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PRELIMINARY INVESTIGATION INTO THE USE OF SHEET METAL AS A MEMBRANE PROTECTION FOR STEEL BEAMS AND COLUMNS

by

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PREFACE

The use of membrane protection for structural components is well recognized in fire protection work. Such membranes have commonly been made of materials such as plaster and concrete. The importance of their remaining in place during a fire is obvious, and steel reinforcement in the form of wire, rod or metal lath is usually used to ensure the necessary integrity of the membranes. The usual practice has been to provide as much protective cover as possible over the steel reinforcement itself.

The tests now reported were incidental to the main program of work carried out under the Steel Industries Fellowship arrangement between the steel industry and the National Research Council on the subject of performance of steel under fire exposure. The results provided a basis for supposing that exposed sheet steel, despite its tendency to soften, might be used successfully in providing membrane protection. It was not possible to extend the work to confirm these possibilities, but they are considered worthy of further attention.

The author, a mechanical engineer, was the first holder of the Steel Industries Fellowship, from 1964 to September 1967.

Ottawa
December 1967

N. B. Hutcheon,
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W. W. Stanzak

'Membrane protection' is a continuous protective layer separating the member to be protected from the fire, without direct thermal contact between the protective layer and the member.

This report describes the results of two fire tests on steel beams protected with loose insulating materials enclosed in a sheet steel membrane case.

The practice of protecting structures against fire by a protective membrane has been carried on for many years. It was only in the late 1950's, however, that protective materials other than plaster and gypsum wallboards were used widely as membrane fire protection. This was largely due to a marked increase in the number of sponsored fire tests carried out by materials manufacturers.

A study of membrane protection was initiated at DBR/NRC in 1965. The study to date has taken three forms:

1. Computer study of heat flow through layer constructions;
2. Floor tests in the small furnace (1);
3. Full-scale tests on steel beams and columns.

A fire test on a steel beam protected with a membrane of gypsum-sanded plaster has been described in DBR Fire Study No. 19 (2). The results of 8 fire tests on steel column sections protected with gypsum-sanded plaster are given in Fire Study No. 20 (3).

The available fire test data and the above mentioned items clearly show that the most vital characteristic of a protective membrane is its ability to remain in place. This was demonstrated in the small furnace by the fact that a 16 GA (0.0598 in.) steel sheet membrane increased the fire endurance time of a brick floor by approximately 23 per cent. Inserting a lightweight mineral wool in the airgap between the steel and the brick resulted in a 220 per cent increase in fire endurance time.

In addition to its ability to remain in place, a protective membrane, to be effective, should have a low thermal conductivity and a high thermal capacity. Materials displaying these properties are rather expensive. Unfortunately, many economical materials that act as good insulators deteriorate seriously from the effects of fire exposure and become prematurely dislodged. It has been difficult, therefore, to develop membrane protection to its full potential.

Sheet steel has not been previously considered as a potential fire protective material. However, its ability to remain in place if properly fastened, and the fact that its presence causes the fire endurance time of a construction to increase, suggested that this possibility should be investigated.

DESCRIPTION OF SPECIMEN

Details of the test specimens are shown in Figure 1. Figure 2 shows the exposed surface of the beam installed in the furnace, and Figure 3 shows the unexposed surface and hydraulic loading equipment. The two specimens were identical except for the piece of 1/2-in. gypsum wallboard which was not included in specimen 1. The item numbers below correspond to the part numbers in Figure 1.

1. Steel wide-flange beam, 8 in. x 5 1/4 in. x 17 lb/ft, 16 ft 0 in. long, steel specification CSA G40.12.
2. Haydite Slab, 4 in. x 31 in. x 36 in., average density 106 lb/ft^3.
3. Steel plate, 1/4 in. x 18 in. x 36 in. tack welded to steel beam.
4. Mineral wool insulation, 3 in. thick (Johns Manville Type 413).
5. Sheet steel membrane, brake-formed from 36 in. by 48 in. galvanized 20 GA (0.0359) sheets.
6. Refractory insulation.
7. Gypsum wallboard (specimen 2 only), 1/2 in. thick.

TEST METHOD

The fire test was carried out essentially in accordance with a tentative revision of ASTM specification E119-61: Tests of Loaded Beams (4). A deviation from the standard was that the floor slab was less than the minimum 5-ft width specified.

Furnace temperature was measured by nine symmetrically disposed thermocouples enclosed in a 13/16 in. O. D. Inconel tube having 0.035 in. wall thickness. The hot junction of the thermocouples were in carbon steel caps on the Inconel tubes and were placed 12 in. below the plane of the underside of the floor slab. Both the individual temperatures at nine points of the furnace and the average of the nine thermocouples were recorded. The fuel input into the furnace was controlled automatically in such a way that the average temperature closely followed the prescribed standard temperature-time correlation.

The steel temperatures were measured by 16 chromel-alumel thermocouples, peened into the beam at locations shown in Figure 4. Temperatures were measured at four sections, symmetrically located along the length of the beam. One of the thermocouples was located on the bottom flange at midspan, as a hot region was expected to develop there.

The beam was loaded so as to develop the stresses contemplated by the design. A typical loading calculation for a beam test is given in Appendix A of Reference 2. Load was applied by four hydraulic jacks, each pair connected with a cross-beam, 36 in. on either side of midspan.

Vertical deflections were measured at the center and quarter points of the span by means of three measuring tapes connected to the floor slab by a mechanical system. The accuracy of the measurements is ± 0.01 in.*

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*In beam tests where the deflection wire is attached to the floor slab deflection readings may be erratic during early portions of the fire exposure. Warping of the floor slab or failure of the slab to follow the deflection of the beam are responsible for this. Deflections during the final stages of the fire test are, however, usually quite reliable, because by this time the slab has weakened sufficiently to follow the deflection of the beam closely.

OBSERVATIONS DURING FIRE TEST

Test No. 1

The deflection due to the applied live load was 0.75 in. This was close enough to the calculated theoretical deflection of 0.775 in. to indicate that the required live load was being carried by the beam.

0 min	-	fire on
10 min	-	sheet metal protection started bulging west of the center of the beam
15 min	-	thermocouple No. 11 on the steel beam near the bulge registered higher readings than corresponding thermocouples at other stations
90 min	-	beam bowed evenly downward without lateral deformation. Protection still in place and without gaps, but warped in places.
97 min	-	explosive spalling at centre of concrete slab on the north side
103 min	-	test terminated due to excessive deflection of the beam; fire out and load removed.

Test No. 2

At 7 minutes, the concrete slab began spalling explosively causing rapid and severe deterioration. Temperatures on the top flange of the beam soon exceeded those on the lower flange, thus making it impossible to gain any useful results from the test. The test was therefore terminated at 80 minutes. The results are on file but will not be recorded here as they are not relevant to the present investigation.

RESULTS

The temperature rise curve for the beam is given in Figure 5 and the deflection curve in Figure 6.

In order that fire tests might be terminated prior to, but reasonably close to ultimate collapse, Robertson and Ryan (5) proposed that the point at which both $\delta_c \geqq \frac{\ell^2}{800d}$ and $\delta'_c \geqq \frac{\ell^2}{150d}$ can be regarded as an indication of load failure. In these expressions δ_c = central deflection, in., δ'_c = rate of deflection, in./hr, ℓ = clear span of principal structural element, in. and d = distance between the upper and lower extreme fibres of the principal structural element, in. The critical rate of deflection was not exceeded during the fire test, although the deflection was large. Therefore, no load failure occurred according to the Robertson/Ryan criteria.

When the test was terminated (103 min) the beam had a large central deflection and could obviously no longer perform its structural function. The fire endurance time of the specimen may, therefore, be assigned at 103 minutes. The fire resistance classification is 1 1/2 hr.

CONCLUSIONS

1. The fire endurance time of the specimen was 103 min, providing a fire resistance classification of 1 1/2 hr.

2. The concept of a sheet steel protective membrane is a valid one which should be more thoroughly investigated.

3. The average temperature on the bottom flange when the test was terminated was 1270°F. This is about 100° higher than the critical temperature for beams of ASTM A-36 steel.

4. A similarly constructed specimen having a beam of A-36 steel would fail at about 75 min (assuming a critical temperature of 1170°F) and receive a fire resistance rating of 1 hour. Therefore, a beam (CSA G40.12) having superior creep properties yields a substantial increase in fire endurance time.

COMMENTS

The successful fire test clearly demonstrated that the concept of a sheet steel protective membrane is valid. It was unfortunate that the second specimen designed to yield a fire endurance of over 2 hours did not perform as expected. Time did not permit a repeat test at this stage.

There can be no doubt, however, that an economical form of protection capable of providing a 2-hr fire resistance can be developed using the sheet steel membrane.

These tests were the first tests of CSA G40. 12 beams to be conducted at this laboratory. The superior creep properties of the CSA G40. 12 steel give the beam excellent fire enduring qualities. It is clear that the slight extra cost of a superior steel is easily offset by savings in the fire protection requirements.

ACKNOWLEDGEMENT

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REFERENCES

1. Blanchard, J. A. C. and T. Z. Harmathy. Small-scale fire test facilities of the National Research Council. DBR Fire Study No. 14, Ottawa, Nov. 1964.

2. Stanzak, W. W. Fire test on a steel wide-flange beam protected with a one-inch gypsum-sanded plaster suspended ceiling membrane. DBR Fire Study No. 19, Ottawa, Aug. 1967. (NRC 9764)

3. Stanzak, W. W. and E. O. Porteous. Fire tests on steel wide-flange column sections protected with gypsum-sanded plaster. DBR Fire Study No. 20, Ottawa. (NRC 9768)

4. Fire Tests of Building Construction and Materials, ASTM Designation E119-61. American Society for Testing and Materials. Philadelphia, Pa.

5. Robertson, A. F. and J. V. Ryan. Proposed criteria for defining load failure of beams, floors and roof construction during fire test. Journal of Research, National Bureau of Standards, 63C, Washington, 1959, p. 121-124.

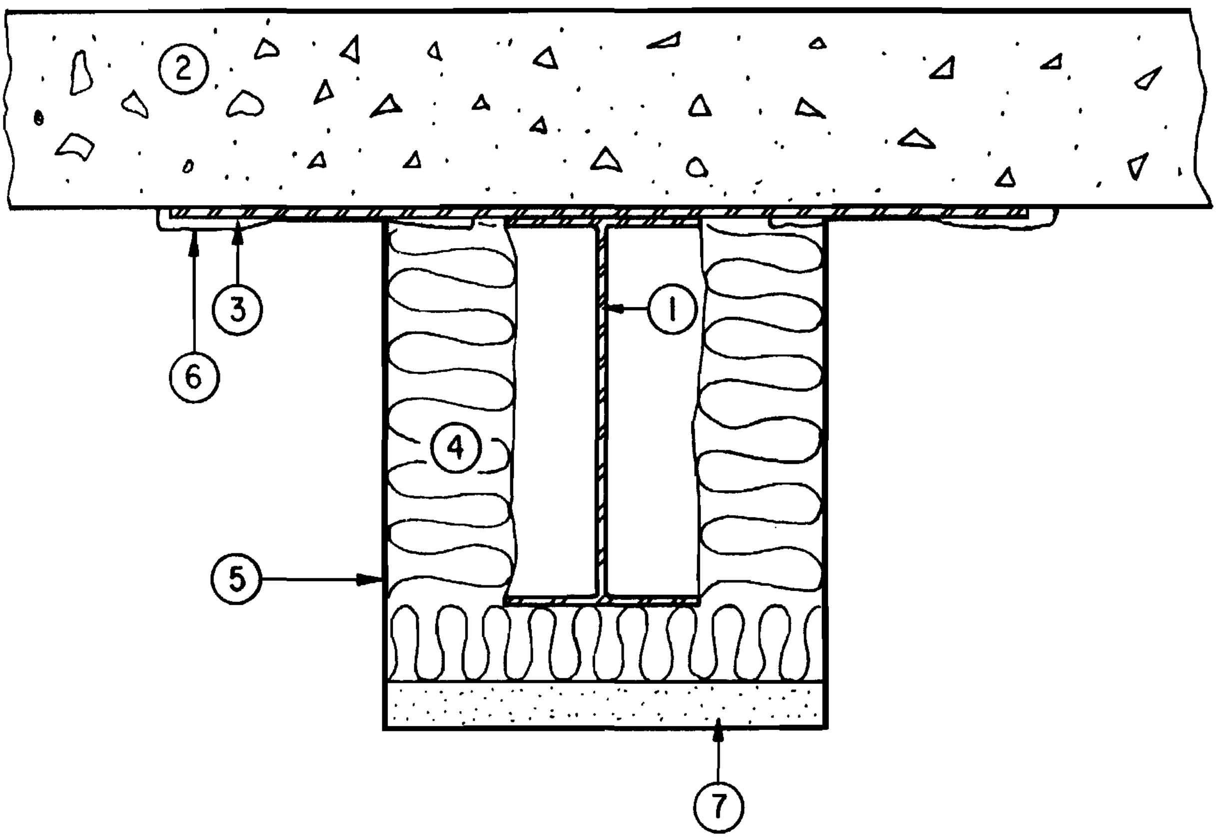

FIGURE 1

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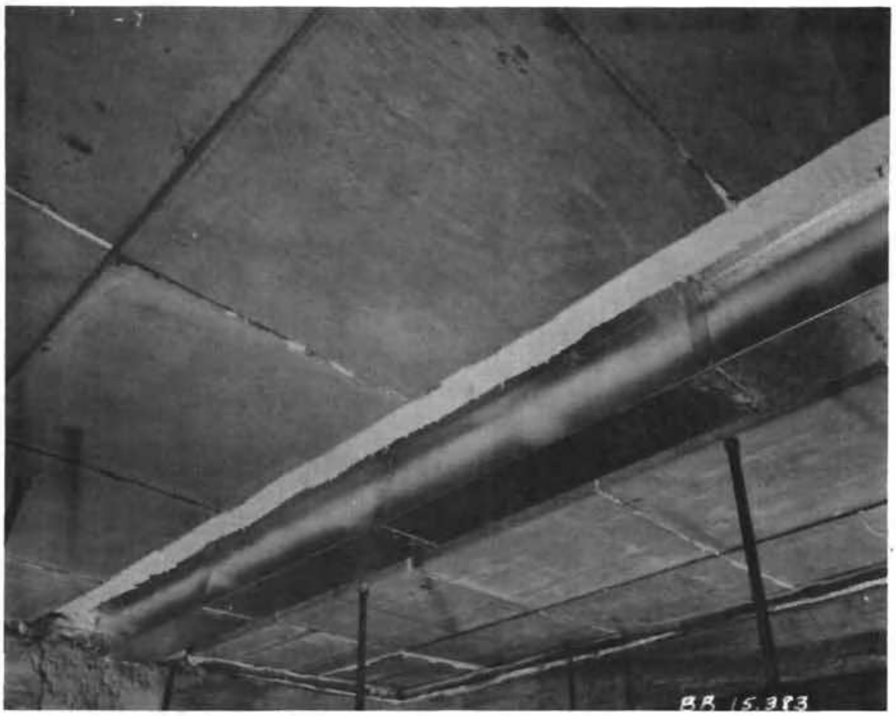

Figure 2 Exposed Surface Before Fire Test

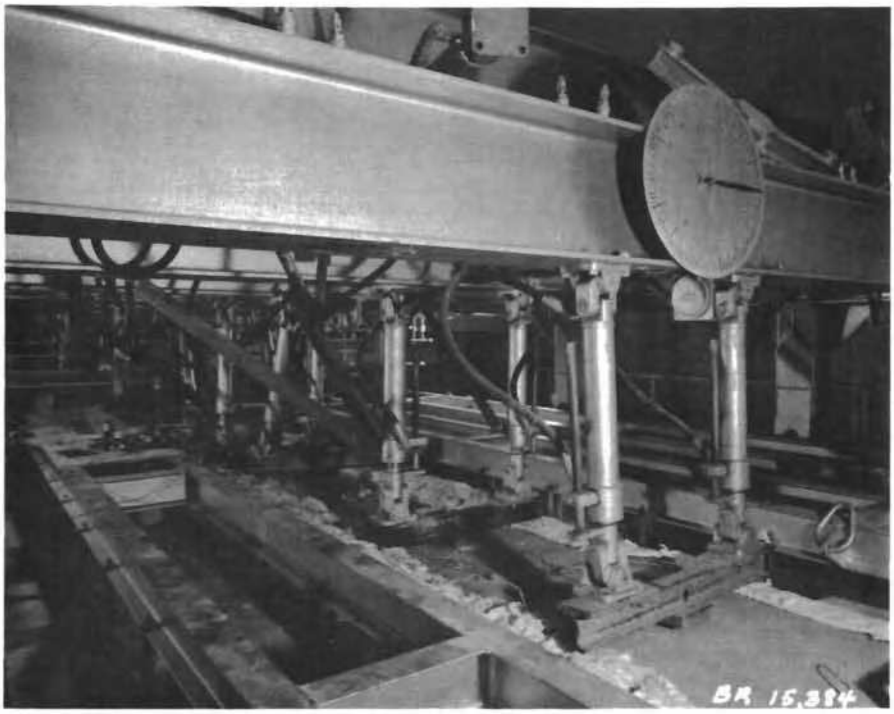

Figure 3   Unexposed Surface Before Fire Test

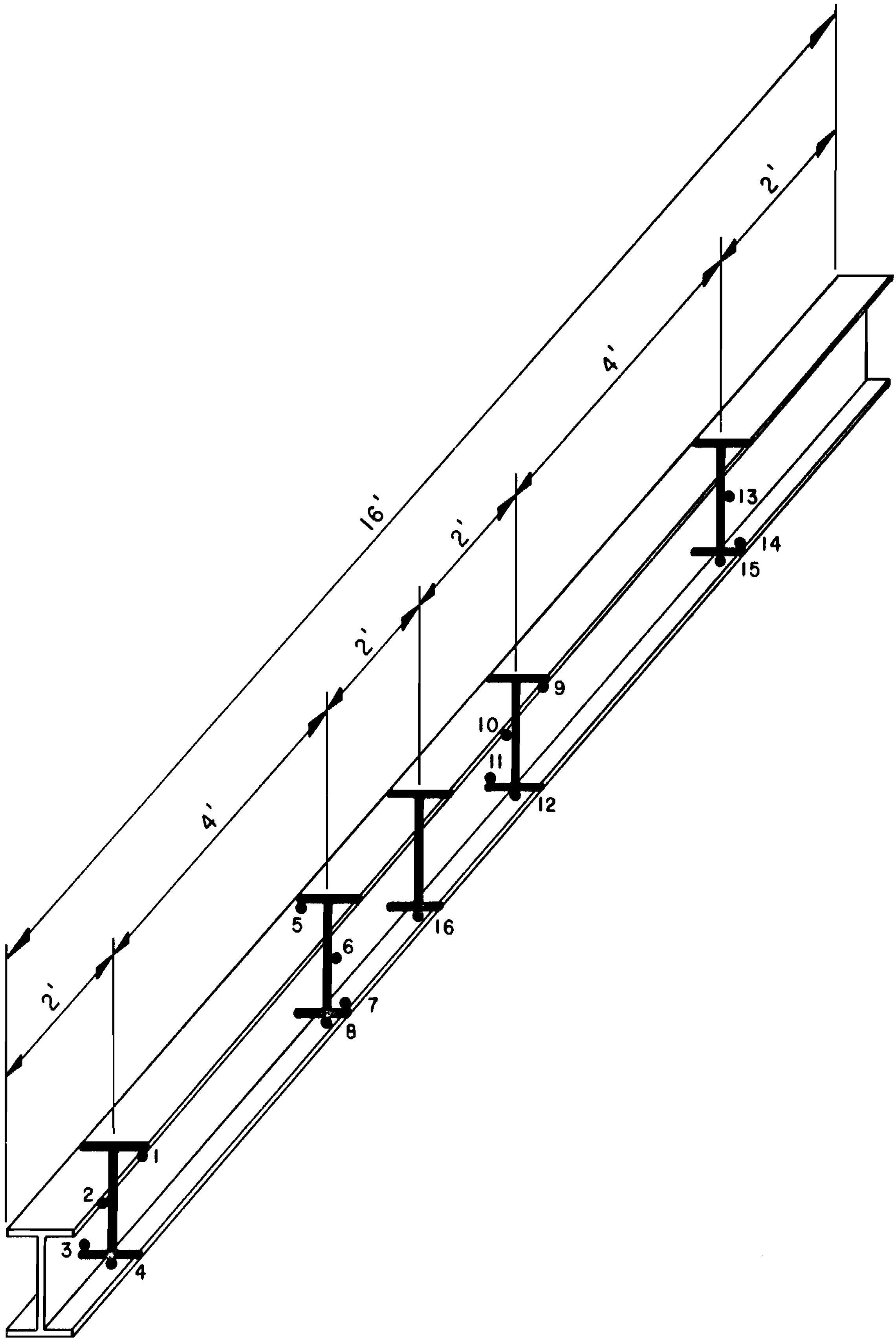

FIGURE 4 THERMOCOUPLE LOCATIONS

BR 4010-2

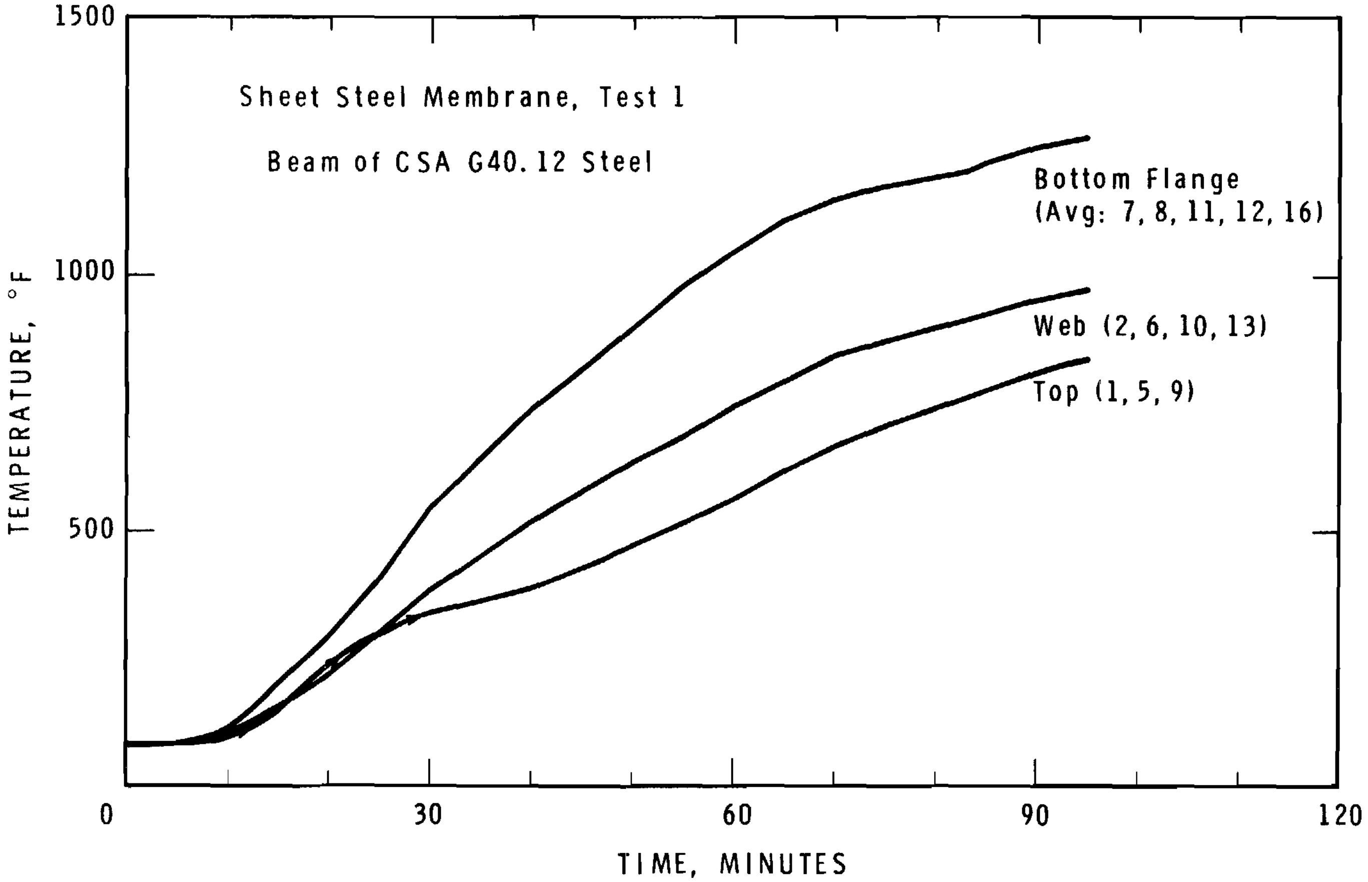

FIGURE 5 BEAM TEMPERATURES

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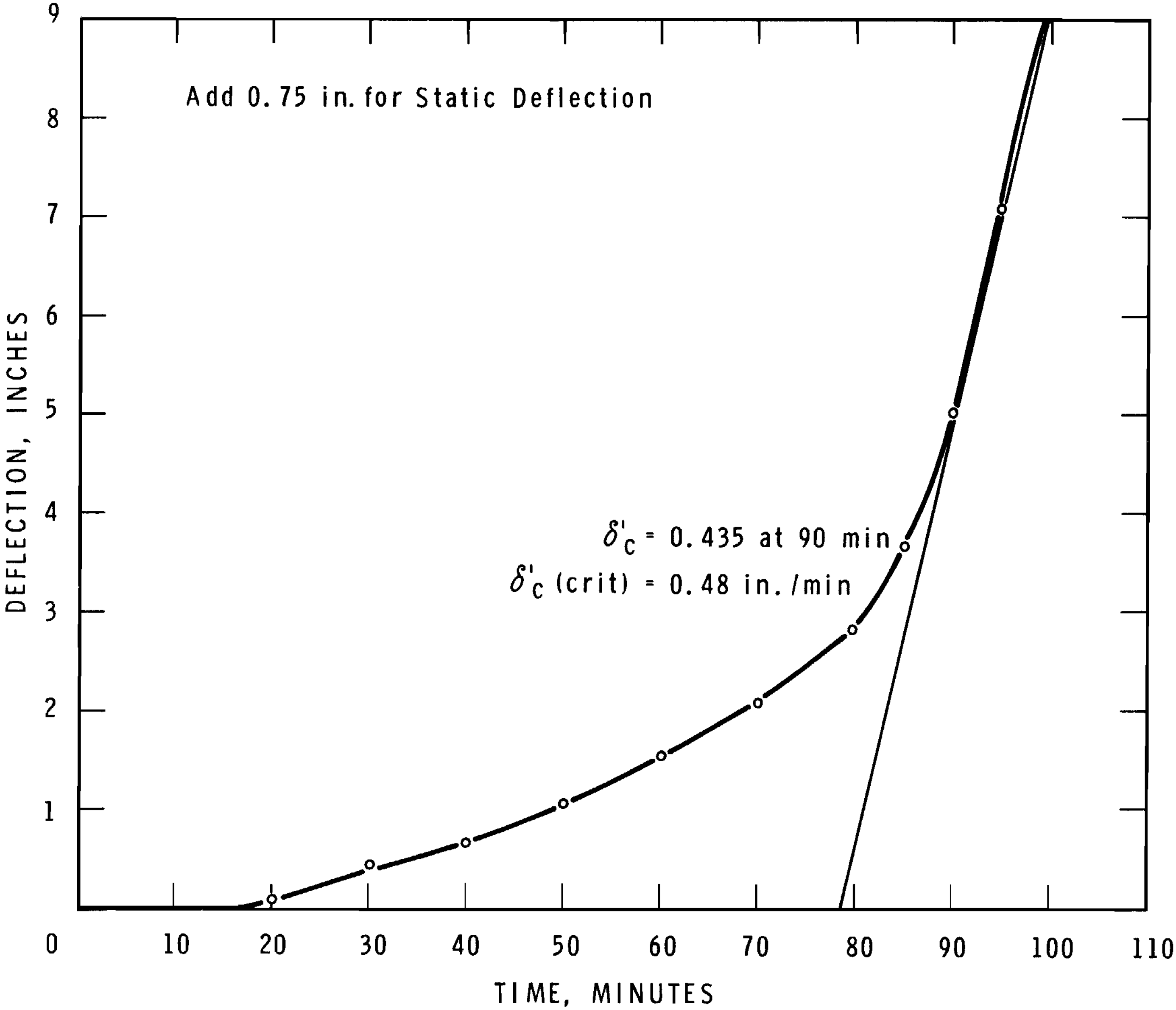

FIGURE 6

DEFLECTION AND RATE OF DEFLECTION

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