Fire Performance of Protected Floor/Ceiling Assemblies and Impact on Tenability

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Introduction

After a previous study of unprotected floor/ceiling assemblies under basement fire scenarios [1], a further experimental program was undertaken to investigate the performance of protected floor/ceiling assemblies and the tenability conditions in a test facility representing a two-storey detached single-family house.

A series of full-scale fire experiments were conducted using four types of floor systems (wood I-joist, steel C-joist, metal web wood truss and solid wood joist assemblies), which were selected from the assemblies that had been tested in the previous study [1]. The test floor assemblies were protected on the basement side (the fire exposure side) by a regular gypsum board ceiling, residential sprinklers or a suspended ceiling. Table 1 shows a matrix for the full-scale fire experiments. The study focused on the impact of the protection measures on the life safety of occupants from the perspective of tenability for occupants and integrity of structural elements as egress routes.

Table 1. Matrix of Full-Scale Fire Experiments.

Test Assembly	Gypsum board ceiling only	Suspended ceiling only	Sprinklered only
Wood I-joist	√	√	√
Metal web wood truss	√		√
Steel C-joist	√		
Solid wood joist	√		

Experimental Facility

The experimental facility represented a typical two-storey single-family house with a basement. Each storey of the test facility had a floor area of 95 m^2 and a ceiling height of 2.4 m. The basement was partitioned to create a fire room (5.3 m long by 5.2 m wide) representing a basement living area (the remaining area was blocked off and not used during the experiments). An exterior opening (2.0 m wide by 0.5 m high) was located 1.8 m above the floor in the south wall of the basement fire room. A removable noncombustible panel was used to cover the opening at the beginning of each experiment.

A 0.91 m wide by 2.05 m high doorway opening located on the north wall of the fire room led into a stairwell enclosure. At the top of this stairwell, a 0.81 m wide by 2.05 m high doorway led into the first storey.

The first storey had an open-plan layout. A 0.89 m wide by 2.07 m high doorway led to the exterior. For each experiment, a floor/ceiling assembly was constructed on the first storey directly above the basement fire compartment. A single layer of oriented strandboard was used for the subfloor of all assemblies without additional floor finishing materials on the test floor assemblies. The test floor assemblies were protected on the basement side with regular gypsum board, residential sprinklers or a suspended ceiling. The overall dimensions of the test assemblies were 5.1 m by 5.2 m. Each test assembly formed ¼ of the floor area on the first storey. The remainder ¾ of the floor area on the first storey was constructed out of noncombustible materials.

The staircase from the first storey to the second storey was not enclosed. The second storey was partitioned to contain three bedrooms, which were connected by a corridor (4.45 m long by 1.10 m wide).

Extensive instrumentation was used to measure the smoke density, combustion gas products and temperatures throughout the test facility and to measure the structural responses of the test floor assemblies (temperatures, deflection and flame penetration). A heat flux meter was installed in the basement fire room. Residential ionization and photoelectric smoke alarms were installed on each level and in each bedroom, which were powered by batteries (new smoke alarms were used in each experiment).

Fuel Package and Fire Scenario

A simple and repeatable fuel package was used in the full-scale experiments. This fuel package consisted of a mock-up sofa constructed with 9 kg of exposed polyurethane foam (PUF), the dominant combustible constituent of upholstered furniture, and 190 kg of wood cribs beside and underneath the mock-up sofa. The PUF was used without any upholstery fabric which is used in typical upholstered furniture. The mock-up sofa was located at the center of the basement fire room and was ignited using a gas burner in accordance with the ASTM 1537 test protocol [2]. The wood cribs provided the remaining fire load to sustain the fire.

The doorway from the basement fire room to the first storey had no door (i.e., open basement doorway) in this series of the experiments. On the second storey, the door to one bedroom was open and the doors to the other bedrooms were closed. The exterior window opening in the basement fire room and the exterior door on the first storey were initially closed. The noncombustible panel that covered the fire room's exterior window opening was manually removed if and when the temperature measured at the opening reached 300°C. This would provide the ventilation air required for combustion and simulate the fire-induced breakage and complete fall-out of the window glass. To simulate occupants evacuating the test house, the exterior door on the first storey was opened at 180 s after ignition and left open.

This fire scenario provided a relatively severe, fast-growing basement fire with a very reproducible fire exposure to provide a reasonable challenge to the structural integrity of the test floor assembly above the basement.

Results and Discussions

The measurement data were analyzed to determine the fire performance of the protected floor/ceiling systems, tenability conditions in the floor areas above the fire, and timeline for fire initiation, smoke alarm activation, onset of untenable conditions, and structural failure.

Four experiments were conducted respectively using a wood I-joist assembly, steel C-joist assembly and metal web wood truss assembly, as well as, solid wood joist assembly with regular gypsum board (12.7 mm thick) on the basement side of the test assembly (i.e. gypsum board ceiling in the fire room). The experiments conducted using the gypsum board protected assemblies exhibited the same chronological sequence of fire events — fire initiation, smoke alarm activation, onset of untenable conditions, and finally structural failure of the test floor assemblies. The smoke alarms in the basement fire compartment took 30 s to activate consistently. Smoke obscuration was the first hazard to arise. The smoke obscuration limit (optical density = 2 m^{-1} at which occupants cannot see more than a distance of an arm's length) was reached around 190 s in these experiments. (People with impaired vision could become disoriented earlier at an optical density lower than 2 m^{-1}). Untenable (incapacitation) conditions were reached shortly after smoke obscuration. Heat exposure reached the incapacitation doses on the first storey after 240-300 s; CO exposure reached the incapacitation doses on the second storey after 300-400 s. Compared to the experiments conducted in the previous study using the same floor structures without gypsum board protection, tenability conditions were similar or improved slightly whilst the structural performance was improved significantly with the gypsum board protected floor assemblies. The times taken to reach structural failure for the gypsum board protected floor assemblies were more than 1200 s, much longer than those with no protection. With gypsum board protection, all engineered test assemblies had the structural failure time similar to that of the solid wood joist assembly under the test fire scenario.

One experiment was conducted using a wood I-joist floor assembly with a suspended ceiling in the basement fire room. Mineral fiber panels were installed on metal tracks below the test assembly in the basement fire room. The experiment with the suspended ceiling followed the same sequence of fire events as mentioned above; the timeline for fire initiation, smoke alarm activation, and onset of untenable conditions was also similar to the experiments with the gypsum board protection. The time to reach structural failure was approximately half of that with the gypsum board protection. The benefit of the suspended ceiling as a floor protection measure was marginal since the floor structural collapse was delayed only slightly compared to the same floor assembly without protection; tenability conditions were also similar to the same floor assembly without protection.

Two different residential sprinkler systems were used in the experiments, respectively. One experiment was conducted using a wood I-joist floor assembly with a two-sprinkler layout in the basement fire room. This sprinkler system used CPVC plastic piping (25.4 mm in diameter) with two pendent sprinklers (K factor 4.9, temperature rating 68°C) installed below the bottom of the exposed wood I-joists and 3.66 m apart along the centerline of the fire compartment. The sprinkler system was designed to operate at 1.0 $\times 10^5$ Pa (15 psi) with minimum 72 Lpm (19 USgpm) flow from each sprinkler. In this experiment, only one sprinkler activated by the heat, provided a pressure of 1.9 $\times 10^5$ Pa (27.9 psi) and a flow of 98 Lpm (25.9 USgpm). This single sprinkler activation was able to control the fire quickly and keep the temperature in the fire room close to the ambient level. Tenability limits were not reached during the 1200-s experiment. There was no structural damage to the test floor assembly and no damage to the sprinkler piping system either.

The second residential sprinkler system used in the experiments was a single sprinkler system with the same type of the pendent sprinkler and CPVC plastic piping. The single sprinkler system was used in two fire experiments conducted with the wood I-joist floor assembly and the metal web wood truss assembly, respectively. The pendent sprinkler was installed below the bottom of the exposed wood I-joist or truss and located 3.05 m (10 ft) from both the south and east walls of the fire compartment. The sprinkler was set to operate at 1.4×10^5 Pa (20.2 psi) with an 83.2 Lpm (22 USgpm) flow. The single sprinkler system effectively protected the structural integrity of the test floor assemblies and kept the conditions tenable in the test house during the experiments. The test floor assemblies had no structural damage and the tenability limits were not reached during the experiments.

Conclusions

With the gypsum board protected floor assemblies, tenability conditions were similar or improved slightly, whilst the structural performance was improved significantly in the experiments, compared to the experiments conducted in the previous study using the same floor structures without gypsum board protection. With gypsum board protection, all engineered test assemblies had similar structural failure times, matching that of the solid wood joist assembly under the test fire scenario.

The benefit of the suspended ceiling as a protection measure for the test assembly was marginal, compared to the same test assembly without a suspended ceiling.

The residential sprinkler systems effectively protected the structural integrity of the test assemblies and there was no structural failure or damage to the test assemblies in the test scenario. The residential sprinkler systems also kept the conditions tenable in the test house during the experiments.

References

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