PLENARIES

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FALLACIES AND FACTS IN DESIGN FOR FIRE RESISTANCE

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ABSTRACT

This paper exposes a number of fallacies about fire resistance in buildings. Much of the conventional wisdom is incorrect. By examining these fallacies, the paper asserts that there is a legitimate role for fire resisting elements in any building fire safety strategy, despite increasing reliance being placed on sprinklers and other active fire protection systems. The paper explores many aspects of fire severity and fire resistance as applied to modern building design, pointing out that there is much more to fire safety than providing buildings with code-specified fire resistance, and that rational consideration of all factors is necessary.

INTRODUCTION

The current trend in modern fire safety design is to place increasing reliance on active fire protection systems, and to rely less on passive systems. The reasons for this trend include the increased regulatory concern with life safety and less emphasis on property protection in fires, and the increased acceptability of active systems such as automatic sprinkler systems. There is no doubt that a sprinkler system is one of the best forms of fire protection, but there is still a place for passive fire protection, including fire resistance, in most buildings.

This paper examines several fallacies commonly circulated about fire resistance, and puts them into a factual context, with themes drawn from a recent paper on structural safety[1].

Fallacy 1 All code-designed buildings are fire safe

The traditional assumption about fire safety is that all code-designed buildings are safe. This is a fallacy. Most building owners want to know only if their building complies with all codes and regulations, rather than bother about safety in the event of a fire which “will never happen to me”.

Most modern fire safety codes allow safety to be provided either by a prescriptive “acceptable solution” or by performance-based fire engineering assessment and design[2]. Complying with a prescriptive “acceptable solution” does not guarantee safety, because most real buildings are different from the hypothetical buildings which were in the minds of the code-writers; and the design and approval are done by people more focussed on the rules than on possible fire scenarios. It is easy to design an unsafe building which complies with all the rules.

As the world moves from prescriptive codes to performance-based codes, building owners and designers are being forced to think more about the actual consequences of a possible fire. This change in focus is the major benefit of performance-based design, but it still does not mean that all code-designed buildings are safe. This is because designers cannot fully investigate all possible fire scenarios, they are under pressure of time and cost, and some are poorly qualified by education or experience for such work.

Even if the design is safe, the building has to be constructed, maintained and operated correctly if safety is to be ensured. Documentation is a critical link between the designer and the finished building, which can break down at many steps along the way if proper care is not taken by all parties[3].

Fallacy 2 All buildings need fire resistance

It is not true that all buildings need fire resistance. Many can meet the required performance levels of fire safety with no fire resisting elements. Provision of fire resistance may be essential, or unimportant, or somewhere in between, depending on the building, its use, size, occupancy and many other factors. Before exploring this further, it is useful to ask:

What is fire resistance?

“Fire resistance” is a characteristic assigned to individual building elements, not to whole buildings. A building element is deemed to have *fire resistance* if it can survive a standard fire resistance test for a particular time, while meeting certain criteria. The criteria are one or more of stability (ability to carry load), integrity (ability to prevent passage of flames) and insulation (ability to prevent passage of heat). Integrity and insulation are *containment* functions, providing resistance to fire spread, whereas the stability criterion is intended to prevent *collapse*.

A building element with an approved level of fire resistance is assigned a Fire Resistance Rating (FRR) or Fire Resistance Level (FRL) which is quantified (in minutes) for stability, integrity and insulation separately.

The expected performance of fire rated elements is that, for a certain time, they can:

- Prevent smoke spread (not specifically assessed in fire resistance tests)
- Prevent fire spread
- Limit deflections
- Prevent collapse

If the appropriate combination of fire rated elements are assembled into a complete building, they can contribute to safety of the building and the occupants in the event of a fire by providing the functions listed above.

Fire resistance applies to fires which have grown to the “post-flashover” stage, where all exposed combustible materials in the room are involved in a “fully developed” fire. A fire resistance test does not assess the early fire hazard properties of materials, such as ignitability or flame spread on surfaces. These are important attributes of materials for fire safety, but are not covered in this paper.

Why provide fire resistance?

Design for fire resistance depends on the fire safety strategy for the building, which in turn depends on the fire safety objectives. Fire resistance can contribute in a major way to both life and property protection, depending on what other fire safety systems are in place. The main reasons for providing elements with fire resistance are:

- to protect the escape paths from the building
- to prevent fire spreading from room to room on the floor of fire origin
- to prevent spread of fire to upper floors of the same building
- to control external fire spread to adjacent buildings
- to prevent collapse of parts of buildings or the entire building

Various combinations and levels of these are required in different situations. The larger and taller the building, the more important these items become.

Fallacy 3 Certain buildings need no fire resistance

It is often asserted that certain buildings need no fire resistance. Two often quoted statements are “No fire resistance is required if we can get the people out quickly” and “Sprinkler protected buildings require no fire resistance”. These assertions, which are often wrong, are examined below.

“No fire resistance is required if we can get the people out quickly”

In some cases this statement is perfectly acceptable, but it all depends on the objectives of the fire engineering design. If an unsprinklered building has no fire resistance, with no compartmentation or structural fire protection, a significant fire will cause major damage or total destruction, even with intervention by fire fighters. Provision of containment elements with some level of fire resistance may be necessary to allow for occupant movement, fire fighter safety and property protection.

Occupant movement

Many designers claim to be able to predict occupant movement in the event of fires. Many evacuations will take place much more quickly than predicted, but there is always the possibility of situations which the escape planner has not accounted for. For example many people in high-rise apartments just don’t bother to leave when fire alarms are sounded. People do not always behave in the way that the computer models want them to.

Fire fighter safety

Fire fighter safety is a difficult matter, because there are some situations where it would be best for fire fighters to watch a building burn and protect adjacent exposures, rather than expose themselves to unnecessary danger by entering the building to fight the fire. However, there are cases where they may need to enter a building, in which case they should expect some level of personal safety. The New Zealand Building Code requires that all buildings have provision for fire fighter safety. This has often been ignored, but a recent determination[4] by the Building Industry Authority (BIA) has made it clear that these provisions will be addressed more seriously in the future in New Zealand.

Property protection

Most building owners are unaware of the likely property losses to their buildings and contents in the event of an uncontrolled fire. Even if the codes require no fire resistance, many owners would be prepared to take extra precautions if they knew that compartmentation or other measures would greatly reduce the likely consequences of a fire.

“Sprinkler protected buildings require no fire resistance”

There is no doubt that automatic sprinkler systems provide extremely effective fire protection for most buildings. If sprinklers operate as intended, fires do not grow to flashover, and the probability of significant fire spread or structural collapse is negligible.

If no fire resistance is provided, there is always the nagging question “What if the sprinklers don’t do their job?” The probability of this is very low, but the possible consequences are devastating, especially in tall buildings. There are many possible reasons for a sprinkler failure, the main ones being a fire in excessive fuel load overwhelming the sprinklers or the water supply being turned off for maintenance. Well managed buildings have systems in place to prevent such events, but not all buildings are well managed.

Many sprinklers will not operate after a major earthquake, because of damaged pipework within the building or leading to the building. This is a major concern in high seismic areas such as Wellington, where a major earthquake will occur in the next few decades. The buildings which are most vulnerable to damage or loss of life in the event of sprinkler failure are buildings with very large floor plans, buildings where people are unable to escape quickly, and very tall buildings. Building codes should have greater requirements for fire resistance in such buildings, even if sprinklered, especially in seismically active areas[5].

Fallacy 4 The standard test fire simulates real fires

A building element is considered to have sufficient fire resistance if the following design equation is satisfied:

$$\text{FIRE RESISTANCE} > \text{FIRE SEVERITY} \qquad (1)$$

Both are measured in terms of the standard fire resistance test, which does not represent the severity of a real fire.

What is fire severity?

In a testing environment, fire severity is the severity of the standard test fire used in most of the world’s furnaces. The standard fire was developed many years ago as a representation of a typical post-flashover fire, but it is well known that this test fire is not representative of most real fires.

Fire severity is quantified using a time-temperature curve. The standard fire grows to about 700ºC after 10 min, 850ºC after 30 min, and continues indefinitely until the testing agency turns off the gas. Some real fires in modern buildings become hot very rapidly after flashover, with temperatures up to 1000ºC in 5 min, whereas it would take one and a half hours to reach this temperature in a standard test. The large amount of plastic fuel in modern homes was not considered when the standard fire was developed.

Most post-flashover fires in rooms are ventilation-controlled, such that the rate of heat release is governed by the amount of air which can come in through the windows, and the amount of combustion products which can get out. The larger the windows the greater the heat release rate. The duration of the fully developed stage depends on the heat release rate and the total amount of fuel available. The temperatures in the compartment depend on the heat release rate, the size of windows available for convection and radiation of heat and the insulating properties of the building materials, such that well insulated rooms will have higher temperatures for the same heat release rate.

The three most common ways of quantifying fire severity are to use a code-specified exposure to the standard fire, an equivalent exposure depending on the building, or a realistic fire curve including a decay phase. All of these methods are based on fully developed fires in small or medium sized rooms. None of them allow for the progressive spread of fire in large spaces.

Code-specified exposure to the standard fire

The traditional approach, still used in most countries, is for the building code to specify a fire resistance rating, say two hours, which implies a fire severity of two hours of standard fire exposure. This does not reflect the expected severity of a real fire.

Equivalent exposure to the standard fire

A more recent approach is to use the fuel load, ventilation, and compartment geometry to estimate the equivalent exposure to the standard fire using a "time equivalent formula", such as that in the Eurocode[2]. The equivalent time is the time of exposure to the standard fire that has similar severity to a complete burnout of the compartment. This type of empirical formula is more realistic than a code-specified exposure, but does not accurately simulate a real fire[6].

Realistic fire curve

There are many methods of generating a realistic time-temperature curve for a real fire. The easiest method is to use a parametric formula, such as those based on the Eurocode. This method provides a time temperature curve for the whole post-flashover fire, including the decay phase[6]. The resulting curve can be used in explicit calculation of fire resistance of structural members or containment elements, to predict resistance to a complete burnout of the compartment of origin.

Fallacy 5 F.R.R. describes fire performance of building elements

It is widely assumed that the fire resistance rating (FRR) describes the real fire performance of building elements. This is not true, for many reasons.

Containment

Some real fires are much more severe than the standard fire, especially in the first ten min of exposure. This can result in insulation and integrity failure at times much less than the FRR achieved in a standard test. For example, recent tests in simulated domestic construction led to failures of 30 min rated systems in only 15 min[7].

Details

Many details of real buildings have never been tested in fire resistance tests. The FRR of an element or assembly represents its performance in a standard test, but the element or assembly will be used in many different ways in real buildings, with a multitude of details for junctions, fittings, outlets etc, all of which can have lower fire resistance unless properly detailed[8].

Loads and support conditions

The loads and support conditions during a fire resistance test may be very different from those found when the same element is used in a real building. For example, the performance of a load-bearing stud wall may be much higher in a fire test than in a real building if a large part of the test load is carried by the end studs which are fixed to the specimen testing frame.

The largest fire resistance furnaces are not large enough to test all elements at full size, so allowances have to be made. In theory, the stresses in a tested element should be the same as when the element is used in a building, but it is not possible to keep the same ratio of flexural to shear stresses, for example, when spans are changed. Fire resistance ratings do not describe the real fire performance of building elements. They should be considered to be a useful comparative method of ranking the fire performance of alternative materials and assemblies.

Fallacy 6 Calculations can eliminate fire resistance tests

It is not true that modern computer-based calculation methods can eliminate the need for fire resistance tests. This is part of an even larger fallacy that “modern computer programs can calculate anything and everything”. Not so. In computer simulations of complex systems, computing power is rapidly outstripping the knowledge of the underlying physics, and input assumptions such as thermal and material properties at elevated temperatures. Many computer modellers have lost sight of the “principle of consistent crudeness”[1], wasting effort by computing part of the problem with a fine level of accuracy out of balance with the crudeness of the least well defined part of the problem.

There have been rapid developments in computer modelling of fire resistance, but such calculation methods will never replace the need for testing. Even the most sophisticated programs are unable to accurately model such phenomena as shrinkage and cracking, moisture movement, falling off of wallboard, creep in structural materials, spalling of concrete, formation of char in wood, etc. Even if programs were available to accurately predict fire performance in a given fire, there is still great uncertainly about other aspects of the fire safety problem such as the fire growth rate, time-temperature curves, smoke movement and human behaviour.

Fallacy 7 Safety factors are not necessary in fire design

In the traditional process of design for fire resistance, prescriptive building codes have specified the required FRR for particular elements, and designers have provided suitable elements with no consideration of the probability of failure, or safety factors. As predictions of fire severity become more accurate, it becomes increasingly important to consider safety factors when providing elements with fire resistance, i.e. when satisfying the design equation (Equation 1).

A probabilistic context now becomes important, and many of the important questions are yet to be answered. For example, is the FRR from a single test the most likely time to failure for typical construction, or does it represent the top end of a distribution, the test specimen having been very carefully constructed, specially for the test? What is the statistical distribution of likely post-flashover fires, and where in this distribution should the design point be? A simple start on this path would be to use higher safety factors for very tall or otherwise significant buildings.

Fallacy 8 Fire resistance of elements indicates fire safety of a whole building

Fire resistance ratings of individual elements do not represent the fire safety of a whole building, for many reasons.

The actual fire performance of a structural element in a building may be better than indicated by a test result, because of beneficial conditions such as flexural continuity or axial restraint which did not exist in the test. It is possible to estimate the effect of such items by calculation[6]. Recent full scale tests in multi-storey buildings with composite steel-concrete floors on unprotected steel beams have shown that the building has much better fire performance than would be predicted by fire tests of the elements alone.

On the other hand, the real fire safety in buildings constructed entirely of elements with a specified fire resistance may be much poorer than the fire ratings would suggest. For example, there is almost no fire test data to evaluate the resistance to vertical fire spread via external windows, or junctions between various fire rated elements. There are no ways of quantifying building management issues such as wedging doors open or reducing fire resistance during maintenance and alterations, especially in concealed areas. Providing individual elements with fire resistance is not enough to ensure safety.

Fallacy 9 Concrete structures are safe in fires

It is a long held fallacy that “fire proof construction” provides adequate fire safety. Dramatic photographs of the fire disasters in multi-storey reinforced concrete buildings in Sao Paulo in the 1970s dispel this fallacy. It is the contents of a building rather than the structure which provides the fire load. Fire spread from one part of a building to the next will be via the weakest link, not through the part with the greatest fire resistance. It is just as easy to have weak links in concrete buildings as in buildings of other materials. Concrete structures do not often collapse in fires, but occasional major collapses have been reported. Weak aspects of the fire resistance of concrete structures are spalling of cover concrete and poor connections of precast concrete elements in tilt-up wall construction.

Fallacy 10 Unprotected steel buildings collapse in fires

It is true that some unprotected steel framed buildings have collapsed during fire exposure, but there are other occasions where there has been no serious damage and no collapse. Unprotected steel can survive fires without serious damage under certain circumstances, including combinations of low fire load, very low ventilation (no flashover), very high ventilation (heat carried away by large roof vents), and low loads on the structure at the time of the fire. As mentioned earlier, recent tests of unprotected steel beams (with protected columns) in multi-storey steel buildings have shown large deflections but no fire spread and no collapse. There are many ways of applying protection to steel member, to provide any desired level of fire resistance.

Fallacy 11 Timber buildings are unsafe in fires

The public often believe that timber buildings are unsafe in fires, because wood burns readily. There was a time when poorly built wooden buildings, with exposed internal and external timber linings and no protective materials, were definitely unsafe in fires, as seen in many historical conflagrations around the world. Modern timber buildings can be designed and constructed to be just as safe as other materials. It is generally the contents rather than the structure which provides the fuel, but it remains unsafe to have large areas of exposed wood-based lining materials on walls and ceilings in unsprinklered buildings.

Large structural timber members require no applied fire resistance because of the predictable rate of charring on exposed surfaces, with the cooler wood beneath being able to resist loads for a considerable time. Structures with light timber framing (most often houses or apartment buildings) have protective sheet materials such as gypsum plasterboard to protect the timber from ignition and charring, and to provide resistance to fire spread.

Fallacy 12 Fire resistant elements are not damaged in fires

If a building element has a two hour fire resistance rating, that does not mean that it can withstand exposure to the standard fire for two hours with no damage. All it means is that the failure criteria (stability, integrity, insulation) will not be reached.

The same applies to building elements in real fires; even if the element does its job of preventing fire spread without collapse, it may have suffered considerable damage, such as large deflections, cracks, charring of exposed wood or protected wood, loss of strength of concrete. Some materials such as mild steel tend to regain full strength on cooling, but others such as cold drawn prestressing steel will have significant loss of strength. Many materials will require replacement or strengthening after a fire, requiring considerable time and expense. If a building owner expects to retain the use of a building immediately after a fire, it is essential to provide a sprinkler system. Without sprinklers, fire spread must be controlled with a much higher than normal level of containment and structural fire protection.

Fallacy 13 Fire resistance is expensive

The cost of providing building elements with fire resistance is often not as expensive as expected, for several reasons. Many existing building elements already have an inherent level of fire resistance, and it is simply a matter of ensuring that details such as junctions and penetrations are protected appropriately to provide sufficient containment. When many lightweight assemblies such as walls and floors are provided with sufficient toughness and mass for structural and acoustic performance, often no extra detailing is required for fire resistance. It is also important to note that performance based design can result in the appropriate level of fire resistance being much less than would have been required by a traditional prescriptive code, and recent advances in understanding of fire resistance have demonstrated acceptable performance of unprotected elements that previously required expensive fire-proofing. In situations such as these, a significant level of passive fire protection can be provided without great expense, providing increased levels of safety for the unlikely occasion when it will be needed.

Fallacy 14 A degree in fire engineering makes you an expert

Fire safety engineering is a huge subject. Only a small amount of it can be taught, even in a full year Masters degree programme such as at the University of Canterbury.

To become a competent fire engineer it is necessary to build on an academic base with wide experience of the building industry, including both design and construction. It is also necessary to learn as much as possible from real fires, to observe the growth and power of uncontrolled fires in buildings, considering the impacts on the fabric and structure of the building, and on the contents and occupants.

CONCLUSIONS

This paper has shown that there are many fallacies about fire resistance in the world of fire safety. Passive fire protection is always going to be a part of any fire protection strategy, but the strengths and weaknesses of passive protection need to be understood by designers and approvers of fire safety systems in buildings.

Current trends in fire protection are moving towards greater reliance on active systems and decreasing reliance on passive systems such as fire resistance. The optimum solution will always be a balance between active and passive systems, the balance being different for every building. If the pendulum swings too far away from passive systems, the world could be left with a generation of buildings with inadequate fire resistance, which will be very expensive to retrofit.

Many building owners would be prepared to take extra precautions to obtain enhanced property protection if they knew how compartmentation and other measures could greatly reduce the likely consequences of an unwanted fire, especially in unsprinklered buildings.

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