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Performance-based approach to determining fire safety provisions for buildings in the Asia-Oceania regions

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A B S T R A C T

With the rapid development of economics in the Asia-Oceania regions, there were big construction projects with new architectural designs in the past three decades. Many of these projects were invested by Hong Kong enterprises. However, large halls without compartmentation, multi-purpose complexes in Central Business Districts, supertall landmark buildings and deep subway stations in old towns failed to comply with the fire safety codes. In such cases, performance-based approach is allowed as an alternative practice for determining fire safety provisions. Furthermore, there are fire safety challenges to green constructions. Consequently, a new fire engineering discipline integrating fire safety and built environment with new architectural features appears. In this paper, performance-based approach implemented for determining fire safety provisions in the past three decades in this part of the world will be reviewed. The four fire code systems available at the moment, namely, (1) prescriptive code, (2) fire engineering approach, (3) performance-based design, and (4) engineering performance-based fire code, will be outlined. Fire hazard assessment methodology for the performance-based approach, together with associated engineering tools, particularly the application of computational fluid dynamics, will be introduced. Examples of projects in Hong Kong failing to satisfy the prescriptive code will be outlined. Problems associated with buildings with fire safety provisions determined by performance-based approach in the past years will be highlighted. It is concluded that more in-depth fire safety research related to the fire safety of big constructions in the Asia-Oceania regions should be carried out to meet the new challenges.

1. Introduction

The economies in the Asia-Oceania countries have grown rapidly over the past three decades. Consequently, many big construction projects are found everywhere in Mainland China, Taiwan, Hong Kong, Macau, Japan, Korea, Singapore, Malaysia and Indonesia. High performance buildings were constructed with new architectural features, instead of repeating the existing traditional building design. Landmarks or symbolic supertall buildings [1] were built or planned to be built. Even public housing estates of lower price in Hong Kong and Singapore have new sustainable architectural designs to provide residential buildings with better living quality. Subway systems are developed in big dense cities. However, as space is limited, long and narrow tunnels [2] have to be constructed in downtown areas. Some subway stations have to be built deep, 70 m below the ground [3]. Many of these big construction projects failed to comply with the current fire codes [4,5]. Therefore, fire safety provisions that were allowed in the codes were designed using performance-based approach [6–19] in Asia-Oceania cities. Performance-based approach is commonly labelled as performance-based design (PBD) [10–17] in advanced countries. Furthermore, green constructions [20–24] are very different from traditional buildings and frequently have conflicts with the fire safety requirements. Tall timber apartment is an obvious example [25]. The fire safety challenges to green constructions have been pointed out recently and have stimulated more systematic studies [22–24]. Performance-based approach has to be applied to determine the fire safety provisions in most of the projects including green buildings. A new professional fire engineering discipline has emerged in the Asia-Oceania countries, being involved in thousands of performance-based approach projects in the past three decades. In Hong Kong, PBD is allowed and is called fire engineering

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approach (FEA) in the code [5–7]. In fact, FEA started in the late 1980s, including the airport terminal project [26] and was implemented officially to determine passive constructions since 1998.

There are many reasons for using PBD-FEA to provide fire safety as summarized in the literature [8–18,27]. Obviously, PBD-FEA supports innovative architectural design in demonstrating equivalence to Prescriptive Code (PC). This encompasses supertall buildings, very deep underground subway stations, and big hall spaces such as airport terminals with long travel distances in enclosed space and high occupant loadings. However, PBD-FEA might be improperly used to reduce [27] the construction cost in cities where the fire officers, not consulting engineers, have to be responsible for the hazardous consequences. As an example, in a project submitted before in Hong Kong even argued that fire resisting structural walls as specified in PC are not required in a library! In many cases, even for vehicular tunnels, the assessment report submitted 20 years ago was only based on small fire scenarios less than 5 MW. Consequently, many problems start to emerge [28,29] all over the world due to absence of updated codes. Numerous works reported [30–40] reviews of the PBD-FEA approach, with aim of identifying fire safety problems in existing buildings. Shortcomings in the interpretation, application and implementation of PBD process in USA, Canada, Australia, Japan, UK and other European countries were pointed out [36]. Challenges related to the current PBD practices are outlined with proposal of a framework for risk-informed PBD for the built environment [38]. On the other hand, scenario analysis is another important approach [40] and is based on the Norwegian practice. The two approaches on design, one by pre-accepted performance requirements and the other by analytical design, should be specified clearly in the design procedure. One important point to note is that the fire safety provisions determined by PBD for existing projects are very different from those expected from new research studies.

Problems on estimating egress time in the timeline analysis by comparing the Available Safe Egress Time (ASET) with the Required Safe Egress Time (RSET) were pointed out by Babrauskas et al. [41,42]. Such concerns on not applying the timeline analysis properly in fire safety assessment in PBD-FEA projects in the Asia-Oceania regions were also raised by researchers [43–45]. Officers approving PBD-FEA projects are now watching the problems carefully and requesting appropriate justifications for all new and existing projects involving timeline analysis, particularly in crowded underground subway stations [46].

All such hidden fire problems [29] in these PBD-FEA projects have to be carefully considered. Although no big fire disasters have occurred in these PBD-FEA projects yet, the insurance premium has increased for these existing projects. Furthermore, the owners concerned were asked to implement very complicated fire safety management. Additional firefighting equipment has to be provided in some fire departments.

In this paper, PBD-FEA implemented in the past three decades in the Asia-Oceania regions will be reviewed. The four fire code systems will be outlined first. Fire hazard assessment methodology in the PBD-FEA approach together with the associated engineering tools will be discussed. Examples of projects failing to comply with the prescriptive fire code will be outlined. Fire models on applying Computational Fluid Dynamics (CFD) [47–49] will be briefly discussed. Problems associated with fire safety provisions determined by PBD-FEA in existing buildings will be highlighted. Examples in Hong Kong, where PBD-FEA has been applied since 1980s, will be referred to as illustrations. Note that there are many construction projects in the Asia-Oceania regions involving Hong Kong fire consultant engineers, particularly in those hundreds of big projects invested by Hong Kong enterprises in Mainland China, Malaysia, Singapore and Taiwan since 1990s. Furthermore, justifications for using the available approaches, data and verification methods in advanced countries [38–43] for buildings in the Asia-Oceania regions are required. Such justifications are needed because the fire hazards, firefighting resources, education and social awareness of safety are very different in regions of different levels of economic development and of different cultures.

2. Fire code systems

At the moment, fire code systems can be summarized as the following four levels [50,51] with a pictorial presentation in Fig. 1. These are PC [4,5], FEA specified in the PC [5–7], PBD [10,11,13] allowed in some countries, and Engineering Performance-Based Fire Code (EPBFC) [52].

Current fire codes are basically prescriptive on passive building constructions and active fire protection systems in many places including Hong Kong. In Australia, these are known as the deemed-to-satisfy (DTS) approach [15]. Applying PC in supertall buildings, large halls in Central Business Districts, deep underground railway stations and green constructions in large-scale construction projects should be carefully watched. It has not been demonstrated that such specifications in existing codes are supported by systematic research with experimental justifications. Fire safety provisions are very important and should be designed carefully. Efforts were made to review the PC and the necessity of upgrading some parts of it in many places. For example, the fire codes in Mainland

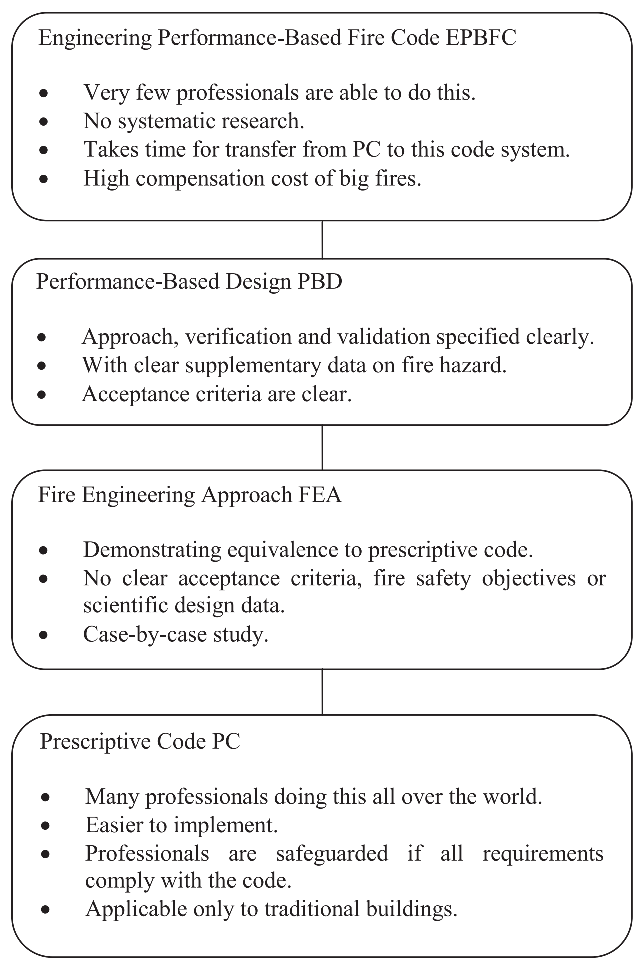

Fig. 1. The four fire code systems summarized by Chow (2013) http://www.bse.polyu.edu.hk/researchCentre/Fire_Engineering/Hot_Issues.html.