BUILDING CODE OF AUSTRALIA IN ACTION

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ECOLIBRIUM™ BRINGS YOU A CASE STUDY ON THE APPLICATION OF A PERFORMANCE-BASED BCA SOLUTION USING FIRE ENGINEERING METHODOLOGY.

ABSTRACT

The following case study details a performance-based assessment undertaken for an existing Cinema Complex in Mandurah, Western Australia.

Seating space for people with disabilities within the actual cinema was proposed to be in the middle level of seating of a typical stadium type cinema. Access to these spaces was via a wheelchair stair lift traveling up one of the two main access/egress aisles.

Use of the wheelchair stair lift in an evacuation situation would constitute firstly the blocking of one of the main aisles and secondly its use as an egress facility for people with disabilities.

A performance based assessment using fire engineering methodology was undertaken to ensure the life safety in the cinemas still complied with the BCA mandatory Performance Requirements.

The final outcome indicated that a system of smoke detection and mechanical smoke exhaust combined with enhanced egress facilities enabled safe evacuation for all occupants.

Scope of the Case Study

The reason why this case study was chosen was to demonstrate how mechanical systems could be employed in a performance based design. In this case, the subject building did not require any form of mechanical smoke exhaust system with the exception of the shut down of the normal HVAC system upon detection of fire.

An issue totally unrelated to mechanical systems arose that required the life and fire safety provisions for people with disabilities to be assessed. As part of the design and assessment, mechanical systems were employed as part of the overall fire safety systems of the building to ensure all occupants including people with disabilities evacuated safety in the event of a fire.

The following case study is an extract from an actual 60 page report. The report involved many complex calculations and spreadsheet analysis. Whilst some basic formulas have been included in this case study, the majority have not been, due to space limitations.

Instead, this case study is intended to provide an overview of the methodology involved in the assessment of an Alternative Solution to the mandatory Performance Requirements of the BCA using fire engineering methodology.

1.0 Description of the Building

The Mandurah Boardwalk Cinema Complex is a free standing building located on a site adjacent to the Performing Arts Centre. The building consists of three levels:

- Six ground floor cinemas and associated foyer, toilet, office, back of house and food and drink sales areas.
- First floor projection room.
- Second floor plant room.

Mandurah Boardwalk Cinema Complex

The building has a floor area of approximately 1700m2 on the ground floor, with a rise in storeys of 2 and is required to be Type B Construction.

Cinema 2, 4 and 6 located on the north side of the building are mirrored on the south side by cinemas 1, 3 and 5. As such, this assessment is to cinemas 2, 4 and 6, which is reflective of all cinema types.

The building is constructed of precast concrete panels and due to the acoustic requirements of a typical cinema; the walls would achieve a minimum fire rating between cinemas of greater than 2 hours. The doors between the cinema and the foyer area are 1 hour fire doors.

The building is fitted with the following fire safety systems compliant with the BCA:

- Emergency lighting and exit signs.
- Portable fire extinguishers and fire hose reels.
- External fire hydrant protection.

Mandurah Boardwalk Cinema - Seating Area

- Smoke detection system in accordance with AS 1670.
- The HVAC system has an automatic shut off system upon activation of the smoke detection system.
- Fire compartmentation of all cinemas.

Each cinema auditorium has stadium type seating. Access to and egress from this seating is via two stepped aisles located at each side of the auditorium.

There are two exits available per cinema. One exit route is via a path of travel through the main foyer area, whilst the other exit is a door directly from the cinema to the outside.

2.0 Building Code of Australia Requirements

2.1 Deemed-to-Satisfy Provisions

The installation of the wheelchair stair lift does affect the compliance of the cinema to the Deemed-to-Satisfy Provisions of the BCA pursuant to Clause D1.6.

Auditoriums 2, 4 and 6 have the following seating numbers and aisle widths outlined below. Included is the BCA Deemed-to-Satisfy required aisle width. (Table 1)

Table 1: Seating capacity and aisle width

Auditorium	Seating Capacity	Required BCA aisle width	Actual current aisle width
Auditorium 2	256	2.5m	2.75m
Auditorium 4	214	2.5m	2.6m
Auditorium 6	141	1.5m	2.6m

The total width of the wheelchair stair lift is 1020mm. The installation of the wheelchair stair lift will effectively close off one aisle in a worst case scenario (fire in a cinema and disabled person using the wheelchair stair lift for egress). This will effectively reduce the available aisle width as shown in Table 2.

Table 2: Available aisle width in the event of a fire in the auditorium

Auditorium	Seating Capacity	Required BCA aisle width	Actual current aisle width
Auditorium 2	256	2.5m	1.375m
Auditorium 4	214	2.5m	1.3m
Auditorium 6	141	1.5m	1.3m

There are currently no BCA deemed-to-satisfy requirements for egress facilities for people with disabilities.

2.2 Performance Requirements

The relevant Performance Requirement that the Alternative Solution must comply with is DP4. DP4 states that "Exits must be provided from a building to allow occupants to evacuate safely with their number, location and dimensions being appropriate to……."

3.0 Methodology

The proposed method of evaluating life safety is through a System Performance Evaluation (SPE) carried out in accordance with the process detailed in the Fire Engineering Guidelines (1). In broad terms, this involves the methodology of Available Safe Egress Time (ASET) verses a Required Safe Egress Time (RSET) calculation. This uses computer modeling as well as manual calculation methods to show that the time required for complete evacuation will be less than the time taken for any of the life safety acceptance criteria to be reached.

Note that the Fire Engineering Guidelines are now superseded by the Fire Safety Engineering Guidelines 2001. The methodology used in this case study is, however, still applicable under the new guidelines.

The report will be broken down to three distinct steps. These are:

- Fire Engineering Design Brief (FEDB).
- Fire engineering analysis.
- Concept design package.

4.0 Fire Engineering Design Brief (FEDB)

The first step in the fire engineering analysis is the FEDB. The FEDB is a systematic documentation process involving all the steps of the preliminary assessment of the building for a fire engineering analysis. The objective of the FEDB is to review the architectural and services proposals, identify potential fire hazards and define the fire safety issues in qualitative terms.

4.1 Fire Safety Objectives

The fire safety objectives that must be achieved by the proposed design are synonymous with the BCA objectives in terms of life safety. Therefore the fire safety objective is aligned with BCA Objective of DO1(b) which requires the design *"to safeguard occupants from illness or injury while evacuating in an emergency".*

In this case the definition of occupants is considered to be all occupants including at least two people with disabilities in each cinema.

4.2 Acceptance Criteria for Fire Safety Objectives

A list of acceptance criteria required to be satisfied was included in the FEDB as follows:

- Hot layer height - to be taken as a minimum height of 2.1m from the floor to the bottom of the hot layer. This was measured at the back row of the seating.
- Heat radiation - radiant heat from a hot layer or from a fire itself should not exceed 2.5kW/m^2 (equivalent to a hot layer temperature of 180°C).
- Toxicity - the maximum allowable exposure to carbon monoxide will be taken as 15,000ppm.min (parts per million per minute).
- Visibility/smoke obscuration – A visibility distance of 10m equates to a maximum optical density of 0.1m-1 (1.0dB/m).

4.3 Hazard Analysis

A hazard analysis was undertaken reviewing all areas of the building including back of house areas, projection rooms, food and drink sales, office and storage areas. Due to the fire compartmentation of the cinemas, the most hazardous fire scenario to the actual affected occupants was a fire in one of the cinemas.

4.4 Fire Scenarios

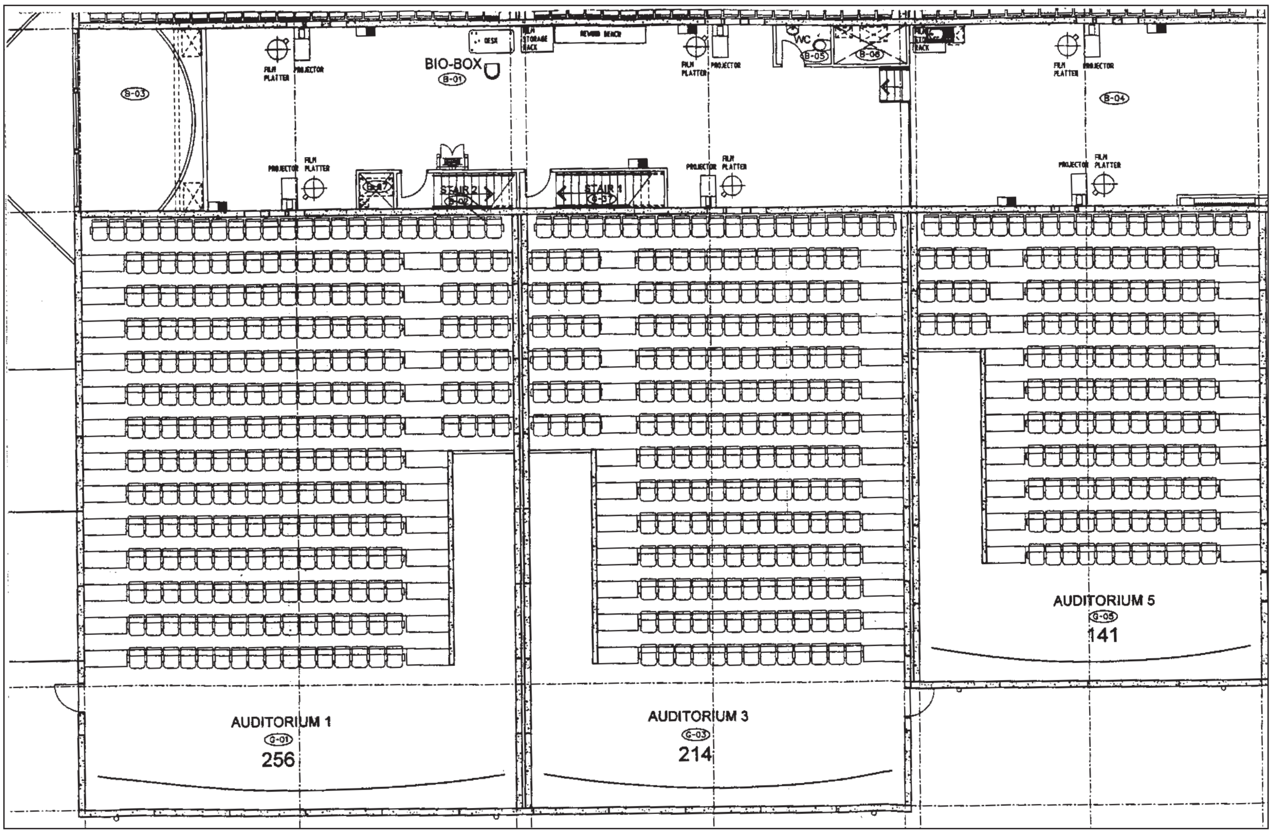
The design fire scenarios to be considered were located in Cinema 2 (largest), Cinema 4 (intermediate) and Cinema 6 (smallest).

Design fires were conservatively assumed as 'fast' as defined under the Fire Engineering Guidelines with the cinema fire sizes being related to Babrauskas' work [2] with upholstered chair burning rates.

4.5 Types of Fire

The type of fire in the cinema is determined by the fire load and ignition source. The Fire Engineering Guidelines have been used to develop the fire growth model. The typical fire scenario considered is the ignition of a single seat. For the purposes of this analysis, it was assumed that a fire on a seat will spread to other seating and possibly drapes dependant upon location.

Figure 1: Mandurah Boardwalk Cinema - Plan View



The Fire Engineering Guidelines indicate that where experimental data or statistical information is not available, a fire can be characterised by the quadratic equation of a T-squared fire of:

$$Q = \_\ t^2$$

Where:

Q is the rate of heat release rate

_ is the fire growth parameter (MW/sec2)

t is time (seconds)

As a conservative approach, a fast fire was selected as the fire type that would occur in a cinema auditorium. This has a fire growth parameter of 4.44 x 10-5 MW/sec2.

Thus the fire growth of a fast fire dependant upon time will have the following heat release rate (HRR).

Time (s)	0	30	60	90	120	150
HRR (kW)	0	40	160	360	640	1000
Time (s)	180	210	240	270	300	330
HRR (kW)	1440	1960	2557	3237	4000	4835

4.6 Fire Safety Sub-Systems

It was proposed to evaluate the existing and possibly new fire safety systems within the building to meet the fire safety objective and mandatory Performance Requirement of the BCA. This includes-

- Fire compartmentation. All cinemas are essentially separate fire compartments.
- Smoke hazard management provisions. The cinemas have an automatic shut down system compliant with the BCA. It was proposed to evaluate the fire scenarios with additional smoke exhaust system activated by the existing smoke detector system.
- Smoke detector system. Spaced to AS 1670 throughout the cinemas.
- Sprinkler system. The building does not have (and is not required to have) a sprinkler system installed. Sprinklers were reviewed as part of the analysis to determine their effectiveness and ultimately cost effectiveness.

4.7 Evacuation Times

In accordance with Chapter 12 of the Fire Engineering Guidelines Occupant Avoidance, the total time required for occupants to evacuate to a place of safety, 'Tr', is represented by the following equation:

$$Tr = t_a + t_{aw} + t_p + t_{ie} + t_{eif} + t_s$$

where:

t_a time for arousal

t_{aw} time to become aware of a fire emergency (receive fire cue)

t_p time to perceive a fire threat (realise they must leave the building)

t_{ie} time to initiate avoidance activities (coping time)

t_{eif} time to evacuate fire threatened area (time of travel)

t_s time to reach a place of safety (time of travel)

t_a and t_{aw} is determined by the activation of the smoke detection system. Time of activation of the smoke detection system is determined when the smoke layer has an optical density of 0.5 for a photo electric detector.

To achieve a quick response and arousal time, (t_p) upon activation of the smoke detection system, the movie must stop and the normal occupant lighting to the auditorium must automatically switch on.

If a life threatening fire was occurring, occupants would initiate avoidance (t_{ie}) fairly quickly. In this case t_{ie} was assumed to be 30 seconds.

t_{eif} was determined by an egress computer model "EVACNET" for able bodied persons. EVACNET is a hydraulic movement computer program that models building evacuations. The program accepts a network description of the building and information on its initial contents at the beginning of the evacuation.

Manual calculations were carried out for people with disabilities based on the same response and coping times. However additional times were allowed for embarking and disembarking onto and off the wheelchair stair lift. Travel time of the wheelchair stair lift is in accordance with the speed times indicated in the manufacturer's specifications.

t_s is considered to be any area outside the cinema auditorium.

5.0 Fire Engineering Analysis

The basis of this analysis was to determine whether all occupants could evacuate the cinema auditorium safely whilst one egress aisle was being used by a person with disabilities on a wheelchair stair lift. Initial investigations indicated that the removal of one egress aisle would dramatically affect the evacuation of the occupants prior to the onset of untenable conditions.

Preliminary investigations indicated that a form of smoke hazard management would be a more viable and appropriate option rather than a suppression system, eg. sprinklers. Refer to section 6.4.1.

5.1 ASET – Available Safe Egress Time

5.1.1 Summary of Results of ASET

The following results were calculated using a spreadsheet, using the HRR of the design fire and programming in certain quantities of smoke exhaust rates. The failure criteria of the hot smoke layer descending below 2.1m above the floor level was taken at the back row, being the worst point on the floor. (Table 3)

Table 3: Summary of available safe egress times (see 5.1.1)

Cinema	Floor Area m^2	Exhaust litres/ second	Time of smoke detector actuation seconds	Hot layer back row descends 2.1m seconds	Radiation criteria exceeds 180° C seconds
Cinema 2	277	No exhaust	NA	160	240
Cinema 2	277	7000	20	320	330
Cinema 2	277	8000	20	340	340
Cinema 2	277	10000	20	Dno	350
Cinema 4	240	No exhaust	NA	150	240
Cinema 4	240	7000	20	310	330
Cinema 4	240	8000	20	330	330
Cinema 4	240	10000	20	Dno	350
Cinema 6	174	No exhaust	NA	150	210
Cinema 6	174	3000	20	220	270
Cinema 6	174	5000	20	270	300
Cinema 6	174	7000	20	330	320

Dno – did not occur within the time frame of 330 seconds

NA – Not Applicable

5.2 RSET – Required Safe Egress Time

5.2.1 EVACNET Results

The main results from the Evacnet computer model are shown below. These times indicate only travel time. (Table 4)

Table 4: Required safe egress times - EVACNET modelling

Cinema	Total travel time to evacuate the cinema seconds	Time occupants evacuated back row seconds
Cinema 2	280	240
Cinema 4	285	250
Cinema 6	195	155

5.2.2 Evacuation times for occupants

The total time of evacuation from the cinemas for able bodied persons was: (Table 5)

Table 5: Total evacuation time from cinemas for able-bodied people

Cinema	t_a and t_{aw}	t_p	t_{ie}	t_{eif}	Tr
Cinema 2	20	0	30	280	**330**
Cinema 4	20	0	30	285	**335**
Cinema 6	20	0	30	195	**245**

The time of evacuation from the back row of the cinemas for able bodied persons was: (Table 6)

Table 6: Total evacuation time from back row for able-bodied people

Cinema	t_a and t_{aw}	t_p	t_{ie}	t_{eif}	Tr
Cinema 2	20	0	30	240	**290**
Cinema 4	20	0	30	250	**300**
Cinema 6	20	0	30	155	**205**

5.2.3 Evacuation times for people with disabilities

The same parameters t_a, t_{aw} and t_{ie} apply for able-bodied persons as they do for people with disabilities.

t_{eif} was determined by the following manual calculations. Manufacturer's specifications indicated that the Model GSL-1 has a speed of 6 metres per minute.

The two wheelchair positions were located in the sixth row of seating. This is 6m travel distance from the upper level to the front area of the cinema. The following times were estimated (in consultation with the manufacturer) for two persons with disabilities using the wheelchair stair lift for egress purposes. (Table 7)

Total travel time of two persons with disabilities using the wheelchair stair lift is 250 seconds (t_{eif}).

The total time of evacuation from the upper row 6 of the cinemas for two people with disabilities is: (Table 8)

Table 8: Total evacuation time for two people with disabilities

Cinema	t_a and t_{aw}	t_p	t_{ie}	t_{eif}	Tr
Cinema 2	20	0	30	250	**300**
Cinema 4	20	0	30	250	**300**
Cinema 6	20	0	30	250	**300**

5.3 ASET v RSET Summary of Results

From the analysis of both fire growth within the cinemas (ASET) and the evacuation times of all occupants (RSET), the following results were obtained. (Table 9)

Note that 8000 l/s exhaust for Cinema 2 and 5000 l/s for Cinema 6 would meet the fire safety objectives. However there is little margin of safety and it was recommended that 10,000 and 7000 respectively would provide an acceptable safety factor.

To permit safe evacuation of all occupants, the following minimum smoke exhaust rates were required after taking into account a margin of safety.

- Cinema 2 – 10,000 litres per second
- Cinema 4 – 10,000 litres per second
- Cinema 6 – 7,000 litres per second

Refer to Figure 2 for typical analysis for cinema 2.

5.4 Other Options Considered

Other options were reviewed to determine the most effective solution. These included:

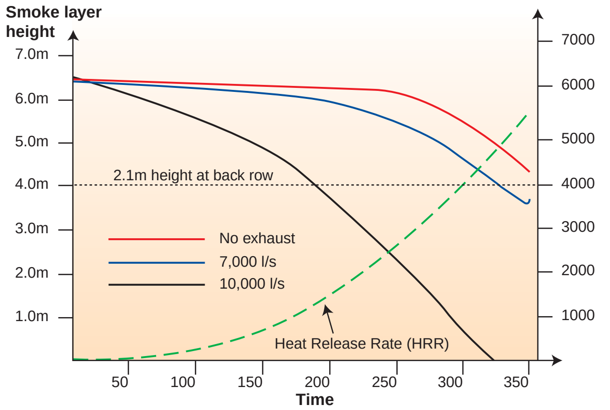
Table 7: Estimated travel times for two people with disabilities

Embark onto platform	Travel time down aisle	Disembark off platform	Travel time up aisle	Embark onto platform	Travel time down aisle	Disembark off platform	Travel to exit door
15 sec	60 sec	15 sec	60 sec	15 sec	60 sec	15 sec	10 sec

Table 9: ASET vs RSET summary of results

Cinema	Exhaust litres/sec	Hot layer in back row < 2.1m Seconds	Radiation criteria > 180°C Seconds	Occupant evacuation time Whole Cinema Seconds	Occupant evacuation time Back Row Seconds	Disabled persons evacuation time Two persons Seconds
Cinema 2	None	160	240	330	290	300
Cinema 2	7000	320	330	330	290	300
Cinema 2	8000	340	340	330	290	300
Cinema 2	**10,000**	**>350**	**350**	**330**	**290**	**300**
Cinema 4	None	150	240	335	300	300
Cinema 4	8000	310	330	335	300	300
Cinema 4	**10,000**	**>350**	**350**	**335**	**300**	**300**
Cinema 6	None	150	210	245	205	300
Cinema 6	3000	220	270	245	205	300
Cinema 6	5000	270	300	245	205	300
Cinema 6	**7000**	**330**	**320**	**245**	**205**	**300**

Figure 2:
Cinema 2 analysis depicting height of smoke layer in relation to time.



5.4.1 Sprinkler protection.

The ceiling heights in the cinemas are a maximum of 9.3m. Sprinkler activation would be considerably delayed due to these heights. Therefore the main benefit of early suppression is lost, with a control function being the main benefit of sprinkler protection. Preliminary calculations indicated that untenable conditions would occur at a comparative early time, prior to sprinkler activation.

Thus sprinklers were not considered a viable or cost effective solution.

5.4.2 Increased door widths

One option was to increase the width of the exit doors to enable quicker evacuation times. However, computer modeling showed that there was minimal queuing at the exit doors with the critical queuing occurring in the seating aisles and stair aisle. Due to the minimal effects on evacuation time, the increased door width option was not considered any further.

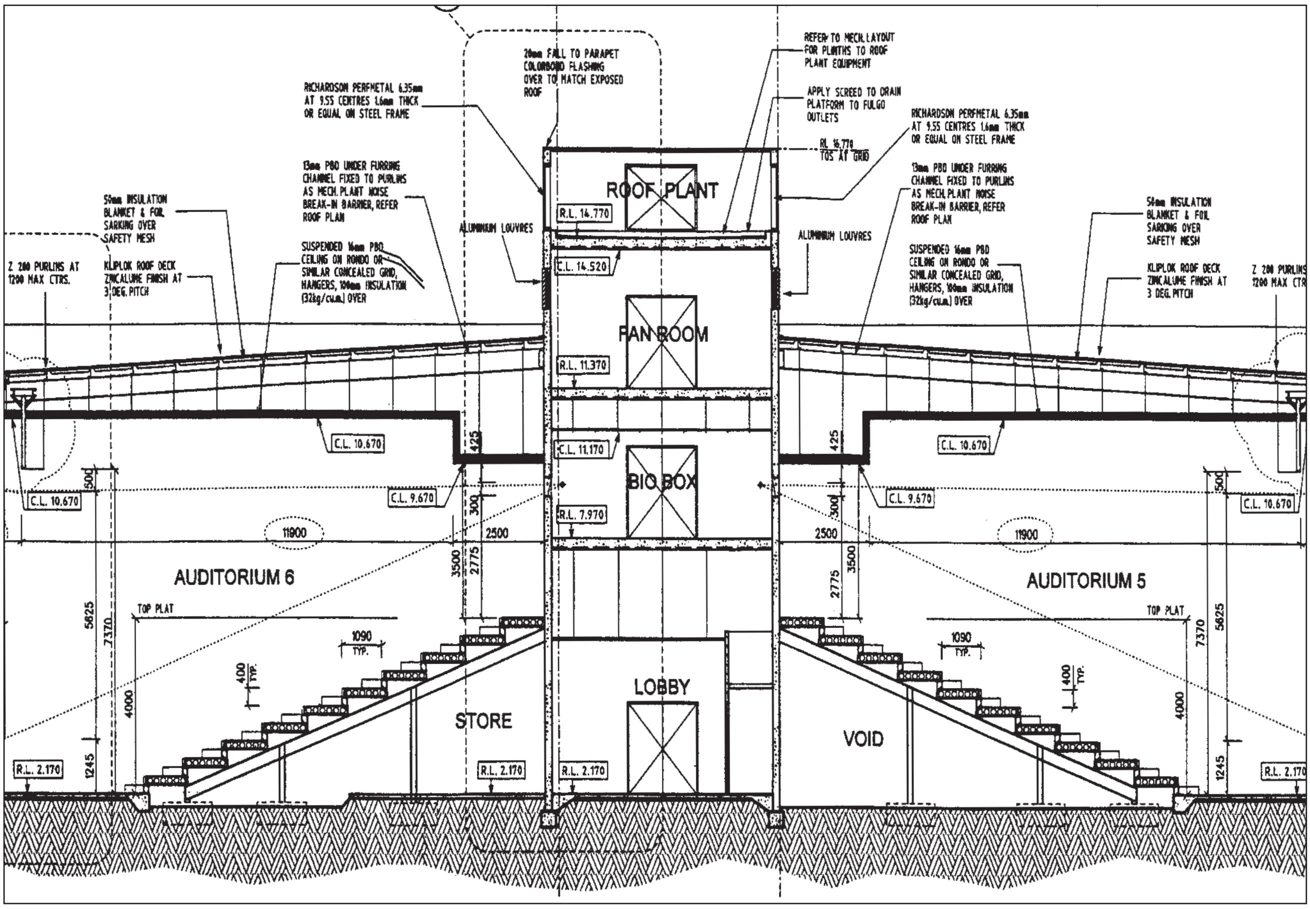
5.4.3 Manual suppression

As a measure of the conservative nature of the assessment, suppression by either occupants (staff or patrons) or the fire brigade was not taken into account for the analysis of the design fire and resultant HRR.

5.5 Sensitivity Analysis

A sensitivity analysis was undertaken to ensure a level of redundancy and conservatism was inherent in the analysis and subsequent concept design.

Figure 3: Plan View Mandurah Boardwalk Cinema - Cross Section View



6.0 Concept Design Package

The concept design package is the main conceptual design arising from the results outlined in the fire engineering analysis.

As such, it was the final recommendation of the report that the most efficient and cost effective solution to the proposal (installation of a wheelchair stair lift) would be to adopt the requirements and provisions which implement a system of smoke detection interconnected with a smoke exhaust system. This option incorporates:

- A smoke detection system installed in accordance with AS 1670.
- A smoke exhaust system installed in accordance with the provisions of Specification E2.2b of the BCA to achieve the exhaust quantities as outlined in this report, namely:

Cinema 1 and 2	10,000 litres per second
Cinema 3 and 4	10,000 litres per second
Cinema 5 and 6	7,000 litres per second

- Interconnection of the smoke detection system with the film and normal lighting operation as outlined in this report.
- The wheelchair stair lift being installed in accordance with the manufacturers specifications, with a full battery back up power supply for operation in the case of mains power failure.
- An emergency evacuation plan being prepared by the management of the cinema complex. Coordinated staff training and fire drills were strongly recommended.

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Other reading

1. Bennetts, I.D., Sims, J.A., Poon, L., O’Meagher, A.J., and Thomas, I. R., “Report on fire safety for the Brisbane International Terminal Building”, Final Draft, BHP Research Melbourne Laboratories (Unpublished).

2. FPE Manual; Mulholland: "Smoke production and Properties", Chapter 2-15.

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