International Journal on Engineering Performance-Based Fire Codes, Volume 10, Number 1, p.1-5, 2011

SIX POINTS TO NOTE IN APPLYING TIMELINE ANALYSIS IN PERFORMANCE-BASED DESIGN FOR FIRE SAFETY PROVISIONS IN THE FAR EAST

W.K. Chow
Research Centre for Fire Engineering, Department of Building Services Engineering
The Hong Kong Polytechnic University, Hong Kong, China

(Received 3 May 2011; Accepted 24 May 2011)

ABSTRACT

'Timeline analysis' was applied in performance-based design for many big construction projects with difficulties to comply with the prescriptive fire safety codes. Both the Available Safe Egress Time (ASET) and the Required Safe Egress Time (RSET) are estimated and compared. This approach is now under challenge with six points of concern identified. Small fire scenarios of only up to 5 MW were used in very big halls in shopping malls and deep underground public transport interchanges for getting longer ASET. RSET was not estimated under crowded conditions to give quick values of evacuation time. The safety margin was only taken as a small percentage of RSET. It is proposed that more realistic fire scenarios with higher heat release rate should be applied to get reasonable values of ASET in the new projects. Higher safety margin of multiples of ASET should be provided to cater for uncertainties. Fire safety management must be enhanced in existing projects with low safety margin, long ASET based on small fire scenarios and short RSET with low design occupant loading. This must be urgently applied to crowded areas such as public transport interchanges and deep underground subway stations without adequate fire safety provisions.

1. INTRODUCTION

There are many big construction projects in the Far East [1,2] with new green architectural features, tall buildings of height over 300 m, subway stations and malls located in deep underground space, halls of large space volume and long tunnels of length up to 30 km. Most of the buildings in these large-scale construction projects had difficulties to comply with prescriptive fire safety codes. Consequently, fire safety provisions were determined using performance-based design (PBD) [3,4]. This is implemented in Hong Kong as Fire Engineering Approach (FEA) for building passive protection [5] since 1998.

In studying evacuation in a building fire, the timeline approach or time-based system by Hinks in 1985 [6] and Malhotra in 1986 [7] was commonly applied, even in crowded halls, public transport interchanges and subway stations. There were no in-depth studies supported by full-scale burning tests nor large-scale field tests on emergency evacuation with actual high occupant loading in the Far East as pointed out [8-10]. Limited studies on real post-flashover fire scenarios were only started under the leadership of the author with some collaboration with China [11-14].

The Available Safe Egress Time (ASET) was estimated [4,15,16] by fire models by comparing with the reported data on tenability criteria on thermal exposure and smoke visibility. In most cases, only carbon monoxide was considered without other species in smoke toxicity assessment [17,18]. The Required Safe Egress Time (RSET) was estimated with evacuation software developed overseas. Justifications of the developed empirical equations under local building characteristics, high occupant loading conditions and living style in those places are not adequately addressed. ASET and REST are then compared by justifying the safety margin SM given by :

$$SM = ASET - RSET \quad (1)$$

In many projects, a safety index SI dividing SM by RSET [15] is used:

$$SM = \frac{SM}{RSET} \quad (2)$$

Engineers then argued that PBD is reasonably safe for many projects in the Far East [8-10], even taking SM as only a small percentage of RSET.

2. SIX POINTS OF CONCERN

However, there are serious concerns while implementing PBD in the Far East, or particularly on FEA in Hong Kong in the past decade, using the timeline analysis. At least six points of concern are identified [8-10]:

Firstly, scenarios with small design fires were used to get long ASET even for construction projects with crowded big halls. A 2.5 MW design fire [19] was used in the 2008 Olympic game hall at Beijing. Very low design fire was even used in deep underground subway stations. Taking train fires as an example, the recent Asia-Oceania Society of Fire Protection Engineers Exchange Meeting on Transportation Fire Safety in the Far East [10] indicated that heat release rates of 20 MW was deduced in Korea [20], and 48 MW in Japan [21]. A design restaurant fire in a Japanese bus terminal was taken up to 70 MW! All these are much higher than a common figure of 5 MW [8,10].

Secondly, the tenability limits included only thermal and smoke effects. Common tenability limits used in Hong Kong [22] on life safety for occupants and firemen following partly CIBSE Guide E 2010 [4] and NFPA 101-2009 [23] with lower values are:

- Radiative heat flux of 2.5 kWm^{-2}
- Smoke layer temperature of 120 ^{o}C
- Smoke layer interface height of 2.5 m
- Carbon monoxide concentration of 6000 to 8000 ppm for 5 minutes exposure

Note that only carbon monoxide was included in those projects. Toxicity effects due to other chemical species were not yet mentioned in the fire hazard assessment [17,18].

Thirdly, human behavior under local conditions was not investigated in depth while estimating RSET as in many other places. Some studies on human behavior during emergency evacuation in those areas were just started [11-14]. No systematic reports appeared in such developing dense urban cities including Hong Kong, Singapore and many other countries in the Far East.

Fourthly, the occupant loading was taken to be low in many PBD projects to give short RSET. Results are very different from those with high occupant loading observed in real scenarios. The Lan Kwai Fong incident [24] was an obvious example. Very long waiting time required during emergency evacuation [25] in the crowded new airport terminal in Hong Kong was pointed out by the author and his graduate students.

Fifthly, the safety margin SM was only taken as a percentage of RSET, not several times of RSET.

Sixthly, the SI was used through dividing SM by the RSET [15]. Note that human behavior takes a large contribution on RSET. However, human behavior was not studied in many PBD projects in the Far East. Even no systematic research reports on emergency evacuation under high occupant loading of public transport interchanges [26] and subway stations in the Far East appeared in the literature. SI calculated by equation (2) would be strongly affected by human behavior, which is uncertain in the Far East.

3. PICTORIAL PRESENTATION

Value of ASET can be plotted against RSET as in Fig. 1. The estimated ASET and RSET demonstrated by A_e and R_e are shown by point P which must be lying within the safety margin. However, as discussed in above, A_e can be reduced by ΔA in real scenarios with much bigger fires. R_e can be extended by ΔR under crowded conditions with unknown human behavior. The point P will be shifted to the unsafe region.

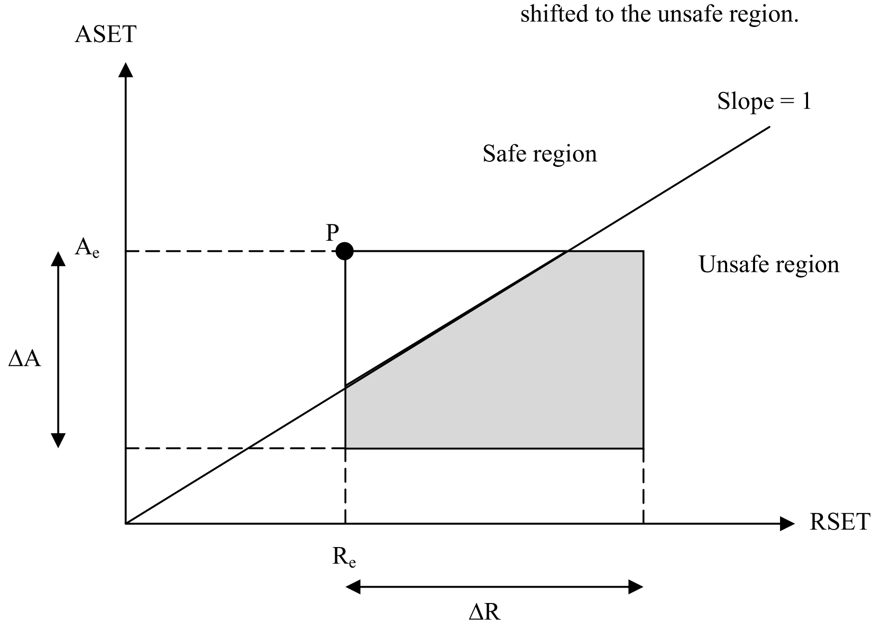

Fig. 1: Timeline approach

4. DISCUSSION

ASET was commonly estimated [8-10] by free fire models [27] with reference to lower values on tenability limits recommended by different international design guides such as CIBSE Guide E [4] and NFPA 101 [23]. Only several small fire scenarios were assessed in estimating ASET. Very few experimental justifications of the predicted results were reported due to low consultancy fee. Some assumed scenarios are very different even from what observed from scale models. Smoke movement in a tilted tunnel [28] is an obvious example. RSET was simulated by evacuation model without including human behavior under local conditions. Smoke toxicity included at most carbon monoxide, but not other toxic gases [17,18].

The timeline approach as in above might be basically good if smoke toxicity is demonstrated to be not important. Examples are in subway stations controlling the luggage carried by the passengers. A book was published by Tubbs and Meacham [16], the design concept behind PBD with timeline approach was clearly described in addition to the comment [29]. This gives a good reference to justify the assumptions made, expected fire scenarios and design from scenarios. However, such approach with studies on ASET and RSET as in above is not adequate for big post-flashover fires encountered [30] recently. On working out the ASET through tenability criteria [4,23], smoke toxicity should be included by taking all gas species. Using only carbon monoxide is not adequate. This approach was even adopted in PBD on open kitchen design in tall buildings with small residential units [8,31]. Again, no experimental studies with real-scale fires are reported.

This timeline approach is now starting to be challenged by the Authority as many post-flashover big fires were observed due to whatever reasons. The timelines of fire development and evacuation process with all those components used before should be reviewed [32]. A modified safety index SI_m is proposed to be determined by taking ratio of safety margin to ASET for reducing impact of human behavior:

$$SI_m = \frac{SM}{ASET} \tag{3}$$

5. CONCLUSION

There are many projects in the Far East adopting the timeline approach. Fire safety in such existing buildings through PBD with ASET estimated from low fire scenario, RSET without human behaviour and estimated under low occupant loading, and projects with low safety margin must be upgraded. There are other concerns in PBD on whether the natural vent (known as static smoke exhaust system in Hong Kong [33]) works under small fires, and mechanical exhaust (known as dynamic smoke exhaust system [33]) works in big fires!

It is difficult to upgrade hardware provisions because of space. Therefore, fire safety management [7] must be enhanced in such existing buildings. All emergency plans must be worked out carefully for those existing buildings with ASET only slightly longer than RSET to ensure that SM would be at least twice as big as ASET.

PBD should not be used in new projects unless it is really necessary as practicing in China Mainland. If PBD is adopted, ASET and RSET calculated in all new PBD projects using equations predicted elsewhere must be justified in the countries concerned. Full-scale burning test is necessary [8-10].

A study on comparing ASET with RSET in existing projects on subway stations [34] is just started with results reported later. Officers can then decide on what to accept in new PBD projects, and how to handle fires in the existing buildings with PBD based on the timeline approach.

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