NATIONAL BUREAU OF STANDARDS REPORT

4594

FIRE TEST

OF

STEEL JOIST ROOF DECK

by

J. V. Ryan

NBS

U. S. DEPARTMENT OF COMMERCE
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REPORT OF FIRE TEST OF STEEL JOIST ROOF DECK for Department of Highways, District of Columbia Government

A fire endurance test was carried out on a roof deck whose primary components were cement bonded shredded wood fiber planks on open-web steel joists. The deck was tested under a total load somewhat less than the design load. The results indicated a fire endurance of 2 hr 22 min for the test specimen.

1. INTRODUCTION

A fire endurance test was carried out in general compliance with the provisions of ASTM E119 except that the load was slightly less than the design load. The specimen was a roof-deck-ceiling assembly of open-web steel joists with a deck of tongue-and-groove planks of shredded cemented wood fiber. The deck was topped with four-ply asphalt rag felt roofing and slag. The ceiling consisted of gypsum-perlite plaster on furred expanded metal lath. The floor surface was approximately 18 ft long by 13 ft 6 in. wide, and the ceiling 17 ft 3 in. by 12 ft 8 in.

2. TEST SPECIMEN

The materials employed and the methods of their assembly are described in the following sections. Some materials were obtained on the open market; others were obtained directly from the manufacturer. Certain parts of the assembly operation were performed by outside contractors or others regularly engaged in such activities; the remainder by personnel of the Fire Protection Section.

2.1 Materials

The steel joists were of the open-web type, designated SJ102 by the Steel Joist Institute, and were manufactured by a member-company of that Institute. They were 13 ft 4 in. long and 10 in. deep. The top chords consisted of two steel angles, 1- by 1- by 1/8-in. The web consisted of a steel rod bent to a zig-zag shape. Rods of 9/16 in. diameter were used near each end, and of 1/2 in. diameter over the center 10 ft. The bottom chords consisted of two steel rods of 1/2 in. diameter, each slightly over 11 ft long. The components were welded together so that one bottom chord rod extended to about 7 in. from one end of the joist, and the other rod an equal distance from the other end. The web and chords formed triangular panels of 12 in. long bases along the center 10 ft. A bearing plate 6 in. long, 3 in. wide, and 3/16 in. thick was welded to each end. Each joist was finished with a black bituminous material. The average weight of the joist was 58.5 lb.

Steel plates 1 in. thick, 5 in. wide and about 17 ft 11 in. long were used as bearing surfaces for the joists.

Flat diamond mesh expanded metal lath, in 96- by 28- in. sheets, was used as the base for the ceiling plaster. The lath, a nominal 3.4 lb/yd^2, weighed 2.88 lb/yd^2.

Cold rolled steel channels, 3/4 in. size, were used as furring for the ceiling lath. The furring channel weighed about 290 lb/1000 ft.

The plaster was fibered gypsum cement of a brand widely available in this country, and marked "for use with lightweight aggregates". It was obtained from a local contractor in bags of 100 lb nominal content. An accelerator, provided by the manufacturer of the plaster, was obtained at the same source.

The plaster aggregate was an expanded perlite, from a local processor, in bags marked 4 ft^3 contents. It weighed an average of 7.9 lb/ft^3.

The roof deck consisted of planks of shredded wood fiber with binders represented by the manufacturer to have been magnesium oxysulfate and silicate cements, and faced on one side with asphalt saturated felt. They were 2 in. thick, exclusive of the felt facing, and 30-5/8 in. wide, including a 5/8 in. tongue along one edge. The other edge was grooved to match. The asphalt felt was carried to the base of the tongue and to the near lip of the groove. The planks were weighed during construction of the specimen and found to average 4.04 lb/ft^2. They were supplied directly by the manufacturer.

Self-tapping 3/16-in. screws, 2-1/2 in. long with a 3/8 in. hexogonal head, were used to secure the roof planks to the joists.

Asphalt saturated rag felt, in rolls 36 in. wide, and roofing asphalt were used for the roof.

Slag granules, prepared for the purpose, were used as the surface finish of the roof.

2.2 Assembly

For the purpose of providing only moderate axial restraint a 1- by 5-in. steel plate was secured to each 4- by 4-in. bearing angle along each side of the furnace by three bolts near each end. A 1- by 1- by 3-in. piece of steel was placed between the plate and the furnace frame near each end as a spacer.

Figure 1 shows the spacer, plate, and bolt heads. Eight steel joists were placed to span the short dimension of the furnace opening and bear on the steel plates. The joists were placed parallel to the transverse centerline of the furnace opening, and spaced symmetrically therefrom. The spacings between joists on each side of the centerline were 18 in., 36 in., 36 in., and 10 in. No joist was located at the centerline. The joist bearing plates were securely welded along both edges to the 1- by 5-in. plates across the entire 5 in. width. Nine-sixteenths-inch rods were welded transversely to the top and bottom chords of the joists as horizontal bridging.

The cemented fiber roof planks were laid on the joists and transversely thereto. They were laid with the asphalt saturated felt face up and were aligned and forced together to form tight, straight tongue-and-groove and butt joints. They were cut to lengths such that the butt joints fell over the centers of joists. Each piece was supported by either three or four joists, including those under the butt joints. Holes were drilled through the roof planks into the horizontal leg of one of the top chord angles and the self-tapping screws, with large washers under the heads, driven in until the tops of the heads were flush with the top surface of the roof planks. Screws were driven 5 in. from each edge and at the center of the 30 in. wide planks, into each joist. The screws were staggered from one to the other of the top chord angles. Figure 2 shows the specimen during this stage of the assembly.

Long length 6 in. wide strips of roofing felt were laid over all the joints between the roof planks and were mopped with hot asphalt. Full 36 in. width felt strips were laid on with hot asphalt mopped on between successive strips. Each strip lapped the preceeding one by 26- to 28-in., to produce a four-ply roof. After all the roofing felt was down, the entire surface was covered with a hot asphalt flood coat of 1/2 lb/ft^2 and slag was spead on at the coverage of 3 lb/ft^2.

The 3/4 in. steel furring channels were tied to the lower chords of the joists, transversely thereto, at 12 in. on centers. Each length of channel had been cut to provide about 1 in. clearance from the furnace wall at each end. The flat expanded metal lath was tied to the furring channels. Six-inch wide strips of metal lath were bent and attached to the ceiling lath and to the furnace wall. Wooden ground strips 11/16-in. thick were tied to the bottom of the metal lath along the center of the furnace and near each side.

The scratch coat plaster was mixed 1 bag of gypsum to 2 ft^3 of perlite to 8 oz of accelerator, applied, and scratched. The brown coat was mixed 1 bag of gypsum to 3 ft^3 of perlite to 8 oz of accelerator, and applied out to the grounds. The ground strips were removed and their places filled with plaster. The plaster was brought down the furnace wall about 4 to 6 in., being carefully formed to curve from ceiling to wall with a 3 in. radius.

The ceiling was given a 1/16-in. white finish coat. The scratch and brown coats were applied on successive days, and the white coat a few days later.

3. TEST METHOD

The specimen was tested in general compliance with the methods defined in the Standard Methods for Fire Tests of Building Construction and Materials, ASTM E119.

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 restraining and specimen support frame, gas-air burners, thermocouples, loading apparatus, means for measuring deflections, and windows for observing the exposed surface during test.

3.2 Aging

The specimen was aged 32 days from the day the brown coat plaster was applied. During the latter 15 days of this period the furnace was closed and the relative humidity was maintained to about 40 percent.

3.3 Loading

The design load specified by the Steel Joist Institute for SJ102 joists of 13 ft span at 3 ft on centers was 83 lb/ft^2 uniformly distributed. The dead weight of the specimen was 17.3 lb/ft^2, as computed from the measured weights of the various component materials. In computing the dead load, the weights of the two end joists were not added in, neither were they counted as supporting any of the live load. Therefore, the uniformly distributed applied live load should have been 65.7 lb/ft^2. However, the loading apparatus applied the load through 36 steel channels, each 5 in. wide and 2 ft long, in six rows of six each, spaced 36 in. on centers along the length of the furnace opening and 27 in. on centers across the width. Each row of loading channels was centered over one of the joists, with the channels at right angles to the joists. The design applied or live load amounted to 422 lb on each loading channel. Since it was felt that the cemented fiber roof planks might not distribute the load uniformly along each joist, the applied live load was reduced to 62.3 lb/ft^2 or 400 lb on each of the 36 loading channels. The load was applied from four hydraulic pistons through a system of triangles.

3.4 Temperatures

Temperatures were measured by means of thermocouples connected to self-balancing potentiometers calibrated to read in degrees centigrade. The thermocouples in the furnace chamber were in porcelain insulators and encased in black iron pipes, the others were in glass fiber sleeving. Thermocouples were placed in the furnace chamber, on the steel joists, on the unexposed surface, on one of the 1- by 5-in steel plates, on the steel H-section restraining frame of the furnace, on the back of the metal lath, in one of the roof planks, and on the heads of two of the screws holding roof planks. The thermocouple locations are indicated in figure 3. The furnace fires were controlled to produce temperatures as close as feasible to those defined by the Standard Time-Temperature Curve in ASTM E119, which included: 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, and 1925°F at 3 hr.

3.5 End-Point Criteria

The Standard Test Method, E119, 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 one point temperature increased 325 degrees F above their initial values. The fire endurance was the time at which the first of these end points was reached, with a correction to the time for variation, if any, of the furnace temperatures from those defined.

4. RESULTS

The fire test was conducted February 7, 1956. All times are from the start of the test. At 26 min, cracks extended the full length of the ceiling along the center and about 1 ft from each side. By 38 min additional full length cracks had formed and that along the centerline was 1/4- to 1/2-in. wide in places. There was a slight sag along the centerline crack. By 41 min the plaster along one side of this crack was offset about 1 in. below that along the other side; the maximum deflection of any of the joists was 0.13 in., the average temperature of the unexposed surface had risen only 13 deg F, and the average temperature of the bottom chords of the joists was 232°F. At 1 hr 4 min, flames issued into the furnace chamber from a crack 1 ft East and 4 to 5 ft North of center, and smoke came from others. By 1 hr 21 min, flames issued from a few other ceiling cracks. By 1 hr 47 min the ceiling surface was moderately irregular. The maximum deflection had increased to 0.8 in., the average temperature rise on the unexposed surface to 93 deg F, and the average temperature of the bottom chords to 817°F. At 2 hrs 8 min, the asphalt under the slag surface was melting. At 2 hr 20-1/2 min a thump was

heard, probably the sound as a weld broke, accompanied by a slight momentary drop of the oil pressure in the loading system. By this time the deflection had reached 4.9 in. and was increasing so rapidly that the specimen was no longer sustaining the applied load satisfactorily and load failure was taken to have occurred. The rise of the average temperature on the unexposed surface was 112 deg F and the average temperature of the bottom chords of the joists was 1008°F. By 2 hr 32 min the specimen had sagged until the ceiling was touching the furnace thermocouple pipes near the center. The live load was removed at 2 hr 34 min. At 2 hr 40 min the asphalt was bubbling on the upper surface in some places. At 2 hr 54 min, the limiting rise of 325 deg F was reached at one point on the unexposed surface and a section of the roof deck broke, permitting hot gases through from the furnace. The asphalt was ignited immediately. The furnace fires were shut off and the blazing asphalt extinguished by a water spray.

The roofing was pulled off and it was found that the wood fiber roof planks had been charred through about half their thickness, leaving a gray ash. Much of the remaining portion was glowing. The specimen was hosed down throughly with water to extinguish this glow. Much of the plaster was knocked down during the hosing.

Deflections were observed at the centers of the third, fourth, fifth, and sixth joists from the North end. The following is a summary of the net deflections from the start of the fire exposure:

	Joist Number			
Time	3	4	5	6
0:00	0.0	0.0	0.0	0.0
:15	0.1	.0	.0	.1
:30	.1	.0	.0	.1
:45	.2	.0	.1	.2
1:00	.3	.1	.2	.3
1:15	.4	.1	.3	.4
1:30	.4	.1	.4	.5
1:45	.5	.3	.6	.8
2:00	.6	.8	1.4	1.5
2:15	1.5	2.6	3.8	3.3
2:20	2.2	3.8	4.9	4.2
2:25	3.3	5.3	6.1	5.1
2:30	4.9	7.7	8.4	6.8

The fire endurance of the particular roof deck tested was limited by load failure at 2 hr 21 min. The one-point maximum temperature rise on the unexposed surface was reached at 2 hr 54 min followed in a few seconds by passage of gases hot enough to ignite the asphalt. By the end of the test the average temperature of the bottom chords of the joists was over 1200° F and the maximum over 1325° F; those of the upper chords were essentially the same. The fire exposure severity, as determined by the ratio of the area under the average furnace temperature curve to the area under the standard time-temperature curve, was 101.1% and the correction to the fire endurance limit was plus 1 min. Therefore, the fire endurance of the roof-ceiling assembly tested was 2 hr 22 min.

Examination after cooling showed that most of the joists were bent down several inches and some were bent transversely, as shown in figure 4, 5, and 6. Several welds in the joists were broken but all between the joists and the bridging were intact, as were all between the joist bearing plates and the 1- by 5-in. steel plates. The 1- by 5-in. steel plates were bent laterally as much as 2-1/4 in. and bent up as much as 1-1/4 in.

5. DISCUSSION

5.1 Supporting System

The joists were secured to the 1- by 5-in. plates by heavy welds. These welds proved stronger than some of the welds in the joists, as evidenced by the fact that several of the latter broke. Also, the 1- by 5-in. plates gave with the joists and were deformed from their initial positions. These two facts indicate that this particular support system for the joists was very strong but sufficiently flexible to provide continuing support as the joists bent. It is possible, if not probable, that some of the joists were acting as suspension members rather than truss members by the end of the fire exposure period.

5.2 Loading

As was mentioned earlier in this report, there was some doubt that the roof deck was strong and rigid enough to insure that the load as applied by the apparatus was distributed uniformly along the joists. On the basis of a preliminary stress analysis, in which it was assumed that the applied live load was concentrated at six points along each joist and that the dead load was given by the nominal weights of materials the applied load was reduced somewhat below the design live load. A second analysis was carried out subsequent to the test, assuming that each joist was loaded along six evenly spaced lengths each equal to the 5-in. width of the loading channels. The stresses in the various members of the joists were computed and found to have been well below the maximum of 18000 $lb/in.^2$ recommended by the Steel Joist Institute. The analysis also was carried out on the basis of a live load of 422 lb per loading channel, computed on the actual dead load of 17.3 lb/ft^2.

Had this live load been applied, coupled with the existing dead load, the resulting stresses would have been significantly lower than the allowable maximum.

6. CONCLUSIONS

The foregoing sections indicate that two conditions existed during the fire exposure test that may have been advantageous departures from normal procedures. First, the joists were secured in such a manner that they could deflect into relatively deep curves without separating from their supports. Secondly, the applied live load was reduced, so that the actual total load was less than the design load recommended. It appears that neither of these two conditions, nor their combination could have the effect of decreasing the fire endurance of the specimen; and that they may have had the opposite effect. While it is not possible to determine what the magnitude of this increase was, except by another fire test, consideration of the results of this test should be made only with an awareness of these conditions.

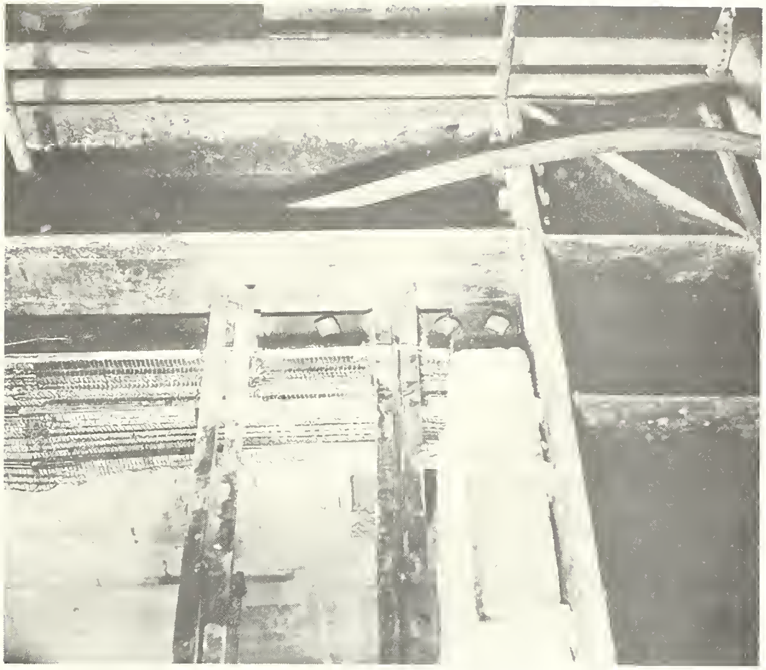


Fig. 1. Corner detail, showing steel plate, bolt heads, spacers, and joists.

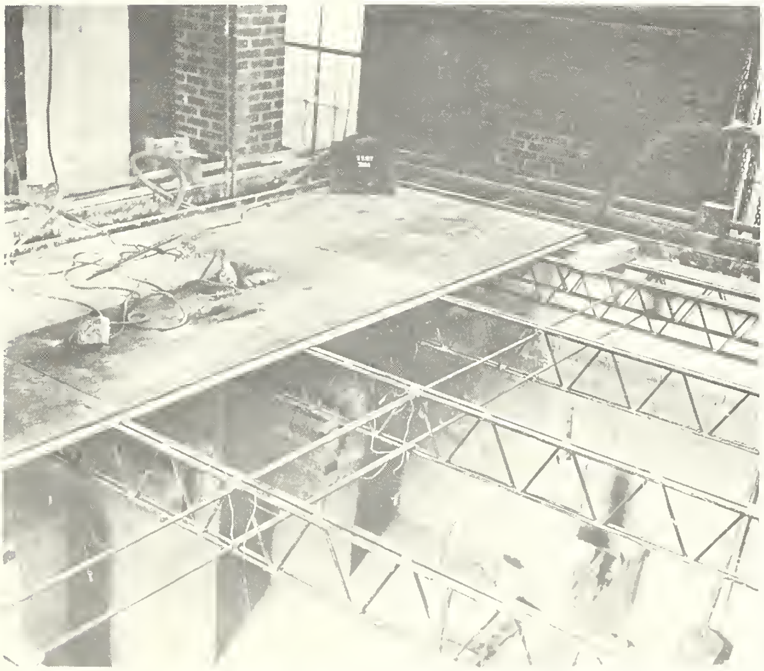
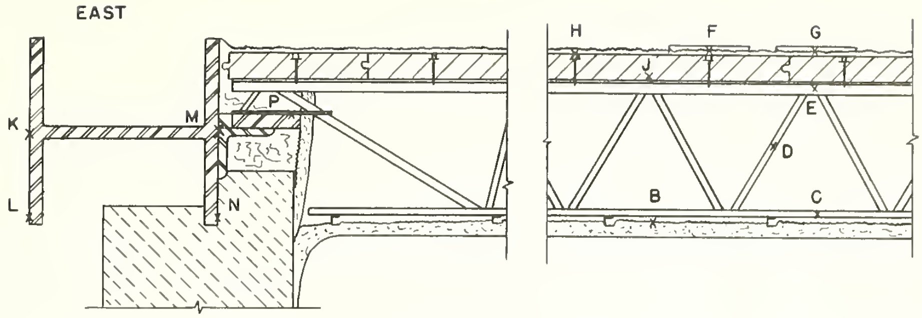
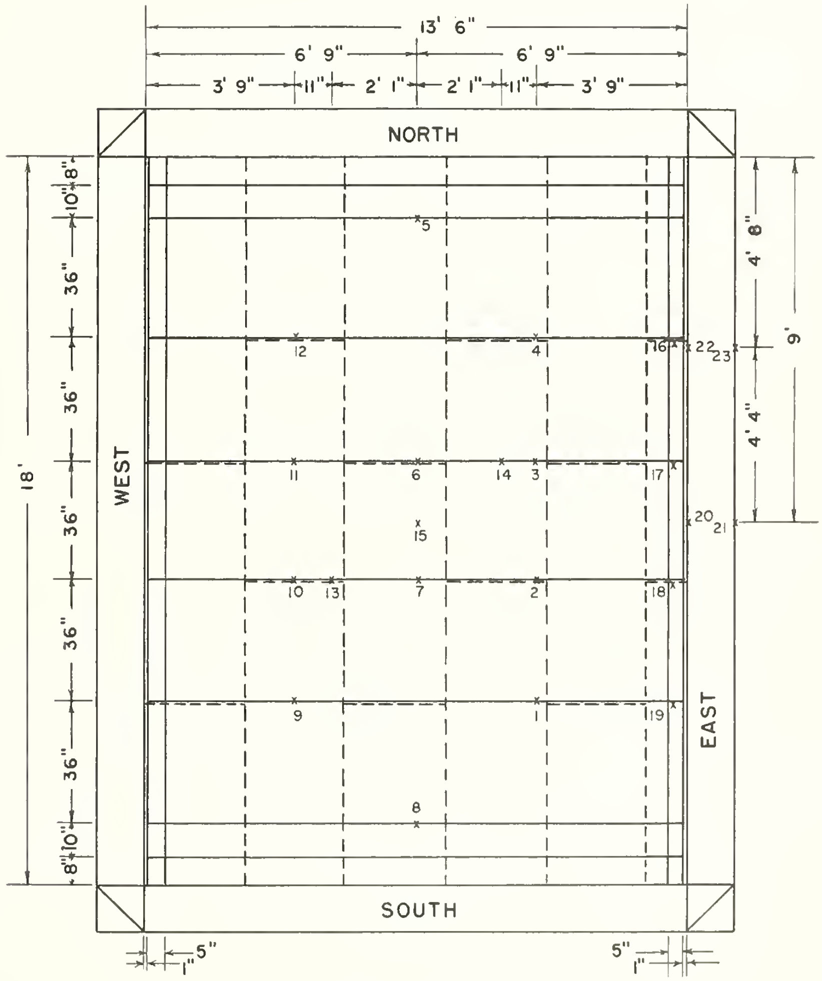


Fig. 2. Specimen during placement of roof planks, also showing joists with bridging.



THERMOCOUPLE LOCATIONS



THERMOCOUPLE LOCATION PLAN

Fig. 3. Thermocouple locations.

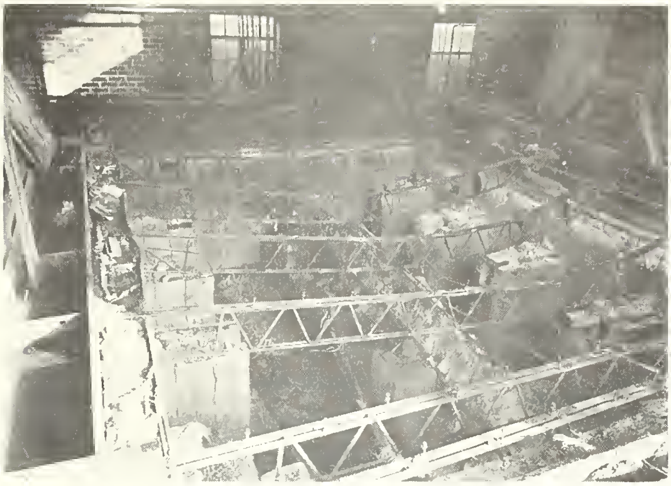
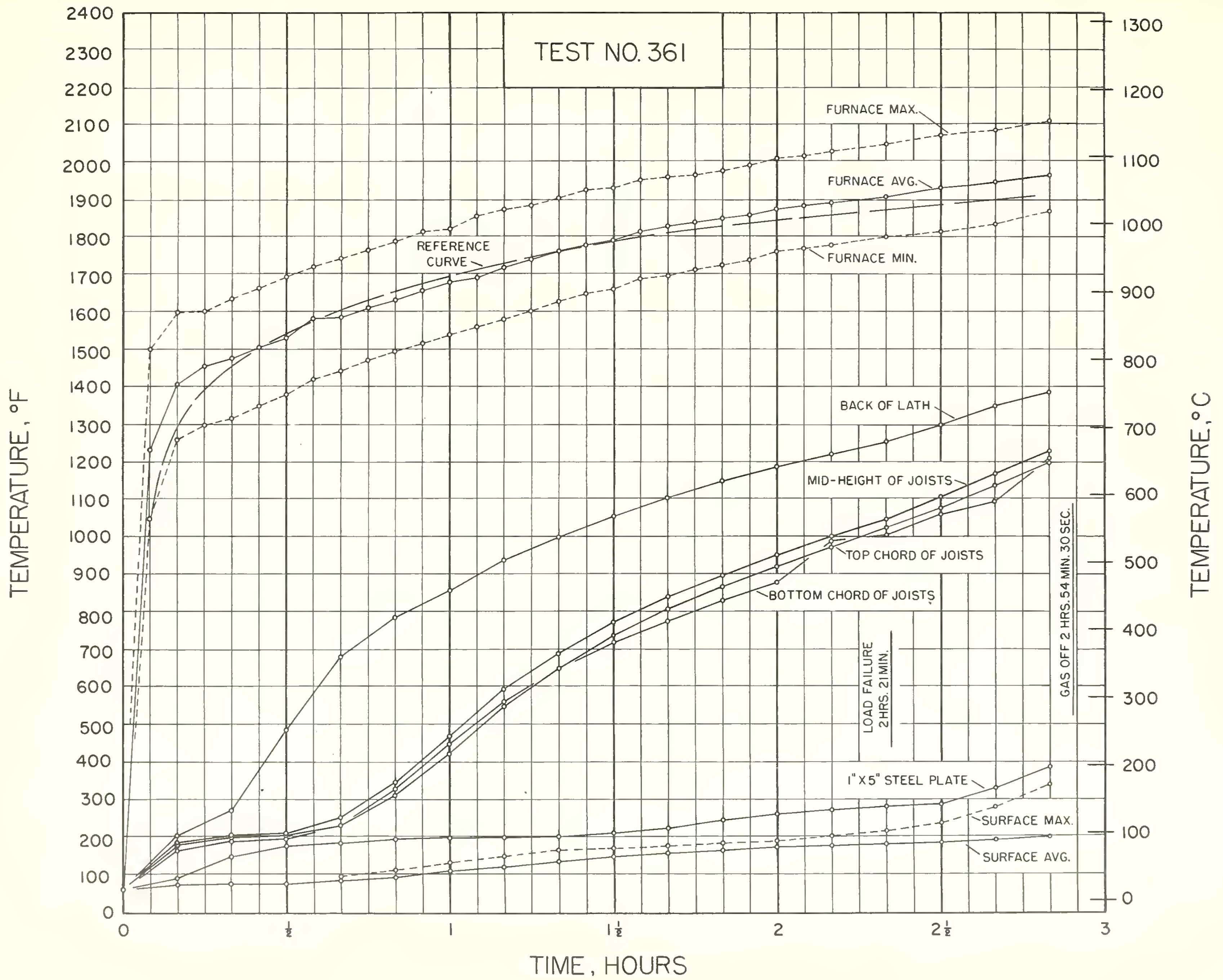


Fig. 4. Condition of joists after test.

Fig. 5. Condition of joists in South half.

Fig. 6. Condition of joists in North half.


TEST NO. 361
TEMPERATURE, °F
TEMPERATURE, °C
TIME, HOURS
FURNACE MAX.
FURNACE AVG.
FURNACE MIN.
REFERENCE CURVE
BACK OF LATH
MID-HEIGHT OF JOISTS
TOP CHORD OF JOISTS
BOTTOM CHORD OF JOISTS
LOAD FAILURE 2 HRS. 21 MIN.
GAS OFF 2 HRS. 54 MIN. 30 SEC.
1" X 5" STEEL PLATE
SURFACE MAX.
SURFACE AVG.

THE NATIONAL BUREAU OF STANDARDS

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