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Fire Tests of

Concrete Channel Slab Roof Deck Constructions

by

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Office of the Chief of Engineers

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ABSTRACT

Two similar channel slab roof decks, with supporting beams, insulation, and built-up roofing, were subjected to fire endurance tests. They differed only in the type of insulation used. The results indicated fire resistances of about 50 min.

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1. INTRODUCTION

At the request of the Office of the Chief of Engineers, Department of the Army, fire endurance tests were performed on two roof deck assemblies for warehouse constructions. Each test specimen consisted of a large concrete beam, concrete channel slab deck, insulation, 5-ply roofing, and expanded slag surfacing. The fire test numbers and dates were: Test 327, May 27, 1953, and Test 328, June 11, 1953.

2. TEST SPECIMENS

The two test specimens were alike in all details except the type of insulation. Each consisted of a reinforced concrete beam, 9 in. wide, by 16 in. deep, reinforced concrete channel slabs having 3½ in. flanges and 1 in. web thickness, 2 in. of insulation, 5 plys of roll asphalt felt roofing, and expanded slag surfacing. All the concrete elements of the assemblies were precast and were placed together in the test furnace only a few days before the test.

2.1 Materials

(a) Beam. The beams for the tests were cast by experienced personnel of the National Bureau of Standards. Each beam was 9 in. wide, 16 in. deep, and 17 ft 10 in. long. With two exceptions the design and construction of the beam followed closely the proposed construction as detailed on Sheet 16 Drawing Number 33-32-56 of "Beam Schedules and Details of Special Area Warehouse Floor on Grade 100' x 200'". One modification involved use of additional reinforcement at the mid-depth of the beam, and the other was necessitated by the limited size of the furnace and involved modification of the method of end support of the beam. For this purpose the bottom

of the 16 in. depth was notched 6 in. high and 5 in. short at each end. The reinforcing in each beam consisted of two 3/4 in. deformed rods 1½ in. clear from the bottom, one 1½ in. clear from each side; two No. 6 deformed rods similarly located in the top corners of the beam; a single No. 7 deformed rod in the center, 1½ in. clear below the top; and two No. 4 deformed rods at the mid-depth, one 1½ in. clear from each side. The latter pair of rods was not required in the design as submitted but was added to provide additional insurance that the beam would remain in useful condition throughout the test period. The reinforcing rods were assembled with two stirrups of 3/8 in. rods at each end. Chromel-alumel thermocouples were peened into holes drilled in the rods to provide for measurement of the steel temperatures during the tests. The assembly of reinforcing rods was placed on chairs in the form and the concrete poured and thoroughly vibrated. The concrete mix was approximately 1:2.2:3.8 by weight of portland cement, Potomac River sand, and Potomac River gravel. The coarse aggregate was specified to be of 3/4 in. maximum particle size. A typical petrographic analysis of Potomac River gravel, as given in PMB12h, Fire Tests of Steel Columns Protected with Siliceous Aggregate Concrete, showed mineral content of 21 percent vein quartz, 30 percent quartzite, 23 percent sandstone, 12 percent chert, no mica, and 6 percent others. As the concrete began to set, metal tabs were inserted along the top center line of the beam, to be bent down over the ends of the channel slabs during assembly. The strength of concrete cylinders 110 days after pouring averaged 4760 psi with a minimum of 4050 psi.

(b) Channel Slabs. The reinforced concrete channel slabs were made by a commercial plant regularly engaged in the production of such slabs. They were 23-13/16 in. wide, 1 in. deep across the central web with 3½ in. deep flanges. These flanges were 1-7/8 in. wide at the bottom. In each flange, a 1/2 in. deformed rod was located centrally and 1/2 in. from the bottom. The design had called for these rods to be 3/4 in. clear from the bottom but the manufacturer inadvertently supplied channel slabs with the rods 1/2 in. clear, a standard clearance. Wire mesh reinforcing, No. 10 ga wire, spaced 4 by 4 in. and 4 by 8 in. was centered in the depth of the 1 in. web. At one end of each channel slab, both flanges were dapped or held 1/2 in.

less depth, from the bottom, for lengths of 5 in. The slabs were made in equal numbers of two lengths, 6 ft 3-5/8 in. and 5 ft 1 in. They were steam cured by the manufacturer. Two of the channel slabs from the same group as those in the test specimens were tested for strength under the provisions of Federal Specification SS-S-531. The channel slabs were supported on pipes 5 ft on centers. The load was applied through two I-beams placed transversely to the channel slab, one at each quarter point of the 5 ft span. The two channel slabs failed under applied loads computed to be equivalent to uniformly distributed applied loads of 190 and 202 lb/ft^2, respectively. Including the dead load of the slabs, 18.2 lb/ft^2, the ultimate loads are 208 and 220 lb/ft^2, respectively. The tests were made the same day as the cylinder tests but the exact age of the slabs was not known. The manufacturer reported ultimate strengths of about 230 to 240 lb/ft^2 of some other samples tested by him.

(c) Insulation. The insulations used in the two assemblies were each 2 in. thick. That in Test 327 was a slab of glass fibers having a phenolic binder and an asphalt paper cover over the ends, one face, and 1-3/4 in. at each end of the other face. It came in 2 by 4 ft pieces and weighed approximately 2 lb per sq ft. It was stiff enough to handle easily and to be cut with a saw. The insulation in Test 328 was opaque frosted or tempered glass which came in blocks 12 by 18 in. There was no evidence of any combustible component. It weighed 1.6 lb/ft^2, was practically rigid, and could be cut by a saw.

(d) Roofing. The roofing above the insulation consisted of hot asphalt, asphalt saturated asbestos felt rolled roofing, and granules of expanded slag. The nominal thicknesses of the roofing were between 3/8 and 1/2 in. The felt came in rolls 36 in. wide and weighed 14.5 lb/100 ft^2 (nominal 15 lb/100 ft^2).

2.2 Assembly

The steel beam for each test was placed with its centerline 6 ft 1 in. from the east side of the restraining frame of the furnace. The channel slabs were placed transversely to the beam with the tapped ends resting thereon and the other ends on the bearing angles along the furnace sides. Over the 6 ft 3-5/8 in. slabs were placed between the beam and the

east bearing while an equal number of the 5 ft 1½ in. slabs were placed on the other side of the beam. Strips of asphalt-asbestos felt, 6 in. wide, were laid over the joints between slabs, hot asphalt was mopped over the entire surface and the insulation laid in the asphalt as the mopping progressed. For Test 327, the glass fiber insulation was placed with the paper side up. The pieces along the ends and edges of the roof deck were cut so that the joints between pieces would be staggered and would not fall above the joints between the channel slabs. Essentially the same result was obtained in Test 326 by the choice of pattern in which the blocks of insulation were laid. The top of the insulation was mopped with hot asphalt and allowed to dry. The five ply roofing was built up by the "shingle" method whereby each 36 in. width overlapped 29 in. of the preceding strip. The hot asphalt mop was run along a portion of the area to be overlapped before each strip of roofing was applied. After all the asphalt-felt roofing was down, hot asphalt was mopped over the whole area and the expanded slag granules distributed over the surface.

3. Test Equipment and Method

The tests were conducted in a furnace designed for tests of floors and roofs. It was in the form of an open-top box, in which top the test specimens were built. The gas fires in the furnace were controlled so that the temperatures agreed as closely as possible with those of the time-temperature curve, defined in the Standard Methods of Fire Tests of Building Construction and Materials, 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, and 1850°F at 2 hrs.

3.1 Temperature Measurements

The temperatures at various locations were measured at 5 min intervals by means of chromel-alumel thermocouples connected to direct reading potentiometers and to recording potentiometers which made a printed record of each temperature measurement every 3 min. Twelve thermocouples, encased in porcelain tubes and iron pipes, were distributed in the furnace. Eight thermocouples were located at each of four levels; on top of the

channel slabs, in the middle of the insulation, on top of the insulation, and on top of the slag surfacing. The latter thermocouples were under felted asbestos pads 6 in. square and 0.4 in. thick, and each group was distributed symmetrically. Thermocouples had been placed on the beam reinforcement when the beam was cast, as described previously.

3.2 Loading

The assembly was designed to support anticipated loads of between 20 and 65 lb/ft^2 in addition to the dead load. Each specimen was tested under an applied load of 45 lb/ft^2. This load was provided by four hydraulic jacks located over the furnace and was distributed to 30 steel channels which bore on the test specimen. The total dead load of the slabs was about 20 lb/ft^2.

3.3 Test Criteria

The test methods followed specify that the fire endurance limit of a floor or roof structure shall be determined by any of the following: 1. passage through the specimen of flame or gases hot enough to ignite cotton waste; 2. failure to sustain the applied load; 3. transmission of heat through the specimen sufficient to raise the average temperature on the unexposed surface 250 degrees or the temperature at one point 325 degrees F above its initial temperature. Each test was continued until one or more of these test criteria had been reached.

4. RESULTS

The results are presented in abbreviated logs of test observations, descriptions of post test condition, and graphs of the various temperatures observed.

4.1 Test 327

The following are the more important observations and measurements made during the test of the roof deck incorporating glass fiber insulation.

(a) Test Log

TIME	OBSERVATION
:06	Spall 5 to 6 in. along lower west edge of beam at center span.
:07	Sound of additional spalling heard.
:11	Two jets of steam through roof.
:16	Bulges in roofing.
:21	Visible sag of long (east) channel slabs.
:34	Steam jets through roof changed to smoke.
:39	Lower reinforcing rods of beam exposed on west from spalling.
:42	Sag of channel slabs on east estimated at 2 to 3 in.
:53	Sag estimated 6 in., load removed.
1:03	Cotton waste over center jet of smoke removed and found ignited.
1:10	First crack in channel slab flange.
1:30	The sag of the long channel slabs has increased to at least 10 in., causing openings under the east ends through which furnace fires are igniting the edge of the roof.
2:05	Gas off. Repeated fires extinguished with water since 1:30.

(b) Condition after Test. Immediately after the gas flow were turned off, the discharge of fog and spray nozzle fire hoses were turned on the fires in the roofing. One channel slab on the east fell, greatly increasing the extent of the roofing fire. By the time all the fires were extinguished, all but one of the long channel slabs had dropped into the furnace from one of its end supports. The short channel slabs on the west remained in place and practically undeflected. The felt strips and asphalt under the insulation, the binder and asphalt paper backing of the insulation were all burned out. In many places the felt roofing was burned. The condition is shown in Figure 1.

(c) Temperatures. Control of the furnace fires throughout the test was such that the fire exposure severity, defined as the ratio in percent of the area under the graph of average furnace temperatures to the area under the standard time-temperature curve, was 98.6 percent. The temperature at one point on the unexposed surface had risen 325 deg. at 1 hr 55 min.

That at one point on the lower reinforcing rods of the beam reached 1200 F at 49 min and the average of the lower rods reached 1000 F at 1 hr 2 min. The temperatures observed during the test are indicated by the curves of Figure 2.

4.2 Test 320

The following are the more important observations and measurements made during the test of the roof deck incorporating foamed or frothed glass insulation.

(a) Test Log

TIME hr:min	OBSERVATION
:10	Steam from edges of roof deck.
:15	Roofing puffed up slightly in several places.
:17	Large spall, 6 in. high by 4 to 5 ft long on lower east edge of beam, in north half, exposing reinforcing rod.
:27	Long channel slabs (on east) sagging slightly.
:30	Spall of lower west edge of beam in south half.
:45	Sag of channels estimated 2 in., much smoke.
:46	Short horizontal crack in center of beam about 4 in. from bottom of east face.
:50	Load removed, channel slab sag 6 in. or more. Extremely smoky.
1:02	Flames into furnace from between channels. Top intact.
1:21	Six cracks in west face of beam, from 1/2 to 1-1/2 ft long; four approximate the line of a catenary, other two near top center. Sag of long channels now 10 to 12 in.
1:30	Slight transverse sag in some of long channel slabs.
1:43	Flanges of long channel slabs cracking.
1:48	Gas off, flames continue below channel joints.

(b) Condition after Test. The long channel slabs remained in place but retained sag of about 1 ft. The beam had three spalls of appreciable size along the lower edges and cracks in each side. Much of the asphalt had run out the edges of the roof. The beam and under sides of the slabs are shown in Figure 3.

(c) Temperatures. The control of the furnace fires throughout the test was such that the fire exposure severity was 86.9 percent of the standard exposure. This exposure severity is not within the limits set in the standard test methods. The low severity resulted from considerable difficulty in keeping the burners lit during the first half-hour of the test. The temperature at one point on the unexposed surface had risen 325 deg F at 1 hr 30 min and the average had risen 250 deg F at 1 hr 40 min. The temperature at one point on the lower reinforcing rods of the beam reached 1200 F at 1 hr 20 min and the average reached 1000 F at 1 hr 17 min. The temperatures observed during the test are indicated by the curves of Figure 2.

5. SUMMARY AND CONCLUSIONS

The general behaviors of the two roof deck assemblies were similar. Each beam suffered some damage and the reinforcing within each was heated to high temperatures. The 6 ft 3-3/8 in. channel slabs underwent considerable deflection, up to about 20 percent of their span.

5.1 Beams

The beams in the two tests were identical in design. Each spalled along the bottom edges, exposing portions of the lower reinforcing rods to the hot furnace gases. Cracks formed along the sides of each beam. The temperature of the lower reinforcing rods reached the temperatures of 1000 F for the average and 1200 F at one point at 1:02 and 0:47, respectively, in Test 327 and 1:17 and 1:20 in Test 328. The load applied to the assembly was not intended to stress the steel to its design capacity. Therefore, the fire endurance of the beam would be limited to 1½ min without full load.

5.2 Roof Decks

The channel slabs, in the 6 ft 3-3/8 in. lengths, did not spall at any time and did not crack until late in the tests but they did sag appreciably. This sag began to be noticeable within the first half-hour and became so extreme as to constitute load failure by 53 and 50 min in the two tests. Because of the fire exposure severities of 82.4 and 91.4 percent,

corrections of -2 and -5 min apply and the corrected fire endurance limits are 51 min and 52 min, respectively. After the removal of the applied load, the sag continued to increase, until, at the end of one test the channel slabs fell from place.

The glass fiber insulation and the foamed glass insulation seem to have been equal at low temperatures but the former showed better resistance to heat transmission at high temperatures. However, the asphalt paper on the edges of the glass fiber insulation is combustible and provides a path for transmission of flame from the bottom of the insulation to the top. The binder in the fiber insulation is combustible and the glass in each fuses at high temperatures, losing its insulating value.

5.3 Complete Assembly

The combined assembly of beam, channel slabs, 2 in. of glass insulation, 5 ply roofing, and expanded slag surfacing has a fire endurance limit of about 30 min. The beam reinforcing is quickly exposed through spalling and, when fully loaded, would sag due to lost strength soon after. The channel slabs did not spall but did sag to a considerable degree. With difficulties, beam and channel slabs, may be extricated to insufficient thickness of concrete around the reinforcing used.

Neither the contents of this report nor the fact that the tests were made by the National Bureau of Standards shall be used for advertising or promotional purposes.

For the Director
by

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