Measurement 78 (2016) 151–167

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Measurement of the neutral plane of an internal fire whirl using the background-oriented Schlieren technique for a vertical shaft model of a high-rise building

ChungHwei Su *, JiaHong Bai

Department of Safety, Health and Environmental Engineering, National Kaohsiung First University of Science and Technology, Kaohsiung City 82445, Taiwan

ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form 1 October 2015
Accepted 9 October 2015
Available online 23 October 2015

Keywords:
Neutral plane
Fire whirl
Background-oriented Schlieren (BOS)
High-rise building
Visualize
Scale modeling experiment

ABSTRACT

Since the height of the neutral plane is related to the direction of the high-temperature smoke and airflow diffusion of fires in high-rise buildings, the identification of the neutral plane is important for both the evacuation of residents and the safety of fire fighters. As yet, there are no effective methods for directly measuring the constantly changing neutral plane position. There are complex internal fire whirl phenomena in the inner space in particular cases. In this study, the background-oriented Schlieren (BOS) technique was used to visualize the neutral plane when a fire whirl occurs in a vertical shaft with a single corner gap. With n-propanol used as the fuel, the scale modeling experiments of fuel trays 5.8 cm and 7 cm in diameter were tested in a 34 cm (W) × 35 cm (L) × 145 cm (H) model for open and covered roof types. It is observed in the experimental process that the height of the neutral plane changes dynamically as the fire whirl is formed. The thermocouples were used to measure the temperature variation at different heights of openings to validate the measurement accuracy of the BOS technique. It is found that once a fire whirl occurs in the inner space of a high-rise building, the height of the neutral plane increases instantly. The experimental results demonstrate that the BOS technique can measure the neutral plane position of a large-scale model of a high-rise building fire scene directly, immediately and accurately.

1. Introduction

1.1. Hazards of high-rise building fires

Quantities of combustible matters can be found in high-rise buildings, and it has been demonstrated that the conditions in high-rise buildings become very severe once a fire has started. High-rise building fires are unlikely to receive outside help in battling the blaze, and must generally rely on their own fire safety equipment for protection. Therefore, the subject of fire safety is a crucial consideration in the design stage of buildings [1–4].

The stack effect is a common phenomenon in high-rise building fires, as shown in Fig. 1. Black identified and assessed some important factors that strongly influence the movement of smoke during a structural fire in high-rise buildings [5]. Shi et al. investigated the influences of the stack effect on fires in the compartment adjacent to a stairwell and conducted a set of experiments in a 1/3 scale 12-layer-stairwell model [6]. To guarantee the safety of super-high-rise buildings, all relevant factors must be addressed through the design, execution, daily management and updating of fire-prevention strategies [7].

* Corresponding author at: Department of Safety, Health and Environmental Engineering, National Kaohsiung First University of Science and Technology, No. 1, Daxue Rd., Yanchao Dist., Kaohsiung City 82445, Taiwan. Tel.: +886 7 6011000x7613; fax: +886 7 6011061.

E-mail addresses: such@nkfust.edu.tw, georgesu2000@gmail.com (C. Su).

http://dx.doi.org/10.1016/j.measurement.2015.10.004
0263-2241/

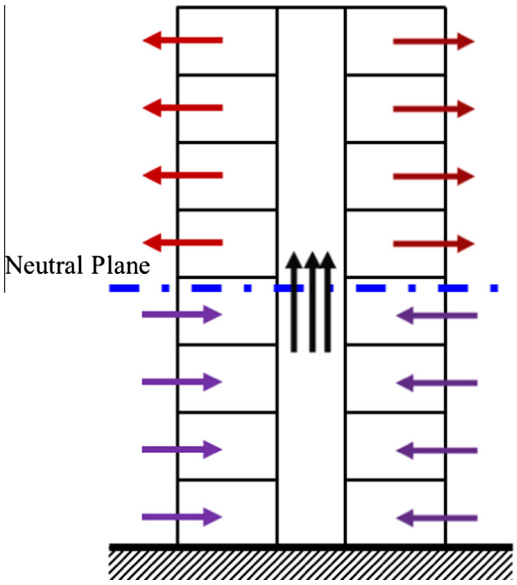

Fig. 1. Schematic diagram of stack effect.

On November 21, 1980, a disastrous fire happened at the MGM Grand, Las Vegas, and the stack effect resulted in 85 deaths [8]. On May 12, 2001, a fire which broke out on the 3rd floor of a 26-story building in Northern Taiwan spread to the area above the 20th floor under the stack effect. This fire burned for 43 h [9].

1.2. High-rise building refuge and rescue

When a high-rise building is on fire, there are two issues of immediate importance: the evacuation of numerous persons and the safety of the fire fighters attempting to save the building. Chow emphasized that smoke was a fatal factor in a high-rise building fire [10]. The dangers of smoke and hot gas diffusion must be considered when evacuating people, as any carelessness could result in mass casualties, especially due to the smoke diffusion in vertical spaces.

Fire fighters are at extremely high risk when performing fire rescue activities at high-rise buildings. Adams and Galea demonstrated that rescuers can easily be killed at the fire scene because of inappropriate rescue strategies [11]. Therefore, how to preserve the safety of the rescuers in dangerous locations is a very important subject.

1.3. Fire whirl phenomenon in the vertical space of high-rise buildings

A fire whirl usually occurs in forests or open areas, and there are some special and complex phenomena at the fire scene which have been discussed in numerous articles [12–14]. A suspected fire whirl occurred in the vertical space inside the Garley Building in Hong Kong during their 1996 fire. Some academic articles have discussed the probable fire phenomena when the patio space of a high-rise building is on fire. In recent years, the number of studies concerned with fire whirls has gradually increased [15,16].

Due to the stack effect, in high-rise buildings the inflow direction of the lower inlet air is orthogonal to the fire plume direction of the upward flame. The flame whirls up under the effect of the inlet airflow. Chuah and Kushida found that the flame height of the fire whirl was several times that of a combustion flame in free space and was the peculiar condition of the fire whirl [17]. Chow illustrated that the fire whirl was influenced by the closed-in space, with the airflow whirling rapidly upward and causing the fire to quickly spread [18].

2. Neutral plane position at high-rise building fire scene

Zhang et al. built a new model to predict the location of the neutral plane inside the shaft space of a building in a fire situation [19]. Himoto et al. conducted a series of reduced-scale experiments to investigate the thermal behavior of window flames, which expose the upper floors as well as adjacent buildings to potential risk as the fire spreads [20]. Fig. 2 displays the actual position of the neutral plane of a fire scene.

The influence of the neutral plane position at a high-rise building fire is crucial, and is governed by two factors:

- The neutral plane position is related to the air flow direction in the building; it influences the flow of smoke, especially that related to the effectiveness of

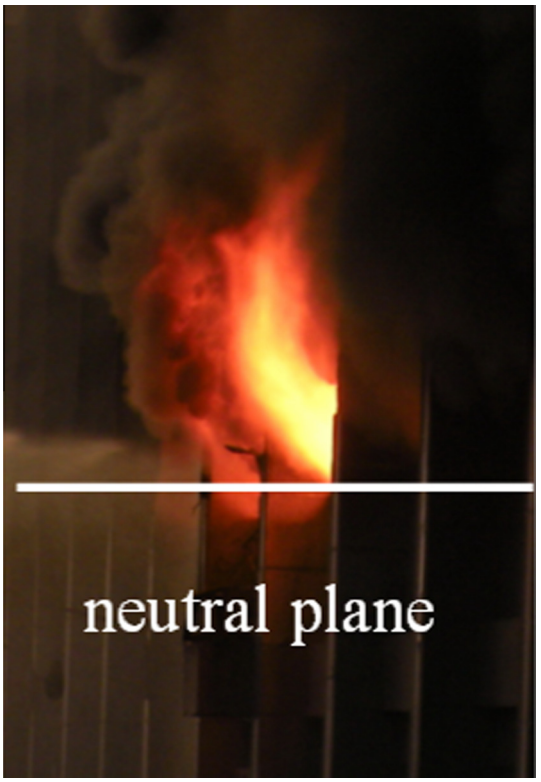

Fig. 2. Neutral plane in the real fire.