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NATIONAL BUREAU OF STANDARDS REPORT

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REPORT OF FIRE TEST OF

CELLULAR STEEL DECK AND BEAM

by

J. V. Ryan

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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for
Department of the Air Force
(AFCIE-ES)

IMPORTANT NOTICE

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

REPORT OF FIRE TEST OF

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ABSTRACT

A fire endurance test was conducted with a floor specimen consisting of cellular steel deck units supported by a steel beam. The beam was encased in metal lath and gypsum-vermiculite plaster. The cellular units had concrete fill above and vermiculite acoustical plastic below. The results indicated a fire resistance of 2 hr 43 min for the particular specimen tested.

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1. Introduction

The use of floors of concrete on cellular steel units has increased in recent years. The cells of the units have been employed or proposed as raceways for electrical wiring and telephone lines. Such use would permit the direct application of ceiling finish or acoustical material without leaving exposed raceways and would lead to reductions of the overall heights of multistory buildings without reduction of the headroom in each story. Because such construction is of interest to the government and the public, a fire test was made to determine the fire resistance of an assembly composed of cellular steel units having concrete fill on top, and vermiculite acoustical plastic applied directly to the under surface of the cellular units. The specimen included a steel beam protected by vermiculite-gypsum plaster on expanded metal lath.

2. Specimen

A steel beam 8 in. deep, 6½ in. across the flange (8WF24 section) and 13 ft 2 in. long was secured to 1 in. thick steel plates at each end by standard steel angle connectors bolted to the web of the beam and to the plates. The plates were bolted to the steel H-section frame of the floor-test furnace with a gap between each plate and the frame. The two gaps totalled 5/8 in. and were intended to allow for some expansion of the beam and some tilting of the plates as the beam deflected downward, thereby permitting consideration of the beam as only partially restrained at the ends. This was intended to be representative of the conditions existing in buildings having such beams. The plates and beam were so located that the latter spanned the short dimension of the 18 ft by 13 ft 6 in. furnace opening and the centerline of the beam was 9 ft 10 in. from one end and 8 ft 2 in. from the other.

Cellular steel deck units 2 ft wide and 3 1/8 in. deep were placed to span from the beam to steel bearing angles bolted to the furnace frame at each end. The units were of two lengths; 9 ft 9 1/8 in. and 8 ft 1 1/8 in. They were welded to the tops of the beam and of the bearing angles at 12 in. oc. Each unit was made of two sheets of metal formed and spot welded together to form nearly rectangular cells 3 1/8 in. high, of 3 3/4 in. average width, with space between cells an average of 2 1/4 in. The upper sheet was of 18 ga steel and the lower of 16 ga steel. The upper sheet was bent along each edge of each unit to form an interlocking joint between units. After all the units were in place and welded, the joints were pinched together at 2 ft oc.

Holes were punched through between the cells and 0.194 in. diameter wires hung through at 12 in. oc along each side of the beam. The wires were about 1/4 in. from the beam at the top. Each was bent to pass under the beam. Pairs of wires, one from each side of the beam, were laid together about 5 1/2 in. directly below the beam and wire-tied. Each of these heavy wires had a loop of about 1 in. diameter at the top, which loop rested on the cellular unit.

Transit-mixed concrete, proportioned 1 part cement, 3 parts Potomac River sand, and 5 parts Potomac River gravel (both siliceous aggregates), was poured on the deck and screeded to a depth of 2 1/2 in. above the tops of the deck unit cells. The upper surface of the concrete was 1 in. above the top of the furnace restraining frame.

Flat, diamond mesh expanded metal lath, nominally 3.4 lb/yd^2, was bent into U- or channel-shaped pieces to fit around the bottom and sides of the beam. The lath was tied to each wire hanger with single strands of 18 ga lathers tie wire at top, center, and bottom of each side and at the center of the beam soffit.

Gypsum-vermiculite plaster was mixed in the proportions of 1 bag (nominal net contents 99.25 lb) unfibered gypsum cement plaster, 2 1/2 ft^3 vermiculite plaster aggregate, 4 oz accelerator. The water averaged 12.2 gal (102 3/4 lb) per batch. The plaster was mixed in a machine built for the purpose. Plaster was trowelled on in strips about 4 in. wide across the soffit and up each side, at the center and about 1 ft from each end of the beam, to form grounds. These strips were carefully checked for level, or vertical, and for minimum depth of 1 1/2 in. from the face of the lath. This plaster was allowed to start to set and then the remainder of the lath was covered by spraying the plaster on with the use of an "Easy-On" machine. The sprayed plaster was rodded and the drop-outs filled by trowelling.

The average density of the 10 ft^3 of vermiculite aggregate used was 7.6 lb/ft^3; of three samples of the freshly mixed plaster 72 lb/ft^3; and of two samples of the plaster as discharged from the spraying nozzle 77 lb/ft^3.

About two to three hours after the plaster application to the beam had been completed, application of vermiculite acoustical plastic to the under side of the cellular deck was started. The deck units had been clean when received. After the application of plaster to the beam, all spatterings were wiped from the deck units before the plastic was applied. The plastic came as a dry, loose material in paper bags and required only mixing with water. Its composition was not determined nor did the manufacturer make any identification of the components. The dry material and water were mixed in the same mixer and sprayed on from the same machine used for the plaster on the beam. For the initial application, the proportions as mixed were one bag (average 23.1 lb) of dry material to 9 1/4 gal (77 lb) of water; the average wet density of the freshly mixed material was 45 lb/ft^3, and of the material after having been sprayed 54 lb/ft^3. This application filled the spaces between the cells of the deck units. The plastic was rodded off flush with the bottoms of the cells.

One week was allowed to elapse during which time the acoustical plastic shrank to produce cracks from 1/8 to 5/16 in. wide along one or both sides of each cell and from 1/4 to 3/8 in. wide across several of the filled spaces. This shrinkage of the plastic caused the surface to recede by as much as 5/8 in. from its original level. Probing with fine wire indicated that the cracks extended the full 1 1/2 in. depth of the between-cells spaces.

For the second application, the proportions as mixed were one bag (average 23.3 lb) of dry material to 10 gal (83 lb) of water, the average wet density of the freshly mixed material was 48 lb/ft^3, and of the material after having been sprayed 53 lb/ft^3. No grounds were used as a guide to thickness, but frequent checks were made with a depth gage as the spraying and rodding progressed. The application was completed to a uniform thickness of 1/2 in. from the bottoms of the cells.

Approximately two weeks after the second application, the surface of the acoustical plastic showed numerous cracks, some of which were filled. Also, the thickness of material, as indicated by probing, varied from 1/4 to 3/4 in. below the cells. Additional material was applied to an area of several square feet near the beam to increase the thickness to 1/2 in. Measurements at twelve points, made the day before test, which was 29 days after the patching of cracks and addition of material, indicated that the thickness ranged from 3/8- to 9/16-in. below the cells, with the average essentially 1/2 in.

3. Test Method

The specimen was subjected to fire test in general compliance with the methods defined in the Standard Methods for Fire Tests of Building Construction and Materials, ASTM E-119. One exception to this involved the placement of thermocouples to indicate furnace temperatures. This exception, and its significance, will be discussed in later portions of this report.

3.1 Furnace

The furnace was in the shape of a large, fire-brick lined box with the specimen filling the otherwise open top. The furnace was equipped with steel frame to support and restrain the specimen, gas-air burners, thermocouples, loading apparatus, means for measuring deflections, and windows through which the exposed surface could be observed during the test.

3.2 Aging

The specimen was allowed to age 30 days from the day the last material had been applied. The period of aging was determined by periodic weighing of a representative sample of the construction. Aging was continued until the sample's weight was essentially constant for five consecutive days.

3.3 Loading

The dead load or weight of the specimen was 45.5 lb/ft^2 of floor area, as computed from the weights of samples of the materials. The applied or live load computed to produce a deflection of 1/360 of the span of the cellular units was 108 lb/ft^2. The design load for the 8WF24 steel beam, on 13 ft 2 in. span, was 20.8 kips. The total floor load provided 16.6 kips. Therefore, weights in the amount of 285 lb/lin ft were placed on the floor above the beam to bring the beam load up.

3.4 Temperatures

Temperatures were measured by means of chromel-alumel thermocouples connected to self-balancing potentiometers calibrated to read directly in degrees C. Thermocouples were placed in the furnace chamber, on the steel beam, the cellular steel deck, and the unexposed surface. The thermocouples in the furnace chamber were in porcelain insulators and encased in wrought iron pipes; the others were in glass fiber sleeving. The thermocouple locations are indicated in figure 1. The furnace fires were controlled to produce temperatures as near as feasible to those of the Standard Time-Temperature Curve defined in ASTM E-119, which include: 1000°F at 5 min, 1300°F at 10 min, 1550°F at 30 min, 1700°F at 1 hr, 1850°F at 2 hr, 2000°F at 4 hr, and 2300°F at 8 hr.

Because the thickness of the deck units was small compared to the depths of joists usually employed in floors, the bottom surface of the specimen was several inches farther than usual from the floor of the furnace chamber. Eight of the twelve furnace thermocouple pipes were placed through fixed openings in the furnace walls. The highest of these openings were so located that the eight thermocouple junctions were about 16- to 17-in. below the specimen, rather than the 12 in. specified in the method. The other four junctions were 12 in. below the specimen. It was felt that this misplacement of thermocouples would have no significant effect because the large volume of gas-and-air delivered at high velocity from the 18 burners produced high turbulence. The resultant mixing was believed to be such that the average of the temperatures at the actual thermocouple locations would be the same as, or not significantly different from, that at the specified locations.

Measurements of temperatures at both sets of thermocouple locations were made in a subsequent test to provide an indication of the validity of this assumption. The findings of those measurements will be discussed in later sections of this report, with the results of this test.

3.5 End-Point Criteria

The Standard Test Method required that: 1) the specimen continued to sustain the applied load, 2) flames, or gases hot enough to ignite cotton waste, not have passed through the specimen, 3) transmission of heat shall not have been such that the average temperature of the unexposed surface increased 250 degrees F nor the temperature at any one point have increased 325 degrees F above their initial values. The fire endurance was defined as the time at which the first of these conditions was attained, with a correction to the time for variation, if any, of the furnace temperatures from those defined.

4. Results

The fire test was conducted March 14, 1957. The observations of deflections, physical behavior, and temperatures are reported together although each was made independently of the others. All times are from the start of the fire exposure. At 7 min, a crack in the unexposed concrete surface extended completely across the specimen. It was located above the steel beam. At 20 min a horizontal crack 3 to 4 ft long was observed near the East end and about 2 in. from the bottom of the North face of the beam protection. By 28 min this crack extended the full length of the beam and there was a vertical crack 2 to 4 ft from each end of the beam. By 1 hr 12 min similar cracks had developed in the South face of the beam protection. The deflection at the center of the beam was 0.2 in., the maximum beam temperature was 250°F, and the maximum temperature on the unexposed surface was 140 degrees F above the initial value. By 1 hr 51 min additional cracks had developed, including two across the beam soffit. At 2 hr 17 min some cracks were 1/4 in. wide and a small section of plaster about 10 in. long by 2 in. wide fell from the beam soffit. The deflection at the center of the beam was 0.8 in., the maximum beam temperature was 826°F, and the average temperature on the unexposed surface was 215 degrees F above the initial value. At 2 hr 42 min, the average temperature on the unexposed surface reached the limiting rise of 250 degrees F. The one-point rise of 325 degrees F was reached at 2 hr 45 min, by which time several cracks in the beam protection were 1/2 in. wide and three pieces of plaster had fallen from the edges of the beam protection. The deflection at the center of the beam was 1.2 in. and the maximum beam temperature was 1005°F. At 3 hr 6 min, an average temperature of 1000°F was reached at one group of thermocouples on the steel beam. By 4 hours, several cracks in the beam protection were 1/2 to 1 in. wide and the deflection of the center of the beam was 3.1 in. By 5 hr 12 min, lath and plaster had fallen to expose about 1 1/2 ft length of the bottom flange of the beam. The load was removed and the gas shut off at 5 hr 23 min. The deflection at the center of the beam was 8.7 in., the temperatures at the 24 thermocouples on the beam ranged from 1245°F to 1915°F; and the temperatures on the unexposed surface ranged from 604 to 801 degrees F above their initial values.

After cooling, the acoustical plastic on the bottom surface of the steel deck was shrunken, covered with cracks or fissures up to 1 in. wide, and its surface was dark and glossy. However, none of the plastic had fallen from place. The bottom flange of the beam was exposed along the center half of its length. There were two long cracks in the concrete slab. The steel deck was bowed and most of the welds between the deck and beam were broken. The concrete and steel deck were still in close contact and the joints between cellular units were closed. The beam was bowed to a permanent deformation of 8 5/16 in. at the center.

4.1 Procedures to Determine Effect of Furnace Thermocouple Placement

As previously mentioned in section 3.4 of this report, the eight furnace thermocouple junctions mounted in iron pipes through fixed openings in the furnace walls were located 4 to 5 in. farther from the test specimen than the start-of-test position defined in ASTM E-119. It was felt that the mixing of hot gases in the furnace chamber was such that no significant error would be introduced in the fire exposure to the specimen. However, after the test, persons interested in the results questioned the validity of this assumption. Consequently, procedures designed to provide an indication of the effect, and its magnitude, were carried out during the next test in the floor furnace.

In the later test, furnace thermocouples were mounted in the same positions relative to the specimen as in the test reported herein, that is, four along a central pier were 12 in. below the specimen and eight through the furnace walls at 16 to 17 in. below the specimen, all in iron pipes. No attempt was made to prevent sag of the approximately horizintal pipes through the furnace walls. Eight additional thermocouples, in iron pipes, were placed through extra holes drilled in the furnace walls so that the thermocouple junctions were 12 in. below the specimen. The iron pipes for the latter thermocouples were supported by nichrome wire in an attempt to prevent, or minimize, sag as these pipes were heated, although this is not required directly or by implication in the Standard Test Method E-119.

The furnace fires were controlled to provide the temperatures of the standard time-temperature curve as indicated by the average of the 12 thermocouples located

12 in. from the specimen at the start of the test. After 6 hours fire exposure, the combined effects of the sag of the specimen plus the limited sag of the eight supported thermocouple pipes through the furnace walls resulted in the thermocouple junctions within the latter being from 12 to 14 in. from the specimen surface. The eight unsupported pipes were deformed so that the thermocouple junctions were from 20 to 34 1/2 in. from the specimen surface.

To permit evaluation of the effect of thermocouple placement, the temperatures observed were averaged in two groups: A, those originally 12 in. below the specimen including eight through the walls and four from the central pier; B, the eight, through the furnace walls, originally 16 to 17 in. below the specimen plus the four from the central pier.

The average temperature of Group A was consistently, but only slightly, lower than that of Group B. The difference varied from about 1 degree F to 16 degrees F. The maximum difference was observed at 15 min, and the difference decreased steadily thereafter. The individual differences were summed over the time corresponding to the duration, of the test reported herein, for which the correction was computed. This sum was applied to the furnace temperature data put into the formula. The resulting correction obtained from the formula differed by only 0.8 min from that obtained using the original data. This difference, which would have decreased the original correction, was not considered significant.

4.2 Fire Endurance Limit

The fire endurance of the specimen was limited by temperature rise on the unexposed surface at 2 hr 42 min. The fire exposure severity was 101.1 percent up to this time and 100.4 percent over the entire 5 hr 23 min duration. The correction to the fire endurance limit, as computed by the formula given in ASTM E-119 and based on the data from the test reported herein, was plus 1 min. Therefore, the corrected fire endurance of the specimen tested was 2 hr 43 min.

5. Summary

The results of this test indicated a fire endurance of 2 hr 43 min for the particular specimen tested, as determined by temperature rise on the unexposed surface. The beam continued to support the applied load for over 5 hours although the steel reached temperatures at just over 3 hours that would have constituted failure of a beam tested without load.

The determination of the effect of furnace thermocouple location, actually carried out during a subsequent test but applied to the results of the test reported herein, indicated that this effect was small enough that no correction was made.

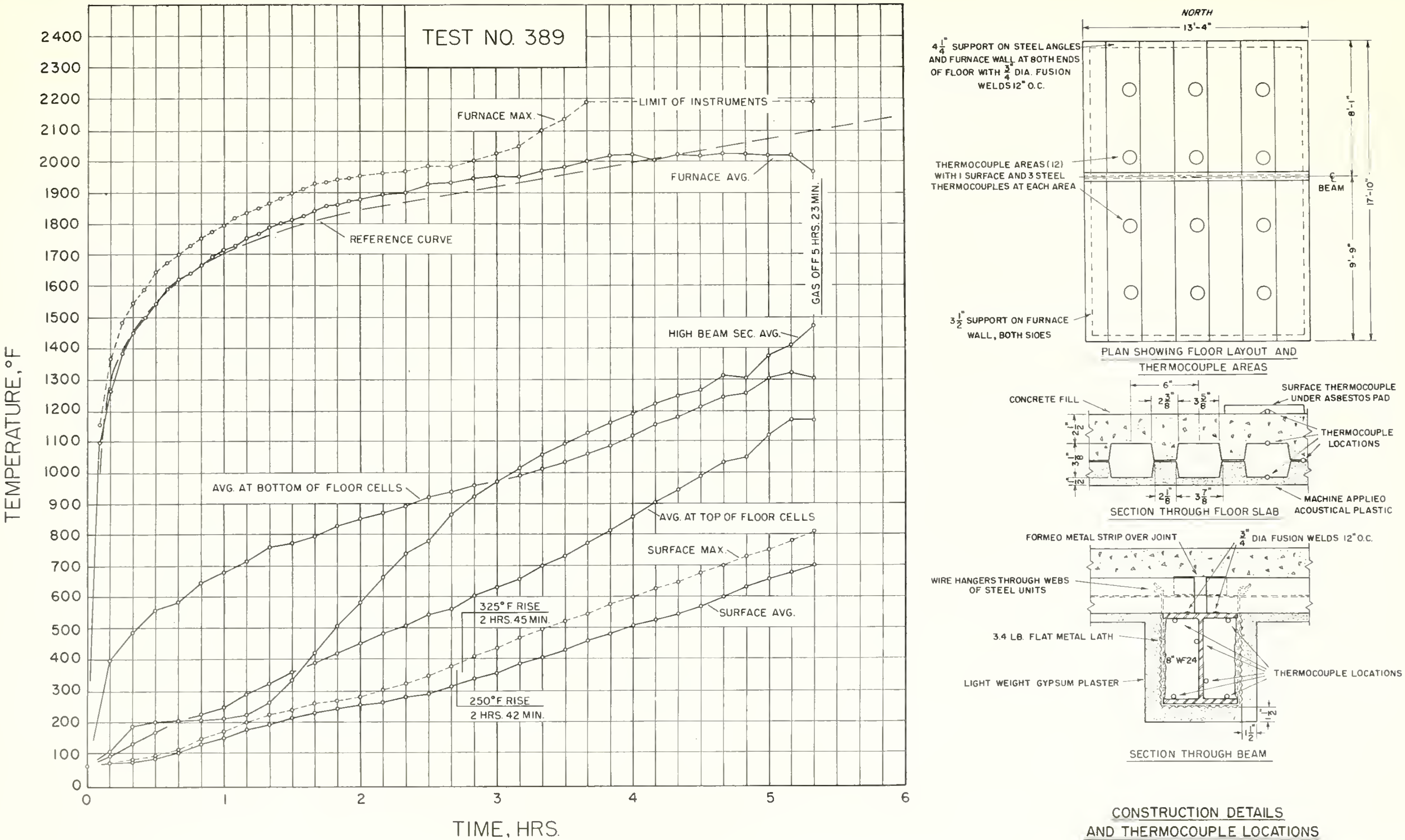

FIG. 1. CONSTRUCTION DETAILS, THERMOCOUPLE LOCATIONS, AND TIME-TEMPERATURE CURVES.

Fig. 2. Shrinkage cracks one week after initial application of acoustical plastic to fill between-cell spaces.

Fig. 3. Condition of exposed surface after fire exposure and cooling.

Fig. 4. Condition of unexposed surface after cooling and removal of loading apparatus.

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