

Simulating the Effect of Sloped Beamed Ceilings on Detector and Sprinkler Response

by

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The rapid activation of fire detection and suppression systems in response to a growing fire is one of the important factors required to provide for life safety and property protection. Rapid activation requires that sensors be located at optimal distances both beneath the ceiling and radially from the fire. Ceiling obstructions, such as beams and joists, and ceiling slope can significantly modify the flow of smoke along the ceiling and must be taken into consideration when a particular detection system is designed. At present, the standards used to guide the design of these systems contain very little quantitative information concerning the impact of beamed, sloped ceilings on detector placement.

A multiyear, International Fire Detection Research Project sponsored by the National Fire Protection Research Foundation (NFPRF) was initiated to provide quantitative information on the impact of beams, ceiling slope, and forced ventilation on the movement of smoke and response of smoke and heat detectors. During the first year of the project, numerical modeling was validated and additional simulations of smoke and heat detectors in level, beamed ceiling geometries for slow, medium, and fast growing fires of 100 kW and 1 MW were completed [1]. Beamed ceilings with beam spacings of 1.2 m (4 ft), 1.5 m (5 ft), 1.8 m (6 ft), 2.1 m (7 ft) or 2.4 m (8 ft) and beam depths of 0.1 m (4 in), 0.2 m (8 in), 0.3 (12 in) and 0.6 m (24 in) were modelled. The ceiling heights modelled included 3.3 m (11 ft), 4.6 m (15 ft), 5.8 m (19 ft), 6.7 m (22 ft), 7.6 m (25 ft) and 8.5 m (28 ft). Smoke detectors were assumed to activate when the temperature reached 13 °C above ambient. Heat detectors were simulated using the model of Heskestad and Smith [2] and were assumed to activate when the temperature reached 57 °C above ambient. It was found that conditions under beams may be equivalent in some cases to conditions in the channels between the beams at an equivalent depth beneath the beam or ceiling. Also, depending on detectable fire size, beam depth and beam spacing, smoke detectors or quick response fusible link may not be required for each beam channel. Recommendations for detector placement were made for the geometries studied.

This presentation describes the results of the second year of the project. During the second year, numerical simulations of smoke movement in response to sloped, beamed ceilings were studied using the computational fluid dynamics model HARWELL-FLOW3D. Sloped ceilings of 10, 25, and 50 degrees were studied for beams running along the ceiling slope. Beam spacings of 1.2 m (4 ft) and 2.4 m (8 ft) with beam depths of 0.1 m (4 in), 0.2 m (8 in), 0.3 m (12 in) and 0.6 m (24 in) were modelled. Medium growth fires of 100 kW and 1 MW were used in the study and ceiling heights above the plume were restricted to 3.3 m (11 ft) and 4.6 m (15 ft). It was found that increasing ceiling slope allowed the parallel beams to channel the smoke more effectively in the upslope direction. Downslope flow decreased substantially as ceiling slope was increased. When smoke flowed into an adjacent beam channel, the conditions under the beam separating the two beam channels were suitable for detector placement. Slow response detectors ($RTI\ 300\ (m\ s)^{1/2}$) require substantially denser placement requirements in order to produce satisfactory detection compared with fast response detectors ($RTI\ 50\ (m\ s)^{1/2}$) or smoke detectors.

Numerical simulations for beams perpendicular to the ceiling were done for ceiling slopes of 10 and 25 degrees. Beam spacing of 2.4 m (8 ft) and beam depths of 0.15 m (6 in), 0.30 m (12 in) and 0.46 m (18 in) were used with the medium growth fires of 100 kW and 1.0 MW. Ceiling heights were chosen to be 3.3 m (11 ft). It was found that increasing the ceiling slope caused the beams to be less effective at slowing the smoke flow up the ceiling. There was also substantially less smoke flow over beams located beneath the plume center on the downslope side of the ceiling. The perpendicular beams produced substantial flow along the beams. For the 0.46 m (18 in) beams, upslope flow tended to occur where the beam meet a side wall rather than occurring directly upslope from the plume.

Special cases of beams with gaps between the top of the beam and the ceiling were also studied. For beams parallel to the ceiling, a ceiling slope of 50 degrees was used for beams separated by 1.2 m (4 ft) on center with a beam gap of 0.08m (3 in) for 0.6 m (24 in) beams. It was found that this gap did increase the smoke flow into adjacent channels.

For beams perpendicular to the ceiling, a ceiling slope of 25 degrees was used for beams separated by 2.4 m (8 ft) on center with a beam gap of 0.13m (5 in) for 0.46 m (18 in) beams. While the beams did provide some resistance to the flow of smoke up the ceiling, the gap provided a substantial increase in the flow rate up the ceiling.

Recommendations for the placement of smoke detectors and heat detectors with RTI ratings of 50, 100, and 300 (m s)^{1/2} are made for both parallel and perpendicular beam geometries for the detection of 100 kW and 1 MW fires.

1. Glenn P. Forney, Richard W. Bukowski, and William D. Davis, Field Modeling: Effects of Flat Beamed Ceilings on Detector and Sprinkler Response, National Fire Protection Research Foundation, Batterymarch Park, Quincy, Mass, USA. 1993.
2. Gunnar Heskestad and Herbert F. Smith. Investigation of a New Sprinkler Sensitivity Approval Test: The Plunge Test. Technical Report Serial No. 22485 2937, Factory Mutual research Corporation, Norwood, MA, 1976. RC 76-T-50