56 u8

NATIONAL BUREAU OF STANDARDS REPORT

5608

REPORT OF FIRE TEST OF

CELLULAR STEEL DECK AND BEAM

by
J. V. Ryan

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Inquiries regarding the Bureau's reports should be addressed to the Office of Technical Information, National Bureau of Standards, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | **NBS REPORT**

1002-30-4820 | October 14, 1957 | 5608

REPORT OF FIRE TEST OF

CELLULAR STEEL DECK AND BEAM

by
J. V. Ryan

for
Department of the Air Force
(AFCIE-ES)

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

REPORT OF FIRE TEST OF

CELLULAR STEEL DECK AND BEAM

ABSTRACT

A fire endurance test was conducted on a floor specimen consisting of a beam supporting cellular steel deck units of two cross-sections. 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 4 hr 25 min for the particular specimen tested.

---

1. Introduction

The use of floors of concrete on cellular steel units has increased in recent years. The cells of various units have been designed and proposed as raceways for electrical wiring, telephone lines, and ducts of air-cooling systems. Such use permits the direct application of ceiling finish or acoustical material without leaving exposed raceways and ducts. This could lead to reduction of overall heights of multistory buildings, or increase in the number of stories, without reduction of the headroom in each story. Because such construction is of interest to the public and the government, a specimen of this type was subjected to fire test, the third of a series of related tests. The specimen consisted of a combination of cellular units of two cross-sections, one suitable for electrical and telephone lines and the other intended to serve as an air duct, with concrete fill above and vermiculite acoustical plastic below. The specimen included a steel beam encased in expanded metal lath and gypsum vermiculite plaster.

2. Materials and Specimen

A steel beam 8 in. deep, $6\frac{1}{2}$ 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 1 1/8 in. and were intended to allow for some expansion of the beam and some tilting of the plates as the beam deflected, 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 were placed to span from the beam to steel bearing angles bolted to the furnace frame across each end. The units were of two cross-sections. For the first, each unit was made of two sheets of metal formed and spot welded together to make four nearly rectangular cells of 3 1/8 in. overall height, 3 3/4 in. average width, with space between cells an average of 2 1/4 in. The upper sheet was of 18 ga (U.S. Std plate) steel, the lower of 16 ga. The upper sheet was bent along each edge to form a standing seam interlocking joint between units. The units were 3 1/8 in. deep and 24 in. wide. For the other cross-section, each unit was made of two sheets of metal formed and spot welded together to make a single cell of 3 1/8 in. overall height and 9 5/8 in. average width. This single cell has been proposed for use as a duct for cool air circulation. Both sheets were of 14 ga steel. The upper sheet was bent along each edge to provide the same joint as the 4-cell unit. The single-cell units were 3 1/8 in. deep and 12 in. wide.

The two types of units were alternated, starting with a 4-cell unit. They were welded to the beam and bearing angles at 12 in. oc for the 4-cell units and 6 in. oc for the single-cell air duct units. After all the units were in place, the joints were spot welded by an electric arc welder. Preformed sheet steel cover plates were placed over the end-to-end joints between units above the beam.

Holes were punched through at the joints between units and between cells of the 4-cell units and 0.164 in. diameter hanger wires dropped through. Each wire had a loop of about 1 in. diameter at the top, which loop rested on the steel deck units. The wires were located at 12 in. oc along each side of the beam. Each was bent to pass under the beam and lap 3 1/2 to 6 in. on a wire from the opposite side. The pairs of wires, one from each side of the beam, were laid together below the beam and tied together with 18 ga wire.

Transit mixed concrete, proportioned 1 part cement, 2 parts Potomac River sand, and 4 parts Potomac River gravel (both siliceous aggregates) was poured on the deck and screeded to a depth of 2 1/2 in. above the top plane of the steel deck units. The upper surface of the concrete was 1 in. above the top of the furnace restraining frame. The concrete delivery ticket indicated that the gravel had passed through a 3/4 in. sieve.

Flat diamond-mesh expanded metal lath (nominal 3.4 lb/yd^2, actual 3.26 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 the wire hangers with single strands of 18 ga wire at top, center, and bottom of each side and at the center of the beam soffit. Corner beads, consisting of a formed sheet metal nose and woven wire legs, were prepared with 3 in. wide strips of metal lath as 4 to 5 in. extensions of the legs at about 2 ft oc. These leg extension pieces were tied to the metal lath on the beam so that the corner beads provided 1 1/2 in. grounds for plaster, as measured from the face of the lath. Wooden screed strips were tied to the face of the metal lath about 2 1/2 in. from the top of the beam. These strips provided 1 1/2 in. grounds.

Gypsum-vermiculite plaster was applied to the metal lath in two coats. The first or scratch coat plaster was mixed in the ratio of 1 bag (nominal 99.25 lb net) unfibered gypsum cement plaster to 2 ft^3 of vermiculite plaster aggregate, with 4 oz of accelerator added per bag of plaster. This coat was applied by trowel and care taken to fill the corner bead and to provide a good key behind the lath. The thickness over the face of the lath averaged about 1/4 in. The plaster surface was scratched with a wire tool for the purpose. The brown coat plaster was mixed in the ratio of 1 bag of gypsum to 3 ft^3 of vermiculite aggregate to 4 oz of accelerator. It was sprayed on by a Thomsen Supply Company "Tommy Gun," a commercially available machine built for this use. The surface was screeded smooth and the wooden ground strips removed. The spaces they had occupied were filled with brown coat plaster. Following the plaster application, the underside of the cellular deck units was wiped carefully to remove all spatterings.

Aluminum foil faced glass fiber insulation board was cemented to the lower surface of the air duct units. The insulation was in pieces 15 3/8 in. wide with a notch in the glass fiber about 1 3/8 in. from each edge. Adhesive was spread on the glass fiber surface of each piece, the pieces bent along the notches, and the glass fiber surfaces pressed against the lower surfaces of the air duct units. After all the air duct units had the insulation applied, the butt joints between pieces of insulation, and the edge joints between the insulation and deck units were covered with a 2 in. wide vapor barrier tape. The 15 3/8 in. wide pieces, with foil, weighed 0.54 lb/running foot.

Copper-clad steel studs (in the same shape as nails) 3/4 in. long, 0.103 in. diameter, with 3/16 in. diameter heads were applied to the under side of the deck by "flash-welding" the stud heads to the steel units. They were spaced 6 in. oc along lines about 8 to 8 1/4 in. from and parallel to the centerlines of the air duct units.

Flat diamond mesh expanded metal lath was cut in strips about 19 in. wide and 97 1/2 in. long. The lath was the same as that used around the steel beam. The strips were placed below and with their long dimensions parallel to the insulated air duct units. They were stretched across the insulation, engaged on the lines of studs and held by locking clips shoved on the studs. The bow of the lath across the insulation left a clearance of about 5/16 in. from the face of the lath to the foil face on the insulation.

Vermiculite acoustical plastic was applied to the under side of the deck. The plastic was prepared by mixing a dry loose material with water. The dry material, a proprietary product, was not identified, either by analysis or by manufacturers statement. The plastic was prepared in the same mixer and sprayed by the same machine as used for the plaster, except that the second application was by trowel. The weights and densities for the acoustical plastic, and for the plaster, are given in Table 1. The first application filled the spaces between the cells of the 4-cell units and was brought out flush with the bottoms of the latter; the second application, by trowel, filled the spaces behind the metal lath strips and built up about 1/4 in. thickness over the lath; the third was intended to build up a thickness of 5/8 in. below the cells of the 4-cell units and 1 1/8 in. from the face of the metal lath under the air duct units; the fourth and fifth were to fill cracks and patch four areas each about 1 ft^2 from which the plastic had fallen or loosened; the sixth an attempt to develop a more uniform contour and thickness; and the seventh a texture coat. The texture coat material contained white pigment, all other coats did not contain white pigment. The various applications were spaced from one to eight days apart. A total of 33 days elapsed from the first to the seventh application. An additional 15 days elapsed before the test.

The day before the test a series of measurements were made with a wire probe to determine the average thickness of acoustical plastic. Measurements from 33 symmetrically distributed points indicated an average thickness of about 11/16 in. under the 4-cell units; and measurements from 16 symmetrically distributed points indicated average thickness of about 1 25/64 in. from the aluminum foil face of the glass fiber insulation. Allowing for the bow of the lath under the insulation (approximately 5/16 in.), the thickness from the face of the lath was about 1 1/16 in.

Some of the details of the construction are shown in figure 1.

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.

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 aged 15 days from the application of the thin texture coat but 22 days from the last application of base coat material to develop the full thickness. The period of aging was determined by periodic weighing of a representative sample of the construction. Aging was continued until the 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.

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 August 15, 1957. By 23 minutes there were two cracks across the beam soffit, one of which extended up the North face of the beam protection. An odor, similar to that of burning plastics, had become fairly strong by 27 min and continued so for the next 1/2 to 3/4 hour. By 1 hr 43 min there were still only two cracks in the beam protection and a crack 1/8 in. wide across the unexposed surface above the beam. The net deflection at the center of the beam was 0.1 in.; at the centers of the floor areas on each side of the beam 0.4 and 0.6 in. The maximum temperature of the beam was about 295°F and the average temperature of the unexposed surface had risen about 85 deg F above its initial value. By 2 hr 12 min there were fine diagonal cracks across all corners of the unexposed surface and appreciable amounts of smoke were issuing from the periphery. At 3 hr 9 min, a loud metallic thump was heard but there was no fluctuation of oil pressure in the loading system nor sudden change of deflection. The net deflections at the centers of the beam and the two sections of the floor were 0.7 in., 0.6 in. and 1.0 in. respectively. The average temperature on the unexposed surface had risen 157 deg F and the maximum on the beam was 725°F. By 3 hr 41 min, the larger of the two cracks in the beam protection was about 3/16 in. wide. The limiting one-point temperature rise of 325 deg F was completed on the unexposed surface at 4 hr 26 min, at which time the maximum temperature of the steel beam was 991°F; and the net deflections at the centers of the beam and the two sections of the floor were 1.4 in., 0.9 in., and 1.4 in. respectively. An average temperature of 1000°F was reached at one section of the beam at 5 hr 27 min. By 6 hrs 1 min there was a crack 1/8 in. wide in the ceiling finish, extending from the beam cover to the North wall. The maximum observed temperature on the beam was 1200°F and the net deflections at the centers of the beam and two sections of the floor were 2.8 in., 0.8 in., and 1.6 in. respectively. At 6 hr 12 min, a piece of ceiling finish about 1 ft^2 was hanging from place near the South wall. The test was stopped at 6 hr 33 min.

After the test, and cooling, there were six cracks across the beam soffit, three of which extended up the sides of the beam protection. There were several long cracks in the ceiling finish parallel to the cellular units and short transverse cracks under the air duct units. The surface of the acoustical plastic was slightly darker than before the fire exposure. However, behind the texture coat, the base coat plastic was a dark brown. During the disassembly of the specimen, it was discovered that the plaster keys of the beam protection were exceptionally heavy, extending to the beam web in several places. It was estimated that the heavy keys filled about one-third to one-half the re-entrant space on each side. The approximate volume filled is indicated on the cross-section of the beam protection in figure 1.

The fire endurance of the specimen was limited by one-point temperature rise of 325 deg F at 4 hr 26 min. The control of the furnace fires was such that a correction of minus 1 min was applicable to the failure time. Therefore, the fire endurance limit was 4 hr 25 min for the particular specimen tested. The beam and floor continued to support the applied load throughout the 6 hr 33 min fire exposure period, although temperatures were reached at 5 hr 27 min that would have been considered indicative of failure in a test of a steel beam without applied load.

Table 1. Weight and Density Data on Plaster and Acoustical Plastic

Material	Quantity Measured - Units	No. of Samples	Mean	Max	Min
Plaster Aggregate - Vermiculite	Density, Dry - Lb/ft^3	9	6.83	7.25	6.34
Plaster - Gypsum Vermiculite Scratch Coat	Density, Wet, From Mixer Lb/ft^3	1	81.8	--	--
Brown Coat	Density, Wet, From Mixer Lb/ft^3	2	71.6	72.8	70.3
	Density, Wet, From Spray Nozzle - Lb/ft^3	2	79.8	80.6	78.9
Vermiculite Acoustical Plastic Base Coats	Weight, Dry Material - Lb/bag	20	23.22	24.18	22.58
	Density, Wet, From Mixer - Lb/ft^3	20	50.1	53.1	45.3
	Density, Wet, From Spray Nozzle - Lb/ft^3	18	57.3	59.7	54.2
Texture Coat	Weight, Dry Material - Lb/bag	2	23.90	24.09	23.71
	Density, Wet, From Mixer - Lb/ft^3	1	51.0	--	--
	Density, Wet, From Spray Nozzle - Lb/ft^3	1	60.5	--	--

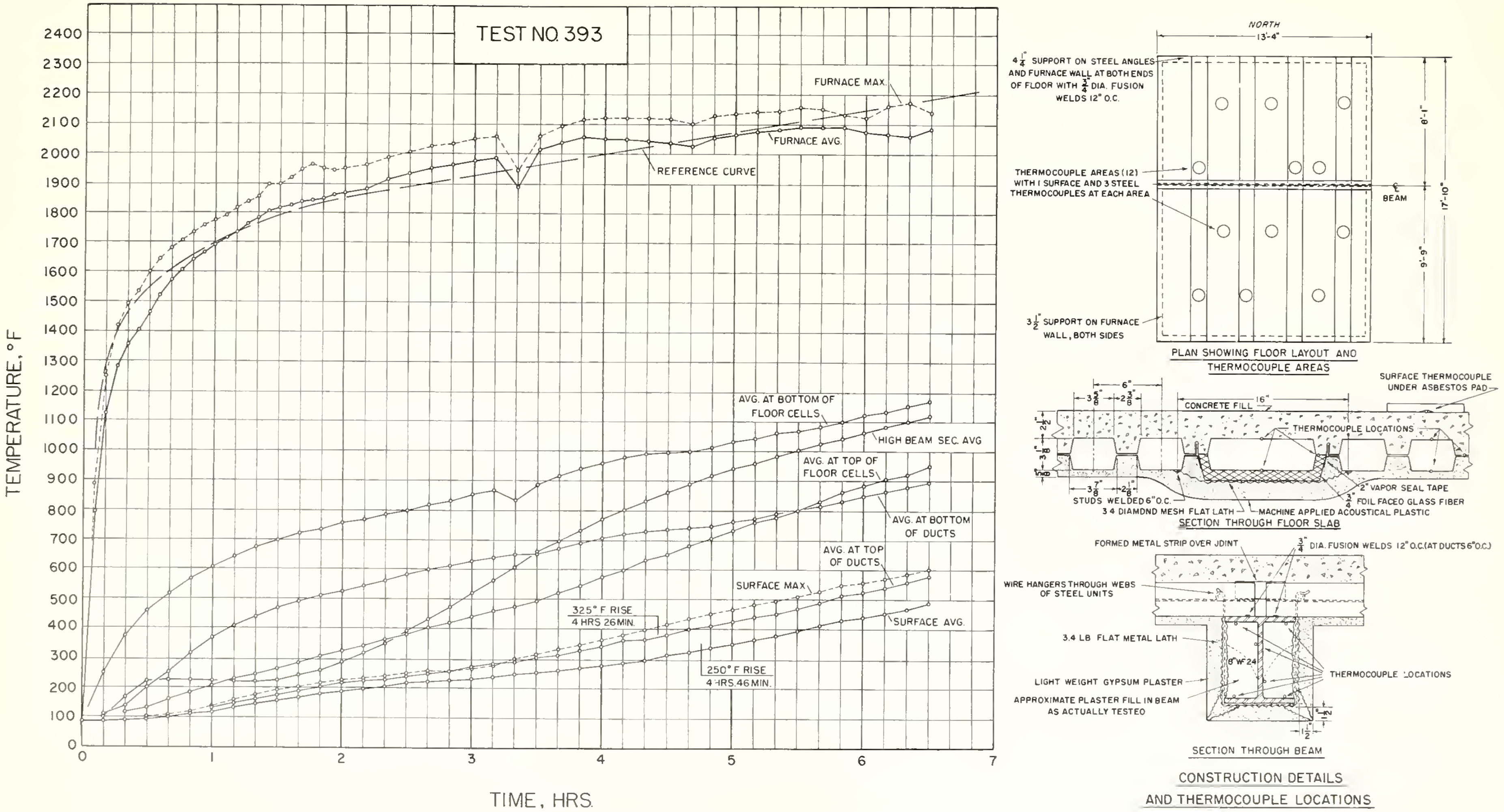

FIG. 1. CONSTRUCTION DETAILS, THERMOCOUPLE LOCATIONS, AND TIME-TEMPERATURE CURVES.

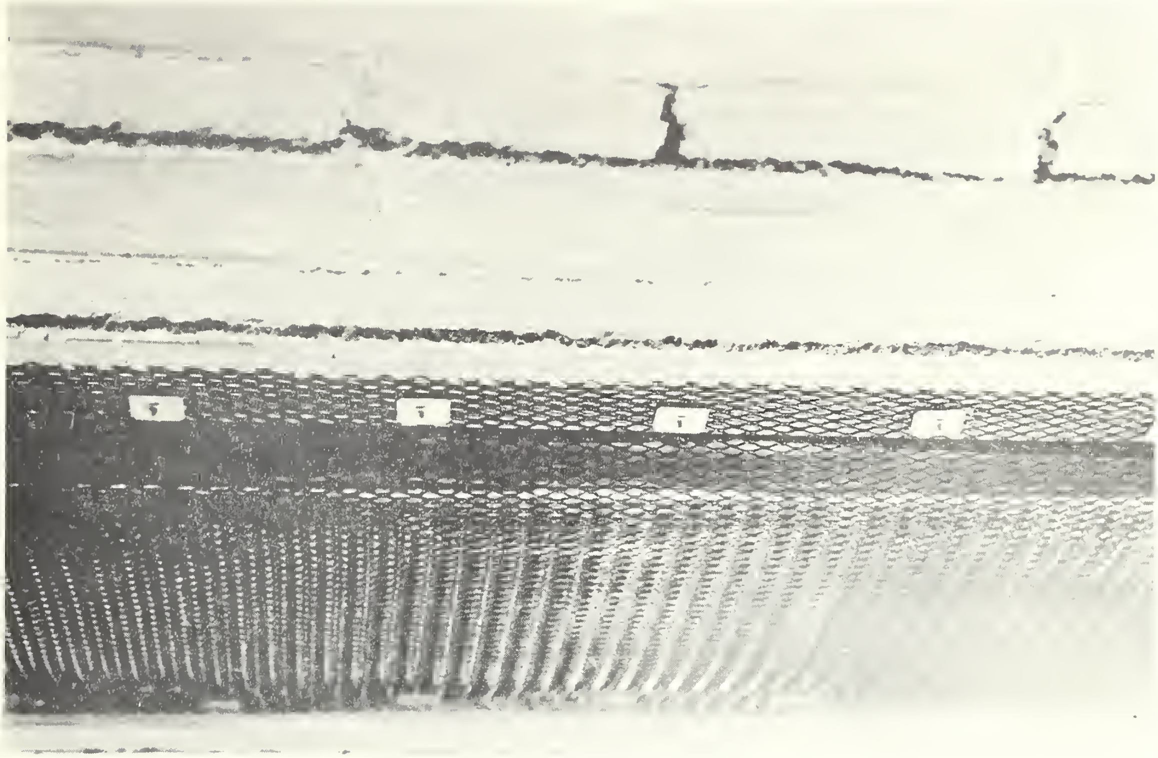

Fig. 2. Method of attachment for metal lath below air duct units. Visible cracks due to shrinkage of initial application of vermiculite acoustical plastic.

Fig. 3. Condition of exposed surface after test. The waviness in the specimen was the original contour, not due to fire exposure.

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside front cover of this report.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Application Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships.

Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering.

Radio Standards. Radio Frequencies. Microwave Frequencies. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

NBS