.
2. 2 layers of 2.5 cm-3.5 cm Rockwool firebatts, density 110/kg/m^3.
3. Rockwool batts with density 30 kg/m^3.
4. 3 mm round bar fasteners welded to beam.

(Reproduced from Thomsen, Acier-Stahl-Steel, 1/1971)

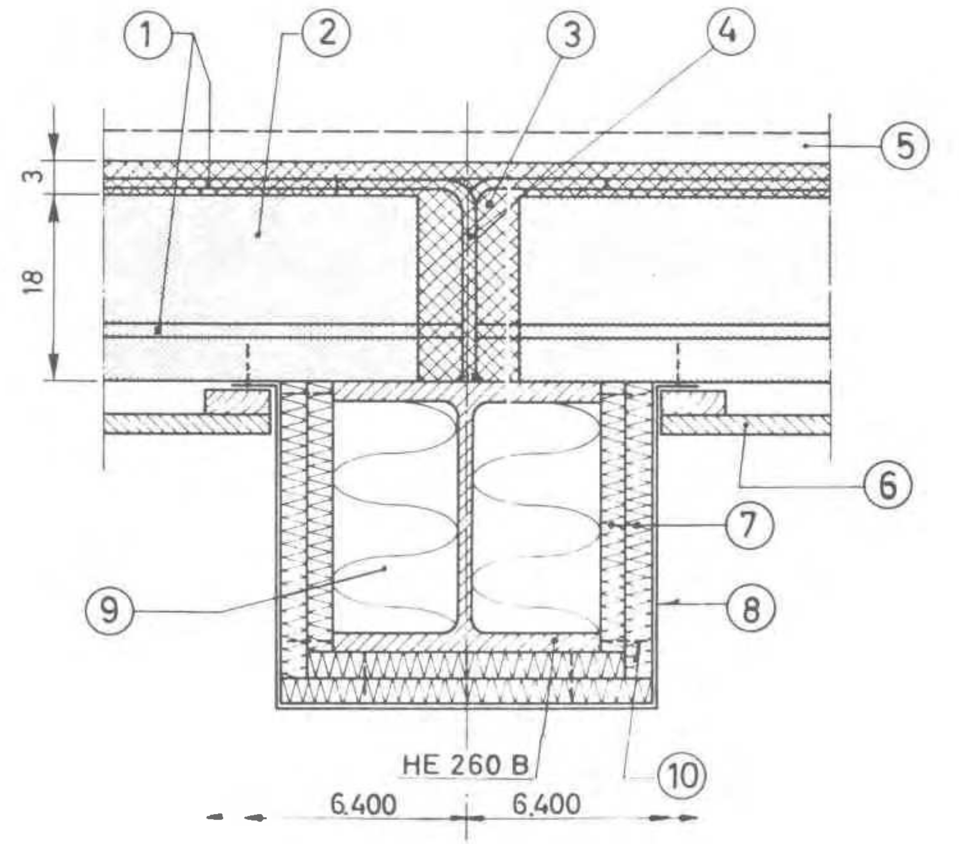

Fig. 1b: Fire Protection of an Interior Beam.

1. Tentor reinforcement.
2. Lightweight tile-concrete slabs.
3. 3 cm in situ cast concrete.
4. Dowels φ 8/30 cm.
5. 3 cm asphalt.
6. 10 mm gypsum plate.
7. Layers of 2.5-3.5 cm Rockwool firebatts.
8. 1 mm cold bent steel sheet fastened to deck.
9. Rockwool batts.
10. 3 mm round bar fasteners welded to beam.

(Reproduced from Thomsen, Acier-Stahl-Steel, 1/1971).

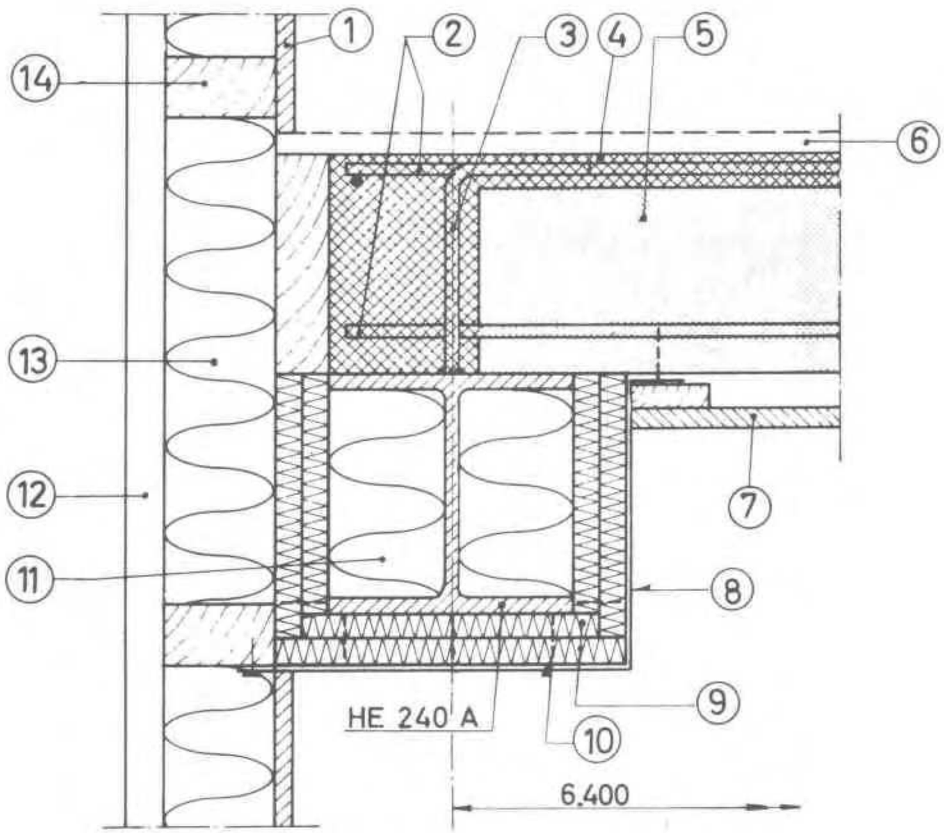

Fig. 1c: Fire Protection of a Facade Girder

1. Gypsum plate.
2. Tentor reinforcement.
3. Dowels φ 8/30 cm.
4. In situ concrete.
5. Lightweight tile-concrete slabs.
6. 3 cm asphalt.
7. 10 mm gypsum plate.
8. 1 mm cold bent steel sheet
9. 2 layers of 2.5-3.5 cm thick Rockwool batts.
10. 3 mm round bar fasteners.
11. Rockwool batts.
12. Corrugated steel sheet.
13. 10 cm Rockwool insulation.
14. Timber piece.

(Reproduced from Thomsen, Acier-Stahl-Steel, 1/1971).

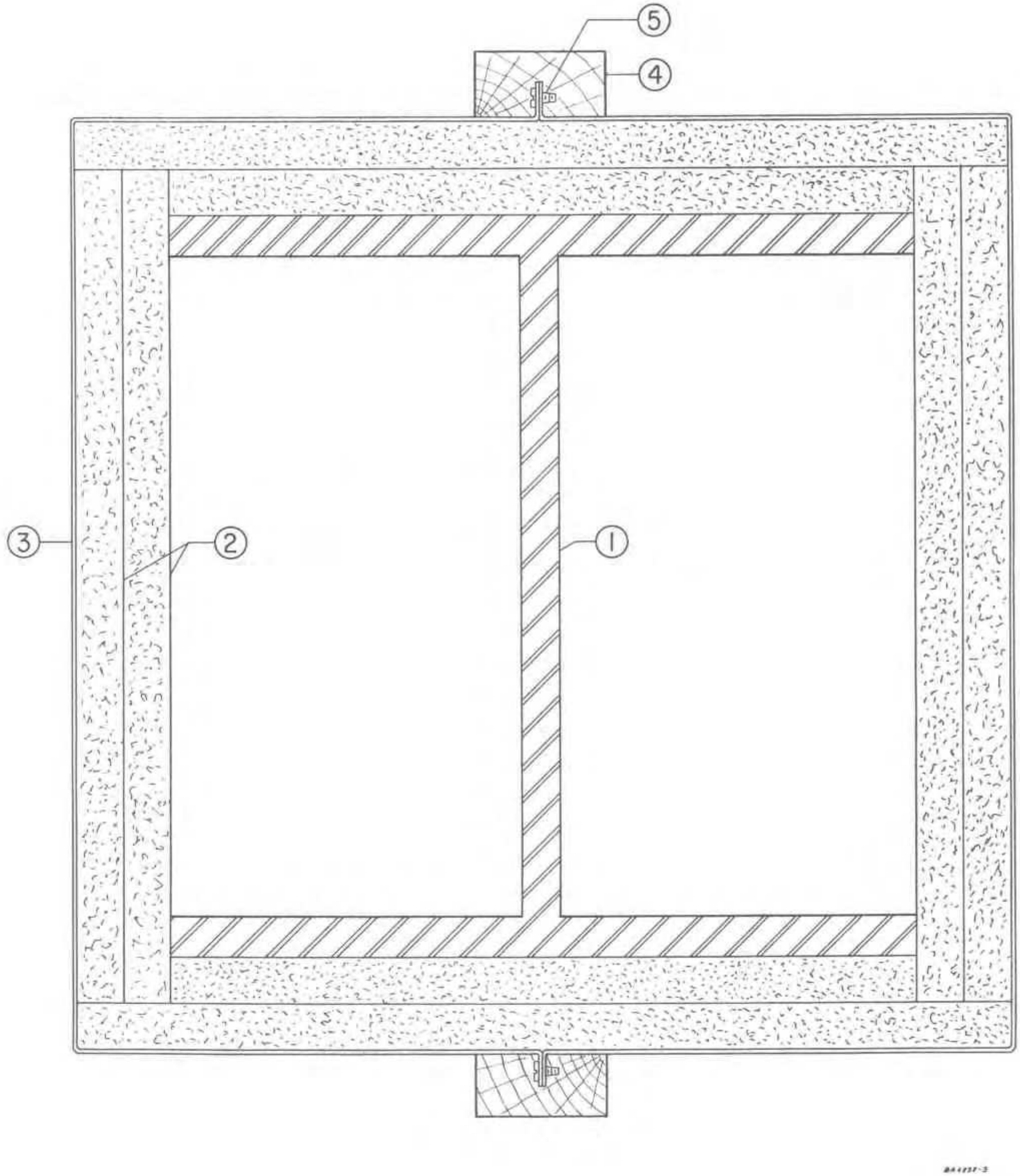

FIGURE 2 TYPICAL TEST SPECIMEN

Figure 3: Attachment of First Protective Layer

Figure 4: Completion of First Layer

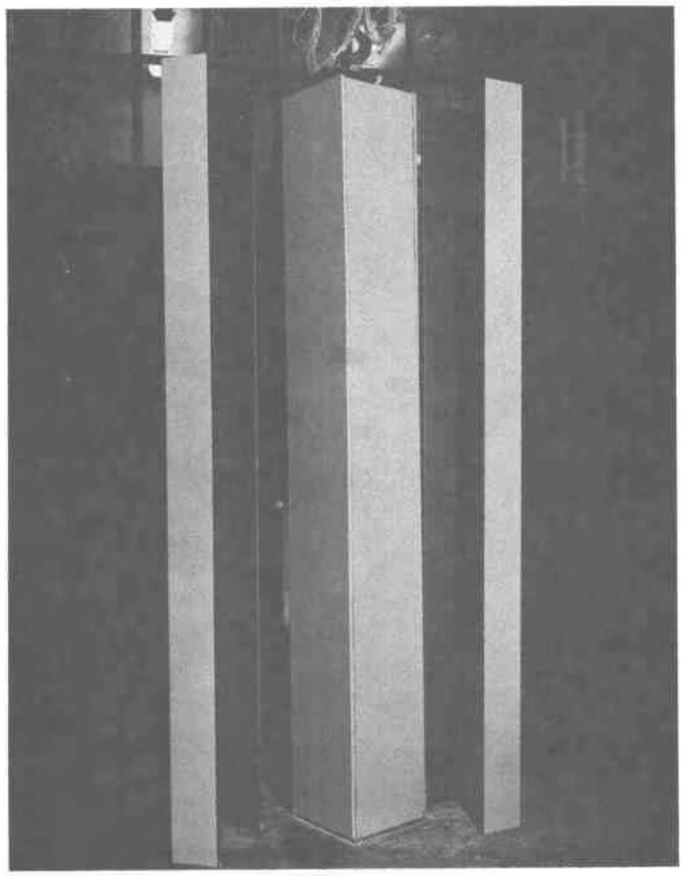

Figure 5: Sheet Steel Cover Positioned Adjacent to Temporarily Taped Wallboard

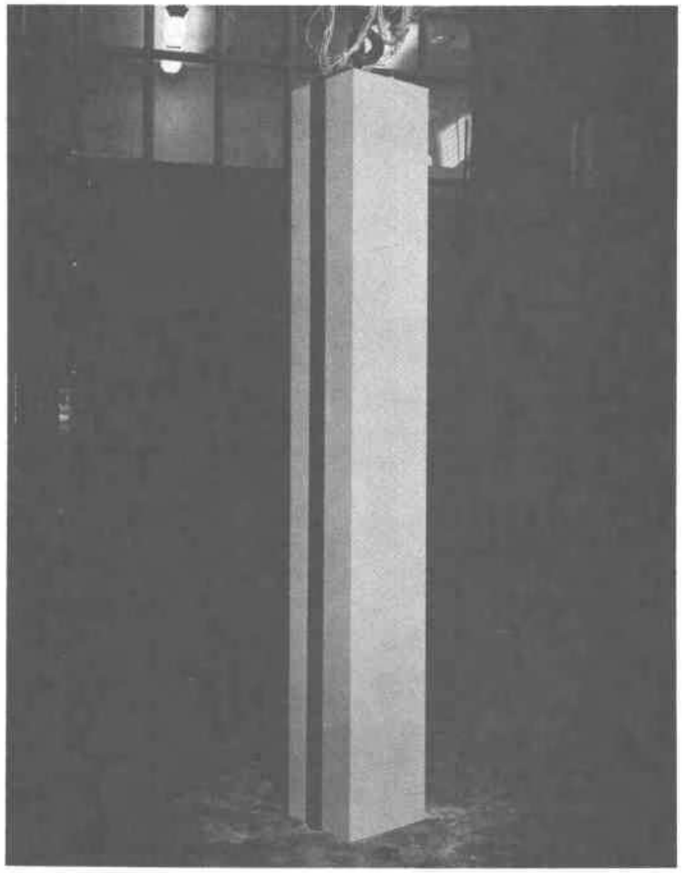

Figure 6: Completed Column

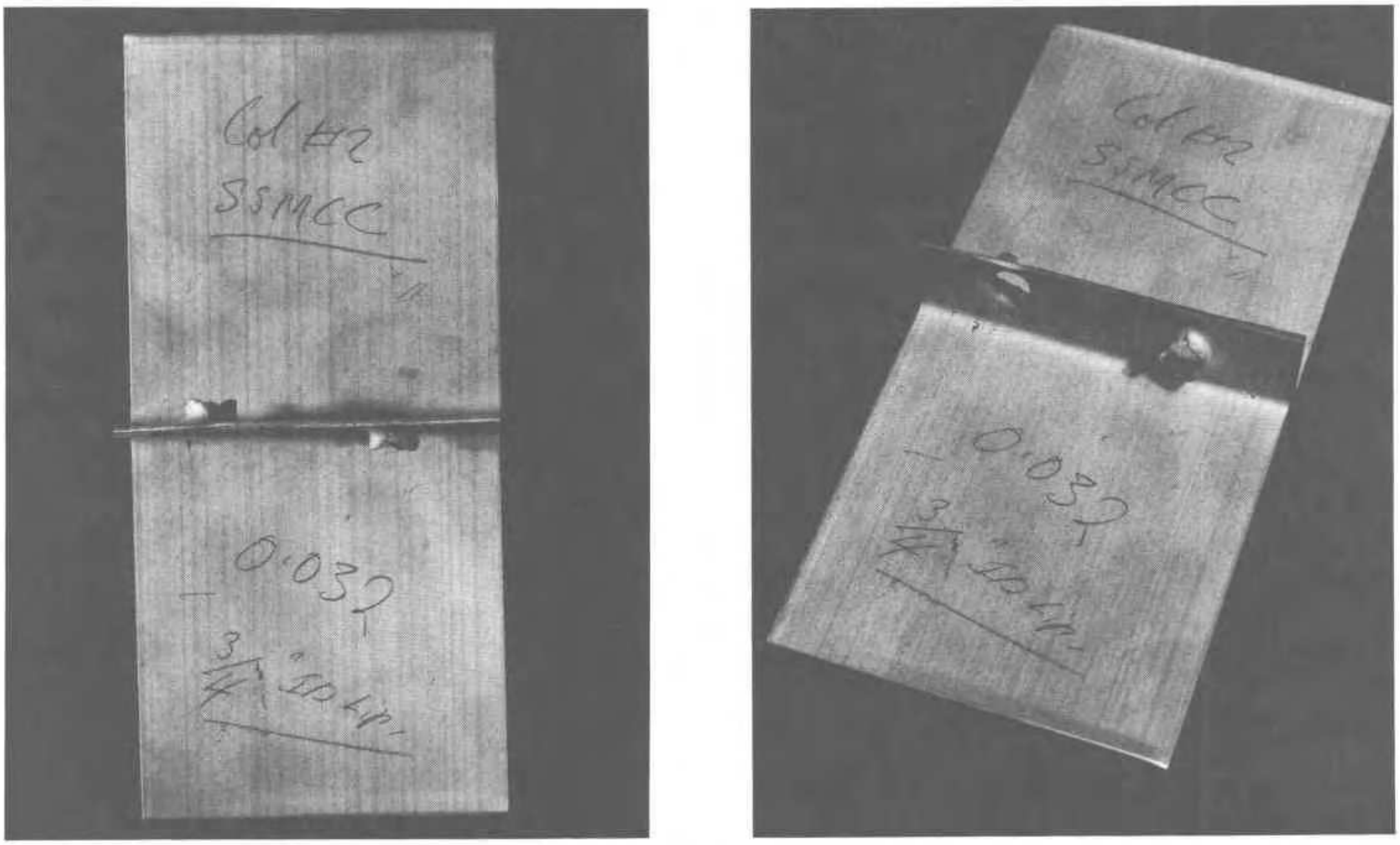

Figure 7: Close-Up of Crimped Seam Joint (Specimen No. 2)

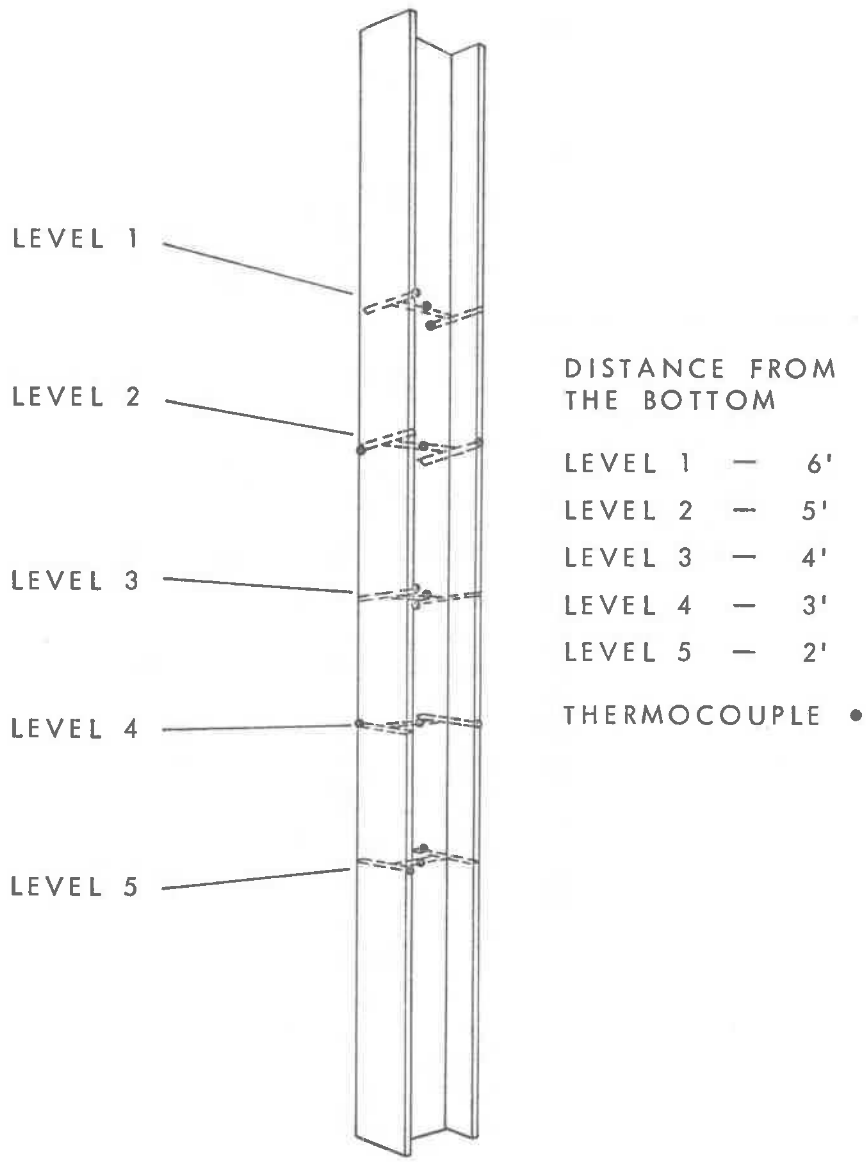

FIGURE 8

LOCATION OF THERMOCOUPLES ON WIDE-FLANGE COLUMNS.

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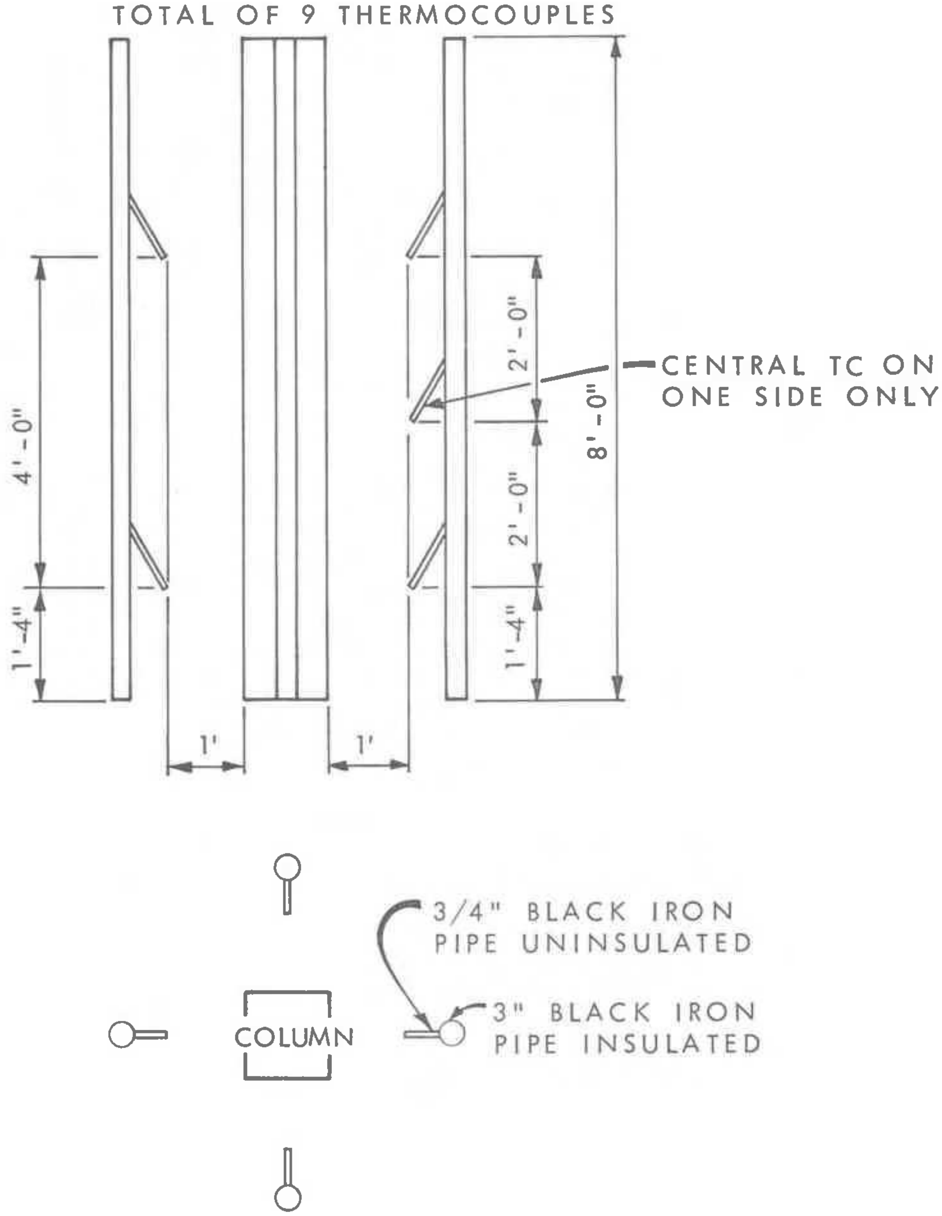

FIGURE 9

LOCATION OF FURNACE THERMOCOUPLES IN RELATION TO COLUMN

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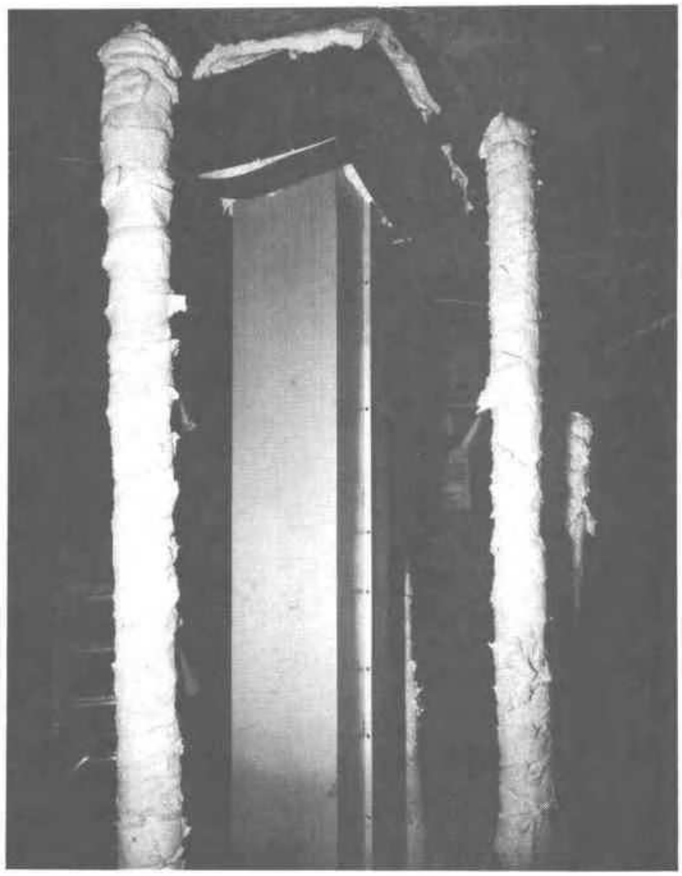

Figure 10: Column No. 2 Installed in Furnace

Figure 11: Column No. 1 in Furnace After Test

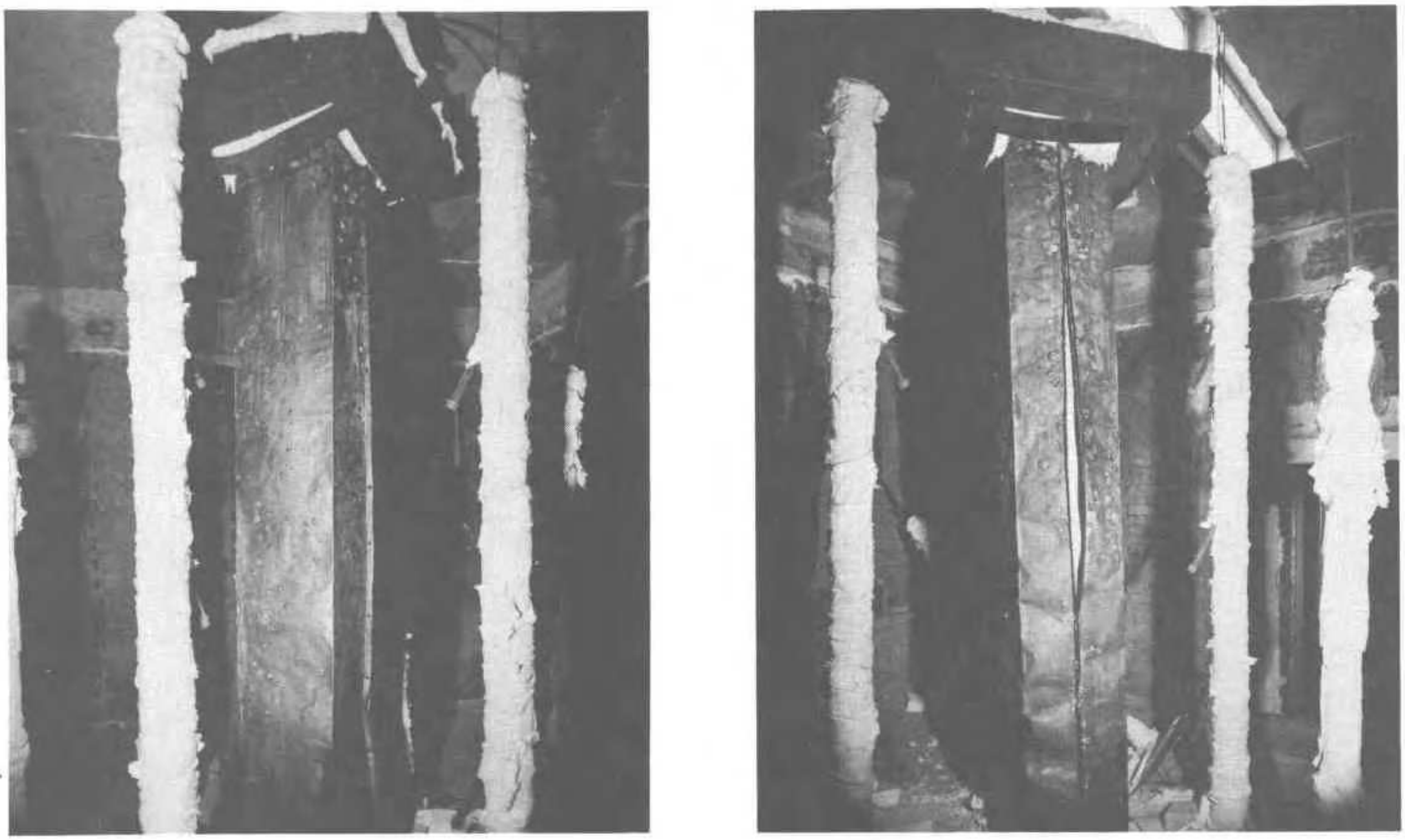

Figure 12: Column No. 2 in Furnace after Test

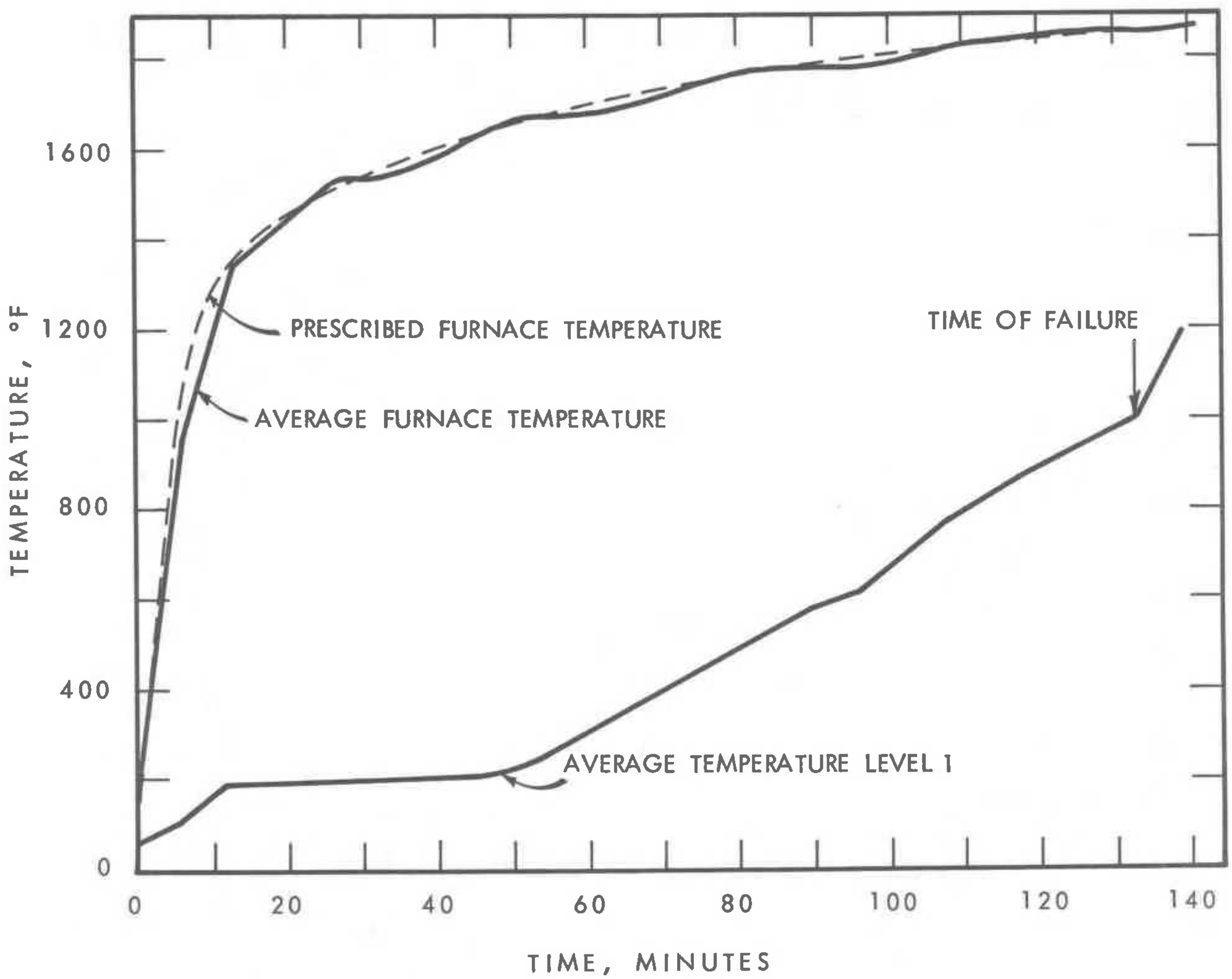

FIGURE 13 COLUMN TEST NO. 1

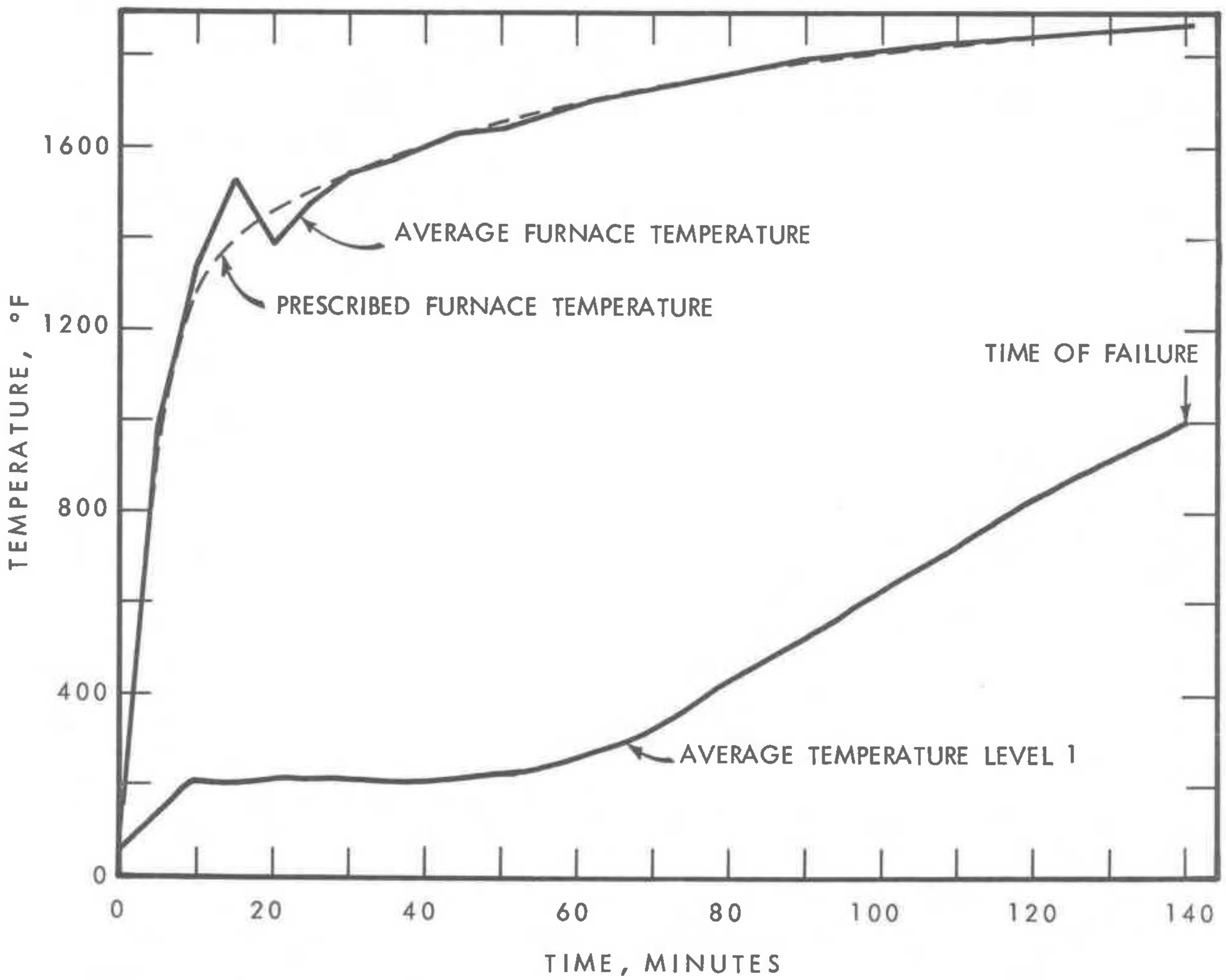

FIGURE 14 COLUMN TEST NO. 2

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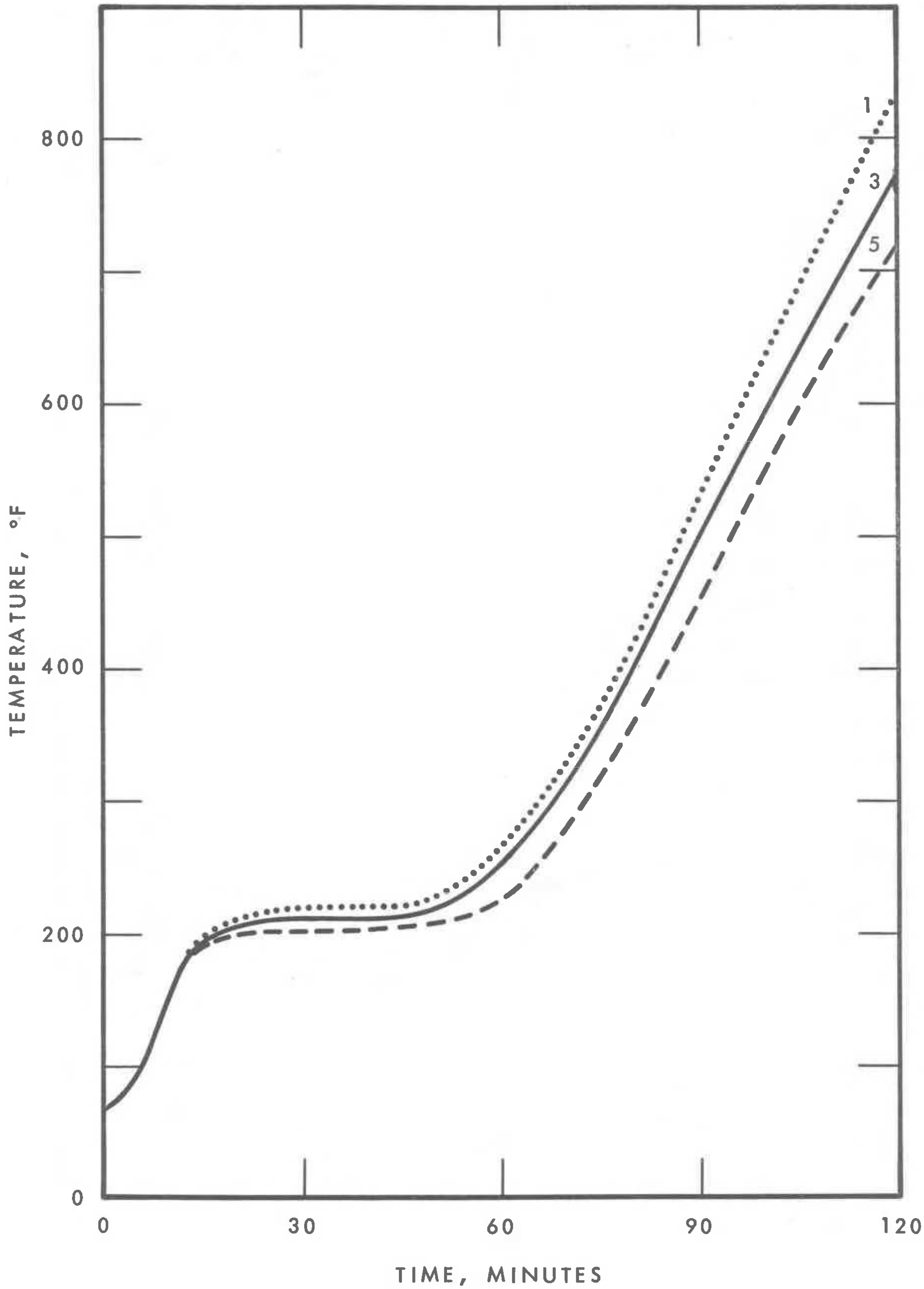

FIGURE 15 TEMPERATURE DISTRIBUTION COLUMN No. 2

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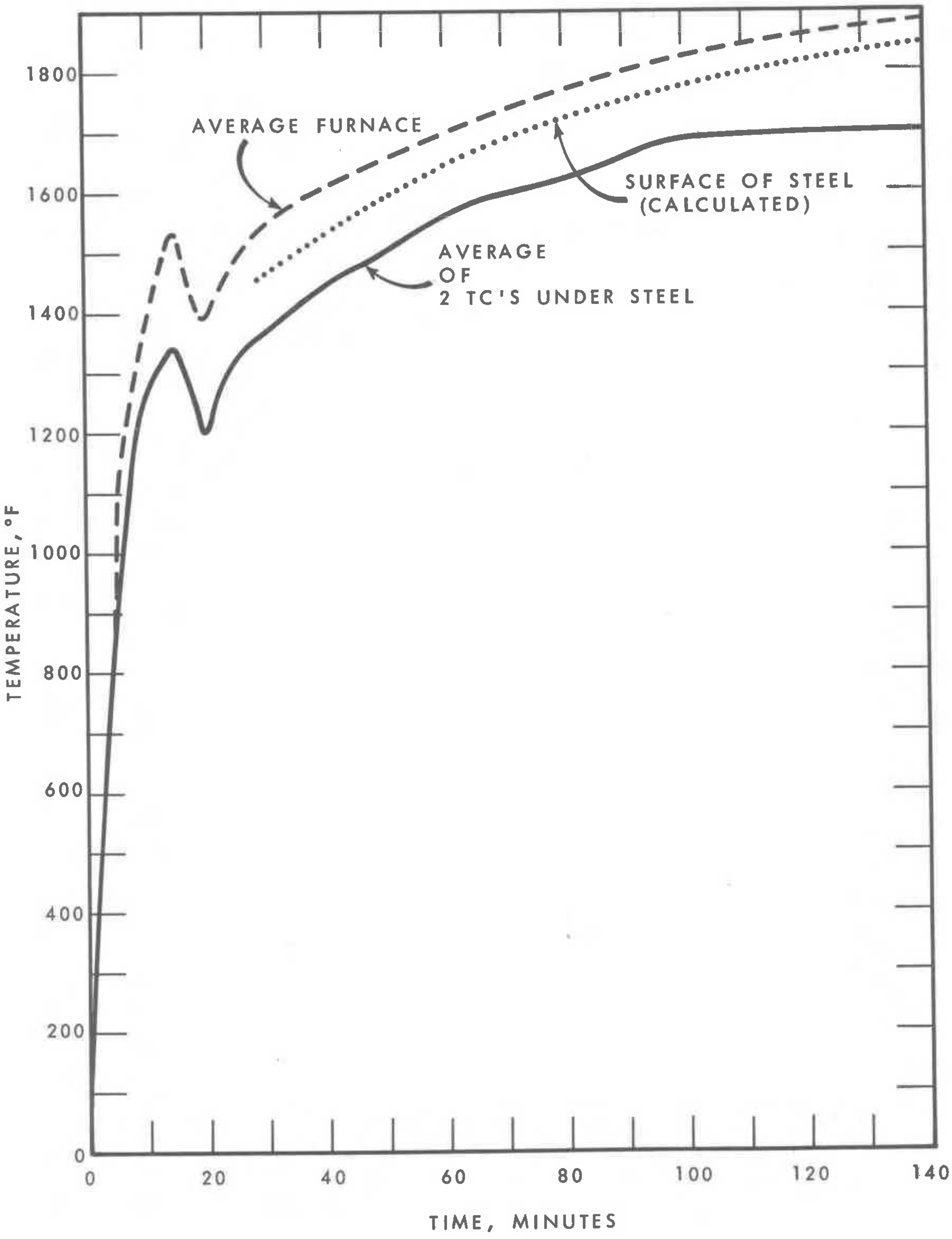

FIGURE 16 COLUMN TEST No. 2, SEPT. 23/71, 2 LAYERS 5/8 GYPSUM BOARD

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