STRUCTURAL DESIGN OPTIONS FOR RESIDENTIAL BUILDINGS IN BUSHFIRE AREAS

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ABSTRACT: *The National Construction Code (NCC) provides two deemed to satisfy (DTS) solutions for housing in bushfire areas: AS 3959 and the NASH Standard. The two standards use different approaches, presenting well-informed designers with opportunities to produce a range of structurally efficient and aesthetically acceptable solutions. AS 3959 prescribes external cladding materials and design tolerances to limit combustibility and the likelihood of ember entry in to the building and building cavities. The NASH Standard uses non-combustible materials for the external cladding, framing and internal lining, with less reliance on specialised materials or close control of construction gaps. Having two DTS solutions invites assessment of the factors to be considered in adopting an AS 3959 solution or a NASH Standard solution. This paper explores these factors with reference to a Case Study of a retirement village development in Bacchus Marsh to the west of Melbourne Victoria. The effects of different structural and cladding choices, within the client's specifications, are discussed in developing NCC compliant solutions.*

KEYWORDS: Bushfire, safety, structural design, non-combustible, robustness, resilience

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1 INTRODUCTION

In Australia the National Construction Code (NCC) Volume Two requires that houses in designated bushfire prone areas be protected from ignition due to bushfire attack [1]. For many years until 2014, the only Deemed-to-Satisfy (DTS) solution for bushfire construction was AS 3959 *Construction of buildings in bushfire prone areas* [2]. AS 3959 is based on the prescription of external surfaces in order to reduce the combustibility and limit ember entry in to the building and building cavities. Close control of construction gaps is required on the building envelope to prevent access by burning embers to combustible structural and non-structural materials behind the external surface.

In 2014, the National Association of Steel-framed Housing Inc (NASH) published a new Standard for buildings in bushfire areas: NASH Standard – *Steel framed construction in bushfire areas* [3]. The NASH Standard is referenced in NCC 2016 Volume Two as an additional deemed-to-satisfy solution. The NASH Standard is based on non–combustible construction using original research and field studies by CSIRO together with fire engineering assessment. Non–combustible construction involves using non-combustible materials for the external cladding, structure and internal lining. It does not rely on specialised external fire protection finishes or close control of construction gaps and therefore represents a cost-effective strategy to protect residential and other buildings from ignition due to bushfire attack.

The scope of the NASH Standard covers steel framed wall and floor systems with non-combustible wall cladding and steel roof framing with steel sheet roofing. Masonry wall systems are also included. Other cladding systems such as tiled roofing were evaluated during the development of the Standard but are not currently included. Windows, external doors, screens, shutters and some roof mounted equipment use AS 3959 solutions for the relevant Bushfire Attack Level (BAL).

With two clear options for bushfire building design available as DTS solutions in the NCC, designers need guidance to navigate the choices and arrive at appropriate solutions. This paper explores the factors to be considered with reference to a Case Study of a retirement village development in Bacchus Marsh to the west of Melbourne Victoria. The impact on ember resistance of different structural and cladding choices, within the client's specifications, are examined in developing NCC compliant solutions.

2 BUSHFIRE ATTACK

2.1 BUSHFIRE EVENTS IN AUSTRALIA

Bushfires in Australia result in significant destruction of natural resources and property in addition to deaths, injuries and community dislocation. Average long term annual property losses are around 100 dwellings representing around A$50 million. [4]. Most losses occur in major events and most are due to ember attack.

Three relatively recent events highlight the scale of the property effects involved. In Canberra in January 2003, more than 500 houses were lost in one afternoon on the western edge of suburban Canberra. Ember attack alone, or in conjunction with some radiant heat from local isolated fires or adjoining houses, accounted for 85% of losses [5]. The destroyed houses were all at a distance of 50 to 300 metres from the vegetation. [6]

In Victoria in 2009, over 173 lives and 2000 homes were lost in Australia's worst ever bushfire event, the majority in the Kilmore East region. The losses were in rural townships and the majority (67%) were due to ember attack alone or in conjunction with some radiant heat [7].

In the Blue Mountains west of Sydney in October 2013, over 200 homes were lost in the townships of Winmalee and Yellow Rock. Whilst many of these homes were in close proximity to bushland, the majority (85%) succumbed to ember attack. [8]

2.2 ATTACK MECHANISMS

Australia's CSIRO has undertaken detailed analyses of bushfire events over many decades [5] [7] [8] [9]. As a result, the mechanisms of bushfire attack on houses and the way different types of construction materials and systems respond are well understood and documented. This research has been used to support national, state and local policies and standards aimed at improving the survival of buildings subject to bushfire attack.

There are three main modes of attack by a bushfire on houses:

- burning embers
- heat radiation
- flame contact.

Not all fires involve all three modes of attack on every house, and different materials are affected in different ways by each mode. Each mode needs to be understood for its effects to be determined and for effective defensive measures to be devised and implemented.

Ember attack is the most common and persistent mode of attack, commencing before the fire front and persisting for several hours afterwards. Ember attack consists of airborne embers that can enter gaps in a structure or ignite fine fuels or combustible surfaces on or adjacent to the building. Radiant heat is at damaging levels for perhaps 5-10 minutes before and after the flame front passes. In the worst case, flame contact may impinge on the building for just a few minutes. Strong winds associated with fires may exacerbate the effects of all three attack mechanisms. Overall ember attack accounts for the overwhelming majority of house loss in Australian bushfire events.

Bushfire events also create local fires that may be as large as or larger than the bushfire itself, in terms of an individual house. Once alight a burning house, outbuilding, vehicle or woodpile creates ember, radiant heat and flame risk to adjacent properties. This mechanism of attack is particularly destructive on smaller allotments in suburban areas. [10]

2.3 BUILDING RESPONSE

A building element ignites when it is exposed to a source of flame or heat and reaches its ignition point. Commonly the source of flame is provided by embers and burning debris. If this burning material breaches the building envelope, or ignites adjacent litter or kindling, building ignition can occur. Houses are not consumed by bushfires, but by house-fires started by the bushfire.

At peak levels, radiation can crack and distort windows, doors and cladding materials, allowing breaches of the building envelope and ember attack on the building structure and flammable contents. Radiation can also preheat a combustible material to the point that it auto-ignites or is readily ignited by embers. Where the source is an adjoining house already alight, the attacked features may be on any side of a house. Flame contact can cause building ignition when exposed materials, dried and prepared by sustained wind, ember and radiation attack, are contacted directly by flames.

Once a combustible building element has ignited, spread of fire to adjoining elements is possible, creating a larger fire that may not be resisted by other elements, and may produce more intense effects than the fire front itself. Local element fires may also impede egress from the building via otherwise safe paths.

3 NCC REQUIREMENTS

3.1 PERFORMANCE

The NCC requires that [1]:

> "A Class 1 building or a Class 10a building or deck associated with a Class 1 building that is constructed in a designated bushfire prone area must, to the degree necessary, be designed and constructed to reduce the risk of ignition from a bushfire, appropriate to the—
> (a) potential for ignition caused by burning embers, radiant heat or flame generated by a bushfire; and
> (b) intensity of the bushfire attack on the building."

The level of attack intensity and the level of risk reduction are not quantified, and "reducing the risk of ignition" is not a particularly high threshold. However, Leonard et al [11] have observed that, similarly to the description of structural performance, the description of bushfire performance of buildings consists of three parts:

(i) the description of the bushfire actions that contribute to the likelihood of ignition,
(ii) the description of measures used to reduce the likelihood of ignition to buildings and
(iii) the description of the methods used to evaluate the solutions.

Approached in this way, rational solutions may be developed that address the NCC performance requirements in a verifiable way. However, there is still very wide scope for solution developers to apply their own interpretations to the performance requirements. Individual solutions may therefore exhibit a wide range of actual performance under real bushfire attack conditions.

3.2 SOLUTION DEVELOPMENT

The onus placed on solution developers by unquantified performance requirements is considerable. Rather than developing the solutions based purely on customary practice, it may be necessary to consider the higher level properties of constructed systems that impart efficiency, security and value in the built environment. These include reliability, robustness and resilience.

Reliability

A key issue is the expected reliability of a design solution which will be a function of:

(a) initial likely reliability of solution;
(b) durability of solution over time which may or may not be a function of maintenance;
(c) level of maintenance required;
(d) likelihood of solution being modified over time and
(e) influence of other structures that may be built after the initial construction, eg fences, sheds, woodpiles etc.

Robustness

Robustness is that property of structural systems that seeks to achieve proportionality of damage to the severity of an overloading event. It will be maximised when bushfire design solutions:

(a) have few “weak links” that allow progressive spread of damage from minor sources;

(b) consist of materials and assemblies that retain physical properties when thermally loaded beyond their design capacity, and

(c) include protection of inherently vulnerable and brittle elements such as windows.

Resilience

Resilience is that property of a building, system or community that facilitates its return to a functional state following overload. In the context of bushfire damage, resilience will be maximised when:

(a) there is a high probability of an attacked building remaining habitable and

(b) There is a low time and cost to make badly damaged buildings habitable.

Against this background, two DTS solutions have been developed and are referenced as Acceptable Construction Manuals in the NCC, as described in the next section.

4 DTS SOLUTIONS

4.1 Available options

The NCC allows both AS 3959 and the NASH Standard as parallel DTS solutions for the design of buildings in bushfire areas. Parallel solutions are very common within the NCC, with other examples including:

- Slabs on ground can be in accordance with AS 2870 or the Acceptable Construction Practice in the NCC.
- Masonry construction can be in accordance with AS 3700 or AS 4773 Parts 1 and 2.
- Roof drainage systems can be designed and installed in accordance with AS/NZS 3500.3 or with the Acceptable Construction Practice in the NCC.

4.2 AS 3959

4.2.1 Bushfire Attack Level

AS 3959 is in two basic parts, the first of which quantifies the Bushfire Attack Level (BAL) to which a property may be subjected. The six levels are based primarily on the radiant heat flux emanating from the flame front: BAL-LOW, BAL-12.5, BAL-19, BAL-29, BAL-40 and BAL-Flame Zone.

The NASH Standard references AS 3959 for the site classification of BAL.

4.2.2 Construction

The approach to ignition resistance used in AS 3959 involves using specified materials and precise gap control on the exterior surfaces of the building. The required ignition resistant properties of the building envelope increase in steps based on BAL, creating a set of acceptable construction measures associated with each BAL. Specified maximum gaps apply equally to all BALs to limit the size of embers that can breach the envelope. The building exterior surface is required to resist all bushfire exposure conditions and environmental actions and protect all structural materials and services that lie behind it.

4.3 NASH STANDARD

A different approach to ignition resistance is to consider the habitable space defined by the interior linings and to construct all elements outside this space from non-combustible materials. A combination of non–combustible facade and cavity construction enables the building to be configured so that failure or damage to one element does not lead to an inevitable failure of the structure or a breach of the habitable envelope. This approach also means that the building’s performance is not highly dependent on the detailing, workmanship and maintenance of the external surfaces. It also results in fewer steps in the set of BALs for which a set of acceptable construction materials is required. The resulting structure is less vulnerable to a BAL assessment that is incorrect or increases post-construction.

4.4 DESIGN CHOICE

The different approaches taken by the two DTS standards have implications for the material selections available to the designer. For example, use of some combustible materials is restricted under the NASH Standard even where the risk is low.

The NASH Standard references AS 3959 for some components such as windows and doors which are commercially available with specific BAL ratings, where these components are consistent with the non-combustible philosophy of the NASH Standard. It is not otherwise possible to “cherry pick” the two standards in the one building.

In short, an early decision has to be made on which DTS solution - AS 3959 or NASH Standard - will be adopted. The next section describes some of the considerations relevant to that decision.

5 EVALUATION FACTORS

5.1 HIGH LEVEL CONSIDERATIONS

The remit of the design practitioner will vary from project to project. Some design decisions will already have been made by the client while others may rest with the designer to present options and recommendations. Therefore there is not a single list of decision factors applicable to every project, but rather a list from which factors relevant to the particular project may be drawn.

The high level attributes of reliability, robustness and resilience discussed earlier may be considerations for the designer, regardless of the base level of each that forms part of both DTS solutions.

For example, if the reliability of window performance with respect to resisting direct flaming (as might be expected in BAL 40 and Flame Zone conditions) is taken as 0.95 per window, then for a house with 10 windows the overall reliability will be 0.60. This indicates that there will be approximately a 60% chance of survival, if occupants were to remain within the house. It is assumed that once the building envelope is bridged, human survival will be unlikely. This hypothetical calculation only considers windows but serves to illustrate that unless the components of the building exhibit a high level of reliability in terms of their fire resistance, the building may exhibit a poor overall performance under bushfire attack.

From a robustness perspective, aging and poorly maintained buildings may become inherently less robust under bushfire attack by allowing ember entry to susceptible places that would not have occurred when new.

From a resilience perspective, a building may be more valuable to its owner if it had a greater likelihood of remaining intact and capable of resisting further post-bushfire damage than if it required immediate demolition.

Tenability (or defendability) and survivability are sometimes cited in discussion of the attributes of housing in bushfire areas. These factors require consideration of occupant behaviour and of human threats such as heat and smoke, and may be regarded as beyond the designer's control. A separate part of the NCC deals with private bushfire shelters – non habitable Class 10c structures intended to shelter limited numbers of occupants for a specified time during and immediately after an extreme bushfire event. Attaching the life sustaining properties of a private bushfire shelter to its associated Class 1 dwelling is not contemplated by current NCC performance requirements or in DTS solutions.

5.2 BAL-12.5 to BAL-40 SITES

For attack levels of BAL-40 and below, the most basic consideration is the choice of structural system. Where framed construction is adopted, the NASH Standard requires the framing to be steel whereas AS 3959 permits any framing to be used. Both standards permit unframed masonry and similar non-combustible wall systems.

For roof claddings, both standards allow steel sheet roofing but construction detailing is simpler with the NASH Standard. AS 3959 permits tiled roofing while the NASH Standard does not.

For external wall cladding, the NASH Standard requires the cladding to be non-combustible. AS 3959 permits timber to be used in certain forms at particular BALs, provided vents, weepholes and gaps are restricted to less than 3 mm. Construction detailing is simpler with the NASH Standard and gap accessories such as weephole mesh are not required.

For unenclosed floor framing, AS 3959 has no requirements at lower BALs while the NASH Standard requires steel framing at all BALs.

The NASH Standard references AS 3959 for some components such as windows and doors which are commercially available with specific BAL ratings.

5.3 BAL-Flame Zone SITES

Designing satisfactory solutions for BAL-FZ conditions is a challenging task. AS 3959 design requires, for many components, proven Fire Resistance Levels to AS 1530.4 or testing to AS 1530.8.2. Tests to these standards do not simulate the radiant heat time-temperature conditions likely to be encountered in a worst case bushfire attack.

The NASH Standard includes roof, wall and floor solutions for BAL-FZ conditions that were developed using test facilities that more closely model actual bushfire conditions.

BAL-FZ sites present particular difficulties for critical features such as windows and doors that have greater uncertainty as to ultimate performance under extreme fire conditions.

6 CASE STUDY

6.1 GENERAL DESCRIPTION

The project selected for study is a retirement village complex in Bacchus Marsh north-west of Melbourne. The site is within a Bushfire Prone Area (BPA), although its location is well away from any forested areas or woodland (Figure 1). At worst, it might be subject to some form of ember attack. However, since 8 September 2011, the Building Amendment (Bushfire Construction) Regulations 2011 [12] requires that all buildings in a BPA are to be designed to achieve a resistance of at least BAL-12.5.

6.2 PROJECT REQUIREMENTS

The project comprises a group of single storey, slab-on-ground dwellings with a variety of wall claddings and a mixture of steel and tile roofing. Earlier stages of the development were constructed prior to the post-Black Saturday regulation changes that reclassified many areas. These stages used steel framing but at that time the site was not considered to be in a BPA and hence did not require a BAL-12.5 construction level.

The client was amenable to considering different approaches that would achieve satisfactory bushfire resistance at equal or lower overall cost. As the NASH Standard was not yet referenced in the NCC at the time of the project, a fire assessment was prepared by Noel Arnold and Associates to support an Alternative Solution. The fire assessment was reviewed by CSIRO in accordance with the procedure required by Victorian regulations.

6.3 SPECIFICATION DETAILS

The initial specification for Stages 2 and 2A called for the following materials:

- Timber roof trusses and wall framing
- Timber roof and ceiling battens
- Tile and sheet roof to specific buildings
- Timber external feature panelling
- Unspecified pergola roofing
- Unspecified roof and wall insulation
- Unspecified downlight construction
- Unspecified ceiling access panels
- Unspecified vents and service ducting in roofspace

Implementing the design via an AS 3959 solution would involve the following considerations and precautions:

- Full sarking of the roof system for both sheet and tile roof cases
- Covering or replacement of lower 400 mm of any combustible external wall cladding
- Non-combustible pergola roofing
- Treatment of vents, weepholes and gaps larger than 3 mm to reduce maximum aperture size to 2 mm.

Implementing the design via a NASH Standard solution would involve the following approach:

- Steel roof trusses, battens and wall framing
- Non-combustible external wall cladding
- Steel or polycarbonate pergola roofing
- Fibreglass or other non-combustible insulation
- Non-combustible roof vents and service ducting
- Screening to downlight units
- Elimination of roof sarking and weephole screening

6.4 COMPARISON

AS 3959 permits the use of a sarking membrane to resist the entry of embers through gaps and fissures. Sarking is noted in Amendment 2 to AS 3959 as being for the purpose of "secondary" ember protection, with mesh and mineral wool being used to prevent ember entry via gaps which are greater than 3mm. For a general roof situation, ember protection to the roof space is important since there may be combustible structural members, insulation or stored materials within the roof space, as well as penetrations through the ceiling membrane such as downlights and exhaust fans that would allow entry of embers into the main part of the building.

The ability of sarking to resist ember attack depends on the type of sarking adopted rather than its flammability index. The latter requirement appears to be aimed at limiting the extent of flaming that could result should ignition of the sarking occur due to ember attack. Testing has demonstrated that sarking acceptable to AS 3959 (with a flammability index not greater than 5) is vulnerable to ember attack [13]. This is a key factor in assessing the expected performance of the original construction specification.

The proposed construction details provide for non-combustible cavities within the walls and ceiling and protection of the interfaces and upper surface of the ceiling with non-combustible fibreglass. These cavities are contained between the exterior non-combustible linings and the interior non-combustible linings, with the cavities containing only non-combustible materials such as steel members and fibreglass. Such construction gives a higher level of ember protection than AS 3959 due to the uncertainties associated with sarking and the absence of combustible framing close to the sarking.

The overall effect of these and similar detail considerations, using the NASH Standard solution, would result in buildings with a higher level of ember resistance than the minimum required. Window and door specifications would be identical under either solution. However, since the site is remote from classified vegetation, radiant heat from that source to present a threat to glazing is not a realistic possibility.

7 SUMMARY/CONCLUSIONS

Ember attack is the destructive action most likely to be experienced by buildings in bushfire prone areas and is by far the most common cause of building destruction in bushfire events. Radiant heat, when it is a factor at all, is most likely to be the result of a local fire source close to the building and not from the forest fuel. When choices of apparently similar merit are available to structural and architectural building designers for projects in bushfire areas, a focus on minimum requirements may not produce the best value outcome for the client, especially when quantifying the minimum is itself challenging. There is value in considering the “big picture” objectives of reliability, robustness and resilience along with the routine details of the design. Careful attention to ember resistance though greater use of non-combustible materials offers a straightforward, verifiable and cost-effective means of improving building performance in bushfires.

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