ASPECTS OF FIRE SAFETY IN ULTRA HIGHRISE BUILDINGS

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ABSTRACT

Aspects of fire safety provisions in ultra highrise buildings will be discussed in this paper. The total fire safety concept of implementing software fire safety management to control hardware provisions in passive building construction and active fire protection system is recommended. Key points on fire safety in these buildings are pointed out for further research. These include fire spread over buildings, crowd movement and control, preventive measures such as applying appropriate fire protective coatings to give a longer fire resistance period, and a feasibility study on using new fire protection systems. A risk management scheme should be worked out scientifically. Education and training of fire engineers are essential. The possibility of inducing an urban mass fire is also pointed out.

1. INTRODUCTION

With the rapid increase in population (of value about 37%) in the Far East, especially the development of big cities in China, and the increasing number of non-accidental fires, fire 'safety' in dense urban areas has to be considered carefully. Big accidental fires had happened before in old highrise buildings such as the big Garley Building fire [1,2], cross-harbour tunnels [3] and buses [4] in Hong Kong (now the Hong Kong Special Administrative Region HKSAR); and in many old highrise buildings and new shopping malls in China. Non-accidental fires reported over the world included arson fires in a bank [5], a karaoke [6], and an underground railway [7] in Hong Kong; terrorist attack fires in the World Trade Centre on 11 September, 2001 (WTC-911) in USA [8]; arson fires in universities in Beijing; and underground railway arson fires in South Korea and Russia. New architectural features such as deep plan, highrise, framed structure and well-sealed buildings; the use of new materials; new style of living; and the growing number of people living in cities or 'city groups' would give new fire safety problems of concern [9].

There are many highrise buildings in the Far East, and those of more than 40 levels are understood as ultra highrise buildings in Hong Kong. Among the top 100 highrise residential buildings in the world, over half of them are in Hong Kong and some of them are of height over 200 m [10]. There are concerns on fire safety in those ultra highrise buildings [11]. A very big fire happened [e.g. 1,2,12] in the old highrise Garley building during the replacement of lifts on 20 November, 1996. Consequent to that big fire, actions taken by the SAR government in addition to the existing fire codes [13-16] were:

- Old highrise buildings, i.e. those erected before 1972 without tight fire regulations, were requested to upgrade their fire safety provisions.
- New Fire Services Ordinance [17] on sprinkler system has been set up.
- Implementation of Fire Safety Inspection Scheme [18] on structural stability, external finishes and fire safety.
- There had been request on installing temporary doors with adequate fire resistance in the lift shaft while replacing the lift.

Whether those actions are workable for the existing highrise buildings is a question. It has not yet been demonstrated that providing these fire safety provisions in ultra highrise buildings will give adequate protection.

Basically, building fire safety codes deal with accidental fires. Consequent to the WTC-911 incident [8] and so many arson fires, there are concerns that whether non-accidental fires should be considered. With so many political and social issues, there will be a higher possibility of having terrorist attack and arson fires than before [7,8]. New architectural features, such as using so many glass constructions, might give additional problems. Cracking and falling down of glass panels due to explosion or failure of the fittings for fixing the glass panels would give a higher air intake rate to sustain combustion. As a result, higher heat release rates would be emitted to cause severe damages. A big fire might be resulted due to storing large amount of combustibles (allowed up to 1135 MJm^{-2}) [13], leading to urban mass fires [19].

The following areas will be pointed out in this paper:

- Typical fire safety provisions in highrise buildings.
- Total fire safety concept [9,20].
- Key fire problems to study in ultra highrise buildings [10,11].
- Impact to structural elements.
- Possibility of having an urban mass fire [19].
- Education and training required [21-23].

2. TYPICAL FIRE SAFETY PROVISIONS IN HIGHRISE BUILDINGS

Fire safety problems for highrise buildings are:

- Direct rescue by ground applications from the building exterior is impossible.
- Direct water application by fire fighting jets from the building exterior is impossible or much hindered.
- Normal escape routes for occupants are downward through staircases or lifts.
- Firemen access and equipment delivery to rescue people and fight against the fire are upward through staircases or lifts.
- Fire fighting techniques (water application, fire ventilation, etc.) are to be applied inside the building.

Current fire safety measures in those highrise buildings are [e.g. 11,13-16,24]:

- Passive building construction [14-16]
  - Building will be finished without these!
  - Difficult to upgrade after the building has been constructed.
- Active fire protection system [13]
  - Used to be installed after the building structure has been constructed.
- Preventive measures
  - Adopted to minimize fire occurrence.
  - Might be taken as part of fire safety management.
  - Includes applying fire retardant to combustibles; good fire training of occupants; and minimum storage of dangerous/flammable goods.
- Objectives [8,25] to clarify on the fire types to be protected against
  - Accidental fire
  - Arson fire
  - Terrorist attack fire
  - Disaster fire

Main passive means are:

- Confine fire area when the 'preventive' defense line is broken, when a fire occurs.
- Items include:
  - Fire-resistant wall, door, floor, etc.
  - Compartmentation, etc.
  - Fire resistance period FRP [26] is larger than the duration of the fire.
- Believed that the fire will be extinguished within the confined area when the combustible materials are consumed:
- Means of escape for occupants
- Means of access for firefighting

Active protection systems are also known as fire engineering systems or fire services installation (FSI) in Hong Kong [13]. These systems might not be successful in controlling fires sometimes. For examples, hot gases spreading out from the confined area due to air-leakage, stack effects, etc.

- Among all the fire-fighting agents, WATER is still the most important agent. It has a good cooling effect and is non-toxic, cheap, and easily available.
- Essential FSI for highrise buildings are fire hydrants, hose reel systems and sprinkler systems.

3. TOTAL FIRE SAFETY CONCEPT

The concept of total fire safety [9,20] in buildings can be achieved by improving:

- Passive building construction for fire safety.
- Active fire protection systems.
- Fire safety management [8,25].

Fire codes, prescriptive [e.g. 13-16,24] or performance-based [e.g. 9,27,28], should be established based on the concept of total fire safety. In fact, prescriptive fire codes are easier to implement. But it has shortcomings when there are new architectural features say in designing green or sustainable buildings, new fire protection systems, new style of living such as staying more time indoor in enclosed buildings with controlled environment, and using more new materials that the fire behaviour has not been tested properly.

Applying performance-based fire codes is only feasible in the transition period when the

prescriptive fire codes are not yet updated, say due to shortage of manpower as it takes a long time to train sufficient number of qualified fire engineers. Performance-based codes, or at least, application of fire engineering approach [9,27,28] is suggested to be applied in complementary to prescriptive fire codes, particularly for buildings not complied with the codes.

The followings should be clarified:

- Fire safety objectives (goals are life safety design for both occupants and firefighters, protection of property, non-disturbance to business and environmental protection) not complied with prescriptive codes. The issues of protecting against accidental and non-accidental fires should be clarified.
- Safety level expected for the design such as with high hazard; ordinary hazard; and light hazard.
- Engineering approach adopted, hazard assessment say with three levels [9] as basic studies; intermediate-level studies; and advanced studies.
- Actions to take on passive building construction; fire services installation; and fire safety management.

4. KEY PROBLEMS TO STUDY

The number of fires due to accidents or other causes appeared to be increasing. Fire safety engineering should be applied to design adequate fire safety provisions. Design fire scenarios must be decided carefully, say to get a typical scenario, the worst scenario or a normal scenario. Statistical theory should be used where necessary.

Studies should include:

- Fire spreading over buildings

  Mathematical modeling on fire spread with thermal radiation; wind effects [e.g. 19] on fire growth and spread to adjacent buildings; and the effects on smoke spreading should be studied. Experimental studies with a fire wind tunnel over fuel packs are recommended.

- Crowd movement and control

  Dynamics of crowd movement include not only motion analogy to track 'fluid particles'. Human factors should be considered and these will be different for different countries, races and styles of living. Topics include the analysis of evacuation pattern to safe places, modeling of crowd movement, and integration with fire detection systems and global positioning systems. The use of personal protection equipment and emergency escape equipment from ultra highrise buildings should be watched. The results should be useful for working out crowd control schemes.

- Prevention measures

  Topics include fire-safe materials, fire-safe furniture and passive building construction for compartmentation, fire resisting constructions, means of escape and means of access. The use of fire retardants for delaying ignition times and reducing heat release rate should be developed through more in-depth studies. Smoke suppressants for plastic materials should be searched.

- Active fire protection systems

  New technology on fire detection and fire suppression for reducing the heat release rate should be developed. Equipments for quicker movement of firemen and rescues, new designs to consume oxygen, heat reduction and installing water network systems through the urban areas for fire fighting should be considered.

- Risk management

  A maintenance plan, a fire action plan, a staff training plan and a fire prevention plan should be worked out [25] based on scientific studies. Care should be taken in dealing with dense population, crowd movement and mass evacuation under heavy traffic conditions. New engineering tools such as computational fluid dynamics had been applied in working out a risk management for gas station explosions in dense urban areas [29].

5. IMPACT TO STRUCTURAL ELEMENTS

Structural members are required to be stable under a fire for some time. In fact, structural stability will be assessed in determining the fire resistance period (FRP), such as having 0.5 hr, 1 hr, 2 hrs or 4 hrs under BS 476 [26] in Hong Kong. There are at least two points of concern:

- The structural members will be tested by a standard fire furnace, following a standard temperature-time curve. The effects of thermal radiation heat flux had not yet been included.
- The standard temperature-time curve was determined from experiments in compartment

fires with wood. Different values of fire load density and ventilation factors of the room were tested. Nothing was mentioned on the heat release rate of burning different materials.

In an enclosure fire, air will not be sufficient after flashover. There is too much fuel and the fire can be classified as a ventilation-controlled fire. Any exposure to ambient such as the breaking of glasses will supply air for combustion. The heat release rate will be highly increased. In this way, the structural members are exposed to a much more severe thermal environment. They might not be able to bear the loading and sustain for the FRP as specified. That was clearly demonstrated in the WTC incident that the FRP of 4 hours could not be sustained under such a big fire.

6. URBAN MASS FIRES

As reviewed [19], the criteria for forming fire storms are a fuel loading greater than 39 kg/m^2, over 50% of structures in an area greater than 1.3 km^2 initially ignited, and a localized heat release of 106 MW over a period of 2 to 3 hrs. Thermal radiation is not the only factor governing spreading, radiation from the burning surface and convection are also important. Sources for giving a mass fire might be due to nuclear weapons, natural disasters and terrorist attacks. Accidental or arson fires are not so likely to give a mass fire in urban areas, apart from gas pipe explosions, petroleum station and storing tank explosions. Buildings with glass constructions storing numerous combustibles exceeding the allowed value (fire load density of 1135 MJm^{-2}) of the regulation [13] should be watched [30].

Further, city fire hazard assessment with intelligent input of physical data measured from fire tests including those from a fire wind tunnel should be carried out. The National 973 Project "Fire Dynamics and Fundamentals of Fire Safety" in China was established [31] with the following objectives:

- Fire control, including detection and suppression improvement.
- Prescriptive fire codes updating and implementation of engineering performance-based fire codes.
- Safety management in dense urban areas.

This is a great move towards achieving safety.

Investigating the possibility of starting a mass urban fire would involve studying the physics of accidental building fires on architectural features. The breaking of those glass constructions with a high fire load density might lead to a mass fire. Statistical analysis of different fire scenarios should be carried out. Places with earthquake risk might have mass fires after those natural disasters.

7. EDUCATION AND TRAINING

To support smooth implementation of the fire safety engineering approach, education and training are required. First degree programmes [e.g. 21], taught master's degree programmes [e.g. 22] and research degrees up to PhD level should be offered. However, it would take over eight years to train adequate number of downstream engineers, even though a full-time first degree programme is offered now. Immediate actions to take are:

- Running high-level Continued Professional Development CPD programmes for practising professionals like architects, engineers or surveyors;
- Organizing joint training and discussion forums with universities and professional institutes and authorities such as Fire Services Department and Buildings Department in Hong Kong; Armed Police, Ministry of Public Security and Ministry of Construction in China.

These courses cannot be offered without research support. More importantly, the training of Hong Kong engineers with adequate theoretical and experimental techniques, and the training of Mainland engineers by exposing them more to advanced building technology in Hong Kong is a key point. This should be a joint function working collectively with universities in the Mainland and Hong Kong, training research degree PhD and taught MSc students as the first step [23].

8. CONCLUSIONS

With so many accidental and non-accidental fires occurred since 1996 such as the one in Garley Building [e.g. 2], building fire safety is a concern. Fire safety provisions in ultra highrise buildings should be designed carefully. Studying the above would help to work out appropriate fire safety design to give adequate public safety [11].

As common practices in safety engineering, technology (T), procedure (P) and behaviour (B) are the three essential elements. Scientific research can give T and P properly, say using the total fire safety concept to work out appropriate software management to control the hardware system [9,25]. However, B is the key point to achieve safety. This

refers to not only the occupants' awareness on fire safety, but also the ability of the building owner and management to take actions as stated in the fire safety plan, and the attitude of the professionals in designing and installing workable systems.

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