FIRE PROTECTION OF TALL STEEL COLUMNS USING WATER SPRINKLERS

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Abstract
A known fact is that the water sprinklers cool down the fire and also the structures. In most countries the requirements for fire protection can be lowered, if the building is equipped with automatic water sprinklers. The cooling effect of different kind of sprinkler types, water flows and droplet size to steel structures has been studied for several years in Finland. The outcome has been a national approval for a fire protection system consisting of a selection of steel structures and certain type of sprinkler systems. This research has been presented in ASFE earlier conferences.
The latest research project concerning this is just about to be finished. The objective of this research was to study the behaviour of long steel columns in case of fire in a typical warehouse or a logistic building equipped with adequate sprinkler system. Columns up to 13,7 meters were studied using verified FDS simulation. Fire load scenarios were taken as storage shelves filled with certain material and fire spread. The unknown fact has been how these sprinkler systems cool down the high columns when the sprinkler systems are attached near the roof as normal. The results of this will be presented in this paper together with some other special cases which might occur in a fire in sprinklered building.

Keywords: fire protection, water extinguishers, cooling, steel structures, sprinklers

INTRODUCTION

The main idea of this research was to study the effect of ESFR (Early Suppression Fast Response) sprinkler system to cool down the fire and steel structures in fire situation in high storage-type premises. This paper is based on a research report done b~~u~~y VTT (Vaari et al, 2012). The main focus was to study the temperatures in tall columns, when the water extinguishers are attached near the roof as usual and there's no rack sprinklers attached. The benefit is that moving the shelves is not dependent upon the rack sprinklers and still the fire safety stays at adequate level. The cooling effect down to the ground level was the main research issue to be able to design the steel columns to adequate dimensions.
The sprinkler system is based on discharging a large amount of water very fast. The K-value is typically around 200-360 l/min/bar$^{1/2}$.
The research also studied the cooling performance of dry systems. The dry systems are used often in cold storages to avoid freezing of the water in pipes. The functioning differs from the wet system, where there is pressurized water in the pipes and therefore the reaction is faster. In dry systems there's a little delay because of the water coming from the tanks after the system starts, i.e. the sprinkler heads are acting or the fire detectors give the signal.
The height of the columns was limited to 13.7 meters. This comes from the sprinkler design standards
The research was done using FDS (Fire dynamics Simulator) by NIST. The validation was based on experimental research and literature. FDS is the most used fire simulation software and this freeware, open source software is updated actively by the scientific network governed by NIST.

1 CALCULATION METHOD

The ability of the sprinklers to cool down steel structures was studied using FDS software, version 6.0.0, SVN12961. This is a tool for especially different flow calculations in fire.
In this work the temperatures of a steel column were studied in cases were the column is either next to the wall or in an open space. The calculation area was 6m x 6m x 13.7m and the resolution was 20cm.
The basic assumption was that the stored things commodities work as an obstacle to the spread of fire and water. The material corresponds to cellulosic, double triwall corrugated cardboard. The fire was modelled as a 2m x 2m burner, in which the time evolution of the heat release rate corresponded to a storage shelf fire. The sprinklers were not assumed to put down the fire, so the heat release rate was allowed to doubled at after the moment the sprinklers activate and then kept steady. This is an assumption often used to be sure of the safety level or overdimensioning.

1.1 Sprinkler description

The sprinkler system in the model had 4 nozzles in a 3m x 3m network. The distance to the column wall was 1.5 m. In the case where the column is next to the wall, it is situated in between two nozzles and in the open space-case the column is centered between the four sprinklers. These are illustrated in Fig 1.

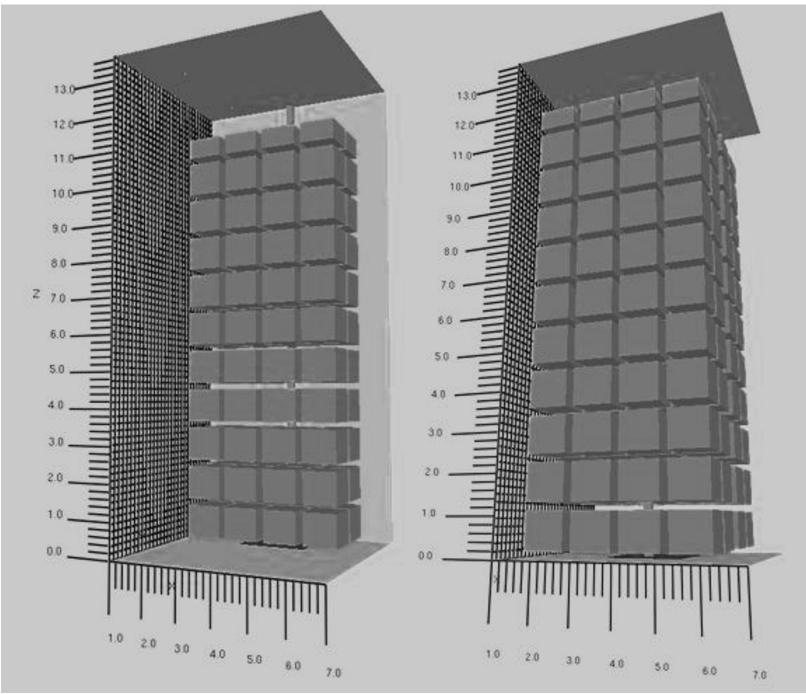

Fig. 1 FDS model for a steel column in local fire in the describes cases.

The spray pattern or spray envelope in these kind of sprinklers is downwars aiming to maximize the water amount watering the area and burning items below. The exact pattern is not very often exactly given.
In this study the water droplets are assumed to be evenly spread in between azimuth angles 50 and 80 to spray sprinklers (used in the dry pipe system) and between 0 and 80 to ESFR sprinklers.

1.2 Steel model

The parameters for structural steel follow Eurocode 3 (EN 1993-1-2) values. The temperature dependence was taken into account. The temperatures were determined in 1mm depth underneath the steel surface. Vertical distance between the measuring points was 1 meter.

2 RESULTS

2.1 Validation of the FDS model

The experimental tests carried out at VTT were used as a validation background. These test results could be used only partly because the situation in this simulation is different from the test. The cooling effect to the gas temperature is less important in this study than cooling down the steel structures.
The freeburn (no sprinklers) case was modelled and compared to the previous test results. It was done with ISO 834 curve. The results can be seen from Fig.2.

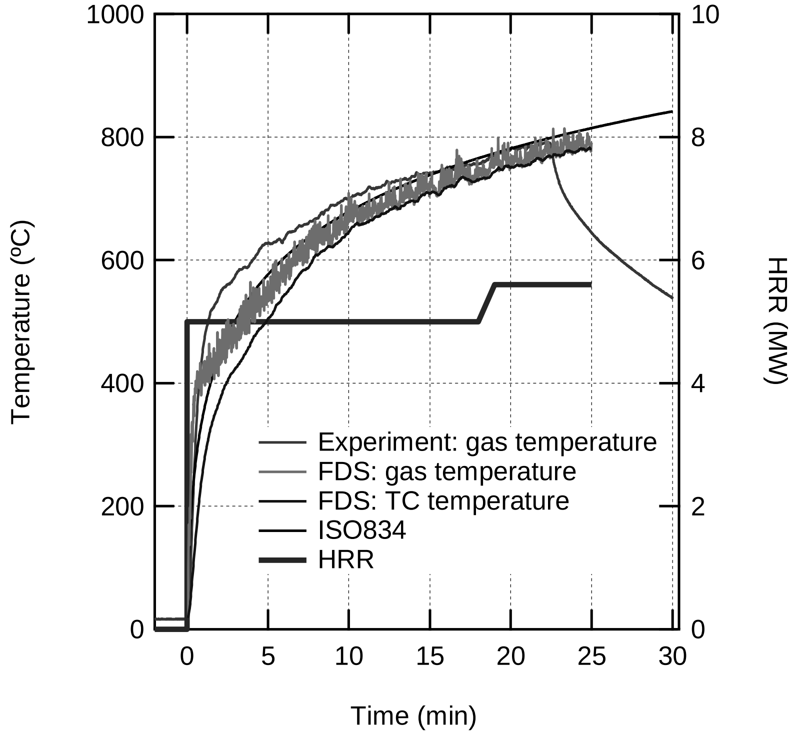

Fig. 2 Time evolution of the heat release rate used in the freeburn experiment, and measured and calculated gas temperatures.

2.2 ESFR-system's cooling effect in high storage

ESFR system is based on fast response to fire and very high water amount together with large droplet size which together put down the fire very effectively even from a high distance.
In this research two scenarios were studied in cases were the column is either next to the wall or in an open space. The idea was to study the cooling effect when there's shelves attached and also when there's a lot of fire load but the column is in open space affected by the fire.
The heat release rate was 5.4. MW in the beginning of water discharge and the flame reached about 4-5 meters high. The biggest effect is naturally to the lower part of the column. This is illustrated in Fig 3.
The development of the stee~~l~~l surface temperature in different heights is illustrated in Fig.4. The column wall thickness was in this case 6mm and it can be seen that the maximum temperature is reached at about 2m height with a temperature around 330°C. This shows the cooling power of ESFR system.

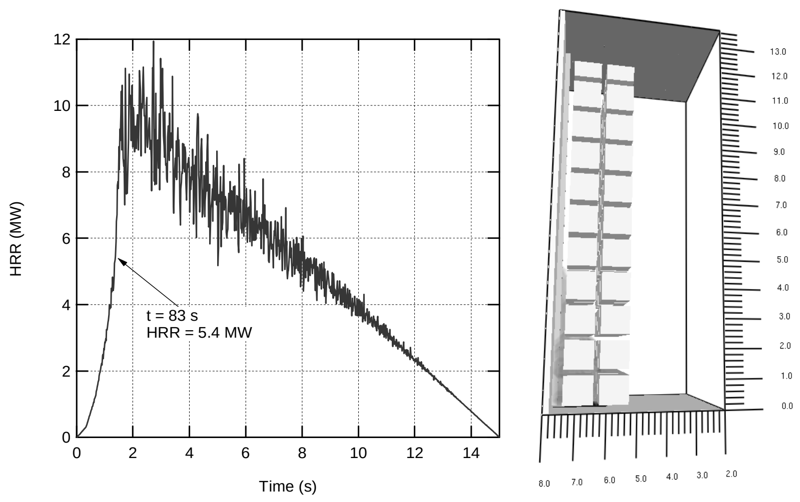

Fig.3 Left: time evolution of the HRR during ESFR cooling experiment with storage racks against a wall. Right: flame shape upon activation of first sprinkler.

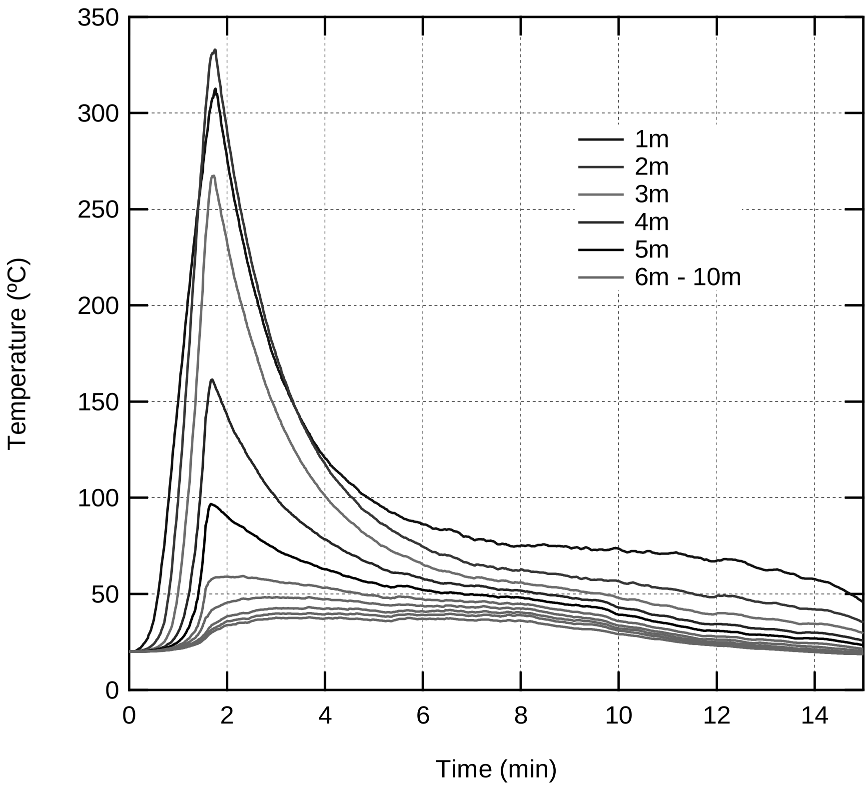

Fig.4 Time evolution of the surface temperature of the steel column during ESFR cooling experiment with storage racks against a wall.

The open space scenario was studied similarly. The heat release rate was 7.6MW in the beginning of water discharge which is a lot higher than used in literature (Kung et.al.) and the flames reached again 4-5 meters in the start. The main effect was to the lower part of the column. The highest temperatures were at 2m height, with maximum of 635°C with 6mm wall thickness. The case, heat release rate and temperature development is presented in Figs. 5 and 6 with a comparison between different wall thicknesses. Naturally this affects the temperature development.

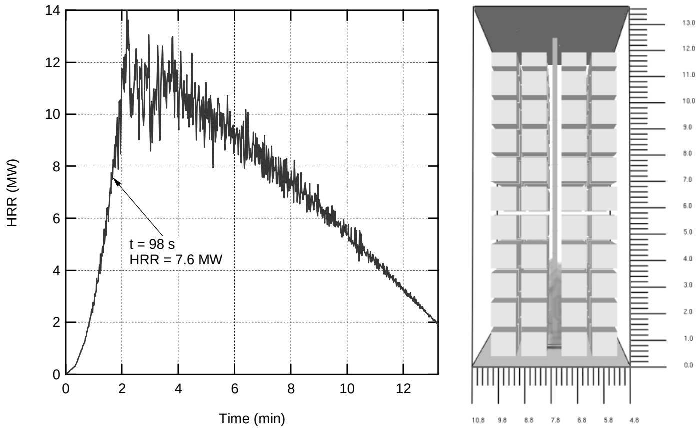

Fig. 5. Left: time evolution of the HRR during ESFR cooling experiment with storage racks in an open space. Right: flame shape upon activation of first sprinkler.

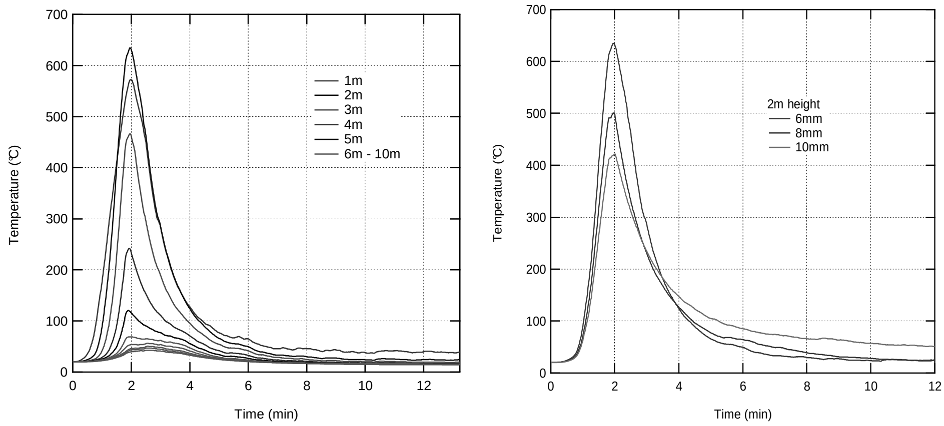

Fig. 6 Left: time evolution of the surface temperature of a 6mm thick steel column during ESFR cooling experiment with storage racks in an open space. Right: the effect of steel thickness on the column surface temperature at 2m height.

2.3 Dry system's cooling effect in high storage

One aim was also to study the cooling effect of so called dry system, where there's a delay of the water coming from the noffles. This was studied with a very maybe too high fire load. The column was in an open space. The heat release rate in the beginning of water discharge was 13.7 MW, because the fire have about 1 minute more to develop before sprinklers work. In Fig. 7 the HRR is presented and in Fig 8 the results are presented for one type column. This has to be studied more thoroughly in the future.

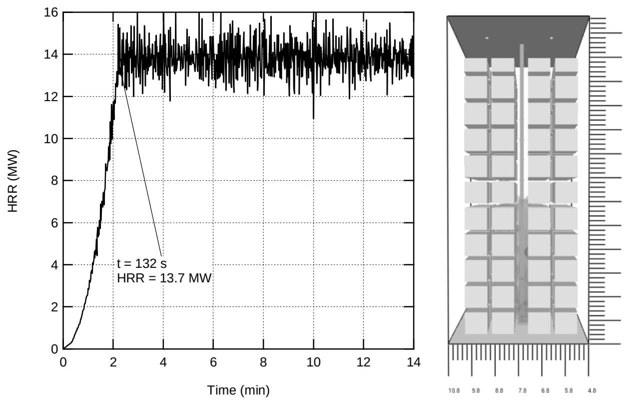

Fig. 7 Left: time evolution of the HRR during dry-pipe system cooling experiment with cold storage racks in an open space. Right: flame shape upon activation of first sprinkler.

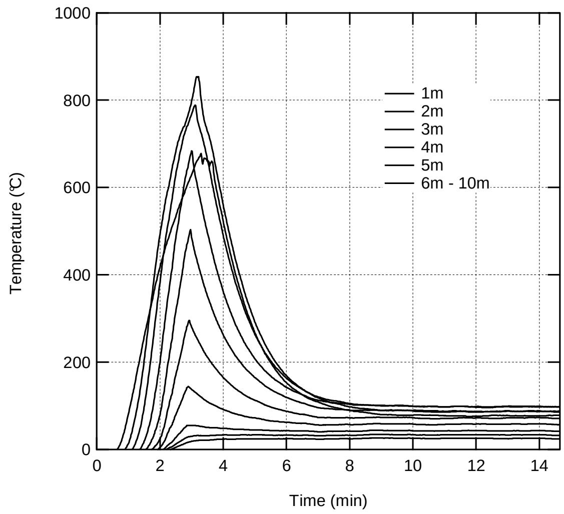

Fig.8 Time evolution of surface temperature of a 10mm thick steel column. Dry sprinkling.

3 SUMMARY AND ACKNOWLEDGMENT

The studied ESFR wet sprinkler system can effectively cool down the columns in different cases. The temperatures rise higher only for a short period of time and this will not cause any structural risk. Using dry system, the delay in the activation of the system causes also temperature rise during this time, but when the system starts to work, the temperatures start decreasing strongly to safe level. The structures reach the highest temperatures just before the first sprinkler heads start to work, as was assumed.

The situation of the column of course affects strongly to the temperatures. The studied cases, column in the middle in open space near the shelves with fire load and near the wall varied from each other naturally and the highest temperatures are of course, when the column is engulfed in fire from all sides.

The basic assumption of the fire model in this work might cause too big thermal exposure to the structures and therefore over-estimate the temperatures of the steel columns.

Altogether the results show the effectiveness of sprinkler protection even in this high cases. Of course the functioning of the system has to be reassured to be able to use it as structural fire protection. This is still not an issue when following the sprinkler rules.

More research is planned and will be done in the following years.

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