PASSIVE FIRE PROTECTION IN HONG KONG – DEVELOPMENT OF PERFORMANCE-BASED APPROACH

P.H. Tsui
Buildings Department, The Hong Kong Special Administrative Region Government

ABSTRACT

Fire safety design concept on passive fire protection with respect to the prescriptive fire codes is briefly reviewed. Necessity for alternative fire engineering approach is recognized. Framework for the performance-based fire safety code and performance requirements for passive fire safety features are introduced. Development of performance-based approach is identified.

OBJECTIVES OF PASSIVE FIRE PROTECTION

Fire safety is a complex system encompassing a large number of factors, particularly for special or large and complex buildings. Fire safety may encompass a number of objectives, which varies with different sectors of the community. In a study [1] conducted by the Buildings Department's consultant, the possible objectives perceived by the society are identified, not in any particular order, as follows:-

- Life safety of occupants
- Life safety of emergency services personnel
- Protection of own properties
- Protection of adjoining properties
- Protection of contents in properties
- Fire prevention
- Law compliance
- Insurance requirements
- Business continuity
- Corporate image
- Heritage preservation
- Environmental protection
- Moral obligation

In terms of the hierarchy philosophy [2], fire safety design can be elaborated by a multi-layered structure. The hierarchical levels under the goal of "fire safety" are objectives, tactics and elements. These levels conform to the hierarchical structure below (Fig. 1) with decreasing generality from the apex.

<table>
<tr><td>Goal</td><td colspan="9">Fire Safety</td></tr>
<tr><td>Objectives</td><td colspan="3">Life Safety</td><td colspan="3">Property Protection</td><td colspan="3">Fire Prevention</td></tr>
<tr><td>Tactics</td><td colspan="2">MOE</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>Elements</td><td>Width</td><td>No.</td><td>T.D.</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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FIGURE 1. General hierarchical structure on fire safety

This fire safety evaluation hierarchy enables the systematic decomposition of attributes to facilitate evaluation. For the goal of "fire safety", the next level of the hierarchy is the objectives, which may be "life safety", "property protection" and "fire prevention". The tactics (components) employed to support the objectives form the next reduced level of generality. For instance, "to provide adequate means of escape" may be employed as a tactic to support the objective of "life safety". The lowest level is the elements level. The elements (attributes) are criteria that suit the tactics but at much lower level of generality. For instance, the elements for the tactic "to provide adequate means of escape" may be "width of exits", "number of exits" and "distance of travel" (see Fig. 1).

In general, the building codes stipulate the requirements on the performance of a building under normal and adverse conditions (e.g. fire) in meeting the health and safety needs of the community [3]. As stipulated in the long title of the Buildings Ordinance (Chapter 123 of the Laws of Hong Kong), the Buildings Ordinance is to provide for the planning, design and construction of buildings and associated works; to make provision for the rendering safe of dangerous buildings and land; and to make provision for matters connected therewith. The desired level of performance for health and safety is described by the prescriptive building codes through a set of minimum requirements that are generic by occupancy. These fire codes reflect the society's expectations of the level of fire safety provided in buildings [3].

In terms of passive fire protection in Hong Kong, life safety is the primary fire safety objective in stipulating the relevant regulatory requirements [1]. Whilst the other fire safety objectives are not a primary aim of these regulatory requirements, they may be a bi-product of these regulatory requirements.

COMPONENTS OF PASSIVE FIRE PROTECTION

Passive fire protection refers to the design of passive building construction that can facilitate the protection of life in the event of a building fire. Design standards on these provisions are stipulated in the Code of Practice for the Provision of Means of Escape in Case of Fire (1996) [4], the Code of Practice for Fire Resisting Construction (1996) [5], and the Code of Practice for Means of Access for Firefighting and Rescue (2004) [6].

As evidenced from these Codes, means of escape (MOE), fire resisting construction (FRC) and means of access for firefighting & rescue (MOA) are the components employed to support the objective of life safety. From the perspective of passive fire protection in Hong Kong, the fire safety hierarchy is as shown in Fig. 2. The attributes of the fire safety hierarchy can be identified from the Codes.

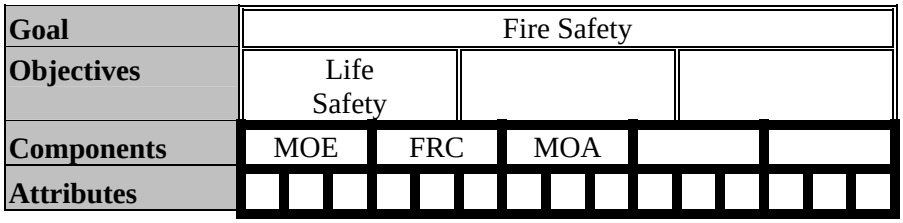

FIGURE 2. Fire safety hierarchy (Passive fire protection in HK)

MAJOR MOE ATTRIBUTES

The general principle of the fire safety design concept on MOE is to ensure that people within the vicinity of a fire can move away from it before becoming unduly affected by smoke or flames. In addition, it has to ensure that people remote from the fire can take refuge or exit the space in an orderly manner with the provision of sufficient information to them.

As a fire may make a building untenable in a very short time [7], the occupants cannot be expected to travel unlimited distances in the building to reach a place of safety whilst the open area at ground level is the most satisfactory place of safety. In addition, the occupants cannot be expected to rely on external rescue. Thus, in order to reduce the chance of trapping the occupants at the fire scene, the occupants should be provided with alternative routes if they do not have immediate access to a place of safety.

Under the fire safety design concept, MOE is the structural means providing a safe route of travel from any point within the building to a place of safety outside. The design has to cater for the horizontal evacuation from any point on a floor to the nearby staircase. The staircase serves as a safety passage for the vertical evacuation from the floor to ground level. At ground level, the staircase leads to an open area which is a place of ultimate safety. The schematic diagram on MOE is as shown in Fig. 3.

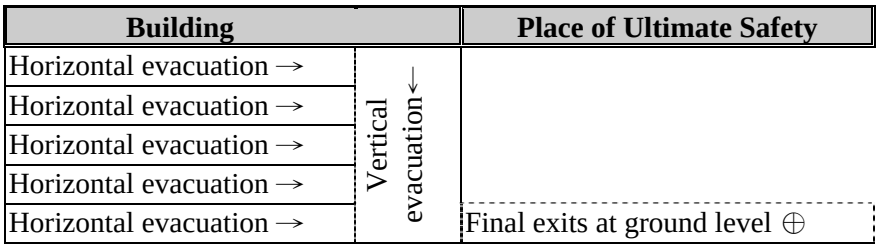

FIGURE 3. Fire safety design concept on MOE

As detailed in the MOE Code, the major MOE attributes are:-

- width of exit from room
- number of exits from room
- width of exit from storey
- number of exits from storey
- distance of travel
- lighting at exit corridor
- simplicity of wayfinding
- capacity of staircase
- lighting within staircase
- staircase geometry
- access to staircase
- availability of refuge floor
- ventilation of refuge floor
- final exit at ground level

MAJOR FRC ATTRIBUTES

The general principle of the fire safety design concept on FRC is to limit the effects of fire in terms of convection, radiation and conduction. When a fire occurs in an enclosed space, hot smoke-laden gases rise directly above the burning fuel to the underside of the ceiling and form a layer. A two-layer system is created in a typical compartment fire [8]. The fire plume gradually increases in height until it reaches the ceiling where it is deflected horizontally to form ceiling jets [9]. The downward radiation of the deflected flames also adds to the speed of fire growth. Apart from convention and radiation, fire spread may also occur by conduction.

If the walls and ceiling of the enclosed space are not constructed of fire-resisting materials, the fire will penetrate through the walls and ceiling to the adjoining spaces. Even if the walls and ceiling are of fire-resisting construction, the fire may spread to other spaces through flame extension out of windows or doors. Flame extension can take place when the fire plume impinges on the ceiling and the ceiling jets are longer than the distance from the plume to windows or doors [8]. Hence, depending on both the size of the fire compartment and the size of the fire, it is possible to have a fire plume that is too large to be contained within the fire compartment, resulting in flame extension outside of the room.

In addition, the fire may spread to adjacent areas through external burning. The upper hot gas layer will spill out of the fire compartment under the soffits of doorways or other openings into adjacent areas when the fire progresses and the upper hot gas layer descends [8]. External burning can take place at an adjacent area when the hot and fuel-rich gases flowing into the area mix with air that has high oxygen concentrations to create a secondary burning zone outside the compartment.

Under the fire safety design concept, FRC is to limit the spread of fire and the premature collapse of a building or portion of the building so as to reduce the effect of smoke and flames on occupants. The design has to cater for the fire separation within the building and between buildings as well as the structural integrity of the building. The schematic diagram on FRC is as shown in Fig. 4.

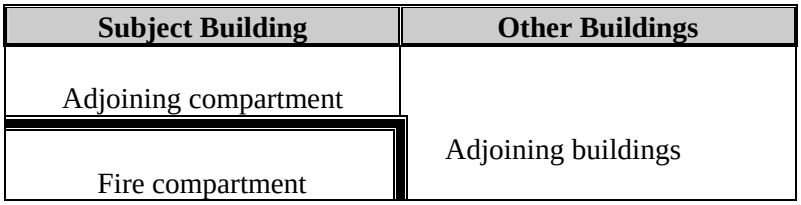

FIGURE 4. Fire safety design concept on FRC

As detailed in the FRC Code, the major FRC attributes are: -

- fire resistance of element of construction
- fire resistance of compartment wall/floor
- fire separation at internal opening
- fire separation at external opening
- fire resistance of wall/roof adjoining other building
- fire separation at bridge/tunnel

MAJOR MOA ATTRIBUTES

The general principle of the fire safety design concept on MOA is to ensure that the firefighting personnel are provided with safe and unobstructed access to the fire scene to perform search and rescue tasks and to control and extinguish fire.

In setting up firefighting and rescue operations, time is of the essence for the purpose of protecting life. With the use of emergency vehicles of the fire brigade, the fire brigade should be able to reach the incident building within a reasonable time limit and through a relatively safe environment. A building should therefore be provided with emergency vehicular access such that fire appliances are able to access from the site entrance to the building at any time when a fire occurs.

While aerial appliances can provide external means of access to individual floors of the incident buildings, internal means of access are more efficient in evacuating occupants and in firefighting. To

avoid undue risk to the health and safety of the firefighting personnel, protected routes should be provided inside a building to minimize their travel distance in the fire environment and thus their direct exposure to fire threat. These protected spaces also serve as temporary refuge for the firefighting personnel.

Under the fire safety design concept, MOA is the structural means providing a safe route of access from an initial access at the site entrance to any point within the incident building. The design has to cater for the access of the emergency vehicles from the site entrance to the incident building. The vertical access will be through protected vertical shaft, i.e. access staircase, fireman's lift and/or firefighting and rescue stairway. The access staircase serves as a safety passage for the vertical access from ground level to the individual floors. The fireman's lift provides an additional safe passage for the vertical access. It also facilitates the traversal between floors and the transport of rescue and firefighting equipment. At each floor, the horizontal access from the protected vertical shaft should be through a protected lobby. The schematic diagram on MOA is as shown in Fig. 5.

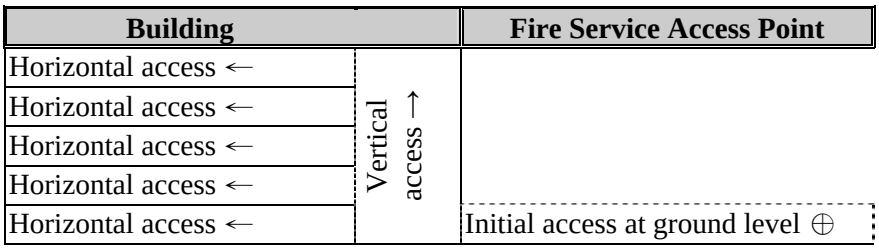

FIGURE 5. Fire safety design concept on MOA

The major MOA attributes are: -

- emergency vehicular access
- fire service access point at ground level
- external vertical access
- availability of access staircase
- availability and coverage of fireman's lift
- availability and disposition of firefighting and rescue stairway
- size of firefighting lobby

USE OF ALTERNATIVE FIRE ENGINEERING APPROACH

Whilst the prescriptive codes specify the means for attaining the specified outcome, they focus attention on only one means of achieving the desired objective. As such, designers may be locked into a single solution with no opportunity to utilise alternative, and possibly more cost efficient, compliance solutions. Sometimes, prescriptive regulations are alleged as suppressing innovation and creating barriers to the uptake of new technology.

Performance-based technical requirements are generally preferred over prescriptive requirements as they provide flexibility while ensuring that the objective is achieved. The major advantage of performance-based requirements is that they can accommodate a range of technical solutions provided the outcomes are the same. Performance-based requirements provide flexibility for designers in terms of demonstrating compliance with outcomes, thus providing scope for designers to innovate and adopt new technology.

It is stipulated in the MOE Code, the FRC Code and the MOA Code that "the Building Authority recognizes that fire safety may be approached in a number of ways the best of which is not necessarily prescriptive. This is particularly pertinent to buildings of special hazards which, because of their size, height, use, design, construction or location, may necessitate special consideration of fire safety objectives and the standards to be set."

These Codes also set out that "the Building Authority assesses the acceptability of any alternative or complementary approach to fire safety in a building by reference to such criteria as the means of escape, the means of access, the fire services installations, the fire resisting construction, the size, the height, the use, the location, and the management of the building." Thus, apart from the MOE, FRC and MOA components, the Codes also recognise that the fire safety hierarchy should include the fire service installations (FSI) component and the fire safety management component.

As an alternative to relying on the prescriptive fire safety provisions, the Building Authority accepts a fire safety engineering approach that takes into account these components and at the same time, applies scientific and engineering principles to the protection of people and property from fire. Fire safety engineering design thus provides a framework for designers to justify that, although some of the design solutions adopted fall outside or short of the prescriptive requirements in the Codes, the performance requirements of legislation can still be met, or even be bettered. Of course additional fire safety measures may have to be proposed to compensate for the deviation or shortfall.

In essence, the fire safety engineering approach stipulated in the Codes is a kind of performance-based requirements which represent a more flexible approach and allow designers to devise the most efficient and effective method of compliance. Performance-based approach requires that the overall fire safety of a building should meet certain basic requirements, but allows designers freedom in details to various design alternatives without reducing fire safety [10]. Fire safety engineering design is required to address the following performance requirements of the legislation [11]: -

(a) Given the function and purpose of the building or installation, the design should not present an unacceptable risk of a fire developing and spreading.
(b) Occupants should have time to reach a place of (temporary and/or permanent) safety without being dangerously affected by heat or smoke from a fire.
(c) A fire should not spread to adjacent property.
(d) A fire (and smoke) should not spread beyond the compartment from which the fire originates.
(e) Firefighting personnel should be able to gain access and set up firefighting and rescue operations without undue risk to their health and safety.
(f) The stability, insulation and structural integrity of the building should be ensured in a fire of specified intensity and duration.

STUDY FOR A PERFORMANCE-BASED FIRE SAFETY CODE

The Buildings Department is now conducting a consultancy study on fire engineering approach and fire safety in buildings. The study is to review and establish the criteria of fire safety, to propose an acceptable fire engineering approach that can be put in practice for Hong Kong, and to draft a code of practice for the purpose. The study proposes a regulatory framework for applying the fire engineering approach to develop alternative solutions to meet the fire safety objectives and performance requirements that are to be stipulated in the performance-based fire safety code (PBFSC).

The performance-based fire safety design framework is proposed to adopt the Nordic Hierarchy, which is a framework best suited to performance based codes[12] (Fig. 6). This simple Nordic hierarchy is based on four levels:

(a) Level 1 – Goals and Objectives that are set in the respective Ordinances, through over-arching statements of intent.
(b) Level 2 – Functional Statements that are set in the respective Regulations, providing a more structured degree of information and further clarifying goals.
(c) Level 3 – Performance Requirements within the Regulations that outline the criteria to be fulfilled for a design to meet the objectives set out in the Ordinances and Regulations.
(d) Level 4 – Acceptance criteria, data or limitations to be followed as part of the design process, provided either within a Code, guidance or standards. Meet through deemed-to-comply solutions or alternative solutions.

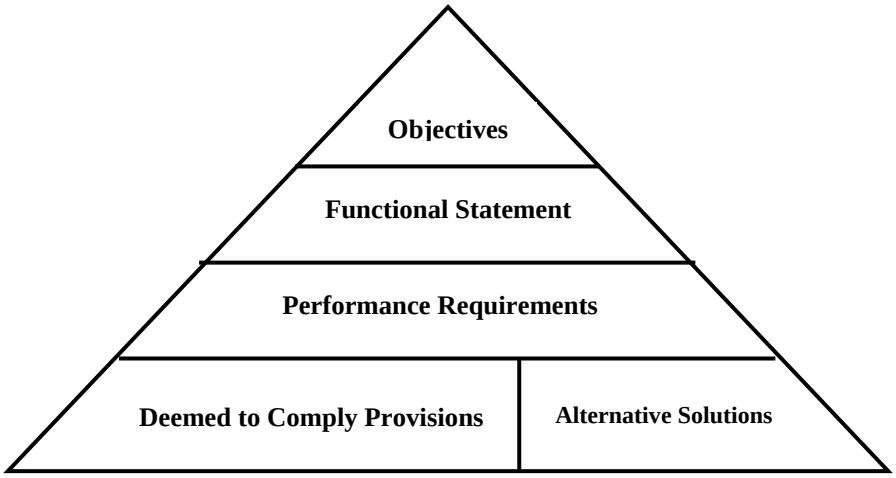

FIGURE 6. Nordic hierarchy

PROPOSED PERFORMANCE REQUIREMENTS FOR PASSIVE FIRE PROTECTION

The draft PBFSC being proposed will contain the performance requirements as well as approved solutions from the prescriptive MOE Code, FRC Code, MOA Code, FSI Code, and proposed new codes on fire safety materials and fire safety maintenance and management[13]. Apart from the detailed objectives for fire safety, respective regulations will provide the performance requirements, which are the only requirements for which compliance must be established. The detailed objectives[13] that form the functional statements are:-

(a) Life Safety – Fire safety provisions to be provided for-
- Life safety of building occupants
- Spread of fire between compartments to be minimised
- Prevention of building collapse as a result of fire
- Facilitation of firefighting and rescue by fire service personnel

(b) Property Protection – Fire safety provisions to be provided for-
- Prevention of building collapse as a result of fire
- Spread of fire between compartments to be minimised
- Spread of fire between buildings and those on adjoining properties to be minimised
- Facilitation of firefighting and rescue by fire service personnel

Performance requirements are then proposed to support these objectives.

For MOE, the proposed performance requirements[14] are as follows:-

- A building is to provide appropriate means of escape to allow all occupants to evacuate safely without being overcome by the effects of a fire emergency.

- To allow occupants to evacuate safely, appropriate exits must be provided to serve the occupants within a storey or compartment.
- A building must have appropriate provisions to protect evacuating occupants from fire.
- A compartment or storey must have appropriate fire safety provisions that provide adequate time for safe evacuation from that part of the building.
- Building exit routes must have appropriate lighting to identify exits and paths of travel to an exit.
- Building occupants must have appropriate warning to evacuate.
- Building owners and/or managers must provide an appropriately managed process to allow for orderly evacuation.
- Signs or other means of identification must be appropriately provided to assist with means of escape.
- To provide public safety, fire safety measures must be maintained to ensure that they continue to perform at the level at which they are originally designed and installed.
- Means of escape for tall buildings must be appropriately designed to provide means of escape for building occupants, to allow for occupants to take a short rest while evacuating, to minimise the threat of smoke within stairs, and to provide an area for fire fighting staging activities.

For FRC, the proposed performance requirements[14] are as follows:-

- A building is to be provided with appropriate fire safety provisions and features to prevent fire spread-
  - to allow occupants to evacuate safely;
  - to adjacent fire compartments;
  - between buildings or other properties; and
  - to allow for fire fighter intervention.
- A building must have construction appropriate to maintain structural stability during a fire to-
  - allow sufficient time for occupants to safely evacuate;
  - allow for fire brigade intervention; and
  - avoid damage to other properties.
- Building elements or assemblies (including surface finishes) must have an appropriate resistance to fire so as not to contribute to the spread of fire, heat or toxic gases.
- Buildings are to have appropriate fire safety provisions such that emergency equipment provided will continue to operate for a period of time necessary to ensure that the intended function of the equipment is maintained during a fire.
- To protect public safety, fire safety measures must be maintained to ensure that they continue to perform at the level at which they are originally designed and installed.
- Fire safety provisions shall be provided to a building or part of a building undergoing construction, demolition, alteration, repair or maintenance building works, appropriate to the hazard represented by the works and the fire safety precautions available.

For MOA, the proposed performance requirements[14] are as follows:-

- Appropriate access must be provided to, around and within a building for fire fighting vehicles and fire fighting personnel, to facilitate fire brigade intervention.
- Every building shall be provided with appropriate emergency vehicular access, which is so designed and constructed as to allow safe and unobstructed access of a vehicle of the Fire Services Department to the building and provide for the safe operation of such a vehicle, in the event of a fire.

The proposed performance requirements for the new section on fire safety of materials[14] are as follows:-

- Building elements that are required to perform the function as a fire barrier to resist the spread of fire must have appropriate protection at openings or penetrations for an adequate level of performance to be maintained.
- Building elements to limit smoke spread must have appropriate provisions to minimise the spread of smoke from one area to another area.

DEVELOPMENT OF PERFORMANCE-BASED APPROACH

As a kind of performance-based requirements, the fire safety engineering approach specifies the desired objective in precise terms but allows the designers to determine their own technique for achieving the outcome. However, the performance-based requirements may have the following constraints on implementation:-

(a) The performance-based requirements may introduce uncertainty regarding what constitutes acceptable compliance;
(b) The performance-based requirements are suitable only in situations where the designers are in a better position than the Building Authority to understand and address the potential causes of problems which the fire codes are designed to address; and
(c) The performance-based requirements may pose difficulties for the Building Authority to monitor and enforce compliance.

Nevertheless, the fundamental point of performance-based requirements is to evaluate the perceived fire risk associated with the building under consideration [15]. An analytical framework has to be worked out for evaluating the fire safety level of the building. For this purpose, the proposed guidelines to fire safety engineering approach[12] will be developed to provide guidance on such aspects as regulatory framework, approach and methodologies, evaluation on fire safety sub-systems, fire engineering design and assessment process, bounding conditions, fire service operations, computer models, and references etc.

In deploying the use of fire safety engineering, fire safety provisions are demonstrated to be equivalent to those specified in the prescriptive fire codes. It is necessary to embark on a total fire safety strategy in order to use the software fire safety management to control hardware provisions (the MOE, FRC, MOA and FSI components). In the process of developing the performance-based approach, the proposed PBFSC will be developed to contain the performance requirements as well as approved solutions from the prescriptive MOE Code, FRC Code, MOA Code, FSI Code, and proposed new codes on fire safety materials and fire safety maintenance and management[13].

The Buildings Department's consultant is now working on the draft guidelines and the draft PBFSC for further consultation. The development of performance-based approach requires knowledge of fire science and engineering, together with practical experience for local conditions. This will invariably involve studies and experience on fire science, fire models, performance of fire materials, fire hazard assessment, passive and active fire protection systems, and fire safety management etc. In the longer run, we need to develop fire safety standards (e.g. safe evacuation time, tenability level of exit routes etc.) and develop control over tools (e.g. computer modules) for predicting risks or demonstrating compliance and over the service of professionals (e.g. fire engineers) [11].

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