Design of Sports Stand Buildings for Fire Safety

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Content

page

Scope

This publication applies to sports stand buildings in open stadia which fall outside the scope of the open spectator stands covered by clause C1.7 of the Building Code of Australia. However, it only applies to buildings which are of non-combustible construction.

Sydney Football Stadium

Melbourne Cricket Ground

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SPORTS STAND BUILDINGS

In recent years, a number of impressive and large sports stand buildings have been constructed. This has certainly been the case in Australia where there is a demand for increased seating capacity—usually with multiple seating tiers, high quality corporate viewing and entertaining facilities, and multi-function spaces within different levels beneath the seating tiers. These facilities are in addition to the traditional change rooms, sanitary facilities and storage areas.

Suncorp Stadium

Structural steel framing features prominently in their construction providing such benefits as:

- fast speed of construction—especially important when critical sporting event milestones must be met
- lighter weight, long spanning ability which simplifies cranage, particularly on sites which have restricted access
- cost effectiveness
- flexibility for future modification or upgrading
- aesthetically pleasing structure having minimal bulk and intrusion into the urban fabric

The deemed-to-satisfy requirements of the Building Code of Australia (BCA) [1] (in cl C1.7) permit an open spectator stand to be constructed as Type C construction if it contains not more than one tier of seating, is of non-combustible construction, and has only change rooms, sanitary facilities, or the like, below the tiered seating. In the case of open spectator stands of Type A construction, the BCA allows “concessions[1]” for some building elements within the stand, such that these elements do not have to satisfy the requirements of Table 3 of Specification C1.1. To be specific, the roof and structural members supporting *only* the roof (ie. columns and loadbearing walls) are not required to have a fire-resistance level (FRL) provided they are non-combustible; and non-loadbearing parts of an external wall may have a reduced FRL if they are within 3 m of a fire-source feature and are non-combustible.

The Brisbane Cricket Ground

Modern sports stand buildings usually provide facilities for corporate viewing, dining, and special functions, in addition to change rooms and sanitary facilities. Several tiers of seating are often provided. These buildings, therefore, may fall well outside the scope of cl C1.7 of the BCA, yet the application of Table 3 in Spec C1.1 may not be appropriate due to the fact that many parts within these buildings cannot be easily classified in terms of the *classes of building* given within the BCA.

The purpose of this publication is to consider the fire safety of these more complex buildings, and to present design principles and procedures which will allow the *fire-safety objectives* and relevant *performance requirements* of the BCA to be satisfied. The satisfaction of the performance requirements depends on many factors, including the correct choice of materials of construction, appropriate egress requirements, adequate fire suppression, and appropriate structural fire resistance.

The design principles and procedures contained in this document are drawn from recent Australian and overseas experience and state-of-the-art fire engineering knowledge, and have taken into account the sub-systems and methodologies given in the Fire Engineering Guidelines [2] prepared by the Fire Code Reform Centre.

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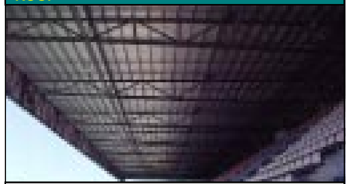
1 In attempting to determine how normal provisions may be modified in the light of alternative solutions, the BCA frequently makes use of the term “concessions”. As these alternative requirements are permitted within the code, it follows that they must be considered to correspond to an *equivalent* level of safety in certain situations—namely the situations specified in the “concession”. The use of the word “concession” unfortunately implies a lower level of safety, which is not the case.

PARTS OF MODERN SPORT STANDS BUILDINGS

ROOF



Construction: Normally of steel construction.
Combustibles: Nil.

BISTRO AND DINING AREAS

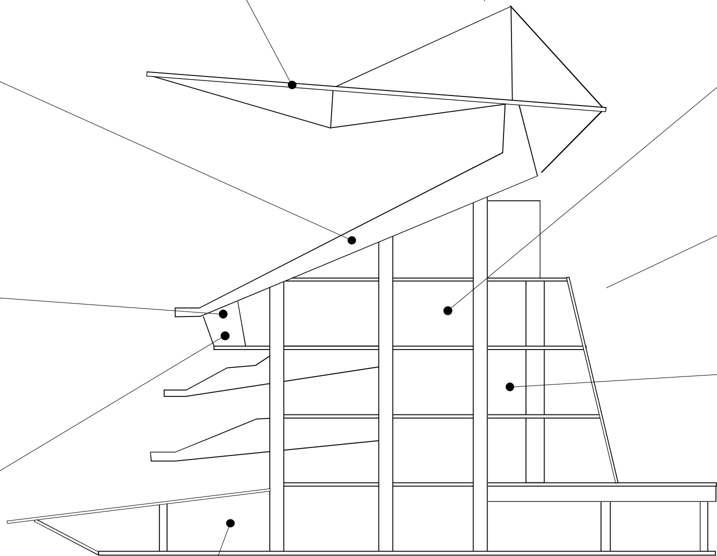
Construction: Often positioned to overlook the playing area with full height glazing along one side. (Cooking is generally not undertaken in these areas.)
Combustibles: Tables, chairs, furniture, carpet.

CONCOURSE AREAS

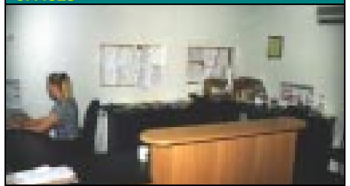
Construction: These areas are contained in the back-of-house construction, provide horizontal access to an adjacent seating tier and also to service areas such as toilets, food and beverage outlets. Designed for a large number of pedestrians as this is the primary means of entrance to the seating tier.
Combustibles: Incidental items such as chairs, tables and boxes.

SEATING TIERS

Construction: Usually constructed from reinforced or prestressed concrete plats which span between girders. Seating shells or benches are connected to the plats and have been constructed from materials including steel, timber, aluminium and plastic (the most common).
Combustibles: plastic seats, rubbish.

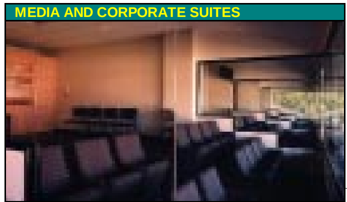


OFFICES



Combustibles: Tables, chairs, books, carpet, paper.

MEDIA AND CORPORATE SUITES

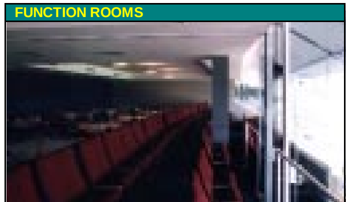


Construction: Generally fully glazed at the front but are separated from the adjacent enclosures by walls offering substantial sound proofing. Dry wall or block work construction is commonly used for this purpose. The glazing at the front of these boxes is frequently extended around the sides for a short distance adjacent to the viewer's seating area. (Food is rarely prepared in these areas although it is commonly reheated and served.)
Combustibles: Spectator seats, tables and chairs, benches, cupboards and carpet.

FOOD AND BEVERAGE OUTLETS

Construction: Usually located adjacent to the concourse areas and typically have a substantial opening in the side adjacent to the concourse to allow serving and access. The opening is generally protected with an open mesh or solid screen when the facility is not in use. A ceiling is often provided in these areas.
Combustibles: Some furniture such as plastic chairs, tables, benches, cardboard boxes and packaging.

FUNCTION ROOMS



Construction: Often positioned to overlook the playing area with full height glazing along one side. (Cooking is generally not undertaken in these areas.)
Combustibles: Tables, chairs, and furniture associated with the serving of food.

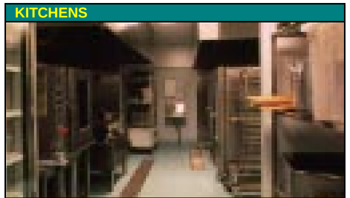
STORAGE AREAS AND PLANTROOMS

Construction: Storage areas are typically located at ground level and under the lower level of seating. Plantrooms are often located at ground level.
Combustibles: Storage areas may contain liquid fuel stored in drums, motorised equipment, and other combustibles such as spare seating shells.

TOILETS AND CHANGE ROOMS

Construction: These areas are accessed via the concourses.
Combustibles: Benches, chairs, rubbish.

KITCHENS



Construction: Normally occupied when cooking is being undertaken. A continuous flush ceiling, such as a plasterboard ceiling, is normally required in these areas to satisfy health requirements.
Combustibles: Cooking oil, some packaging.

There have been many fires in older sports stand buildings where combustible construction has been used (see for example [3]). Fortunately, with the exception of the Bradford Stadium fire in the United Kingdom, there have been few deaths due mainly to the fact that these buildings were not occupied at the time of the fire, or that there was sufficient time for evacuation.

Bradford Stadium Fire, UK, 1985 [4]

In this fire 56 people lost their lives and many were injured. The fire developed in an isolated (unoccupied) location—in the substantial volume below the seating plats—before it was noticed by the occupants in the stand above. The combustibles below the seating consisted of rubbish that had accumulated over the years from the disposal of materials via gaps between the seating plats to the volume below. The fire location and size made it almost impossible to fight with hose reels or fire hoses—even if they had been available. As the fire further developed, its rate of spread was accelerated through the involvement of combustibles in the stand and roof covering materials. This fire resulted in high levels of radiation and the loss of life would have been much higher, should escape on to the playing field not been possible.

Following the Bradford fire and various incidents involving crowd violence, the Home Office in the United Kingdom conducted an Inquiry into crowd safety at sports grounds [4]. This was followed by a publication entitled “Guide to Safety at Sports Grounds” [5] which seeks to address all safety matters associated with the design and operation of sports grounds and gives general guidance and principles for this purpose. Fire-safety issues are considered briefly.

In 1988, Hughes Associates [6] published a report which reviewed fire safety incidents in sports stadiums in the United States from 1971 to 1986. These buildings varied from combustible to non-combustible construction and were from 1-9 storeys in height. It was found that deaths were rare (3 deaths). The paper recommended the use of non-combustible construction; proper separation of storerooms used to store combustible materials; wall linings used throughout construction to have a low flame-spread rating; sprinklers for such areas as storerooms, shops, offices, restaurants, and dining areas; and a communication system for relaying essential messages to all parts of the occupied facility.

Texas Stadium Fire, USA, 1993 [7]

This fire commenced in a corporate suite, but the stand was not occupied at the time of the fire. The fire was burning vigorously by the time an alarm was sent to the fire station. By the time the fire brigade arrived and set up (approx 8 minutes after the alarm was received) the fire had spread to five suites on the lower level, seven suites on the upper level, and to the plastic seating at the front of the lower level suites. The fire was almost extinguished after several minutes. However, due to a failure of the local water supply the fire flared up again and it finally took another 28 minutes for the fire to be finally extinguished. Firemen reported heavy smoke in the corridors behind the suites even though the doors into the suites were closed.

It was established that fire initiated in one of the upper suites and spread horizontally via the fronts of the suites once the glazing had broken. The fronts of some of the suites had been clad in clear plastic and this fell burning onto the seats below, starting a fire amongst this seating. This fire, in turn, spread to the lower suites located above these seats. It appears that there was no aisle between the seats and the front of the suites.

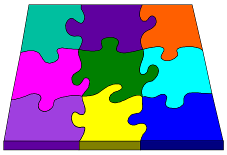
In 1989, British Steel reviewed a number of specific examples where sports stand buildings had been designed using fire-safety principles as opposed to complying with local regulations. The publication highlights examples where unprotected structural steel has been used [8].

FIRE SAFETY ASPECTS

Introduction

A rational engineering approach which takes into account the unique features of these buildings is essential to ensure cost-effective construction and high levels of fire safety. In this context the term “fire safety” should be taken as referring to both “life safety” and “property protection”. It is the opinion of the authors, that if the building is properly designed for life safety (which is primarily the concern of the BCA), then it will possess a level of protection against property loss. This matter is further considered again later in this section.

Factors Important for Fire Safety



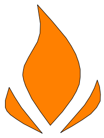
There are many factors that have an influence on the level of fire safety offered by a building. Some of the more significant factors are listed below:

- numbers and types of fire starts
- likelihood of fire suppression by the occupants
- reliability and effectiveness of the detection and alarm systems
- communication systems
- emergency procedures and staff training
- reliability and effectiveness of the sprinkler system
- fire characteristics (flames and smoke)—rate of spread, size, severity
- means of evacuation
- number of occupants and their behaviour
- reliability and effectiveness of the smoke control system
- the action of the fire brigade
- performance of the building structure

Modern sports stand buildings, because of their volume and openness, generally offer efficient mechanisms for venting smoke in the event of a fire. Also their form of construction means that they are, from a structural viewpoint, highly redundant and therefore overall building failure is almost inconceivable given any *credible* fire. In addition, practical egress requirements associated with the need to efficiently move people out of the building after a sporting event mean that evacuation times are short.

A fire-engineering approach to the design of these buildings requires systematic consideration of such aspects as smoke management (smoke control and occupant evacuation), fire extinguishment and fire fighting, and the structural adequacy of the building as it relates to occupant safety. The above aspects are particularly dependent on the choice of design fire and this, in turn, must be determined from the range of possible fire scenarios.

Fire Initiation and Development

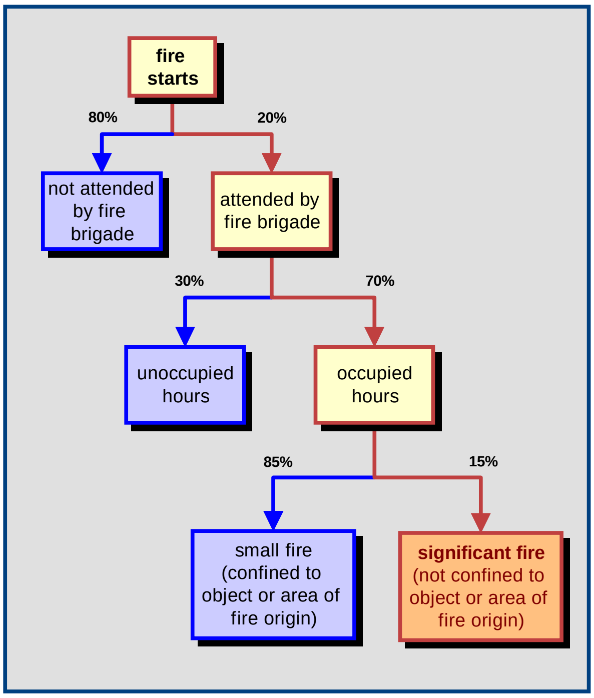


Fires may occur in many parts of these buildings including the seating tiers. As the seating shells are usually plastic (typically polypropylene) it is *possible* that a substantial fire could develop within the seating but this would require a significant ignition source and sufficient time. The ignition source will need to be substantial (as with rubbish burning below several seats) if the fire is to spread beyond one seating shell due to the separation between seating shells and between rows of seats. It is unlikely that sufficient rubbish will be allowed to accumulate below the seats, and more importantly, the occupants within the stand (assuming it is occupied) will most likely extinguish any fire while it is small. Fires associated with the spectator seating of public viewing areas (other than that associated with corporate suites) are therefore considered not to present a hazard, given the presence of adequate controls (eg. housekeeping to avoid rubbish build-up).

Areas such as concourses (excluding food and beverage outlets which open into the concourses), toilets and change rooms, generally present a low fire hazard due to their low level of combustibles.

However, all other areas within the sports stand building should be considered as potential sites for fire starts. An estimate of the average probability of fire starts in these latter areas can be obtained by using the rate identified for retail buildings [9] and multiplying by the total floor area of these areas. This rate is 2.5×10^{-4}/yr/m^2 and includes the fire starts which are *not* reported to the fire brigade. These latter fire starts represent the majority and have been deduced from insurance records and other sources. It is considered that it is reasonable to apply this fire start rate to these buildings because many of the areas where there are combustibles are associated with retail activities (food and beverage)—although they are areas of relatively low fire load. Furthermore, fires can be divided into those that occur when the building is occupied and those that occur when the building is unoccupied. These buildings are large public buildings which are used for functions other than major sporting competitions and the services associated with the building must be operated to allow for this. It is known from retail fire statistics that about 70% of fires occur during the occupied hours. Thus the number of fires occurring during occupied hours can be estimated by multiplying the above number by 0.70.

Although it is possible to estimate the number of fire starts associated with a particular building during the occupied hours, it is necessary to determine the range (and corresponding severities) of the resulting fires. Again, it is known from overseas fire statistics [9], that at least 80% of these fires will be so small that they will not result in the attendance of the fire brigade. Of the remaining 20% of fires that will be attended by the fire brigade, more than 85% will be confined to the object or area of fire origin through the action of the occupants and/or the fire brigade. These latter fires are likely to have little impact on either the occupants or the structure of the building. Thus, in summary, 97% (100-20×0.15) of fires, during occupied hours, will be small and not require a detailed fire engineering assessment. The provision of adequate fire-fighting facilities, emergency procedures, staff training, and the like, can be considered to constitute an adequate response to these fires. It is the remaining 3% of fires that have the potential to become large and which may extend beyond the room of fire origin, and it is these which may pose, by far, the greatest threat to the occupants of the building.



The population within these building is low most of the time and it is only during major events that the it reaches the maximum number. If it is assumed that this occurs for only one afternoon or evening per week and occasionally more frequently, then the average probability of having a significant fire during a time when the building is occupied close to full capacity can be taken as 1/10 of the probability of having a significant fire during occupied hours.

It is also not common for these buildings to be fitted with sprinklers. However, if sprinklers are incorporated they will further reduce the likelihood of a major fire. In the context of this document, a sprinklered building should be understood as a building where sprinklers are provided throughout all areas with the exception of concourses, toilets and change rooms. It is considered that it is not necessary to sprinkler such areas. A sprinkler effectiveness[2] of at least 98% can be assumed.

The above observations on the occurrence of a significant fire are summarised in the table below. The resultant rate in the table of 5.25×10^{-6}/yr/m^2 is derived from $2.5\times10^{-4}\times0.7\times0.03$ and the variable A (m^2) in is the total area associated with storage areas, shops, offices, corporate and media suites, function rooms and bistro and dining areas.

Estimated Average Number of Significant Fires per Year during Occupied Hours

Occupant Situation	Sprinklers not Present	Sprinklers Present
Normal	$5.25\times10^{-6}\times A$	$5.25\times10^{-6}\times0.02\times A$
Major Event	$5.25\times10^{-6}\times A\div10$	$5.25\times10^{-6}\times0.02\times A\div10$

Substitution of typical values for *A* into the above expressions gives an estimate of the average probability of having a significant fire in a year.

Example:

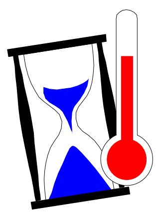
Probability of occurrence of a significant fire during a major event.

Assume A = 2000 m^2

Average number of fires per year if sprinklers not present = $5.25\times10^{-6}\times2000\div10$ = 0.00105, ie.

- a significant fire can be expected to occur during a major event once in 952 years if the occupancies are not sprinklered
- a significant fire can be expected to occur during a major event once in 47,619 years if the occupancies are sprinklered

Design Fires



A fire-engineering approach to the design of these buildings requires the adoption of appropriate design fires. In this regard, it is important to understand that the *same* design fire must be used when considering each element of the fire-safety system whether it influences occupant evacuation, management of the smoke, or the structural stability of the building, etc.

Building without Sprinklers

In this case *it is proposed that the design fires must include those flashover fires which may occur within any one of the relevant parts of the building* such as: storage areas, shops, offices,

[2] Sprinkler *effectiveness* refers to the combination of *efficacy* (ability to control or extinguish a fire) and *reliability* (whether the system will deliver water in the first place) and has been estimated from statistical data for NSW retail buildings as being 98%. It is likely that the systems in these buildings will be even more effective due to the lesser levels of combustibles and the fact that isolation of the sprinklers will be extremely rare given sound management of the system.

corporate and media suites, function rooms and bistro and dining areas.

The following observations may be made for these buildings:

i. From the above probability calculations for non-sprinklered buildings, it will be found that the likelihood of having a significant fire is very small.

ii. the areas within these buildings that have a significant fire load are generally broken into small enclosures due to the need to maintain exclusive use or security of these areas and the passages needed for access and egress. In the event of a fire, this will reduce the rate at which the fire spreads, the probability of fire spread and the severity of the fire at any time.

Fire characteristics such as the time-temperature relationship may be determined directly from relevant tests or by means of an appropriate model (see Appendix 1). These should take into account the fire load and ventilation relevant to the enclosure.

The fire load densities given in the table below may be considered to apply to various parts of these buildings. These fire loads have been derived from [10] or from calculations based on direct observation of combustibles in such enclosures. Some sports stand buildings incorporate gaming machine areas. The fire load in such areas can be taken as being equivalent to that associated with offices.

Fire Load (kg of wood equivalent per m^2 of floor area)	
Storage Areas	< 80
Offices	< 40
Function Rooms	< 30
Bistro and Dining Areas	< 25
Media Suites	< 25
Food and Beverage Outlets	< 20
Corporate Suites	< 18
Gymnasium	< 5
Concourse Areas	< 5
Kitchens	< 5
Toilets and Change Rooms	< 5

Building with Sprinklers

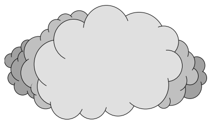
In the case of sprinklered buildings it is proposed that the design fire is a *sprinklered fire.* This is considered to be appropriate since the likelihood of having a significant non-sprinklered fire is very low, and the addition of a sprinkler system, which has been properly designed, commissioned and maintained, will *further* dramatically reduce this likelihood.

In this regard, it is important to note that there will be very little reason for the sprinkler system to be isolated (very few tenancy alterations[3]) and this, combined with the fact that the ceilings are low and the fire load is generally not in racking, would be expected to give very high levels of sprinkler effectiveness.

Nevertheless, the consequences of a non-sprinklered fire should be considered but balanced against the extremely low probability of such an occurrence. The presence of practical measures such as a sound fire-safety management strategy at the venue and a redundant building structure (see later discussion) can be taken as providing sufficient assurance against the effects of a significant non-sprinklered fire and to guard against the possibility of catastrophic failure.

In the context of this document, it is assumed that a sprinkler system, if provided, will be commissioned, maintained and managed to maximise its effectiveness. A formal management system to ensure that this is the case will be necessary.

Smoke Development and Management



It is known that a primary cause of death in fire is due to the exposure of the occupants to the products of combustion—smoke; although burns are also commonly noted as a contributing factor. Smoke is generated by combustion and contains, in addition to toxic gases, small particles of matter suspended in air. It is these particles that indicate the presence of potentially toxic gases and assist in the containment of heat within a smoke layer. The temperature of a hot smoke layer can also present a threat to the occupants.

In the event of a fire, because it is hotter than the ambient air, smoke will tend to rise and move through a building including enclosures and pathways used by the occupants—thereby putting them at risk. *Smoke management*, when understood in the broadest sense, is concerned with managing smoke within the building such that the likelihood of exposure of the occupants to *debilitating smoke* is minimised. Other objectives include assisting the activities of fire fighting through maintaining visibility and minimising the property damage associated with smoke. Strategies for achieving these objectives include:

- keeping the fire small—such fires generate small quantities of smoke
- providing adequate egress paths and evacuation strategies—to quickly move people away from the smoke-affected areas

[3] The major source of a loss of reliability of a sprinkler system is associated with the system being isolated for building upgrade.

- providing adequate venting/extraction where appropriate—removing smoke from the building and away from the occupants
- providing barriers to minimise the spread of smoke

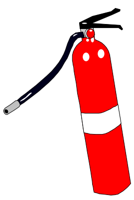
Thus, smoke management is about managing the smoke in relation to the building occupants. The term *debilitating smoke* was used above to emphasise the fact that not all exposures to smoke will lead to serious injury or death. Injuries can vary from minor irritation to serious injury and death—the seriousness of the injury being a function of the density and content of the smoke and the length of exposure to it.

As noted previously, the population in these buildings is only likely to be a maximum for about one half a day per week. During the remaining part of the week various parts of the building will be used to differing extents. Certainly, this will be the case if the sports stand has function rooms and there are various social clubs. The maximum number of people in these buildings is related to the seating capacity.

The people within the building will behave similarly to people in other buildings where the occupants are awake and aware, and the presence of dense smoke will serve to reinforce the need for occupants in the vicinity of the fire to move away from the fire-affected part of the building. In the event of a major fire there almost certainly will be interaction between people attempting to move into the concourse areas from the seating and the back-of-house construction. Thus queuing will occur and this must be taken into account when considering evacuation of part of the building.

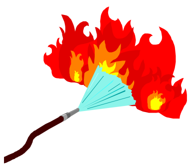
Fire Fighting

Occupant Fire Fighting



As previously observed, a high proportion of fires in buildings are extinguished without the fire brigade being called, and even when they are called, more than 80% of these fires are confined to the object and area of fire origin. These facts suggest that the occupants of the building have an important role in early fire fighting, or in controlling the fire until the fire brigade arrives. This emphasises the importance of adequate fire-fighting facilities and staff training.

Brigade Fire Fighting



The fire brigade's charter relates not only to safety of the occupants of the building but also to the protection of property—including the building in which the fire originates. They are not expected, however, to take unnecessary risks. The BCA, on the other hand, is primarily concerned with maintaining a high level of life safety, although it is concerned with minimising the damage to *adjacent* properties and buildings. The latter objective is less relevant for these buildings as they are generally well separated from adjacent properties.

The fire brigade is an important part of the fire safety system, and in the event of an alarm, may be considered to have the following specific functions:

i. where there is no other evidence of fire, investigate the situation and the probable cause of the alarm

ii. extinguish fires that are small or that are being controlled by the occupants or a sprinkler system

iii. participate in evacuation of the occupants in the event of a significant fire—if that has not already occurred

iv. undertake any reasonable measures to control, and finally extinguish, a significant unsprinklered fire

v. limit fire spread to other parts of the building or other buildings

Factors which can have an important influence on the *ability* of the fire brigade to fulfil the above functions include: receiving an alarm; activities and timing including travel and setting-up times; fire-brigade facilities; and the size of fire confronted.

In considering the role of the fire brigade in attacking a fire in a non-sprinklered building, it is important to estimate the time at which they will be effective in limiting the spread of the fire and reducing its heat output (ie. impacting the fire) in the enclosure of fire origin. Such action is considered to be feasible in these buildings due to the fact that easy access can be obtained to most parts of the building and that it is broken into many enclosures. Thus, after a certain period of time it can be assumed that the fire will be impacted by the fire brigade. This time is variable and is a function of the time at which the alarm is received at the fire station, the travel time to the building, the setting-up time once the fire brigade has arrived and the time to impact the fire. Conservative estimates have been made for each of these times[4].

The time for detection of a fire and for calling the fire brigade is likely to be fairly short if the building is occupied. Also, in this case, it is very unlikely that the fire will have reached flashover before the alarm is given. It is conservative therefore, to assume that the brigade has been notified by the time flashover occurs.

The time for arrival of the fire brigade to a major sports stand is estimated as 10 minutes, and in

[4] Estimated times for setting up and travel time are based on advice from various fire brigades [11].

practice, is likely to be considerably less. The setting-up time for the brigade, prior to supplying water to the fire, is estimated as 10 minutes. This timing assumes that there is little interference between persons evacuating the building and the brigade who are trying to gain access to the seat of the fire. If this is not the case then the set-up time may be considerably longer and the fire spread may be considerably greater, and in this situation, one has to question the value of brigade intervention.

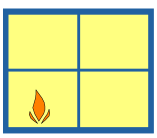
It is therefore important to manage the evacuation process to minimise the brigade/occupant interference and/or to provide independent access for the brigade to various locations. If this cannot be achieved then consideration should be given to sprinklering the building from a property protection viewpoint.

The supply of water to the fire will result in reducing air and structure temperatures in the enclosure of fire origin. Given the size of flashover fires possible in these buildings, it is likely that application of water for a period of about 10 minutes will be required before the air and structure temperatures reduce significantly.

In summary, the fire brigade is an important part of the fire-safety system, and for the fires likely to be encountered in a modern sports stand, can be assumed to be effective in influencing a fire within 30 minutes of flashover for most areas within these buildings—subject to an evacuation plan or alternative paths which minimise interference to brigade activities. Of course, it is likely that the fire will have exhausted itself in less than 30 minutes.

The effect of the fire brigade in reducing fire severity is taken into account in determining the level of protection required to maintain structural adequacy.

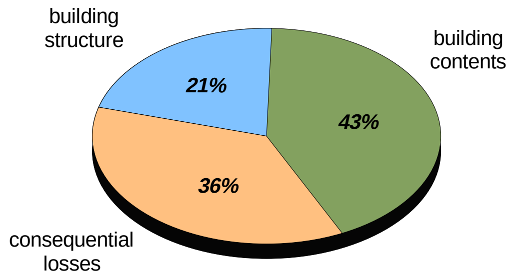
Structural Adequacy



Section C (Fire Resistance) of the BCA gives a series of performance requirements, some of which relate to the building structure. A careful study of these requirements reveals that the building must be designed to provide safety for the occupants and fire fighters, and so that fire does not spread to other properties. The latter matter is rarely an issue with these buildings due to the fact that they are generally well separated from adjacent buildings; whilst the former is achieved by designing for the appropriate design fire and through recognition that these buildings offer a high level of structural redundancy.

Property Protection

The issue of property protection is of importance to both owners and operators of sports stand buildings. From overseas statistics [12] the average costs associated with fires in buildings are divided as follows:



Consequential losses include those associated with the loss of business, and in the case of sports stand buildings, it is likely that these will be much higher than the above proportion. In any case, it can be seen that the building structure losses are a small part of the total losses.

The *most* effective way that a property can be protected against fire *is to not have a fire start in the first place*. This cannot always be achieved in these buildings but routine surveillance and housekeeping audits will be effective in reducing fire incidents. These activities therefore offer value with respect to property protection.

If a fire start cannot be prevented, the next best action is to confine the fire to the object or area of fire origin through the action of staff or the occupants. The majority of fire starts (70%) occur during the hours that the building is occupied and are associated with the demand for services and electricity and the activities of the occupants. However, during occupied hours, the presence of people will result in the fire being mostly extinguished before the sprinklers are able to activate. This is less so during the “unoccupied” times when only a skeletal staff occupies the building; but even then, it appears that many of these fires will not go beyond the area of fire origin. Housekeeping, the establishment of fire-response procedures, and the training of staff in such procedures can provide additional levels of property protection.

A soundly-managed sprinkler system is the remaining way of restricting a fire to the area of fire origin—although activation of sprinkler heads may result in water damage. Nevertheless, this damage will be substantially less than that experienced if the sprinklers are not present or functioning.

High levels of structural fire resistance will not necessarily provide high levels of property protection. If property protection is a major concern, then the building should be sprinklered.

Design Strategy

To provide means for safe egress of occupants put at risk by a fire.

Design Principles

i. All enclosures[5] and areas within the building shall be designed to avoid entrapment.

ii. All enclosures and areas shall have sufficient egress paths to allow staged (progressive) evacuation to a safer place, open space, or roadway, prior to the achievement of untenable conditions.

iii. A plan to assist the staged evacuation of the building shall be developed and implemented.

Details

In designing these buildings for evacuation, it is important that entrapment is avoided as this has been found to be one of the major sources of deaths in buildings. This is normally achieved through the provision of sufficient alternative egress paths from each enclosure or area of the building. This is the purpose of the first principle. Egress paths are those parts of the building that are intended to be used by the occupants when evacuating the building. They may include such areas as concourses, walkways, corridors, doorways, stairways, ramps, etc. Smoke may flow through corridors and concourses and up ramps or stairs and care should be taken to ensure that in such cases adequate alternative means of egress are available from all areas and enclosures that may be affected.

The first principle may mean that egress paths will, at least, be provided at each end of an enclosure or area. This is not practical for all enclosures and the BCA and current experience suggest that this principle need not apply to enclosures with a maximum plan dimension of 20 m or less. However, each situation needs to be carefully evaluated. For example, in an unsprinklered building, corporate suites where the only means of egress is via a narrow corridor at the back of the suites may represent one situation where entrapment could occur—especially if the corridor at the rear could become smoke logged due to a fire in an adjacent part of the building before the occupants of the suites become aware of the fire.

5 The term enclosure refers to a part of the building which is surrounded by wall construction which may be fire-resistant and which may contain significant voids. Concourses are not considered as enclosures in this publication.

For the purpose of this publication, well-ventilated concourses are regarded as areas, not enclosures, as their principal purpose is to provide access to an adjacent seating tier and also to areas such as toilets and food and beverage outlets. These areas are also designed to provide an efficient means of egress for occupants as they leave the building at the end of a sporting event. Similarly, in the event of a fire, the occupants will seek to move into the concourses as they move towards the exit stairs and/or ramps. Thus the movement of evacuees through these areas is of critical importance and will have a significant impact on the overall evacuation time for these parts of the building.

Similarly, the passageways which provide exclusive access to and from corporate viewing and other private areas must be designed to ensure timely evacuation.

Part D of the BCA specifies the aggregate width of *exits* or path of travel to *exits* and distances of travel to these *exits*. An example of the application of this part to a sports stand building is given in Appendix 2.

The *exit* width requirements in the BCA appear to have worked well with respect to facilitating the safe movement (absence of panic, crowd pressure) of large numbers of people through these buildings under non-fire conditions. Designers need to be cautious in varying from these width requirements. However, variation of the travel distances and *exit* spacings may be appropriate.

Some egress paths will be preferred over others. Preferred paths are those that are used most commonly by the occupants—as opposed to *fire-isolated stairways* which are rarely used, and which are only likely to be used for evacuation when there is no alternative means of egress.

Efficient, staged (progressive) evacuation of significant parts of these buildings will be assisted by the existence and implementation of an evacuation plan. Those occupants closest to the fire (vertically and horizontally) should be evacuated first, with those further away being evacuated later, should this be necessary. The evacuation plan should consider various fire locations and scenarios and be developed accordingly.

Efficient, staged evacuation will be assisted by the use of a public address system, in combination with direct guidance from staff positioned within the part of the building to be evacuated.

In the event of a significant fire it is recommended that *the game or event is stopped* to ensure that people will take any instructions seriously.

Although it is not generally permitted, it may be possible to evacuate some of the occupants from the lowest seating tier on to the playing field in the event of an emergency. However, it is not recommended that this is taken into account in calculating times for evacuation.

Times for evacuation of various enclosures and areas may need to be calculated *irrespective* of whether the *exit* spacings comply with Part D of the BCA. These times must be less than the time to untenable conditions in those areas (see section *on Smoke Development and Management*). However, it should be noted that calculations of evacuation times or of the time to untenable conditions will not be necessary if the building is sprinklered, or if the enclosures or areas in an unsprinklered building are sufficiently small or well ventilated. Further details on the situations where such calculations are not required is given in the section on *Smoke Development and Management*.

Methodology

EXIT **Evacuation**

The time for evacuation of the occupants from a particular enclosure or area within the building shall be taken as:

$$t_e = t_{pm} + t_m$$

where t_{pm} is the pre-movement time and includes all of the events required to make the decision to evacuation, and t_m is the total movement time for the occupants to move to a safer place.

Pre-movement Time

Within the enclosure of fire origin it can be assumed that the decision to evacuate will be made well before flashover—probably at the point that it is recognised that occupant fire fighting is not effective. In reality, the majority of occupants will have left the enclosure well before this point and it will only be those attempting to extinguish the fire that must escape as the fire continues to grow. It is estimated from the observation of fire development that this time period is likely to be at least two minutes from fire initiation and several minutes before “flashover”.

However, in areas or enclosures away from the enclosure of fire origin, the occupants may not move away until flashover within the enclosure of fire origin occurs. As this occurrence will be accompanied by large quantities of dense black smoke and considerable heat, it is reasonable to assume that those closest to the fire will begin to move first and that this will take place shortly after flashover. Evacuation of other parts, further from the fire, will only commence as smoke begins to threaten or when the occupants are directed to evacuate by management. As noted above, if a significant fire develops in the building, the game should be stopped.

Total Movement Time

The total movement time shall be determined taking into account:

- the available tenable egress paths
- the speed of travel
- queuing within the egress path
- the evacuation plan

The population of each area of the building shall be based on the seating capacity. It is not necessary to consider additional occupants such as staff unless special circumstances arise where the additional occupants make up a significant proportion of the total population.

Movement time calculations are considered further in Appendix 3 which also presents examples based on the building presented in Appendix 2.

Design Strategy

To provide means for the safe egress of occupants put at risk by a fire.

Design Principles

The building shall be designed so that:

i. areas and enclosures shall remain tenable for a period sufficient to allow evacuation from the area or enclosure

ii. egress paths from each area and enclosure shall remain tenable for the expected duration of evacuation from that area or enclosure

Details

The above design principles mean that for any enclosure or area, the time to untenable conditions must be greater than the time for evacuation of that part of the building. The time for evacuation must be determined in accordance with the section "*Occupant Avoidance*".

It may not be necessary to consider the times for evacuation or tenability in those small enclosures where it is obvious that awake and aware occupants can evacuate quickly enough to avoid a fire. The BCA implies that this is the case for enclosures with a plan area less than 500 m^2. In the case of sprinklered buildings it is unlikely that any detailed consideration of evacuation or tenability will be necessary since there is a very low probability of the occurrence of a significant non-sprinklered fire.

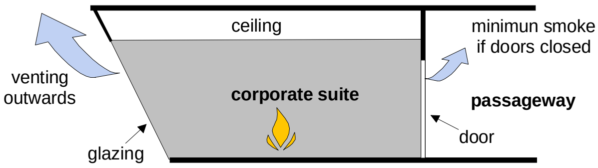
Similarly, where more-than-sufficient natural ventilation (see *Methodology*) is provided, little analysis of smoke flows and smoke layer depths is required.

The majority of the occupants in sports stand buildings will normally be in open areas and thus at little risk due to smoke from a fire. Occupants in enclosed areas and in partially-closed concourses, etc, will be at greater risk from a fire that introduces smoke into those areas and the egress paths from them. Due to the nature of these buildings the evacuation time from most areas of the building is short provided all or most egress paths are useable.

In the areas of these buildings open to the general public (ie. the majority of the occupants), the possible locations of fires are limited (eg. concessions or food and beverage outlets) and are naturally separated by concourses, stairways and ramps, and enclosures such as toilets. Therefore the spread of fires in these areas is likely to be limited to a very small proportion of the building. The concourses in such areas can be designed for smoke tenability using natural ventilation (openings in the sides) with suitably placed barriers or curtains. Other paths such as ramps and stairways at the rear of the concourse will allow venting of smoke provided they have sufficient natural openings. In these public areas, the judicious use of natural ventilation will limit the effect of the smoke from fires in these areas to those in the immediate vicinity of the fire.

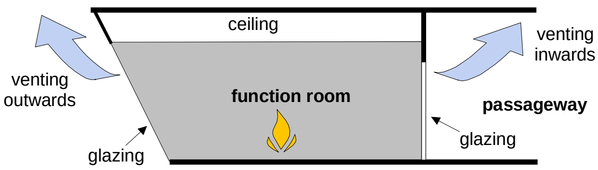
Any ventilation system, whether natural or mechanical, should be designed such that smoke from a fire will be spilled to the outside of the building (that is, on the side away from the playing field) except perhaps in the most adverse weather conditions or where this is unavoidable.

In many cases, enclosures such as corporate suites will have glazing *only* on the playing side, and in the event of a fire, the glazing may break and the smoke be largely vented outwards into the open air rather than into the adjacent passageway from which the corporate suites are entered. Untenable conditions may still be achieved in the adjacent passageway (see Texas Stadium example) even if the doors to such enclosures are closed, due to gaps around the doors. This space could also be rendered untenable by fires from other enclosures opening directly into this passageway.



Food and beverage outlets generally have their main opening (often completely open) onto concourses. However, provided these areas have more-than-sufficient ventilation, this should not present a problem.

Function rooms may have glazing on both the playing side and the passageway (opposite) side. In such cases smoke may be vented in both directions and attention to adequate venting, particularly of the passageway, may be required.



Smoke Reservoirs

Areas and enclosures may be designed taking into account available reservoirs for smoke (formed naturally by walls and ceilings, etc, and by placement of smoke barriers or curtains) provided that smoke will be able to fill these areas under the range of weather conditions (particularly wind) expected for the building location.

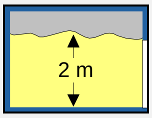
Mechanical Smoke Control System

Large contiguous enclosed areas of the building may require a mechanical smoke control system. The design of such systems should be appropriate to the size and usage of the area. Alternatively, if sprinklers are installed, it is unlikely that mechanical smoke control will be required.

Natural Ventilation

It is expected that in many buildings of this type natural ventilation will be acceptable and sufficient to satisfy the above design principles for all or most areas of the building.

Methodology



Tenability

Tenable conditions may be considered to exist in an enclosure or area if the smoke layer in that enclosure or area is greater than 2 m from the floor. This criterion is considered to be sufficiently conservative that detailed consideration of the smoke hazard is not necessary. If a lower smoke layer height is used, then detailed consideration of the smoke hazard (temperature, toxic properties, etc) should be undertaken.

The rate of smoke production from a fire depends on such factors as the fire size, the height to which the smoke rises before hitting an obstruction (such as a ceiling, floor, upper deck, etc), the plan area of the enclosure and the height of the bottom of the smoke layer. Formulae for estimating the smoke production rate and the height of the bottom of the smoke layer for these cases and cases involving balcony spill and window plumes or confined flows are given in such publications as NFPA 92B [13], Klote and Milke [14] and CIBSE [15]. Zone models may also be used to estimate these quantities with adequate accuracy in many instances.

As noted previously, if more-than-sufficient natural venting is provided, little analysis of smoke flows and smoke layer depths may be required.

The design of more-than-sufficient ventilation will depend on the details of individual designs but the following principles may be of assistance:

i. Such ventilation should be designed to take advantage of the natural tendency of smoke to rise. Thus pathways for smoke from possible fire locations should not incorporate decreasing elevations of the roof or ceiling towards the vents to the open air. Preferably, the elevations of the roof or ceiling should gradually increase towards the vents.

ii. Concourses, stairways, ramps, etc that have more than 20% of the total external wall area open at the top of the walls may be considered to be equivalent to being in the open air provided that the openings are not separated by more than 10 m.

iii. Concourses, stairways, ramps, etc, in naturally-ventilated areas should not incorporate doors or other impediments to smoke flow unless at least 70% of their area is open and such openings are located at the top of the potential barrier. Concourses, stairways, ramps, etc in such areas and with more-than-sufficient ventilation need not be considered as enclosures.

iv. The roof or ceilings in concourses, stairways, ramps, etc, should be at least 3 m high and preferably 4 m.

If more-than-sufficient natural venting is not provided to a large enclosure (ie. > 500 m^2) then it will be necessary to assess the tenability of that enclosure by, for example, using either the relevant equations for smoke production or zone modelling (some details are given in Appendix 1), as described above. This must be done considering a local fire within the enclosure under consideration, and then a "flashover" fire in any adjacent enclosure (assuming a flashover fire can occur). In the latter case, the smoke from a fire in an adjacent enclosure will spill into the enclosure under consideration and the modelling must take this into account.

FIRE DETECTION AND SUPPRESSION
BRIGADE COMMUNICATION AND RESPONSE

Design Strategy

To provide sufficient means of detection and fire fighting for the occupants and the fire brigade.

Design Principles

i. Sufficient means of detection shall be provided.

ii. Sufficient means of alerting staff and fire brigade shall be provided.

iii. Sufficient portable extinguishers shall be provided and suitably located within the building to enable occupant fire fighting.

iv. Sufficient hose reels shall be provided and suitably located within the building to enable occupant fire fighting.

v. A training program for staff in fire awareness and the use of portable extinguishers and hose reels shall be developed and implemented.

vi. Sufficient fire brigade access shall be provided.

vii. Sufficient hydrants shall be provided and suitably located to facilitate brigade fire fighting.

Notes on Design Principles

The occupants of the building will be most effective in detecting fire in occupied areas. In unoccupied areas, detection must be by other means (eg. smoke detectors). This is likely to be particularly important from a property protection viewpoint. However, in the case of a sprinklered building, it is not considered necessary to incorporate alternative detectors.

If a fire is detected in an occupied area, it is very likely that the fire will be extinguished by the occupants. Should a fire develop in an unoccupied area, it will be necessary to alert the ground staff and the fire brigade. This will be achieved by detectors via the Fire Indicator Panel.

Portable extinguishers provide an important means of fire suppression for occupants and are more likely to be used as an immediate response to a fire start than a hose reel. Therefore the placement of such equipment close to areas where fires are more likely to start is important.

Hose reels can also have an important (but lesser) role in occupant fire fighting and should be provided throughout the building. In many of the open public areas, these may be used for other purposes such as cleaning, and in this case, will be connected to the domestic water supply. The use of such equipment for this purpose is considered as an acceptable practice as it provides a check on the operational status of the equipment.

Adequate access to (and into) the building must be provided if the fire brigade is to be effective in impacting a spreading fire. Vehicular access to hydrant boosters and major entrances into the stand is therefore important. The speed with which the brigade can reach areas within the building is a function of the number of people (moving in the opposite direction), the distance from the entry point, the means of access into certain areas (eg. lifts, ramps or stairs), and their knowledge of the building layout. As far as the latter factor is concerned, the brigade will need to be guided to the fire-affected area by ground staff. The use of staged evacuation will minimise interference with the brigade. The presence of a sprinkler system will reduce the urgency of brigade response.

Hydrants may be external or internal and provide a source of water for the fire brigade to connect hose lines. Typically, the fire brigade will connect a fire-fighting appliance (ie. truck) to the hydrant booster and connect hose lines to the relevant hydrants. However, it is known from statistics collected by the fire brigade that *internal* hydrants are very rarely used, with working from an appliance being the preferred approach. It appears that an internal hydrant will only be used where there is no other equivalent means of providing water (via hose lines) to a particular location within the building.

Details

Detection System

If the building is not sprinklered, a smoke detection system in accordance with AS1670 [16] shall be provided. However, in kitchens and similar areas heat detectors may be installed in lieu of smoke detectors.

Communication

Detector or sprinkler activation shall result in an alarm to ground staff and the fire brigade via the Fire Indicator Panel.

Access

In the case of a building that is not sprinklered, access to various parts of the building shall be provided to ensure that the brigade can reach necessary locations within the required time interval, taking into account the assistance of ground staff and staged evacuation. A joint ground staff/fire brigade action plan to facilitate access to necessary locations shall be developed and implemented.

Fire Extinguishers

Portable extinguishers to AS2444 [17] shall be provided in all enclosures where there is power distribution equipment, the cooking of food (eg. kitchens, dining rooms, food and beverage outlets), or the storage of hazardous goods or flammable liquids, or any enclosure which cannot be practically reached with a hose reel—ie. an enclosure where the hose must pass through a self-closing door.

Hose Reels

Hose reels to AS2441 [18] shall be located throughout the building such that the nozzle end of the fully extended fire hose fitted to a reel, and laid to avoid any partitions or other physical barriers, will reach every part of the building.

Hydrants

The water supply shall have adequate flow and pressure characteristics and any occasional isolation shall be properly managed.

Hydrants shall be provided generally in accordance with the requirements of AS2419.1 [19] and each part of the building shall be able to be reached from an external or internal hydrant.

An internal hydrant need only be provided where water cannot be delivered efficiently from an appliance or external hydrant, taking into account the likely direction of attack. Efficient delivery of water is dependent on the number of lengths of hose line that must be laid, and the height above an external hydrant/appliance. It is considered that the limiting number of lengths of hose line that may be laid from an external hydrant or appliance is two (60 m), and the limiting height (beyond which it will be difficult to drag hose lines) is two storeys above the external hydrant/appliance location. The length of the hose stream may be taken as 10 m in accordance with AS2419.1.

Spacing of internal hydrants shall be based on the assumption that one length of hose line (30 m) only can be laid from each hydrant. In this case the length of the hose stream may be taken as 6 m.

In the case of a sports stand building which is sprinklered, it is considered that general concessions may be sensible with respect to the number and location of internal hydrants. One possible concession is that only external hydrants need be provided on the condition that the total hose length does not exceed 120 m or the height above the hydrant is not greater than 4 storeys. Such allowances are possible due to the fact that the probability of having a significant non-sprinklered fire is very low.

Deemed-to-Satisfy Solutions

BCA Part E1

Design Strategies

To minimise the number of occupants put at risk by a fire.

To allow safe egress of occupants put at risk by a fire.

To provide an adequate level of safety for fire fighters.

Design Principles

The building shall be designed so that:

i. there is little risk of spread of fire from the area or enclosure of fire origin

ii. the risk of fire spread from an area or enclosure to another area, enclosure or egress path is not such that the safe egress of occupants having to evacuate is threatened

iii. there is no likelihood of combustible materials building up in cavities or concealed spaces

Details

In the areas of these buildings open to the general public (the majority of the occupants) the possible locations of fires (concession areas, etc.) are naturally separated by concourses, stairways, ramps, etc. Therefore the spread of fires in these areas is likely to be limited to a very small proportion of the building by the separation of combustible materials, provided non-combustible construction is used. Combustible cladding and construction has in the past led to extensive fire spread through buildings of this type.

The roof structure over the major spectator areas of these buildings is very unlikely to be subjected to a significant fire. Therefore these roof structures need not be designed for fire resistance.

The seating tiers usually consist of reinforced or prestressed concrete plats supported on girders. The plats are normally not required to be designed for fire resistance unless they directly form the roof of an enclosure (below). If this is the case then they should be designed as a floor.

Achievement of the design principles will be assisted by designing the relevant building elements to have sufficient fire resistance. In this regard, floors (floor slabs, beams, and in some cases, seating plats), columns, and loadbearing walls shall be designed to maintain structural adequacy, integrity and insulation (as relevant for the member) for the duration of the *design fire* with an appropriate level of safety, or 30 minutes from flashover, whichever is the least. The resultant time is referred as the *design duration*.

The above duration of 30 minutes is dependent on little interference between evacuees and fire fighters attempting to reach the fire. As indicated previously, this can be achieved with a sound evacuation plan or by providing alternative access for fire fighters. If such is not provided, and the building is not sprinklered, the duration associated with the impact of the fire brigade should be extended to 60 minutes. This will have an impact on the design duration.

A comprehensive assessment has been undertaken of the above building elements when subject to the relevant design fires corresponding to various locations within the building. In each case, the range of possible geometries and enclosure characteristics associated with the particular location have been taken into account in determining the protection requirements (if any) for structural steel and other members. These analyses have been used to develop solutions which cover a wide range of situations and which can be conservatively adopted for design purposes. These solutions are given in the *Deemed-to-Satisfy* part of this section and applies when the *design duration* is up to 30 minutes.

Buildings of this type are composed of many structural members which are connected together to form a complex and continuous structure. The removal of one or even several members will not impair the *overall* stability of the building. It follows therefore, that the presence of a localised intense fire which severely reduces the strength of several structural members, is unlikely to effect the overall stability of the building or the ability of the occupants to move away from the fire.

Design principle iii stems from fires such as the Bradford Stadium fire where accumulated rubbish in such a space was set alight with disastrous consequences.

Bradford Stadium: combustibles burning in space below seats

Methodology

Fire Resistance

The fire resistance of a member may be determined using the following procedure:

i. Obtain or estimate the time-temperature relationship for the relevant design fire. This may be based upon test data or calculation (see Appendix 1). In the case of a sprinklered fire, the air temperature within the vicinity of the structural member may be taken as less than 100°C and no further analysis of fire resistance is required.

ii. Identify the relevant design criteria for the member.

If the member is loadbearing then it will be necessary to demonstrate *structural adequacy*. However, if the member is either a wall or a floor slab it will also be necessary to consider *integrity* and *thermal insulation*.

iii. Estimate, using a transient heat-flow analysis, the temperatures throughout the member including unexposed surface temperatures if *thermal insulation* is a relevant criterion.

iv. Determine the load on the member (if any) The level of load applied to the member in the fire situation is defined by AS1170.1 [20] as:

$$w_f = 1.1G + 0.4Q$$

where G is the dead load and Q the live load.

v. Undertake appropriate structural analysis of the member if loadbearing.

Analysis of the structural member will need to take into account the effect of temperature on the mechanical properties of structural steel, reinforcing and prestressing steel, and concrete. In this regard the properties given in AS4100 (steel structures) [21] and AS3600 (concrete structures) [22] may be used. The normal assumptions of structural mechanics may be considered to apply in the analysis.

vi. Check compliance with design criteria.

If the design criterion is *structural adequacy*, then it is necessary to show that the applied load can be supported by the member for the *design duration*. If the criterion is *thermal insulation*, then the temperature of the unexposed face will need to be calculated and found to be less than 140°C above the ambient temperature.

Deemed-to-Satisfy Solutions

i. For members (eg. floor slabs, walls, beams and columns) required to have a fire resistance, and in the absence of fire-engineering calculations or other deemed-to-satisfy solutions, an FRL of 60 minutes.

ii. Based on fire-engineering calculations, the following solutions apply for steel beams and columns. The exposed surface area to mass ratio (k_{sm}) is the key parameter in determining the temperature of a steel member when exposed to fire. The lower the value, the lower will be the temperature achieved.

TABLE A: Steel beams and columns within enclosure

maximum k_{sm} (m²/tonne)		
no sprinklers:	**beam**	**column**
gymnasiums	30	30
concourses & walkways	30	30
change rooms & toilets	30	30
corporate suites		
- depth <7.5 m & 10 min ceiling†	30	26‡
- depth ≥7.5 m & 20 min ceiling†	30	26‡
function rooms		
- depth <7.5 m & 20 min ceiling†	30	26‡
- depth ≥7.5 m & 30⁺min ceiling†	30	26‡
Dining rooms (30⁺min ceiling†)	30	26‡
food & beverage outlets (10 min ceiling†)	30	26‡
storage areas & offices	(60 min FRL)	(60 min FRL)
with sprinklers:	**beam**	**column**
(all areas)	30	26

† ceiling systems:
10 min = plaster tiles on steel runners
20 min = 13 mm plasterboard screw-fixed to steel runners
30⁺min= 13 mm fire-resistant plasterboard screw-fixed to steel runners
Note that openings within a ceiling (eg. for lights) should be positioned such that they are not closer, in plan, than 1 m from a beam.
‡ clad with 16 mm plasterboard wrapped around column and penetrating the relevant ceiling. k_{sm} values are those based on the profile area (see Appendix 4).

TABLE B: Steel beams and columns outside enclosure

maximum k_{sm} (m²/tonne)		
no sprinklers in enclosure:	**beam**	**column**
food & beverage outlets:		
>2 m from opening	30	30
≤2 m from opening	18.5	18.5
(other areas)	§	§
with sprinklers in enclosure:	**beam**	**column**
(all areas)	no req	no req

§ Columns and beams should be positioned so that the members are *not* located adjacent to openings. Otherwise, the members should be protected as if they were within the adjacent enclosure.

The k_{sm} for BHP steel sections can be found in Appendix 4. Only members which have a k_{sm} value less than or equal to the relevant value given in the above tables are acceptable. Worked examples of checking the adequacy of steelwork are contained in Appendix 5.

CONCLUSIONS

This publication gives design principles and details which address the fire-safety objectives of the BCA. By implication, the performance requirements of the BCA are also considered. The design approach described herein will lead to greater flexibility and economy of construction—and in many situations, a greater level of safety. Sructural steel with little or no fire protection can be used in these buildings and offers advantages with respect to speed of construction, reduced costs, and flexibility for future building modifications.

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APPENDIX 1 Modelling of Fire Characteristics

Introduction

The characteristics of flashover fires are a function of the likely combustibles, the ventilation available to the fire, and the geometry of the enclosure. Fire load is expressed in terms of the calorific value of the combustibles per unit floor area (typically wood equivalent expressed in kg/m^2 of floor area); whilst the area of ventilation available to the fire is taken as the total area of windows and openings that are associated with an enclosure—it being generally assumed that any glazing will break and form an opening through which air can enter and through which smoke and heat will be exhausted. Values of fire load relevant to each of the types of enclosures within a sports stand building are given earlier (see *Fire Safety Aspects*).

Other factors which have an influence on the development of the fire are the nature of the combustible contents and the thermal characteristics of the materials lining the walls and ceilings.

Computer modelling

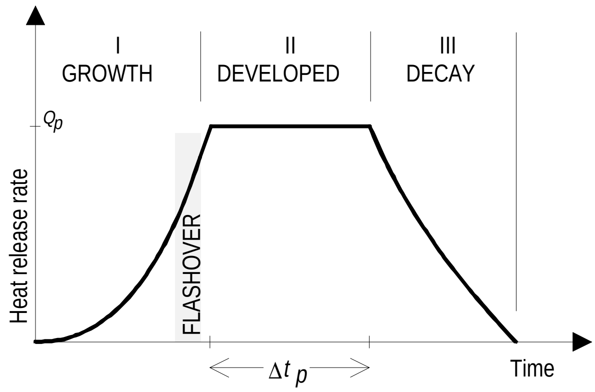
There are essentially two approaches (models) to calculating the air temperatures associated with a fire. These are *field* models and *zone* models. Neither approach models the fire itself (ie. the combustion process) and it is necessary to input the heat release characteristics of the fire. The models allow the air temperatures throughout an enclosure to be estimated based on different sets of assumptions.

Field models

Field models divide an enclosure into a grid of small elemental volumes and solve equations of mass, momentum and energy for each elemental volume. They generally require substantial computer resources.

Zone models

Zone models, in contrast, solve the conservation equations for relatively large elemental volumes, usually considering the enclosure to be broken into only one or two volumes. Each volume is assumed to have uniform properties. A one-zone model assumes that the entire enclosure has uniform temperatures. Two-zone models are more common and they divide the enclosure into a hot upper layer and a cool lower layer. Unlike field models with fixed unit volumes, the size of each zone in a two-zone model changes to reflect the transfer of mass and energy between the layers. The interface between the layers usually provides a good indication of the smoke layer height. The two most advanced zone models that are presently available are CFAST [23] and BRI2 [24].



Idealised stages in an enclosure fire

For both field and zone models, the fire is usually modelled based on a specified rate of heat release. A methodology for determining the heat release rate for such a purpose has been developed [25]. This methodology has been compared with four full-scale real fire tests of enclosures ranging from floor sizes of 4 m × 4 m to 12 m × 12 m and appears to give an adequate prediction of the air temperature as a function of time. Three of the tests used office type furniture as fuel and one used wood cribs. When used with CFAST, the heat release rate given by the methodology tends to produce time-temperature predictions which are conservative (ie. air temperature on the high side and a longer duration at air temperatures above 500°C) and even more so for high fire loads. This is partly due to the limitations of semi-empirical equations within CFAST. It is also due to the methodology which, because it is based on the burning of wood cribs, uses a more efficient burning characteristic than may be encountered with real furniture. In addition, due to the limited validation mentioned above, the methodology may not be appropriate for enclosures beyond the tested range *or* for excessive fire loads (> 60 kg/m^2 wood equivalent).

Within its tested range, the methodology generally gives reliable predictions for most enclosures and fire load situations.

APPENDIX 2 Application of BCA Access and Egress Requirements to a Building

Introduction

This Appendix illustrates the application of the BCA access and egress requirements to a two-tier sports stand.

Cross-sections through the stand and plan views at various levels are shown by the attached drawings. It will be noted that *fire-isolated exits* are highlighted in yellow and *open space* in blue at each level. The distance travelled by occupants from the extreme position on the seating tiers to an *exit* is traced with a red dotted arrow. The *exits* at each level are indicated on these drawings.

In the BCA, the following definitions apply:

> *Open Spectator Stand* means a tiered stand substantially open at the front.
>
> *Exit* means -
>
> (a) Any, or any combination, of the following if they provide egress to a road or *open space*:
>
> (i) An internal or external stairway
>
> (ii) A ramp
>
> (iii) A *fire-isolated passageway*
>
> *(iv)* A doorway opening to a road *or open space*
>
> (b) A *horizontal exit* or a *fire-isolated passageway* leading to a *horizontal exit*.
>
> *Horizontal Exit* means a *required* doorway between two parts of a building separated from each other by a *fire wall*.
>
> *Open Space* means a space on the allotment, or a roof or similar part of a building adequately protected from fire, open to the sky and connected directly with a public road.

No. of paths of travels and no. of exits

BCA cl D1.2 states:

(f) **Exits in open spectator stands** - In an *open spectator stand* containing more than one tier of seating, every tier must have not less than 2 stairways or ramps, each forming part of the path of travel to not less than 2 *exits*.

Example: It will be noted from the drawings that the upper seating tier (see Plan—Level 4) has many stairs leading to a concourse that is completely open at the rear and which allows direct movement to two sets of open stairs to the road and two *fire-isolated stairways*. In the case of the lower tier of seating (Plan -Level 3) there are again many stairs down to the lower concourse which then provides (see dotted blue line on Plan—Level 2) many paths of travel to external stairs or *open space*.

Do the exits need to be fire-isolated?

BCA cl D1.3 states:

(b) Class 5 to 9 buildings—Every *required exit* must be fire-isolated unless-

(ii) it is part of an *open spectator stand*

Example: As will be noted from Plan—Levels 2-4, some *fire-isolated exits* have been provided in this building. As the building is an *open spectator stand* none of the *exits* are required to be fire-isolated. However, as will be found later, the total distances of travel to an *open space* or roadway via non *fire-isolated exits* exceeds the limits given in the BCA at several points in the building. Thus *fire-isolated exits* were incorporated.

Exit travel distances

BCA cl D1.4 states:

(e) *Open spectator stands*—The distance of travel to an *exit* in a Class 9b building used as an *open spectator stand* must be not be more than 60 m.

Example:

Lower seating tier

The maximum distance of travel from the farthest point on the lower seating tier to a path of travel = 28 m (see Plan—Levels 2, 3). The maximum distance along a path of travel to an exit = 31 m.

Therefore maximum distance of travel to an *exit* = 59 m which is < 60 m.

Corporate suites

Note that Level 3 (ie. corporate facilities) comprises two fire compartments, with the gross floor area of the larger compartment being less than 2000 m^2 in order to meet the smoke hazard management requirements of the BCA, Table E2.2b.

The maximum distance of travel from the farthest point on Level 3 to an *exit* from the building is calculated as:

> the maximum distance of travel from the farthest point on Level 3 (playing field side of corporate suites) to a path of travel = 10 m (see Plan—Level 2); plus
>
> distance along path of travel (ie. corridor and foyer) to *exit* = 32 m. Therefore, the maximum distance of travel to an *exit* = 42 m which is < 60 m.

Therefore, the maximum distance of travel to an *exit* = 42 m which is < 60 m.

Upper seating tier

Note that the Level 4 concourse is completely open on the road side, has openings (vomitories) on the playing field side, and is substantially open to the sky. It is also directly connected to the road. The concourse may be regarded as *open space*. Open stairways provide a direct link between the *open space* and the road.

The maximum distance of travel from the most extreme point on the upper seating tier to an *exit* from this tier is (see Plan—Level 4):

distance from the back of upper seating tier to the start of the stairs (or vomitory) = 18 m < 60 m

Travel by an exit

BCA cl D1.9 states:

(a) A non *fire-isolated stairway* or non *fire-isolated ramp* serving as a *required exit* must provide a continuous means of travel by its own flights of stairs and landings from every *storey* served to the level at which egress to a road or *open space* is provided.

(c) In a Class 5 to 9 building, the distance from any point on a floor to a point of egress to a road or *open space* by way of a *required* non *fire-isolated stairway* or non *fire-isolated ramp* must not exceed 80 m.

(e) In a Class 5 to 8 or 9b building, a *required* non *fire-isolated stairway* or non *fire-isolated ramp* must discharge at a point not more than-
- (i) 20 m from a doorway providing egress to a road or *open space* or from a *fire-isolated passageway* leading to a road or *open space*; or
- (ii) 40 m from one of 2 such doorways or passageways if travel to each of them from the non *fire-isolated stairway* or non *fire-isolated ramp* is in opposite or approximately opposite directions.

Example:

In accordance with BCA cl D1.8 an external stairway has been incorporated at the end of the building.

The maximum distance of travel to the start of these stairs is 38 m (see Plan—Level 3), and the distance of travel down the stairs (ie. to the point of egress to open space) is 7 m. The total distance of travel is 45 m < 80 m.

Discharge from exits

BCA cl D1.10 states:

(a) An *exit* must not be blocked at the point of discharge and where necessary, suitable barriers must be provided to prevent vehicles from blocking the *exit*, or access to it.

(b) If a *required exit* leads to an *open space*, the path of travel to the road must have an unobstructed width throughout of not less than-
- (i) the minimum width of the *required exit*; or
- (ii) 1 m

whichever is the greater.

(c) If an *exit* discharges to *open space* that is at a different level than the public road to which it is connected, the path of travel to the road must be by-
- (i) a ramp or other incline having a gradient not steeper than 1:8 at any part, or not steeper than 1:14 if *required* by the deemed-to-satisfy provisions of Part D3; or
- (ii) except if the *exit* is from a Class 9a building, a stairway complying with the deemed-to-satisfy provisions of the BCA.

(d) The discharge point of alternative *exits* must be located as far apart as practical.

(e) In a Class 9b building which is an *open spectator stand* that accommodates more than 500 persons, a *required* stairway or *required* ramp must not discharge to the ground in front of the stand.

Example: *Exits* from the building are clear of obstructions and are each greater than 1 m in width. They are also well distributed and provide egress to the road or *open space*.

Exit dimensions

BCA cl D1.6 states:

In a *required exit* or path of travel to an *exit*-

(a) the unobstructed height throughout must not be less than 2 m; except the unobstructed height of any doorway may be reduced to not less than 1980 mm; and

(b) if the *storey* or *mezzanine* accommodates not more than 100 persons, the unobstructed width except for doorways must not be less than-
- (i) 1 m; or
- (ii) ……….

(c) if the *storey* or *mezzanine* accommodates more than 100 persons but not more than 200 persons, the aggregate width, except for doorways must not be less than-
- (i) 1 m plus 250 mm for each 25 persons (or part) in excess of 100; or
- (ii) ……….

(d) If the *storey* or *mezzanine* accommodates more than 200 people, the aggregate width, except for doorways, must be increased to-D1.6
   (i) 2 m plus 500 mm for every 60 persons (or part) in excess of 200 persons if egress involves a change in floor level by a stairway or ramp with a gradient steeper than 1 in 12; or
   (ii) in any other case, 2 m plus 500 mm for every 75 persons (or part) in excess of 200; and

(e) in an *open spectator stand* which accommodates more than 2000 persons, the aggregate width, except for doorways, must be increased to 17 m plus a width (in metres) equal to the number in excess of 2000 divided by 600; and

(f) the width of a doorway must not be less than-

(iii) the width of each *exit* provided to comply with (b), (c), (d) minus 250 mm.

Example: The upper seating tier holds 5500 persons. The lower seating tier holds 4000 persons including 400 in corporate (open) boxes. The Level 3 corporate suites, media rooms, members dining room, function room and staff facilities hold an additional 840 persons. No allowance is made for concourses or passageways (see cl D1.13(a))

Lower seating tier

Aggregate width of *exit*s or path of travel to *exits* associated with travel from lower seating tier and corporate boxes to road or *open space*:

4000 persons ∴ aggregate width required is 17+ (4000-2000)÷600 = 20.3 m (see D1.6(e))

Ten *exits* approximately evenly spaced provide an aggregate width of 28 m (>20.3 m)

Also has more than one *exit* (see D1.2(f)).

Corporate facilities

Aggregate width of *exit*s or path of travel to *exits* associated with travel from Level 3 to road or *open space*:

840 persons ∴ aggregate width required is (840-200)÷75 = 8.5 ⇒ 9 ∴ 2+9×0.5 = 6.5 m (see D1.6(d)(ii))

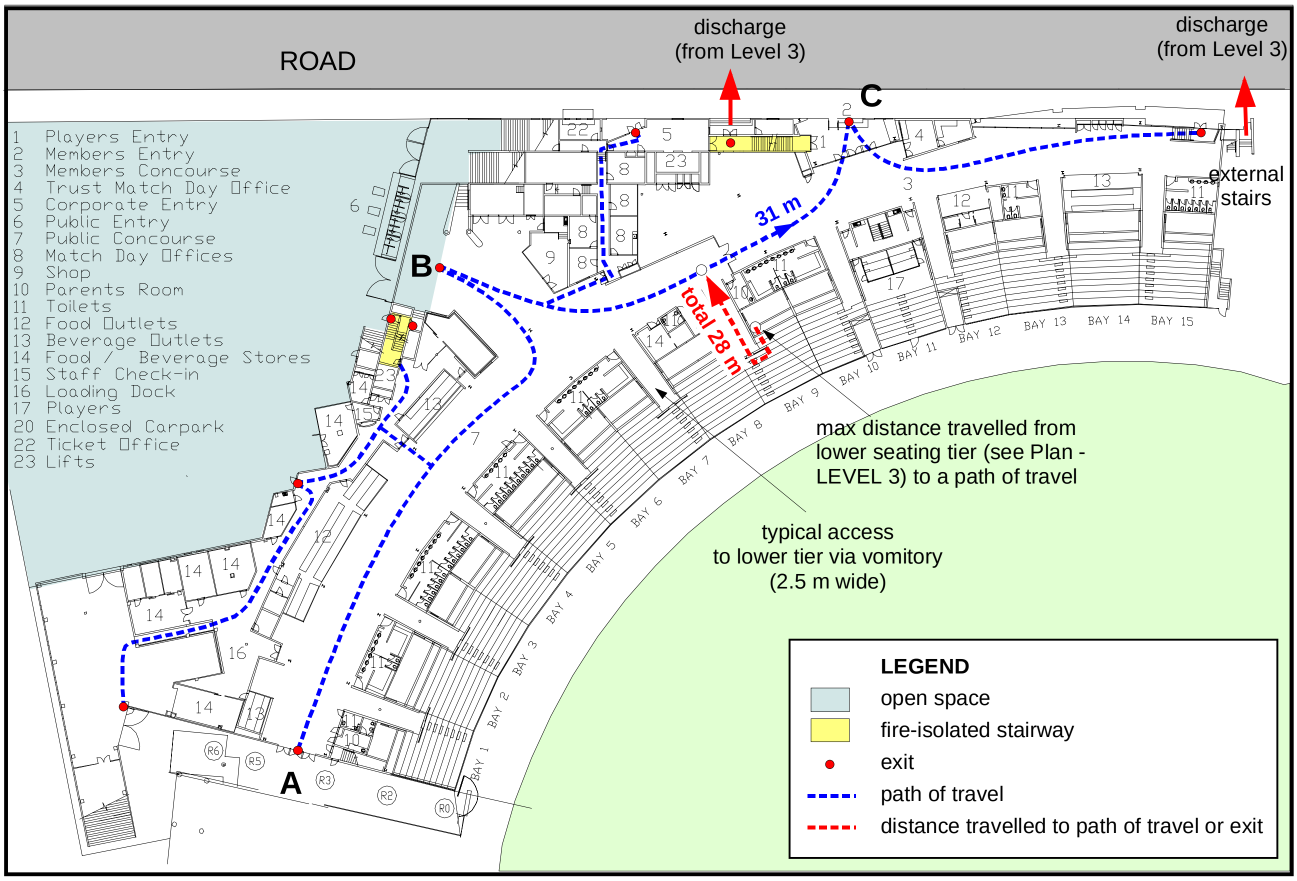
Nine *exits* at an aggregate width of 11 m are provided (>6.5 m). More than one *exit* is provided (see D1.2(f)).

Upper seating tier

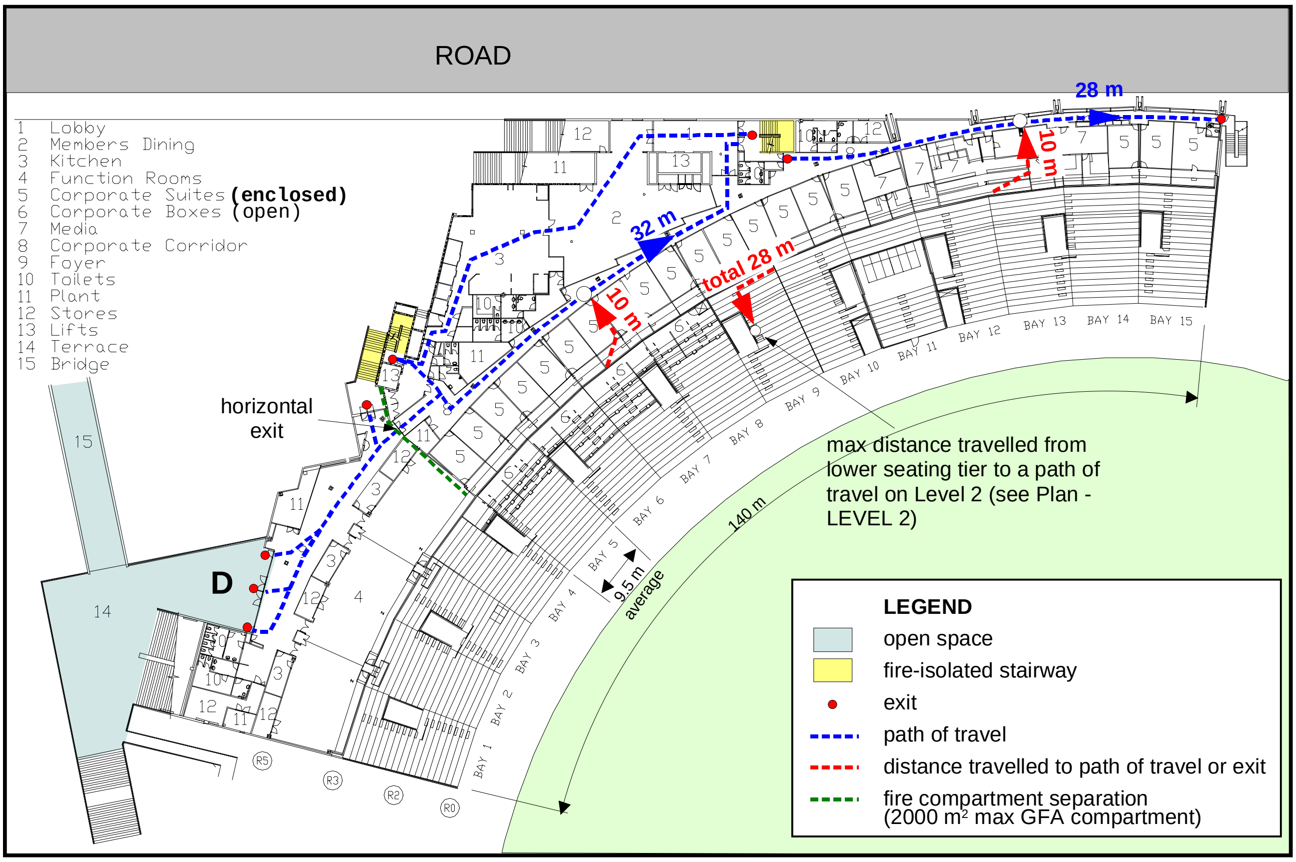
Aggregate width of *exit*s or path of travel to *exits* associated with travel from upper seating tier to *open space* (Level 4 concourse):

5500 persons ∴ aggregate width 17+(5500-2000)÷600 = 22.8 m (see D1.6(e))

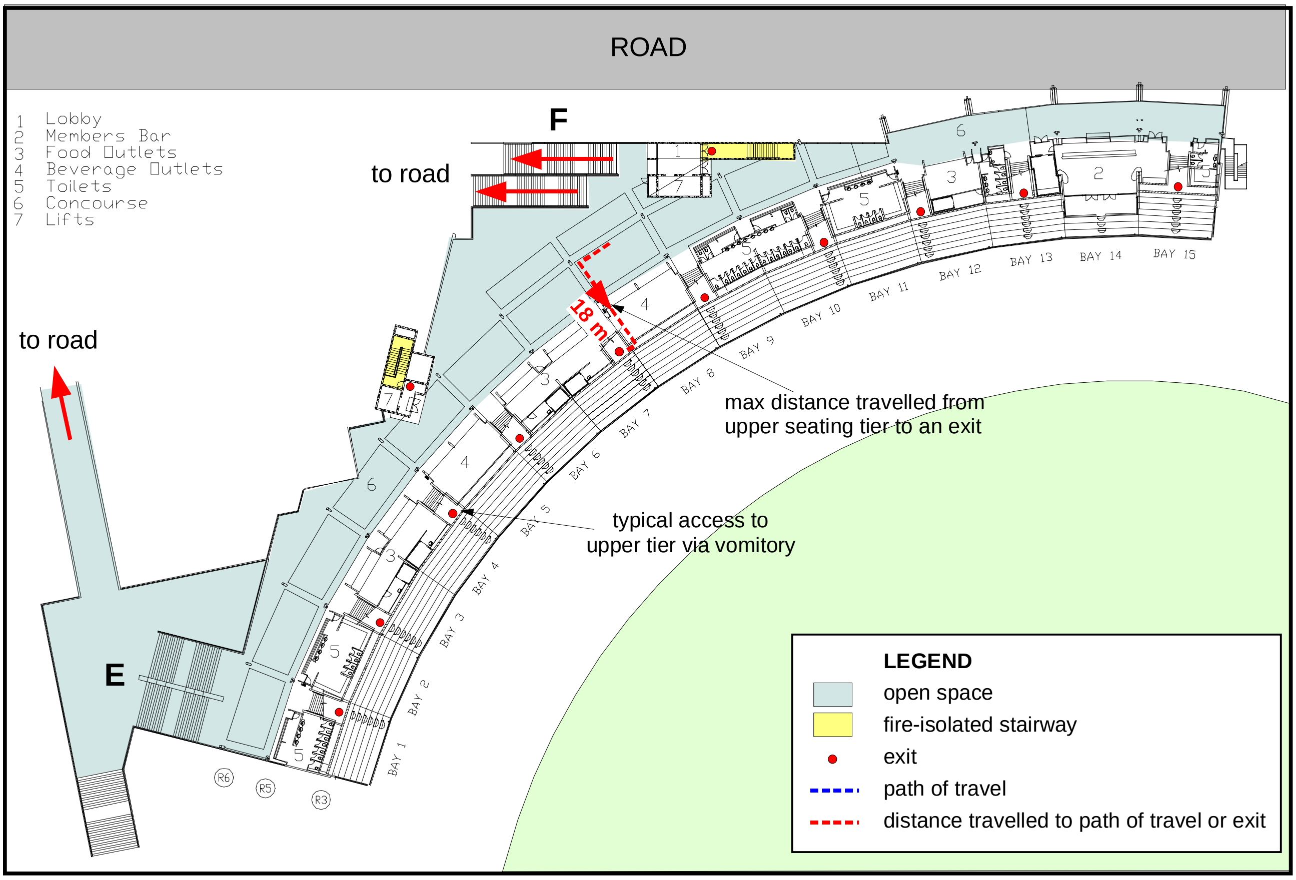
Ten *exits* approximately evenly spaced at 2.5 m width = 25 m (>22.8 m). More than one *exit* is provided (see D1.2(f)).



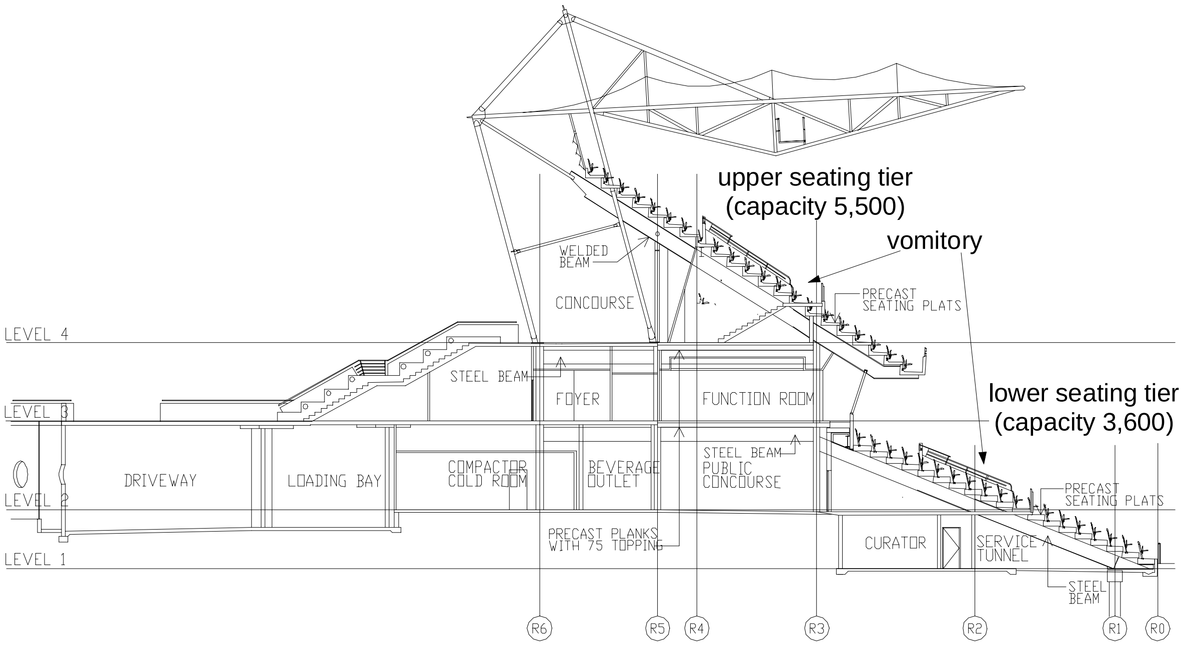
PLAN—LEVEL 2



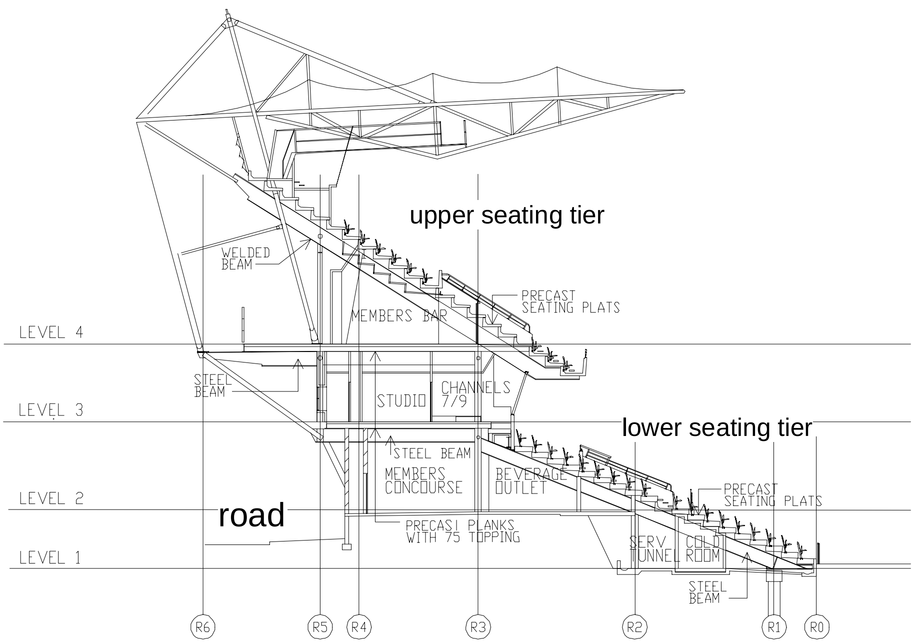
PLAN—LEVEL 3



PLAN—LEVEL 4



SECTION—BAY 1

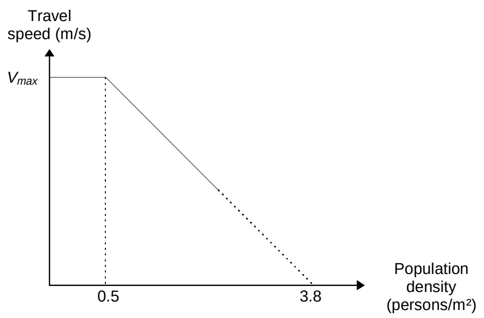


SECTION—BAY 14

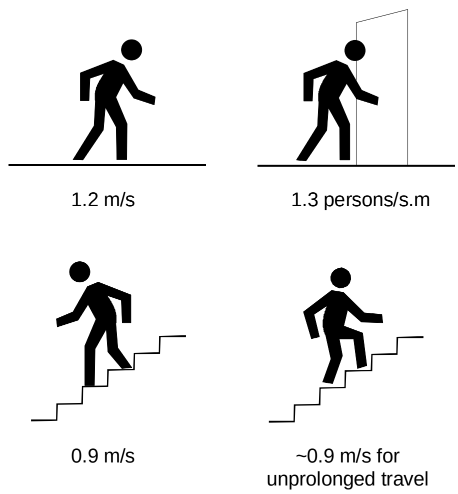
Introduction

There are a number of means by which the evacuation times for a building may be calculated. For buildings with relatively simple layouts, simple hand calculations based on initial travel distances and flow through openings would suffice. This method is adequate provided the occupant flow rate is uninterrupted and the direction of travel is straightforward.

As the layout increases in complexity, merging of flows or decisions on the choice of egress paths may affect the continuity of flow. When the flow rate varies, the density of occupant flow fluctuates and affects the travel speed. Because the variation of travel speed with occupant density is non-linear, the effects of congestion and queuing on the overall flow become harder to determine. In fact, queuing approaches a stochastic process in that its occurrence and duration is probabilistic and varies with time.



Hand calculations which demonstrate the effects of variation of occupant flow on travel speed can be found in [27]. Despite the fact that the example considered is a nine-storey building with simplified floor layout and flow assumptions, the calculations are tedious. In situations where occupant flow is uninterrupted and is only affected by the rate of flow through the final point of egress, the calculations are significantly simplified by assuming constant travel speed and flow rates [9],[28].



Constant free-flow rate assumptions

Computer calculations for evacuation have evolved to facilitate the calculation of evacuation times in building situations where the flows and paths are complex. There are many such models. These range from simple travel-time models [28] to network models [29] and more recently those which allow a detailed representation of human decision making [30-33].

Simplified calculations (as per hand calculations) can provide quick estimates of the time for a group of people to evacuate a given space. These models assume free flow to the points of egress from the space and are therefore not suitable for spaces where movement to these points of egress may be impeded by crowdedness or obstacles in the flow.

Evacnet+ [29] is a networking optimisation model which produces the minimum evacuation time for the building being analysed. It associates a travel speed between nodes and an average flow volume which corresponds to a specified "level of service"[6] which does not vary with population density or time. Occupants are assumed to always take the shortest route possible. It is representative of the "hydraulic model" which is based on the following assumptions [27]:

- All persons start to evacuate at the same time
- Occupant flow is unaffected by decisions of the individuals involved
- Persons evacuating will move at the assumed speed of the group. That is, it is not possible to take account of the movement characteristics of individuals

EvacSim [30] is a discrete-event simulation model for building evacuation which has been developed to accommodate the complex behavioural activities of occupants during the evacuation process in a fire. It models the travel speed of occupants as a function of occupant density and includes various decision-making attributes on the choice of egress path. The choice of egress path is a function of a number of factors including queue length, distance to point of egress, familiarity with egress paths and environmental conditions (eg. smoke levels). It also allows for the impact of a warden system for controlling the evacuation of the building in accordance with a prescribed evacuation management plan.

This appendix further considers the use and limitations of simplified calculations. The movement times associated with the evacuation of various parts of the building described in Appendix 2 are analysed using EvacSim.

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[6] The level of service may be interpreted as the maximum flow rate through a node per unit effective width.

Although one of the main features of EvacSim is the ability to model the dynamic interaction of occupants with the social and physical environments during evacuation, this is not undertaken in the following example. Instead, only the inherent occupant movement features are utilised. These are the dynamic travel speed, based on occupant density, and the exit choice behaviour as described previously less the environmental factors.

Worked Example

In the case of the sports stand building presented in Appendix 2, the egress routes for the upper and lower seating tiers and Level 3 are all independent.

The egress routes for each part of the building are assumed to be those with which the occupants are likely to be familiar. These do not include the *fire-isolated stairway* or external stairs, and are as follows:

Lower seating tier

All occupants in the lower seating tier are assumed to evacuate via Level 2 (see Plan-Level 2) as follows:

The public uses the doors at the end of the concourse (3×1.6 m) (location A) and the main entrance (1×5 m) (location B). Members will only use the doors at location C (3×1.6 m).

Corporate facilities (Level 3)

All occupants in Level 3 (see Plan-Level 3) are assumed to evacuate as follows:

Members and staff evacuate via the foyer through two double doors (2×1.6 m) and two single doors (2×0.8 m) at location D. Note that the main access into Level 3 is by lifts.

Upper seating tier

All occupants in the upper seating tier exit are assumed to evacuate via the Level 4 concourse (see Plan-Level 4) to the stairs (2×6 m) at location E and at location F (2×4 m).

For both the lower and upper seating tiers, ten vomitories, each measuring 2.5 m wide, connect the seating areas to the concourses.

The following populations are assumed for the purpose of calculation:

Lower seating tier	= 4000	(during game)
Level 3	= 220	(during game)
	= 840	(pre-game)
Upper seating tier	= 5500	(during game)

The pre-game population for Level 3 includes occupants in the corporate suites (220), dining room (210), function rooms (330) plus about 10 percent allowance for kitchen/service staff and media. The population in Level 3 is less during the game because the occupants of the function room and dining room are assumed to move to the seating areas.

Simplified Calculations

As mentioned above, simplified calculations are suitable for occupant flows which are uninterrupted and impeded only at points of egress. This will be the case when small numbers of people are to be evacuated from a fire-affected area—as will often be the case with managed or staged evacuation. However, such calculations may be questionable when considering the evacuation of large numbers of people such as the whole building or an entire seating tier.

In the case of the evacuation of the seating tiers, the total movement time is a function of the time of travel to the points of egress and the level of queuing. The time for movement of the occupants to the points of egress is relatively difficult to determine as several movements are involved—horizontal, stepping up and stepping down—and these are different depending on the position of the occupants within the seating tier. Such calculations are best done using a computer program such as EvacSim.

The total movement time associated with the evacuation of the occupants of the corporate suites during a game is now considered. For the purpose of this example, it is assumed that a significant fire develops within the corporate suite directly adjacent to the fire compartment wall. This means that the *horizontal exit* through this wall cannot be used and that evacuation must be via the *fire-isolated stairway* and the external stairs. It is assumed that the occupants will be distributed equally between these points of egress.

As the external stairs have the narrowest width, this point of egress will govern the total movement time. The effective width[7] of the external stair can be taken as 1 m and the maximum distance that must be travelled to the stair as 50 m. Using a maximum specific flow of 1.3 persons/s·m, the time to pass through the external stair is 220÷2÷(1.0×1.3) = 85 s. The travel time to the stairs can be taken as 50÷1.2 = 42 s. If these times are added (this overestimates the total movement time) then the total time for the occupants to move to safety can be taken as being between two, and two and one-half minutes. This is not the evacuation time as that must include some allowance for pre-movement activities. In this case it is suggested that the pre-movement time will be low—probably no more than 2 minutes after it has been recognised that the fire within the suite cannot be extinguished by the occupants.

7 The effective width is the nominal width of the opening less the width occupied by hardware such as handrails or that due to the partial obstruction from doors.

EvacSim Calculations

EvacSim has been used to model the sports stand by defining the layout of the building as closely as possible to the layouts shown in Appendix 2. Nodes are used to define the outline of each space and walls are specified as links between nominated nodes. Openings are defined within the walls and connectivity between the spaces is worked out internally by the program. Movement of the occupants is continuously calculated as a function of occupant density within each space. It has been assumed, for this example, that all occupants within the seating tiers and Level 3 must be evacuated.

Results of the simulations are shown in the figures below. For the purpose of these calculations it has been assumed that the fire is located such that the preferred egress paths (ie. those used most commonly used by occupants within the building) are used for evacuation rather than the *fire-isolated stairways* or external stairs.

The egress routes for the seating tiers and Level 3 are independent of one another. The following graphs plot the population (ie. number of people remaining) within these areas of the building after evacuation has commenced.

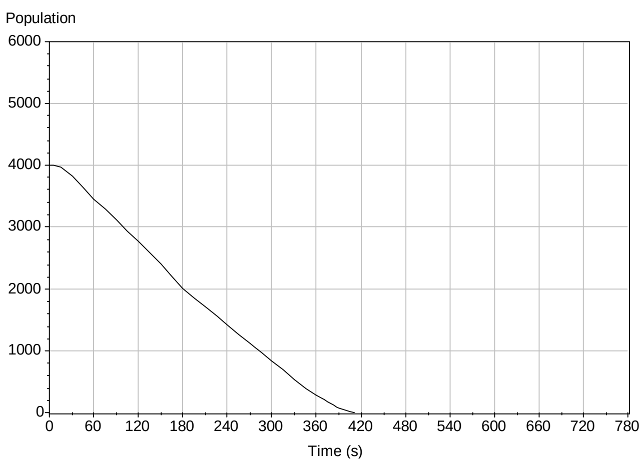
The total movement times are summarised as follows:

Lower seating tier:	411 s (6.9 mins)
Level 3:	660 s (11 mins)
Upper seating tier:	735 s (12.2 mins)

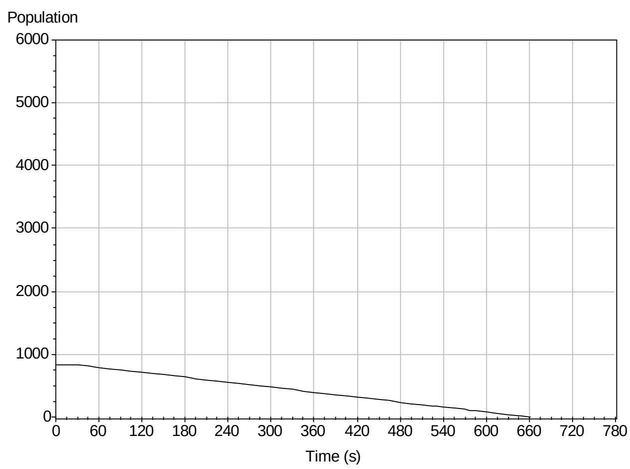
In the case of Level 3 it has been assumed that all occupants evacuate via the *horizontal exit* and then through the 2×1.6 m and 2×0.8 m doors beyond the fire wall. No account has been taken of the *fire-isolated stairway* or external stair at this level. This assumption results in the total movement time associated with Level 3 being significantly longer than for the two seating tiers.

It takes 494 s (8.2 mins) to clear the upper seating tier to the Level 4 concourse and a further 241 s (4.0 mins) to clear the concourse via the stairs from the concourse to the road.

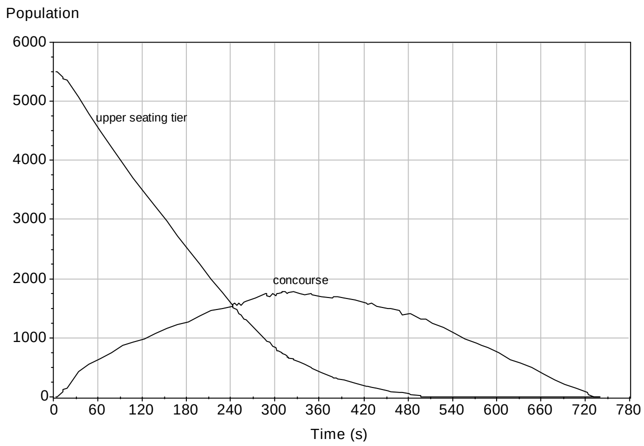
The above calculations determine the total movement times associated with the evacuation of various parts of this sports stand. They take no account of pre-movement activities and the associated times must be added. However, these are expected to be short.



Lower Seating Tier Population



Corporate Facilities (Level 3) Population

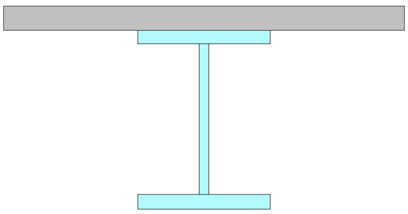


Upper Seating Tier Population

APPENDIX 4 Exposed Surface Area to Mass Ratio of Steel Sections—k_{sm} (m^2/tonne)

Beams

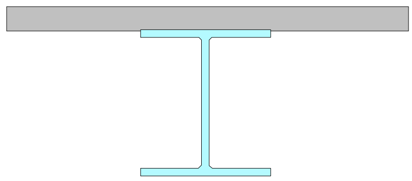
welded-plate sections



section	k_{sm}
1200WB455	8.51
423	9.10
392	9.79
342	10.4
317	11.1
278	12.1
249	12.6
1000WB322	10.0
296	10.8
258	11.8
215	13.4
900WB282	10.7
257	11.7
218	13.0
175	15.3
800WB192	13.1
168	14.5
146	16.5
122	18.9
700WB173	13.0
150	14.3
130	16.3
115	18.4

section	k_{sm}
500WC440	5.41
414	5.78
383	6.21
340	7.30
290	8.51
267	9.22
228	10.7
400WC361	5.48
328	6.11
303	6.56
270	7.34
212	9.25
181	10.7
144	13.4
350WC280	6.08
258	6.54
230	7.30
197	8.49

hot-rolled sections

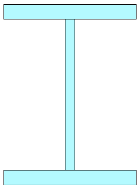


section	k_{sm}
610UB125	14.9
113	16.3
101	18.1
530UB 92.4	17.8
82.0	19.9
460UB 82.1	17.7
74.6	19.4
67.1	21.4
410UB 59.7	21.9
53.7	24.1
360UB 56.7	21.1
50.7	23.4
44.7	26.3
310UB 46.2	23.2
40.4	26.2
250UB 37.3	24.7
31.4	29.0
200UB 29.8	26.3
180UB 22.2	27.1
150UB 18.0	28.3

section	k_{sm}
310UC158	9.66
137	11.0
118	12.7
97	15.3
250UC 89.5	13.9
72.9	16.8
200UC 59.5	16.8
52.2	18.9
46.2	21.2
150UC 37.2	20.3
30.0	24.6

Columns

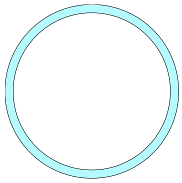
welded-plate sections

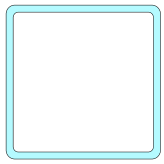


section	k_{sm}
1200WB455	9.61
423	10.3
392	11.1
342	11.5
317	12.4
278	13.3
249	13.7
1000WB322	11.2
296	12.1
258	13.1
215	14.8
900WB282	12.1
257	13.3
218	14.6
175	17.0
800WB192	14.7
168	16.1
146	18.4
122	20.9
700WB173	14.5
150	16.0
130	18.3
115	20.6

section	k_{sm}
500WC440	6.55
414	6.99
383	7.52
340	8.77
290	10.2
267	11.1
228	12.9
400WC361	6.59
328	7.33
303	7.88
270	8.82
212	11.1
181	13.0
144	16.1
350WC280	7.33
258	7.89
230	8.82
197	10.3

hollow sections

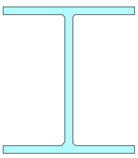




section	k_{sm}
457.0×12.7CHS	10.3
9.5CHS	13.7
6.4CHS	20.2
406.4×12.7CHS	10.4
9.5CHS	13.7
6.4CHS	20.2
355.6×12.7CHS	10.4
9.5CHS	13.8
6.4CHS	20.3
323.9×12.7CHS	10.4
9.5CHS	13.8
6.4CHS	20.3
273.1×9.3CHS	14.2
6.4CHS	20.4
4.8CHS	27.0
219.1×8.2CHS	16.1
6.4CHS	20.5
4.8CHS	27.1
168.3×7.1CHS	18.7
6.4CHS	20.7
4.8CHS	27.3
114.3×6CHS	22.4
4.8CHS	27.7
88.9×5.5CHS	24.7
4.8CHS	28.1

section	k_{sm}
250×250×9.0SHS	14.6
6.0SHS	21.7
200×200×9.0SHS	14.7
6.0SHS	21.8
5.0SHS	26.0
150×150×9.0SHS	14.9
6.0SHS	22.0
5.0SHS	26.2
125×125×9.0SHS	15.1
6.0SHS	22.1
5.0SHS	26.3
100×100×9.0SHS	15.4
6.0SHS	22.4
5.0SHS	26.6
89×89×6.0SHS	22.5
5.0SHS	26.7
75×75×6.0SHS	22.8
5.0SHS	27.0

hot-rolled sections



section	k_{sm}
610UB125	16.7
113	18.3
101	20.3
530UB 92.4	20.0
82.0	22.4
460UB 82.1	20.0
74.6	21.9
67.1	24.2
410UB 659.7	24.8
53.7	27.4
360UB 56.7	24.1
50.7	26.8
310UB 46.2	26.8
250UB 37.3	28.6

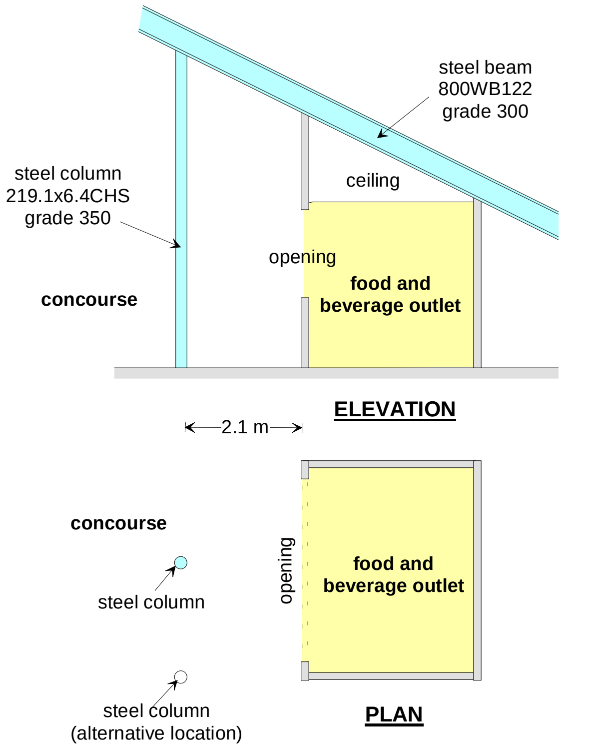
section	k_{sm}
310UC158	11.6
137	13.3
118	15.3
96.8	18.4
250UC 89.5	16.8
72.9	20.3
200UC 59.5	20.2
52.2	22.8
46.2	25.6
150UC 37.2	24.4
30.0	29.7

APPENDIX 5 Checking of Steel Members for Fire Adequacy

The purpose of this appendix is to illustrate the procedure for the checking (and selection) of structural steel members using the *Deemed-to-Satisfy Solutions for Fire Spread and Management*.

Two cases are considered, for both sprinklered and non-sprinklered options.

Case 1—Food and Beverage Outlet



Steel Beam within Enclosure

(see Table A, page 17)

From Appendix 4, k_{sm} of the steel beam (800WB122) = 18.9 m^2/tonne.

Option 1: No sprinklers within enclosure

Maximum acceptable k_{sm} = 30 m^2/tonne (require a 10 min ceiling system)

k_{sm} of the steel beam = 18.9 < 30 ∴ OK

Option 2: With sprinklers within enclosure

Maximum acceptable k_{sm} = 30 m^2/tonne (no ceiling required)

k_{sm} of the steel beam = 18.9 < 30 ∴ OK

Steel Column outside Enclosure

(see Table B, page 17)

From Appendix 4, k_{sm} of the steel column (219.1x6.4CHS) = 20.5 m^2/tonne.

Option 1: No sprinklers within enclosure

Column located at > 2.0 m ∴ maximum acceptable k_{sm} = 30 m^2/tonne

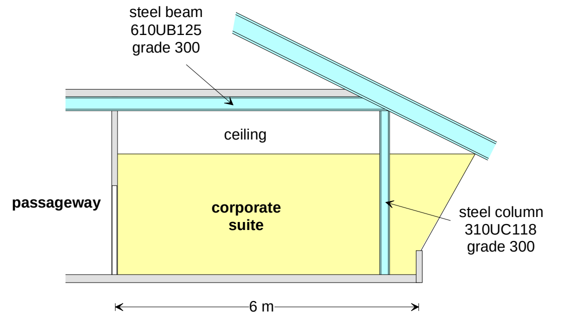
k_{sm} of the steel column =20.5 < 30 ∴ OK

In some situations, the column may be located at the edge of the opening (see "alternative location" in the above figure. In this case, the column will not get as hot and a greater k_{sm} may be permitted. The use of a greater k_{sm} value will need to be justified by fire-engineering calculations.

Option 2: With sprinklers within enclosure

No limit is set for the maximum k_{sm} (ie. any size steel column will suffice for fire adequacy purpose).

Case 2—Corporate Suite



Steel Beam within Enclosure

(see Table A, page 17)

From Appendix 4, k_{sm} of the steel beam (610UB125) = 14.9 m^2/tonne.

Option 1: No sprinklers within enclosure

Depth of enclosure < 7.5 m, ∴ maximum acceptable k_{sm} = 30 m^2/tonne (require a 10 min ceiling system).

k_{sm} of steel beam = 14.9 < 30 ∴ OK

Option 2: With sprinklers within enclosure

Maximum acceptable k_{sm} = 30 m^2/tonne (no ceiling required)

k_{sm} of the steel beam = 14.9 < 30 ∴ OK

Steel Column within Enclosure

(see Table A, page 17)

From Appendix 4, k_{sm} of the steel column (310UC118) = 15.3 m^2/tonne.

Option 1: No sprinklers within enclosure

Depth of enclosure < 7.5 m, ∴ maximum acceptable k_{sm} = 26 m^2/tonne (require a 10 min ceiling system and protection of column by cladding it with 16 mm plasterboard, penetrating ceiling).

k_{sm} of steel column = 15.3 < 26 ∴ OK

Option 2: With sprinklers within enclosure

Maximum acceptable k_{sm} = 26 m^2/tonne (no ceiling and no protection of column are required)

k_{sm} of the steel column = 15.3 < 26 ∴ OK