Comparison of sprinkler activation times under flat and corrugated metal deck ceiling

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ABSTRACT

The distance of sprinklers below ceiling is of fundamental importance since it has a great influence on activation time. Accepted distances are specified in different sprinkler standards such as NFPA 13, FM 2-0 and EN 12845 for different configurations. This distance is unambiguously defined for flat smooth ceilings, but for corrugated ceilings, such as corrugated metal deck ceilings found in many warehouses, the distance can be measured from either the top or the bottom of the deck. NFPA 13 states that it should be measured from the bottom if the thickness of the deck is below 75 mm and from the top if it is higher. The requirement in NFPA 13 has been adopted from the FM datasheets, but the authors have been unable to identify any background to this requirement.

In this paper, the activation time of sprinkler heads at different distances below a corrugated ceiling with thickness of 125 mm was simulated using FDS 6.6.0 and compared to distances below a flat smooth ceiling. The case was based on a warehouse with 6-tier storage of Uncartoned Expanded Plastics (UEP) with a ceiling height of 11.2 m and clearance to storage of 2.6 meters. Only the activation of the first sprinkler was simulated since it was expected that the drag from droplets of previously activated sprinkler heads would thicken the ceiling jet, making the activation time of additional sprinkler less sensitive to the distance from ceiling.

The results show that the corrugated ceiling has a large influence on the ceiling jet allowing sprinklers further from the ceiling to activate.

In the case studied, the activation time of sprinklers below the corrugated ceiling more closely resembled those under a flat smooth ceiling when the distance below the corrugated ceiling was measured from the bottom of the deck. More simulations and experiments are however needed before any guidance on changes in sprinkler standards can be given.

KEYWORDS:
suppression; CFD; sprinkler activation; corrugated ceiling
INTRODUCTION

The distance of sprinklers below ceiling is of fundamental importance for effective operation since it has a great influence on activation time. If the sprinkler is located too far from the ceiling, it will not be affected by the ceiling jet of the fire and will therefore fail to activate according to the fire tests on which the design is based. When the sprinkler eventually activates, the fire might be too large for the specified sprinkler flow and the system will fail to achieve its intended goal.

For flat smooth ceilings, the distance below ceilings are unambiguously defined, but for corrugated ceilings such as corrugated metal deck ceiling the distance can be defined as either the top or bottom of the deck. NFPA 13-2017 [1] specifies in point 8.5.4.1.2 that this depends on the depth of the corrugated ceiling, if this is below 75 mm the distance should be measured from the bottom and if it is above 75 mm it should be measured from the top. This was adopted to the 2007 edition of NFPA 13 based on a proposal to the committee [2]. The requirement was adopted from a similar requirement in FM datasheet 2-0 [3]. The authors have been unable to identify any empirical background to this requirement.

The depth of the corrugated metal deck is chosen to achieve the needed stiffness of the design which is, among other things, dependent on snow load. Therefore, at least in many northern countries, the depth of the corrugated ceiling is almost always above 75 mm and therefore the distance from ceiling should be measured from the top of the metal deck ceiling. This often poses a practical challenge for sprinkler design since the designer must put the pipe below beams and other similar obstacles.

The flow patterns in non-flat ceilings are rather complex and continuous obstructions close to the ceiling is known to push the ceiling jet downwards towards the sprinkler head and therefore sprinklers are generally allowed to be placed further from the ceiling in such situations (defined as obstructed ceilings in NFPA 13). This effect can be expected to occur to some extent also in corrugated metal deck ceilings, but the extent is unknown.

In this paper numerical experiments [4] are performed using FDS to investigate the influence of the corrugation of the ceiling on the sprinkler activation time.

METHODOLOGY

Two different cases were compared where one had a corrugated ceiling and the other had a flat smooth ceiling. The comparison was performed using simulation in FDS version 6.6.0 [5]. The quantity of interest was the activation time of the first sprinkler since after the first activation, the turbulence of the ceiling jet is increased by the drag of the sprinkler droplets. This will lead to a thickening of the ceiling jet and therefore the activation time of the following sprinkler can be assumed to be less dependent on the distance from ceiling compared to the first sprinkler.

Since only the time of activation of first sprinkler is sought, the cooling of the sprinkler by other sprinklers are not needed. Further, the heat conducted from the bulb to the the sprinkler and pipe are neglected. Therefore the sprinkler bulb temperature can be calculated using the equation below [6].

\[
\frac{dT_i}{dt} = \sqrt{\frac{u}{RTI}} (T_g - T_i)
\]  

Where $T_i$ is the temperature of the sprinkler bulb and $T_g$ and $u$ are the gas temperature and velocity vector respectively. The quantity $RTI$ is a measure of the thermal inertia of the sprinkler bulb.

Geometry and boundary conditions

The geometry used represents a part of a warehouse with a ceiling height of 11.2 meters with a six-tier rack storage (8.6 m). The distance between the boxes was 0.4 meters in both the horizontal and vertical direction. The corrugated ceiling had dimensions according to below.
The simulated domain was 7.0 x 5.5 meters with open vents in all vertical boundaries. The thermal boundary condition for the ceiling and floor was set to a fixed value (ambient, 20°C).

Since mesh boundaries in regions with high velocity gradients is not recommended due to limitations in the pressure solver [7] the cell size was identical from the floor to the ceiling in region containing a 4 x 4-meter floor area. The chosen cell size was based on the need to resolve the geometry of the corrugation and was set to 25 mm. A grid independence study was performed for a limited case using a 12.5 mm grid. Outside this well resolved area, a crude mesh with 50 mm cell size was simulated spanning 1.5 meters in three directions outside the well resolved mesh to locate the open boundaries away from the region of interest. The forth direction (away from the sprinkler head) was judged not to affect the results and therefore the open boundary was placed directly on the well resolved mesh.

The sprinkler had an activation temperature of 68°C and an RTI of 36. The location is furthest away possible from the point of ignition given a 3 x 3 m spacing. The values are chosen based on that they are representative for the type of occupancy considered. The sprinkler was located under the higher part of the ceiling which was found to have a very limited effect on activation time, but slightly conservative for the comparison.

Fire
A study made for rack storage fires shows that the fire growth for a 5-tier (7.3 m) storage of Uncartoned Exposed Plastics (UEP) is 860 kW/s [8]. The current storage configuration consists of a 6-tier storage rack, which could result in a slightly higher fire growth rate. However, the expected fire growth rate is difficult to anticipate since no tests has been made for a 6-tier rack storage fire. Furthermore, a slightly higher fire growth rate is only assumed to affect the sprinkler activation time in absolute numbers and not the comparison between corrugated and flat roof. Therefore, a fire growth rate correspondent to a 5-tier rack storage fire is selected. The heat release rate per unit area was set to 350 kW/m².

The heat release rate of the different surfaces of the boxes was prescribed based on an analysis of videos from actual experiments and was found to be approximately according to below. The heat release rate per unit area was assumed to be the same for all surfaces once they ignite.

- 0-4 seconds  Inside of tier 1
- 4-8 seconds  Inside of tier 2
- 8-16 seconds Inside of tier 3 and outside of tier 1
- 16-24 seconds Inside of tier 4 and outside of tier 2
- 24-32 seconds Inside of tier 5 and outside of tier 3

After 32 seconds the heat release rate is 27.5 MW and sprinkler activation is assumed to have occurred and the simulation is terminated.

RESULTS
In this chapter, results from both the grid validation study and the comparison between flat and corrugated ceiling are presented.

Grid validation study
Since it was not feasible to run the entire case with a finer grid, a limited case was simulated which had the same geometry apart from that the ceiling height was reduced to 2 meters and the fire was simulated as horizontal, radially growing, fire at floor level following an ultra-fast curve (0.188 kW/s²). This was performed to verify that the simulations adequately captured the flow patterns in the corrugated ceiling. The grid size is very well resolved compared to the fire size and therefore no grid sensitivity analysis relating to the fire was needed.
The quantities that are compared are gas temperature and velocity since those are the quantities, together with sprinkler temperature rating and RTI, that determine the sprinkler activation time (see Eq. 1). The location of measurements is indicated in the figure below.

![Fig 2. Roof configuration and location of measurement probes](image)

The points are located 100 mm (A), 450 mm (B) and 200 mm (C) from the top of the deck ceiling. The results are shown in the figures below. Note the different scales in the different diagrams.

![Fig 3. Impact of grid resolution on temperature and velocity on different locations A-C in fig. 2](image)
Comparison between flat and corrugated ceiling

Below a representative figure of the sprinkler link temperature under a flat and corrugated ceiling can be found.

![Graph showing sprinkler link temperature under flat and corrugated ceiling](image)

**Fig 4.** Typical diagram of the sprinkler link temperature at a certain distance from ceiling (in this case 450 mm) depending on type of ceiling.

The time to activation of first sprinkler can be found below.

![Graph showing activation time for sprinkler under flat and corrugated ceiling](image)

**Fig 5.** Activation time for sprinkler under flat and corrugated ceiling depending on distance from ceiling

DISCUSSION

The chosen grid resolution (25 mm) was found to be sufficiently grid independent (fig 3) apart from velocity inside the rills of the corrugated ceiling. Given the small dimensions of this volume, this was expected and can be accepted since the area of interest are further away from the ceiling as given by location “B” and “C” in fig 2.

The expected phenomena were the ceiling jet are pushed down by the corrugated ceiling was identified and did have a significant effect on the sprinkler link temperature (fig 4) and thus the sprinkler activation time (fig 5).
The results in fig. 5 indicate that the activation time is significantly lower at the same distance from flat and corrugated ceiling when measuring the distance in according to NFPA 13 and FM datasheet 8-9 (top of deck). The results are much closer when an alternative method of measuring the distance to the bottom of the deck are employed. The tested configurations are, however, too limited to give any conclusive results to the generalizability of the results to other similar configurations.

CONCLUSION

The results indicate that measuring the distance to sprinklers from the top of corrugated ceilings provide very conservative results and, at least in the configuration tested, the distance from the bottom of the corrugated ceiling gave results that more closely resembles those of flat ceilings. The tested configurations are, however, too limited in scope to give any guidance to possible changes in sprinkler standards. More numerical and experimental work should be conducted in the future to assess the generalizability of the observation. These studies should assess both the effect of ceiling geometry and sensitivity to, for example, ceiling height and fire growth rate.

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