FIRE SAFETY REQUIREMENTS ON LIFT SYSTEM FOR EVACUATION IN SUPERTALL BUILDINGS

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ABSTRACT

Fire safety requirements on lift system used for evacuation in supertall buildings were discussed in this paper. Designs for fire and smoke protection for lift systems for evacuation were reviewed. Lifts are not yet designed to be used by most of the occupants in fire. Two major safety concerns were identified on the hazards due to smoke spread to the lift shafts and lobby; and the fire resisting construction required under big fires. Fire safety protection for evacuation is not demonstrated to be adequate for supertall buildings. Key issues and problems need to be addressed were discussed.

1. INTRODUCTION

Many supertall (with other names as mega-high-rise, super-high-rise or ultra high-rise) buildings, defined to be over a height of 984 feet (300 m) according to the Council on Tall Buildings and Urban Habitat [1], were built or to be built in many other cities. Evacuation has been identified [2] as a key concern when a supertall building is under fire.

It takes a long time for all occupants to leave the building due to whatever reasons [3,4]. Phased-evacuation or the "stay-in-place" approach [5] appears in the fire safety management plan of many supertall buildings. Refuge floors are required every 20 to 25 floors [6] in tall buildings in Hong Kong since 2000. With the rapid development in China since 2000, such requirements are specified in their fire codes. A protected space is also provided in many new places, such as the refuge place in Taipei 101 building. Occupants can wait in the refuge place for rescue, or to move between stairways of every eight levels [7]. However, the unexpected quick collapse [8] of the World Trade Centre buildings in 2001 led to concerns on using refuge floors and places. Occupants are not willing to delay egress by staying at the refuge places. Consequent to this event, adequacy of phased evacuation plans for tall buildings are under review [7].

The number of stairs in many supertall buildings in the Far East appears to be not adequate to give short evacuation time. At least 2 hours are required for total evacuation as reported in the Petronas Towers in Kuala Lumpur, Malaysia [9]. Note that some supertall buildings even provide fewer number of staircases than the requirement specified in the code [2,4]. Further, they are not comfortable to rely solely on staircases for total evacuation of all occupants. There are starting interests in the use of lift system for egress and access all over the world [10].

Lift has been designated since 1980s to be used in a fire by firefighters and the disabled only, but not for the general public in many countries [10]. Obviously, using lifts would speed up evacuation [11]. The lift system can be an effective alternative if it is reliable, accessible and safe under a big fire. Upgrading the fire safety provisions for the lift system to stand a big fire is necessary. The first stage is to deal with fire and smoke hazards on lift lobbies and shafts.

In this paper, existing fire safety requirements and protection for lifts used for evacuation were reviewed. Two major safety concerns on smoke hazards on the lifts shafts and lobbies; and fire resistant rating of construction elements under big fires were reported in this paper. Key issues and problems need to be addressed in providing lifts for evacuation for supertall buildings were discussed.

2. FIRE PROTECTION FOR LIFTS USED FOR EVACUATION

Evacuation has been identified [2-4,7] as a key concern affecting the fire safety of supertall buildings. That is because of the large number of people staying inside, long vertical travel distance and long walking down times. Full evacuation through the existing staircase systems in many supertall buildings is impossible to complete within normal total evacuation time, say 30 minutes as in a railway station. It took [9] 2 hours to evacuate the occupants in a normal fire drill in the Petronas Towers in Kuala Lumpur, Malaysia. The cost of increasing the number or width of the stairwells in a building is high for existing buildings. Using lifts seems to be a viable option to give quicker exit routes. A significant reduction in total evacuation time can be achieved by using lifts [12,13].

However, lifts are not supposed to be used in a fire emergency at this moment. It is only feasible until the performance of the lift system during a fire has been properly evaluated with adequate fire safety provisions. Possible reasons why lifts are unsafe in fire emergencies highlighted by Sumka [14] are:

- Elevators might not respond to a call from a specified floor, causing loss in egress time for the waiting occupants;
- Elevator responds, but stops at the floor where the fire exists because smoke enters;
- Overcrowding stops the closing of the elevator doors;
- Entrapment in the elevator due to power failure.

A research project, funded by the US General Services Administration (GSA), was carried out [11] to develop techniques for occupant use of lifts during building evacuations. It is focused on fundamental system considerations, engineering design considerations, design analysis, and human behavior. An interactive computer program, ELVAC, was developed based on idealized flow. Results showed that use of lifts in addition to stairs during a fire emergency allows occupants and firefighters an additional system of vertical transportation [15].

A set of requirements to assure safe lift operation during fire emergencies was identified by Chapman [16]:

- Complete building sprinkler protection;
- Pressurized elevator shafts;
- Elevator lobby enclosures on all floors;
- Pressurized elevator lobbies;
- Air intakes for pressurization systems located in a smoke free area;
- Smoke detectors in elevator lobbies, water resistive elevator systems;
- Elevator recall when power fails;
- Dedicated emergency power for all elevators;
- Pressurized stairways for all elevator lobbies;
- A means of two-way voice communication between all elevator cars and fire command location;
- A means of two-way voice communication between all elevator lobbies and fire command location;
- A program for the priority response of elevators during fire emergencies.

Among these issues, water infiltration was determined by Klote and Braun [17] to be the area requiring further studies. Protection of the lift system against water damage is necessary. Preliminary methods were suggested to conduct laboratory tests for working out recommendations for protection of lift system from water. Water damage to lift components was suggested by Klote and Fowell [18] to be the most significant factor affecting lift usage. Lifts should be designed using wet resistant components and located to minimize water infiltration.

Discussion on preplanning for lift use during major fires was conducted by Cook [19]. Based on analytical studies, it is possible to improve safety, evacuation and fire operations in high buildings by using new technology and ideas, developing multi-agency contingency plans, cross training firefighters and lift mechanics, and training building occupants.

A study agenda to measure the efficacy of such a procedure was proposed by Proulx [20]. This agenda paper was not aimed at discussing the technical issues but proposing an occupant interface to ensure the successful use of lifts by occupants during an emergency. Even all technical problems on the hardware fire protection provisions are solved. Software safety management on a lift evacuation procedure should be developed. Work focused on evacuation studies and human behavior was also conducted by Sekizawa [21]. A simplified model was developed to evaluate evacuation time by lifts. Some case studies were conducted to examine the feasibility and issues of lift use for evacuation. From the result of case studies, lift evacuation would only be effective for a small part of occupants such as disabled people. Other occupants were suggested to use stairs for evacuation.

Risk assessment models for analyzing evacuation effectiveness based on risks related to human behavior, fire hazards and operational mechanism were studied by Sharma [22]. The target was to analyze the risks associated with the use of lifts and the need for lifts as an alternative emergency evacuation facility in buildings. It was pointed out that combining lifts and stairs would give significant advantages in a hypothetical building with 38 floors. Performance-based design on lift evacuation system was developed. However, this study was limited to apartment buildings where the occupant load is low and fire load density much lower than the upper limit of 1135 MJm^{-2} in the Hong Kong codes [23].

Performance criteria based on practical objectives are proposed by Bukowski [24,25]. More reasonable revisions with human behaviour were upgraded to design practice. However, these suggested regulatory thresholds need to be justified by the authority. There are no regulations that permit egress lifts. Alternate solutions are applied through performance-based design [26]. There are many reservations in such fire engineering approaches [27]. Large-scale evacuation studies with full-scale burning tests would be applied in further justification. Such design in existing buildings must be upgraded but there is no in-depth research on fire safety provisions for these lift systems. Therefore, studies on how to achieve safe lift system usage under big fires in supertall buildings should be carried out urgently.

3. SMOKE MOVEMENTS IN THE LIFT SHAFTS AND LOBBIES

Big fires reported in tall buildings demonstrated that lift shafts are vertical paths for smoke and fire spread throughout the building. A fire, which resulted in 2 deaths, 30 injuries, and 10 million dollars damage in a fifty-story tall building in New York City, started from the 32nd floor. It spread rapidly because of plastic materials and the failure of some smoke dampers [28]. Another big fire occurred in a 21-story building in Seoul, South Korea, with 163 people killed. The fire and smoke spread through the shafts, burned from the lower three floors and the upper floor towards the middle floors of the building [29]. A fire occurred in the First Interstate Bank Building in Los Angeles, California. Smoke spread through the service lift connected the ground to the 62nd floor [30]. The big Garley Building fire in Hong Kong occurred with fire spread along through lift shaft under refurbishment [31]. The fire started in a lift shaft, grew significantly and spread to the lower and upper levels. Eventually, flashover occurred in part of the building. A big post-flashover fire with duration longer than twenty hours resulted. Therefore, smoke hazards should be considered in using lift system for egress. Smoke movement and control in the lift shafts without protection must be understood.

Studying the spreading mechanism of smoke and hot gases through the lift shaft is essential. Smoke can spread [32] due to buoyancy of hot smoke, expansion of the hot gases, wind effect, stack effect and airflow controlled by the mechanical air handling equipments. Stack effect gives the pressure differential due to the temperature difference between the air inside the building and that outside the building. Turbulent mixing of hot smoke with the upper cool air in a fire would take place within the shaft [33].

A joint project of the National Institute of Standards and Technology (NIST) in the United States and the National Research Council of Canada (NRCC) was carried out to study smoke control by pressurization for lift evacuation systems [34-41]. Detailed review of the concerns in using lifts was reported. A series of full-scale fire experiments were conducted at the NRCC's ten-story fire research tower near Ottawa [37]. Two 2.5 MW propane burners located on the second floor were used. Pressure differences due to the thermal effect across the lift lobby wall were studied. Fire and smoke spread to the lobbies and the lift shaft. Test results showed that if the fire room temperature was 600 °C, the pressure difference was 6.2 Pa for the low fire temperature and 7.5 Pa for the high fire temperature. Pressurization was proposed to protect the lift system from smoke by providing positive pressure in the shafts and at lobbies. The system was suggested to be activated before filling up the lift shaft and lobbies with smoke. Both lift shaft and lobby pressurization would give better performance. Equations were developed for designing pressurization systems with variable supply air with feedback control and relief dampers.

Wind effect on the pressure difference across a lift lobby wall was investigated by Tamura [42]. Tests were conducted with wind speeds of 25 to 40 km/h under several different opening conditions. The pressure differences across the lift lobby wall on the second floor were positive; varied from 0.0 to 6.0 Pa when only the leeward vent was opened, the flows from the lift shaft into the lobby. The pressure differences were negative, varied from -0.1 to -0.5 Pa and from -1.5 to -9.6 Pa in other cases, they represented flows from the lift lobby into the lift shaft. Hazard conditions occurred only when the windward wall vent was open. Mechanical pressurization of the lift shaft greatly reduced the possibility of smoke spread to the lift shaft and lobbies due to wind effect, stack effect and their combination.

A joint project addressing the impact of pressure disturbances caused by lift car motion on smoke control was carried out [34-36]. Piston effect would be created as a lift moves pass a fire floor. It pulls smoke into a pressurized lift lobby. This gives adverse impact on efforts to control the smoke movement from the fire floor. A method for analyzing the upper limit of the pressure difference across a lift lobby caused by piston effect was developed by Klote [34]. A set of experiments was conducted in a 15-story hotel in Mississauga, Ontario, to investigate the piston effect and evaluate the analysis model [35]. The pressure differential, measured at floor level of the top floor, combined with modeling results indicated that lift piston effect can be a big concern for fast cars in single car shafts. However, results were not significant in the case of low speed cars and multiple car shafts. Impact of piston effect on the performance of lift smoke control system was investigated by Klote [36]. Smoke infiltration for a hazard was analyzed.

The smoke movement pattern in a lift shaft was studied with a scale model by Sun and Chow et al. [43]. Experiments were conducted to investigate the smoke movement in a full-scale six-storey stairwell induced by a fire in an adjacent compartment.

Pressure distribution caused by stack effect in tall residential buildings was studied by Jo and co-workers [44] using the field measurements and simulation case studies. Two tall residential buildings in Korea were selected for the field measurements, characteristics and problems found were confirmed in several simulations of tall residential buildings. The thermal draft coefficients varied from 0.20 to 0.49 in the field measurements and simulation results. Stack pressure difference in tall residential buildings acted mainly on interior partitions rather than on exterior walls. Serious problems due to large pressure differentials can occur on the inside of the building. Excessive pressure difference problems were found to occur around the core area. Installing ‘airlock doors’ between lift doors and residential entrance doors on typical floors was proposed to solve the pressure difference problems.

Lift shaft and stairwell shaft-pressurization systems are studied as means of smoke migration prevention through the stack effect in a 30-story model residential building. Simulation using the CONTAM software was carried out by Miller and Beasley [45]. Results showed that, compared with stairwell pressurization, substantially larger fan flow rates were required to achieve the required minimum pressure differences in lift shaft pressurization system. Prohibitively large pressure differences across upper-floor lift doors were found for all cases. However, smoke could spread to the shaft and then to all parts of the building by the fan system. This was due to the large leakage areas for lift doors than for stairwell doors. Substantial pressurization of the ground-floor building interior would be resulted. There is a strong coupling between the fan speed requirements of the stairwell and lift shaft pressurization systems.

A network model was developed by Black’s study [46] for smoke control in a tall structure. All complex interactions among the variables affecting smoke movement through a lift shaft and then into occupied floors within the structure were described. The program was applied to study smoke spread to a standard building with 45 floors under a standard fire. Parameters affecting smoke movement such as top vent area, tightness of lift doors, construction of lift shaft, building height, floor pressurization equipment, wind velocity and construction of building exterior were explored. Factors affecting the neutral plane height were discussed.

4. FIRE RESISTING CONSTRUCTION UNDER BIG FIRE

Tall office buildings are often with high occupant loading and storing high amount of combustibles. Offices for small and medium enterprises (SME) stored combustibles over the maximum allowed value of 1135 MJm^{-2} in the local codes [23,47]. This high fire load leads to a particular concern in the onset of a big fire and the according failure of a tall building. Fire resistance rating of the construction elements under big fires should be higher than that for normal or small fires.

There are many curtain walled office buildings. Big fires breaking the glass windows [48] would supply more air to give a big fire. The temperature-time curve resulted will be much higher than standard ones. Several big fires in tall buildings with glass facades have been reported [49,50]. The equal area hypothesis on temperature-time curve [51] with respect to the standard value was commonly adopted to study equivalent fire resistance. Study on evaluating fire shutters under big fires by Chow [52] indicated that the approach should be carefully reviewed for fires bigger than the design value. Full-scale burning test on assessing a fire shutter with 2-hour FRP under a big fire was carried out. Results appear to deviate from that estimated by t-equivalent rule under such big fires. Therefore, concerns due to the thermal radiation acting on the construction elements of lift system under big fires should be further investigated.

5. CONCLUSION

Fire aspects on lifts and lift shafts used for evacuation in tall buildings were reviewed. Lift used for evacuation, smoke movement in the lift shafts and lobbies, and reduction in fire resistant rating of construction elements under big fire were discussed. Such results are only good for normal tall buildings. Little progress on the evacuation in supertall buildings was made in the following years. Applying all works to normal tall buildings to supertall buildings over 300 m should be justified. That depends on how big is the fire. Key issues and problems need to be addressed for developing lift system for emergency evacuation in supertall buildings are:

- A better understanding of the fire environment in lift shafts and adjacent lobbies in supertall buildings, such as the main driving forces for smoke movement in supertall buildings which will be very different from that in a normal tall building, and smoke movement and fire spread into the vertical lift shafts and lobbies under big fires, etc. Identification of the safety requirements for lift systems used for evacuation means should be developed.

- Positive pressure in the lift shafts and lobbies for the lift system in tall buildings should be studied. Works on staircase pressurization systems and smoke movements in lift shafts were only under small fires [53]. Pressurization of lift shafts and lobbies in supertall buildings should be thoroughly studied. Issues related to opening doors upon pressurization of lift shaft and lobbies should be studied carefully.

- On evaluating fire shutters under big fires [48], both thermal radiation and gas temperature have to be considered in fire hazard assessment. Full-scale burning test with big fires should be carried out to better understand the radiation effect. Requirements of fire resistance and heat protection for the lift system for supertall buildings under big fire should be evaluated.

Full-scale fire experiments are necessary to fully understand the fire behavior impact on the lift shafts and lobbies. As for supertall buildings, it may not be practical to apply the necessary fire loads to a full-scale experiment target which could be too large to reproduce at realistic scales. Scaled experiments offer an economical and simple alternative for laboratory study.

Mathematical models with computational fluid dynamics (CFD), such as the Fire Dynamics Simulator (FDS) [54] developed by NIST and full burning tests on scale models and part of the lift shafts and lobbies should be carried out to study the fire environment in the supertall buildings. Further works should be carried out to investigate appropriate evacuation strategy.

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