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by

J. V. Ryan

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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for
Department of the Air Force
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FIRE TEST OF STEEL DECK FLOOR SYSTEM AND BEAM

ABSTRACT

A fire endurance test was conducted with a floor specimen consisting of cellular and fluted steel deck units supported by a steel beam. The beam was encased in metal lath and gypsum-vermiculite plaster. The deck units had concrete fill above and vermiculite acoustical plastic below. The results indicated a fire resistance of 3 hr 41 min for the particular specimen tested.

1. Introduction

Formed steel deck units, with concrete fill above, have found increased use in buildings. The units act as structural support during construction and as form upon which to cast a concrete slab, or fill, without the need for the inclusion of reinforcement such as bars or wire mesh in the slab. Some of the units are corrugated, or fluted, in a cross-section nearly rectangular rather than curved, and others are cellular, formed by facing one side of a fluted unit with a flat plate or with another fluted unit. The cellular units are suggested to provide enclosed raceways for utility services such as electricity and telephone. This utilization permits the direct application of suitable finish materials directly to the under surface of the floor system without exposed utility service conduits and raceways. This produces a thin floor-ceiling system, leading to reduction of building height without reduction of head room.

Because such construction is of interest to the public and the government, a specimen of this type was subjected to fire test, the second of a series of related tests. The specimen consisted of a combination of cellular and fluted units, with concrete fill above and vermiculite acoustical plastic on the bottom surface of the units. The specimen included a steel beam encased in gypsum-vermiculite plaster on metal lath.

2. Materials and Specimen

A steel beam, 10 in. deep (10WF21) and 17 ft 9 in. long was secured to $1\frac{1}{4}$ in. thick steel plates by conventional angle connectors. The plates were bolted to the furnace frame, a 14 in. steel H-section, so that the centerline of the 10WF21 beam lay along the centerline of the 18 ft by 13 ft 6 in. furnace opening. A gap was left between each plate and the furnace frame to permit thermal expansion of the beam and some tilting of the plates as the beam deflected. The two gaps totalled 3/4 in. This arrangement permitted 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.

Formed steel deck units of two types were used. The units of the first type were fluted. The flutes were spaced 6 in. on centers, were $1\frac{1}{2}$ in. deep, 2 3/8 in. wide at the top and 2 1/8 in. wide at the bottom. Both edges of each unit were formed in such a manner that an interlocking joint between adjoining units was provided. Each unit was 2 ft wide by 6 ft 9 in. long, and was made of 14 gage steel. The units of the second type were cellular, consisting of two sheets of steel. The upper sheet was of 18 gage steel formed to the same shape as the fluted unit just described except that the edges were not formed for the interlocking joint. The lower sheet was 16 gage steel and, except for the formed edges, was flat. The two sheets were spot welded together to make a unit 2 ft wide and 6 ft 8 in. long.

The steel deck units were placed to span from the steel beam to the bearing angles bolted to the inside of the furnace frame along the two long sides of the furnace opening. The arrangement was symmetrical with both the transverse and longitudinal centerlines of the furnace opening. Starting at one end, the order of units was: one fluted, one cellular, two fluted, one cellular (centered on transverse centerline of furnace opening), two fluted, one cellular, and one fluted. The ends of the cellular units butted together over the beam; those of the fluted units were crimped slightly and overlapped approximately 2 in. The cellular units were welded to the beam and bearing angles at 12 in. on centers. The fluted units that were on the bottom of the overlap joint were welded to the beam at 12 in. on centers before the overlapping units were placed. The overlapping units were welded to the beam on 12 in. centers but staggered 6 in. (one flute) from the welds of the lower units. After the units had been welded, the interlocking joints were pinched together at 2 ft on centers.

Holes were punched through the units and 9 gage wire hangers dropped through. The hangers were 6 in. from each end of the beam and then 18 in. on centers. They were about $\frac{1}{4}$ to $\frac{1}{2}$ in. out from each edge of the top flange of the beam. They were bent to turn under, and in contact with the bottom flange of the beam. Pairs of wires, one from each side of the beam, were laid together for about $4\frac{1}{2}$ in. directly below the beam and wire tied.

Transit-mixed concrete, proportioned 1 part cement, 2 parts Potomac River sand, and 4 parts Potomac River gravel (both aggregates of a siliceous composition) was poured on the steel deck and screeded to a depth of $2\frac{1}{2}$ in. above the tops of the fluted and cellular units. No reinforcing bars or mesh were included in this concrete fill. The concrete supplier stated that the gravel had passed through 3/4 in. sieve.

Sheets of flat diamond mesh 3.4 lb/yd^2 expanded metal lath were bent to form long channel-shaped pieces of such size that they boxed the beam and fit against the wire hangers. The lath was tied to the hangers by 18 gage lathers' tie wire. Corner beads, consisting of a formed sheet metal nose and woven wire legs, were tied to the metal lath along the two bottom edges of the beam protection. The corner beads were positioned to provide grounds for not less than $1\frac{1}{2}$ in. of plaster, as measured from the face of the metal lath, on the soffit and up both sides of the beam.

Gypsum-vermiculite plaster was applied to the metal lath in two coats. The first or scratch coat was prepared in two batches; the first proportioned $1\frac{1}{4}$ bag (nominal

99.25 lb/bag) unfibered gypsum cement to $2\frac{1}{4}$ ft^3 of vermiculite plaster aggregate; the second $\frac{1}{2}$ bag to 1 ft^3. The second, or brown coat, was proportioned 1 bag of unfibered gypsum cement to 3 ft^3 of vermiculite plaster aggregate for each of three batches. Each batch included 4 oz of accelerator. The water averaged 10.2 gal (85 lb) per bag of cement for the scratch coat and 13.4 gal (111 lb) per bag for the brown coat. Each batch of plaster was mixed in a commercial plaster mixing machine. The scratch coat was applied by trowel to fill the corner beads and to provide about half the total thickness. Strips of plaster were built up to full thickness at the center and about 1 ft from each end. The surfaces of those on the sides were checked for plumb. After about $4\frac{1}{2}$ hours had passed, the brown coat was applied by spraying from a commercially available machine designed for this use. The surface was screeded.

The average density of the vermiculite aggregate used was 7.4 lb/ft^3; of the freshly mixed plaster was 77 lb/ft^3 for two samples of the scratch coat and 67 lb/ft^3 for three samples of the brown coat. The average density of the brown coat plaster as discharged from the spray nozzle was 78 lb/ft^3.

Vermiculite acoustical plastic was applied to the underside of the steel deck. The plastic was prepared by mixing a dry loose material with water. The dry material was a proprietary product. Its composition was not identified, either by analysis or by manufacturer's statement. The first two base applications were made with the "regular" material; the last two with material that contained white pigment. It came in bags which contained an average of 22.4 lb each for the base coats and 24.7 lb for the white pigmented coats. The contents of each bag were mixed with 10.5 gal (88 lb) of water for the initial application, 9.8 gal (82 lb) for the second, and 10.7 gal (89 lb) for the third. The plastic was prepared and applied utilizing the same mixer and spray machine as for the plaster

The deck units had been clean when received. After the application of plaster to the beam, all spatterings were wiped from the units before the plastic was applied. The first application was started the day after the plastering of the beam had been completed; the second

6 days after the first; the third 8 days after the second; and the final 24 days after the third. No grounds were used as a guide to thickness but frequent checks were made with depth gage or wire probes. The average wet densities of the freshly mixed plastic and of the plastic as delivered from the spray nozzle, respectively, were 49 lb/ft^3 and 58 lb/ft^3 for the first application; 47 lb/ft^3 and 56 lb/ft^3 for the second; and 50 lb/ft^3 and 58 lb/ft^3 for the third.

Shrinkage of the acoustical plastic, as each application dried, produced numerous cracks over the surface. In most instances the subsequent applications covered the existing cracks satisfactorily. Between the third and final applications, cracks in and parallel to the flutes were patched by trowelling considerable added material into the flutes. This was followed by application of the final thin texture coat. The combination of spraying and trowelling resulted in a surface with flutes of curved or V-shape rather than nearly rectangular cross-section.

The day before and the day of the fire test, a series of measurements were made of the thickness of acoustical plastic by probing with fine wires. Measurements were made of the thickness beneath the flat plates of the cellular units and beneath the flutes and between the flutes of the other units. The maximum, minimum, and average under the cellular units were 1 11/16 in., 1 1/16 in., and about 1 7/16 in. respectively; under the flutes 1 3/4 in., 1 in., and about 1 3/8 in. respectively; and between the flutes 2 9/16 in., 1 1/16 in., and about 1 5/8 in., respectively. The overall average of these measurements was about 1 7/16 in. (1.46 in. actually).

3. Test Method

The specimen was subjected to fire endurance test in general compliance with the methods defined in the Standard Methods for Fire Tests of Building Construction and Materials, ASTM E-119.

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 21 days from the day of the last patching of cracks and application of texture coat. The period of aging was determined by weighing a representative sample of the construction until the weight was essentially constant for four consecutive days and gained slightly on the fifth day.

3.3 Loading

The dead load, or weight, of the specimen was 44.4 lb/ft^2 of floor area. The live or applied load computed to produce a deflection of 1/360 span of the weaker floor unit was 87.5 lb/ft^2. The design load for the 10WF21 beam on 17 ft 9 in. span was 16.2 kips. The combined dead and live loads on the floor were such that the portion carried by the beam was 14.6 kips. Therefore, about 1.6 kips extra load on the beam was provided by weights on the floor directly above the beam.

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 beam, the steel deck units, and the unexposed surface. Those in the furnace chamber were in porcelain insulators and encased in wrought iron pipes. The pipes were placed so that the thermocouple junctions were 12 in. below the specimen. The other thermocouples were in glass fiber sleeving. Their 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,
2000°F at 4 hr and 2300°F at 8 hr.

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 May 28, 1957. The observations of physical behavior, temperatures, and deflections are reported together although each was made independently. At 12 min there was a vertical crack at the center of the West face of the beam protection. At 36 min there was a similar crack in the East face. At 47 min there was a small piece of plaster protruding from the East edge of the beam soffit at center span. Around 1 hr 22 min to 1 hr 25 min several mild thumps were heard — probably the muffled sounds of breaking of welds between beam and deck units. At 2 hr 1 min a few more thumps were heard. There were no cracks in the concrete and only three fine cracks in the plaster around the beam. There were a few small black spots in the acoustical plastic. The net deflection at the center of the beam was 0.6 in., the maximum beam temperature was 524°F, and the maximum temperature on the unexposed surface was 175 degrees F above the initial value. By 3 hr, the two vertical cracks in the beam protection were about 1/8 in. wide but there were no other noticeable changes in the appearance of the specimen. The net deflection at the center of the beam was 1.6 in., the maximum beam temperature 815°F, and the maximum rise on the unexposed surface 220 degrees F. At 3 hr 41 min the limiting average temperature rise of 250 degrees F was reached on the unexposed surface. The maximum rise of 325 degrees F at one point was reached at 4 hrs. By 4 hr 35 min, the vertical crack in the center of the East face of the beam plaster was about 1/4 in. wide, that on the West about 1/8 in. wide. The net deflection at the center of the beam was 3.0 in. and the maximum temperature on the beam was 1024°F. By the end of the test at 6 hr 4 min, the deflection of the beam had exceeded 5.6 in., the cracks in the beam cover were 1/4 to 1/2 in. wide, and there were very fine cracks across the corners of the concrete fill.

After the test, and cooling, the only significant cracks in the beam cover were those across the soffit and up each side at the center of the beam. The plaster was a light brown color, somewhat darker than before the fire exposure. Measurements were made of the thickness of the fire exposed plaster, from the face of the metal lath. The soffit varied from 1 3/8 to 1 7/8 in. and averaged 1 1/2 in.; the West side varied from 1 9/16 to 2 in. and averaged 1 3/4 in.; the East side varied from 1 1/2 to 2 5/16 in. and averaged 1 13/16 in. One section of the East side was 1 5/8 in. thick at the bottom and 2 5/16 in. about 2 in. from the top. The beam had a permanent deflection of 5 in. at its center. The acoustical plastic was covered with craze cracks and fissures, some 1/2 to 1 in. wide and deep. The original surface was a slightly darker brown than the beam. However, the base application material that showed in the cracks and fissures was a very dark brown and fairly shiny.

The concrete fill had hairline cracks across the four corners plus two 1/16 in. wide East-to-West cracks, one about 5 ft from the North end and the other the same distance from the South end. The former was about 10 ft long, the latter about 3 ft long. The concrete was still in close contact with the steel deck units and the joints between units were closed.

The fire endurance of the specimen was limited by 250 degree F temperature rise on the unexposed surface at 3 hr 41 min. The furnace fire control was such that no correction was applicable to the failure time. The fire exposure severity, as determined by the ratio of the area under the curve of average furnace temperatures to the area under the Standard Time-Temperature Curve, was 100.4 percent. The beam continued to support the applied load for 6 hours although temperatures were reached at about 5 hrs which would have been considered indicative of failure in a test of a steel beam without applied load.

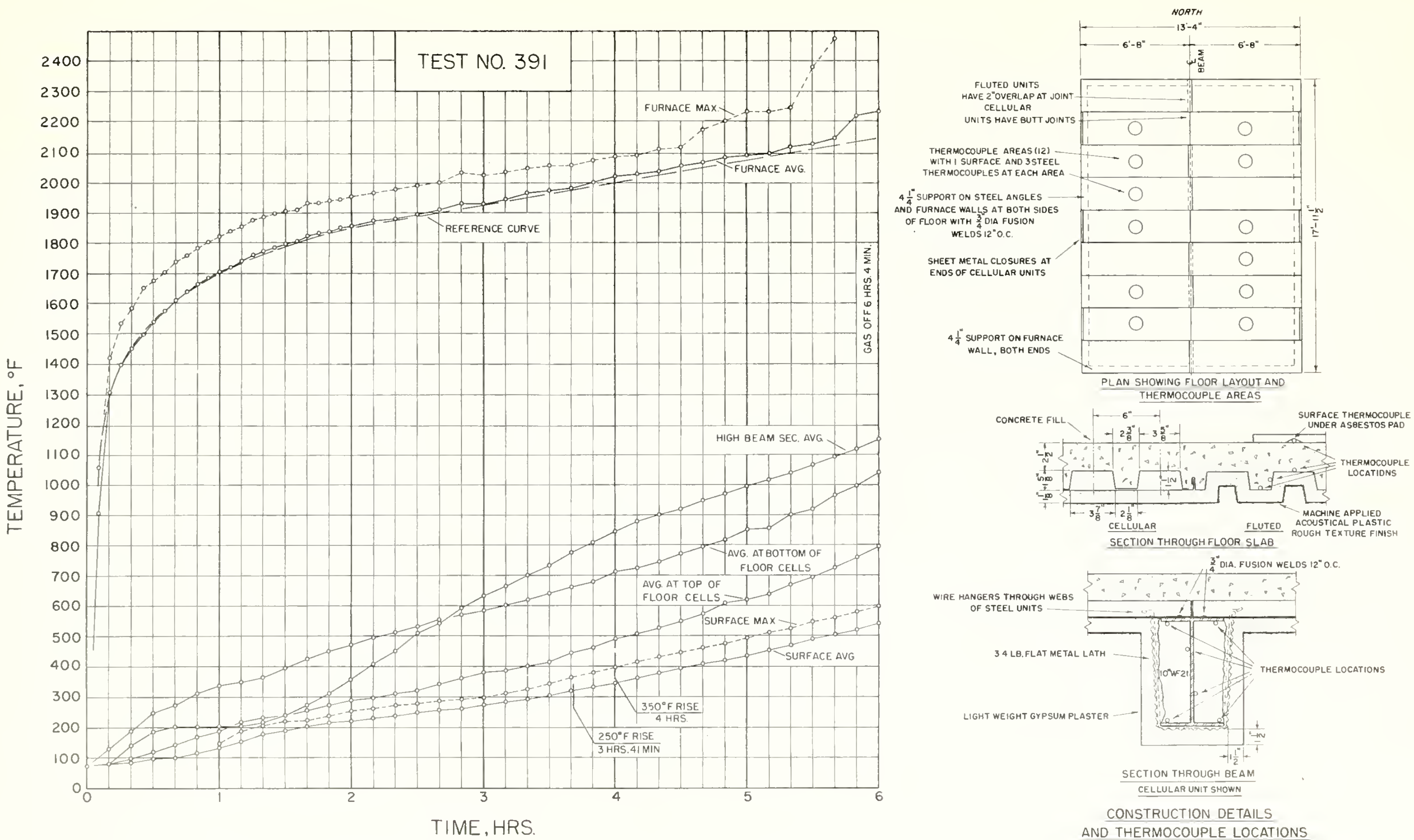

FIG. 1. CONSTRUCTION DETAILS, THERMOCOUPLE LOCATIONS, AND TIME-TEMPERATURE CURVES.

Figure 2. Undersurface of deck units; and beam encased in metal lath with corner beads in place.

Figure 3. Undersurface of specimen just before fire exposure.

Figure 4. Undersurface of specimen the day after fire exposure.

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