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ANALYSIS OF PREDICTED SPRINKLER ACTIVATION TIME IN AUTOMATED CAR PARKINGS

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Abstract: *In the past few years car parking has developed different technologies. Protection against fire must to develop properly to ensure the minimum level of security and protection.*
Many studies regarding fire behavior on an enclosed car parking were made. Fire suppression and smoke control it's a commonly issue of this studies.
This paper is focused on the calculation methods and computational fluid dynamics models that can predict the activation time of sprinkler systems mounted on an enclosed automated car parking.

Key words: *sprinkler, car stacker, standard response, test plunge*

1. Introduction

In car parking fire can spread easily because of the smaller distance between the cars and the higher quantity of flammable liquids and combustible materials such plastics. A particular case of car parking is represented by multiparking car stackers.

Serious concerns were expressed regarding the fire safety of stackers. These are automated car parking devices of various types were cars are located above one another with no fire resisting floor or ceiling between them.

2. Fire behavior on car stackers

Automated car parks like stackers are becoming increasingly common and there are a variety of different automated car parks types, some involving a hollow, other using simple jack ramps to double capacity.

This equipment allows two or more cars to be parked on the place of a single car. Such innovations have implications for fire fighters due to the very rapid development of fire in the second car. Studies [1] demonstrated that the fire growing faster in the lower car on stacker and spread very rapidly to the car above in about 5 or 6 minutes. The complexity of stacker structures may also cause difficulties in the application of water.

Potential benefits of installing sprinkler systems on car parks have been demonstrated by many studies [2], but design fire engineering codes don't take into account the activation time.

Because the distance between cars is very small fire can spread rapidly from a car to another and the activation time of

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sprinkler system become an essential parameter in this case.

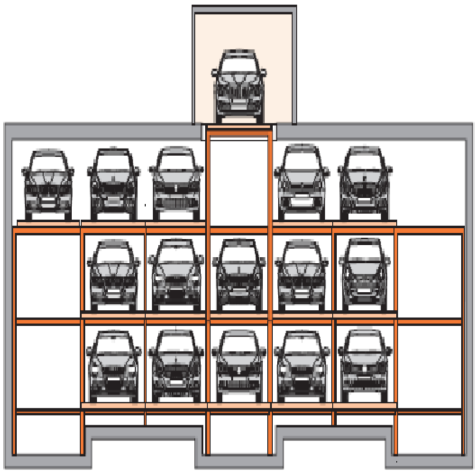

Fig. 1. *Automated car parking*

During the growth stage of a fire, the smoke environment in an enclosed car parking can be represented by two layers, a hot upper layer and a cool lower layer. In early stages of fire development, the temperature of the lower layer is close to ambient.

The temperature of the upper layer rises as the plume above the fire transports smoke and hot gases into the upper layer along with a significant volume of entrained air.

Once the plume reaches the ceiling in a radial direction away from the plume. This hot gas flow is known as the ceiling jet, the properties of which strongly influence the operation of sprinkler systems.

The activation time of the sprinkler is the time at which the temperature of the sprinkler link reaches the nominal activation temperature.

Convective heat transfer from the flowing gases in the ceiling jet to the sprinkler link is the primary heat transfer mechanism.

However, for an enclosure where the ceiling jet is immersed in a hot layer, additional heat transfer from the hot layer to the sprinkler occurs.

The operation of a sprinkler depends on several factors other than the given activation
temperature, Nash and Young [3] describe the factors as:

- actual operating temperature of sprinkler.
- thermal capacity of those parts of the sprinkler which affect operation is quantified by RTI and c-factor.
- ease of transfer of heat from the air to the affected parts of the sprinkler (RTI/c-factor).
- rate of growth of the fire in terms of its convective heat output.
- height of the ceiling below which the sprinkler is mounted.
- ceiling configuration below which the sprinkler is mounted.
- thermal qualities of the ceiling assembly.
- distance between sprinkler and ceiling.
- horizontal distance of sprinkler from fire.
- extraneous factors affecting the pattern of flow of the gases from the fire to the sprinkler.
- rate of rise of air temperature surrounding the sprinkler.

The sensitivity of a sprinkler head depends on the RTI and conduction factor.

Basically the more sensitive the sprinkler head, the quicker it will activate at given fire.

3. Response Time Index (RTI)

The RTI is a measure of thermal sensitivity, which indicates how fast the sprinkler can absorb heat from its surroundings sufficient to cause activation. The RTI is calculated taking account of the actual function time of a link mounted in a sprinkler or other devices in given standard conditions and its usually determined by plunging into a heated laminar airflow within a test oven.

It is calculated using the following:

- operating time of the sprinkler;
- operating temperature of the sprinkler's heat responsive element which is determined in a bath test;
- air temperature of the test oven;
- air velocity of the test oven;
- sprinkler's conductivity (c) factor, which is the measure of conductance between the sprinkler's heat responsive element and the sprinkler mounted oven;

A classification of sprinkler heads regarding RTI and conductivity "c" - factor it's been presented in SR EN 12259-1+A1:2002, Fixed firefighting systems – Components for sprinkler and water spray systems – Part 1: Sprinklers.

Sprinklers defined as fast response have a thermal element with an RTI of 50 $m^{1/2}s^{1/2}$ or less, defined as special response have a thermal element with an RTI between 50 $m^{1/2}s^{1/2}$ and 80 $m^{1/2}s^{1/2}$, defined as standard response

A have a thermal element with an RTI between 80 $m^{1/2}s^{1/2}$ and 200 $m^{1/2}s^{1/2}$ and defined as standard response B have a thermal element with an RTI of 200 $m^{1/2}s^{1/2}$ or more.

Factory Mutual Research Institute developed a test apparatus to determine the RTI of sprinkler heads.

In the test, called plunge test, the sprinkler head is plunged into the flow of heated air.

The temperature and velocity of the gas are known and are constant during the test. The equation for the change in the link temperature is

$$\frac{dT_d}{dt} = \left(\frac{1}{\tau}\right)\left(T_g - T_d\right) \qquad (1)$$

Since the gas temperature is constant during the test, the solution to this equation is

$$T_d - T_a = \left(T_d - T_a\right)\left[1 - \exp\left(\frac{-t}{\tau}\right)\right] \qquad (2)$$

Rearranging the equation gives

$$\tau = \frac{t}{\ln\left(T_g - T_a\right)\left(T_g - T_d\right)} \qquad (3)$$

In therms of the response time index, equation becomes

$$RTI = \frac{t_r u_0^{1/2}}{\ln\left[\left(T_g - T_a\right) \big/ \left(T_g - T_r\right)\right]} \qquad (4)$$

Sprinkler data sheets presents RTI value for every sprinkler head. Knowing the RTI, the change in temperature of similar units can be calculated for any history of fire gases flowing past it. The form of the heat transfer equation is:

$$\frac{dT_d}{dt} = \frac{u^{1/2}\left(T_g - T_d\right)}{RTI} \qquad (5)$$

This equation is used to calculate the temperature of a sprinkler head exposed to fire gases. It can be used to determine the time at which the sprinkler bulb or link reaches its operating temperature.

Alpert [4] present a fire model with ceiling jets having a near constant gas temperature and velocity wich can be modeled using the following series of equations

$$T_g - T_a = \frac{\left[5.38\left(\dot{Q}/r\right)\right]^{2/3}}{H}\,{}^{o}C = \frac{\left[4.74\left(\dot{Q}/r\right)\right]^{2/3}}{H}\,{}^{0}F \tag{6}$$

Where r/H > 0.18, and

$$T_g - T_a = \frac{\left(16.9\dot{Q}^{2/3}\right)}{H^{5/3}}\,{}^{o}C = \frac{\left(14.9\dot{Q}^{2/3}\right)}{H^{5/3}}\,{}^{o}F \tag{7}$$

Where r/H $\leq$ 0.18, and

$$u = \frac{\left(0.20\dot{Q}^{1/3}\quad H^{1/2}\right)}{r^{5/6}}\,m/s = \frac{\left(0.25\dot{Q}^{1/3}\quad H^{1/2}\right)}{r^{5/6}}\,ft/s \tag{8}$$

Where r/H $\leq$ 0.15.

This model assumes that the temperature and velocity of the fire gases at a point away form the source are related to the instantaneous heat release rate of the fire.

For a constant gas temperature and constant gas velocity, the basic heat transfer equation can be

$$\frac{dT_d}{dt} = \frac{T_g - T_d}{\tau} \tag{9}$$

$$dT_d = \int_0^1 \frac{1}{\tau}\left(T_g - T_d\right)dt \tag{10}$$

$$\Delta T_d = T_d - T_a = \left(T_g - T_a\right)\left[1 - \exp\left(\frac{-t}{\tau}\right)\right]{}^{0}C \tag{11}$$

or, substituting the equation for RTI

$$\Delta T_d = T_d - T_a = \left(T_g - T_a\right)\left[1 - \exp\left(\frac{-tu^{1/2}}{RTI}\right)\right]{}^{0}C \tag{12}$$

The RTI is the product of the thermal time constant of the heat responsive element and the square root of the associated gas velocity.

$$RTI = \tau u^{1/2} \quad (13)$$

$$\tau = \frac{m \cdot c}{h_c \cdot A} \quad (14)$$

The conductivity c - factor is a measure of how much of the heat picked up from the surrounding gas is conducted into the sprinkler frame from the glass bulb.

Computational programs such as Fire Dynamics Simulator or BranzFire that can predict the activation time of a sprinkler head uses a model based on a differential equation including convective heating of the sensing element and conductive losses to the sprinkler frame.

$$\frac{dT_d}{dt} = \frac{\sqrt{u}}{RTI}\left(T_g - T_d\right) - \frac{c}{RTI}\left(T_d - T_m\right) - \frac{C_2}{RTI}\beta u \,. \quad (15)$$

4. Experimental condition and procedures

For the experiments two standard response sprinkler heads with same characteristics were placed in a 5,5 x 3,1 x 2,3 m fire compartment made form concrete of 10 mm thickness. There was no open vents in the experimental construction and to bring oxygen during the fire tests a door with 1,4x2,0 m dimensions was open 20 cm from the closed position. Sprinkler heads were mounted at 35 cm bellow the ceiling at 1 m distance from each other. For the first test a 10 l ethanol pan was placed into the corner of the room to simulate a single car fire and then the same pan with ethanol was covered with a 5 mm steel flange at 90 cm above the floor to simulate a simple two cars stacker.

To record temperatures inside the fire compartment three thermocouples type K were placed into the wall at 30, 60 and 90 cm above the floor.

5. Conclusions and results

The aim of this study was to investigate the sprinkler activation time in automated car parking and to identify all critical parameters that can influence it.

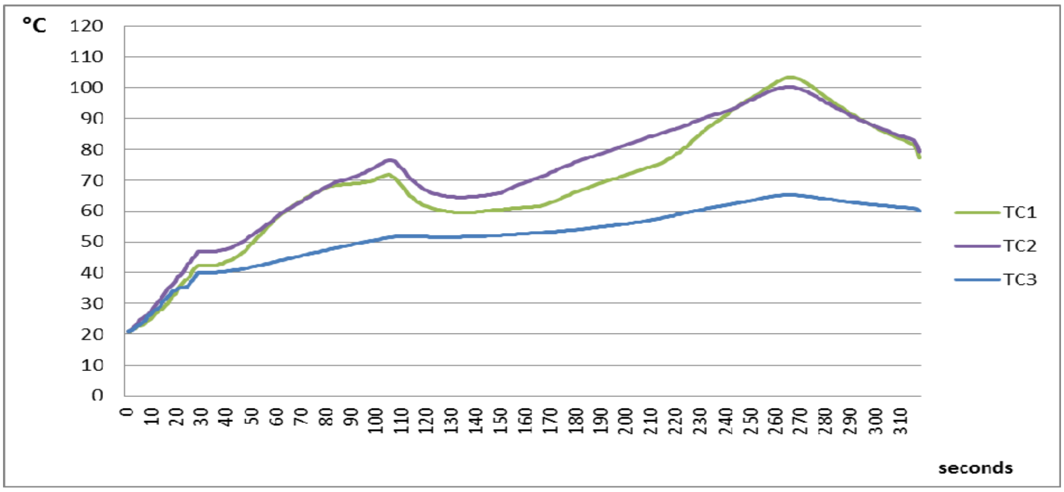

Fig. 2 *Temperature evolution inside the fire compartment*

The results as shown in the table 1, led to the following observations regarding to the activation time:

- the steel flange influenced the movement of the hot gases inside the fire compartment;
- sprinkler activation time was bigger in the stacker case;
- fire safety engineers should carefully calculate the activation time of sprinkler systems especially in automated car parks because the activation delay in such fire compartments can cause a rapid development of fire and extinguish process can failed;
- in rack sprinkler system must be installed to decrease the activation time;
- fast response sprinkler heads would be more efficiently than other sprinkler head types;
- when people presence is not necessary to park the cars an appropriate fire prevention system should be take into account at fire safety designing.

Experimental results Table 1

Activation time [sec]	Car stackers	Regular car park	FDS Car stackers	FDS Regular car park
Sprinkler no. 1	125	92	137	108
Sprinkler no. 2	143	92	152	117

After the experimental work the results show that the difference between Fire Dynamics Simulator and fire compartment test is not bigger than 25 %. Fire Dynamics Simulator activation times is reasonably well, being within 25 % of the actual times and it tend to be conservative.

Nomenclature

A – area of the sprinkler body (m^2)
c – conductivity factor $(m/s)^{1/2}$
C_2 – Di Marzo constant empirically determined to be 6 x 10^6 $k/(m/s)^{1/2}$
H – compartment height (m)
h_c – convective heat transfer ($kW/m^2 \cdot {}^0C$)
M – mass of sprinkler body (kg)
$\dot{Q}$ - total heat release rate (kW)
r – radial distance from the axis of the fire plume (m)
RTI – response time index $(m \cdot s)^{1/2}$
T – time (s)
T_a – ambient temperature (${}^0C$)
T_d - link temperature (${}^0C$)
T_g – gas temperature (${}^0C$)
T_m – temperature of the sprinkler mount (${}^0C$)
u – gas velocity (m/s)
u_0 – gas test velocity (m/s)
β - volume fraction of water in the gas stream
τ - time constant

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