International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-4, Issue-1, January 2017

Numerical Investigation of Impulse Ventilation System in Underground Car Park

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***Abstract*— In this paper smoke control capacity of impulse ventilation system (IVS) was examined in an underground car park with three different fire positions. An analysis is results are related with jet fan thrust, fresh air and exhaust flow rates, size of fire and fire positions. Flow rates of both fresh air and smoke exhaust fans and jet fan placement is indicated before CFD analysis. Fire Dynamic Simulator 6.1.2 is applied to 115 m long, 57 m wide and 3.5 m height domain with simulating car fire whose peak heat release rate (HRR) is 4 MW resulted from burning propane as a fuel in which scoot yield 0.024 kg soot/ kg fuel for three different locations. Velocity, temperature, visibility and CO results obtained by CFD method show that they completely met with indicated standard assumptions.**

***Index Terms*— Car park Ventilation, CFD, Fire Modeling, Jet Fan System.**

I. Introduction

Nowadays, variety of underground car park examples can be given in urbans. Shopping malls, buildings and hospitals just a few examples of this due to the growing population. Since there are lots of cars in these areas, quantity of carbon monoxide and other polluting gases increase. Evacuating these gases is done with jet fan or duct system. Another type of ventilation is natural ventilation but most cases it is not sufficient for evacuation. Because of this, mechanical ventilation is mostly obligated. Smoke and other gases are removed by directing them from exhaust shaft to the fresh air shaft in the impulse ventilation system. Fresh air and exhaust duct fans and radial and/or axial jet fans are used in this system. An example of impulse ventilation system in car park is described in Figure 1[1].

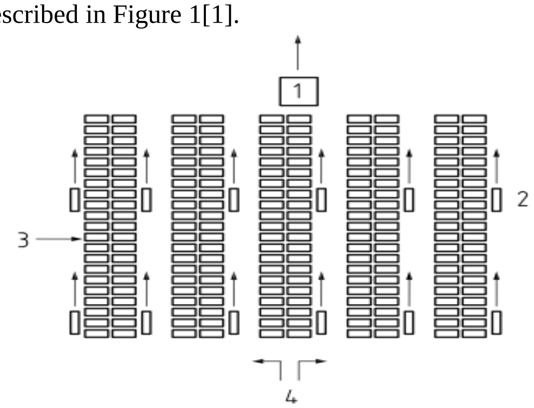

Figure 1: Impulse ventilation system.

Jet fans are known as it thrust force and they have thrust distance which has been provided by manufacturer. After required flow rate calculation, jet fans are placed according their thrust distance in the project section. As air director, axial or radial jet fans is used according for some cases. In case of low floor height and beam presence, radial jet fan can mostly be preferred.

Optimum jet fan placement, efficiency of duct fans' flow rates and sufficiency of ventilation of car park are determined by the help of computational fluid dynamics analysis. This analysis is also used for supporting firefighting teams in evacuating process during/after fire.

Some assumptions in the standards state whether the car park is efficient or not. These assumptions are related at average human eye level of velocity, temperature, visibility and CO gradient. Visibility must be above 10 meters in NFPA 130 [2]. BS 7346-7-2013 standard state that the velocity of air within escape routes and ramps should not exceed 5 m/s. This standard also figures the limit of concentration of carbon monoxide not more than 30 ppm over an 8 hours' period and within the ramps and exits, not to go about 90 ppm for periods not exceeding 15 minutes [1]. About temperature of car park, ASHRAE Principle of Smoke Management expresses that temperature should not exceed 60℃ except for fire zone and maximum temperature should be below 121℃ [3].

BS734-7-2013 standards also describes the dimensions of fire parameters. It is stated that indoor car park without sprinkler system should be 4 MW heat release rate for 2 m x 5 m dimension car [1].

Mechanically ventilated car parks such as impulse ventilated car parks, polluted air should be changed periodically. The rate of this changing is stated in BS 7346-7-2013 standard as 10 air change per hour for the building with engines running [1].

There are variety of studies about car park ventilation. Averio et al. [4] experimentally and numerically investigated of one floor carpark for different fire points. They procured numerically acceptable velocity result with experimental values. They obtained that the placement of jet fan is sufficient. Senveli at al. [5] numerically investigated an 8-storey parking lot both ventilation and fire cases. They eliminated dead zones where air is stagnant since they created effective jet fan placement. They also obtained great conformity to indicated standards as velocity, temperature and visibility parameters. S. Lu et al. [6] examined performance of impulse ventilation system (IVS) in an underground car park. They compared impulse ventilation system and ducted ventilation system and they obtained that impulse ventilation system has better visibility results.

II. CAR PARK MODEL DETAILS

Computational domain has 115 m long, 57 m width and 3.5 m height as shown in Figure 2, is considered for CFD simulation. Domain consist of one fresh air shaft, one exhaust shaft, fire model and jet fan as equipment. Place of fresh air shaft is signed with triangle shape and exhaust shaft is signed with square shape In Figure 2.

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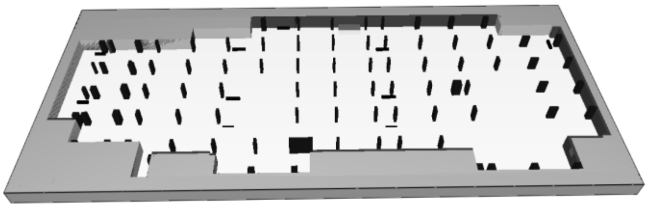

Figure 2: Underground car park model.

A. *Flow Rate Calculation*

In closed car parks, flow rates of smoke exhaust fans and fresh air fans are dependent on volume of car park and air change rate per hour.

$$V = A.h \quad (1)$$

$$V_{exhaust} = V.ACH \quad (2)$$

$$V_{Fresh} = 0.8V_{Exhaust} \quad (3)$$

By using these formulation exhaust and fresh air fans' flow rates was calculated like shown in Table 1.

Table 1: Selected fans.

Fan	Volume Flow Rate [m^3/h]
Exhaust Fan	230,000
Fresh Air Fan	184,000

For directing air from exhaust shaft to fresh air shaft, eight axial jet fans are used. Jet fan are also selected as F300/2h fire resistance. Characteristics of jet fan are remarked in Table 2.

Table 2: Jet fan characteristics.

Parameter	Value
Diameter	400 mm
Length	1500 mm
Thrust	20/80 N
Fire Resistance	300°C / 2h

B. *Mesh Model*

Dimensioning cell in the domain is one of the most important step for CFD simulations. FDS solves bigger cells with failure and smaller cells with redundant times. Balance of this is give the correct cell sizes. 1,461,880 tetragonal cells were generated to carry out car park CFD simulation. Each cell has 0,25 m x 0,25 m x 0,25 m sizes.

C. *Solver and Governing Equations*

FDS solves forms of conservation equations for slow speed, heat flux and smoke evolution with Large Eddy Simulation (LES) method. Partial derivatives of mass conservation equations, momentum and energy are approximated with time dependent finite differences method [7], [8]. Governing equations are stated in the following lines.

$$\frac{\partial \rho}{\partial t} + \nabla.\rho = \dot{m}_b''' \quad (4)$$

$$\frac{\partial}{\partial t}(\rho Y_\alpha) + \nabla.\rho Y_\alpha u = \nabla.\rho D_\alpha \nabla Y_\alpha + \dot{m}_\alpha''' + \dot{m}_{b,a}''' \quad (5)$$

$$\frac{\partial}{\partial t}(\rho u) + \nabla.\rho uu + \nabla p = \rho g + f_b + \nabla.\tau_{ij} \quad (6)$$

$$\frac{\partial}{\partial t}(\rho h_s) + \nabla.\rho h_s u = \frac{Dp}{Dt} + \dot{q}''' - \dot{q}''' - \nabla.\dot{q}'' + \varepsilon \quad (7)$$

$$p = \frac{\rho RT}{M} \quad (8)$$

D. *Boundary Conditions*

As air supplying, 230,000 m^3/h and for air exhausting 184,000 m^3/h flow rates were applied. As indicated in BS7346-7-2013 standard dimension of burned car was chosen as 2 m x 5 m with 4 kW heat release rate. All walls include bottom and ceiling of car park was chosen inert. Atmospheric conditions were chosen as 101325 Pa, 40% relative humid and 20°C environmental temperature which were default values of software. Curve of change of fire load with respect to time is shown in Figure 3.

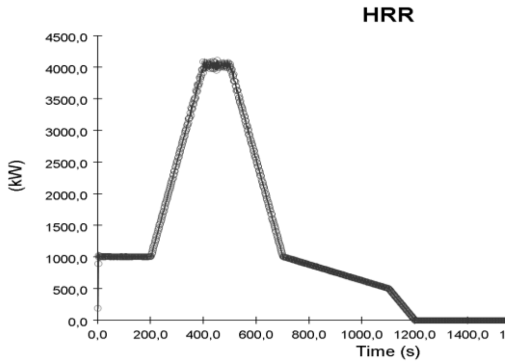

Figure 3: Heat release rate curve.

III. NUMERICAL RESULTS

After calculated three different fire simulation, the results which also shown in Table 4 were obtained. Fire position is defined for the first case, middle of the car park and near the wall, for the second case far away from the exhaust shaft and near the wall and for the third case just middle of the car park. Results are recorded for the maximum HRR (500th seconds). For all cases smoke was successfully evacuated at 1500 seconds.

Table 4: Numerical Results

Case	Velocity [m/s] Max.	Visibility [m] Min.	Temperature [°C] Max.	CO Fraction [ppm]
1	5	10	35	10
2	4.5	10	69	20
3	5	10	33	9.5

For the first case, maximum CO fraction was seen in the areas close to the exhaust shaft. Average value of CO fraction in the car park is 4.2 ppm. As visibility result, minimum value of this is 10 m which covered just a little bit area close to the exhaust shaft. Average value of visibility is viewed 20 m along car park. Temperature value of human eye level was recorded maximum 35 °C near firing car and exhaust shaft and within the remaining area, average value is 27°C. Maximum velocity was seen near the axial shaft fans whose maximum values is 5 m/s. Average value of velocity was recorded 2.5 m/s with no dead zone in the car park. Smoke distribution in the car park at maximum HRR values for the first case was shown in Figure 4.

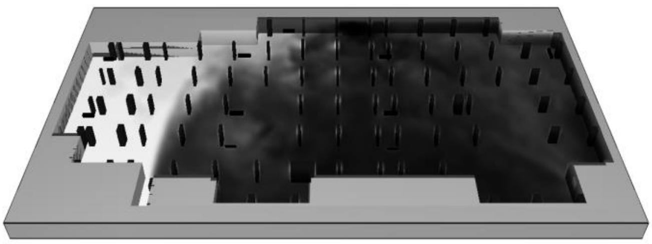

Figure 4: 1st Case smoke distribution at maximum HRR.

For the second case where fire location is close to the fresh air shaft, maximum CO fraction is viewed near the fired car. Since the fire and fresh air interaction was increased, mass fraction also increased. In the remaining area, average mass fraction was recorded nearly 10 ppm. Another result is that, visibility values of whole car park except fire location is above 10 m. Maximum temperature values of second case was recorded 69℃ which is near the fire zone. Average value of temperature is 28℃. Maximum velocity value decreased since smoke blocked the fresh air velocity. Average velocity value was observed as 2 m/s. Since deep smoke-air circulation, there is also no dead-zones in this case. Smoke distribution in the car park at maximum HRR values for the second case was shown in Figure 5.

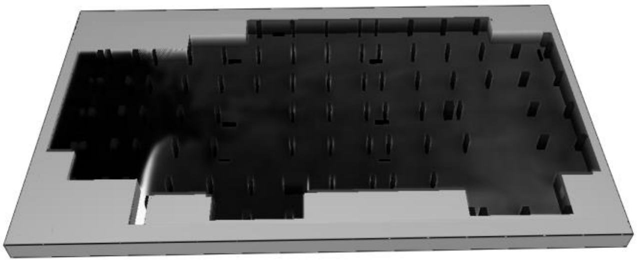

Figure 5: 2nd Case smoke distribution at maximum HRR.

For the third case, maximum CO fraction value which is 9.5 ppm was seen near the exhaust shaft. Average value of this was recorded as 3.8 ppm in the car park. The area close to the fresh air shaft has almost no CO particle. Minimum visibility value was also viewed at near the exhaust shaft. Remaining area of car park has good visibility value which changes between 13 – 31.5 m. Maximum temperature values which is 33 ℃ was seen between fire zone and exhaust shaft. Average temperature value of car park was recorded as 26.5 ℃. Maximum value of velocity was viewed as 5 m/s different from second case since there is no smoke prevention. It is recorded that there is also no dead zone for the third case. Smoke distribution in the car park at maximum HRR values for the third case was shown in Figure 6.

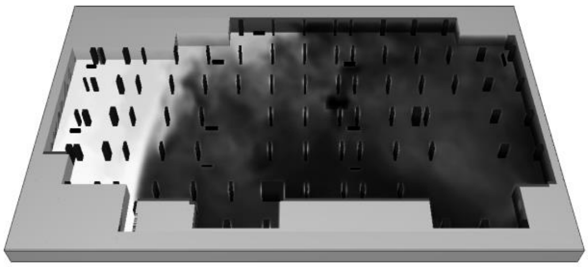

Figure 6: 3rd Case smoke distribution at maximum HRR.

Another examination done in this study is whether the temperature resistance of selected jet fans is appropriate. As stated in Table 5, it was observed that the maximum temperatures in the jet fan height are lower than temperature resistance of the fans. This situation showed that selected jet fan is suitable for this car park.

Table 5: Temperatures at jet fan level

Case	Temperature [℃] Max.
1	110
2	155
3	105

IV. CONCLUSIONS

This CFD analysis fulfilled in the study has a great significance in terms of fire condition for impulse ventilation system in underground car park. Beside the capacity of fresh air and smoke exhaust fans, jet fan placement and fire location has also great importance for smoke evacuation. As it can be seen from the difference between cases two and others, capacity of impulse ventilation system must be examined for different cases.

CFD results was carefully compared with standard values. CO, temperature, visibility and velocity values were examined separately at maximum heat release rate and it was found that the system designed for this car park full met the conditions specified in the standards. Due to the optimum jet fan placement and adequate flow capacity, there is no dead zone was seen in these numerical studies.

This simulation also shows that, CFD analysis give good and economical ideas for car park applications. It allow the efficiency of the parking lot be increased before installation and operation.

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