SPREAD OF FIRE UP BUILDINGS VIA WINDOWS.

Report for: A.H.Buchanan ,
Written by: G.W.Jolly and T.W.Munnerley.

Table Of Contents.

A.

✓

Very tidy report.
All the main points and
not too long

Abstract.

External vertical fire spread up multi-storey buildings poses a very serious threat to the occupants and contents of such structures, and control and prevention of this mechanism of fire spread should be of a high priority in design considerations.

This report takes a general look at the two main ways that external vertical fire spread occurs in multi-storey buildings and some of the solutions that have been created to try and combat this deadly threat to the people and property in them.

✓

Introduction.

Studies done into the mechanisms of vertical fire spread in multi-storey buildings have shown that a large proportion of vertical spread occurs externally via windows.[2] This spread is accomplished, generally, in two ways:

- broken windows allowing flames to climb up to the next storey, breaking its windows and igniting the rooms contents.

- hot gases and smoke penetrating the gap between curtain wall facades and the main structure of a building, due to inadequate provision of fire stopping.

either or both of these may occur in a fire and may have disastrous consequences if not properly controlled.

Spread Of Fire By Exterior Windows

Actual Fire Experience

The presence of windows in adjacent stories of a building can introduce an additional concern. Flames discharging from a fire on the floor below may ignite combustibles on the floor above.

An extreme example[1] of this is the building on the cover of this report. The fire was in a 31 story Andraus Building in São Paulo, Brazil. At 4:00pm a store employee noticed a fire involving combustible storage items. When he and other employees opened windows to operate extinguishers (and probably the fire with a fresh supply of air) the fire spread across combustible ceiling tiles. Fire then travelled down to the fourth floor internally and then up to the sixth and seventh floors via open stairs. On the north side of the building, heat broke the glass on all four floors, forming a fire front and exposing three to four floors above the seventh floor. Radiant heat from the flames then ignited combustible ceiling tiles and partitions on each floor. As more floors became involved, the flames increased in height. By 4:26pm, when the fire fighters arrived, the flames extended above the roof. The total mass of the fire was 40 metres wide and over 95 metres high.

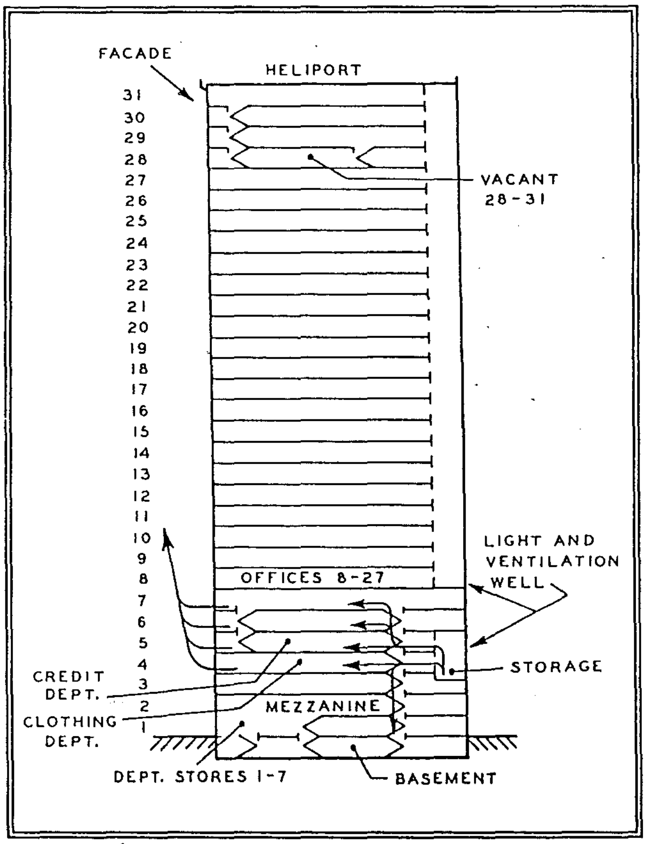


Figure 2[1] Elevation showing open areas and direction of fire spread.

On most floors of the building the combustible contents were totally consumed. However the fire damage was less severe on the four top floors of the building. This was apparently due to the suspended non-combustible gypsum tile ceiling and less fire loading from contents. One major factor which seems to have been a major contributor to the large scale of the fire, is the combustible ceiling tiles. As the fire could have spread easily along the ceiling, each floor would have been consumed by fire very quickly.

Many people, to escape the fire moved to the heliport on the roof of the building. The heliport remained free of fire damage even though the flames extended above the heliport level. The fact that the heliport sustained no damage brings in the use of overhangs (parapets) as a means of deflecting flames discharging from a window.

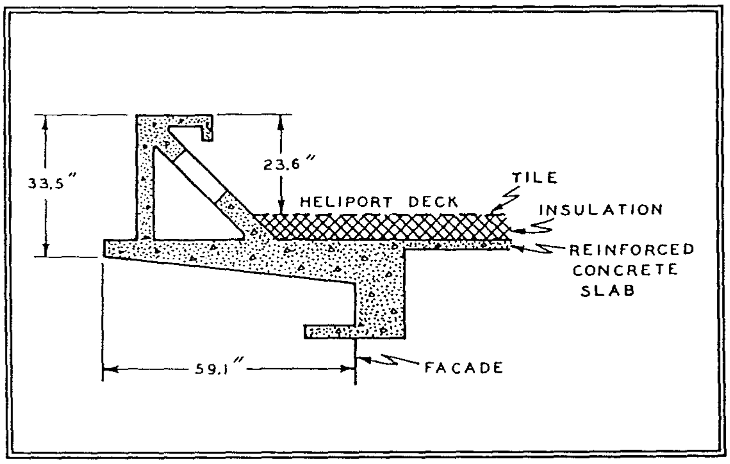


Figure 3[1] Heliport Parapet Detail

The details of the heliport parapet in Figure 2 show that the total overhang is about 1.43 metres (59.1 inches), which is larger than the design code requirements for most, if not all countries. At present the New Zealand design code requires a minimum horizontal projection of 600mm, the United States requires 760mm, and Australia requires 1100mm.[2] (The figures given for the United States are for an unsprinklered building). Sweden, Canada and Britain however, do not have any design requirements, only recommendations. Full scale fire tests and information gained from actual fires have shown that barriers constructed to current codes will not reliably prevent vertical fire spread[3]. A systematic study conducted in Australia[4] confirmed earlier British findings that 2-ft projections over the windows cannot prevent the flames issuing from windows from curling back and igniting the storey above. It was found that projections wider that 3 to 4-ft are effective in keeping the flames away from the face of the building and in reducing the radiation hazard from the flames.

The parapet on the heliport may have been an effective flame deflector, but there was no such deflector or even vertical spandrel between the floors in the rest of the building. Figure

3 gives the details of the facade between the floors. From the drawing it is easy to see what little effect the facade would have had in resisting the spread of fire between floors. The problem is also worsened by having the combustibles (ceiling tiles, curtains, partitions etc) right next to the windows.

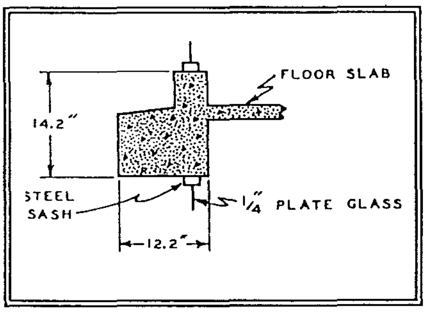


Figure 4[1] Facade Detail Between Floors

Another example of fire spread between floors via exterior windows was the fire at the Las Vegas Hilton on February 10th, 1981. Fire spread from the eighth to the thirtieth storey via the exterior windows. The exterior wall contained windows which were recessed 457mm (18 inches) and separated vertically by 1016mm (40 inches). The exterior wall was a prefabricated assembly of masonry, plaster and gypsum wall board on steel studs. When the exterior walls were examined after the fire, the wall assembly was still intact indicating that the exterior walls had not contributed to the height of the flame.

Behaviour of Exterior Flame Plumes

The way in which a flame plume will behave when projecting from a window is influenced by many factors such as fuel loading and it's proximity to the opening, window dimensions and shape, wind direction, ventilation to room, overhangs above the window, and many other factors.

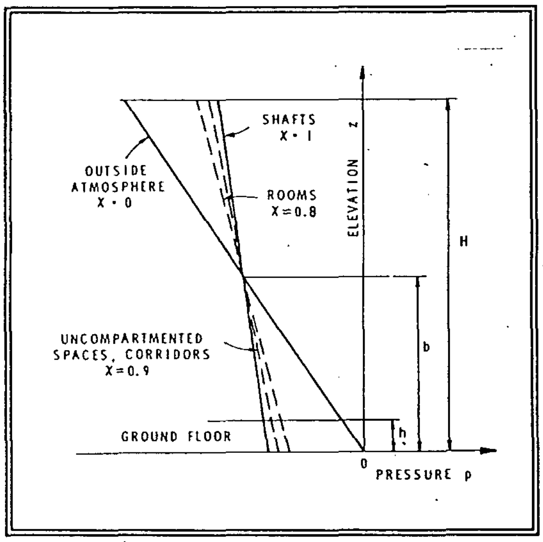


Figure 5[4] Pressure Distribution in Buildings

The shape and size of a window has been found to significantly affect the height and direction of the flame plume. Full-scale experiments conducted in Great Britain[3] showed that smaller windows produced higher flame plumes. It has been found that the projection of a flame plume from a window is more prevalent in the floors above the neutral pressure plane of a building. The neutral pressure plane is usually at mid-height for a building without mechanical ventilation and is the height at which the internal and external pressures in the building are equal, but can be lowered with the presence of mechanical ventilation or with winter heating. Figure 4 shows a graph of pressure distribution within buildings. In the floors below the neutral pressure plane the flames will tend to move to the centre of the building, whereas on those floors above the plane the flames will tend to move to the outside of the building, due to the pressure differences.

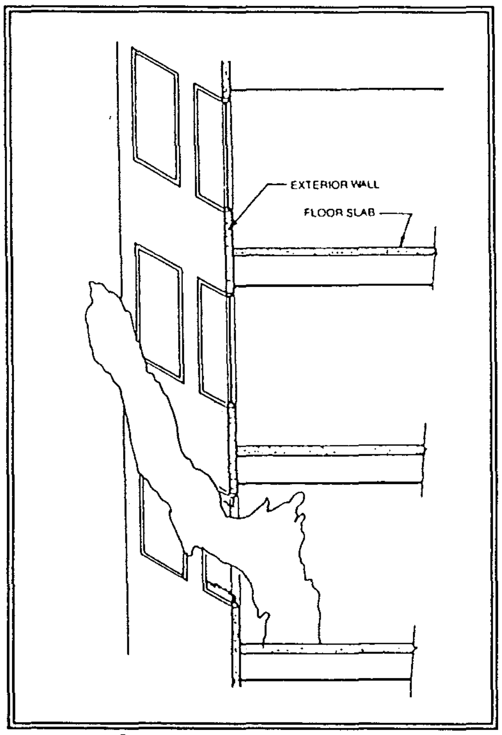


Figure 6[3] Assumed Flame Trajectory Where Window Width is Half of Height

The shape and size of a window has been found to significantly affect the height and direction of the flame plume. Full-scale experiments conducted in Great Britain[3] showed that smaller windows produced higher flame plumes, which tended to move away from the wall.(Refer Figure 5) This is probably due to ventilation as "fuel gases" flow out the window and entrain air, burning occurs in the plume outside the building. Also a series of eleven experiments, using a four storey structure were completed. Each room was 10 feet wide, 10 feet deep and eight feet high. The window sizes varied, but most were 3.5 feet wide by 5 feet high. After the start of a test, it would take only about 1½ minutes for the windows in the story above to break. In one of the experiments where glazing was from floor to ceiling, flames reached a height of 16 feet above the ceiling of the fire floor. Only 4 minutes into the test with floor to ceiling glazing the curtains and hardboard trimmings had ignited. A significant discovery from these tests concerned the spandrel (or under-window panels). Although the spandrel assembly offered little fire resistance they were not penetrated by the fire, even when using a very high fuel loading in the fire floor. This would indicate that minimal fire resistance is required by the spandrel due to the loss of energy in the flames to the atmosphere.

Research done by Yokoi[5] used a variety of conditions in a small scale model to determine the plume trajectory in the upper stories of buildings. Using a ratio of n=2W/H (W=width H=height), he found that as the value of n increased, the flame flume tended to stick to the wall. This theory, confirmed by Yokoi later with a full scale experiment would seem to agree with the results of the British experiments which were completed later. This result shows that we can affect the direction of the flame plume. This could be quite useful, as the heat radiated to the floor above from the flame plume would be lessened. Using tall windows with a smaller width in association with flame deflectors could in theory help prevent fire spread between floors.(Refer Figure 6) However it must be noted that as earlier stated, deflectors to be effective must be at least 3ft to 4ft wide. Deflectors with an insufficient horizontal width may allow the flames to curl back into the face of the building, as is shown in Figure 7.

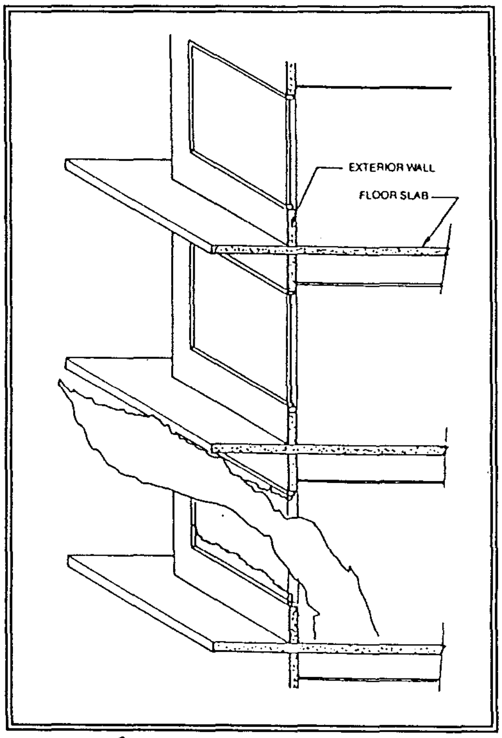


Figure 7[3] Assumed Flame Trajectory with Horizontal Flame Deflector

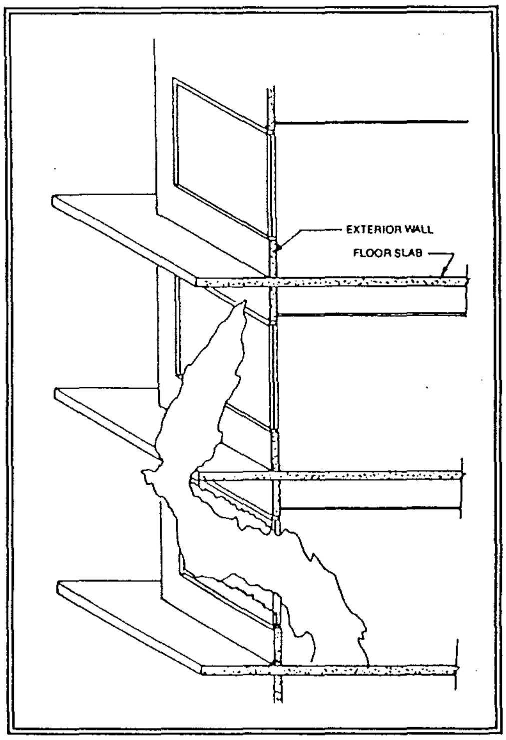


Figure 8[3] Flame Trajectory hits Insufficient Deflector Width

Curtain Wall Facades.

In more recent times, due to the current trends in architecture, curtain wall facades have become common on many of the new multi-storey buildings being erected. The curtain wall concept allows the large, unsightly, structural elements of the building to be concealed behind a thin curtain wall facade, usually constructed from glass and light framing. This method of construction has created a new, potential, mechanism of vertical fire spread through sometimes inadequate fire stopping being provided between the curtain wall and the main structure.

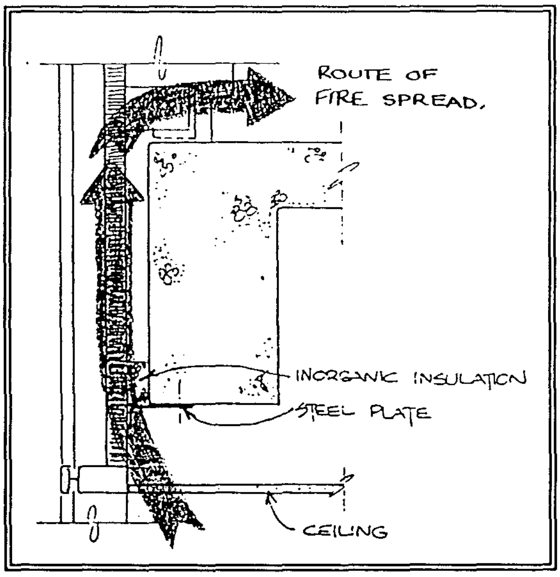


Figure 8 Typical Curtain Wall Setup.

This new method of fire spread and its destructive potential was soon discovered through some major fires overseas and this also highlighted inadequacies in the current design code, [NZS 1900: Ch.5], inadequacies which were not envisaged before the popularisation of the curtain wall concept.

Recognising this problem the Standards Association of New Zealand (SANZ) , in 1988, issued a recommendation in the standards magazine stating:

"The connection between the floor and the spandrel wall is required to resist fire for the same period as the floor." [12]

This recommendation was similar to the requirements established in other countries, but was only a recommendation and not a requirement and was open to interpretation by local approving authorities.

From a life safety point of view, the fire stopping need only remain intact long enough for the building occupants to egress, this usually involves a time of about 15 minutes. Property protection may require longer fire stopping capacity, but in a fully developed fire, non fire rated glass will probably have broken and vertical fire spread will now be able to occur via windows.

As a result of this problem being recognised, fire stopping construction methods have been developed[2] (See appendix) all of which should prevent the spread of most of the hot gases and smoke to the next storey, some of these, however, could be improved. Use of aluminium detailing, as in Figures 9 , 10 and 11 (appendix), is undesirable because of the low temperatures required to distort or melt aluminium, which could lead to the failure of the fire stopping. Another area of concern is in the lack of detailing of the use of sealants in the fire stopping. This is important as sealants which burn or melt will reduce the effectiveness of the fire stopping, and no sealant could render the stopping ineffective. Figures 12 and 13 (appendix) are the most effective of the examples given, in Figure 12 the weakest point is probably the window, unless fire rated glass is used.

The adoption, in the near future, of a new design code will hopefully address these problems in curtain wall construction, thus greatly improving the level of safety provided to the occupants of the building in the event of fire.

Sprinkler Systems.

Of all the options available to try and prevent the vertical spread of fire in multi-storey buildings, perhaps the most effective action that can be taken is the installation of a sprinkler system. The sprinkler system is not only an effective means, in itself, of controlling the fire, but it also compliments the other methods of control previously discussed in the report. Indeed most codes have differing requirements regarding the dimensions of vertical and horizontal projections between windows, etc. dependant on whether a sprinkler system has been provided within the building. Both the buildings mentioned in the section on spread by windows were not equipped with sprinklers, which, if they were present, may have reduced a major catastrophe to a small contained fire.

Conclusions.

Because of the unpredictable nature of fire, it is virtually impossible to reliably model or predict how it will spread and hence how to prevent it occurring in a devastating way.

This report has shown many methods that can be used to reduce the probability of vertical fire spread such as horizontal and vertical projections, window geometry, better construction of fire stopping etc. Also a major component of vertical fire spread is having combustibles, in the form of ceiling tiles, partitions and curtains, next to the window. It has been shown in this report that combustible ceiling tiles play a major component in vertical fire spread and also fire spread within individual floors. Regarding design requirements, it has been found that most if not all countries, do not have adequate design requirements regarding vertical fire spread, in fact in many countries there are no specific design requirements, only recommendations.

Perhaps the most effective step that can be taken in the prevention of vertical fire spread is the installation of a sprinkler system, which should control the size of the fire and dramatically reduce the chance of external vertical fire spread occurring, as it combines with the other passive design concepts discussed in this report.

Appendix.

Examples of current Fire Stopping methods used in New Zealand.

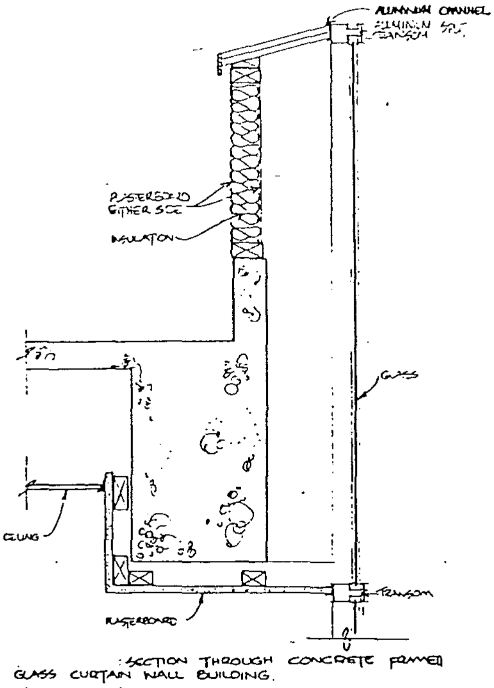


Figure 9[2]

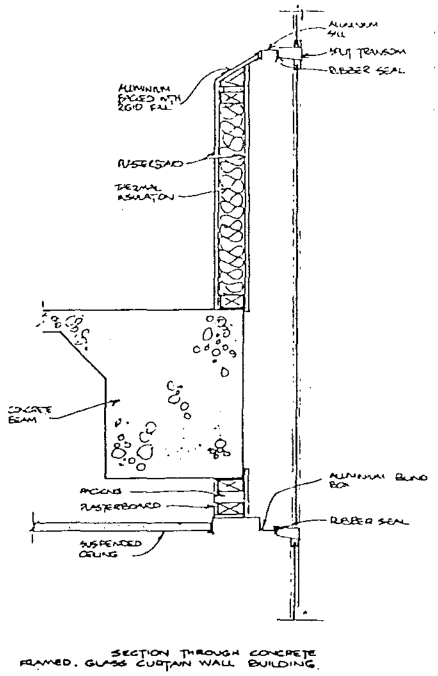


Figure 10[2]

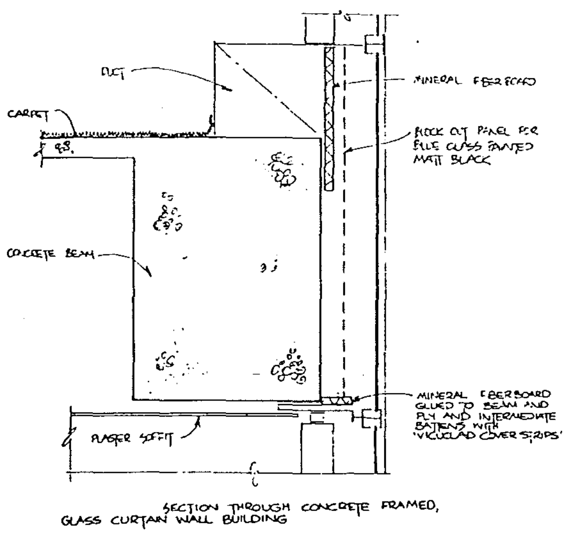


Figure 11[2]

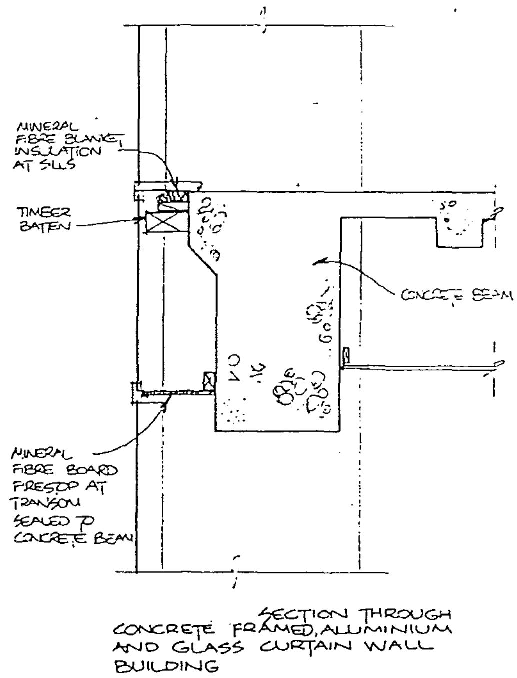
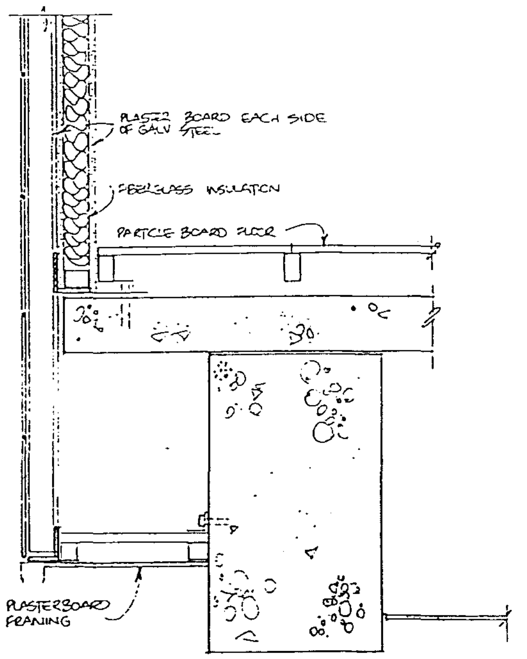


Figure 12[2]

These could be within the text.

Appendix.



SECTION THROUGH CONCRETE FRAMED ALUMINIUM AND GLASS CURTAIN WALL BUILDING.

Figure 13[2]

References.

1. *"High Rise Building Fires and Fire Safety."* , National Fire Protection Association [A.H.Buchanan].

2. *"Facade Fire Spread in Multi-Storey Buildings."* , A.G.Moss , BRANZ Study Report No.32 (1990) [A.H.Buchanan].

3. *"External Walls of Buildings - Prevention of Fire Spread from Storey to Storey."* , Donald Belles , Building Standards May-June, 1986 [BRANZ Library, WELLINGTON].

4. *"Design of Buildings for Life Safety, Parts I & II"* , T.Z.Harmathy , Fire and Technology, Vol.12 #2 & #3, 1976, [Engineering Library].

5. *"Symposium on Design of Buildings for Fire Safety"* ,Editors E.E.Smith & T.Z.Harmathy, ASTM (1978), [Engineering Library].

**** Source of reference given in square brackets, [....] .***