THREE CASE STUDIES OF INNOVATIVE SOLUTIONS TO FIRE-SAFETY ENGINEERING PROBLEMS

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ABSTRACT

Fire Safety Engineering has been applied by the CSIRO in Australia for a number of years in situations where the application of prescriptive building regulations is costly and restrictive in terms of building design. The flexibility that Fire Safety Engineering can offer designers is dependent on innovative solutions to fire-safety problems. This paper discusses three case-studies where fire science has been used in conjunction with fire safety engineering to address various aspects of building design involving sprinkler systems. The first case involves an exhibition hall where sprinklers were replaced by an alternative fire suppression system. The second case discusses an airport where the sprinkler system was rationalised and savings of one million dollars were realised. The final case is associated with balconies in a non-sprinklered 12 storey apartment and where a partial sprinkler system provided the solution to the problem of fire-spread between floors.

CASE STUDY 1
AN ALTERNATIVE TO SPRINKLER PROTECTION IN AN EXHIBITION HALL

The exhibition hall in question is part of the Brisbane Convention and Exhibition Centre. The exhibition hall is 280 m long, 70 m wide and has a roof which varies in height between 14 m and 24 m. The hall is able to be subdivided into 4 separate halls.

Sprinkler Efficiency in the Exhibition Halls.

There are a number of reasons why sprinklers would not provide effective fire suppression in this exhibition hall. These are discussed below.

Limited impact of sprinklers due to high roof.

One of main reasons for installing a sprinkler system is to ensure that any fire that does occur is kept small and manageable, if not totally extinguished.

In an office for example where the ceiling is relatively low, sprinklers do make a significant impact. By calculation it can be shown that in a sprinkler protected office with a 3m ceiling height, sprinklers would activate when the fire intensity is approximately 2.5 MW, and a properly designed and installed sprinkler system would ensure that the fire did not grow any further. In an unsprinklered office a fire could reach 10 MW quite easily, depending on the ventilation factor and fuel load. A reduction of fire intensity from 10 MW to 2.5 MW is quite significant.

Morgan and Hansell [1] have shown from an investigation into actual fires that for sprinklered offices the maximum floor area involved in fire was around 16 m^2, while in the unsprinklered case the likely fire size was about 47 m^2.

In the Exhibition Hall, however, sprinklers are not likely to produce such a meaningful reduction in fire size. Calculations using fast-response sprinklers with a Response Time Index (RTI) of 50 and a sprinkler activation temperature of 68^{o}C, show that the lowest sprinklers, namely those at 14.5 m above the floor, would activate when an ultra-fast fire [2] is at an intensity of approximately 4.4 MW. For the sprinklers at 20.5 m high, the fire size at sprinkler activation is approximately 10 MW. Significantly, in approximately 50% of the building the ceiling is above 20.5 m and the resultant fire size at sprinkler activation would be greater than 10 MW. Where the highest sprinklers (24.5m) were located the shape of the roof in this building makes predictions on sprinkler activation times unreliable.

The concern was that with or without sprinklers, a fire could grow to an intensity of 10 MW or more. Such a fire would not only likely to cause considerable damage in itself, but the task of bringing such a fire under control by either automatic or manual means, would be made more difficult.

Reduced effectiveness of sprinkler water spray due to fire intensity.

With fires of intensities around 10 MW the interaction of sprinkler water droplets with the fire plume would reduce the suppression and fire control effectiveness of the sprinklers due to the upward velocity of the hot gases in the plume and the evaporation of the water due to the heat.

Alpert and Delichatsios [3] have shown that the significant factors in sprinkler/fire interaction are the plume velocity, the water spray velocity and the droplet size. These factors are encompassed in the fire intensity and the ceiling height, and the authors have demonstrated that an increase in ceiling height (from 3 m to 6 m) significantly reduces the spray penetration through the plume. Similarly they show that the spray penetration through the plume would be reduced when the fire intensity was increased from 2 MW to 4 MW.

In addition, the drop size distribution of a sprinkler spray is such that not all droplets would be capable of penetrating the fire plume due to the upward velocity of the hot gases and evaporation. In the subject building the average plume velocities in a 10 MW fire would be of the order of 5 m/s, and the average plume temperature below a height of 15 m exceeds 100°C .

The implications in the Exhibition Hall where 50% of the ceiling height s more than 20 m and where the fire intensity would be more than 10 MW was that the effectiveness of the sprinklers would be significantly reduced.

Is a 10 MW fire a realistic scenario in an exhibition hall?'

Discussion.

A selection of fire loadings in exhibition halls taken from the Workshop CIB W14 [4] is listed below;

Car exhibitions	200 MJ/m^2
Furniture exhibitions	500 MJ/m^2
Machine exhibitions	80 MJ/m^2
Exhibition of Paintings	200 MJ/m^2

For comparison, the same source lists the following;

Department store	400 MJ/m^2
Furniture store	400 MJ/m^2
Chemical Laboratory	500 MJ/m^2

In addition one must consider the situation when the exhibitions are being set up or dismantled, at which time there is an excess of packaging materials (cardboard boxes, timber crates etc), which add to the fire hazard during these periods. The Chicago McCormick Place exhibition centre fire [5] occurred when exhibits for a home show were being completed.

The answer to the question "Is a 10 MW fire a realistic scenario in an exhibition hall?" is therefore "Yes".

An Alternative to Sprinklers.

Meeting the design criterion.

On the assumption that the fire growth rate could be ultra-fast, the 10 MW heat output would be reached in approximately 4 min from the time that the fire reached the so-called established burning stage of around 10 kW). On this basis it would not be sufficient to rely on Fire Brigade intervention alone. Although Fire Brigade response time might be in the vicinity of 4 min, additional time would be required to locate the seat of the fire, and set to up hoses for fire fighting. Attack on the fire is also not likely to commence until evacuation is complete.

In terms of water quantity and effectiveness of fire fighting, hydrants would theoretically be adequate to control a 10 MW fire. If a system providing water equivalent to that from a hydrant or hydrants could be designed to get water onto a fire in less than 4 mins then the design objectives (10 MW max) could be met.

The Method

In considering the approach used in some large aircraft hangars where automatic foam monitors are used to apply a foam solution over the floor in the event of an aircraft fuel spillage, it was decided that one could control a 10 MW fire in the Exhibition Halls by a similar method, namely fixed monitors, but without the foam.

A major benefit of such a monitor system would be its ability to apply water to the seat of the fire from the side of the plume, rather than from above the plume as is the case with sprinklers. This would obviate the difficulty of having to penetrate the plume for its full height, and the fire suppression effectiveness would be substantially enhanced.

The Design and Operation of the Monitor System that was installed.

In order to ensure total coverage of the floor area, bearing in mind high obstructions that could be part of an exhibit, four monitors were installed in each Hall. The monitors were mounted at an elevated position at a height of approximately 4 m above the Exhibition Hall floor. The nozzle size was selected by the mechanical consultants (Norman Disney and Young) on the basis of the quantity of water that should be delivered to provide a density at least equal to that of a sprinkler system, together with the maximum distance that the water had to be projected. The maximum effective distance reached by each monitor was 40 m, using four monitors per hall. Being attached to the Hydrant system the water supplies were required by the authorities to allow the hydrants to operate simultaneously with two monitors. In operation, each monitor would be preset to oscillate through a certain arc and at a certain elevation when activated. Activation could be either remotely from the Control Room or manually by an operator at the monitor. The operators of the monitors would be either trained staff or Fire Brigade personnel.

In conclusion , the fire safety engineering solution to the fire suppression problem in this building was not only effective but achieved significant cost savings.

CASE STUDY 2
AIRPORT SPRINKLER SYSTEM COST REDUCED BY $1,000,000

This case study outlines fire-safety engineering methods that were used in a study of a sprinkler system which had been designed in accordance with the Australian Sprinkler Code AS 2118, and for which the estimated cost was in excess of ten million dollars. The engineering approach was motivated with cost savings in mind, but at the same time fire-safety objectives as required by the current building regulations, the Building Code of Australia, were to be maintained.

The building in question was the International Terminal Building at Sydney's Kingsford Smith airport. The study addressed the fire hazard associated with easily defined and separate areas typical of airports, such as Arrivals and Departures Concourses, Departures Hall, Baggage Claim Hall and Baggage Handling Areas, and because the layout, usage and fire loading in different compartments varied, a variety of methods were employed in the analysis. Four of these are discussed below.

First floor concourse (departures)

This concourse was approximately 300 m long had a fire load consisting of seats along both sides of the 10 m wide concourse.

Because the seats contained foam rubber filling it was necessary to establish the likely worst-case fire scenario as accurately as possible. To this end it was decided burn a selection of the seats in a furniture calorimeter in order to obtain data on their burning characteristics. This was done in the CSIRO furniture calorimeter in Melbourne.[7]

From the results gave us a likely worst case fire scenario was established taking into account fire growth rate and maximum fire intensity.

An analysis of corresponding sprinkler response times resulted in an increase in sprinkler spacing across the corridor, from the 4 m maximum allowed by the code, to 5.2 m. This arrangement would not give rise to any loss of sprinkler effectiveness because it was considered that those areas where the water application density was below standard would be at the pedestrian aisle between the rows of seats where the fire load was negligible.

Departures hall

In the Departures Hall the sprinkler code required sprinkler spacing in accordance with 'Ordinary Hazard' requirements, with a maximum coverage of 12 m^2 per sprinkler head.

Although the floor areas are very large (around 10,000 m^2), the average fire load was very low, and more importantly, those parts having a significant fire load, namely check-in counters, groups of seats or carousels full of baggage, were separated by unfurnished floor areas. Calculations using FIRECALC Program 'Sprinkler' [8] showed that for an assumed worst case fire, namely, an ultra-fast fire in a check-in counter full of baggage, sprinklers at the Extra Light Hazard spacing of 21 m^2 per sprinkler, would operate when the fire had reached an intensity of approximately 4 MW. For adjacent check-in counters to be ignited, an intensity of around 8 MW would be required, as calculated using FIRECALC Program 'Radiation' [8].

It was concluded that the sprinkler system would not be required to handle a fire involving more than one check-in counter, and hence the recommendation to use Extra Light Hazard instead of Ordinary Hazard in this area was justified.

Canopy at roadway outside departures hall

In the context of the Sprinkler Code this canopy (140 m long) required two rows of sprinkler heads. A likely fire scenario was a car on fire at the kerb of the roadway. Being beyond the edge of the canopy there would be no convected flow of hot gases to activate the sprinklers. However, Grubits and Moulen (1983) [9] have shown that sprinklers can effectively be activated by radiant heat and FIRECALC Program 'Radiation' [8] was used to establish an optimum location for the sprinklers. It was also shown that a single row of sprinklers would provide adequate protection for the building in the assumed fire scenario.

Radiant Heat calculations showed that in the event of a car fire at the kerb of the roadway, the windows of the building closest to the car could be subjected to a heat flux of up to 13.5 kW/m^2, which was likely to break the glass and result in some risk of fire or smoke spreading into the building. Thus there was a need for some protection under the awning.

A single row of sprinklers below the awning ceiling was considered to provide sufficient protection in the assumed fire scenario. Calculations show that the radiant heat intensity likely to be received at a sprinkler head which is located 2m from the building widows, would be 19 kW/m^2, while the windows will be receiving around 13.5 kW/m^2 at the same time. Both the sprinkler bulb and the glass of the windows can be expected to break when the radiant heat intensity reached 10 kW/m^2, but because the sprinklers were closer to the source of radiant heat, they would be likely to reach this level before the windows.

Ceiling space above departures hall

This large compartment (approximately 10,000 m^2) varied in height between 1.5 and 3 m, and contained a timber floor and other combustibles such as electrical wiring. The concrete slab above consisted of inverted troughs which were 2.5 m wide and arranged in groups of five. Between each group was a narrow trough approximately 0.5 m wide.

The Sprinkler Code required sprinklers to be installed in the narrow troughs but it was evident that the effectiveness of these sprinklers was questionable on two counts. Firstly, if the sprinklers were installed at the optimum distance from the slab (around 100 mm) the water spray would be baffled by the sides of the troughs. Secondly, heat from a fire immediately below a narrow trough would travel very quickly along the trough and activate an excessive number of sprinkler heads.

Assuming that there were no sprinklers in the narrow troughs, the behaviour of hot gases from a fire below these troughs was examined. Using FIRECALC Program 'Plume' [8] in conjunction with the smallest fire that would activate the sprinklers, namely a 253 kilowatt (kW) fire, we found that a 10 m length of the narrow trough would be filled with hot gases in less than 5 s. Therefore, if baffles were placed at 10 m intervals along the trough, the hot gases would overflow from the narrow trough and into the adjoining larger troughs where the sprinklers would be activated with a minimal delay.

This resulted in the deletion of the 400 sprinklers from the narrow troughs.

The overall saving achieved in the airport by this fire safety engineering approach to sprinkler system design was 2800 sprinkler heads.

CASE STUDY 3
PREVENTING SPREAD OF FIRE FROM FLOOR TO FLOOR IN A 12-STOREY APARTMENT BUILDING

The issue in question arose because a developer wished to enclose a number of balconies with glass, thus making them into rooms instead of balconies.

The problem associated with enclosed balconies in a multi-storey building is related to the fire spread objectives of the Building Code of Australia (BCA) [10]; in particular, the upward spread of fire from one storey to those storeys above the fire affected storey.

The Building Code seeks to prevent the upward spread of fire by the provision of a spandrel, the function of which is to minimise the heat impact on windows above when flames are issuing from a window below.

Where balconies are not enclosed flames issuing from a fire would be deflected horizontally by the balcony above and this would prevent spread of fire to the floor above. In this case the balcony above would act as a spandrel. Where balconies were enclosed, the spandrel effect was effectively removed because the enclosed balcony becomes a room capable of reaching flashover conditions in a fire. Flames issuing from the windows of the enclosed balcony (having been broken by the heat of the fire) would then put the apartment above at risk.

In an effort to overcome this problem it was proposed to install sprinklers in the enclosed balconies. The apartments were not sprinkler protected.

This assessment examined the extent to which the above proposal would meet the vertical fire spread objective of the BCA.

<u>Fire Scenarios</u>

Because sprinklers would be installed only in the enclosed balconies and not in the apartments two fire scenarios were addressed, firstly a fire originating in the enclosed balcony and secondly, a fire originating in the adjoining apartment.

Fire Scenario 1

On the basis that the sprinklers installed in the enclosed balconies were installed to the requirements of Sprinkler Code AS2118 (as far as the Code can be applied in that situation) it may be assumed that a fire occurring in an enclosed balcony would be controlled by the sprinklers and flashover is unlikely. In these circumstances fire spread to the upper level would not occur.

Fire Scenario 2

For fire scenario 2 a fire is assumed to occur in an apartment adjoining an enclosed balcony. Because the apartment is not sprinkler protected it was assumed that the fire would reach flashover proportions and break the windows to the enclosed balcony and then the external windows of the enclosed balcony.

As a result there would be a flow of hot fire gases from the apartment through the enclosed balcony and out of the balcony window. The sprinklers in the balcony would be activated and the hot fire gases would then be flowing through the sprinkler water spray.

The Effect of Balcony Sprinklers.

In a flashover fire the temperature of the fire gases would be in the vicinity of 1100°C. As the flames and hot gases flowed out of a window the gases would be cooled by mixing with outside air. According to Butcher and Parnell [11] flame temperatures when they reach the floor level of the storey above would be about 600°C. At this temperature radiant heat from the flames issuing from the window below would be sufficient to cause breakage to the windows above, resulting in a potential for spread of fire to the level above the fire.

Where sprinklers are installed in the balcony the hot gases from the room of fire origin will be cooled by the sprinkler water spray before they issue from the window.

Theoretical studies by Morgan [12] indicate that the extent of cooling of the gases flowing through the water spray is related to the velocity of the gases - the lower the velocity, the greater the cooling. For a particular situation investigated by Morgan gases at 210°C flowing through sprinkler water spray at approximately 20 m/s were cooled by about 42°C. At approximately 7 m/s the gases would be cooled by about 140°C (a 67% drop in temperature).

In Fire Scenario 2 the hot gases flowing through a typical balcony were not likely to have a velocity higher than 7 m/s (the actual velocity would depend on the area of the window opening through which the gases are flowing).

Experimental work was carried out by Madrzykowski [13] in 1991 to measure the effects of sprinklers on tenability and temperatures of fire gases in a corridor adjoining a burn room. With a fire of 1 MW in the burn room and no sprinklers in the corridor gas temperatures up to 184°C were measured in the corridor (1.5 m above the floor). With a single sprinkler operating in the corridor and not affecting the fire, the maximum gas temperature in the corridor was 73°C. This is a 60% drop in temperature.

In Fire Scenario 2 the temperature of the fire gases flowing into the balcony would be around 1100°C and the cooling effect of the sprinklers would be more efficient than that described above due to the faster evaporation of the sprinkler water spray at this higher temperature. Assuming a conservative degree of cooling of 50% the gases would issue from the balcony at approximately 550°C. Subsequent cooling as the gases mix with the outside air (Butcher and Parnell [11]) would reduce the temperature even further, to an estimated 350°C.

A calculation using FIRECALC Program Radiation [8] showed that in a typical situation based on Butcher and Parnell [11], the radiant heat received by a window from flames at 600 ° C issuing from a window below would be 22 kW/m^2, while with gases at 350 ° C in the same situation the window would receive less than 6 kW/m^2. Standard windows can safely withstand a radiant heat intensity of up to 10 kW/m^2.

It was concluded therefore that the provision of sprinklers in an enclosed balcony would reduce the temperature of fire gases flowing through the balcony to such an extent that there would be radiant heat hazard to the windows in the floor above.

CONCLUDING REMARKS

Over the past few years the CSIRO has provided innovative solutions to fire safety engineering problems in a variety of buildings including hospitals, shopping centres, casinos, factories, warehouses, aircraft hangars and a nuclear reactor building. Fire safety engineering is currently the subject of much international activity including the preparation standards and performance based building regulations. A documented record of all unusual fire safety engineering solutions used to date is being prepared by the CSIRO as a reference for future fire safety engineers.

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