CTBUH Research Paper

ctbuh.org/papers

Title: **The Skybridge as an Evacuation Option for Tall Buildings in High-Rise Cities in the Far East**

Authors: Antony Wood, University of Nottingham
Wan-ki Chow, The Hong Kong Polytechnic University
Dean McGrail, WSP Hong Kong Ltd.

Subjects: Building Case Study
Fire & Safety

Keyword: Fire Safety

Publication Date: 2005

Original Publication: Journal of Applied Fire Science Vol 13 Issue II

Paper Type:
1. **Book chapter/Part chapter**
2. Journal paper
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

© Council on Tall Buildings and Urban Habitat / Antony Wood; Wan-ki Chow; Dean McGrail

J. APPLIED FIRE SCIENCE, Vol. 13(2) 113-124, 2004-2005

THE SKYBRIDGE AS AN EVACUATION OPTION FOR TALL BUILDINGS FOR HIGHRISE CITIES IN THE FAR EAST

A. WOOD
University of Nottingham

W. K. CHOW
The Hong Kong Polytechnic University

D. McGRAIL
WSP Hong Kong Ltd

ABSTRACT

Consequent to the World Trade Center (WTC) tragedy, research into the safety of tall buildings has been concentrated almost exclusively on the improvement of structural systems, fire proofing, and vertical evacuation systems. While this work is vital toward making tall buildings safer, it is in itself not enough. The problem should be considered at a more fundamental design level, not as an alternative but in addition to the improved safety provisions suggested before. Horizontal evacuation at height is proposed through creating skybridge linkages between towers. This is a good choice when vertical (usually downward) evacuation routes out of the tall building cuts off in a fire. A skybridge can increase the evacuation efficiency without increasing the number of fire stairs. This is well demonstrated in the Petronas Towers in Kuala Lumpur, Malaysia. There are many big cities in the Far East having so many highrise buildings (in highrise cities) built closely together. The possibility of linking currently empty refuge floors with skybridges is worthwhile to consider, especially for building clusters owned by the same developer. Skybridges retrospectively into an existing tall building cluster in the central business district of Hong Kong is taken as an example. Possible improvement on the evacuation efficiency is suggested. This can be extended to be a strategy toward the possible inclusion of skybridges in high-rise design as an improved fire safety provision of tall buildings all over the world.

© 2006, Baywood Publishing Co., Inc.

1. INTRODUCTION

With the rapid increase in population in the Far East, many cities and "city clusters" have developed. Highrise buildings close to each other are erected, giving a dense urban environment with tall buildings.

Since September 11th and the World Trade Center Towers collapse [1], the improved safety of tall buildings has become of prime importance across the world [2]. International groups considering the implications [3-5] have made recommendations in three areas:

- improvement of structural systems, especially with respect to progressive collapse;
- improvement of fire proofing to structure, fabric and evacuation routes; and
- improvement of evacuation systems, concentrating specifically on vertical evacuation; elevators and stairs.

While this work is vital towards making tall buildings safer, it is not enough. The risk to those big cities is increasing through terrorism, war, and accident as urban densities increase. It is necessary to tackle the problem at a more fundamental design level, not as an alternative but in addition to the improved safety mechanisms suggested above.

An evacuation assessment of several high-rise buildings simultaneously has been conducted for the Canary Wharf UK. In addition to assessing the evacuation procedures of a single tower, how several towers evacuating together (as a distinct possibility within an extreme event) was handled on an urban scale [6]. Since the events of September 11th, existing tall building owners have been understandably anxious about the safety of their buildings in the event of an extreme emergency. Many have commissioned full evacuation studies to determine total evacuation times, potential problems for improvement.

As the number of fires due to accidents or other causes appear to be increasing, there are concerns on fire safety in those highrise buildings. There are even more concerns on supertall buildings, understood to be those taller than 40 levels in Hong Kong [7, 8]. It is obvious that direct rescue by ground applications from the building exterior is impossible. The normal escape route for occupants is downward through staircases or lifts, but firemen access and equipment delivery to rescue people and fight against the fire are upward also through the same staircases or lifts. Thus, there is a potential circulation conflict here. Taking Hong Kong as an example, there are tight building fire codes for new projects [9-12]. For existing buildings, new Fire Services Ordinance on sprinkler system has been set up [13]. The Building Safety Inspection Scheme has been implemented on structural stability, external finishes, and fire safety. Whether those actions are workable for existing highrise buildings is debatable. Existing codes have not yet demonstrated that providing these fire safety provisions in highrise buildings will give adequate protection. Fire safety engineering should be applied to design adequate fire safety provisions.

Crowd movement and control under fire is a key part [14, 15]. It is difficult to upgrade the means of escape in existing highrise buildings. Evacuation paths are normally downward and fire fighting path upward, conflicting each other. But highrise buildings are often built together in big cities of the Far East due to the high land price. Clusters of buildings in public residential estates housing and commercial districts are commonly found, say in Hong Kong and Singapore. It is worthwhile to study whether additional evacuation paths can be provided by skybridge [16-18] or skylinks. There has already been such skybridges, in some building estates owned by the same property groups in the Central Business Districts (CBD) of the Far East, for providing normal access. The concept should be further explored as pointed out in this article.

2. SKYBRIDGES

One possible method of improving the safety of tall buildings is by introducing horizontal evacuation at height through use of a skybridge linking towers. The concept of being able to evacuate occupants at a level other than ground, should the building be at risk, seems sensible, especially if any emergency in a tall building effectively cuts off vertical evacuation routes and thus the connection to the ground plane. Implications of incorporating skybridges in high rise buildings in Hong Kong was proposed recently as a strategy for the improved fire safety of cities with dense highrise buildings [18]. In Hong Kong, refuge floors are required in the codes for new highrise buildings with more than 25 levels [9]. By making further use of these refuge floors for means of escape and commercial activities via high level linkages "skybridges" could not only greatly increase the level of life safety for building occupants but also add increased commercial viability to these usually "dead" spaces.

The idea of the skybridge is not new [e.g., 19]. From the 16th century when Antonio Contino's Bridge of Sighs joined Venice's Pallazo Ducale to the adjacent prison, connections between buildings above the ground plane have been an instrumental element of both fictional and realized visions. Some existing buildings around the world have already been connected by skybridges at height. Buildings with skybridges included: the National Congress Complex built in 1960 at Brasilia, Brazil; Kajimi Corporation Headquarter (1971) at Osaka, Japan; UN Plaza Hotel (1983) at New York, USA; Kashii Twin Towers (1989) at Fukuoka, Japan; Umeda Sky Building (1993) at Japan; Title & Trust Center (1993) at Chicago, USA; Tuntex & Chein Tai Tower (1997) at Taiwan; Petronas Towers (1998) at Kuala Lumpur, Malaysia; Plaza 66 Building (2000) at Shanghai, China; Genex Building (2001) at Belgrade, Yugoslavia; Twin Towers (2001) at Vienna, Austria; and Kingdom Centre (2001) at Riyadh, Saudi Arabia.

Apart from those famous buildings, there are some in the Far East with such features. As shown in Figure 1 for Beijing, China and Tokyo, Japan, these skybridges have potential use as means of escape. Use of the skybridge to date, though, has been restricted to these isolated, one-off examples. Impact of adopting skybridges on evacuation efficiency should be assessed as a strategy toward their inclusion in high-rise design as a mechanism for the improved safety of tall buildings.

Preliminary investigations were started by surveying the existing buildings over the world with skybridges. The aim was to establish the historical precedent. Impact of how these horizontal connections on tower design and operation can then be estimated. Preliminary findings were reported in the literature [6].

3. REFUGE FLOORS

Refuge floors are required in high-rise buildings in some cities like Hong Kong. All new buildings which exceed 25 storeys in height are required to have a refuge floor located at every 25th floor throughout the building [9]. An example is shown in Figure 2.

The incorporation of a refuge floor into a building obviously has a huge impact upon the design of the building, not only from the additional recommendations that are required by the other fire safety provisions such as ventilation, drencher systems, and fire resisting floors but also from the effect that they have upon the lettable area of the building. From the point of view of a developer, to lose two whole floors in a 75 storey building to what is in effect dead space might be a massive loss to the lettable revenue. That depends on how the "plot area ratio" is interrupted.

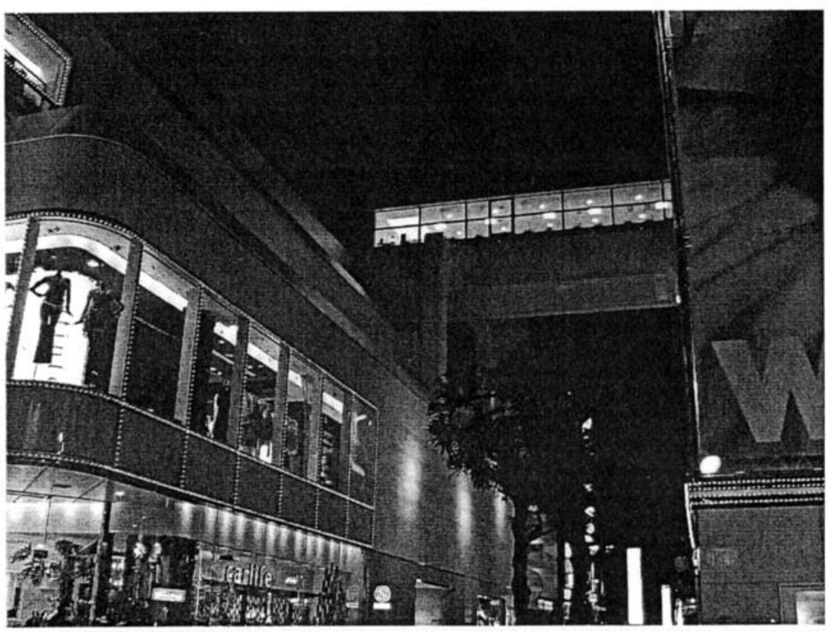
Anyway, functional objectives of a refuge floor [20] include, at least:

- serve as a place of rest for evacuating occupants;
- break up evacuation stairs on the refuge floor— this reduces the possibility of smoke logged stairs and also reduces the possible stack effect created;
- serve to protect disabled/ injured people for a long period of time until fire fighters can rescue them;
- act as a command point of the rescue teams to assist evacuation and achieve orderly evacuation of the building;
- serve as a fire-fighting base for fire fighters to attack the fire; and
- serve as a starting point for using lifts for evacuation, if this is possible, depending on severity and location of the fire, lift design, and number of occupants required to be evacuated.

There might also be a possibility of serving as a fire "barrier" to cut off fire spreading from different levels.

Therefore, in order to allow the removal of the refuge floor, all of the above functional objectives should be satisfied. By incorporating a "skybridge" between

(a) Beijing, China



(b) Tokyo, Japan

Figure 1. Examples on skybridge.

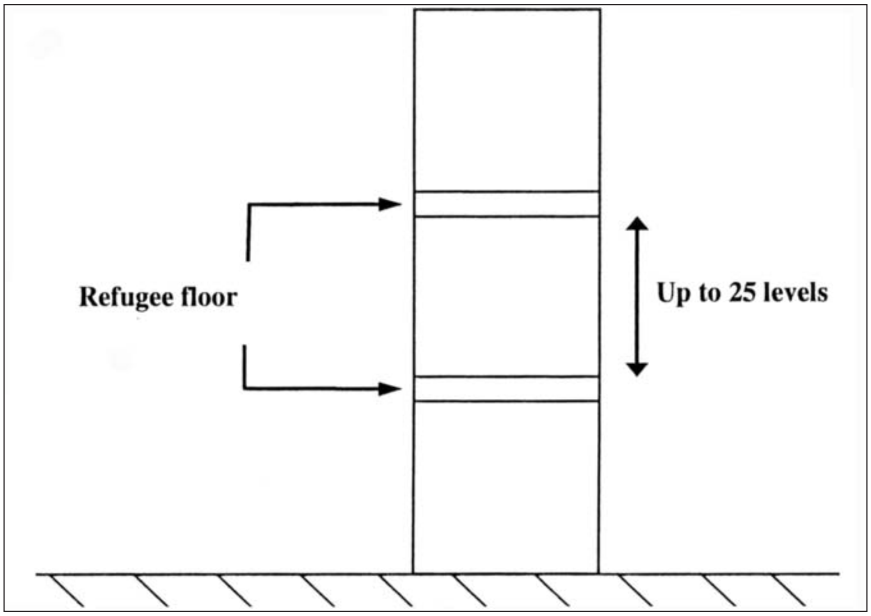


Figure 2. Refugee floors.

two or more buildings, all of these objectives might be satisfied while increasing the let usable area. For example, as opposed to having a "dead" space at the 25th floor of every high rise building, interconnected retail areas or restaurants could be allocated. Only in the case of a fire is the "skybridge" required to fulfill its secondary function as a means of escape to an adjacent place of safety.

The "skybridge" also provides an increased level of life safety when compared to a refuge floor. With a refuge floor, people always remain in the same building in which the fire incident has occurred. With a "skybridge," people can move away from the initial fire incident into another building unaffected by fire.

In order to persuade both clients and approval authorities that the incorporation of "skybridges" into a building design aids real benefit, two fundamentally different criteria should be satisfied. While a client will always be interested in providing the most cost effective solution for the safety of his building occupants, the approval authorities, on the other hand, are not concerned about cost effectiveness but life safety, which can obviously cause interesting problems. If a building design is to incorporate a "skybridge," then the client will want to see a real benefit in terms of cost and the approval authorities will want to see real benefits in terms of life safety. Both these criteria will be addressed in detail in this project through fire safety engineering.

4. SKYBRIDGES AT HEIGHT

Many highrise buildings around the world have been designed with a *phased evacuation strategy* in mind; i.e., evacuating a number of floors at a time and leaving the majority of the building occupants in place. Given the high public profile of the events of the World Trade Center Towers' collapse, it is now doubtful that tall building occupants will feel comfortable to remain in a tall building in an emergency situation, as is required of this phased evacuation approach [21]. The alternative simultaneous evacuation strategy, where all building occupants are evacuated at once, would have a huge impact on the design of tall buildings; e.g., increasing the number and width of fire stairs, the consequential impact on floor space, and retrospective incorporation in existing buildings.

Incorporation of physical connections at height throws up considerable challenges: structurally, operationally, and psychologically as well as in design and occupant terms. If skybridges are to become a realistic proposition for the improved safety of tall buildings in dense cities such as Hong Kong, the following implications should be studied:

- impact on client brief;
- impact on internal planning; the skylobby;
- optimum vertical placing of the skybridge;
- strategic planning for incorporation; and
- impact on structure and fabric; the skyportal.

It is obvious that, potentially, skybridges could be a significant element in the quest to make tall buildings safer. As in Figure 3, there will be an additional horizontal path at height to safe place. For a building with N stairs, there will be (N + 1) exits. The entire evacuation pattern is changed as people can move up for evacuation. However, there is not yet an empirical expression for discharging occupants upward to an outside safe place. As the travel speed up the stairs would be decreased significantly with height, further study including upward evacuation is necessary.

In addition, the use of skybridges gives an opportunity for the maximizing of commercial floor space through increased evacuation efficiency. In Petronas Towers, Kuala Lumpur, Malaysia, for example, by fire-rating the skybridge and providing an alternative escape route, not only were evacuation times for a single tower significantly reduced, it was also possible to omit two fire escape stairs from the design which would otherwise have been needed [17].

5. APPLICATION ON PUBLIC ESTATE

A potential application is to the existing public estate in Hong Kong. There might be many blocks of buildings with height over 40 levels. Putting in a

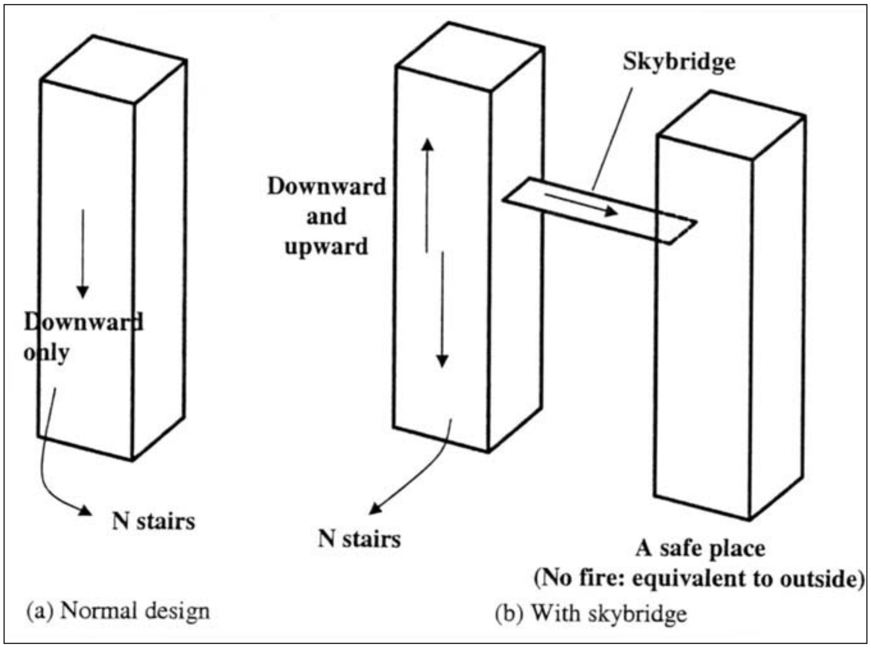


Figure 3. Evacuation in highrise building.

skybridge at height will give better evacuation. It is technically feasible, as such buildings are closely packed together.

A typical public estate in Hong Kong for citizens at fundamental class is shown in Figure 2. This estate has a population of 23,000, with about 6,300 units of floor areas 30 to 60 m^2. There are 13 residential building blocks with height up to 40 levels. Designing a skybridge in linking up all blocks for such an estate will provide better fire safety. The evacuation time can be reduced as the design on means of escape needs not all go downward.

However, in Hong Kong, access at the same level of a building in some public estates might be isolated due to security reasons. Two parts are then divided on each level by the barrier as in Figure 4. Residents staying at the same level of the building but at different ends have to travel downward and upward again to reach the other part. Such design might reduce the evacuation time. The doors, used to be steel fences, do not have any fire resisting design. This point should also be considered carefully.

For those new building estates with refuge floor at the same level, linking them up by skybridges at such refuge floor would definitely improve the evacuation pattern.

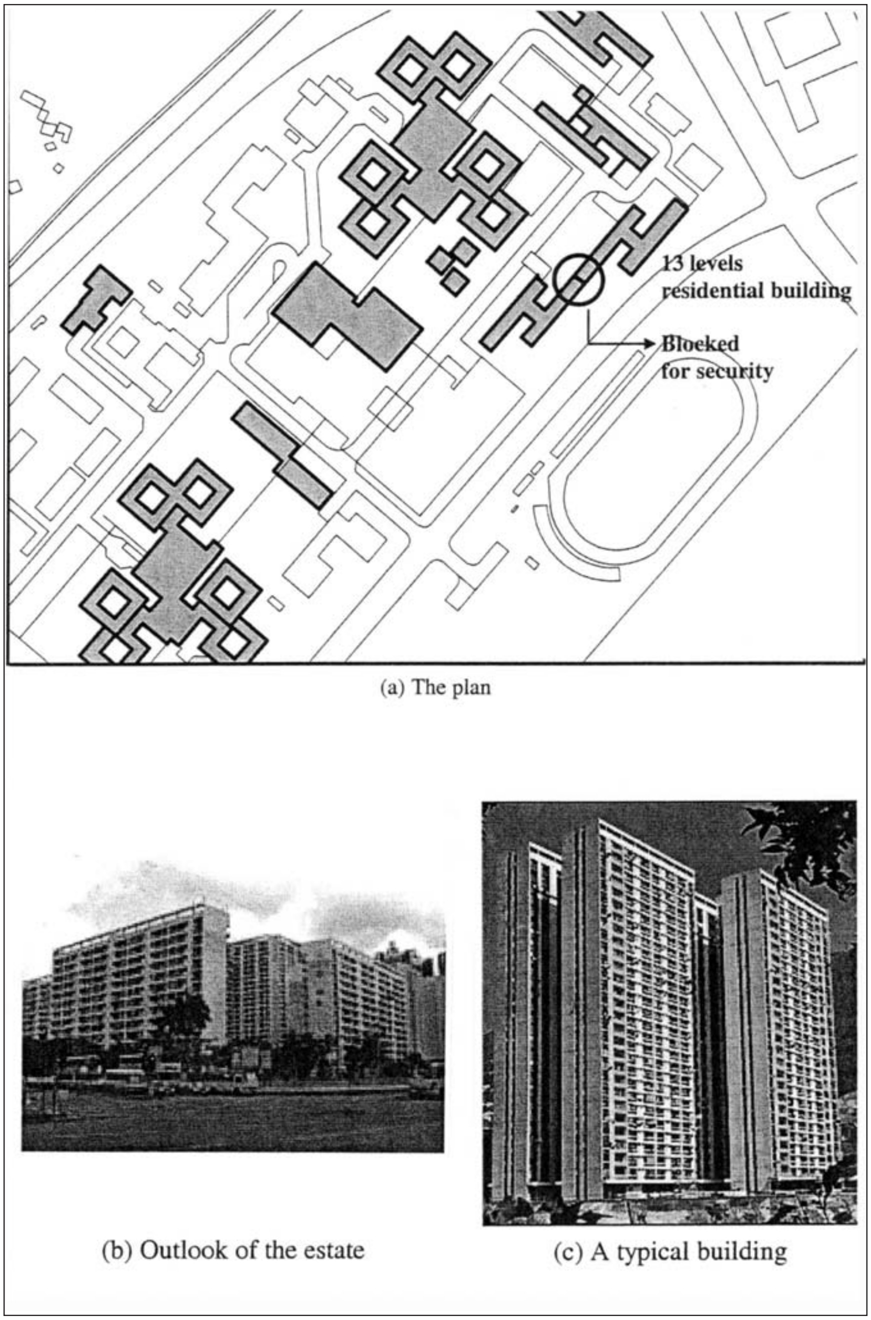


Figure 4. A typical public estate.

6. CONCLUSION

Consequence to the collapse of the World Trade Center towers, improving safety of tall buildings becomes the prime importance of the construction industry all over the world. The work has tended to concentrate only on the improvement of some existing tall building systems to make them safer; structure, fire proofing, and vertical evacuation systems through lifts or stairs. While many of these groups also allude to the importance of alternative evacuation options such as skybridges, there is currently no significant works reported in this area. There have been no studies on the economic implications and integration with fire safety management for buildings with skybridges yet.

The need to build tall in many world cities, especially those in the Far East, is obvious. Confidence in the safety of those buildings needs to be re-established. The above review suggested that the skybridge concept is vital, with the following long-term impact and main beneficiaries:

- High-rise building occupants, through improved evacuation and safety systems;
- governmental and regulatory bodies concerned with the safety of tall buildings;
- high-rise building developers, through both a safe return on investment and the opportunity to maximize saleable floor space through horizontal connection at height allowing the omission of extra fire stairs;
- existing high-rise building owners, through the potential for retrospective incorporation of skybridges in building clusters; an obvious example is the public estates with high-rise buildings densely packed as in Hong Kong, as shown in Figure 4;
- fire safety consultancies, through being able to offer skybridge evacuation as a potential improvement of evacuation to building clients; and
- the urban public in general.

REFERENCES

1. Federal Emergency Management Agency, *World Trade Center Building Performance Study: Data Collection, Preliminary Observations and Recommendations,* FEMA 403, May 2002.
2. A. Pearson, *The Skyscraper of the Future, Building Design,* London, November 9, 2001.
3. J. Roberts, *Safety in Tall Buildings, and Other Buildings with Large Occupancy*, ISTRUCTE London, July 2002.
4. F. Wainwright and P. Bressington, *Extreme Events: The Arup View,* Arup UK, May 2002.
5. Foster & Partners, *Tall Bldgs Study: Safety Considerations After 11 September,* London, 2002.

6. A. Wood, *Pavements in the Sky: The Use of the Skybridge in Tall Buildings*, paper accepted for the CIB (International Council for Research and Innovation in Building and Construction)/CTBUH (Council on Tall Buildings and Urban Heritage), International Conference on Tall Buildings, Kuala Lumpur, October 2003. See Website: http://www.cibklutm.com/ (2003).
7. W. K. Chow, Fire Control Safety Idea of Super Building (in Chinese), *Safety Bimonthly (An Quan), 25*:3, pp. 7-11, 2004.
8. W. K. Chow, Aspects of Fire Safety in Ultra Highrise Buildings, *International Journal on Engineering Performance-Based Fire Codes, 6*:2, pp. 47-52, 2004.
9. *Code of Practice for Provisions of Means of Escape in Case of Fire and Allied Requirements,* Buildings Department, Hong Kong, 1996.
10. *Code of Practice for the Provision of Means of Access for Firefighting and Rescue Purposes,* Building Authority, Hong Kong, 1995.
11. *Code of Practice for Fire Resisting Construction*, Buildings Department, Hong Kong, 1996.
12. *Codes of Practice for Minimum Fire Service Installations and Equipment and Inspection, Testing and Maintenance of Installations and Equipment,* Fire Services Department, The Hong Kong Special Administrative Region, 2005.
13. *Fire Safety in Composite Buildings/Domestic Buildings,* advisory letter to the Building Owners/Incorporated Owners/Mutual Aid Committees, Ref. no. (4) in FP(FS) 341/03 II, Fire Services Department, Fire Safety Command, The Hong Kong Special Administrative Region, 2002.
http://www.hkfsd.gov.hk/home/eng/source/safety.html
14. G. Proulx, Section 3/Chapter 13 Movement of People: The Evacuation Timing, in *SFPE Handbook of Fire Protection Engineering* (3rd Edition), P. J. DiNenno (ed.), National Fire Protection Association, Quincy, Massachusetts, pp. 3-342 to 3-366, 2002.
15. H. E. Nelson and F. W. Mowrer, Section 3/Chapter 14 Emergency Movement, in *SFPE Handbook of Fire Protection Engineering* (3rd Edition), P. J. DiNenno (ed.), National Fire Protection Association, Quincy, Massachusets, Society of Fire Protection Engineers, Boston, Massachusetts, pp. 3-367 to 3-380, 2002.
16. J. Xie and P. A. Irwin, Application of the Force Balance Technique to a Building Complex, *Journal of Wind Engineering and Industrial Aerodynamics, 77 & 78,* pp. 579-590, 1998.
17. C. Pelli and M. Crosbie, *Petronas Towers: The Architecture of High Construction,* Wiley-Academy, 2001.
18. A. Wood, D. McGrail, and W. K. Chow, Immediate Action in Providing Fire Safety in Cities with Dense Highrise Buildings: The Possibility of Incorporating Skybridges, *Proceedings of the Shenyang–Hong Kong Joint Symposium 2004 on Healthy Building in Urban Environment, Shenyang, China,* July 29-30, 2004, pp. A77-A85, 2004.
19. A. Wood, Pavements in the Sky: The Use of the Skybridge in Tall Buildings, *Architectural Research Quarterly, 7*:3/4, pp. 325-332, 2003.
20. P. Olsson, *Performance-Based Fire Safety Design of Super High-Rise Structures,* Proceedings from the Building for the 21st Century Conference, The Council on Tall Buildings and Urban Habitat, London, 2001.

21. D. Barber, *Will Occupants of Tall Buildings Obey Instructions from Wardens in Staged Evacuations?* CIB-CTBUH International Conference on Tall Buildings, Kuala Lumpur, October 2003, CIB Publication No. 290, 2003.

Direct reprint requests to:

W. K. Chow
Chair Professor of Architectural Science and Fire Engineering
Research Centre for Fire Engineering
The Hong Kong Polytechnic University
Hong Kong, China
e-mail: bewkchow@polyu.edu.hk