REPLICATE FIRE ENDURANCE TESTS OF AN UNPROTECTED WOOD JOIST FLOOR ASSEMBLY[1]

Robert H. White and *E. L. Schaffer*

Forest Products Technologist, Fire Design Engineering and
Wood Construction Specialist, State and Private Forestry
Forest Products Laboratory,[2] Forest Service, U.S. Department of Agriculture
Madison, WI 53705

and

Frank E. Woeste

Associate Professor
Agricultural Engineering Department, Virginia Tech
Blacksburg, VA 24060

(Received March 1983)

ABSTRACT

To encourage new developments in building technology, a solid basis for building code requirements is needed. Fire endurance is a code requirement, yet no objective procedure exists for computing a structure's chances of failing (degree of risk) in a fire. However, a model for predicting the fire endurance of part of a structure, a conventional unprotected wood joist floor, is available. The aim of this study was to determine the fire endurance performance of an unprotected wood joist floor for use in the model.

Eleven ASTM Standard E 119 floor tests were conducted. All the floors were 2 by 10 Douglas-fir wood joists, sixteen inches on center with $^{23}/_{32}$-inch-thick plywood as the floor sheathing. In addition to one trial test, five tests were conducted using a live load of 11.35 lb/ft^2. For the other five tests, the live load was 79.2 lb/ft^2. Twenty joists were tested for modulus of elasticity and modulus of rupture.

The joist population had a mean modulus of rupture of 5,280 lb/in.^{2} and a mean modulus of elasticity of 1,530,000 lb/in.^{2}. For the five floors loaded to 11.35 lb/ft^2, the mean time for initial joist failure was 17.9 min with a coefficient of variation (COV) of 3.7%. For the five floors loaded to 79.2 lb/ft^2, the mean time was 6.5 min with a COV of 11.6%. Based on linear interpolation of these results, first joist failure would have occurred in 13.1 min if a 40 lb/ft^2 live load had been used, which is the typical live loading specified in the building codes for residential one- and two-family dwellings.

As a result of this study, fire-resistance performance of a wood floor is known for a specific population of wood joists with known structural properties. These results can be used to verify and revise the model for predicting fire endurance.

Keywords: Fire resistance, fire endurance, floor.

INTRODUCTION

Fire endurance of structural components or assemblies is the duration of exposure for which they will contain a fire or retain their structural integrity. Fire

---

[1] This article was written and prepared by U.S. Government employees on official time and is therefore in the public domain (i.e., it cannot be copyrighted).

[2] Maintained at Madison, WI, in cooperation with the University of Wisconsin.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

endurance is a basic part of fire-design engineering and is generally evaluated according to the procedures in ASTM Standard E 119 (ASTM 1979). Usually, the fire endurance of a type of assembly is based on testing only one assembly. Thus, previous tests have not indicated the variability of the fire-endurance performance of all assemblies of this type.

An objective procedure to compute the degree of risk would provide a solid basis for building code requirements that insure sufficient fire endurance for life safety while not restricting new developments in building technology. Reliability analysis could help determine the probable degree of fire protection. The potential of reliability analysis in fire-design engineering depends on the availability of data on the mean and variability of the fire-endurance of assemblies.

The aim of this study was to determine the fire endurance of a conventional light-frame unprotected floor and to use this information in a probabilistically based predictive model. Information on the variability of the fire endurance of the full-scale floor specimens and the mechanical properties of the joists used in the floor specimens was required for verification of the model. The reliability analysis model of Woeste and Schaffer (1979, 1981) evaluates the probability of structural failure of the floor. This research report covers the experimental results of the fire tests. Comparison of the experimental results with the predictions of the model will be covered in a future paper.

BACKGROUND

Current requirements for fire resistance are numerical ratings based on results of a standard fire test. A more comprehensive approach to fire safety would have requirements based on probabilistic analysis. These requirements would incorporate the degree of risk and economic factors. A specific risk-based methodology has been developed for unprotected wood joists. The standard test, probabilistic analysis, and the specific model for an unprotected wood joist are briefly discussed in this section.

Standard fire test

The standard test for evaluating fire endurance is ASTM Standard E 119, Fire Tests of Building Constructions and Materials (ASTM 1979). The standard time-temperature curve that defines the fire exposure requires a furnace temperature of 1,000 F at 5 min and 1,550 F at 30 min. The continuous curve is given by ASTM E 119. The exposure to fire occurs at the underside of the floor assembly.

In the standard test, the fire endurance period is ended when any one of these conditions is observed: (1) the floor fails to sustain the applied load, (2) the transmission of hot gases or flames through the assembly is sufficient to ignite cotton waste, or (3) the transmission of heat through the specimen has raised the average temperature on its unexposed surface more than 250 F above its initial temperature or the maximum individual temperature more than 325 F.

Probabilistic analysis

Barriers with specified fire endurance are used to divide buildings into smaller compartments in order to limit the spread of a fire. The probabilistic analysis of fire safety can be used to determine the amount of fire endurance required to minimize both the cost of increasing fire endurance and the cost of probable loss from fire, of human lives or property during the planned life of a building (Baldwin 1975a, 1975b; Burros 1975; Lie 1972, 1974; Magnusson 1973; Magnusson and Petersson 1981). Lie (1974) defines loss expectation as the product P_tP_fV. The three factors are probability of occurrence of a significant fire (P_t), probability of occurrence of structural failure (P_f), and value of risk (V). Lie (1972, 1974) uses the loss expectation factor to evaluate the optimum fire endurance of the structure.

Compartmentation is also a part of the General Services Administration (GSA 1972) decision tree approach to building fire safety. Here compartmentation considers the probability that the physical form and barriers of the building will be sufficiently tight and stable as to prevent the passage of fire beyond these barriers and the failure of structural elements resulting in collapse of the barriers or collapse of other building elements.

Analysis of wood floor assemblies

Woeste and Schaffer (1979, 1981) have presented a risk-based methodology using second-moment approximations for assessing the fire endurance safety of two unprotected light-frame assemblies—a conventional joist assembly and a floor-truss assembly. Based on test results in the literature, the following empirical model for exposed floor joist was selected as the best predictor of the time to structural failure:

$$\frac{M(d - Ct_f)/2}{(b - 2Ct_f)(d - Ct_f)^3/12} = \frac{B}{1 + \left(\frac{b + 2d}{bd}\right)\gamma t_f}$$

where

M = the applied moment due to both dead and live loads (in.-lb)
d = the initial joist depth (in.)
C = the char rate (in./min)
t_f = the time to failure (min)
b = the initial joist width (in.)
γ = an exposed joist performance factor
B = the joist modulus of rupture at room temperature (lb/in.^{2})

We assume that the failure is due to charring of the three exposed sides of the joist, and this loss of section, coupled with elevated temperatures, causes rupture of the joist. The exposed joist performance factor, γ, includes the effect of load sharing between joists, the load-carrying contribution of floor sheathing, and the loss of strength due to temperature rise of the uncharred section. An improved estimate for this parameter is one of the objectives of this series of tests. Comparison of the experimental results with this model will be discussed in a future research paper.

MATERIALS

Two hundred pieces of 14-foot, nominal 2 by 10 Douglas-fir dimension lumber were purchased from a Madison, Wisconsin lumberyard. After visual inspection, the population was reduced to a more uniform sample of 161 Douglas-fir joists. Joists from this population were randomly assigned to the twelve load-bearing locations within each of the eleven test floors and to a group of twenty for modulus

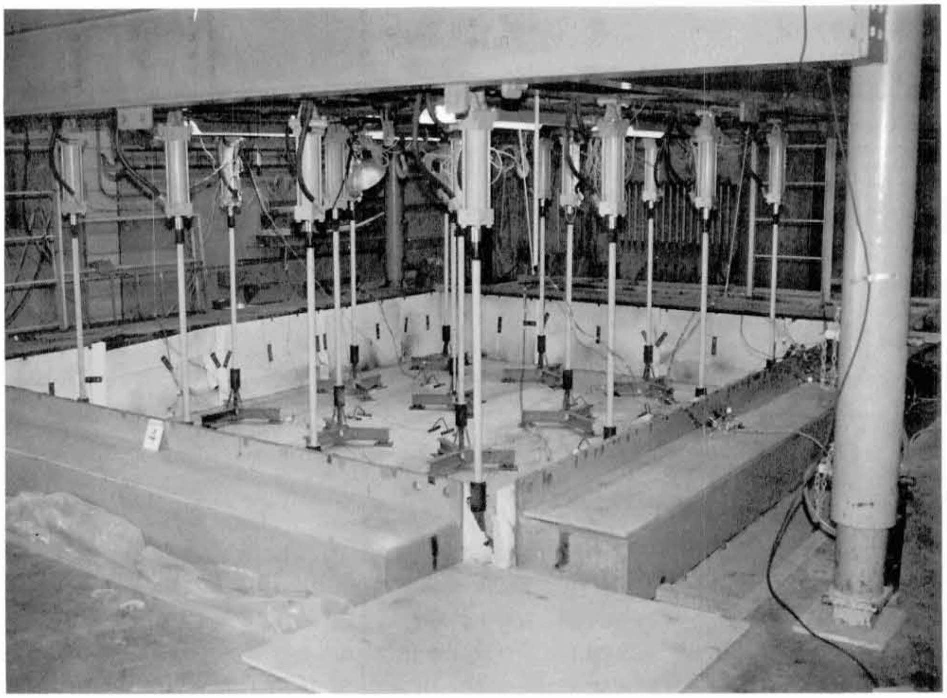

FIG. 1. Overall view of ASTM E 119 test furnace and floor specimen.

of rupture (MOR) tests. This left seven joists for substitution if needed. The other thirty-nine pieces out of the original 200 were used as the nonload-bearing joists at the outer edge of the floors and in five preliminary small-scale tests. Additional nominal 2 by 10's, 18 feet long, were used as headers. The sill plates were nominal 2 by 6 dimension lumber.

For a floor covering, 4- by 8-foot sheets of plywood were also purchased from the Madison, Wisconsin lumberyard. The $^{23}/_{32}$-inch-thick plywood had tongue-and-groove edges along its long edge and is intended for use as a combined subfloor-underlayment panel. Two thicknesses of particleboard were obtained for the small-scale tests.

METHODS

We fire tested a total of eleven 14-foot by 18-foot unprotected joist floors that supported a maximum floor load as described in ASTM E 119 (79.2 lb/ft^2) or a load more typical of that encountered in a house (11.35 lb/ft^2) (Corotis and Doshi 1977). These loads induced stresses that were approximately 28% and 5%, respectively, of the average short-term ultimate strength of a sample of twenty joists destructively tested. Five replicates were conducted at each load condition. One trial test was conducted using the 11.35 lb/ft^2 load to insure that structural failure would occur before flames through the floor required the test be stopped.

In addition to the full-scale ASTM E 119 floor fire tests, other supplementary tests of materials and partial assemblies were conducted as follows:

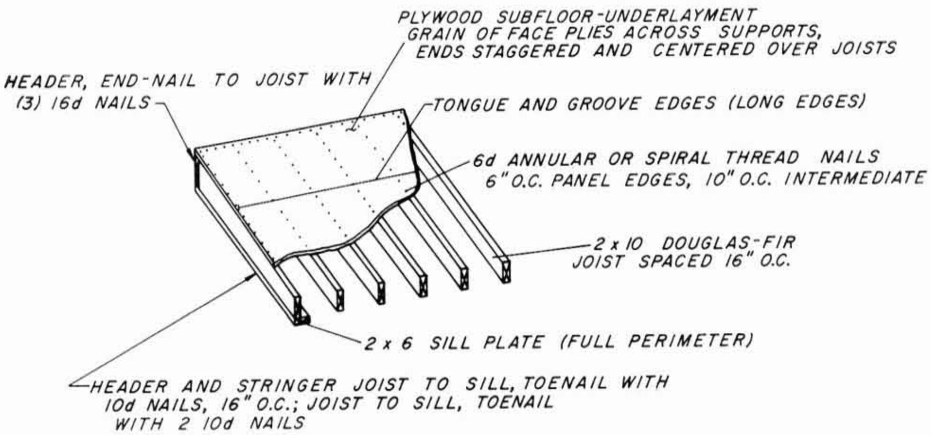

FIG. 2. Schematic diagram of floor construction.

1. Estimates of structural properties of the joists. The dynamic modulus of elasticity (MOE) for all 161 joists was determined using the E-computer (Galligan et al. 1977). A randomly selected group of 20 joists were tested in bending to obtain modulus of rupture (MOR) and MOE. Density was recorded as well. These tests defined the structural properties of the population of joists.
2. Plywood flooring fire resistance. Small-scale fire tests on 5- by 6-foot floor sections were conducted to insure that the plywood had sufficient fire resistance to allow structural failure of the joists before test termination in the large-scale ASTM E 119 fire tests.

The fire tests were conducted at the Construction Technology Laboratories' fire test facility at Skokie, Illinois.

Supplementary tests

E-computer.—The E-computer (Galligan et al. 1977) measures the weight and period of vibration to obtain an estimate for the MOE. With the joists laid flat on knife-edge supports, vibration was induced in the joist. Using the length and cross-sectional dimensions of the boards in addition to the weight and period of vibration, the E-computer calculates the dynamic MOE of the board.

Static bending test.—Twenty joists were tested for flexural properties according to ASTM D 198 (ASTM 1976). The joists were tested on their edges with lateral restraint to limit lateral buckling. With a span of 162 inches, the load was applied equally at the two one-third points. The rate of loading was 0.4 in./min. Before testing, the joists had been conditioned at 73 F, 50% relative humidity (RH) to produce a target equilibrium moisture content (MC) of 9%.

Based on the load-deflection curve and load at failure, the apparent MOE and the MOR were computed for each joist. Specimens were taken from each board to determine specific gravity (SG) and moisture content (MC).

Small-scale tests.—Five nonload-bearing floor sections were subjected to ASTM

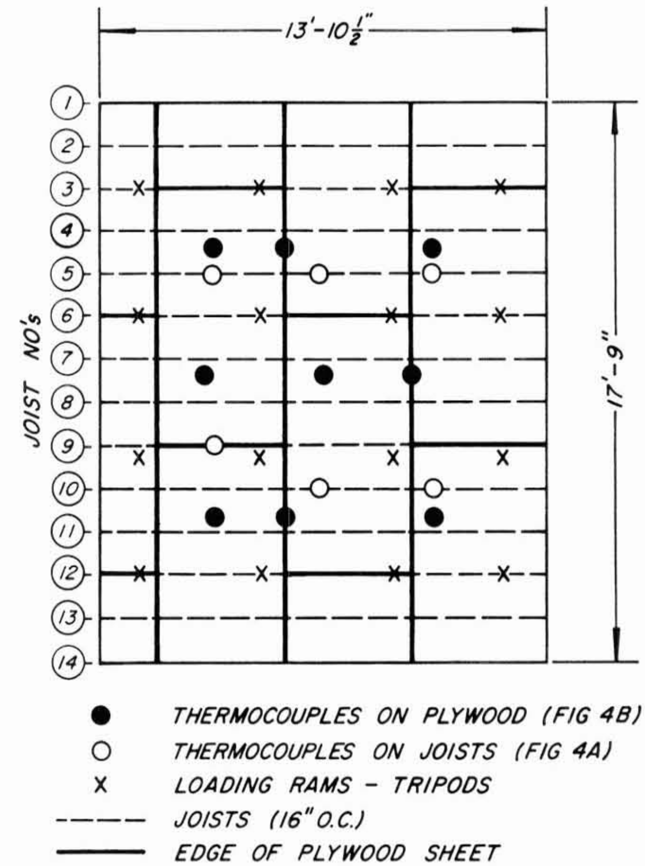

FIG. 3. Diagram of floor specimen indicating locations of thermocouples and loading rams.

E 119 fire exposure. During the tests, we observed the charring of the joists and the fire penetration of the floor covering.

In three tests, the floor material was just the $^{23}/_{32}$-inch-thick plywood. One test specimen had ½-inch-thick particleboard over the plywood and one test specimen had ⅝-inch-thick particleboard over the plywood. The 73- by 64-inch test specimens were constructed with five joists and two headers. Thermocouples were placed at different locations on the test specimens including five under asbestos pads on the unexposed side.

ASTM E 119 tests

The standard ASTM E 119 fire tests were conducted in a 14- by 18-foot floor furnace (Fig. 1). The floor furnace (Carlson and Hubbel 1969) is essentially a rectangular-shaped box in which the test specimens serve as the top closure. Gas burners within the furnace provide the standard fire exposure to the test specimen. A structural live load is imposed on the top of the specimen. In addition to visual observations, thermocouples record the temperatures within the furnace and on the test specimens, the atmospheric pressure within the furnace is recorded, and deflection of the floor is observed.

Test specimens.—The test specimen was constructed with the nominal 2- by

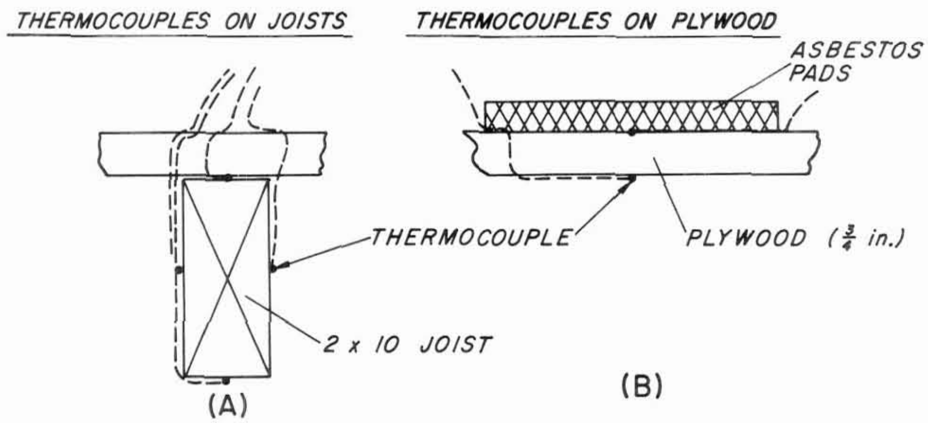

FIG. 4. Illustration of types of thermocouple locations.

10-inch joists and $^{23}/_{32}$-inch-thick plywood (Fig. 2). Fourteen joists and two headers were used to construct the 14- by 18-ft frame (Fig. 3). The joists spanned the 13-ft 10.5-in. width and were spaced 16 inches on center along the 17-ft 9-in. length. Butt ends of the plywood sheets were located over joists. Plywood joints perpendicular to the joists were tongue and groove. Plywood was nailed to joists with 6d spiral thread nails spaced 6 inches on center along the panel edges and 10 inches on center at intermediate joists. There was no blocking or bridging.

Bare thermocouples were located at several locations (Fig. 3). These thermocouples recorded temperatures at the bottom of the joists, at midheight of each side of the joist, at the interface of the plywood and the joist, and on the exposed and unexposed surfaces of the plywood (Fig. 4). As specified in ASTM E 119, the thermocouples on the unexposed surface were under asbestos pads. Temperature data were recorded at 1-min intervals.

Fire exposure.—Six high-capacity natural gas burners provided fire exposure. The gas flow was adjusted so the average furnace temperature followed the ASTM E 119 time-temperature curve. Thermocouples in sealed iron pipe tubes projecting up from the furnace floor measured furnace temperatures at fifteen locations. Consumption of natural gas was recorded at 1-min intervals. The area of the floor subjected to direct fire exposure was 12 by 16 feet.

Four ports in the furnace floor provided downdraft removal of flue gas. Draft pressure within the furnace was sampled at a single port located at one wall. The furnace was run at a slightly negative pressure.

We made observations of the fire exposure and the behavior of the specimen through a number of windows in the furnace wall.

Loading.—An hydraulic loading system applied the vertical live load. The loading system consists of 16 hydraulic cylinders mounted vertically on a structural steel load reaction frame (Fig. 1). Cylinders were positioned 42 and 54 inches center to center in 14- and 18-foot directions of the floor, respectively. Tripod load pads attached to the piston rod extensions of the cylinders further distributed the load. The 5-inch-square pads were 12 inches from the center of the cylinder. The total hydraulic pressure of the system was continuously recorded at a chart speed of 0.1 in./min. No restraints were imposed at the supports.

The two levels of uniform live load used in the fire tests were 11.35 lb/ft^2 and

TABLE 1. *2 by 10 Douglas-fir joist properties.*

Property	Destructive tests (20 joists) Mean	Destructive tests (20 joists) Coefficient of variation	Nondestructive tests (161 joists) Mean	Nondestructive tests (161 joists) Coefficient of variation
		%		%
Specific gravity	0.43	10	0.43	9
Moisture content, %	9.6	4	13.0	9
Modulus of rupture, lb/in.^{2}	5,280	47	([a])	([a])
Modulus of elasticity—static, klb/in.^{2}	1,530	25	([a])	([a])
Modulus of elasticity—E-computer, klb/in.^{2}	1,540	19	1,560	25
Width, in.	1.47	1	1.47	2
Height, in.	9.02	1	9.11	1

[a] Not measured.

79.2 lb/ft^2. The 11.35 lb/ft^2 was the average live load found by Karman (1969) in surveys of 183 domestic dwellings in Budapest (Corotis and Doshi 1977). It is consistent with the 10.0 lb/ft^2 average live load found in later surveys of single-family residences in the metropolitan Washington, D.C., area (Issen 1980). The 79.2 lb/ft^2 represents a maximum loading condition as described in ASTM E 119.

Using a span of 12 ft 11.5 in. and the average dimensions (1.47 in. by 9.11 in.) of the joists, the calculated extreme fiber stress in bending for a simple beam is 270 lb/in.^{2} for the 11.35 lb/ft^2 loading and 1,470 lb/in.^{2} for the 79.2 lb/ft^2 loading. If the standard dressed dimensions (1.5 in. by 9.25 in.) of the joists are used, the calculated outer fiber stress is 5% less.

Procedure.—After construction, the floor sections were kept in a storage room. At time of testing, a floor section was placed on top of the furnace. Four hours before the start of the test, the vertical live load was applied.

Once the burners were ignited at the start of the test, they were controlled so the average furnace temperature followed the ASTM E 119 time-temperature curve. Hydraulic pressure of the total load was continuously recorded. Furnace pressure, gas consumption, and temperatures were recorded every minute. Visual measurements of the deflection at the center of the floor were also made every minute. As required, visual observations were made on conditions inside the furnace, on the exposed surface, and on the unexposed surface of the floor. The test was terminated once structural failure of the center joists had occurred. The times of structural failure were based on visual and acoustic observations.

RESULTS AND DISCUSSION

Joist properties

The mean MOE of the twenty static bending tests was consistent with the mean obtained from the 161 E-computer tests (Table 1). The distribution of the results is illustrated in the histograms of the E-computer's MOE (Fig. 5) and the bending MOR (Fig. 6). In the bending tests, three-fourths of the joist failures initiated on the tension side of the joists. The difference in MC of the twenty joists and 161 joists (Table 1) occurred because the E-computer tests were conducted before conditioning had been completed.

On the basis of past experience, the distribution of MOR and MOE of the

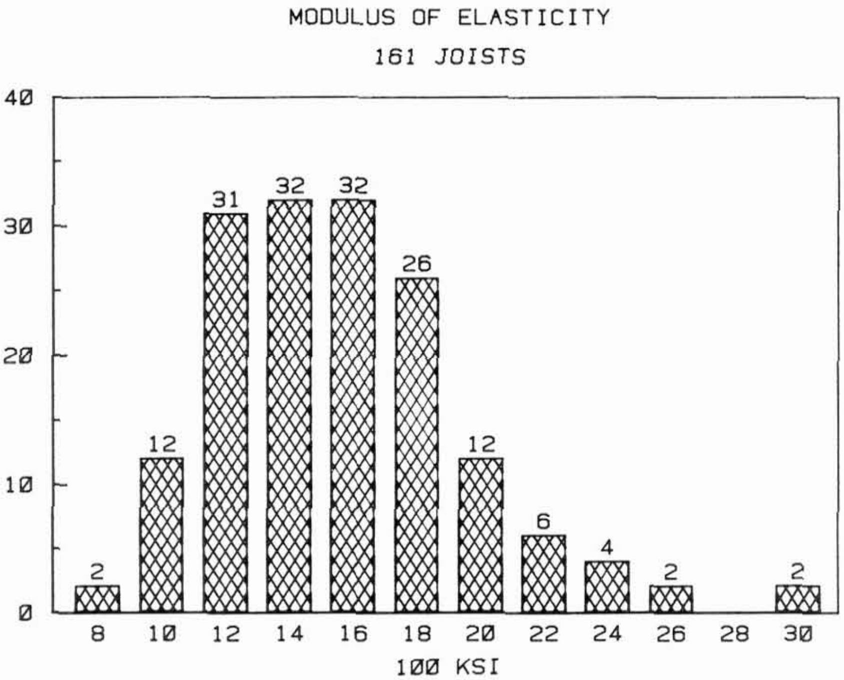

FIG. 5. Histogram of E-computer's modulus of elasticity of 161 joists.

selected twenty joist specimens was fitted to a Weibull distribution. A program developed by Simon and Woeste (1980) was used to estimate the 3 parameters. For the 3-parameter Weibull distribution model given by:

$$f(x;\eta,\sigma,\mu) = \left(\frac{\eta}{\sigma}\right)\left(\frac{x-\mu}{\sigma}\right)^{\eta-1} \exp\left\{-\left(\frac{x-\mu}{\sigma}\right)^{\eta}\right\}$$

the values of the parameters are:

	MOR	MOE
Shape, η	2.20	3.83
Scale, σ	5,630 psi	1,390,000 psi
Location, μ	270 psi	270,000 psi

The data were plotted versus the theoretical line predicted by the above parameters using an approach recommended by Nelson and Thompson (1971). The coincidence of the data with the theoretical curve was good (Fig. 7).

Small-scale floor-sheathing tests

The five small-scale tests were conducted to insure the adequacy of the floor sheathing for the ASTM E 119 tests. The two tests with a layer of particleboard on top of the plywood were terminated before fire penetration of the particleboard. In the three tests with only plywood, the initial flame penetration occurred at 18.9, 19.2, and 19.0 min. In two tests, failure was at the tongue-and-groove joint. In the third test, failure occurred under a thermocouple pad. Charring of the

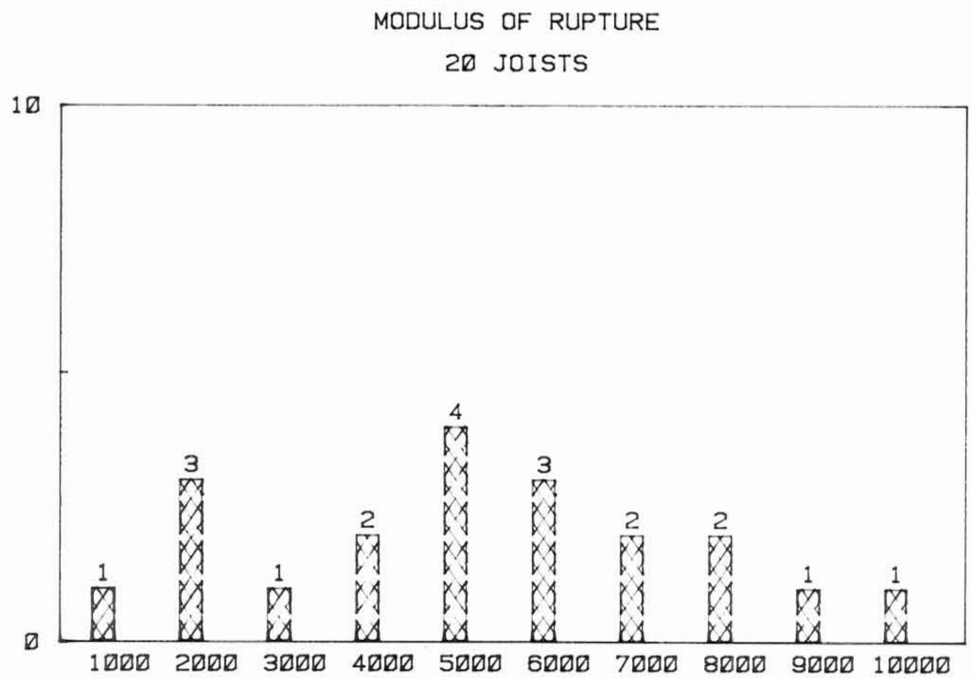

FIG. 6. Histogram of modulus of rupture of 20 joists tested in destructive bending test.

tongue-and-groove joints first occurred at about 13 min into the tests. On the basis of the high degree of charring of the joists at the end of the tests, we concluded that the single layer of plywood would be sufficient for the standard tests.

ASTM E 119 tests

Test conditions.—Before testing, the eleven floor specimens were kept in a storage room in which daily temperature measurements ranged from 68 to 80 F and daily RH measurements ranged from 32% to 68%. This represents a possible range in equilibrium MC of 6.1% to 11.5%. In measurements with a portable resistance-type moisture meter at the time of testing, the MC readings of the joists ranged from 8.2% to 12.0%. The mean MC's of the joists for the individual floors were approximately 10% with coefficients of variation (COV) of about 5%.

The furnace room atmospheric conditions were 72 to 84 F and 50% to 61% RH. The eleven tests were conducted during the months of June, July, and August of 1981.

Furnace pressure during the tests was maintained at between −0.01 and −0.30 in. of water. In the eleven tests, the mean pressures were −0.08 in. of water and the COV's were typically 50%. While negative furnace pressures were always recorded, we saw evidence that possible positive pressure developed at times near the top of the furnace. This conclusion was based on the significant volume of smoke that sometimes escaped from the top of the specimens.

Fire exposure and temperature development.—Based on the area under the time-temperature curve and above 68 F, the fire exposure was, in most cases, more severe than the ASTM E 119 time-temperature curve. The differences in areas

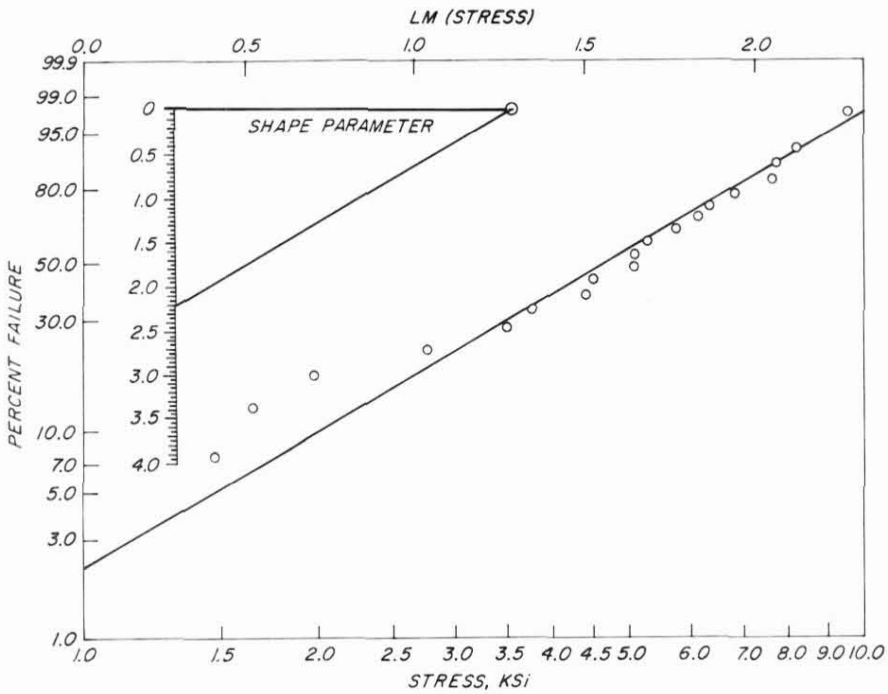

FIG. 7. Weibull probability plot of modulus of rupture data (20 joists).

were 2 to 12% greater, except for test 5, which was 4.8% less severe than the standard curve.

Typical time-temperature curves are shown in Figs. 8 and 9. The bare thermocouples on the exposed surface of the specimen reflect the erratic nature of the fire exposure. In contrast, the temperatures recorded by the thermocouples in iron pipe tubes increased smoothly. There was about a 1-min lag in the initial response of these sealed thermocouples.

The temperature of the thermocouples at the bottom of the joists was close to the ASTM E 119 time-temperature curve. Average temperatures for the thermocouples at midheight on the joist and on the exposed surface of the plywood were usually somewhat lower than the average temperatures at the bottom of the joists.

The pattern of gas consumption was consistent. The gas consumption rates for several time periods during the low-load tests were computed. In the first 3 min, gas was consumed at a rate of 420 ft^3/min; for the period from 3 to 7 min at a reduced rate of 151 ft^3/min; from 8 to 11 min returning to a higher rate of 358 ft^3/min; and for the rest of the test, 11 to 17 min, at the lower rate of 222 ft^3/min. Changes in the gas consumption rates are reflected by the dips in the time-temperature curves of the bare thermocouples (Figs. 8 and 9). The initial high gas consumption rate is required to follow the ASTM E 119 time-temperature curve. Intense energy input is needed to get the 186 F per min rise required in the first 5 min. In the subsequent 5-min periods of 5 to 10, 10 to 15, and 15 to 20 min, the required temperature rise is 60, 20, and 13 F per min, respectively.

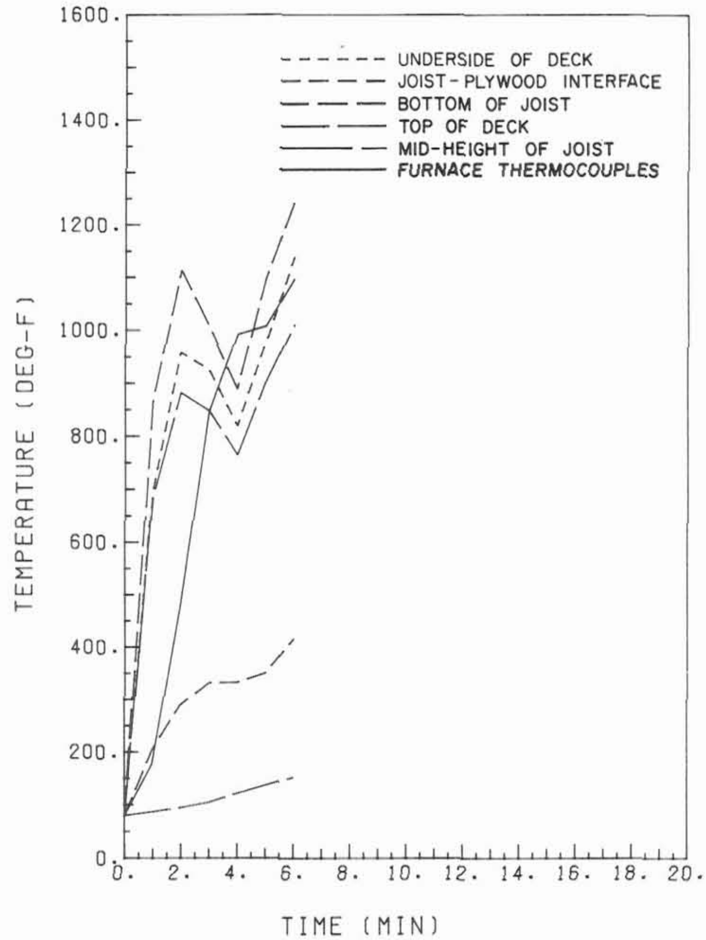

FIG. 8. Typical time-temperature curves for average temperatures in tests with high-load level.

Floor performance.—In most of the tests, smoke was observed streaming from the butt joints in the plywood flooring within the first minute. These joints were located over the joists. In the high-load tests, the floor rippled at 3 to 6 min. Rippling was characterized by deflections of the sheathing along the lines of the application of the loading rams. This was followed by failure of the joists at 5 to 8 min (Table 2). Fire penetration was associated with the failure of the joists.

In the low-load tests, fire penetration occurred at the plywood tongue-and-groove and at butt joints before failure of the joists. At 8 to 14 min, there was charring along the plywood joints. Based on the temperatures (Fig. 9) recorded by the thermocouples under the asbestos pads (Fig. 4), the times to reach the critical temperature rise at 250 F average or 325 F maximum range from 12.9 to 15.1 min (Table 3). These thermocouples recorded the charring temperatures of 550 F at 16.0 to 17.5 min (Table 3). Burn through at the joints occurred at 12 to 17 min (Table 3). Sometimes openings occurred and the interior of the furnace was visible just prior to actual burn-through. Surface flaming was controlled by

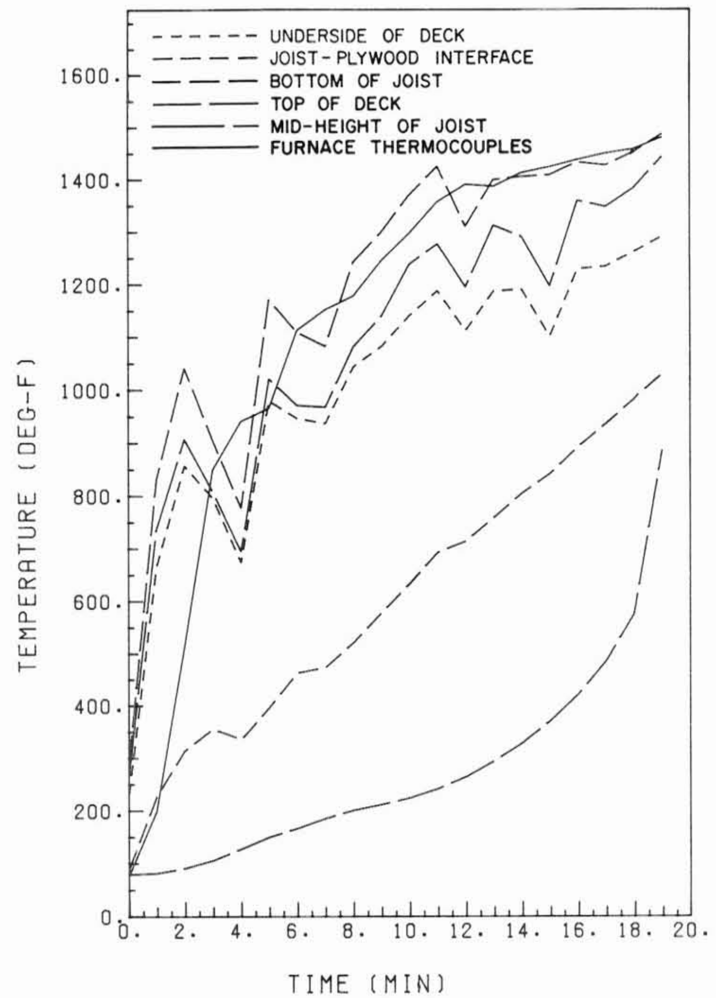

FIG. 9. Typical time-temperature curves for average temperatures in tests with low-load level.

sprinkling with water as necessary to continue the test. In these low-load tests, failure of the joists occurred at 16 to 19 min (Table 2).

Consistent results were obtained for the times of structural failure (Table 2). With the low load of 11.35 lb/ft^2, the mean result was 17.9 min for the failure of the first joist. The COV was 3.7%. For the high load of 79.2 lb/ft^2, the mean result for first joist failure was 6.5 min and the COV was 11.6%.

The typical live loading specified in the building codes for residential one- and two-family dwellings is 40 lb/ft^2. Based on linear interpolation of the experimental results, first joist failure would have occurred in 13.1 min if a 40-lb/ft^2 live load had been used.

In addition to visual observations, the structural performance of the joists is indicated by the deflection at the center of the floor (Figs. 10 and 11). The deflection measurements reflect primarily joists Nos. 6, 7, and 8 near the center of the floor.

TABLE 2. *Observed times-to-failure of wood joists.*

Floor no.	Live load level	First joist failure		Second joist failure		Third joist failure	
		Joist no.	Time	Joist no.	Time	Joist no.	Time
	lb/ft²		*min*		*min*		*min*
Trial	11.35	2	16.7	7	17.0	8	17.0
1		5	17.8	7	18.0	3	18.5
2		5	16.8	4	17.2	3	17.4
3	11.35	4/5	18.0	4/5	18.0	2	18.5
4		6	18.4	7/9	18.8	7/9	18.8
5		6/7	18.5	6/7	18.5	8	18.9
Mean[a]			17.9		18.1		18.4
6		5/6	6.2	5/6	6.2	—	—
7		12	6.8	8/9	7.6	8/9	7.6
8	79.2	3/5	7.5	3/5	7.5	7	7.7
9		6	5.5	7	5.6	9	6.3
10		6	6.3	7	6.7	9	6.8
Mean[b]			6.5		6.7		7.1

[a] Coefficients of variation of results are 3.7%, 3.2%, and 3.2% for first, second, and third joist failure, respectively.
[b] Coefficients of variation of results are 11.6%, 12.4%, and 9.4% for first, second, and third joist failures, respectively.

Visual observations were for the individual joists. The deflection data were recorded between 1-min intervals and do not necessarily reflect behavior within the 1-min time.

In the high-load tests, deflection increased steadily from ignition to 4 min into the tests (Fig. 10). From 4 to 8 min, rapid deflections (Fig. 10) associated with failure occurred. These deflection measurements basically agreed with the visual observations.

In the low-load tests, rapid deflection at the center occurred after 17 min (Fig. 11). Again, these deflection measurements are in agreement with the visual observations of joist failure times. For tests 6, 8, and 10, the last deflection (Fig. 11) readings were just prior to initial joist failures. In tests 2 and 4, deflection was read after initial joist failures.

The overall behavior of the floor is indicated by the ability to maintain the

TABLE 3. *Thermal performance of ASTM E 119 test specimens.*

Floor no.	Times for critical temperature rise[a,b]	Times for observed burn through of plywood[c]	Times for temperature of 550 F[a,d]
	min	*min*	*min*
Trial	13.9	13.5	>16[e]
1	15.1	14.0	17.1
2	13.9	12.3	16.0
3	14.4	12.1	16.8
4	15.0	15.1	17.5
5	12.9	14.3	14.4

[a] Temperatures are for thermocouples under asbestos pads on the unexposed surface of the floor.
[b] Critical temperature rise criteria are 250 F average temperature or 325 F individual thermocouple.
[c] Burn-through occurred at the joints.
[d] 550 F can be assumed to be the charring temperature of wood.
[e] Last reading was at 16 min.

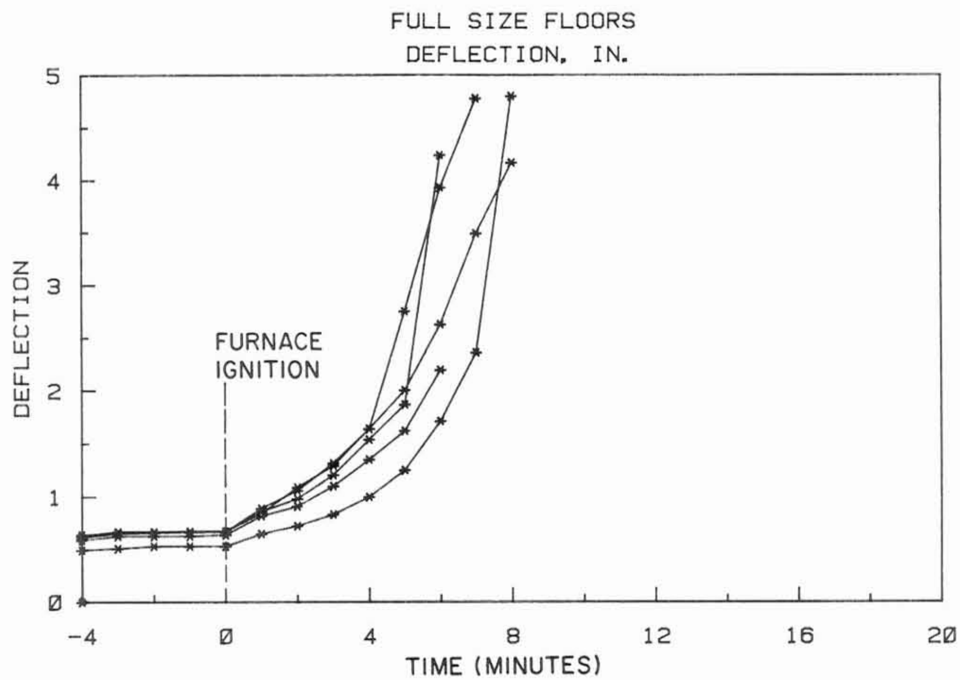

FIG. 10. Deflection at center of floor specimen in tests with high-load level.

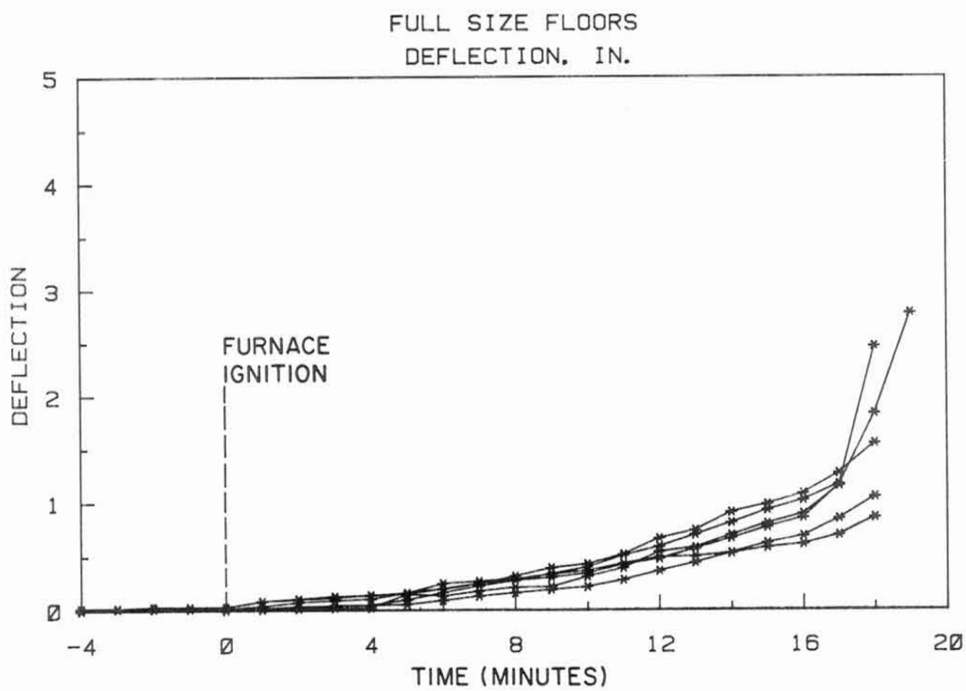

FIG. 11. Deflection at center of floor specimen in tests with low live load.

hydraulic pressure in the loading system. Loss of hydraulic pressure occurred when the rate of deflection was greater than the ability of the hydraulic system to maintain the applied load. In several of the tests, the recordings of the pressure indicated a recovery of the load-bearing capacity after the initial joist failure. The load was apparently transferred to the remaining joists. The hydraulic pressure was shut off shortly after the failure of the center joists.

Linear regression analysis was used to investigate the variability in the results. No consistent statistically significant correlations were obtained because of the small number of tests relative to the number of variables affecting the test results. The analysis did suggest that the variation in severity of the fire exposure and the MOE of the joists were factors affecting the results. Fire severity variation, as well as the density and MC, would affect the rate of charring. The effect of MOE probably reflects its strong correlation with MOR. The charring rate and MOR are included in the analytical model for fire-exposed floors.

SUMMARY

For a population of 2- by 10-inch Douglas-fir joists with known structural properties, a total of 11 ASTM E 119 tests were conducted of an unprotected wood joist floor system. The joist population had a mean MOR of 5,280 lb/in.^{2} and mean MOE of 1,530,000 lb/in.^{2}. For the five floors loaded to 11.35 lb/ft^2, the mean time for initial joist failure was 17.9 min with a coefficient of variation of 3.7%. For the five floors loaded to 79.2 lb/ft^2, the mean time for initial joist failure was 6.5 min with a coefficient of variation of 11.6%. There was one trial test using a load of 11.35 lb/ft^2.

Visual and acoustic observations of joist failures were generally consistent with deflection measurements. Fire resistance and load-carrying capacity by the floor sheathing itself and load sharing between joists were evidenced in the data and visual observations.

Future research needs include the experimental verification of the model for unprotected floor-truss assemblies and the expansion of existing models to protected floor-ceiling assemblies.

REFERENCES

American Society for Testing and Materials. 1976. Standard methods of static tests of timbers in structural sizes. ASTM D 198-76. ASTM, Philadelphia, PA.

———. 1979. Standard method of fire tests of building construction and materials. ASTM E 119-79. ASTM, Philadelphia, PA.

Baldwin, R. 1975a. Cost effectiveness-optimization. Build. With Steel No. 19. British Steel Corp.

———. 1975b. Economics of structural fire protection. Build. Res. Establ. Curr. Pap. CP45/75. Fire Research Station, Borehamwood, England.

Burros, Raymond H. 1975. Probability of failure of building from fire. J. Struct. Div., ASCE 101(ST9):1947–1960.

Carlson, C. C., and J. B. Hubbell. 1969. Design and operation of the PCA floor furnace. Portland Cement Assoc., Skokie, IL.

Corotis, Ross B., and Viresh A. Doshi. 1977. Probability models for live-load survey results. J. Struct. Div., ASCE 103(ST6):1257–1274.

Galligan, William L., Delos V. Snodgrass, and Gerald W. Crow. 1977. Machine stress rating: Practical concerns for lumber producers. USDA For. Serv. Gen. Tech. Rep. FPL-7. For. Prod. Lab., Madison, WI.

GENERAL SERVICES ADMINISTRATION. 1972. Interim guide for goal-oriented systems approach to building fire safety. Appendix D of Building Fire Safety Criteria. PBS P5920.9 CHGE 2.

ISSEN, L. A. 1980. Single-family residential fire and live loads survey. NBSIR 80-2155. Nat. Bur. Stand., Washington, DC.

KARMAN, T. 1969. Statistical investigations on live loads on floors. Int. Counc. for Build. Res., Stud. of Doc. Comm. W 23 (RILEM Session), Madrid, Spain.

LIE, T. T. 1972. Optimum fire resistance of structures. J. Struct. Div., ASCE 98(ST1):215–232.

———. 1974. Economics design for fire safety. Build. Int. 7:289–304.

MAGNUSSON, SVEN ERIK. 1973. Probabilistic analysis of fire safety. ASCE Natl. Struct. Eng. Meet., San Francisco, CA, Apr. 9–13.

———, AND OVE PETTERSSON. 1981. Rational design methodology for fire exposed load bearing structures. Fire Saf. J. 3(4):227–241.

NELSON, W., AND V. C. THOMPSON. 1971. Weibull probability papers. J. Qual. Technol. 3(2):45–50.

SCHAFFER, E. L., AND F. E. WOESTE. 1981. Reliability analysis of a fire-exposed unprotected floor truss. Metal Plate Wood Truss Conf. Proc. For. Prod. Res. Soc., Madison, WI.

SIMON, J. C., AND F. E. WOESTE. 1980. A system-independent computer program to obtain maximum likelihood estimates of the 3-parameter Weibull distribution. Trans. ASAE 23(4):955–958.

WOESTE, F. E., AND E. L. SCHAFFER. 1979. Second moment reliability analysis of fire-exposed wood joist floor assemblies. Fire Mater. 3(3).

———, AND ———. 1981. Reliability analysis of fire-exposed light-frame wood floor assemblies. USDA For. Serv. Res. Pap. FPL 386. For. Prod. Lab., Madison, WI.