InfraBuild

Building futures through sustainable steel

Steel Framed Carparks

Fire Design Guide | No. 1

2021 Edition

InfraBuild

InfraBuild is Australia's only manufacturer of steel long products, with a steel-making capacity of approximately 2.5 million tonnes per year. It is also Australia's leading steel distributor and reinforcing steel supplier.

Its history traces back over a hundred years to BHP Steel. The transition began in 2000 when OneSteel was spun out of BHP with the amalgamation of various BHP Steel business units. In 2017 OneSteel's brand name was changed to **Infra**Build.

With its history spanning from BHP Steel to OneSteel and now **Infra**Build, it is proud to be an essential partner to the Australian building industry and will continue to lead through innovation, passion for customers and supply of quality products and services.

More information on **Infra**Build can be found on its website:

https://www.infrabuild.com/steel/about-us

This publication

This publication is produced as part of **Infra**Build's continuing contribution to provide the building industry with education and guidance in the use of steel in building construction.

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This publication is freely available for download from the following website:

https://www.infrabuild.com/resources/

It forms part of the Fire Design Guide series. Other publications of the series can also be found and are freely available from the same website.

Disclaimer

Contents

Terms and abbreviations

bare steel	steel members that have no fire-protective coating
AS	Australian Standard
BCA	Building Code of Australia (for this publication, it also means NCC Volume One)
DTS	Deemed-to-Satisfy
ESA/M	Exposed Surface Area to Mass Ratio
FEB	Fire Engineering Brief
FER	Fire Engineering Report
FRL	Fire-resistance Level
FSF	Fire Source Feature
NCC	National Construction Code
PBDB	Performance Based Design Brief
PBDR	Performance Based Design Report
RIS	Rise in Storeys
SOU	Sole Occupancy Unit

Preface

This publication is prepared as part of a series of **Infra**Build Fire Design Guides to assist developers, builders, architects, engineers and other building practitioners in adopting steel structures for building construction. The series includes Fire Design Guides for supporting construction, carparks, low-rise offices and shopping centres.

The series is prepared based on an earlier set of similar documents prepared by BHP Research in late 1990s and early 2000s. They were first published by BHP Steel and later updated and republished by OneSteel.

This Fire Design Guide for Carparks is prepared based on the original document titled *Economical Carparks A Guide to Fire Safety*, which was first published in 1999 and revised in 2005. This, along with others in the series, is a major revamp to suit the current regulatory, design practice and building industry environments. Much effort has been invested to make the Fire Design Guide easy to use so that fire safety design of buildings is more widely understood by the building industry.

I have been privileged to be involved as a key author of the original set of publications and was responsible for the document design, typeset and preparation of the illustrations in the documents. The documents, which were produced in hardcopy, were well received.

Much has changed since with respect to fire safety design including building regulatory framework, knowledge level of building industry and fire engineering practice.

I am again privileged to be requested by **Infra**Build to revamp these documents into a new series to cater for these changes and the current market.

In order to improve the clarity of the document, further materials have been added. Most of the illustrations have been updated with an aim to better convey the intended guidance to readers.

I hope that this new series will provide readers with a clearer understanding of the fire safety requirements for building design. I also kindly request all readers to provide feedback and comments on the document to InfraBuild so that further improvement may be made in future revisions of the documents.

Lastly, but not the least, I wish to gratefully thank Anthony Ng and David Bell of **Infra**Build for their suggestions and review of the document.

Dr Weng Poh *BE(Hons), MEngSc, PhD, FIEAust, CPEng , NER*

Carpark Design Guide

Economical Carparks – A Design Guide is a publication that compliments this Fire Design Guide. It assists engineers, builders, developers, architects, quantity surveyors and other building construction practitioners to develop and cost preliminary designs for steel framed carparks.

The Carpark Design Guide has eleven different carpark modules, with extensive information for each, such as:

- a detailed and dimensioned layout drawing
- slab details
- steel beam sizes
- shear connector and beam camber requirements
- steel column sizes, for up to an 8 level carpark
- connection details
- corrosion protection options; and
- cost indicators.

The Carpark Design Guide is available from: www.infrabuild.com

Introduction

- Why use steel for carpark construction?
- How to achieve compliance?

Why use steel for carpark construction?

Steel framed carparks

Using structural steel for the construction of carparks offers many advantages, including:

- cost competitiveness with other forms of construction
- greater usable space due to smaller columns
- increased flexibility (the ease with which the building can be modified)
- greater speed of construction
- reduced foundation cost.

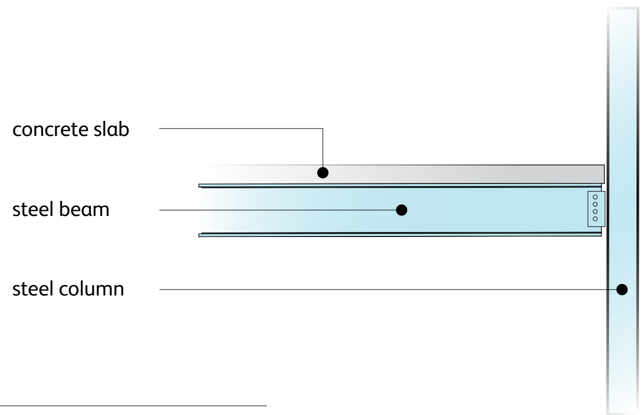
Since the mid-1980s, over a hundred multi-level carparks have been constructed in Australia and New Zealand using steel columns in conjunction with steel beams and reinforced concrete or composite floors (see survey result in *Economical Carparks – A Design Guide*).[1]

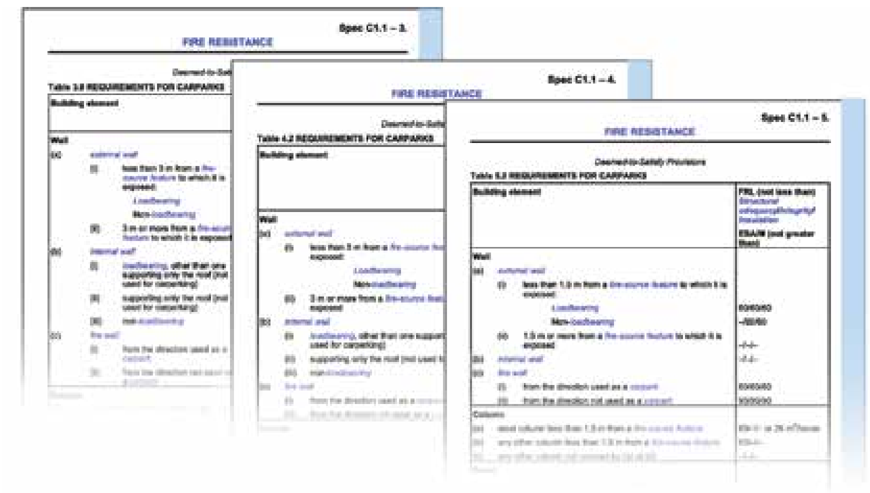
The success of steel carparks can be attributed to the research work carried out by BHP in the 1980s, when series of full-scale fire tests on carparks structures were conducted (see Appendix A). These tests and other research overseas demonstrated the significant benefits of open-deck arrangements and sprinkler protection to the fire resistance of carpark structures. As a result, the first edition of the *Building Code of Australia* (BCA)[2] in 1988 introduced the Deemed-to-Satisfy (DTS) Provisions that allow the use of bare steel, without fire protective coating, in open-deck carparks and sprinklered carparks.

In 1996, the Australian Government made a landmark change by introducing the performance-based design approach into BCA96,[3] creating greater opportunities for other innovative solutions. At the same time, another significant amendment was made to allow the use of bare steel in carparks located below a non-carpark part in multi-classified buildings (see also *Supporting Construction – A Guide to Fire Safety*)[4].

These regulatory changes have provided huge advantage to steel carparks, allowing the benefits of steel construction to be realised.

This Guide has been prepared to assist architects, builders, developers, engineers and other readers to better understand the requirements of the BCA and the situations where it allows bare steel in carparks as a DTS Solution. It also outlines the process of designing carparks using bare steel in other situations as a Performance Solution.





[1] *Economical Carparks – A Design Guide*, OneSteel Market Mills, Nov 2004.
[2] *Building Code of Australia*, Australian Uniform Building Regulation Co-ordinating Council, 1988.
[3] *Building Code of Australia 1996, Volume 1 – Class 2 to 9*, Australia Building Code Board, 1996.
[4] *Supporting Construction – A Guide to Fire Safety*, OneSteel, 2006.

How to achieve compliance?

NCC BCA

In Australia, buildings must be designed to comply with the requirements of the National Construction Code (NCC) published by the Australian Building Codes Board. The NCC[5] is a uniform set of technical provisions for the design and construction of buildings and other structures, and plumbing and drainage systems throughout Australia. It consists of three volumes. The first and second volumes are the Building Code of Australia (BCA) and the third is the Plumbing Code of Australia.

This guide relates to design of carpark structures for fire safety and concerns only BCA Volume One of the NCC[6]. For the sake of simplicity, BCA Volume One of the NCC is hereinafter referred to simply as the BCA.

Compliance pathways

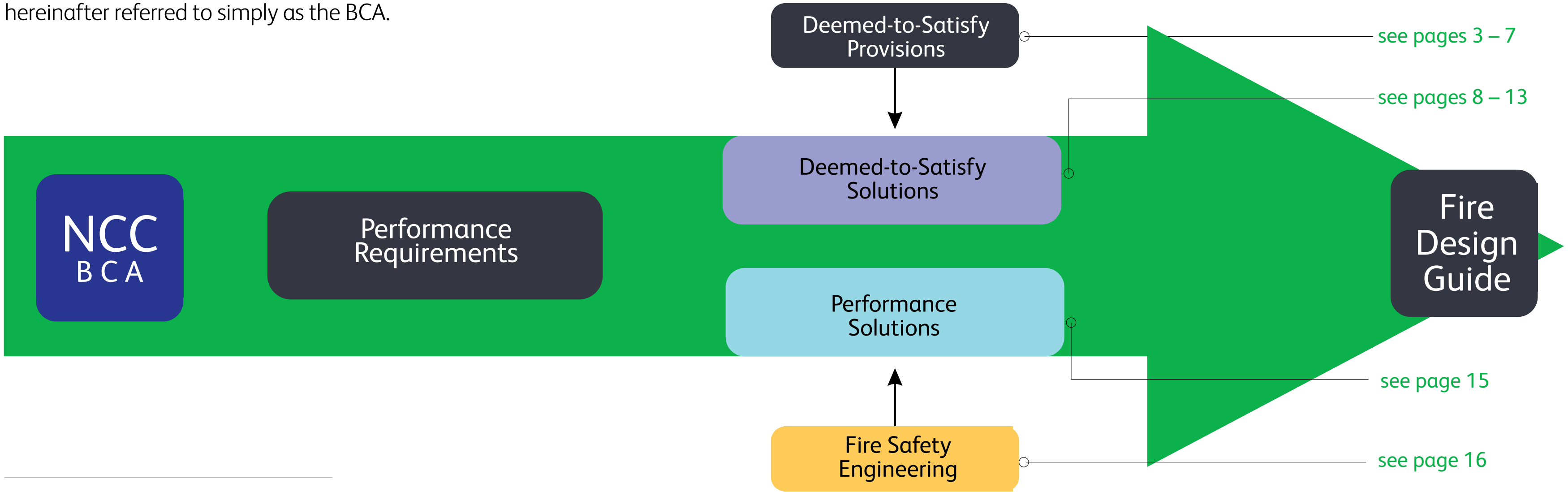
The BCA sets out Performance Requirements which states the level of performance which a building solution must meet. The Performance Requirements can be satisfied (BCA Clause A0.2) by a:

- DTS Solution which satisfies the DTS Provisions of the BCA; or
- Performance Solution which meets the Performance Requirements other than by a DTS Solution; or
- combination of the above.

This Fire Design Guide

This Fire Design Guide aims to present in clear format:

- The key concepts of the DTS Provisions with respect to carparks and fire resistance requirements
- Situations where bare steel can be used in carparks as a DTS Solution
- The objectives and key Performance Requirements to satisfy when using bare steel as a Performance Solution
- The fire engineering process for designing buildings as a Performance Solution.



[5] *National Construction Code, Volumes One to Three*, Australia Building Code Board.

[6] *National Construction Code, Volume One*, Building Code of Australia, Class 2 to 9, Australia Building Code Board.

Deemed-to-Satisfy Provisions

- What is a carpark and open-deck?
- Which situations require sprinklers?

What is a carpark and open-deck?

Carpark

The BCA (Clauses A3.2, A1.1) defines a carpark to be a Class 7a building that is used for the parking of motor vehicles, but is neither a private garage nor used for the servicing of vehicles, other than washing, cleaning or polishing.

If the advantages offered for open-deck and sprinklered carparks are to be realised, the carpark must be primarily for the parking of cars but may include an administration area associated with the functioning of the carpark.

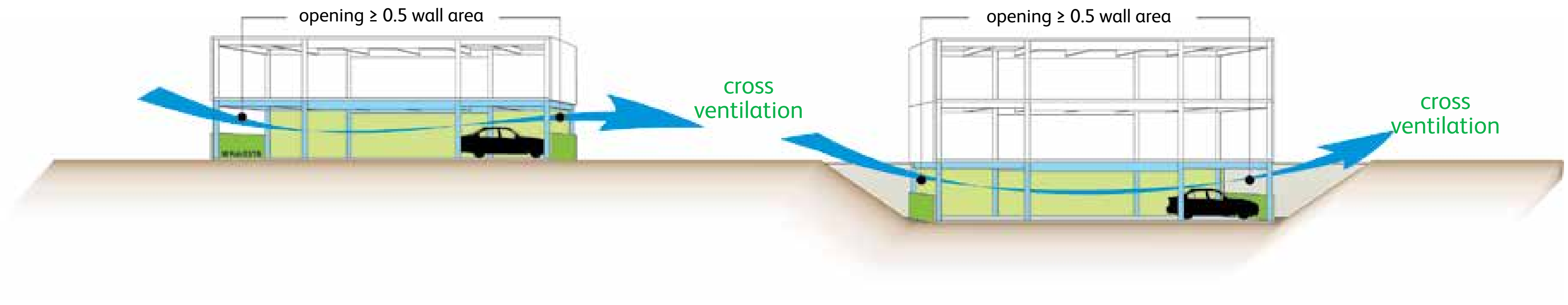
If the carpark is sprinklered and provides carparking for separate sole-occupancy units (SOUs) in a Class 2 or 3 building, then 10 % of each carparking area can be used for purposes ancillary to the SOUs (BCA Specification C1.1, Clauses 3.9, 4.2, 5.2).

Open-deck

The BCA defines an open-deck carpark as a carpark which is cross ventilated in at least two approximately opposite sides. The sides that provide ventilation must be at least 1/6 of the area of any other side and the opening must be at least 1/2 of the wall area (BCA Clause A1.1).

Underground carparks are usually closed carparks. However, an underground carpark can be constructed as open-deck in an excavated ground situation.

The excavation detail surrounding the carpark to provide the necessary cross ventilation may need to be discussed with the relevant approval authority.

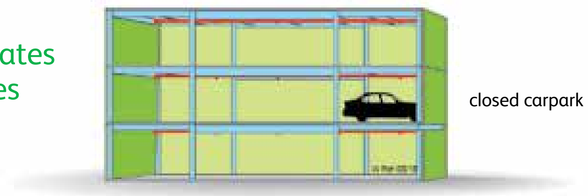


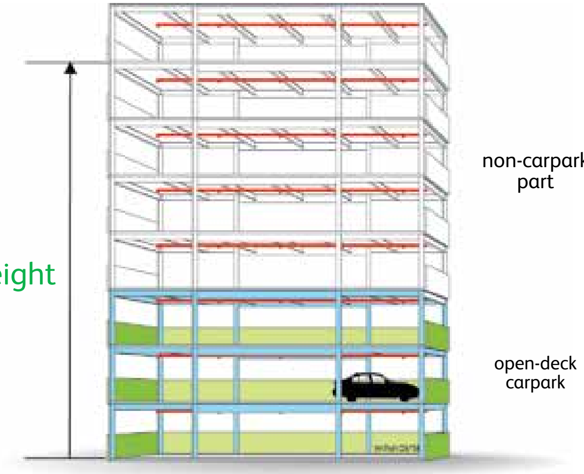
Which situations require sprinklers?

Effective height and closed carparks

The BCA requires a closed carpark to be sprinklered if its effective height is more than 25 m; or if it accommodates more than 40 vehicles (BCA Table E1.5).

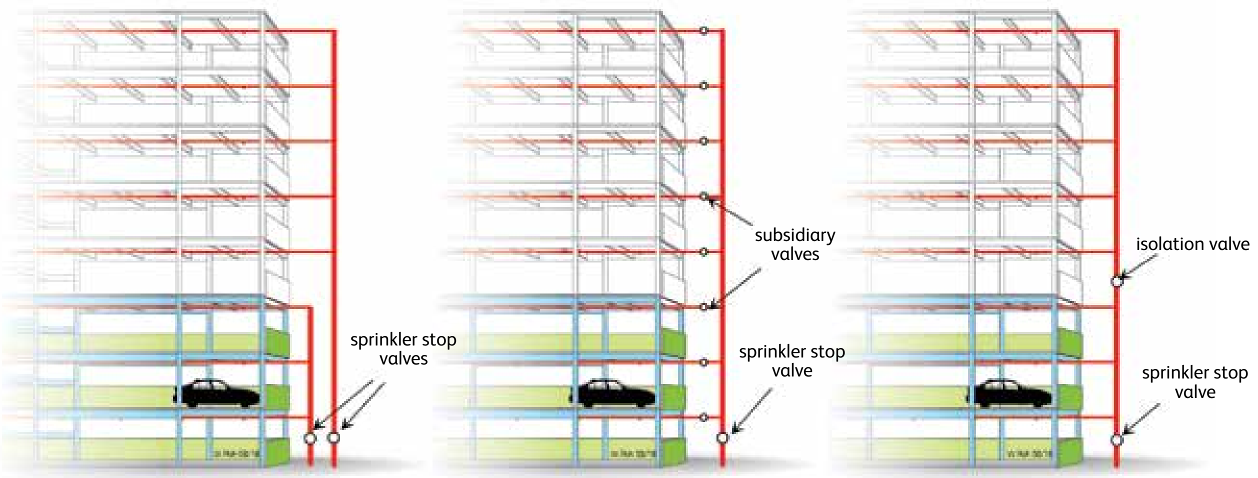
When an open-deck carpark is constructed within a multiclassified building, the BCA requires the building to be sprinklered if its effective height is more than 25 m (BCA Table E1.5).





Sprinkler requirements

Sprinklers must be installed in accordance with AS2118.1[7]. In buildings of Type A construction, the BCA requires the sprinkler system to be designed such that non-carpark part of the building can be isolated separately to the carpark part of the building (BCA Specification E1.5, Clause 11). There are several ways of achieving this and these are shown schematically on the right.



[7]AS 2118.1, *Automatic Fire Sprinkler System, Part 1: General Systems*, Standards Australia, (year edition as referenced by the BCA).

What type of fire-resisting construction is required?

Fire-resisting construction

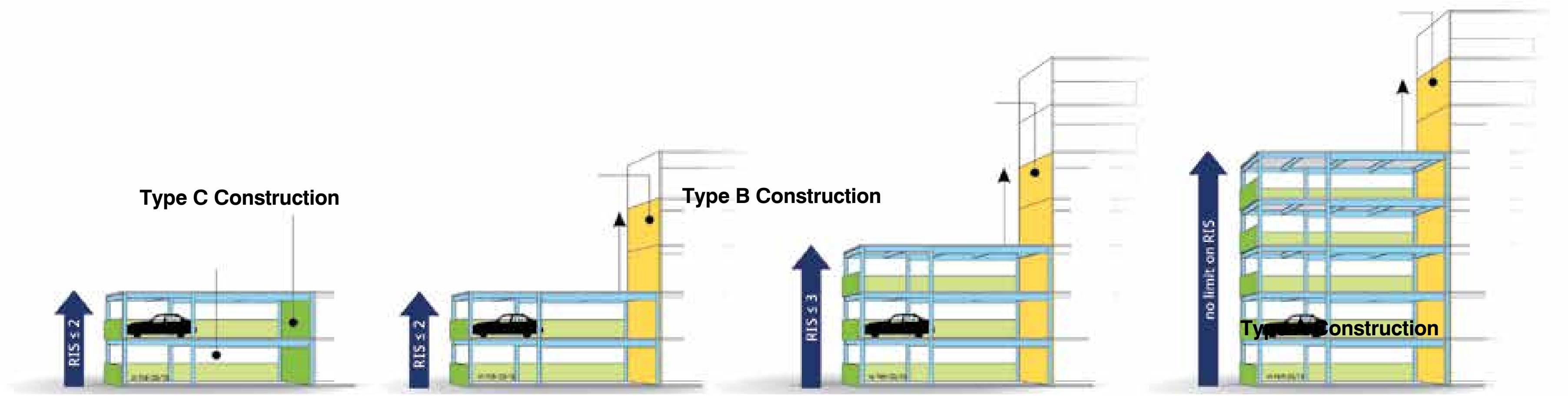
The BCA (Clauses C1.1, C1.3) requires buildings to be a minimum of Type A, B or C fire-resisting construction based on their rise in storeys (RIS) and the building classification of the topmost storey. Type A is the most fire resistant whilst Type C the least.

A carpark (Class 7a) building may be of Types C and B construction when its RIS is up to 2 and 3 respectively. For a RIS of greater than 3, Type A construction is required.

If the carpark is located below another building part, the required Type of construction remains the same if the top storey is a Class 5, 6, 7 or 8 part (e.g. office, retail, factory, or warehouse building). However, if the top storey is a Class 2, 3 or 9 part (e.g. apartment, hotel or public building) the building, including the carpark below, may be of Types C and B construction when the buildings RIS is up to 1 and 2, respectively. For a RIS greater than 2, Type A construction is required.

For each Type of construction, the BCA (Clause C2.2, Table C2.2) also imposes a maximum limit on the floor area and volume of fire compartment in the building. For an example, for a closed carpark that is unsprinklered and required to be of Type C construction the maximum floor area and volume limits are 2,000m^2 and 12,000m^3, respectively. Other limits apply for other 3 building classifications and other types of construction (BCA Clause C2.2, Table C2.2).

It is noted that fire compartment size limits do not apply to open-deck or sprinklered carparks and hence there is no floor area or volume limit on these carparks.



Type C Construction

Type B Construction

What fire-resistance level is required?

FRL

For each Type of fire-resisting construction, the BCA (Specification C1.1) prescribes the minimum fire-resistance level (FRL) building elements, including walls, columns, beams, floors and roofs, must achieve.

The FRL is expressed as the required durations, in minutes, for the building elements to maintain the three criteria of structural adequacy, integrity and insulation. It is determined in accordance with AS1530.4[8] when exposed to a standard fire, expressed as a temperature-time relationship.

The three criteria are a measure of the following performance:

- **structural adequacy** – to maintain stability and adequate loadbearing capacity
- **integrity** – to resist the passage of flames and hot gases
- **insulation** – to maintain the unexposed face sufficiently cool so that fire will not initiate on the unexposed side.

The first criterion is applicable to all loadbearing elements and the second and third to elements providing a fire separation function.

The FRL required is expressed as three numbers, separated by /, for the three criteria. For an example, 120/-/- means a 120 minute FRL requirement for structural adequacy, and no requirement for integrity and insulation. Where no FRL is required, the FRL is either not stated at all or specifed as -/-/-.

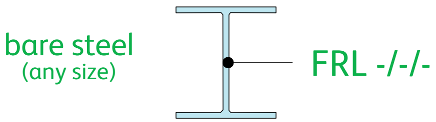
Bare and protected steel

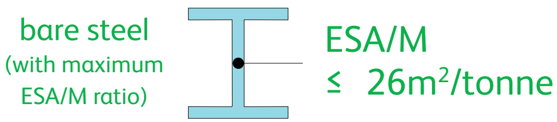
Where the required FRL of a beam or column is expressed as -/-/- any bare steel section may be used. No fire-protective coating is required.

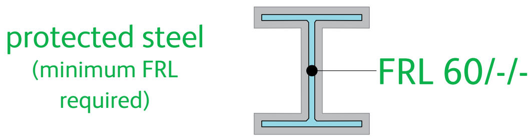
For open-deck or sprinklered carparks, the BCA (Specification C1.1, Tables 3.9, 4.2 and 5.2) allows the use of bare steel beams and columns. The fire resistance requirements for these are expressed either as -/-/- or as a maximum exposed surface area to mass ratio (ESA/M) in m²/tonne (see Appendix B for ESA/M values of steel sections). Again, no fire-protective coating is required.

Where an FRL is specified (e.g. 60/-/-), steel members may be used if they are protected by a fire protective coating to achieve the required FRL.

In this Guide, beams and columns where bare steel can be used are coloured light blue. Steel beams or columns that need to be further protected are coloured orange and the required FRL is given.







[8]AS 1530.4, *Methods for Fire Tests on Building Materials, Components and Structures, Part 4 Fire-resistance Tests on Elements of Construction*, Standards Australia, (year edition as referenced by the BCA).

Deemed-to-Satisfy Solutions

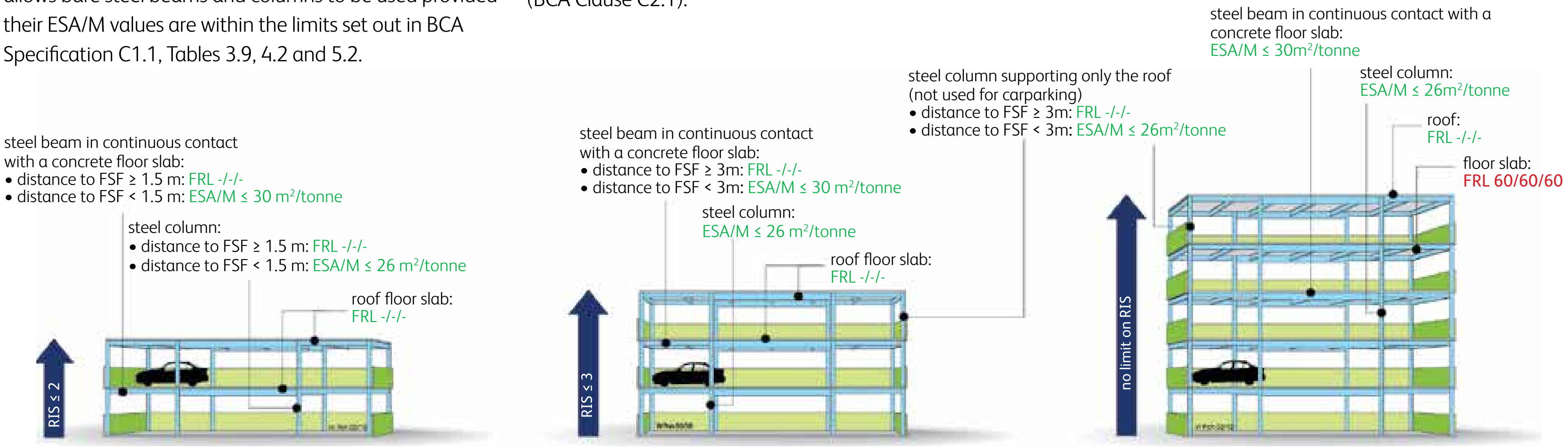
- What situations allow bare steel in carparks as a separate building?
- What situations allow bare steel in carparks **above** other parts?
- What situations allow bare steel in carparks **adjoining** other parts?
- What situations allow bare steel in carparks **below** other parts?

What situations allow bare steel in carparks as a separate building?

Open-deck or sprinklered

In a carpark building that is open-deck or sprinklered and does not vertically support a non-carpark part, the BCA allows bare steel beams and columns to be used provided their ESA/M values are within the limits set out in BCA Specification C1.1, Tables 3.9, 4.2 and 5.2.

The BCA does not impose any limit on the RIS or any floor area and volume of the size of the fire compartments (BCA Clause C2.1).



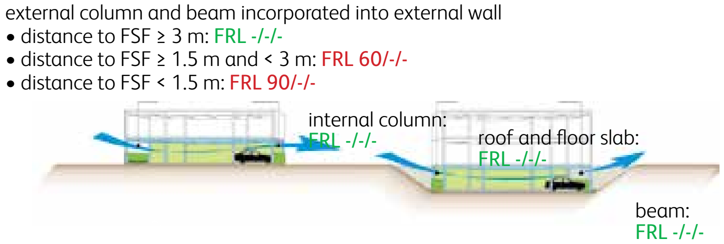
Type C Construction (BCA Spec C1.1, Table 5.2)

Type B Construction (BCA Spec C1.1, Table 4.2)

Type A Construction (BCA Spec C1.1, Table 3.9)

Closed and unsprinklered

In a closed carpark that accommodates less than 40 vehicles and is unsprinklered, the BCA allows use of bare steel beams and columns only in Type C construction (BCA Specification C1.1, Table 5). This limits the building to a maximum RIS of two. Also, the total floor area and volume are limited to 2,000m² and 12,000m³, respectively (BCA Clause C2.2, Table C2.2).



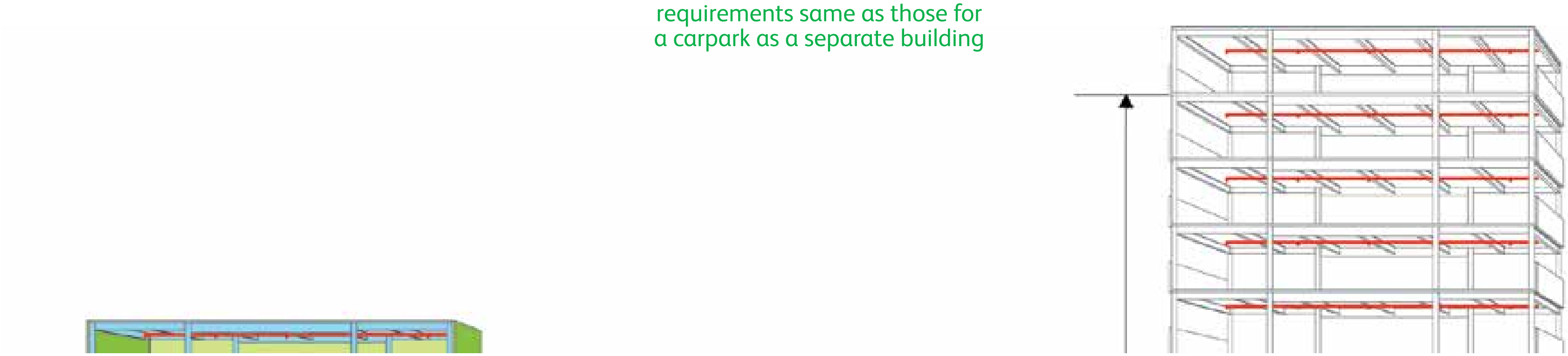
Type C Construction (BCA Spec C1.1, Table 5)

What situations allow bare steel in carparks above other parts?

Open-deck or sprinklered

The requirements for an open-deck or sprinklered carpark which is situated above a non-carpark part, are similar to those for a carpark as a separate building (BCA Specification C1.1, Tables 3.9, 4.2, 5.2).

Again, no limits on the RIS, floor area, volume of the fire compartments are imposed (BCA Clause C2.1).

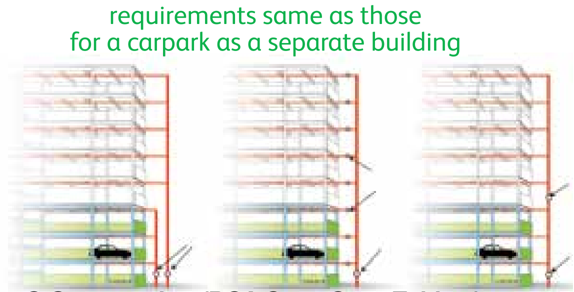


Type C Construction (BCA Spec C1.1, Table 5.2) **Type B Construction (BCA Spec C1.1, Table 4.2)** **Type A Construction (BCA Spec C1.1, Table 3.9)**

Closed and unsprinklered

In a closed carpark that accommodates not more than 40 vehicles and is unsprinklered, the BCA allows bare steel beams and columns to be used only in Type C construction (BCA Specification C1.1, Table 5).

Therefore, bare steel can be used for a building with a maximum RIS of two. Also, the total floor area and volume are limited to 2000m^2 and 12000m^3, respectively (BCA Clause C2.2, Table C2.2).



Type C Construction (BCA Spec C1.1, Table 5)

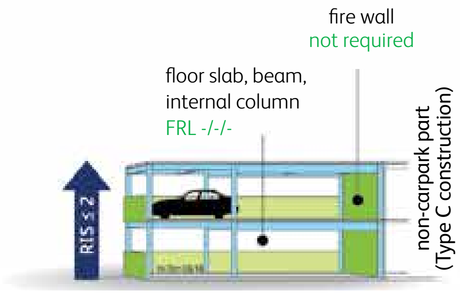
What situations allow bare steel in carparks adjoining other parts?

Open-deck or sprinklered

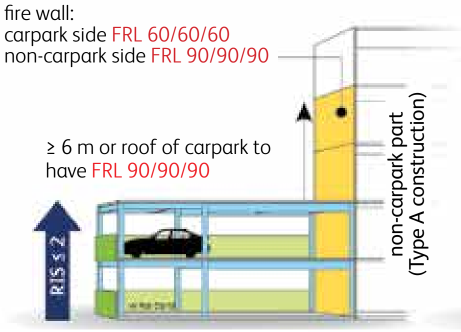
A carpark often horizontally adjoins a non-carpark part. If the carpark is open-deck or sprinklered and is separated from the remainder of the building by a fire wall, it can be considered as a separate building (BCA Clause 2.7(b)) and the requirement as described for carparks as a separate building apply (BCA Specification, C1.1 Table 3.9, 4.2 or 5.2).

If the carpark is not separated from the remainder of the building by a fire wall, the BCA requires each building element in that storey to have the higher FRL prescribed for that element for the classifications concerned (BCA Clause C2.8(a)).

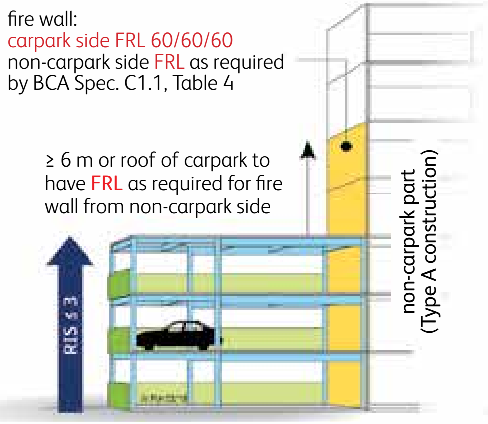
If the carpark is not separated from the remainder of the building by a fire wall, bare steel can generally be used only if the carpark and the adjoining part are of Type C construction.



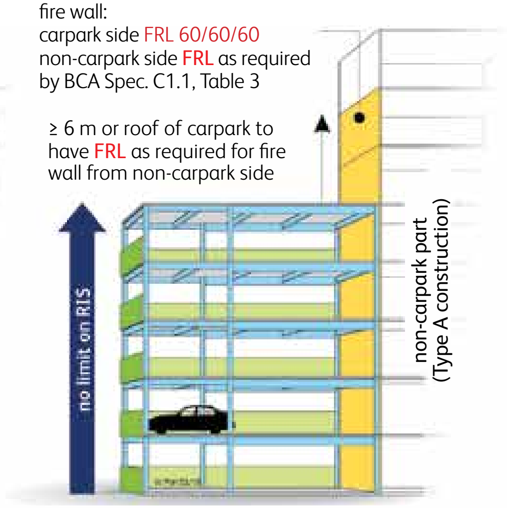
Type C Construction
(BCA Spec C1.1, Table 5)



Type C Construction
(BCA Spec C1.1, Table 5.2)



Type B Construction
(BCA Spec C1.1, Table 4.2)

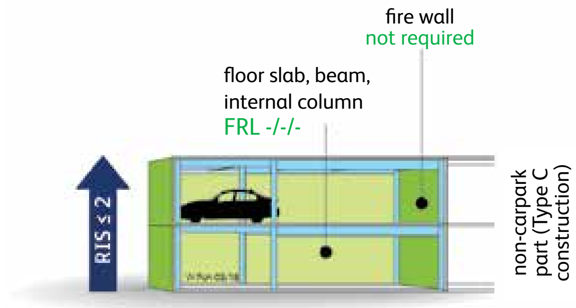


Type A Construction
(BCA Spec C1.1, Table 3.9)

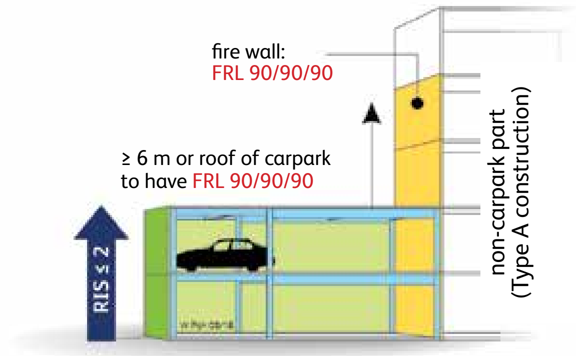
requirements same as those for a carpark as a separate building

Closed and unsprinklered

This applies only to carparks that accommodate not more than 40 vehicles. In such situations, bare steel can be used if the carpark is of Type C construction.



Type C Construction
(BCA Spec C1.1, Table 5)



Type C Construction
(BCA Spec C1.1, Table 5.2)

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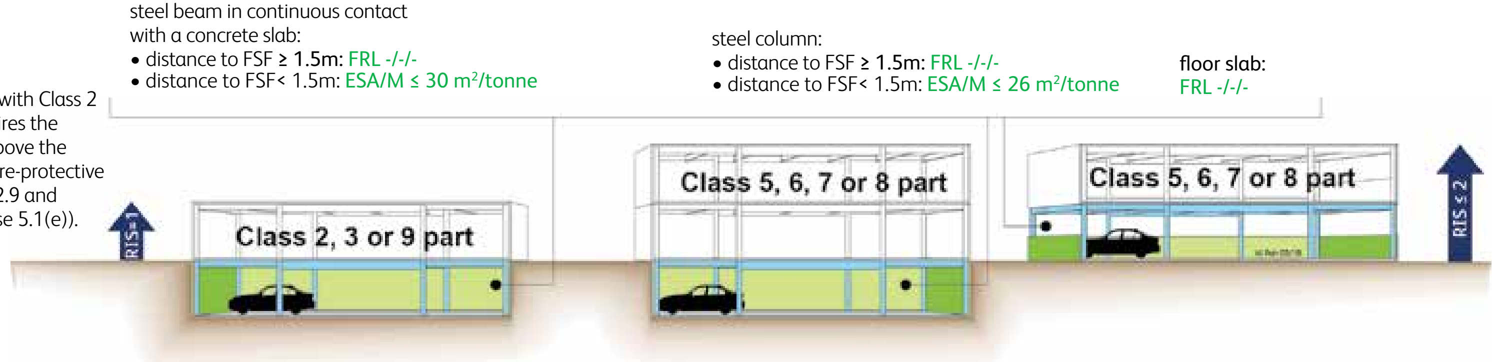
What situations allow bare steel in carparks below other parts?

Open-deck or sprinklered

If the carpark is constructed under a non-carpark part, the BCA allows bare steel beams and columns in the carpark only when the building is required to be of Types B or C construction (BCA Specication C1.1, Tables 4.2 and 5.2). This includes buildings up to a RIS of 2, when the topmost level of the building is a Class 2, 3 or 9 part (eg. apartment, hotel, public buildings).

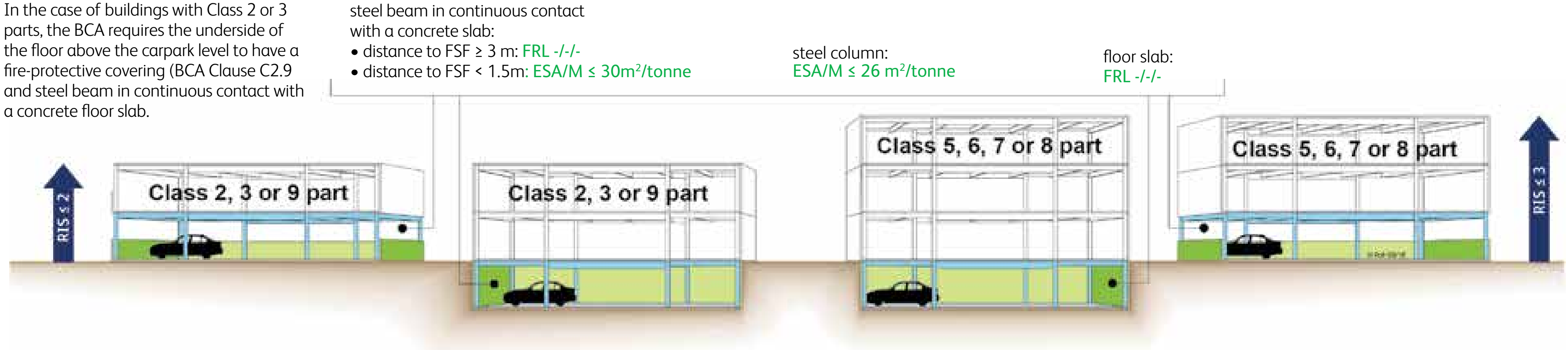
In the case where the topmost level is a Class 5, 6, 7 or 8 part (eg. office, shops, factory, warehouse buildings), buildings with a RIS of up to 3 are allowed. Otherwise, bare steel beams are permitted in all situations but columns are required to have an FRL of 60/-/-.

In the case of buildings with Class 2 or 3 parts, the BCA requires the underside of the floor above the carpark level to have a fire-protective covering (BCA Clause C2.9 and Specification C1.1, Clause 5.1(e)).



Type C Construction (BCA Spec C1.1, Table 5.2)

In the case of buildings with Class 2 or 3 parts, the BCA requires the underside of the floor above the carpark level to have a fire-protective covering (BCA Clause C2.9 and steel beam in continuous contact with a concrete floor slab.

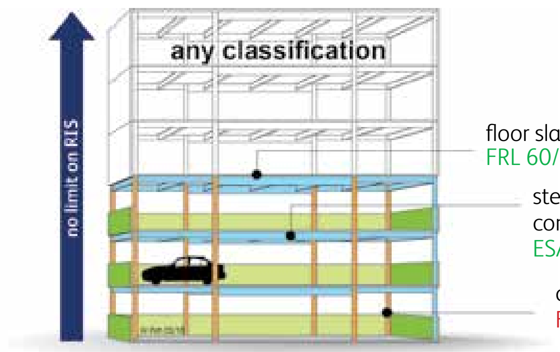


Type B Construction (BCA Spec C1.1, Table 4.2)

What situations allow bare steel in carparks below other parts?

Open-deck or sprinklered

In buildings with a RIS greater than three, Type A construction is required. Bare steel beams still can be used but the columns are required to have an FRL of 60/-/-.



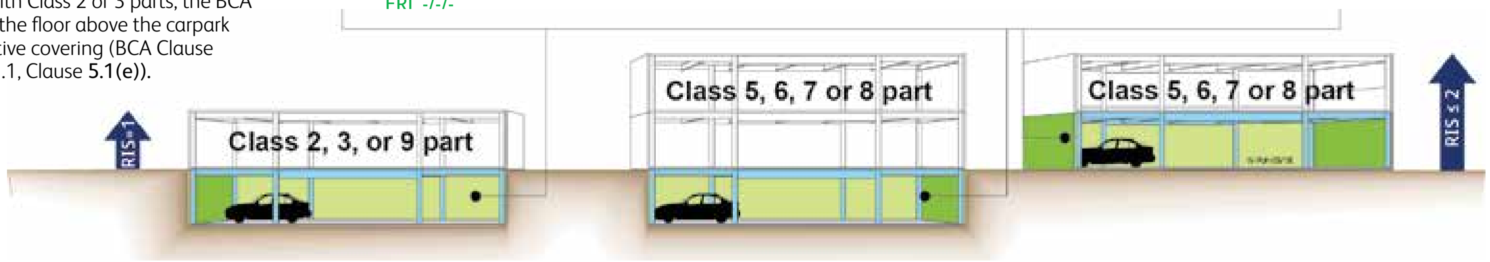
Type A Construction (BCA Spec C1.1, Table 3.9)

* This interpretation is not shared by all regulatory authorities. Some require the floor slab to have an FRL which is equal to that required for the level above.

Closed and unsprinklered

For closed and unsprinklered carparks constructed under other non-carpark parts, bare steel is allowed only within buildings of Type C construction.

In the case of buildings with Class 2 or 3 parts, the BCA requires the underside of the floor above the carpark level to have a fire-protective covering (BCA Clause C2.9 and Specification C1.1, Clause 5.1(e)).



Type C Construction (BCA Spec C1.1, Table 5)

Performance Solutions

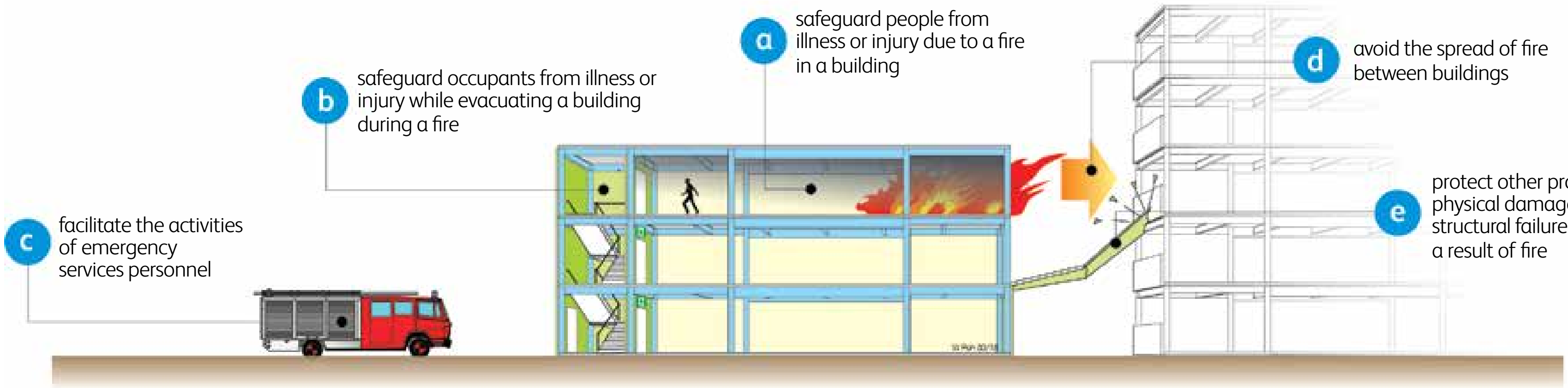
- What must a building structure achieve?
- What is the fire engineering design process?

What must a building structure achieve?

BCA Fire safety objective

Bare steel may be used as a Performance Solution for situations other than those allowed as a DTS Solution. This is to be assessed individually on a case-by-case basis.

The assessment is to ensure the building structure achieves the relevant Performance Requirements which reflect the BCA fire safety objective for building fire safety (NCC Guide to BCA Vol 1, CO1).[10]

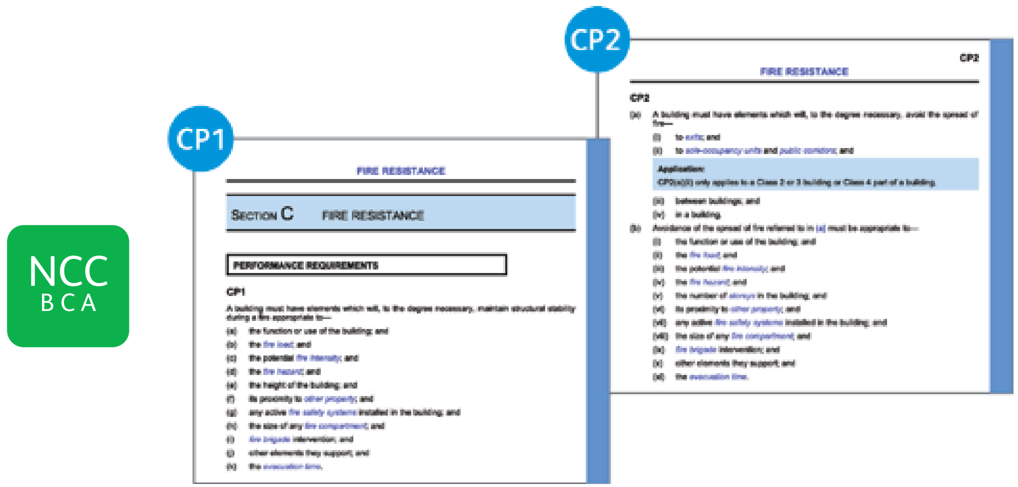


BCA Objective CO1

BCA Performance Requirements

The primary Performance Requirements a Performance Solution utilising bare steel in carparks must satisfy are CP1 and CP2, which relate to structural stability and prevention of fire spread, respectively, for achieving the BCA objective.

Other Performance Requirements may also be relevant depending on the building design. Advice is to be sought from the authority having jurisdiction to confirm the relevant Performance Requirements for each design.



[10] *Guide to NCC Volume One*, Australia Building Code Board.

What is the fire engineering design process?

Fire engineering design process

A rigorous assessment of a design to achieve compliance with the relevant Performance Requirements will require a fire engineering evaluation of the design. This is conducted by a Fire Engineer (also called Fire Safety Engineer) who is suitably qualifed or registered in accordance with the regulatory requirements of the relevant State or Territory.

The fire engineering design and evaluation process is outlined in the International Fire Engineering Guideline.[9]

In the evaluation, all relevant factors outlined in the relevant Performance Requirements must be taken into account.

The evaluation may include qualitative and/or quantitative analyses (including fire, structure and occupant evacuations modelling), testing and other suitable methods at the disposal of the design team. Past research and experimental testing is a useful resource for supporting the design evaluation.

A design satisfies the relevant Performance Requirements when the fulfillment of all relevant criteria are demonstrated and accepted by the authority having jurisdiction.

FEB and FER

Central to fire engineering design is the production of two documents: Performance Based Design Brief (PBDB) and Performance Based Design Report (PBDR) which have been more commonly referred to as Fire Engineering Brief (FEB) and Fire Engineering Report (FER), respectively.

The FEB is prepared collaboratively with the design team and documents the scope of work for the fire engineering evaluation and the basis for evaluation as agreed by stakeholder.

The FER is prepared subsequent to the fire engineering analysis to document the outcome and any recommendations arising from the evacuation. It forms part of the approval documents for the Performance Solution concerned.

[9] *International Fire Engineering Guideline*, Australia Building Code Board, 2005.

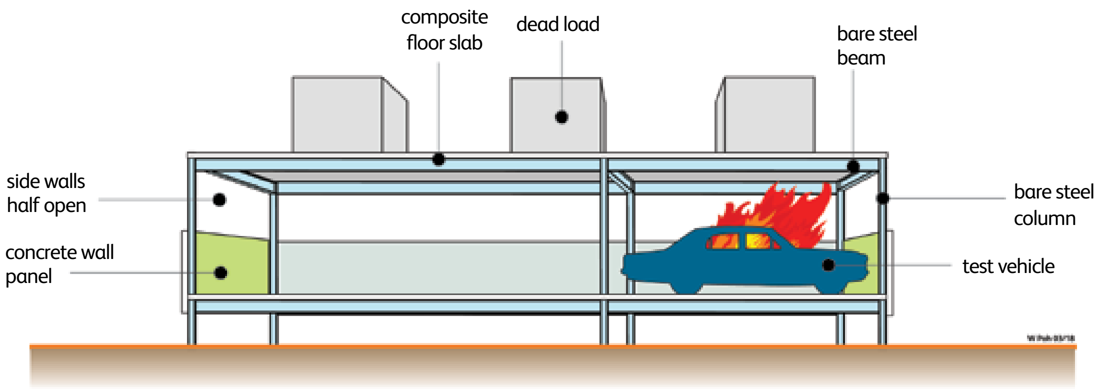
Appendices

A. Carpark Fire Tests

B. Exposed Surface Area to Mass Ratios of Steel Sections

A: Carpark fire tests

From 1985 to 1989, BHP Research conducted a series of fire tests on carpark structures. The tests were conducted following a number of similar overseas test programs, but used vehicles and building constructions more typically observed in Australia.



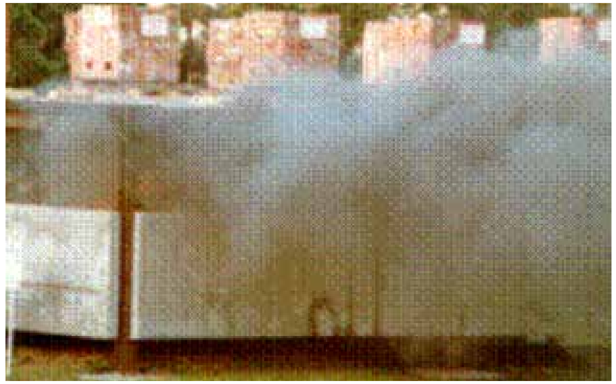
Open-deck carpark

The first series involved two fire tests to study the behaviour of fire in open-deck carparks.[11] The carpark structure was constructed of bare steel columns, beams and composite floor slabs. The floor above the structure was loaded to simulate a full carpark level above.

Multiple cars were used in each test. They were closely spaced and the windows left down. Fires were initiated in cars which had steel and plastic petrol tanks, as well as one car which had an LPG tank.

In each test, spread of fire between the vehicles took some time with eventually three cars being involved. The test structure supported the loads throughout both tests. A large quantity of dense smoke was generated, but this vented through the open sides. Measured temperatures showed that a significant factor of safety could be associated with bare steel construction under fire conditions.

The results of these tests formed the basis of the current BCA DTS Provisions (Specification C1.1, Tables 3.9, 4.2, 5.2) which allows the use of bare steel in open-deck carparks.



Three views showing smoke produced during test

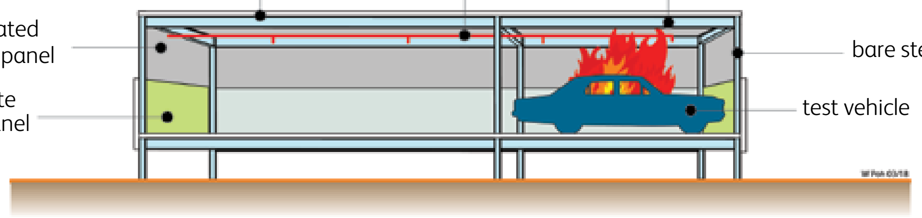
[11]Bennetts, I. D., Proe, D. J., Lewins, R. R., and Thomas, I. R., *Open-Deck Carpark Fire Tests*, BHP Melbourne Research Laboratories Report Number MRL/PS69/85/001, August 1985.

A: Carpark fire tests

Closed carpark

The second series involved nine tests conducted in a closed carpark using the same test structure as the open-deck carpark tests, but the side walls were closed and a sprinkler system was fitted.[12] Again, bare steel construction was used. Most of the tests were conducted with five cars within the test structure with a spacing of 400-500 mm between vehicles. In each test, a fire was initiated in a large sedan with either a plastic or steel fuel tank. Tests were conducted with and without sprinklers.

The tests demonstrated that without a functioning sprinkler system in a carpark, fires will spread to other vehicles, with very large quantities of dense toxic smoke being generated. In contrast, in tests where sprinklers automatically operated, they suppressed the fire, halted its spread to adjacent vehicles, greatly reduced the volume of smoke, and signicantly reduced the toxicity of the smoke.



Due to these findings, the provision of protecting closed carparks accommodating more than 40 cars with sprinklers was incorporated into the BCA.

It was also found that with a functioning sprinkler system, the temperature of the steel beams and columns was low (less than 100°C) and therefore it was concluded that in a sprinklered closed carpark, no protective coating is required for the structural steelwork.

Test structure

The structure after the fire test

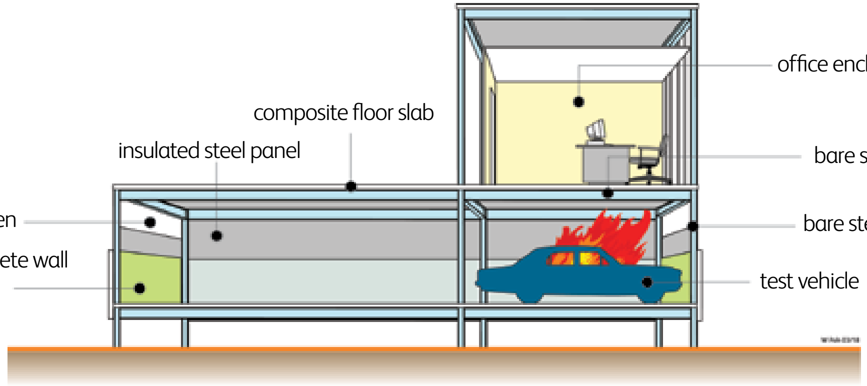
During the fire test view inside test structure showing test vehicle alight

[12] *Fire and Unprotected Steel in Closed Carparks*, BHP Melbourne Research Laboratories Report Number MRL/PS98/87/001, August 1987.

A: Carpark fire tests

Partially open carpark

The third series was conducted with the side walls partially open to observe the effect of burning cars in a carpark with ventilation conditions between those of the open-deck and closed carparks previously tested.[13] The same building structure was used with the exception that a small office was constructed above the carpark as these tests were also used in a research project on fires in multi-classified buildings.



Three tests were conducted with vehicles, and a further eleven were conducted using either trays of fuel or a fuel tank to better understand the effect of various ventilation conditions. Of particular interest was the rate of fire spread and the conditions created within the carpark. These tests showed that fire could spread rapidly in a partially-open situation, with large amounts of smoke being generated. Therefore, it is considered that such carparks should be treated as closed carparks. The smoke associated with the burning of a 60-litre plastic tank of petrol is shown below and illustrates that smoke from a significant carpark fire without sprinkler protection may present a major hazard to life.


view of test structure during test


view outside test structure during test showing flame


view inside test structure showing test vehicle alight

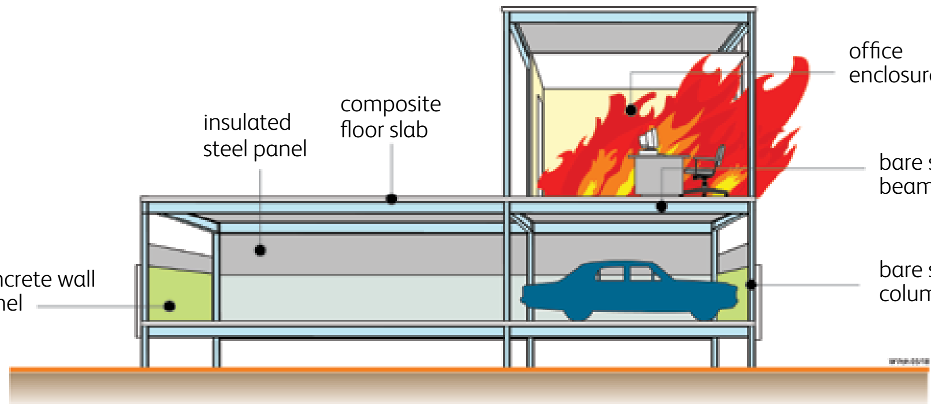

view outside test structure showing large amount of thick smoke produced


60 litres of petrol in a plastic tank placed inside test structure

[13] Bennetts, I. D., Thomas, I. R., Proe, D. J., Lewins, R. R., and Almand, K. H., *Fire Safety in Carparks*, BHP Melbourne Research Laboratories Report Number MRL/PS69/89/006, August 1989.

A: Carpark fire tests

Carpark in multi-classified building

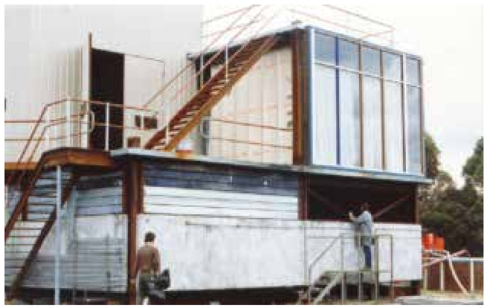


A series of tests, similar to the partially-open carpark tests, was conducted to study the situation where a carpark is located below levels of another class of building.[14] The same structure as in previous carpark tests was used with a furnished office level constructed directly above the opening to the carpark. The office was penetrated by bare steel columns from the carpark below. No edge spandrel was provided at the edge of the floor between the carpark and the office.

An office fire test was conducted in addition to the partially-open carpark fire tests, and conditions were monitored in the carpark and the office. It demonstrated that adequate separation of the storeys is achieved even when the doors are penetrated by bare steel members. They also illustrated that the effects of a fire in one storey are experienced only in storey(s) above the fire, posing no threat to the storey(s) below it. The temperatures attained by the steel members in the enclosure of fire origin were a function of the fire temperatures in that enclosure. However, the effect of the fire on the steel members in the adjacent enclosure was negligible. Thus, it was concluded that the support of another part provisions of the BCA (the requirement for supporting construction to have equal fire resistance to that which it supports) is inappropriate for structural members in different enclosures.

The outcome of this test series formed the basis for the amendment in BCA96 with respect to the support of another part provisions in 1996.


view inside simulated office enclosure before test


view of test structure before test


view of office enclosure at full involvement

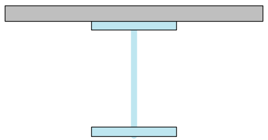

view of test structure showing fire in office above imposed little threat to the carpark below

[14] Thomas, I. R., Almand, K. H, Bennetts, I. D., Proe, D. J., and Lewins, R. R., *Fire in Mixed Occupancy Buildings*, BHP Melbourne Research Laboratories Report Number MRL/PS69/89/004, August 1989.

B: Exposed Surface Area to Mass Ratios of steel sections

Steel beams in continuous contact with a concrete floor slab (exposed to 3 sides)

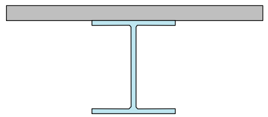
Welded-plate sections



Section	ESA/M m^2/tonne
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	ESA/M m^2/tonne
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



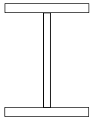
Section	ESA/M m^2/tonne
610UB125	14.9
113	16.3
101	18.1
530UB 92.4	17.8
82.0	19.9
460UB 82.1	17.7
74.6	19.4
67.1	21.4
410UB59.7	21.9
53.7	24.1
360UB56.7	21.1
50.7	23.4
44.7	26.3
310UB 46.2	23.2
40.4	26.2
250UB 37.3	24.7
31.4	29.0
200UB 29.8	26.3
180UB 22.2	27.1
150UB 18.0	28.3

Section	ESA/M m^2/tonne
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

B: Exposed Surface Area to Mass Ratios of steel sections

Steel columns (exposed to 4 sides)

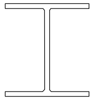
Welded-plate sections



Section	ESA/M m²/tonne
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	ESA/M m²/tonne
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	8.22
212	11.1
181	13.0
144	16.1
350WC280	7.33
258	7.89
230	8.82
197	10.3

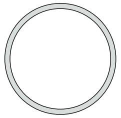
Hot-rolled sections

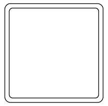


Section	ESA/M m²/tonne
610UB125	16.7
113	18.3
101	20.3
530UB 92.4	20.0
82.0	22.4
460UB 82.1	20.0
74.6	21.9
67.1	24.2
410UB59.7	24.8
53.7	27.4
360UB56.7	24.1
50.7	26.8
310UB 46.2	26.8
250UB 37.3	28.6

Section	ESA/M m²/tonne
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

Hollow sections





Section				ESA/M
mm		mm		mm/t
610	x	9.5	CHS	13.6
		6.4	CHS	20.1
457	x	12.7	CHS	10.3
		9.5	CHS	13.7
		6.4	CHS	20.2
406.4	x	12.7	CHS	10.4
		9.5	CHS	13.7
		6.4	CHS	20.2
355.6	x	12.7	CHS	10.4
		9.5	CHS	13.8
		6.4	CHS	20.3
323.9	x	12.7	CHS	10.4
		9.5	CHS	13.8
		6.4	CHS	20.3
273.1	x	9.3	CHS	14.2
		6.4	CHS	20.4
		4.8	CHS	27.0
219.1	x	8.2	CHS	16.1
		6.4	CHS	20.5
		4.8	CHS	27.1
168.3	x	7.1	CHS	18.7
		6.4	CHS	20.7
		4.8	CHS	27.3
165.1	x	5.4	CHS	24.4
		5.0	CHS	26.3

Section						ESA/M
mm		mm		mm		m²/t
400	x	400	x	16.0	SHS	8.23
				12.5	SHS	10.5
				10.0	SHS	13.0
350	x	350	x	16.0	SHS	8.27
				12.5	SHS	10.5
				10.0	SHS	13.0
				8.0	SHS	16.2
300	x	300	x	16.0	SHS	8.33
				12.5	SHS	10.6
				10.0	SHS	13.1
				8.0	SHS	16.3
250	x	250	x	16.0	SHS	8.42
				12.5	SHS	10.6
				10.0	SHS	13.2
				9.0	SHS	14.6
				8.0	SHS	16.3
				6.0	SHS	21.7
200	x	200	x	16.0	SHS	8.55
				12.5	SHS	10.8
				10.0	SHS	13.3
				9.0	SHS	14.7
				8.0	SHS	16.5
				6.0	SHS	21.8
				5.0	SHS	26.0
150	x	150	x	10.0	SHS	13.5
				9.0	SHS	14.9
				8.0	SHS	16.7
				6.0	SHS	22.0
				5.0	SS	26.2

InfraBuild
Building futures through sustainable steel