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FACADE FIRE SPREAD IN MULTI-STOREY BUILDINGS

A.G. Moss

PREFACE

This work was carried out in order to provide information for code writers and designers concerned with reducing the risk of vertical fire spread via facades in multi-storey buildings.

This report is intended for code writers, researchers and designers.

FACADE FIRE SPREAD IN MULTI-STOREY BUILDINGS

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A.G. Moss

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ABSTRACT

The advent of curtain wall cladding systems in multi-storey buildings has brought with it problems in preventing fire and smoke spreading from the fire floor to the floors above through the windows, or the gap which sometimes exists between the curtain wall and the floor of the structure.

This paper reviews the current knowledge and research on fire spread in this manner, identifying the mechanisms of spread and possible methods to prevent or restrict it.

A comparison is made between the current New Zealand code, NZS 1900 Chapter 5 1988, and those of some other countries as well as comparing current and future test methods in these countries. A method for calculating the flame height out of windows and the thermal exposure of the wall above is also investigated.

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INTRODUCTION

In recent years taller buildings using curtain wall cladding systems have introduced fire safety problems which were not envisaged when NZS 1900: Chapter 5: Fire Resisting Construction and Means of Egress (SANZ,1988) was written.

Incidents where fire spread up the exterior facade has been a major or contributing factor have occurred overseas but none have occurred in New Zealand to date. The fact there are relatively few multi-storey buildings in this country is one of the factors likely to contribute to this good record.

High-rise buildings continue to be built in our cities, and the majority of these are over 25 m high - above the height which fire-fighting appliances can adequately reach. Thus any fires which occur in the upper floors have to be fought from inside the building leading to delays in attacking the blaze. Some buildings may not have adequate passive protection to ensure the safe evacuation of occupants in the event of fire. This aspect and others have been recognised in the need for a major revision of NZS 1900 Chapter 5 since 1970.

The rapid spread of fire from floor to floor via non-fire rated windows in some buildings is more likely than the successive breaching of fire-rated floor/ceiling separations. The introduction of curtain walling has introduced another hazard as the separation which often exists between the curtain wall and the main structure of the building can allow the passage of smoke and flames and increase the rate of fire spread if not properly stopped.

These problems are not new overseas and this paper reviews the current knowledge of the mechanisms of this type of fire spread and identifies measures which can be taken to limit the hazards. This has been done by investigating overseas literature, code requirements, test methods used to measure the performance of facades and the modelling of facade fire spread.

MECHANISMS OF FIRE SPREAD IN ACTUAL FIRES

A search of Fire Journal and Fire Prevention Journal provided information on the frequent mechanisms of vertical fire spread in multi-storey buildings, they are:

- flaming from broken windows causing the windows of the storey above to break and allowing fire to enter;
- inadequate fire/smoke stopping of the gap between the edge of the floor slab and the exterior wall allowing flames and hot gases through;
- heat induced distortion of low melting point metals or alloys, such as aluminium, causing fire stopping to become ineffective and possibly fall out;
- areas around lift shafts and in stairwells acting as chimneys to hot gases and flames; and
- inadequate stopping of service penetrations and gaps formed when services are retrofitted.

Of these five the first three are relevant to this study.

The first mechanism tends to be the most spectacular and can be life threatening. This is demonstrated by the large fires in Sao Paulo, Brazil (Willey, 1972 and Sharry, 1974), the Las Vegas Hilton (Demers, 1981&1982) and the First Interstate Bank, Los Angeles (Klem 1989, Nelson 1989 and Barnett 1989).

The second mechanism of spread is not as spectacular as the first but can be a contributing factor in the spread via the exterior and, as was seen in the fire at the One New York Plaza (Powers, 1971a), the threat to lives and property is just as great. This was also demonstrated in the Avianca Building in Colombia (Sharry, 1974).

A combination of lack of fire stopping and buckling of the external wall was the cause of minor fire spread in the fire at 919 Third Avenue, New York City (Powers, 1971b). This fire could have been worse if the fire had started out of the reach of the Fire Department's hose streams.

RESEARCH

Research in this area has been carried out by several organisations. The most recent work has been done in Canada at the Institute for Research in Construction (IRC) and in Sweden at the Lund Institute of Technology. Both research programmes have resulted in full-scale test methods being developed. Other research has been carried out by the Building Research Establishment (BRE) in Great Britain as well as in Europe, America and Australia.

Canada

Work carried out at IRC has concentrated on two mechanisms of vertical fire spread:

(1) "leap-frogging" from one window to another;

(2) flame spread over the outer face of the exterior wall.

This work has been reported in detail (Oleszkiewicz 1987 and 1989a and b and Young and Oleszkiewicz 1988).

The initial work used a modified standard ASTM burn room (Figure 1) to assess the effect of window shape and horizontal and vertical projections on the flame plume from a window. The results of the test showed:

- the ratio of the window height to its width controls the flame plume;
- tall windows tend to project flames away from the building; and
- squat windows produce plumes which hug the building exterior.

Hence the thermal exposure of the exterior wall is affected by the fire heat release rate, window geometry and facade geometry. Horizontal projections offer protection to the wall above an opening and vertical projections tend to channel the flame plume thus increasing the intensity of exposure and the area of wall exposed. More work in this area is planned to consider the best geometry and positioning of horizontal projections as well as the effects of combustible facades under the projections.

Full-scale and small-scale test facilities were designed and built for the testing of combustible exterior wall assemblies. The full-scale test rig is shown in Figure 2. Initial testing was done using wood cribs as the fuel source then propane burners were used with the gas flow regulated so as to duplicate the conditions of the wood crib fires. The small-scale facility is called the "Vertical Channel Test" and is attached to the side of the full-scale test facility as shown in Figure 2.

Full-scale tests have been carried out on various cladding systems. Heat fluxes on the outer face of the wall and temperatures on the outside and on the outer face of each distinctive layer of the assembly were recorded. This provided the data needed to evaluate other test methods, namely, the vertical channel test, the Steiner tunnel test (Underwriters' Laboratories of Canada ULC-S102.2-1978, Standard Method of Test for Surface Burning

Characteristics of Flooring, Floor Covering and Miscellaneous Materials), IMO surface flammability test (referred to in Oleszkiewicz 1989a) and modified roof deck test (American Society for Testing and Materials (1988b) E 108 - 83, Standard Methods of Fire Tests of Roof Coverings).

In the evaluation, the most important criterion was the ability to adequately differentiate between assemblies in terms of their flame spread characteristics in real fire scenarios. The IMO test did not give a good correlation with the results of the full-scale tests, mainly due to the small size of the apparatus. The modified roof deck test did not heat the specimens sufficiently resulting in less penetration of fire into the assemblies than in the full-scale tests. There were also problems with debris falling on to the burners and obstructing them. The vertical channel test gave indications of flame spread characteristics similar to those obtained in the full-scale tests. The Steiner tunnel test was able to differentiate between some specimens on the basis of flame spread characteristics but it was not able to adequately predict the performance of multi-layered assemblies.

From these results the researchers decided to refine the vertical channel test to see if more reliable results could be obtained and to reduce its size so it can be accommodated in usual laboratory facilities.

Further research using the full-scale test apparatus showed some combustible claddings could support the vertical spread of flame whereas others could not sustain flame on their own. This suggests a test like this could be used to assess the flame spread characteristics of combustible claddings and rate them accordingly.

The most recent work to be published by Oleszkiewicz (1989b) has been a paper on the heat transfer from a window flame to the facade above. This describes a mathematical model of heat flow based on one developed by Law (1978) and discusses its applicability in comparison with the results obtained in the full-scale experiments. Calculated values of the total heat flux density, at a particular height above the window, were generally higher than those measured. A comparison of the heat transfer to the wall above the window for "normal" fires produced calculated values which were mostly lower than those measured, with the values closer to the windows giving a better correlation. This model seems to be conservative but not excessively so. More work is being carried out in modifying the model to more realistically represent fires which involve large quantities of fast burning materials such as plastics.

Sweden

This work (Ondrus 1985 and Ondrus & Pettersson 1986) was carried out in the Department of Building Fire Safety and Technology at Lund Institute of Technology.

This research dealt with externally added thermal insulation, usually as part of a cladding system for a facade.

The hazards examined were:

a) the surface spread of fire with the surface of the facade contributing to the fire;

b) spread within the construction e.g., through burning of insulation, wall studs and via air cavities;

c) spread via the windows; and

d) spread resulting from large sections of the insulation collapsing.

Initial tests were carried out using a three-storey test building. The fire simulated a compartment fire with synthetic furnishings and had a fire load density of 110 MJ/m^2 of total internal surface area, This producing a thermal exposure of approximately 140 kW/m^2 on the facade and approximately 75 kW/m^2 on the second floor window. From these tests the test rig shown in Figure 3 was developed. This uses a fire load density of 110 MJ/m^2 of total internal surface area which is produced using a trough (0.5 m wide x 2.0 m long x 1 m deep) containing 60 litres of heptane. The test facility is constructed of aerated concrete and the system to be tested is attached to the front as it would be in practice.

The second series of tests looked at three types of external insulation systems:

1) Mineral wool insulation with wood studs and steel or aluminium sheet cladding;

2) Mineral wool insulation with a relatively thick layer of plaster;

3) Cellular plastic insulation and a relatively thin layer of plaster.

These were then classified according to the following criteria:

1) No collapse of major sections of the external additional thermal insulation system.

2) The surface spread of flame and the fire spread within the insulation should be limited to the bottom part of the window on the third floor. External flames which could ignite eaves are not permissible.

3) There must be no spread of fire to the second floor through the windows - deemed verified if the total heat flow towards the centre of windows was 80 kW/m^2.

All three criteria were to be applied to buildings over eight storeys and those between five and eight which did not allow for fires to be extinguished from the outside. For all other buildings only the first two were to be applied.

Thirteen different configurations were tested and the combination and order of the materials and constructional detailing were found to have more effect on the performance than the ignitability of the individual materials.

This test method is now specified as SP FIRE 105 (Ondrus 1989), and in the new Swedish building regulations facades have to be of non-combustible materials or have passed the full-scale test according to the above criteria (Ondrus 1989).

The results of this test are likely to be conservative due to the use of a short wide window in the fire room. This is thought likely because Canadian research has indicated this window configuration produces a flame plume which hugs the wall above the window causing a more severe exposure than in a normal square window.

England

Recent work done in England has concentrated on overcladding systems which include insulation. These systems are used over traditional brick exteriors to upgrade the appearance of a building and provide additional thermal insulation (Figure 4).

Work done at BRE by Rogowski, Ramaprasad and Southern (1988) involved a four-storey rig which is 9.2 m high and 3.7 m square in plan, with windows at the second and third floors. The fire source was a wooden crib designed to provide at least 20 minutes of fully developed flaming impinging up to 2 m on the facade and with a heat flux of at least 100 kW/m^2 on the facade. Eight tests were carried out on systems where the insulation was sandwiched between the rendering and the wall (Figure 5) and seven on systems where there was a cavity between the insulation and the cladding (Figure 6). The following BRE recommendations are of interest to this study:

- combustible insulants may be used without a specifically designed system of surface protection only if shown by a full-scale fire test to be satisfactory;

- proposed systems incorporating combustible insulants with sheeted overcladding should be designed to incorporate fire barriers in the ventilated cavity every two storeys;

- combustible insulants incorporated in non-sheeted systems are likely to suffer only limited fire spread if the following recommendations are applied:-Cementitious rendered metal lathing over thermoplastic insulants should be provided with sufficient metal pins (about one every square metre) to stabilise the cladding and fire barriers should be installed every two storeys from the second floor upwards; - cementitious rendered metal lathing over thermosetting insulants should be provided with sufficient metal pins (about one per square metre) to stabilise the cladding; and

- in-situ sprayed polyurethane or polyisocyanurate foamed insulants protected only by a flame retardant coating are not suitable for multi-storey housing developments.

Stirling and Southern (1989) carried out an investigation into the effectiveness of existing methods for fixing cladding and the effect of fire barriers. The effect of fire barriers was determined by first testing a system without barriers and then with barriers. This comparison was carried out for lath and glass fabric claddings. The results of these experiments showed metal fixings are the most effective and, especially for glass fabric claddings over external insulation, horizontal fire barriers at every storey between the cladding and the wall provide support for the insulation, restrain the cladding and restrict damage. For rendered metal lath systems fire barriers at every second storey can significantly reduce fire damage. These systems can be adequately fixed using a combination of metal and plastic fixings,but not plastic fixings alone.

As a result BRE has published a Defect Action Sheet (Building Research Establishment 1989) which details the use of fire barriers in overcladding systems and how far apart they should be. This is not directly applicable in New Zealand because overcladding is as yet not common.

Other Countries

Bechtold (1978) from Germany has carried out a series of full-scale tests using a four-storey masonry building, one of which had curtain walling and PVC insulation attached to part of the exterior wall. There are no firm conclusions in this paper and the results are similar to those reported elsewhere.

Jeffs, Klingelhofer, Prager and Rostek (1986) from Belgium used a two-storey test rig to investigate the performance of an insulated facade when exposed to flames from a room fire and conclude vertical fire spread would continue above the second storey if vertical fire stops were not included in the construction.

There has been a variety of work published in the United States recently (Belles 1986, Belles and Beitel 1988, Creed, D.C. 1982, Bletzacker and Crowder 1988(a & b) and Leavitt 1988), but there are few details of extensive testing and no full-scale test method is known to have been adopted by the main building codes, ASTM or the National Fire Protection Agency (NFPA). Of most relevance to this study is a publication by the Architectural Aluminium Manufacturers Association (AAMA) (1979) which includes a section on fire safety. This gives guidelines for fire safety design and the use of fire stopping and notes fire stopping must be permanently fixed in position. Some examples of these details are shown in Figures 7, 8 and 9.

Horizontal Projections

Research has been carried out on the effect of horizontal projections on flame shapes and the results have shown their effectiveness is dependent on the fire load and the size and position of the projection. The most extensive study into a variety of configurations of projections was carried out by Moulen (1974). This gives suggestions on the most appropriate combinations of vertical and horizontal projections for different situations. Other investigations have usually been as part of work on fire spread up facades of buildings as in Canada (Oleszkiewicz 1987).

In general, horizontal projections reduce the exposure of the building directly above the window, hence reducing the radiation to the facade above the window. On the other hand the flames extend higher than without projections so more of the facade is exposed to the fire. A deciding factor must be the expected fire load and flame front during a fire. The effect of a horizontal projection was noted in a fire in Illinois (Best, 1975) where fire was apparently prevented from spreading externally to the next floor because of a cantilever design which provided a six-foot (1.8 m) wide horizontal barrier between the adjacent storeys.

CODES

A comparison of the requirements in various countries is shown in Table 1. This considers the main features which could influence the vertical spread of fire. The test methods mentioned in this table are those which could be interpreted as being required by that code, with the exception of the Swedish full-scale test.

Although not providing comprehensive details on requirements for exterior cladding and allowed openings, Table 1 shows the relative similarity of requirements. Sweden has the most non-prescriptive code which includes the use of calculation and a newly developed full-scale test as means of compliance. The 1990 National Building Code of Canada (unsighted by the author) includes the full-scale test developed by IRC. It is believed the code will allow combustible claddings for buildings up to three storeys high, if not sprinklered, and up to six storeys high if sprinklered, provided the cladding is protected by a thermal barrier from the inside of the building and has performed satisfactorily in a full-scale test such as the one at IRC.

As can be seen from Table 1, the present requirements of NZS 1900: Chapter 5 are similar to those from other countries. One aspect of concern is the rapid increase in the use of lightweight facade systems in New Zealand since fires overseas (discussed earlier) have shown they provide little resistance to fire.

Spandrel Panels

Spandrel panels are required by the Australian Building Code (Australian Uniform Building Regulations Co-ordinating Council 1988) and the Standard Building Code (Southern Building Code Congress International 1985)(U.S.A) when the building is unsprinklered whereas NZS 1900 Chapter 5 requires a spandrel panel or horizontal projection regardless of whether sprinklers are installed. The values of 900 mm for vertical spandrels and 600 mm for horizontal projections have come from very early code requirements. The origins of these values are unknown to the author.

The adequacy of the vertical spandrel has been questioned as a result of observations and calculations showing flames often extend much further than 900mm above the top of an opening. Yokoi (1960) was one of the first researchers to develop a calculation method based on extensive testing. These calculations show the flame height out of a window depends on many parameters including the size and shape of the window, the shape of the fire room and the fire load. As far as the author knows there has not been any research providing a conclusive answer on the subject of spandrel height. One option is to treat the spandrel as a specific design and use calculations to decide on the best solution.

Fire Stopping

Also shown in Table 1 are the requirements for fire stopping. It is evident there is still some disagreement in the codes about the usefulness of any form of fire stopping. The most comprehensive code requirements are provided by Great Britain (Her Majesty's Stationary Office 1985).

At present in New Zealand there are no specific requirements for fire stopping but the Standards Association of New Zealand (SANZ) issued a recommendation regarding this in the Standards Magazine (Anon. 1988). This relates to clauses 5.13.6 and 5.16.1 of NZS 1900 Chapter 5. The recommendation states: "the connection between the floor and the spandrel wall is required to resist fire for the same period as the floor." The recommendation was intended to assist local authorities and manufacturers to come to a consistent understanding of the intentions of Chapter 5. Although this is similar to what is required in other countries there is still the problem of it being an interpretation and not a specific requirement of the code. This means some approving authorities may not require fire stopping, leading to inconsistencies in the safety of multi-storey buildings.

The lack of adequate fire stopping between the floor slab and the exterior wall has been one of the major contributors to the rapid spread of fires in multi-storey buildings (Powers 1971a&b, Sharry 1974, Klem 1989 and Nelson 1989). From a life safety point of view the fire stopping only needs to ensure the integrity of the floor/wall system is maintained long enough to allow for the evacuation of occupants. This would be approximately 15 minutes as within that time the windows will have broken and all occupants will have left the building. Property protection measures may necessitate longer periods of resistance, however, there seems little point in providing more than the time necessary for fire spread to the floor above via windows and the external facade.

Test Methods

The tests presently specified in the codes are shown in Table 2. The tests do not vary much in their main points, apart from Sweden and Canada who are the only countries to have full-scale test methods in use.

The test methods shown in Table 2 are for the testing of materials used in facade systems. These methods all examine the effects of fire exposure on one side of the facade only, whereas facades are often exposed on the outside by flames from a fire inside the building, as shown in Figure 10. This means the standard tests provide only comparative information rather than information on actual fire behaviour. A recent CIB W14 workshop report on facade fire testing (Hildebrand 1988) summarises the results of an international questionnaire on test methods in use and the results on four different types of facades. Both full-scale and small-scale test methods were reported and detailed descriptions of all the full-scale facilities were provided. A detailed description of the objectives of the testing and suggestions on the size of samples, window shape and the measurements to be taken was also prepared. This was done because the variation of existing test facilities provided results which were difficult to compare on a scientific basis. No further information has been received on this topic.

New Zealand Code Review

In 1986 the Building Industry Commission was set up with the aim of producing a new building code to replace the existing standards with one document. The code will have five levels of statements of which the first three are mandatory and the other two are means of compliance. The means of compliance are verification methods and acceptable solutions. The Building Code is expected to be in force in 1991. No major changes in the means of compliance affecting facade fire spread are expected at present.

CALCULATION METHOD

As a result of the uncertainty noted about the usefulness of spandrel panels it was decided to investigate calculation methods for flame heights out of windows.

The equations used in texts and by most researchers were found to originate from work done by Yokoi(1960). The most thorough publications on the calculation of flame plumes out of windows were found to have been produced by the American Iron and Steel Institute (1979) and Law and O'Brien (1981). The latter publication is an expansion of the former, with an expanded method and worked examples. It has been written in SI units rather than Imperial.

Using sections B2 and B3 of Law and O'Brien an approximate flame shape emitting from a window and the temperature distribution along the flame axis can be estimated. The radiation from the flame to the spandrel can be calculated using section B6, however this is fairly complex and requires calculation of configuration factors.

A recent paper by Oleszkiewicz (1989b) outlines a simple mathematical model, derived from a model developed by Law (1978), which calculates the heat transfer from a flame plume to the wall above a window. This assumes a triangular flame shape as shown in Figure 11 and provides equations for both radiant and convective flux density.

Other work on this subject has been carried out by Seigel (1969), Thomas and Law (1974) and Thomas (1986).

On occasion in New Zealand this type of calculation has been used and accepted by approving authorities.

SYSTEMS CURRENTLY IN USE IN NEW ZEALAND

In recent years an increasing variety of products have become available for use in facade systems. The main types in use in New Zealand are:

- Precast Concrete
- Glass Reinforced Concrete
- Aluminium Curtain Walling
- Glass Curtain Walling
- Lightweight Panel Systems (with various finishes)
- Exterior Insulation and Finish Systems (EIFS)

EIFS is the most recent import and comprises a backing panel, like plasterboard, with a foamed polymeric insulation sheet affixed and the panel coated with a plaster finishing surface (Figure 12). These systems are popular with builders as they are lightweight and include thermal insulation. The main problem is the foamed polymeric insulations are usually flammable and this has caused some debate over whether they should be used and in what situations. One of the most striking examples of the fire risk from this type of product occurred in Manchester New Hampshire (Bletzacker and Crowder 1988a), where an adjacent building clad with an

EIFS turned into a fireball. Although this report is not looking at this type of fire exposure it is an example of what can happen.

Fire Stopping

In addition to the examples noted earlier (Figures 7 to 9), examples of fire stopping methods used in New Zealand are shown in Figures 13 to 20.

These examples would generally prevent the majority of hot gases and smoke from penetrating to the next storey. The use of aluminium detailing as in figures 13(a), (b) and (c) is undesirable in an unsprinklered building because aluminium starts to distort at 300 °C and melts between 570 °C and 660 C, this means that in a fully developed fire the aluminium detail would fail within approximately 15 minutes.

Another problem is the lack of detailing of the sealant between a board and transom or facade as shown in figure 20. This is an important detail as a sealant which flames or melts reduces the effectiveness of other fire stopping measures and the lack of sealant renders the fire stopping ineffective.

Figures 14(d) and (c) are the most effective of those shown, in figure 14(c) the weakest point is probably the window which is to be expected unless fire resistant glazing is used.

RECOMMENDATIONS

The increasing use of a diverse range of facade and cladding systems has provided the impetus for some extensive work overseas and for this study. This study has lead to the following recommendations for New Zealand:

- fire and smoke stopping should be provided between the floor slab and the facade system at every storey and this should be adequately attached;

- close contact with Canadian researchers should be maintained to enable New Zealand to evaluate the usefulness of the small scale test method being developed to assess the performance of cladding systems;

- the development of the Eurocodes for 1992 should be closely followed in New Zealand by maintaining continued contact with CIB.

CONCLUSIONS

After a study of overseas research and fire reports on vertical fire spread in multi-storey buildings the following conclusions can be made:-

Fire spread has three important mechanisms:

(1) flames issuing from a window can break the window above allowing the fire to enter (often referred to as leap-frogging);

(2) inadequate fire and smoke stopping between the floor slab and the exterior wall allowing flames and hot gases or smoke to pass through the gap; and

(3) heat induced distortion of low melting point metals and alloys causing fire stopping to become ineffective and allow flames and hot gases through.

Whilst it is possible spandrel panels and well designed horizontal projections can hinder vertical fire spread, little quantifiable data exists which can be used to verify present code provisions or recommend alternatives.

Internal spread between the floor slab and the facade is best addressed by the use of fire and smoke stopping materials. These should be fixed to the floor slab and the facade using metal or alloy clips and fasteners which will ensure the integrity of the whole wall/floor system is not compromised within the required fire resistance time for both the floor and the wall.

The New Zealand fire regulations, although dated, are comparable to those of similar countries in all the areas examined except for fire-stopping requirements in facade systems.

Current tests in New Zealand and overseas for evaluating materials used in facades are not specifically designed to test the properties of facade systems in real fires. Recent work in Canada and Sweden has seen both countries develop full-scale test methods and the latest version of the Swedish Building Code specifies the full-scale test as a means of compliance to the code requirements. In Canada work is continuing to develop a small-scale test which is being validated using results from the full-scale tests. The full-scale test has been incorporated in the 1990 Canadian Building Code.

The use of a calculation method to estimate the shape and temperature of flames from a window, and hence the radiation to the exterior face of the wall above, has been investigated and reference made to publications which could be used for this purpose.

A deficiency in fire stopping was found in the lack of detailing of sealants. It should also be noted that reliance on aluminium sections alone for fire stopping is undesirable in unsprinklered buildings because of the relatively low melting point of aluminium.

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Table 1: Comparison of Code Requirements

Country & Code	Spandrel	Exterior Cladding	Opening	Fire Stopping (floor to external wall)	Test Standards	Reference
	Feature					
New Zealand	If floor required to be >= 1hr and windows vertically above each other then vertical min 900mm or horizontal projection min 600mm.	Depends on the separation and construction.	Depends on the separation and construction. lowered if sprinklered.	No specific regulations. (recent SANZ interpretation is that the gap between the floor slab and the curtain wall must be filled with a material that will prevent fire spread for the same period as the FRR for the floor.)	BS 476 parts 4 and 22, AS 1530 parts 1 and 4 and ISO 834.	Standards Association of New Zealan 1988
Australia	Vertical 900mm (if no sprinklers) extending 600mm above floor & 450mm to side of opening. Horizontal min 1100mm.	Depends on the separation but sprinklered non-combustible curtain walls are exempt	Depends on the separation.	Between the curtain wall and the spandrel panel. Non-combustible, and not likely to fall out.	AS 1530 parts 1 and 4.	Australian Uniform Building Regulations Co-ordinating Council 1988
Britain	No specific requirements. separation.	Depends on type of building and	Depends on the separation and use.	As cavity barriers, rigidly fixed. At joints to be of limited combustibility.	BS 476 parts 4, 6, 7 and 22.	Her Majesty's Stationery Office 1985 and 1988
Canada	No specific requirements.	Depends on type of building and separation (more stringent for plastics)	Depends on the separation and use.	In concealed spaces in wall at every floor.	CAN4-S101 S102 and S114.	National Research Council Canada 1985 a and b

Sweden	No specific requirements.	Mainly non combustible and fire resistant.	Separation vertically must be at least 1200mm	Should prevent fire spread for the same duration as the associated floor.	Full scale test SP Fire 105. (1988)	National Board of Physical Planning and Building 1984
U.S.A.	No specific requirements. separation.	Depends on type of building and use, 3/4 hr if separation is less than 6 m.	Depends on the separation and	No specific requirements.	ASTM E84, ASTM E119 and ASTM E136.	International Conference of Building Officials. 1988
U.S.A.	Vertical min 900mm horizontal min 760mm, when unsprinklered.	Depends on type of building and separation.	Depends on the separation and use.	Should cut off all concealed draught openings, form a fire barrier between floors, be non-combustible and securely fastened.	ASTM E84, ASTM E119 and ASTM E136.	Southern Building Code Congress International 1985

Table 2: Comparison of Test Methods

Test and Type	Specimen Details	Pre-test Treatment	No. of Samples	Failure Criteria or Rating	Measurements and Observation	Reference
BS476/4 Non-combustibility	40 x 40 mm 50 mm high 80 cm3	None	3	Temperature in furnace or on specimen rises more than 50 C Flaming for more than 10 seconds	Furnace and sample temperatures Visual observation of flaming Duration: 20 minutes Specimen behaviour	British Standards Institution 1970
AS1530.1 Non-combustibility	Cylinder diameter 45 mm, 50 mm high 80 cm3	60 C for 24 - 48 hrs., then cooled for up to 72 hrs.	5	Sum of the flaming time (if over 10s) divided by 5 > 0 Mean furnace or specimen temperature rises more than 50 C	Temperatures at centre and surface of specimen and in the furnace Flaming timed Behaviour of specimen Mass loss Duration: at least 30 minutes	Standards Association of Australia 1984
ASTM E136 Non-Combustible Materials	40 x 40 mm 50 mm high	60 C for 24 - 48 hrs.	At least 4	Internal and surface temperature rise > 730 C above furnace. Flaming after 30 s Weight loss > 50% and specimen temperature rises above furnace temperature at start of flaming	Temperatures at centre and surface of specimen and in furnace Flaming and smoke Mass loss Duration: until temperature maximum or failure	American Society for Testing and Materials 1988(d)
BS476/6	225 mm	10 - 21 C	3 - 5	Indices relating to	Time-temperature	British

BS476/22 Fire Resistance of Non-loadbearing Elements of Construction	3 m high minimum	None	1	Collapse or sustained flaming on unexposed face Flames or hot gases cause cotton pad to flame or glow, or a 6 mm diameter gap is formed with a length of 150 mm or a 25 mm gap is formed Temperature rise: mean > 140 C or individual > 180 C Results to nearest minute	Deflections Temperature on surface Flaming Gap formation >6 x150mm Cotton pad ignition Heating to ISO curve	British Fire Standards Institution 1987(b)
ISO 834 Fire Resistance of Elements of Building Construction	3 m x 3 m minimum	None	1	Temperature rise: mean > 140 C individual > 180 C or individual temperature > 220 C Flaming for more than 10 s, ignition of cotton pad	Deflections Temperature on surface Flaming Gap formation and cotton pad ignition Heating to ISO curve	International Organisation Standard-isation 1975
Can 4-S101 (ULC-S101) Fire Endurance Building Construction and Materials	> 9.3 m2 and neither dimension > 2.75 m	23 C and 50% relative humidity	1	Flames or gases ignite cotton pad Fire or hose stream causes passage of flame or gases to ignite cotton pad or hose stream passing through sample to furnace Temperature rise: mean > 140 C individual > 180 C	Temperatures on surface Cotton pad ignition Flaming Gap formation Deflections Heating to ASTM curve	Underwriters' Laboratories of Canada 1980

Fire Propagation Test	square, maximum 50 mm thick	and 55 - 65% relative humidity		behaviour during: 0.5 - 3 minutes 4 - 10 minutes 12 - 20 minutes	response ofsample (flue gas temperature) Chamber temperature Duration: 20 minutes	Standards Institution 1981
BS476/7 Surface Spread Flame	925x280 mm, maximum 50 mm thick	23 C and 50% relative humidity	6 or 9	Four classes and symbols: R if more then 6 samples used Y if softening or behaviour that may effect flame spread D if modified test due to surface variations	Time to sustained flaming and extent of horizontal spread after 1.5 and 10 minutes Time when flame crosses vertical reference lines Maximum flame spread after first 1.5 minutes Maximum extent of flame spread (max. duration 10 minutes)	British Standards of Institution 1987(a)
ASTM E84 Surface Burning Characteristics	500 mm wide 7.3 m long	23 C and relative humidity	1	Flame spread and smoke indices	Smoke release (photo-meter) Temperature Flame spread distance Duration: 10 minutes	American Society for Testing and Materials 1988(a)
AS1530.4 Fire Resistance	3 m high minimum	None	1	Collapse or excess deflection Cracks or openings passing flames or hot gases Temperature rise: Mean > 140 C or individual > 180 C Results to nearest minute	Deflections Temperatures Flaming, both intermittent or over 10 s duration Gap formation Heating to ISO curve	Standards Association of Australia 1990

ASTM E119 Fire Test of Building Construction and Materials	> 9.3 m2 and neither dimension < 2.75 m	22 C and 50% relative humidity	1	Flames or gases ignite cotton pad Fire or hose stream causes passage of flame or gases to ignite cotton pad or hose stream passing into furnace Mean temperature rise > 140 C	Temperatures on surface Flaming Gap formation Cotton pad ignition Heating to ASTM curve	American Society for Testing and Materials 1988(c)

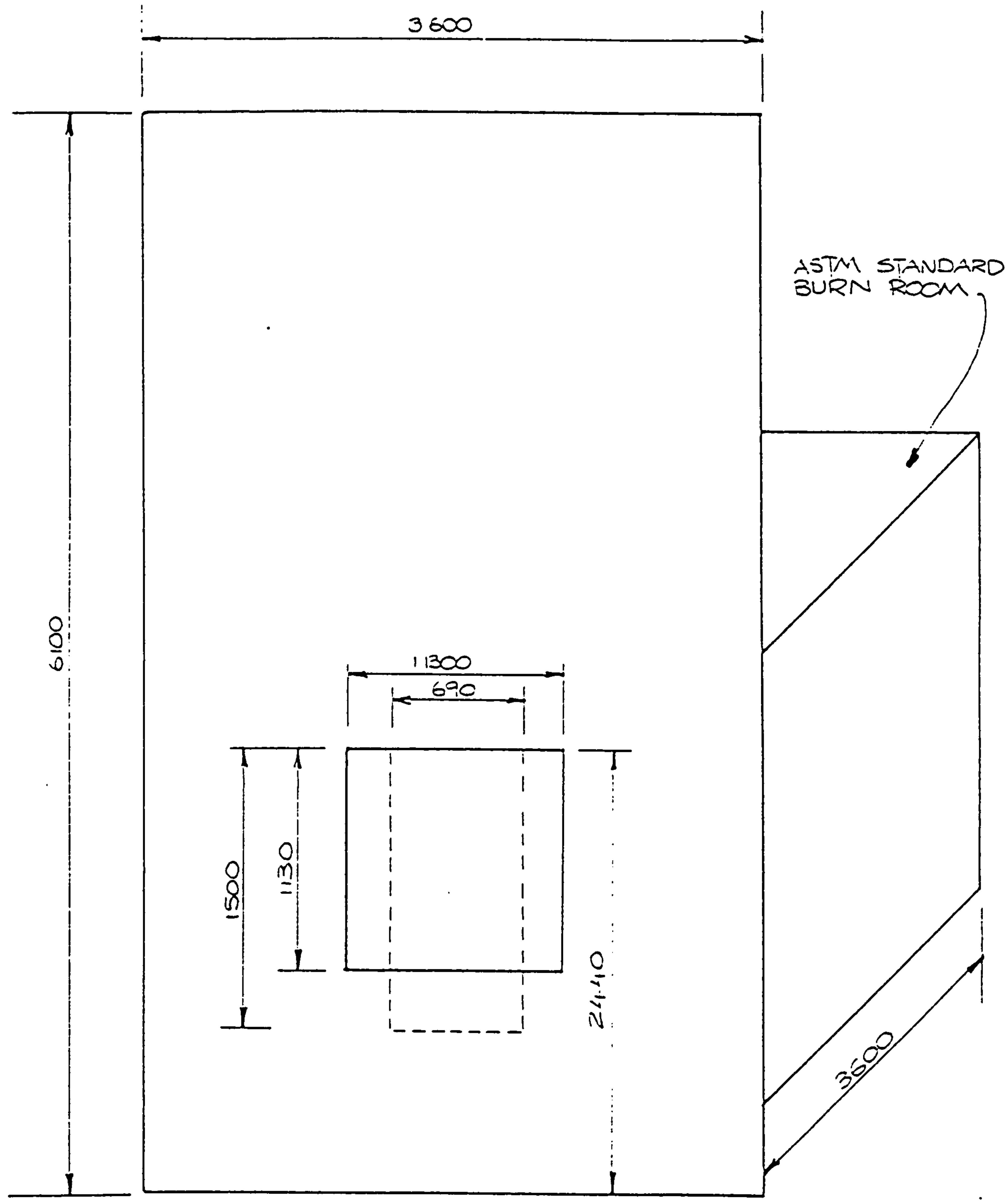

FIGURE 1: ASTM STANDARD BURN ROOM MODIFIED TO STUDY EXPOSURE TO EXTERIOR WALL

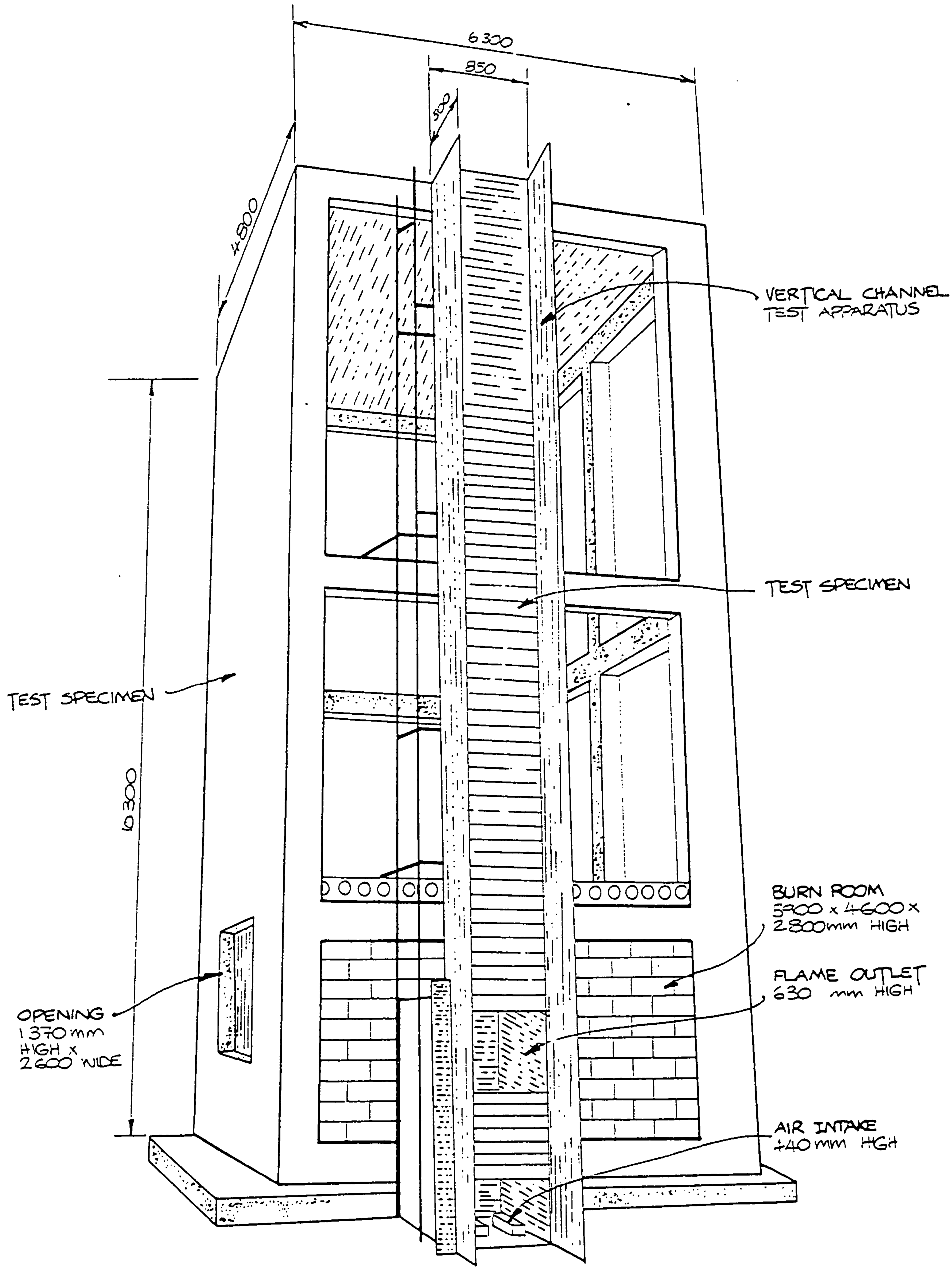

FIGURE 2: EXTERIOR WALL FIRE TEST FACILITY AND VERTICAL CHANNEL FLAME SPREAD TEST APPARATUS

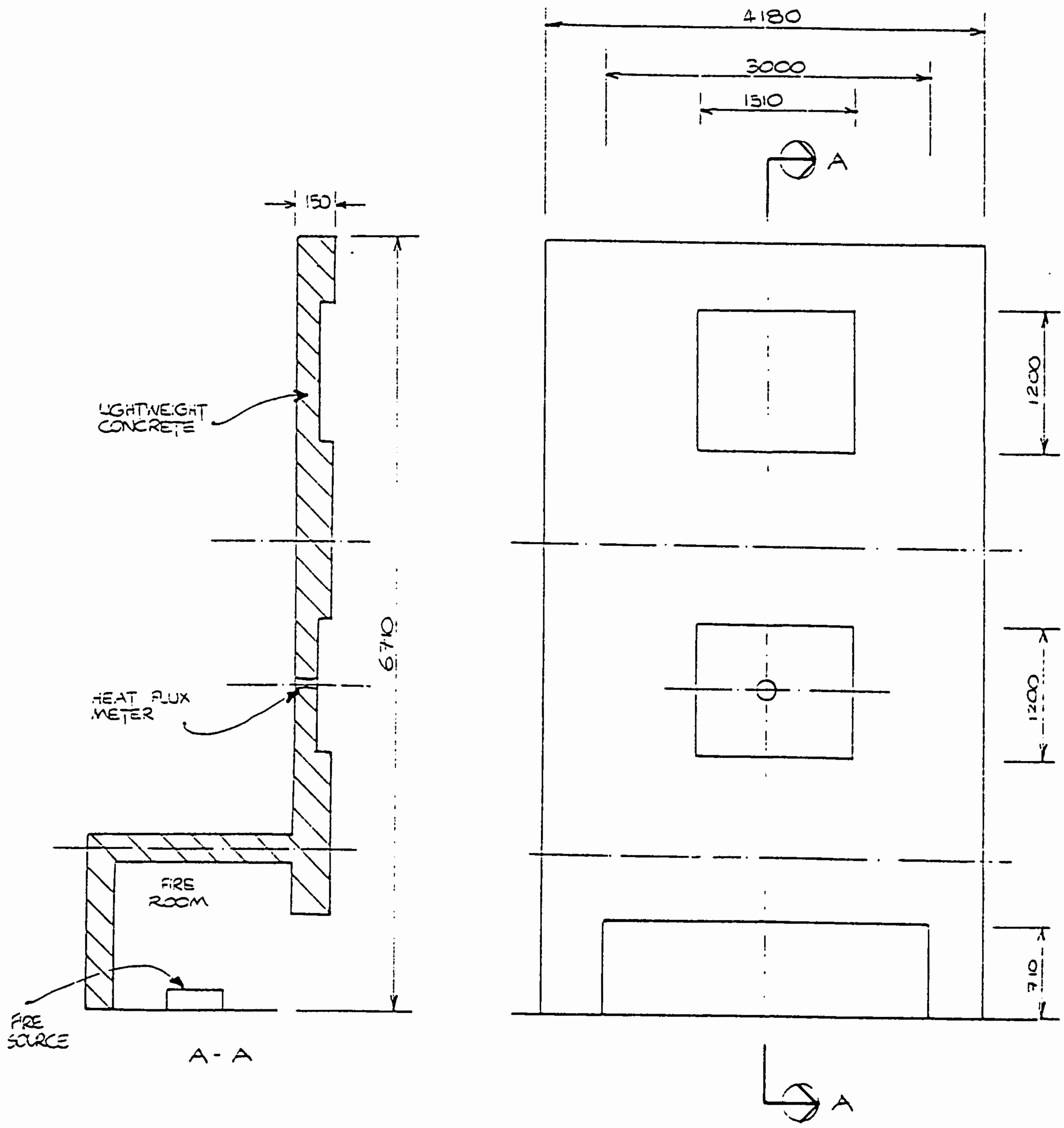

FIGURE 3: FULL SCALE TEST APPARATUS USED IN TEST SPFIRE 105.

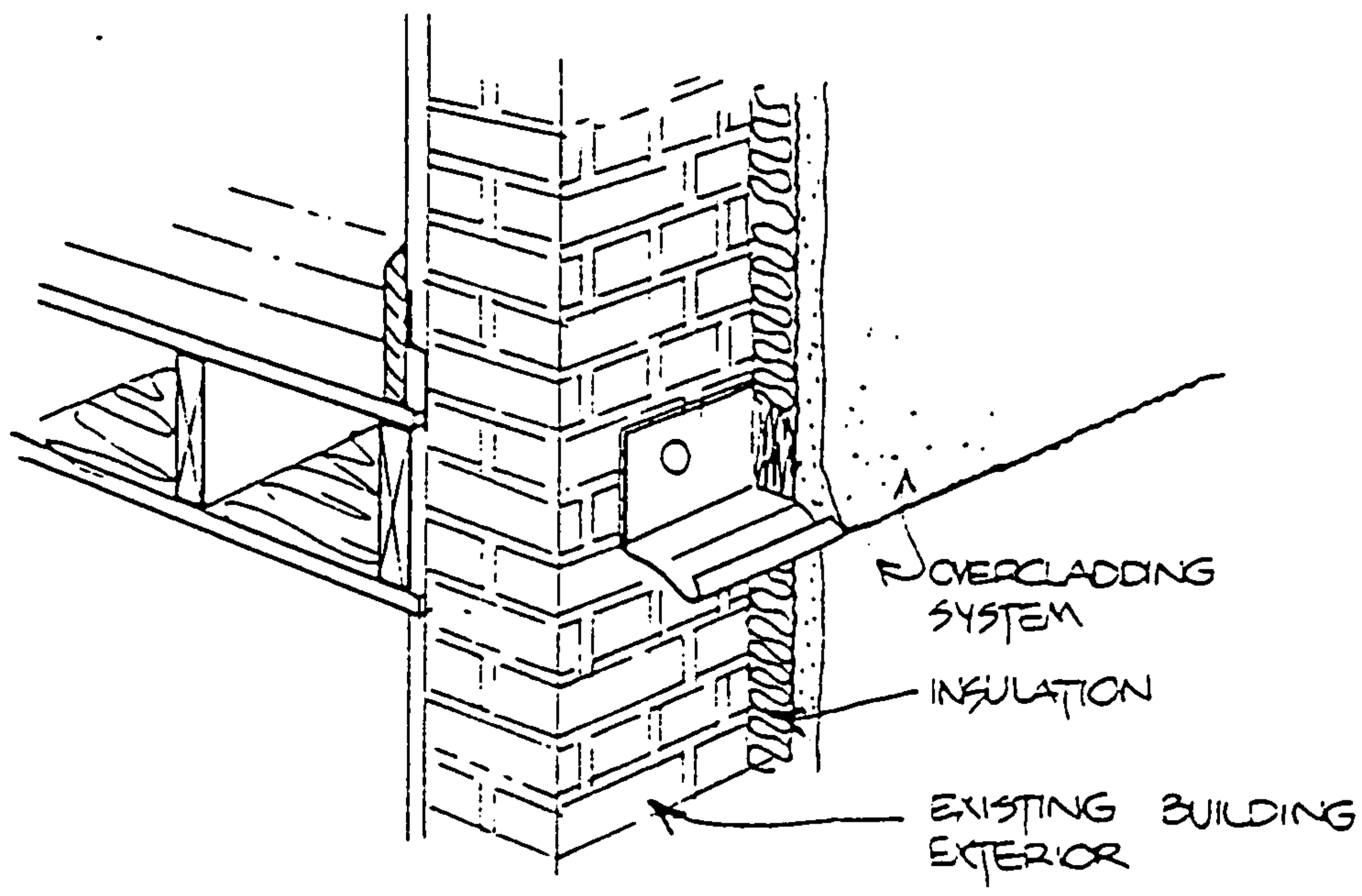

FIGURE 4: EXAMPLE OF OVERCLADDING

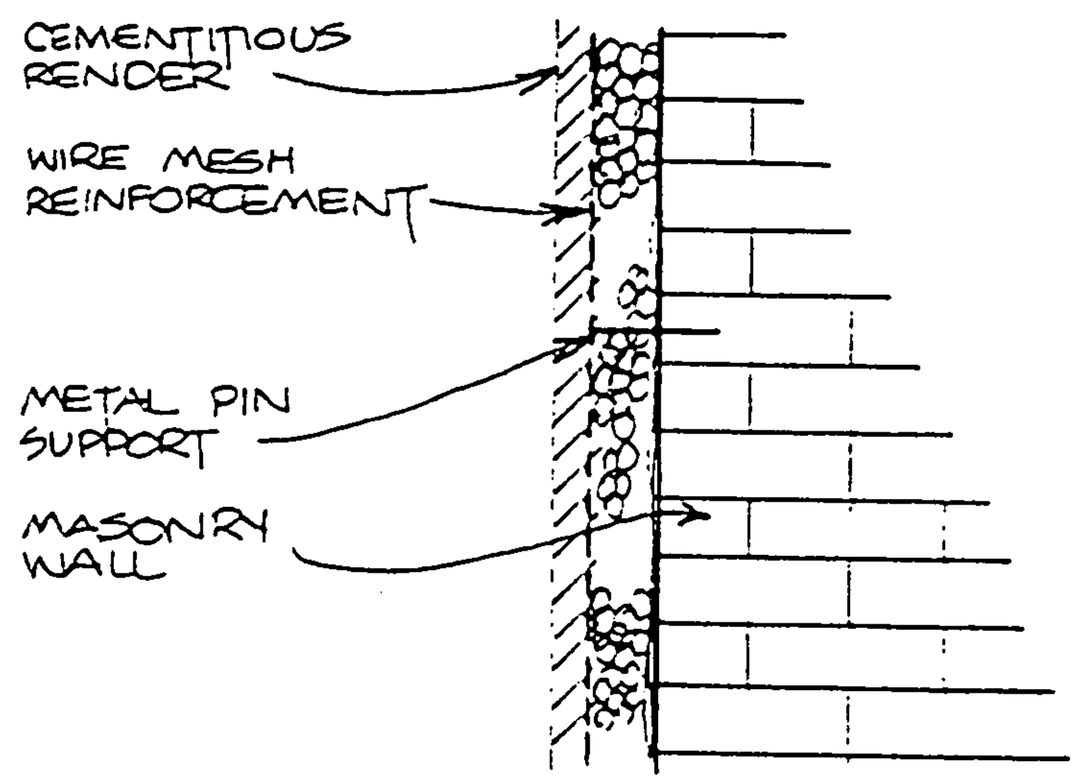

FIGURE 5: INSULATION SANDWICHED BETWEEN WALL AND RENDERING.

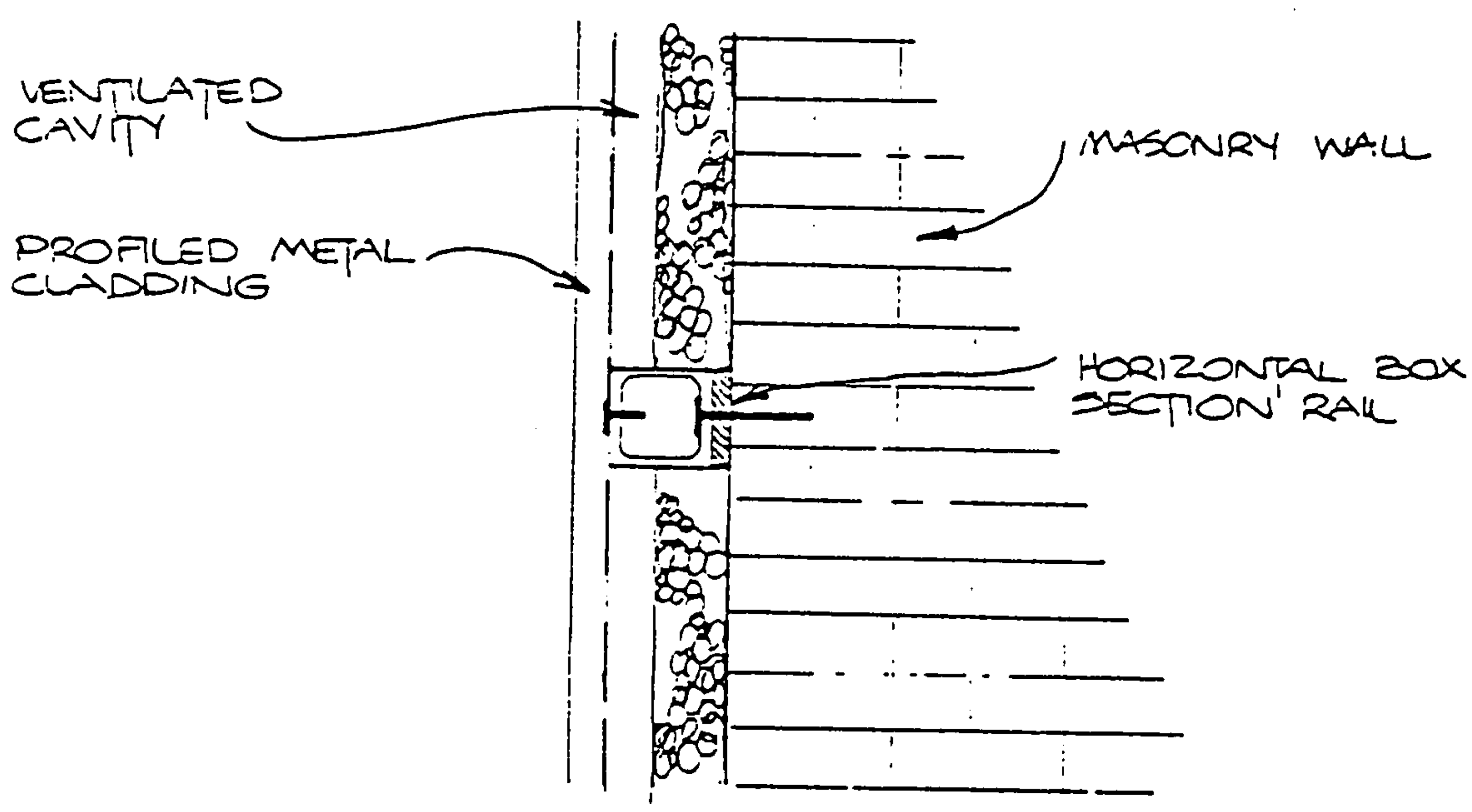

FIGURE 6: CAVITY BETWEEN INSULATION AND CLADDING.

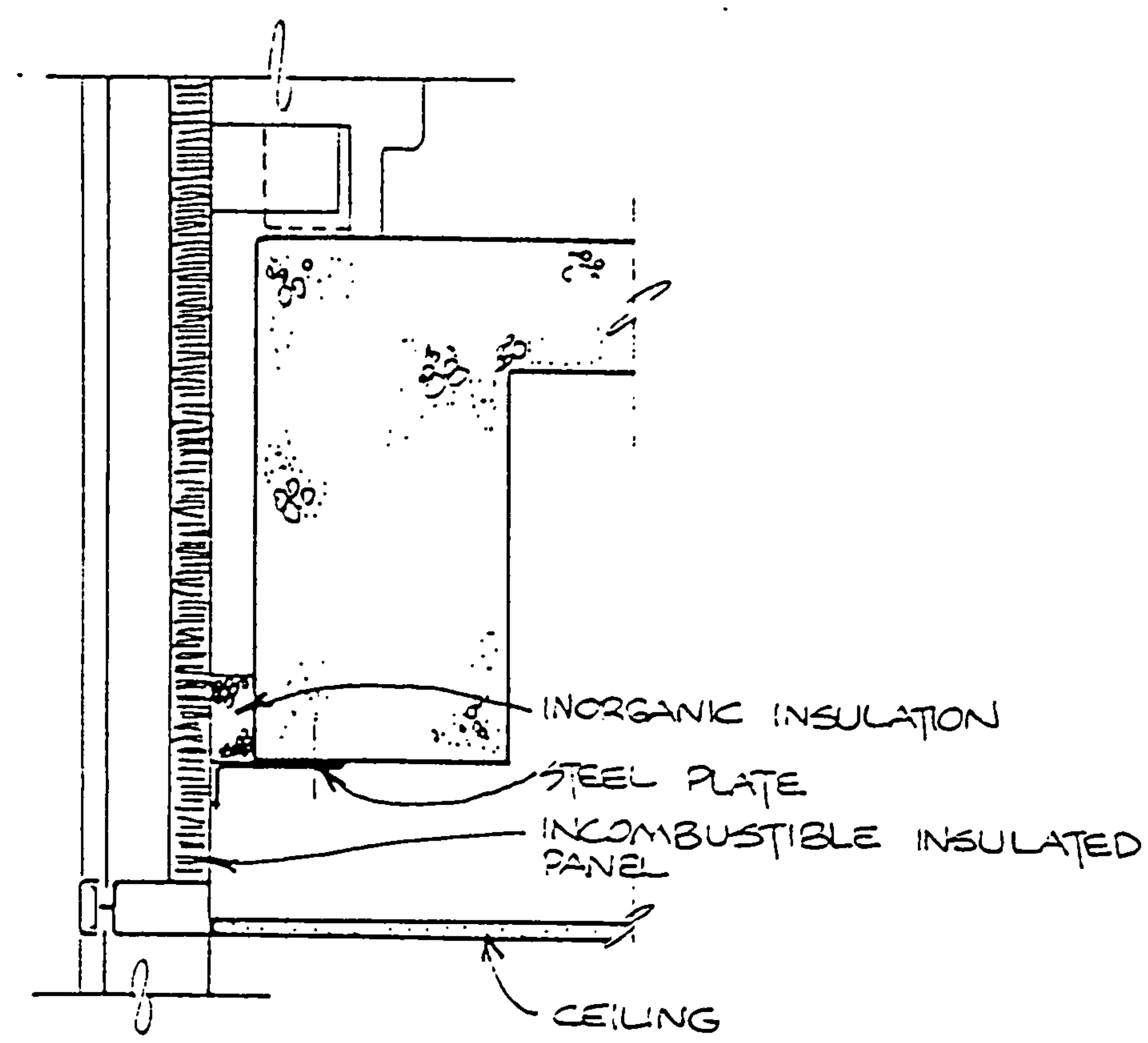

FIGURE 7: IN A FLUSH WALL THE SPANDREL PANEL INSULATION SHOULD BE PLACED TO THE INTERIOR. THIS SHOULD BE STIFF ENOUGH TO PERMIT PACKING OF THE INSULATION AGAINST THE STEEL PLATE.

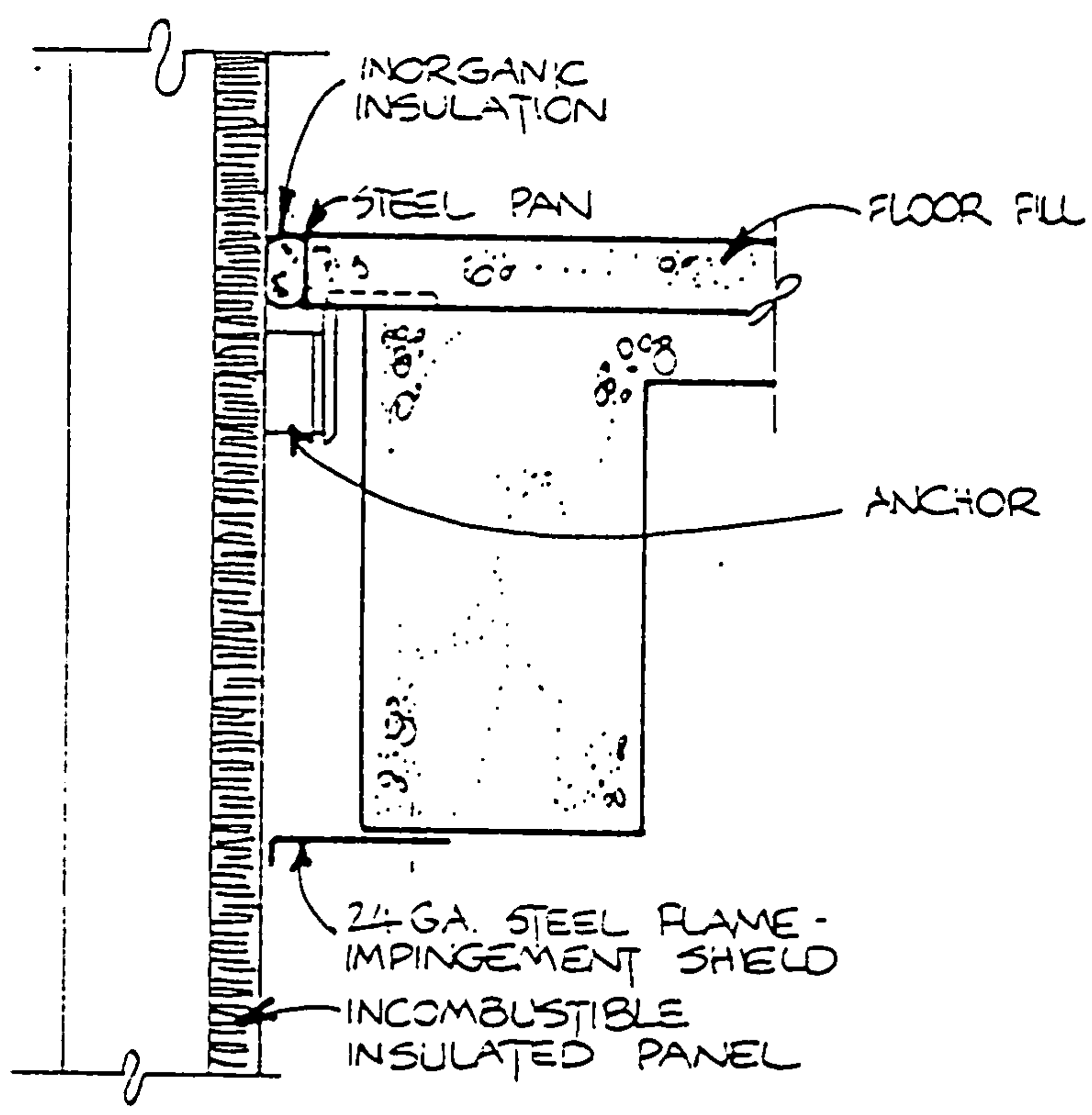

FIGURE 8: WHEN THE ANCHORS MUST BE BELOW THE FINISHED FLOOR, INSULATION MUST BE PACKED BETWEEN THE INSULATED PANEL AND THE STEEL PAN TO STOP SMOKE AND GAS.

THE STEEL SHIELD WILL KEEP FLAMES OUT OF THE CONFINED SPACE BETWEEN THE PANEL AND SPANDREL BEAM.

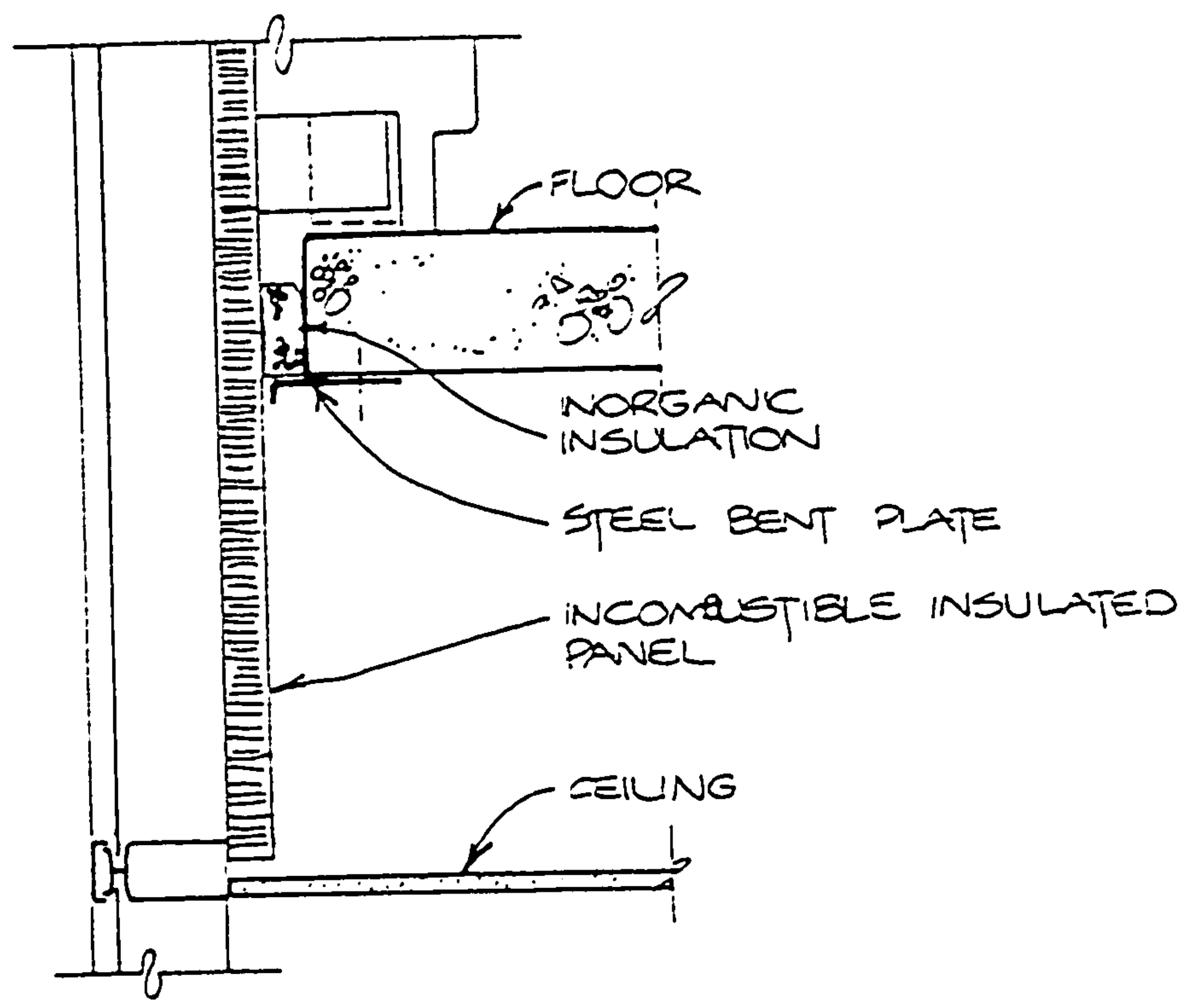

FIGURE 9: IN THIS CASE THE INSULATED PANEL COMPLETELY COVERS THE INTERIOR FACE OF THE MULLION. THIS ARRANGEMENT GIVES THE GREATEST PROTECTION AGAINST HEAT BUILD-UP WHEN THE SLAB IS CANTILEVERED AND FIRE TRAVELS ABOVE THE CEILING OR THE CEILING IS DESTROYED.

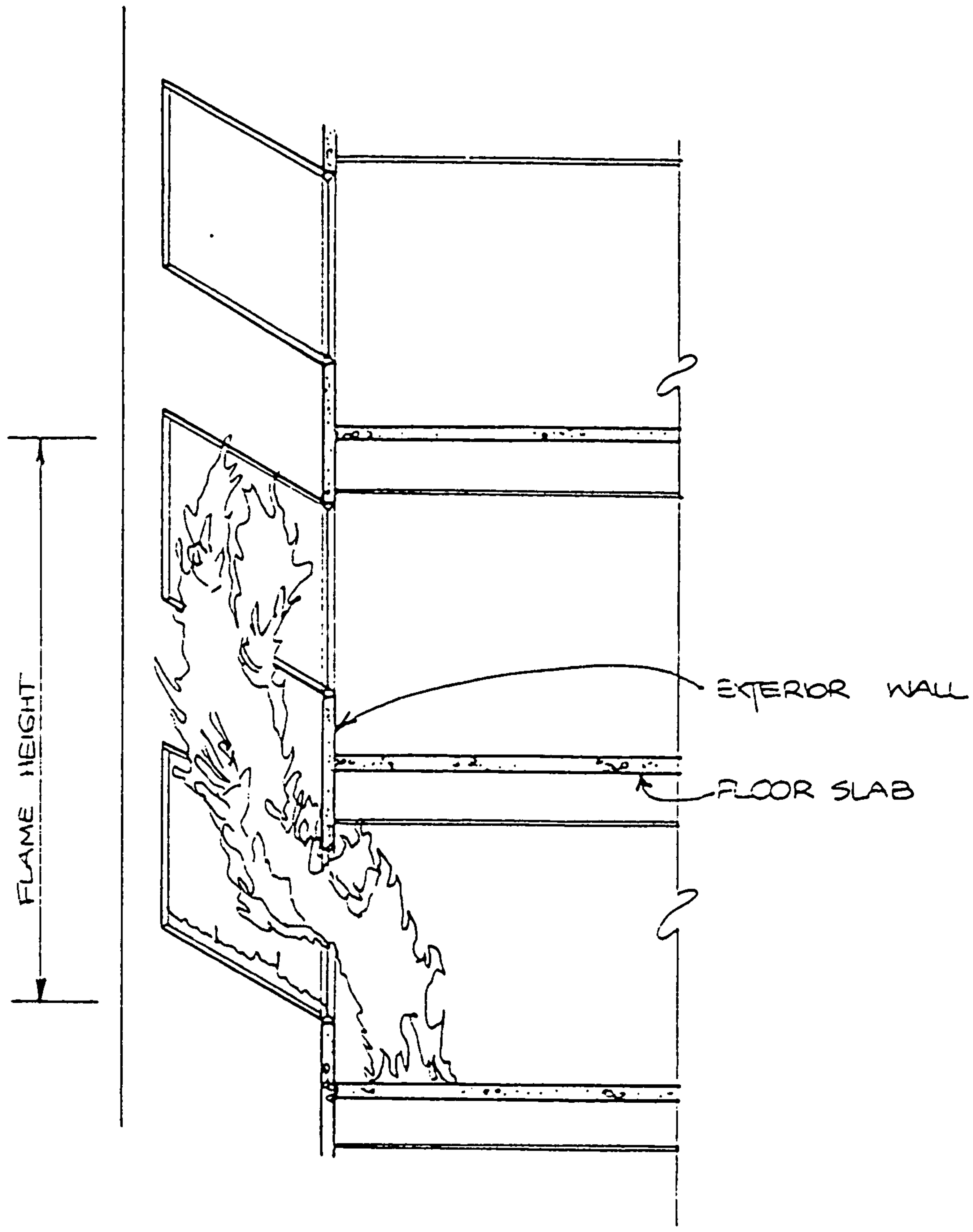

FIGURE 10: EXAMPLE OF FIRE EXPOSED TO FACADE.
NOTE: FLAME HEIGHT VARIES WITH RATE OF BURNING AND AREA AND HEIGHT OF WINDOW.

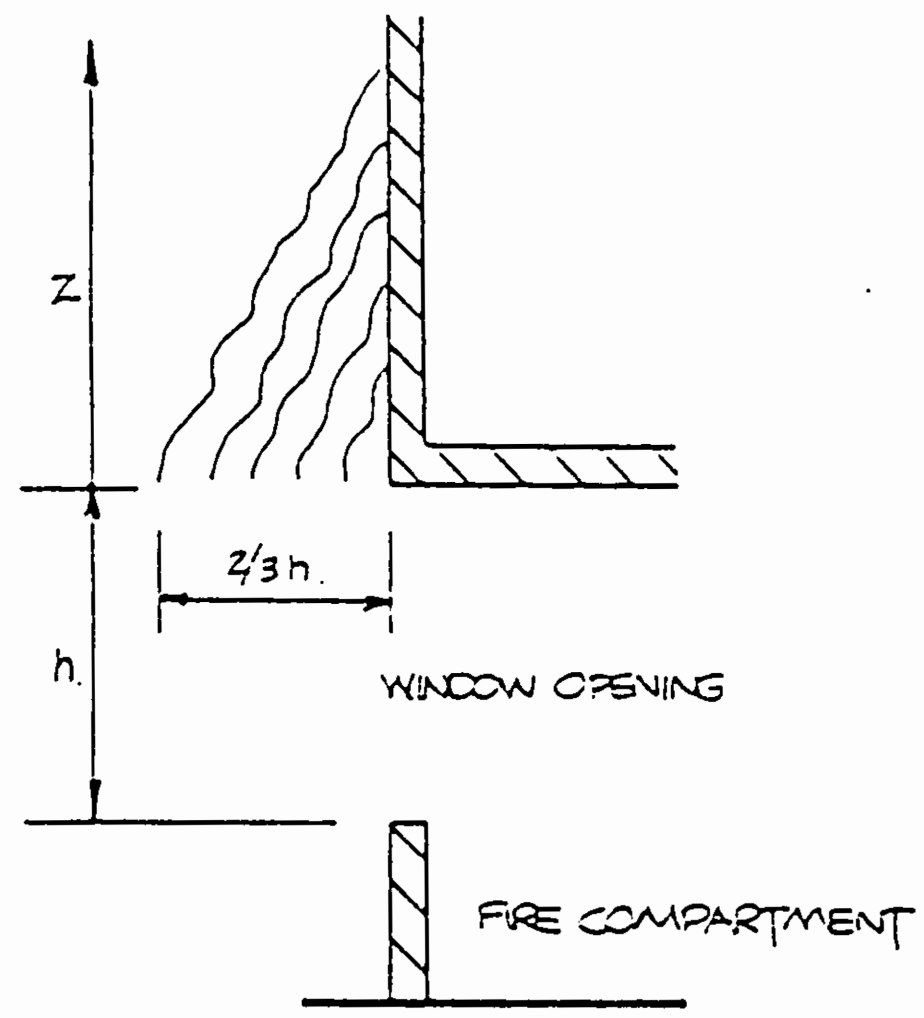

FIGURE 11 : ASSUMED SHAPE OF EMERGING FLAME

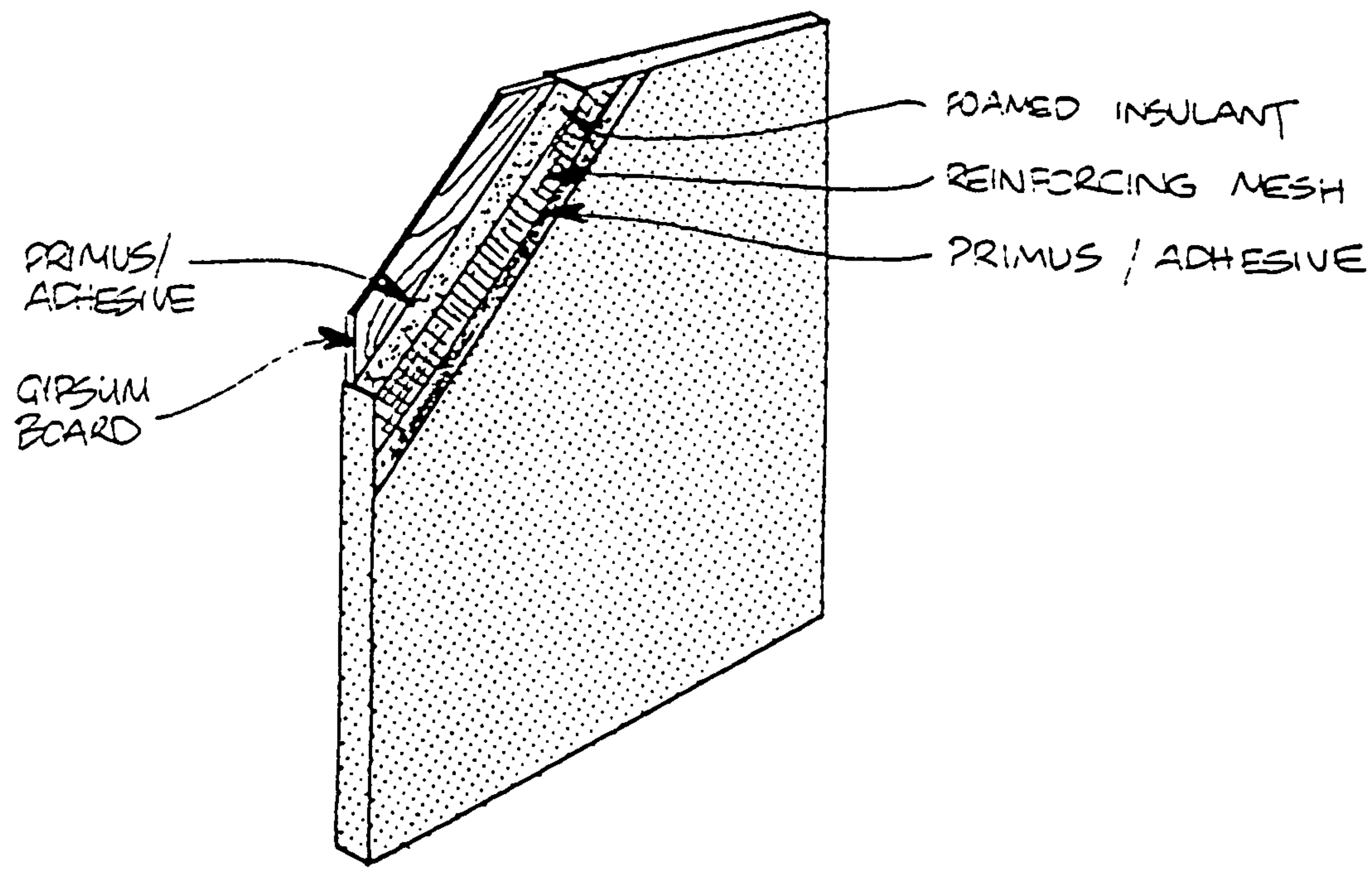

FIGURE 12: EXTERIOR INSULATION & FINISH SYSTEM, WITH FOAMED POLYMERIC INSULATION SHEET AFFIXED & THE PANEL COATED WITH PLASTER FINISHING SURFACE.

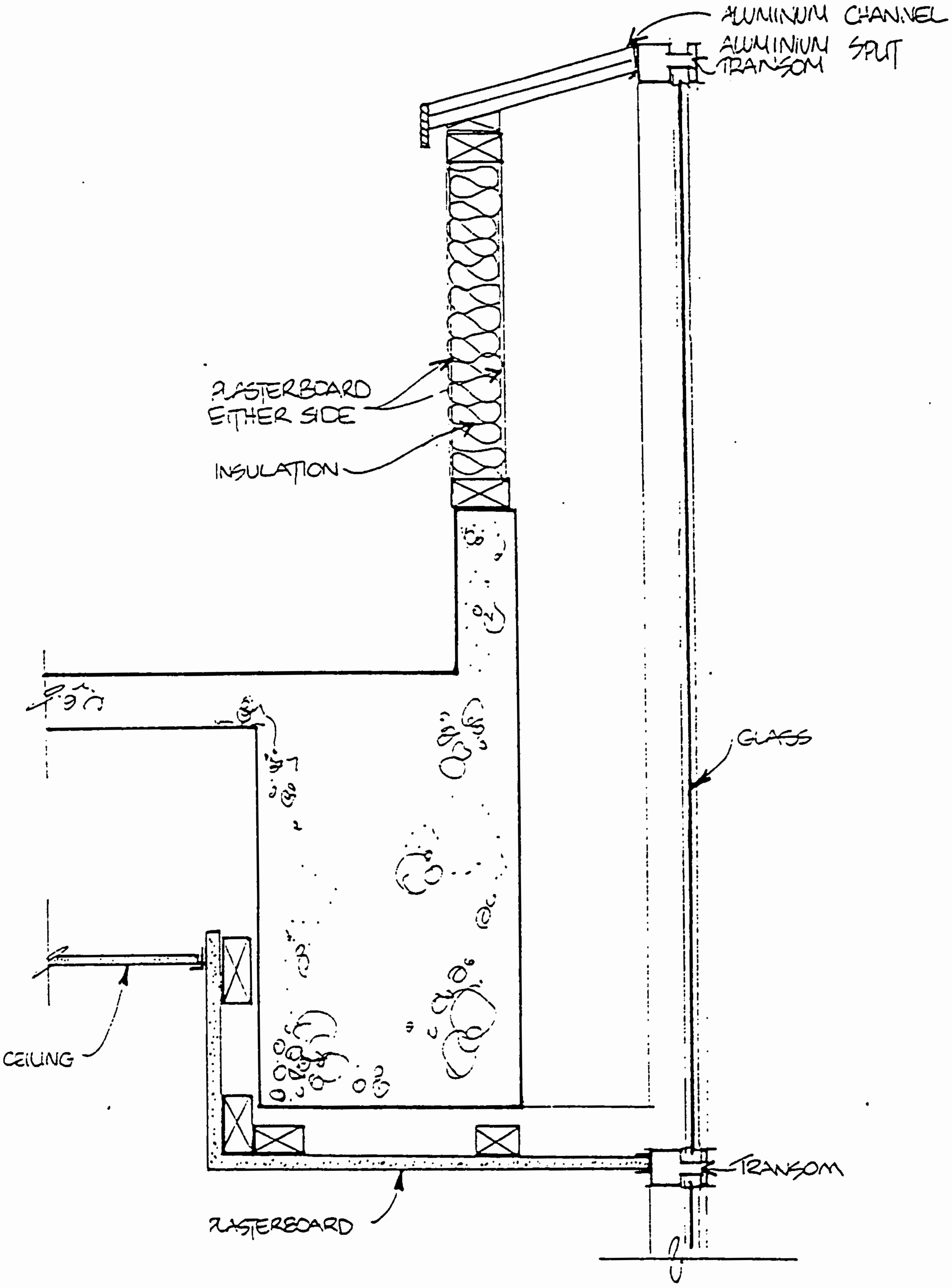

FIGURE 13(a): SECTION THROUGH CONCRETE FRAMED GLASS CURTAIN WALL BUILDING.

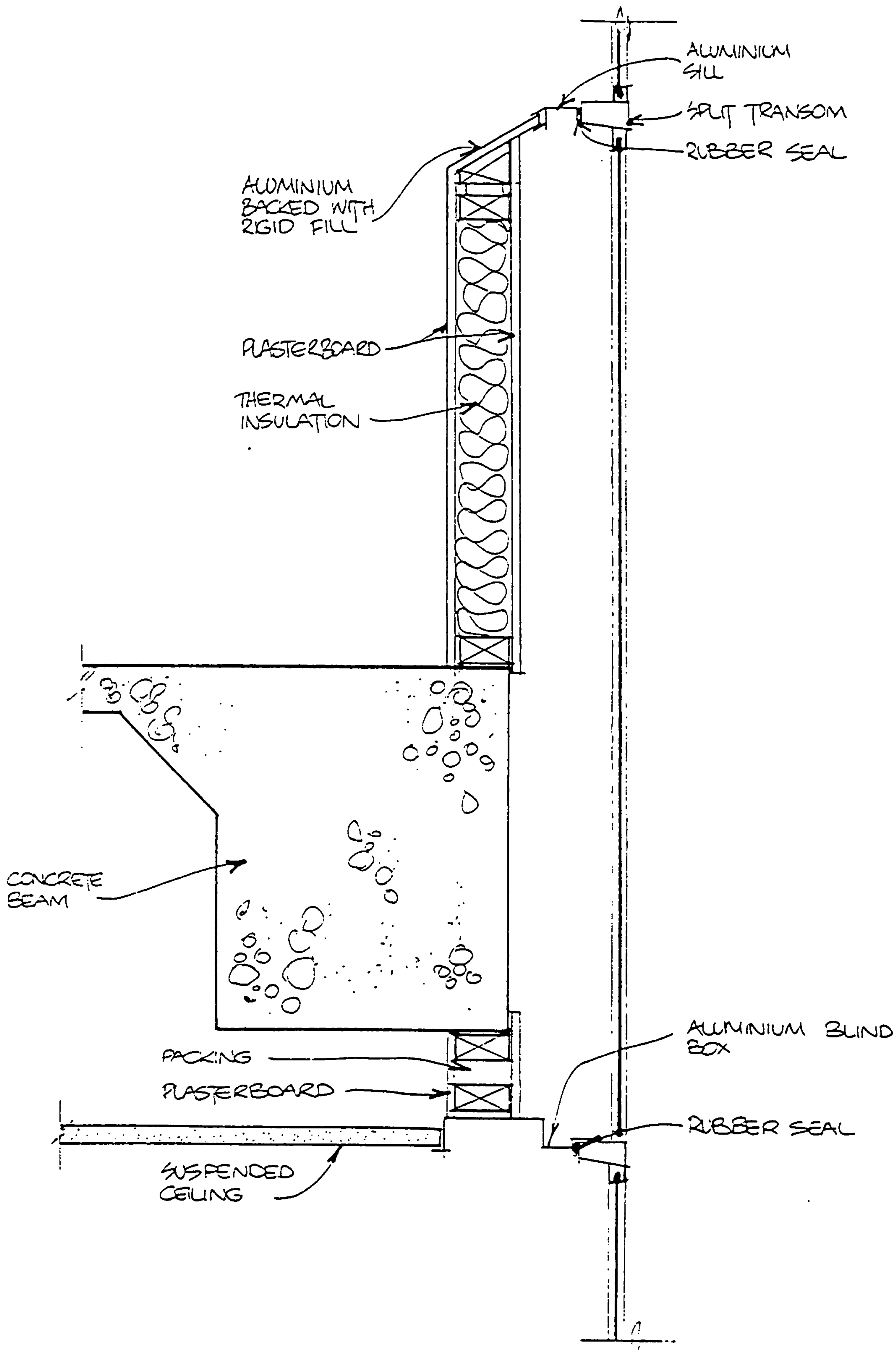

FIGURE 13(b): SECTION THROUGH CONCRETE FRAMED, GLASS CURTAIN WALL BUILDING.

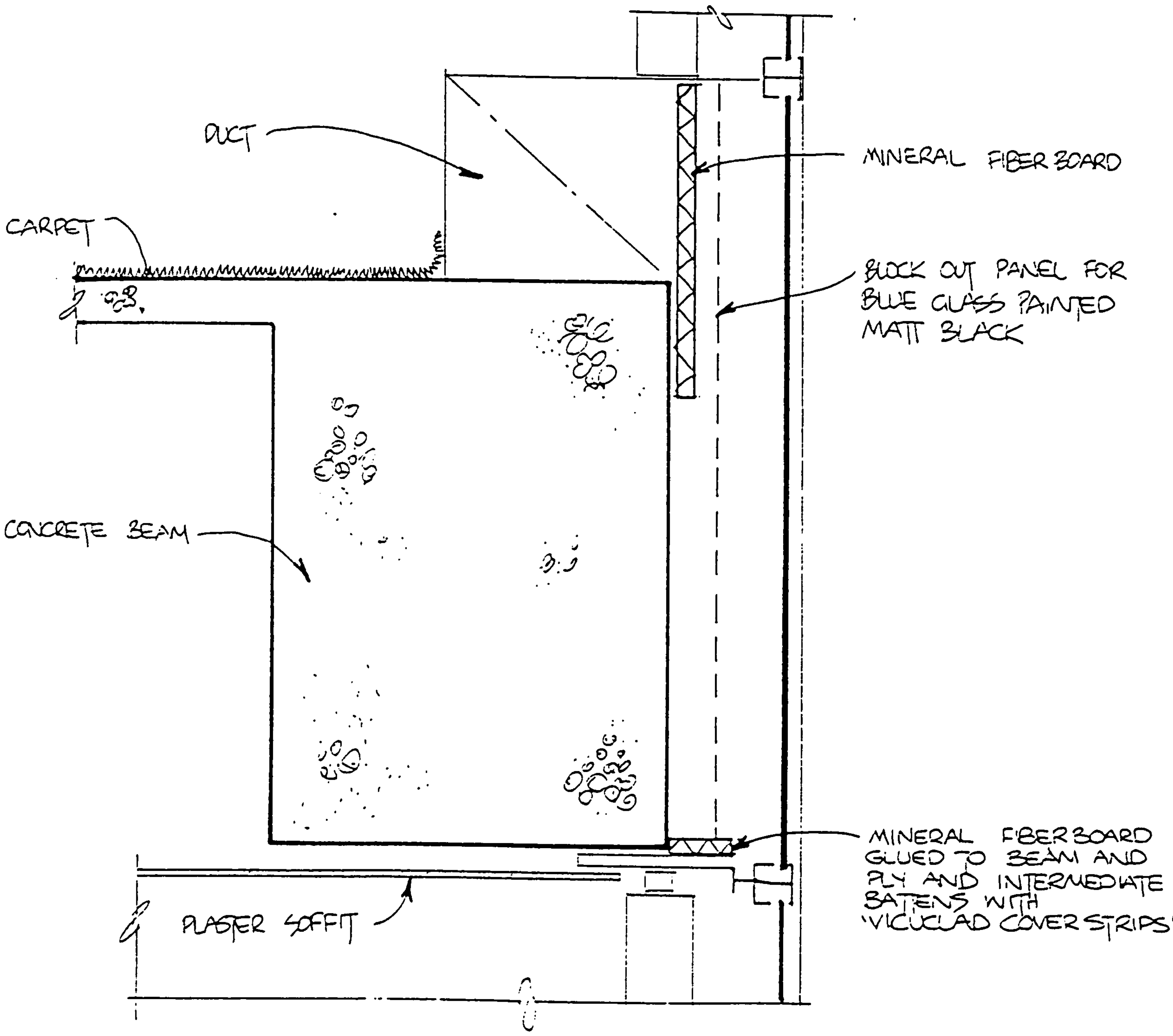

FIGURE 13(c): SECTION THROUGH CONCRETE FRAMED, GLASS CURTAIN WALL BUILDING

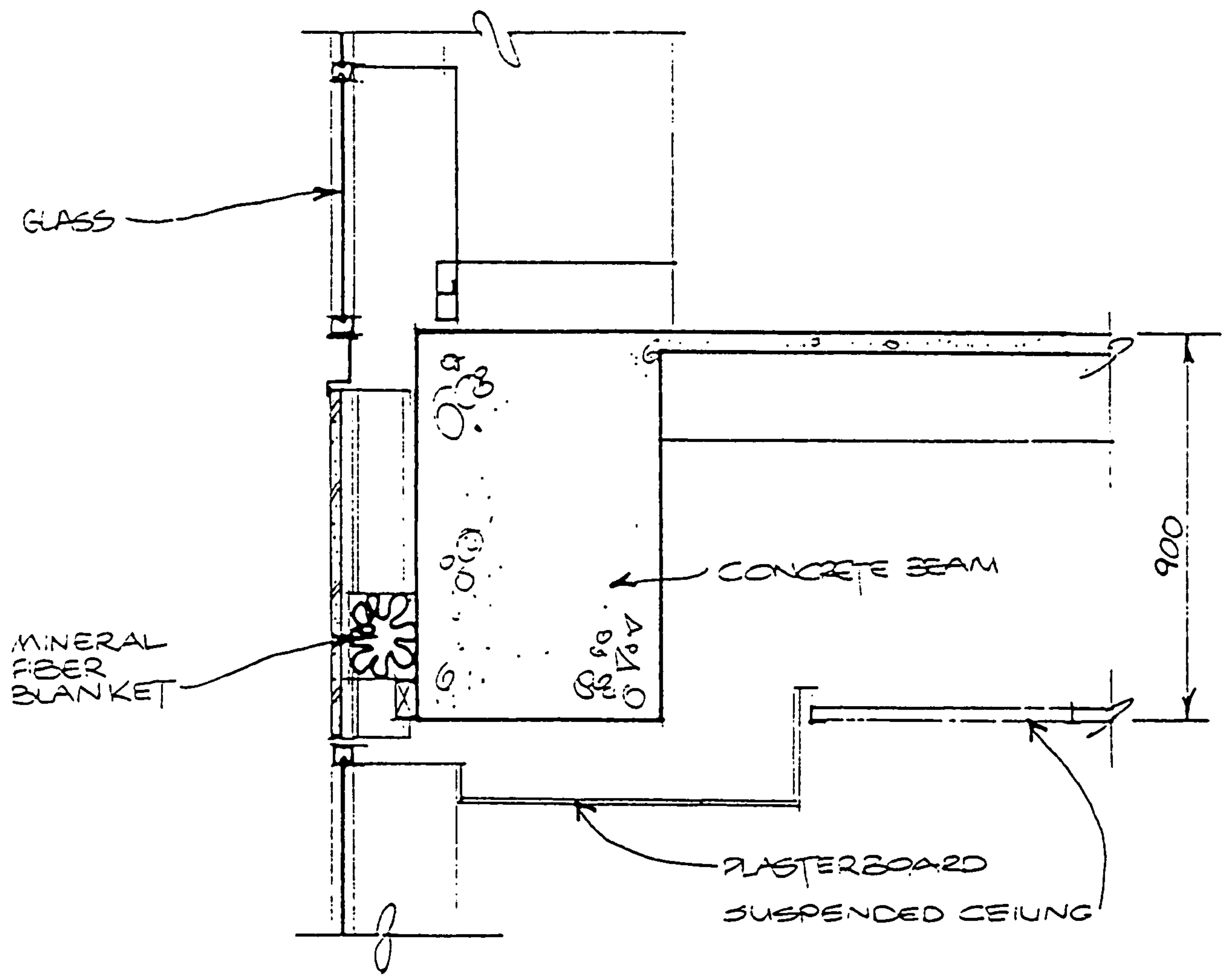

FIGURE 13(d): SECTION THROUGH CONCRETE FRAMED GLASS CURTAIN WALL BUILDING

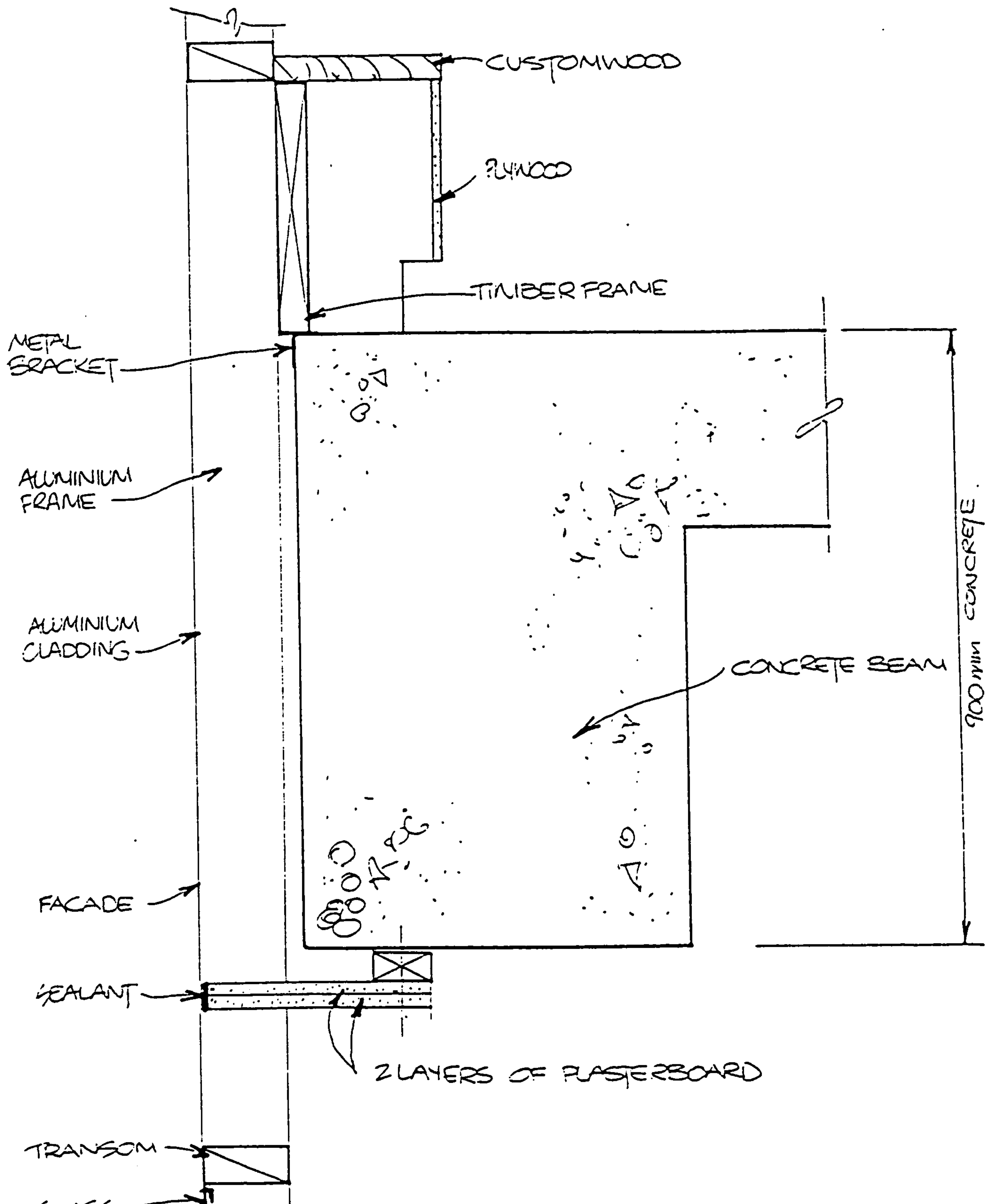

FIGURE 14(a): SECTION THROUGH CONCRETE FRAMED, GLASS AND ALUMINIUM CURTAIN WALL BUILDING

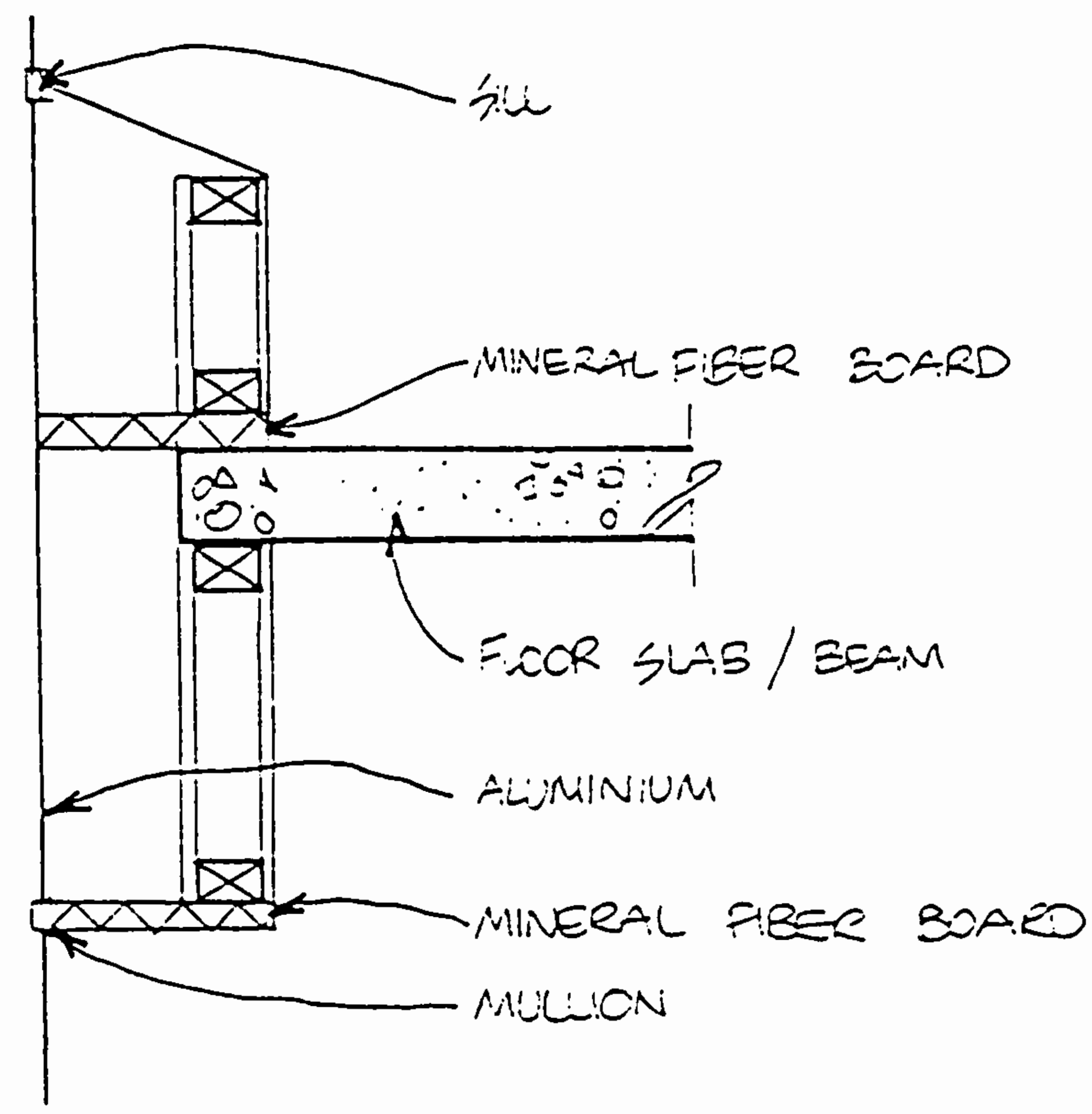

FIGURE 14(b): SECTION THROUGH CONCRETE FRAMED, ALUMINIUM AND GLASS CURTAIN WALL BUILDING

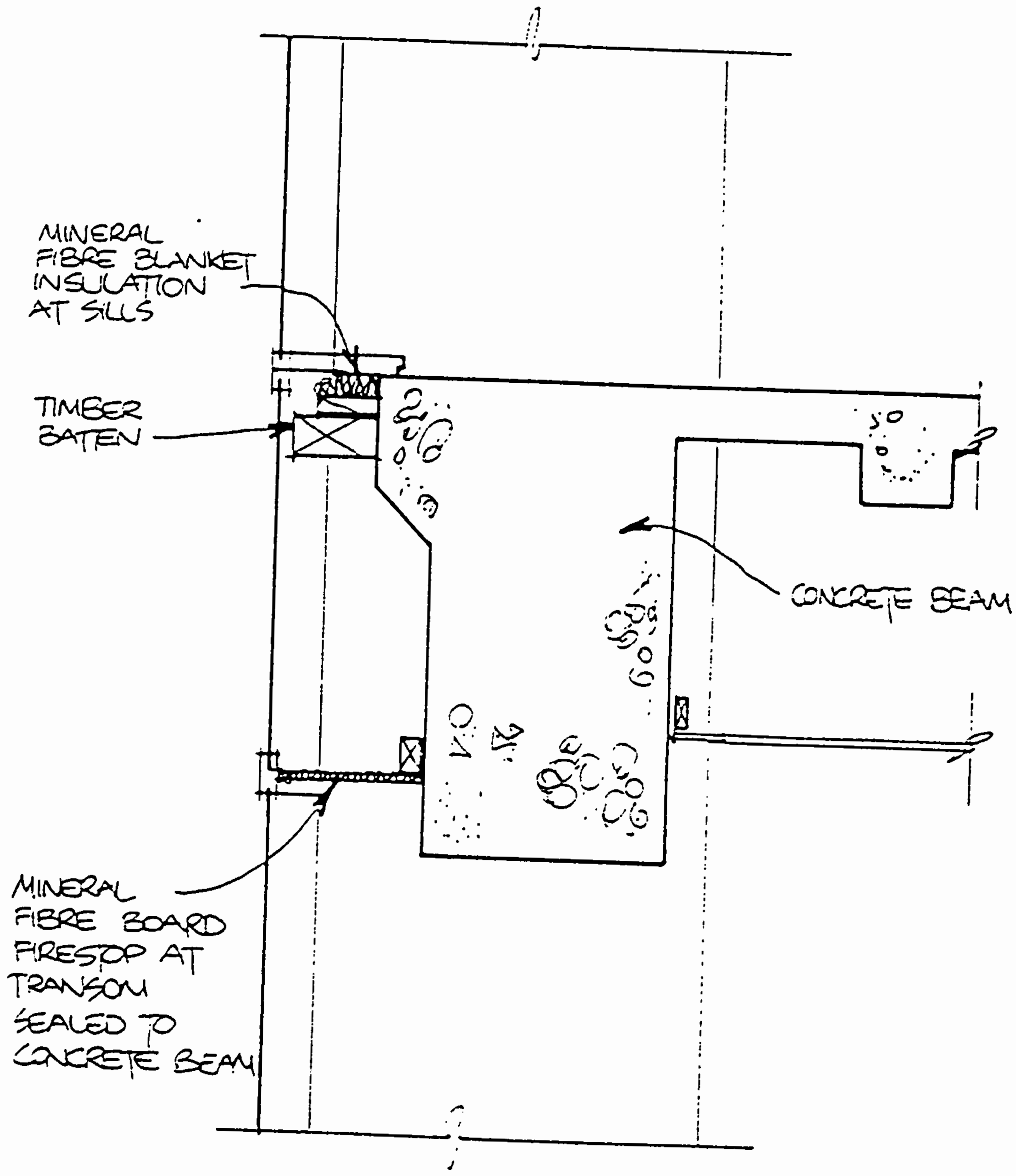

FIGURE 14(c): SECTION THROUGH CONCRETE FRAMED, ALUMINIUM AND GLASS CURTAIN WALL BUILDING

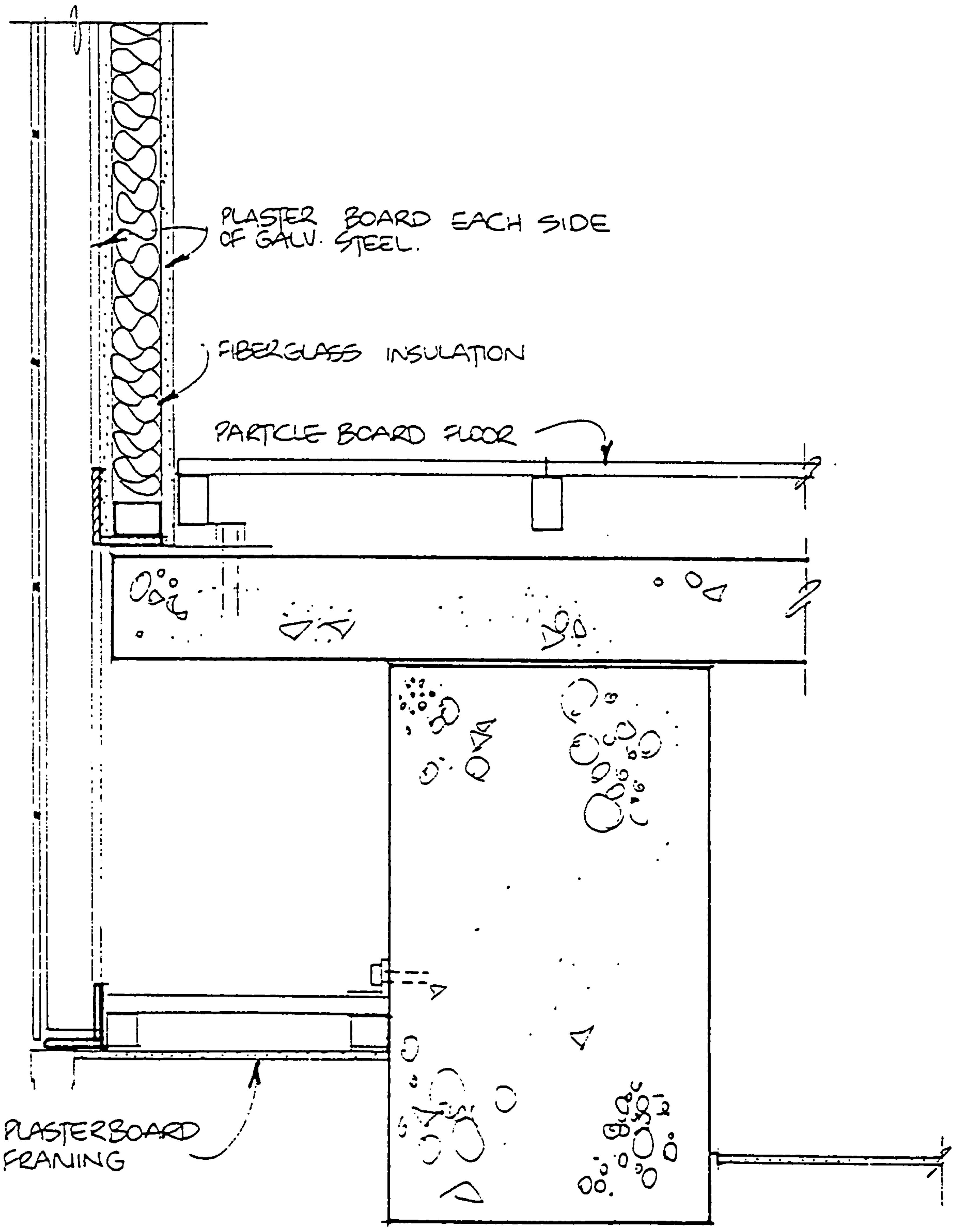

FIGURE 14(d): SECTION THROUGH CONCRETE FRAMED, ALUMINIUM AND GLASS CURTAIN WALL BUILDING.

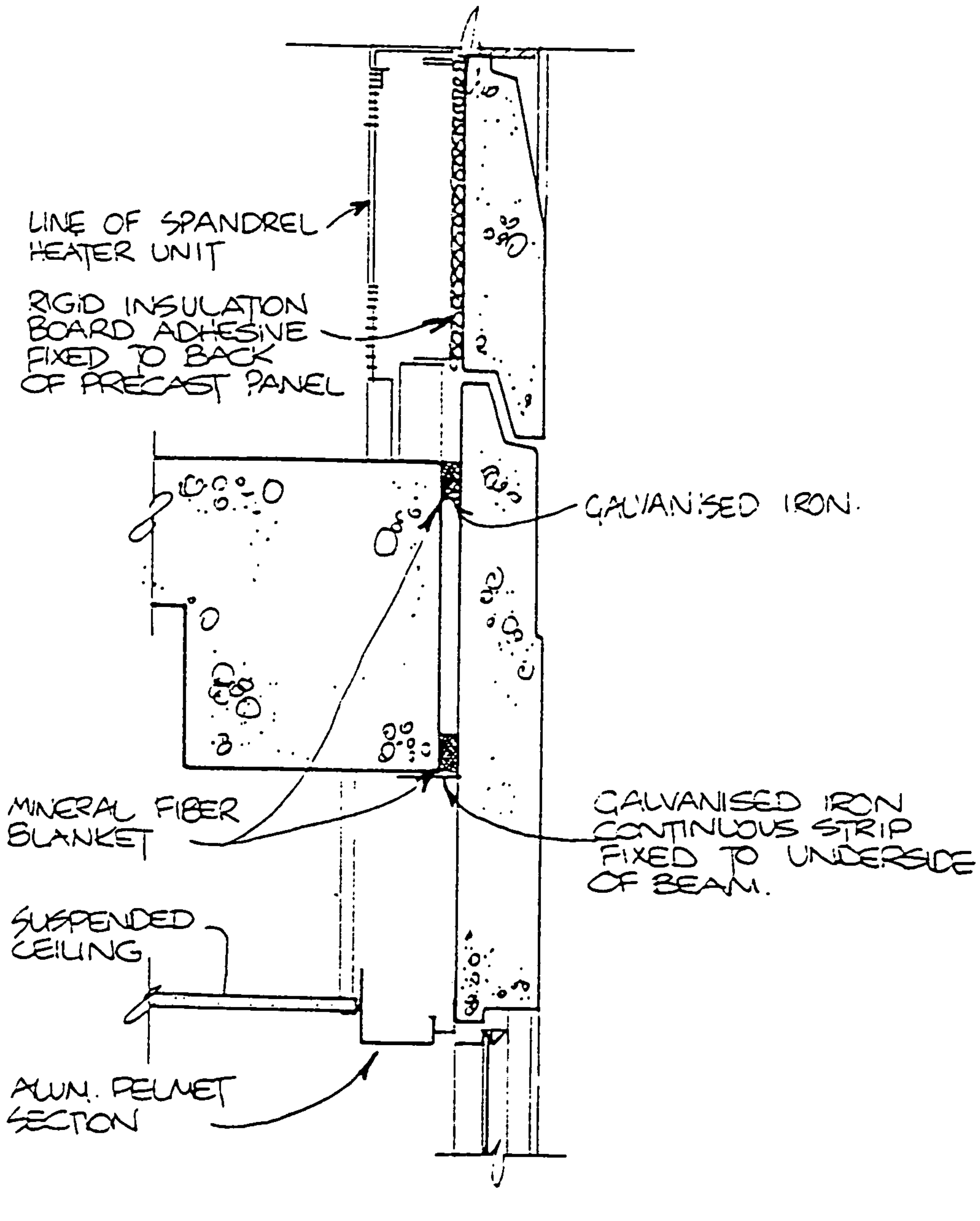

FIGURE 15: SECTION THROUGH CONCRETE FRAME, CONCRETE PANEL AND GLASS FACADE BUILDING

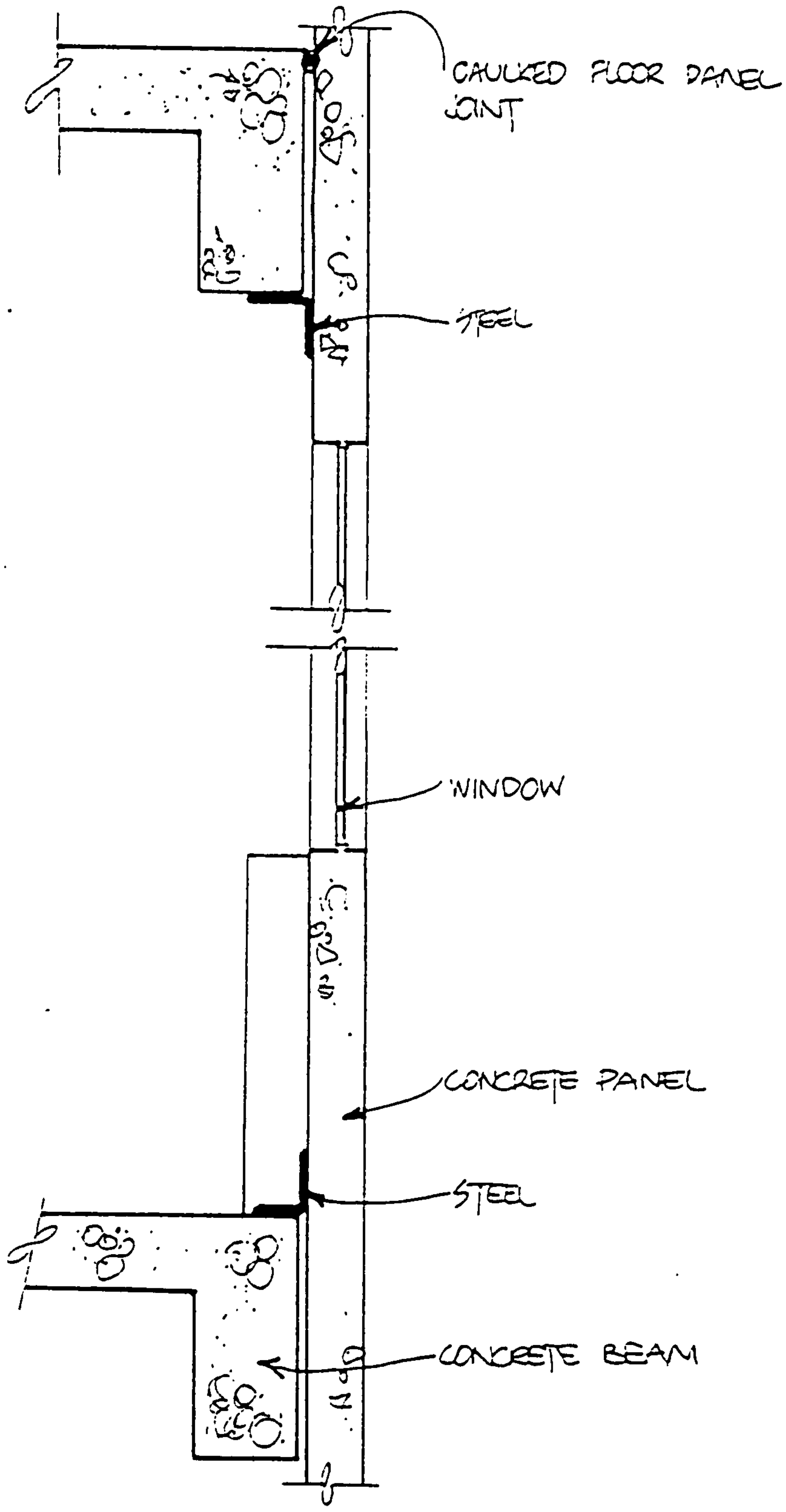

FIGURE 16 : SECTION THROUGH CONCRETE FRAME, CONCRETE PANEL BUILDING.

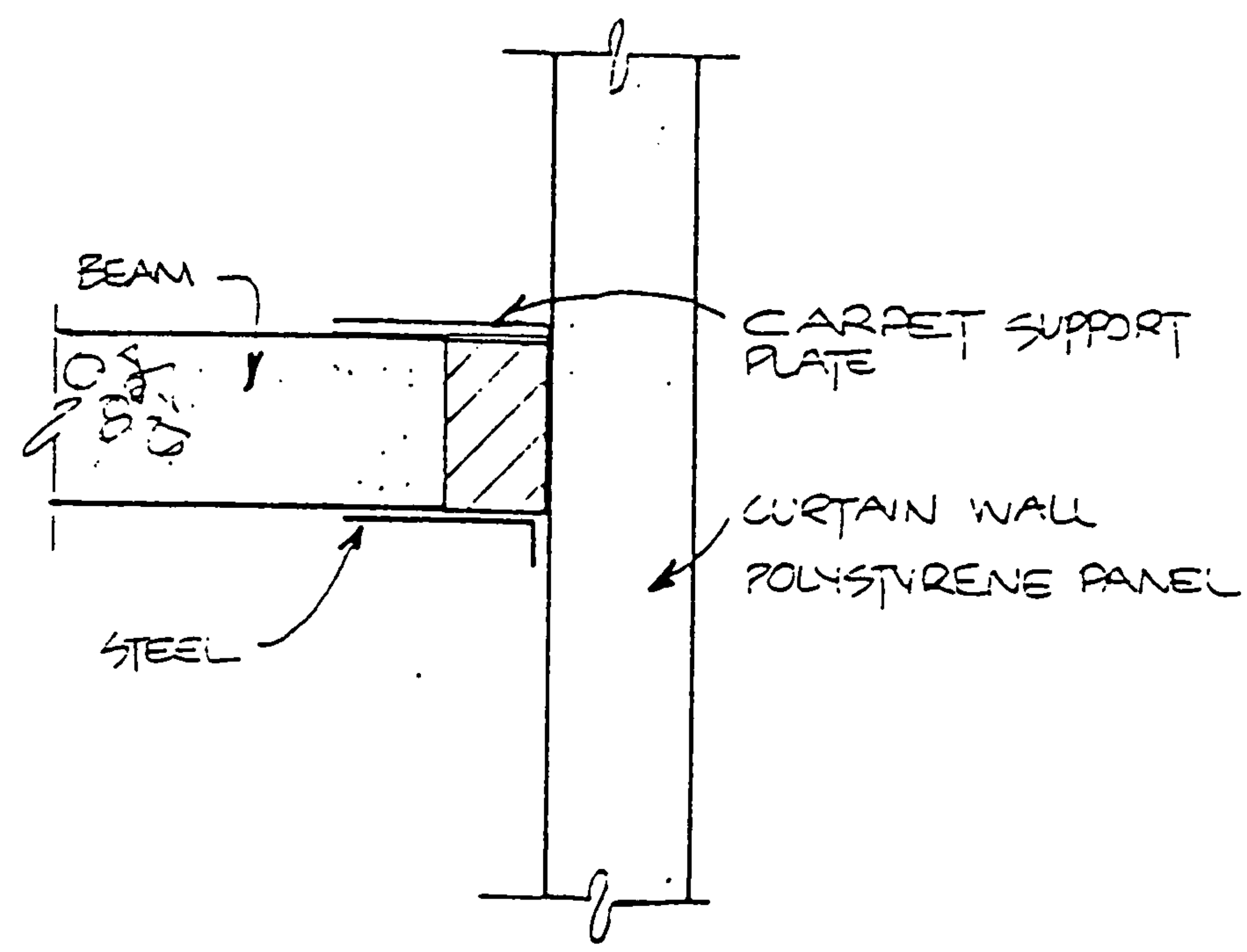

FIGURE 17: SECTION THROUGH CONCRETE FRAMED BUILDING WITH POLYSTYRENE / GLASS CURTAIN WALLING

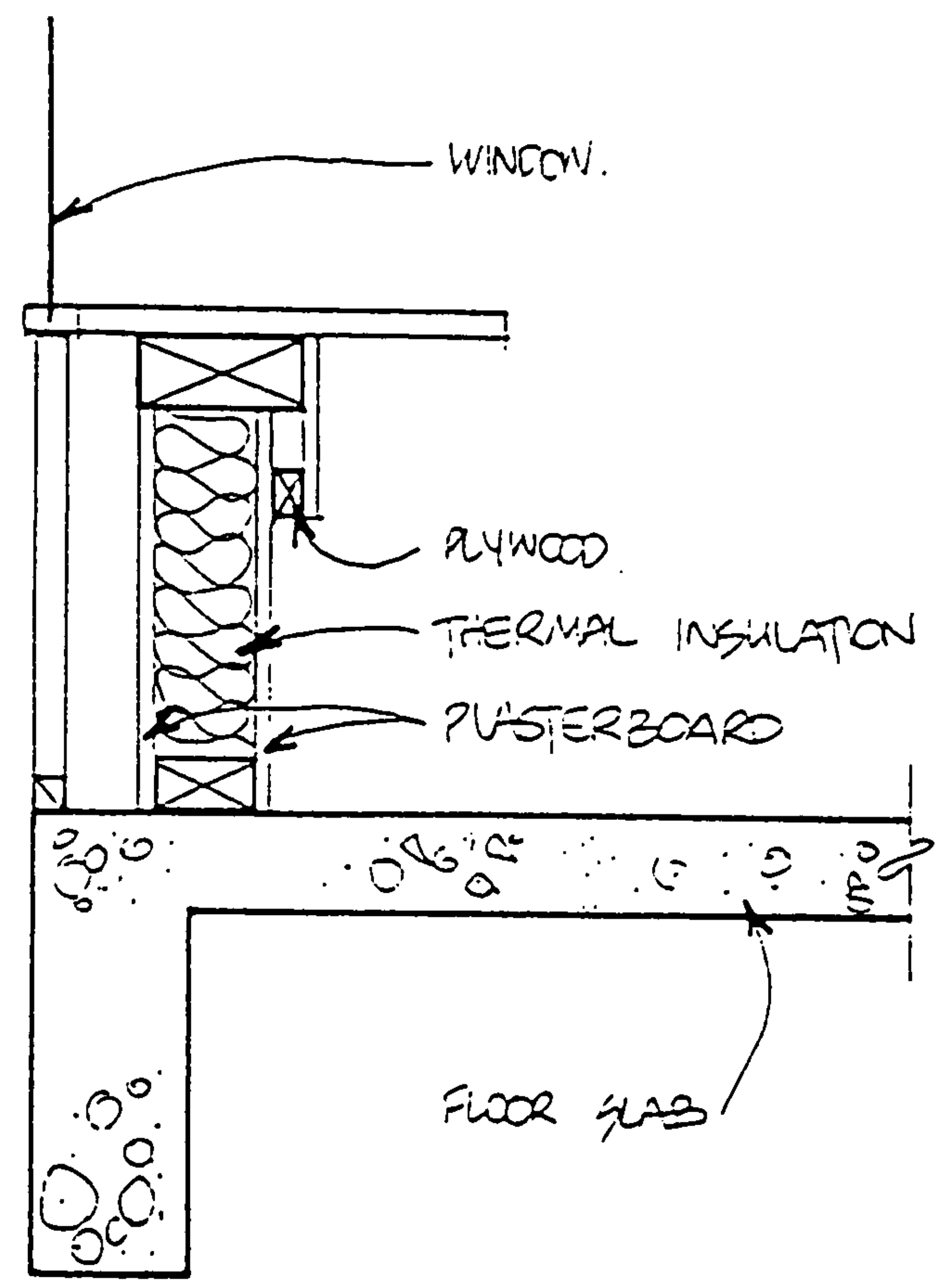

FIGURE 18 : SECTION THROUGH CONCRETE FRAME, CONCRETE AND GLASS EXTERNAL WALL BUILDING.

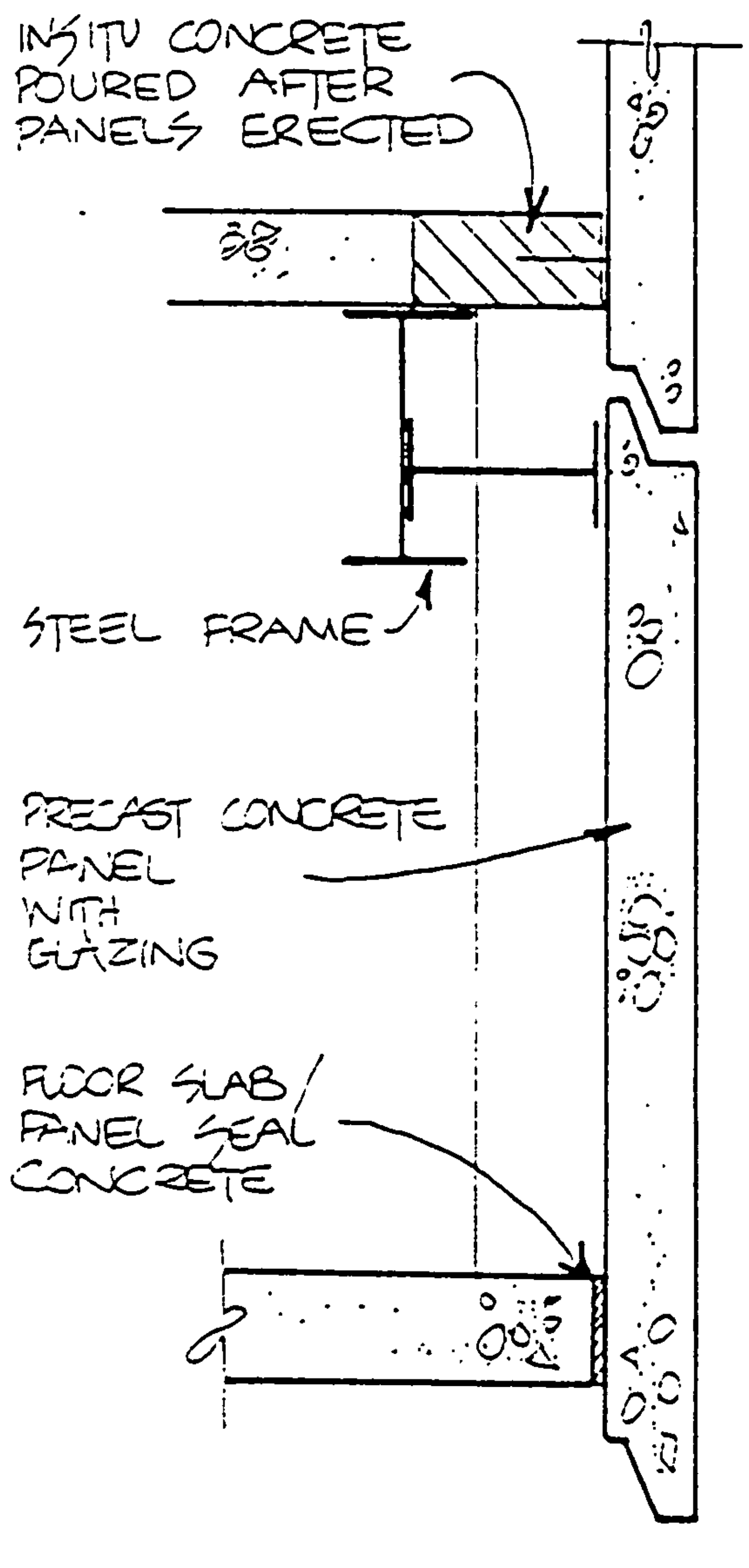

FIGURE 19: SECTION THROUGH STEEL FRAMED, PRECAST CONCRETE PANEL BUILDING

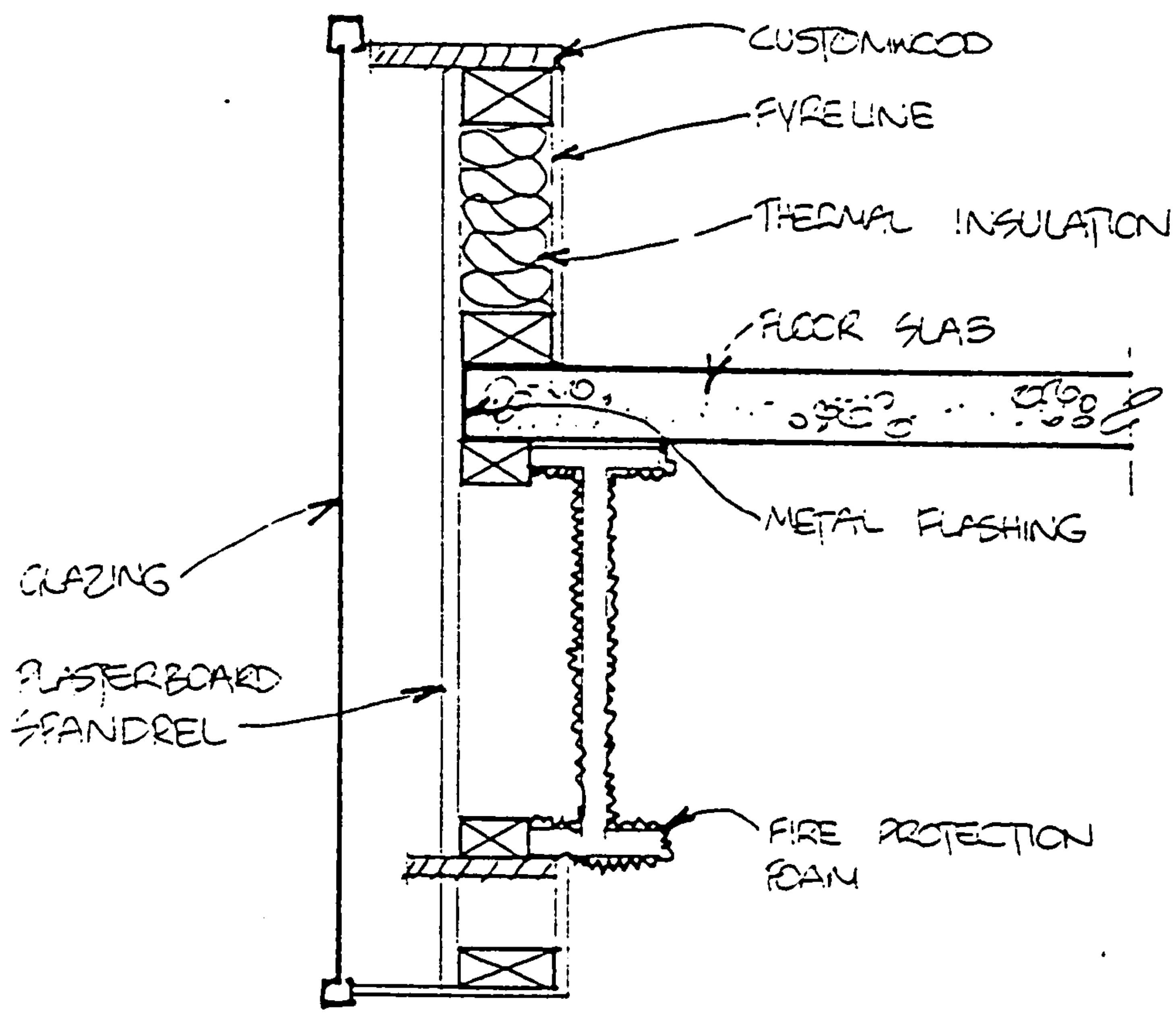

FIGURE 20: SECTON THROUGH STEEL FRAMED, GLASS CURTAIN WALL BUILDING

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