PRELIMINARY VIEWS ON IMPLEMENTING ENGINEERING PERFORMANCE-BASED FIRE CODES IN HONG KONG: WHAT SHOULD BE DONE?

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ABSTRACT

Engineering performance-based fire codes (EPBFC) are to be developed in Hong Kong. Before implementing EPBFC, or even writing down what should be done, such as the fire safety objectives, current prescriptive fire codes should be understood. This will be a very big project to be tackled step by step, certainly not regarded as a normal consultancy project which can be completed within a short period of, say three years.

Key points on suitability of implementing EPBFC in Hong Kong, or preserving prescriptive codes but with active updating are discussed. Approaches used overseas are briefly reviewed to illustrate that this is not so easy in comparing with prescriptive codes. Points to be considered including fire safety objectives, full-scale burning tests with building characteristics and materials used, social responsibility and education are highlighted. Nevertheless, EPBFC should not be implemented just for reducing the cost on fire safety provisions. In fact, higher cost might be required as higher safety level should be provided. Bearing in mind that public safety is the first criterion to consider.

1. INTRODUCTION

Architectural features in Hong Kong have changed rapidly in the past 20 years, along with the expansion of the construction industry [1]. There are many big shopping malls, atria, multi-purpose complexes and public transport interchanges. Although Hong Kong is now under very critical conditions with its many advantages over other cities such as cheap and efficient workforce lost, price for apartment is still more than double that ten years ago. The Asian economic depression has brought the construction industry back to a more reasonable state, so that the price is not so abnormal. Citizens can no longer earn high income within a short time through ‘easy’ investment. They have to go back to the golden age of development where their earlier generations had to work diligently for survival. Manpower, both quality and cost, are under challenges from China, Taiwan, Korea, Singapore and others. Despite these, new projects such as the new railway lines, Cyber Port and numerous real estates are to be constructed. High-rise commercial and residential buildings have emerged since the 1960s. Consequent to several big fires [e.g. 2,3], including the one at the new airport terminal before its coming into operation, local citizens are very concerned about the fire safety provisions in Hong Kong. Several actions were taken by the new Special Administrative Region (SAR) government:

- Upgrading the fire safety provisions in old high-rise buildings [4].
- Setting up new regulations for karaoke establishments [5,6].
- Implementing Building Safety Inspection Scheme (BSIS) [7] to take care of structural stability, external finishes and fire safety for existing buildings.
- Acceptance of building submission through fire engineering approach [8] with appropriate committees established to assess the designs having difficulties to satisfy the local fire codes [9-12].

Upon smooth reunification to China, the SAR government is very open. Before setting up or implementing any new codes or regulations, comments will be invited from the professionals including local academics and consultation papers [e.g. 5] will be distributed. Many cases, such as the Karaoke Establishments Bill [6], were turned down by the Legislative Council because the SAR government could not demonstrate the usefulness of the codes. Government officers are upgrading themselves by attending Continued Professional Development (CPD) programmes including MSc degree programmes, with strong support from their departments. Buildings Department (BD) is one of the best examples in sending their staff to attend useful CPD programmes. This is a move towards the right direction of being a world class city, being politically stable with an open, clean and responsible government!

It is obvious that fire codes [e.g. 9-12] have to be updated frequently to cope with the development of the construction industry. For example, 'green building' utilizing more daylight and natural ventilation by increasing the glazing area might lead to fire safety problems [1]. Safety and security issues should be considered in addition to environmental protection to give an overall picture on building performance.

Bearing this in mind, local fire codes [9-12] were updated frequently by the government departments responsible for fire safety. Basically, passive building design (PBD) is taken care of by the BD [9-11]; and active fire protection systems (known as fire services installation FSI in Hong Kong) [12] are assessed by the Fire Services Department (FSD). These codes are prescriptive in nature. Fire safety design based on the engineering approach (EA) [8] will also be considered if there are difficulties in following the codes.

To cope with the new architectural design features, in addition to updating the prescriptive codes, implementing engineering performance-based fire codes (EPBFC) [13-34] is another possible candidate to consider. Note that EPBFC is not the only choice and there are lots of problems associated with that as demonstrated while assessing fire safety design based on EA. Active updating of prescriptive codes might be easier to follow. A consultant was appointed to study how EPBFC can be implemented. However, the period of 3 years is rather short. There is no mention of in-depth research support, say with full-scale burning tests [e.g. 35] in the project brief [36].

In fact, before deciding whether to stick to prescriptive codes with active updating or to use EPBFC, well-planned long-term investigational works should be carried out. This should also be a 'life-long' research project for upgrading the code to solve new problems encountered. This was well recognized by The Hong Kong Polytechnic University (PolyU). There, EPBFC has been studied since 1995 with some support of Area of Strategic Development: Construction Industry Development Studies and Research Centre. A journal [37] reporting the development, problems encountered, scientific principles, engineering judgements and practical examples was established. It appears that if EPBFC is applied properly by experts with good training in fire safety engineering such as those holding PhD degrees, and with practical engineering experience up to Chartered Engineer status, the following can be achieved as reported in the literature [13-34]:

- Better fire safety provisions than described in the older versions of prescriptive codes for both passive and active fire safety measures [18].
- Regulations requiring systems that might not work in a fire or even give adverse effect can be pointed out and updated. The requirements of installing sprinkler at high headroom atrium and in escape staircases are obvious examples. This is similar to imposing the local speed limit of 50 km per hour in downtown areas where almost all drivers will not pay attention to! Those drivers who follow the code and drive slower than the limit might be in trouble.
- Higher flexibility in selecting different fire safety provisions to satisfy the individual building requirement and use.
- Good demonstration that the fire safety provision is safe through scientific analysis and engineering judgement.

Of course, there are good reasons [38] for keeping the prescriptive codes with active development:

- Easier to implement by the Authority.
- Officers are well-trained to enforce the codes.
- Developed for many years and professionals are familiar with the requirement.
- Clearly presented in shorter wordings than those for EPBFC, so relatively easier to follow. For EPBFC, even the terms 'goals' and 'objectives' [32] have to be distinguished.

But for buildings with special geometry or uses such as karaoke establishments [5,6,35], which are not yet included in the codes, there might be some problems in deciding the fire safety requirements. However, similar problems might also be encountered in applying EPBFC to these buildings if there is no in-depth research to support the methods to be used, or the fire safety objectives have to be revised when accidents are reported in those buildings. In this paper, preliminary discussion on implementing EPBFC is presented. This will help government officers to assess the proposed works and give some indications on what should be done in Hong Kong.

2. BACKGROUND

There are four key prescriptive fire codes in Hong Kong [38]:

- Means of Escape (MoE) Code [9]
- Fire Resisting Construction (FRC) Code [10]

- Means of Access for Fire Fighting and Rescue (MoA) Code [11]
- Fire Services Installation (FSI) Code [12]

The first three codes [9-11] concern the passive means of fire safety design and are taken care of by BD. There are many figures, tables and data specified without further explanation nor appendixes as in the NFPA Life Safety Code [e.g. 34] on citing the references. Therefore, giving a wrong impression that local codes were set up without good reasons. This point is not too correct. In fact, most codes come from practices in U.K. as Hong Kong was under British Administration for over a century. British Standards, U.K. practices and design guides in fact are all supported by in-depth investigations from government officers, scientists, building professionals and even manufacturers. There are lots of papers in the literature describing the physical basis behind. Perhaps, more time should be spent on reviewing the background literature to understand why the codes were set up.

The fourth code [12] is governed by the FSD and is quite 'performance-based' already. Very few design data such as space volume of 28,000 m^3 and upper limit on fire load density of 1,135 MJm^{-2} are included. Again, there are reasons for using those figures [e.g. 39]. Officers will discuss with the engineers concerned on the type of FSI required and the associated design data. Criticisms are always welcome and advices from academics used to be sought. Officers in FSD are also eager to attend CPD programmes and enroll in programmes up to MSc degree level.

Further, codes set up at different time would have different requirements. It is not fair to ask all existing buildings to upgrade their fire safety provisions by following all requirements specified in the new codes. PBD cannot be changed easily as the refurbishment works are expensive and will disturb normal business operation. An obvious example is to extend the corridor width from 1.05 m to 1.2 m in karaokes [5,6]. Even FSI cannot be installed at any time the occupants like. For example, it is not easy to get rooms to house the sprinkler water tank. Therefore, engineering approach [8] on alternative fire safety design is accepted for all buildings where there are difficulties in following the new fire codes, both for PBD and FSI.

3. THE CONSULTANCY PROJECT

The project title on EPBFC is "Consultancy Study on Fire Engineering Approach and Fire Safety in Buildings". The aims are [36]:

- To carry out a detailed study on fire safety in buildings.
- To carry out a detailed study on fire engineering approach.
- To produce the relevant Codes of practice and handbook for use by local building professionals.

All standards, codes, legislations on means of escape, means of access, fire resisting construction, fire services installations, emergency vehicular access and testing of building materials related to fire safety should be reviewed. Buildings include both new buildings and existing buildings.

It is interesting to learn how all these can be completed within 36 months!

Can a design handbook be prepared and demonstrated to be applicable in Hong Kong within 36 months?

Technical contents in the codes are expected to be very complicated as demonstrated in reviewing the proposed practice of EPBFC overseas later in this paper. Even holding meetings and seminars on dealing with explanations, clarifications, arguments and debates might take several years! Perhaps the project brief was decided with too optimistic views. Note that such a study has been carried out for years with a large team of experts in U.K., only a technical report is published at the moment [20,28], though a draft guide is under review.

4. BRIEF REVIEW ON SOME OVERSEAS APPROACHES

Fire safety engineering and performance-based fire protection had been considered carefully elsewhere. In fact, EPBFC has been implemented in some countries. The approaches to be used in U.K. and European countries via the BS ISO/TR 13387:1999 Fire Safety Engineering [28]; and the SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings 2000 [32] of the Society of Fire Protection Engineers in U.S.A. are taken as references to demonstrate the complexity for local professionals.

In the U.K./European approach, there are three key elements in the basic fire safety design process:

- Qualitative design review (QDR)
- Quantitative analysis of design
- Assessment against criteria

QDR is the key element [40] which includes review of architectural design, setting up objectives and scope of study, fire hazard identification, trial design, fire scenarios, acceptance criteria and method of analysis. Outputs of QDR such as agreed fire safety objectives will be used for quantitative analysis. Quantitative analysis of design is to carry out a time-based quantified analysis using the appropriate subsystems. Knowledge on fire dynamics [e.g. 41] is expected. Evaluation of fire safety design of a building is divided into five subsystems SS1 to SS5 for simplification in this technical report [28]:

- SS1: Initiation and development of fire and generation of effluents.
- SS2: Movement of fire effluents.
- SS3: Structural response and fire spread beyond the enclosure of origin.
- SS4: Detection, activation and suppression.
- SS5: Life safety: occupant behaviour, location and condition.

Scientific knowledge and practical engineering judgements have to be applied in dealing with SS1 to SS4. Full-scale burning tests are desired to verify some design or extract key empirical data, if necessary. Scenarios not yet considered before, say for new architectural features, should be studied more carefully. For example, empirical correlations such as the relationship between the atrium smoke filling time t_s and its time constant τ_{Atrium} with and without considering the traveling time of smoke front to the roof will be very different [42,43].

$$t_s = \begin{cases} 2.48\tau_{Atrium} & \text{without traveling time of smoke front included} \\ 2.597\tau_{Atrium} & \text{with traveling time of smoke front included} \end{cases} \qquad (1)$$

It is obvious that mathematical fire models [44-48] will play a key role.

For the SFPE approach [32] in U.S.A., basic building design and construction process includes the following:

- Feasibility studies
- Conceptual design
- Schematic design
- Design development
- Design documentation
- Construction and installation
- Commissioning
- Certificate of occupancy
- Use and maintenance
- Change in use and refurbishment

Steps in the performance-based analysis and the conceptual design procedure for fire protection in this approach [32] include:

- Defining project goals
- Identifying goals
- Defining stakeholder and design objectives
- Developing performance criteria
- Developing design fire scenarios
- Developing trial designs
- Evaluating trial designs
- Testing whether selected design meets performance criteria
- Developing a fire protection engineering design brief
- Selecting the final design
- Performance-based design report
- Prepare design documentation
- Specifications, drawings, operations and maintenance manual

Again, mathematical fire models will be a key element though it is not equivalent to EPBFC as pointed out by Sheppard and Meacham [49].

5. WHAT SHOULD BE DONE?

EPBFC has been studied at PolyU, with the mission to offer 'Quality Teaching', i.e. teaching supported by research to serve the society including the country, for over 6 years. The backbone of EPBFC, i.e. mathematical fire models [44-48] (though should not be taken as equivalent to EPBFC as pointed out by Sheppard and Meacham [49]), had been studied for 20 years with more than 20 PhD students graduated. Both fire field models or application of Computational Fluid Dynamics (CFD) [e.g. 48] and fire zone models [e.g. 47] are studied in depth. Research and consultancy projects on advanced fire science and engineering are now grouped under the Research Centre for Fire Engineering. Preliminary studies indicated that the following should be considered:

- Providing reasonable fire codes well-supported by experimental studies with active development should be a long-term project. Three years will definitely be insufficient! The time is not even enough for a more detailed review on the physical basis of the present MoE code [9], the fire safety objectives, the limitations of using it, and the areas for improvement.
- EPBFC should not be taken as putting something not satisfying the code requirements; or for reducing the costs of fire

safety provisions. An obvious example is not to provide adequate fire resistance to some structural members. It is not easy to convince people that structural steel with glass structures can be installed without fire protective coating! If anything happens with loss of human lives, it will take a long time for sorting out the legal affairs and the associated compensation.

- Proper implementation of EPBFC might be even more expensive as higher safety level will be achieved. The whole design process should be carried out scientifically, allowing a good chance to apply advanced fire science to solve practical engineering. Japan is one of the countries with engineering design on fire safety carried out properly through engineering experience, physical experiments (both full-size and scale modeling) and numerical simulation since the early 1990s. Full-scale burning tests were carried out for some projects such as allowing timber to be used as building materials for apartments [e.g. 50]. There is also high-level scientific inspection of fire services installation designs based on fire safety engineering for shopping malls and airports in Taiwan [51].

Both building features and occupants characteristics in Hong Kong are very different from elsewhere. Basically, the building features in Hong Kong can be summarized as follows:

- Structural elements are non-combustibles, either concrete with steel reinforcement or steel framework with fire protection. However, timber products were extensively used as partition walls before 1996 when fire-rated gypsum plaster boards were not so popular.
- Glazing is used extensively in commercial buildings and the FRC codes [10] should be revised to consider thoroughly the fire resistance requirement by taking into account new research results such as interaction with water-based system. Behaviour of the glazing under typhoon should be watched as glass was peeled away in a typhoon before.
- Adequate provisions of evacuation routes for buildings built after 1972.
- Good provision of FSI [12] for new buildings.
- Tight control on combustibles used or stored by keeping the fire load density to be less than 1,135 MJm^{-2} [9-12].

Further, occupants characteristics, especially their sense of social responsibility are different. Overseas citizens might complain when they see some fire extinguishers are not put in the right positions; or when there is inadequate ventilation in an underground carpark. Local citizens seldom complain and security guards in some factories might even lock the emergency exits by chains!

Therefore, the performance requirements, design objectives, acceptance criteria and assessment methodology should be worked out carefully for local use. Without clear performance-based design guides standardized and tailored for local use, significant amount of professional efforts and time would be required. Note that cost-effectiveness is not only counted for the cost-effective building design (benefit to developers), but also for saving engineering and documentary time of architects, fire engineers, developers and government officers (benefit to the public/taxpayers). But this can never be achieved without in-depth research.

The following items listed in the three parts on documentation, design levels and topic specific intent of International Code Council (ICC) [52] should be judged, if necessary:

- Fire safety objectives and acceptance criteria.
- Design parameters.
- Characterization of buildings and its occupants.
- Identification of potential fire hazard scenarios and their possible consequences.
- Assessment against the safety criteria.

As summarized by Lillicrap [40], questions on the acceptable fire safety level; factors limiting solutions; the worst hazard scenario and its consequences; method of scenario analysis; and fire safety measures, both PBD and FSI, to be provided; have to be addressed to fit local needs.

This would require knowledge of fire science and engineering together with practical experience under local conditions. Mathematical fire models [e.g. 44-48] are a key element for analyzing potential fire scenarios. Full-scale burning tests [35,53], scale models studies [e.g. 54] and site measurements [e.g. 55] should be carried out when necessary.

6. MATHEMATICAL FIRE MODELS

Mathematical fire models [44-48] are useful in the analysis of consequences of fire hazard scenarios. Instead of carrying out physical tests, they have to be used in implementing EPBFC. There are arguments and debates on using fire models. If the predicted results are not verified scientifically, say by full-scale burning test [35,53], the process would appear as a 'curve-fitting exercise'. Since the intermediate chemistry in burning materials, mixing of air and fuel due to turbulence and thermal radiation are difficult to model in a fire, the heat release rate is taken as the input parameter in most mathematical fire models. Full-scale burning tests should be carried out to establish a heat release rate database on local materials and consumable products.

Zone models [e.g. 47] can be applied to understand the fire environment with a certain design fire. However, care should be taken for tall buildings and buildings with large floor areas. Concerns that can be jotted down immediately are:

- Time taken for a smoke layer to develop in large buildings.
- Traveling time of smoke front up a tall building.
- Assessment of the ventilation opening conditions.

Fire field models or application of CFD [e.g. 48] are good only for studying smoke movement at the moment. Problems encountered in addition to the hardware constraints are:

- Assignment of free boundaries by extending the computing domains to outside the building.
- Although commercial CFD packages are user-friendly, theories behind CPD should be well understood. Experts are required to carry out CFD simulations for studying fire-induced air flow, not just relying on an engineer without good training in CFD.

Note that CFD itself is a rapidly developing subject. Even in describing the turbulent effects, there had been lots of arguments on using different approaches such as Reynolds Averaging the Navier-Stokes equation or Large-eddy simulations [e.g. 56]!

7. CONCLUSIONS

Local codes used to be blamed that the data are outdated as they are prescriptive and so EPBFC has to be used. It is obvious that fire codes including EPBFC, have to be changed frequently to cope with the living standards, building features, and crucially, the sense of social responsibility (links with general education) of citizens. Implementing EPBFC is not just solving a scientific problem, but also a social problem concerned by the government officers, developers, building professionals, and most importantly, the citizens. EPBFC should not only be targeted for new projects, but also on upgrading the fire safety provisions for existing buildings.

However, setting up EPBFC for local use must be supported by in-depth systematic research with full-scale burning tests [35,53]. It is no good just following overseas fire codes, both prescriptive and performance-based. Responsibility of citizens and their awareness on safety should be taken into account. Reference can be made to overseas practices but not direct applications. In fact, carrying out feasibility study on the suitability of overseas codes for Hong Kong will take time.

In the process of developing performance-based design approach, the initial step should be thorough revision of the current prescriptive codes and evaluation of its inadequacy. It is then possible to decide whether the prescriptive code has to be revised; or to establish EPBFC with an appropriate approach. This step is considered necessary and is in progress with results to be reported in forthcoming articles [e.g. 57].

There are no government officers who are taking the role of 'Science Advisors' as in other countries; nor any government building research laboratories. Perhaps, this is the right time to consider establishing such facilities. At least, the government should consider funding 'Applied Research' projects on this subject area.

Education and training [58,59] are important to give adequate number of qualified engineers. Taught degree programmes up to MSc degree level should be offered. More research students should be involved in studying MPhil or PhD degree. Finally, practical training should not be forgotten. This applied particularly to the building management team as fire safety management [e.g. 28] should be included in the fire safety codes.

Upon smooth reunification to China in 1997, local government is now very open in accepting expert advices from the society. Consultation papers [e.g. 5] used to be issued before implementing new regulation or even revising the old codes. Officers are eager to attend CPD programmes with strong support from their departments. All these are good indication that Hong Kong is moving towards the right direction of getting a politically stable, open, clean and responsible government. Fire codes, either updated prescriptive fire codes [9-12] or EPBFC [8], which are workable for local buildings, would certainly be developed and implemented to give fire safety to Hong Kong.

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