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Construction Details for Air Tightness

Record of the DBR Seminar/Workshop
October, November 1977 and January 1978

Proceedings No. 3

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NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF BUILDING RESEARCH

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of the
Division of Building Research

Ottawa, April 1980

PREFACE

For many years DBR/NRC has held seminars dealing with various aspects of building design, construction and materials as a means of providing information to the building industry. The seminars have taken the form of presentations made by DBR members, and frequently also by experts from the industry, followed by a discussion or "workshop" of particular aspects of the presentations.

The seminar on "Construction Details for Air Tightness" was presented in ten cities, and sometimes more than once in some locations. Even so, the total number of persons who could be reached by this means amounted to just over a thousand. These Proceedings have been compiled, therefore, to make this information available to a wider audience.

These Proceedings present the texts of the talks given in the DBR Seminar/Workshop entitled "Construction Details for Air Tightness," presented in October and November, 1977, and in January, 1978.

Ottawa
April 1980

C.B. Crawford
Director DBR/NRC

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The following people assisted in the preparation of material for the seminar and in its presentation: D,C. Tibbetts, DBR Halifax; C.P. Hedlin and H.W. Orr, DBR Saskatoon; W.H. Ball, DBR Vancouver; and R.G. Brand, Carleton University, Ottawa.

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* PCL Construction Ltd., Edmonton, Alberta

DESIGN PRINCIPLES

by G.O. Handegord

Although the importance of air tightness has been stressed for the past 25 years in the technical literature dealing with the design of building enclosures, we still construct buildings that provide their owners with excessive energy costs, that make the occupants uncomfortable because of drafts and the infiltration of contaminated air, and that suffer from problems of condensation and the deterioration of their components and materials, which require high costs for repair and maintenance. Air tightness, accordingly, should be the primary objective in the design and construction of walls, windows, floors and roofs of buildings.

The following reasons for the lack of achievement of air tightness in practice may be cited: (1) a lack of appreciation by designers, builders and materials manufacturers of its importance; (2) the assumption that by simply specifying an air vapour barrier the problem is solved; (3) a resignation to the belief that in the practical case air tightness cannot be achieved; and (4) the traditional attitude that some air leakage is necessary in order to provide adequate ventilation.

The notion that air leakage is necessary for ventilation must be dispelled. Instead, air leakage through the building enclosure must be regarded as undesirable, unnecessary and uneconomical, because air leaking into a building cannot be treated or conditioned, nor can its rate of supply or distribution throughout the building be controlled. Similarly, air leaking out of a building not only constitutes a waste of energy but results in condensation and deterioration of the building fabric. Any openings in the building envelope and even those in floors and partitions disrupt the intended operation of heating, ventilating and air-conditioning systems, make it difficult to control noise, and increase the danger of the spread of fire and smoke. In addition, a wall that suffers from air leakage may also suffer from rain leakage if it is exposed to wetting by rain.

In a Canadian Building Digest dealing with fundamental considerations in the design of exterior walls for buildings,[1] Dr. N.B. Hutcheon provided a list of requirements, the first seven of which, termed the "barrier requirements," related to the control of the flow of mass and energy through the enclosure. All of these flows, except for those involving light and solar or other radiation, are influenced by the size, location and distribution of cracks and openings in the building enclosure.

It has been demonstrated that substantial amounts of heat can flow through small cracks and openings. These also provide the primary means for the transport of water vapour into the cold regions of walls, which takes place mainly by the mass flow of air rather than by vapour diffusion through materials. Recent information concerning the control of noise shows that a relatively small opening in a wall can alter considerably its sound transmission properties; thus an opening equal to one one-hundredth of one per cent of the area of the separating element can reduce its sound transmission class by 10 dB. Similarly, openings in a wall affect its fire resistance; thus in the "Standard Method of Small-scale Fire Tests of Walls and Partitions Penetrated by Small Pipes," issued by Underwriters' Laboratories of Canada,[2] one of the failure criteria is the development of an opening "through which hot gases issue at a substantial rate." This can occur when the openings are no larger than 0.1 sq in. (0.6 cm^2).

Air leakage through openings results from air pressure differences created by wind forces, stack effect, and the operation of fans. The pressure created by wind depends on the geometry of the building, as well as the wind's velocity and direction. In most cases, wind pressure will not exceed its stagnation pressure, which is the pressure resulting from the conversion of the wind's kinetic energy to static force. The greatest variation in wind pressure occurs at the edges of a building, while negative pressure or suction is created by vortices and turbulence on the leeward side and over roofs. The amount of suction developed is influenced by the parapet height, and negative pressures several times as large as the stagnation pressure may occur.

The pressure difference across the enclosure due to stack effect results from the difference in temperature of the air inside and outside the building. The exterior barometric pressure varies with height as does the pressure in the building, but the variation with height is less inside because the air is less dense.

When there is little restraint to vertical air flow in the building, an inward movement of air will take place through the openings in the lower half of the building while an outward movement occurs through openings in the upper half of the enclosure. Where the openings in the enclosure are uniformly distributed, the maximum pressure differences across the walls will occur at the bottom and the top, and there will be no pressure difference across the openings at some point near mid-height where the inside and outside pressures are the same, i.e., the neutral pressure plane.

If the building is pressurized by means of fans or blowers, the increased interior pressure will result in the lowering of the neutral pressure plane. An excess of exfiltration over infiltration will take place through the walls; accordingly, the total air exchange will be in excess of that experienced when no fans are used. This approach is sometimes used to eliminate air infiltration in the lower floors, with the object of improving the comfort of the occupants or preventing the entry of contaminated air. Although these objectives may be achieved, such pressurization will not only result in an additional energy loss, but by increasing the quantity of air moving outward through the building envelope, it increases the risk of condensation and deterioration.

If an exhaust system is employed, the decreased pressure within the building results in the raising of the neutral pressure plane. Accordingly, air movement will be inward over most of the wall area, with exfiltration through the exhaust fan and through those portions of the building that are at a higher pressure than outside. This will also increase the air exchange rate and energy loss, with possible discomfort due to drafts on lower floors.

The effect of wind is to create different conditions on the windward and leeward sides of a building. On the windward side, the outside pressure increases with respect to that inside and the neutral pressure plane is raised; accordingly, air infiltration will occur over more of the windward face, while exfiltration occurs only through the area where the interior pressure exceeds that outside. In contrast, on the leeward side, suction is produced, the neutral pressure plane is lowered, and exfiltration occurs over most of the leeward face of the building.

The maximum pressure resulting from stack effect depends on the building height and the temperature difference between the inside and outside. For a 20-storey building maintained at 70°F (21°C) inside, surrounded by air at -20°F (-29°C), a pressure difference equivalent to that produced by a wind of 25 mph (40 km/h) is generated as a result of stack action. Since average wind velocities are usually in the order of 10 - 15 mph (16 - 24 km/h) it can be readily appreciated that stack effect usually overrides wind pressure for high buildings under winter conditions.

Because the pressure differences created by mechanical systems are required for air distribution within the building, and because nothing can be done to change the pressure differences resulting from wind and stack effect, the only solution to minimizing their effects is to reduce the size and number of openings through the enclosure. The objective, therefore, should be to provide as airtight an enclosure as possible. The requirements for fresh air and for exhaust must be met by a separate ventilation system capable of adjustment and control to meet the specific needs of the occupancy.

It has been generally assumed that leakage through the building enclosure occurs primarily at the doors and windows where recognizable joints occur. The Handbook of Fundamentals of the American Society of Heating, Refrigerating and Air-Conditioning Engineers[3] provides information on leakage through doors and windows as well as that occurring between their frames and the wall in which they are installed. Values of air leakage are also provided for masonry construction and wood-frame walls. A masonry wall, for example, will allow substantial air leakage because of the numerous small fissures and openings between the units and mortar; by simply plastering such a wall, however, its air tightness is improved, in some cases by a factor of 100.

Studies undertaken on houses in Ottawa have demonstrated that the air leakage associated with windows and doors constitutes about one fifth of the total, while the leakage through the ceiling and outside walls ranges from 8 to 70 per cent of the total. Studies on large buildings have shown actual air leakage rates far in excess of the values listed by the National Association of Architectural Metal Manufacturers for curtain walls or windows. It is important that all possible leakage paths be identified in order that appropriate drawings, details and specifications can be developed.

Leakage openings can exist in hollow frame walls of wood or metal, either in the framing components themselves or created as the holes and openings cut for services. If cladding materials are not drawn tight to metal studs, leakage paths are formed. In wood-frame walls, subsequent shrinkage of the framing members can result in gaps between these members and the interior or exterior finishes applied to them, allowing air to flow between the wallspaces. Polyethylene film and other membrane barriers have been employed in wood-frame construction to provide a seal over these openings.

Although the plastering of masonry walls provides a substantial degree of air tightness, it is often omitted in such places as the wall area above the level of a dropped ceiling or that behind a radiator unit. In some cases, the furred out vertical shafts provide channels for the movement of air from lower levels into the space above a dropped ceiling.

It should not be assumed that the application of gypsum board or other sheet material to a masonry wall will provide the same degree of air tightness as plaster. Because of the uneven surface of the masonry, intimate contact will not be achieved between it and the surface of the sheet material unless a full bed of adhesive is used. If not, the open space between the masonry and the sheets provides a path for air leakage.

In addition to the openings in a building enclosure caused by expansion and shrinkage of materials, are those resulting from deflection caused by structural forces on the building and its components. Cracks and openings so formed allow air leakage to take place, with the danger of resulting condensation and deterioration.

An important consequence of air leakage is the waste of energy. Extremely leaky buildings, under pressure differences due to stack effect alone, suffer losses due to air leakage amounting to as much as 60 per cent of the total energy required for heating in winter. If such buildings had been constructed to meet the air tightness requirements of organizations such as the National Association of Architectural Metal Manufacturers, the heating load due to infiltration could have been reduced to 6 per cent of the total.

There is merit in improving the air tightness of floor systems and partition walls, particularly in high-rise buildings, because this reduces the pressure difference acting across the exterior walls.

Improved air tightness also assists in the control of ventilation and air distribution, including the control of smoke movement in the case of fire. In addition, it enables a more equitable apportioning of energy charges to be made between the individual units in apartment buildings.

Improving the air tightness of walls, windows, floors and roofs must be regarded as an essential step toward energy conservation in building. Air leakage should never be relied upon for ventilation but should be recognized as an impediment to the proper operation and control of a ventilating system. Such a system, having a specific means of air supply and exhaust, should be required in all buildings to provide an adjustable fresh air supply and used-air exhaust, and should incorporate energy recovery devices. Under such conditions it will be easier to evaluate the actual air leakage characteristics of the completed building, easier to monitor the energy needs associated with ventilation, and easier to predict the performance of the building under the anticipated climatic conditions.

References

1 Hutcheon, N.B. Requirements for exterior walls. National Research Council of Canada, Division of Building Research, CBD 48, 1963.

2 Underwriters' Laboratories of Canada. Standard method of small scale fire tests of walls and partitions penetrated by small pipes. ULC-S115-1977.

3 American Society of Heating, Refrigerating and Air-conditioning Engineers. Handbook of Fundamentals. Issued every four years.

APPLICATION OF DESIGN PRINCIPLES IN PRACTICE

by J.C. Perreault

Webster defines the word "detail" as a "small or unimportant part," but a construction detail is not unimportant. Rather it is of extreme importance. It should not be small. On the contrary, it should be big, easy to read and easy to understand.

A good or bad detail will often make the difference between a good or bad installation. Building designers should bear in mind that those who actually build the buildings usually have no design background. They should not be forced to guess the designer's intention, or to play the role of designer, but should only be expected to build carefully, as detailed. That is why a detail must be precise, easy to understand and practicable. There should be no guess-work; if a problem arises in understanding the function or purpose of any item or specification or if a detail does not appear to be good practice, it should be queried. If a detail appears to be impossible to build, no attempt should be made to build it.

Attention to detail in design and construction is of prime importance if air tightness is to be achieved. In this regard one single thing will make a detail a success or a failure. This is the presence of holes. Indeed, in the investigation of many building problems an appropriate saying would be "cherchez le trou" (look for the hole). In practically all cases it will work.

Many examples of building problems directly resulting from openings or holes can be documented. In a certain hotel, for example, water appeared at the ceiling line of many bathroom walls, badly staining them. As usual, the first call went to the roofer, but because the problem occurred in mid-winter it could not be blamed on a roof leak. Because there were no windows in the bathrooms the window installer could not be blamed either. The leakage was eventually traced (by putting dye in the toilet water) to holes in the soil pipes. The pipes had inadvertently been placed in the wall directly behind the location chosen for the installation of the towel racks. In drilling holes in the walls to install the racks, the workman in many instances also drilled holes into the soil pipes, providing the paths for leakage.

Another example of "cherchez le trou" involved a shopping centre that had an outside pedestrian area beneath a large roof overhang (Figure 1*). Water dripping out of openings, intended originally to serve as air vents for the soffit space, did not concern the management except that the water froze on the sidewalk, forming patches of ice that were hazardous to the customers. The first proposed solution to the problem was simply

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*Figures are presented at the end of these Proceedings.

to install heating cables in the sidewalk to prevent the water from freezing, but it was decided to try to find out what was causing the drips.

The overhang was formed by extending the corrugated steel roof deck over a concrete block wall. The soffit space was enclosed by the roof deck on top, by the block wall that separated the soffit space from the building, by precast concrete panels on the other three sides, and on the bottom by stucco applied to mesh, which was suspended by wires that passed through holes in the flutes of the corrugated deck.

In the soffit space it was found that frost, in some places to a depth of 1 1/2 in. (38 mm), had formed on the concrete panels, the steel truss members and the suspension wires. Large masses of ice were also present, apparently formed from water melted from the frost, which had run down the panel surface and had frozen into ice near the air vents. When the temperature in the soffit space became warm enough, the ice melted and the water-dripping problem began.

At first it was thought that the holes that caused the problem, by allowing warm moist air to move from the building to the soffit space where the water vapour condensed on cold surfaces, were those provided by the flutes of the roof deck, which formed openings between the top of the block wall and the underside of the deck. Although the drawing of the detail of this area called for these spaces to be filled, the material specified, glass wool insulation, did not provide an air seal, but served merely to filter the air passing through. It was replaced by polyurethane foam, and caulking was applied to any opening that could be found, but even after this had been done ice continued to form in the soffit space, and the water-dripping problem continued.

Another path for air leakage was eventually discovered, this being the space in the upper flutes of the deck. Air leakage by way of these flutes was possible because of holes drilled in the flutes to take the wires of the suspended soffit (Figure 1). Water formed by the condensation of water vapour collected in the flutes, and when its level reached that of the holes it flowed out and down the wires, many of which were coated with ice.

The air tightness of a building can be predicted from a study of the detailed drawings, which usually reveal openings in the enclosure, particularly when corrugated roof decks are used, whose spaces are difficult to seal. In fact on many drawings their sealing is not even specified. The detailed drawings also often reveal areas where it is impossible to install an air or vapour barrier; it is appropriate that designers use a dotted line to represent a vapour barrier because in practice it is usually incomplete or full of holes.

When things go wrong in a building, a good place to start the "cherchez le trou" technique is at the window heads, where many pieces of metal usually penetrate the wall, making it difficult, if not impossible, to install an air barrier. Another common source of trouble is the wall above a suspended ceiling, from which the vapour barrier and insulation are frequently omitted, thus allowing air leakage to take place through this part of the wall.

Insulation and vapour barriers are the two most misunderstood items in construction today. Many builders and designers apparently do not know exactly what these two things are supposed to do. Sometimes designers get carried away and provide two vapour barriers on the same element, but they never seem to be able to connect the vapour barrier of one element with that of another element.

In the choice and application of material for building, care must be taken to ensure that one specified material or installation does not destroy or interfere with other specified items. Sometimes two materials, seemingly good in themselves, when combined together can harm the other. In a certain building, for example, foil-covered insulation was specified to be glued to the back of precast wall cladding, a difficult installation job because of all the precast anchors, sway braces and furring channels that the insulation had to be cut around and sealed to. But in addition, the specification called for wet concrete to be poured against the aluminum foil, to cover precast anchors and provide fire separation between floors. The product data sheet for the insulation, however, clearly indicated that: (1) the material backing the foil contains water soluble salts, and if it becomes wet these salts have a corrosive action on the foil; (2) the foil, when placed in contact with wet plaster or mortar, will corrode. In spite of these warnings, however, both specification and drawing for the foil's application in this instance called for wet cement to be poured against it.

An interesting case of problems arising from air leakage involved one of the first high-rise buildings built on the rain-screen principle in Alberta. An account of this building and its performance, prepared by G.O. Handegord for a DBR Building Science Seminar,† referred to the construction and the problem as follows:

> "The wall consists of an inner wythe of 8-in. (200 mm) thick common brick together with cast-in-place reinforced concrete spandrel beams. Expanded polystyrene insulation, 1 in. (25 mm) thick, was installed on the exterior with spot applied asphalt adhesive."

> "The outer rain screen is a 4-in. (100 mm) thick precast concrete panel 18 in. (460 mm) long and approximately 5 ft (1.5 m) wide suspended to create an air space 1 in. (25 mm) wide between its inner face and the outer face of the insulation. The space is open to the outside at the bottom above

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† DBR Audio-Visual Presentations No. 12A and 12B, Feburary 1972. Presented at the Building Science Seminar "Walls, Windows, and Roofs," October 1971.

> the window head and connected to the outside at the top by means of a special aluminum sill. The spandrel beams provide the air vapour barrier above the suspended ceiling and a polyethylene film acts in this capacity over furring on the inside of the masonry wall. The furring provides a means for securing the metal induction units and supporting the vapour barrier."
>
> "In the early spring of the building's first year of occupancy, the outside temperature rose to a sudden and unusual high of 40°F (5°C) under sunny conditions. A series of icicles formed along the bottom edge of the precast panels on every floor and on every orientation except the south."
>
> "It was eventually concluded that the primary source of moisture causing the icicles was that which had found its way into the inner wythe during the period of winter construction. The problem has not recurred to our knowledge, thus tentatively confirming the analysis. The situation prompted additional comments by those concerned as an example of the effectiveness of the system in allowing the escape of moisture which might ordinarily be trapped inside the wall to cause serious problems."
>
> "Further observations by the designers indicated that some of the board insulation had become detached from the inner wythe as evidenced at the opening above window heads. The problem was remedied by the installation of small wedges between the precast panel and insulation. It is a credit to the designers that these difficulties have been reported by them in the literature for the benefit of others and the improvement of design technology."

The problem, however, did not stop; icicle formations, not as large as the first, showed up from time to time and the problem has required the expenditure of $50,000 in investigation and remedial work. The owner found it more and more costly to maintain heating and cooling operation and something had to be done to reduce air leakage and revamp the insulation.

In applying the "cherchez le trou" technique to this building, a source of air leakage was found where the anchors for the precast panels were located above and below windows, and at the corners of the building. The openings around the anchors were not sealed, permitting air leakage to take place, with the resultant condensation and icicle formation.

As is evident by the variety of buildings that are completed daily in Canada, there is no lack of creative genius and ingenuity on the part of designers and builders within the construction industry, but there seems to be a lack of understanding of the design process by builders. Much would be gained by the builders and owners if they tried to understand the design process. The architect's lot is not an easy one, even if one discounts the frustrations attendant on being an adjudicator, financial adviser, decorating consultant, and guardian of culture and aesthetics. His job is not made easier by the proliferation of new and inadequately understood methods and materials, and a quickened pace of construction. The successful performance of the building depends on his ability to choose the right material or system.

Just as builders must try to understand the designer's job, so must the designer realize that putting up a modern structure is also a formidable task. The construction superintendent spends a third of his time pushing papers and answering the phone. If he has to spend half of his remaining time figuring out how to build a particular detail and once it is done, he has to spend the other half of his time around a conference table trying to explain why he did it that way or why it doesn't work then he will not be able to do what he is good at doing, which is putting up the building.

The problems resulting from the faulty design and construction of buildings, and the need for joint action by designers and builders to overcome them, have been well summarized in the following words prepared by M.C. Baker for a DBR Building Science Seminar¶ which are worth repeating as a summary of this account of the application of design principles in practice:

> "In this age of unprecedented technological expertise, it should be possible to predict performance. The construction industry, however, appears to be plagued by an ever increasing amount of extremely poor performance, including buildings that leak, stream with condensation, overheat in summer or whose appearance is marred by streaking, discoloration, and material break-down on the exterior. It is obviously necessary to get back to scientific principles in the design and construction of enclosures for building. All details must be examined to ensure the continuity of air and vapour barriers, and the construction must be carried out in a manner that achieves this continuity. There is no doubt that the present unsatisfactory performance of many buildings, and building elements, can be overcome by a concerted team effort on the part of designers and builders."

¶ DBR Audio-Visual Presentation No. 11, February 1972. Presented at the Building Science Seminar "Walls, Windows, and Roofs," October 1971.

MASONRY WALLS

by K.N. Burn

In the following discussion of masonry walls in relation to the air tightness of buildings, panel walls constructed of concrete blocks will mainly be considered. The primary function of such a wall is to close the space between the floors of a building in such a way that the desired and controlled environment on the inside is isolated from the natural environment on the outside by means of a barrier that will prevent the movement of air and whatever it contains. This can only be achieved if the panel wall is constructed of some material that is not permeable to air and if it is fitted into the space between the floors without leaving cracks or holes around the perimeter.

Most common building materials, including cast-in-place and precast concrete, gypsum board, plywood, sheet metal and glass are relatively impermeable to air. When joints between components made of these materials are adequately sealed an effective air stop or air barrier can be formed. In contrast, however, masonry walls, constructed of concrete blocks held together with mortar, are quite permeable to air for a number of reasons. Mortar shrinks about 10 times as much as concrete block and the differential movement produces numerous fine tension cracks in the mortar. In addition, when a block is laid in mortar there may be areas where bond does not develop between the bottom surface of the block and the top surface of the mortar. Another cause of the permeability of block walls is the incomplete filling of mortar joints, particularly the vertical ones.

Shrinkage of concrete blocks also plays a part in the problem of the permeability of such walls. Concrete blocks made with dense aggregate may shrink as much as 0.04 per cent after being placed, while lightweight blocks generally shrink twice as much. Autoclaved blocks shrink less than those cured at low pressure, but even so, their shrinkage is not generally less than 50 per cent of that of blocks not autoclaved. This amount of shrinkage means that for a 10-ft (3 m) high panel wall the vertical shrinkage amounts to between 1/20 and 1/10 in. (1.3 - 2.5 mm). Horizontal shrinkage also occurs but is usually somewhat less than the vertical because of the restraint caused by frictional resistance to movement along the base of the wall under its own dead weight.

It can be seen, therefore, that panel walls of concrete blocks placed within a rigid structural frame providing 20 ft (6 m) bays and 10 ft (3 m) spacing between floors, could produce, because of shrinkage, a continuous opening between each panel and the frame, at both sides and across the top, of 1/20 in. (1.3 mm) or more. The quantity of air flowing through this crack, at 1/10 in. (2.5 mm) water pressure difference,*

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* The pressure difference of 0.1 in. (2.5 mm) of water was selected for these examples because it is frequently encountered in all types of buildings. Pressure differences in high-rise buildings may be several times greater and the air leakage volumes would increase accordingly.

would be 120 cfm (3 m^3/min) or 7000 cu ft (190 m^3) per hour. This amount of air leakage when multiplied by the number of perimeter bays and floors in a building may represent a very large waste of energy.

In addition to perimeter air leakage there is leakage occurring through the panel itself. In brick walls, under a pressure difference of 1/10 in. (2.5 mm) of water, the air leakage may amount to 800 cu ft (22 m^3) per hour, for an area of 100 sq ft (9 m^2). Because of the fewer mortar joints in a given area of concrete block wall than in one of brick, it can be estimated that the air leakage rate will be between 250 and 400 cu ft (6.7 - 10.8 m^3) per hour, for an area of 100 sq ft (9 m^2). Fortunately, however, a masonry wall can be treated to perform as a suitable air barrier by applying to it a layer of mortar, plaster or some other material such as heavily textured paint or mastic which will seal the multitude of small openings in the units and the mortar joints. In this way air leakage can be reduced to as little as one-hundredth of that through the untreated wall; thus air leakage through 100 sq ft (9 m^2) of concrete block wall under a pressure difference of 1/10 in. (2.5 mm) water may be reduced to a value between 5 and 20 cu ft (0.1 - 0.6 m^3) per hour.

In this discussion of the effect on air tightness of the shrinkage of concrete panel walls, it has been assumed that the building structure is rigid, which in practice is not the case. Steel and reinforced concrete experience dimensional changes with changes of temperature when load is applied to them, and, in the case of concrete, when subjected to change in moisture content. In order to determine realistic values for the sizes of the cracks and holes that will develop at the joint between the structural frame and an infill panel, it is therefore necessary to know how much and in what direction the structure will deflect under its service conditions.

Under sustained compressive stresses, concrete suffers considerable deformation called "creep," which has been observed to continue for periods of up to ten years, although the most significant part of it generally occurs in from one to two years. Columns shorten and beams and floors continue to deflect until the deformations eventually become 2 to 5 times the initial or elastic deflections, but in most cases the ratio of creep to elastic deflection for structural concrete is 2 1/2 to 3. This means that if the design of a spandrel beam called for an elastic deflection of 1/480 of the span, for a column spacing of 20 ft (6 m) (which would be 0.5 in. (13 mm)) the creep deflection could be a further 1.5 in. (38 mm). (If the design deflection were limited to 1/1000 of the span the creep deflection could still be as much as 3/4 in. (19 mm).) In addition, a column that deflects 1/20 in. (1.3 mm) elastically may show creep shrinkage of a further 1/10 in. (2.5 mm) within the first two years after construction.

Steel, unlike concrete, does not develop creep strains. It is a more nearly elastic material in the range of stresses normally imposed on it in building construction. Therefore, its deformations are proportional to the load and are more predictable than for concrete.

For the development of the details used in this and the following discussions, the general approach was adopted that the insulation be placed outward of the structure and its panel walls to take advantage of the increased dimensional stability that results when the temperature variations they experience are minimized. The insulation, placed immediately to the cold side of the air barrier, is protected by a rainscreen on the outside, which shields it from the weathering effects of sun, wind and rain.

A design approach to the foundation wall/ground floor junction is illustrated in Figure 2. The outer face of the concrete block panel wall, placed flush with the foundation wall, supports the air barrier that is formed by the application of a suitably textured mastic. Besides sealing the cracks in the block faces and mortar joints, the mastic may also serve as an adhesive for fixing semi-rigid glass-fibre insulation to the wall. This configuration places the wall and foundation insulation in the same plane, making it easy to form an unbroken cover and thus avoid a thermal bridge at the edge of the floor slab. It also allows the cutting of service chases in the inner face of the block without interrupting the air barrier.

The insulation over the basement wall may be foam plastic or a rigid glass-fibre insulation; the latter would serve the added purpose of providing adequate drainage through the soil to the perimeter tile thus avoiding the cost of hauling in granular material for backfill. If foam plastic insulation is used, it needs to be protected against the effects of ultraviolet radiation and both types of insulation would need protection against mechanical damage at this level, which may be provided by an asbestos-concrete board, or by parging.

The brick rainscreen is supported by a normal-size shelf angle from a wedge insert in the edge of the floor slab, and a spacer fabricated from a hollow rectangular structural section. Adjustment in three directions of the position of the shelf-angle is permitted by a horizontal slot in the shelf angle, a vertical slot in the wedge insert and a selection of sizes of sections for the spacer. This type of support was chosen in preference to an angle with longer legs fastened directly to the edge of the slab mainly because the heavier section required would be much more difficult for the masons to handle. Where steel reinforcement of the masonry wall is required to resist earthquake loads the block and brick wythes must be reinforced and tied together and to the structure.

Windows usually account for large heat losses, because of air leakage through both the window sash and frame and through the space between the frame and the opening in the wall into which it is fitted. Good window design takes care of the first; the second is a construction problem that arises from the common practice of fixing windows by wedging the frame into the opening and securing it to the wall with mechanical fasteners. This generally leaves a gap of at least 1/2 in. (12 mm) wide around the frame and, even though the finish materials on the inside may hide it, the gap remains and air finds its way through.

A design approach to window openings is shown in Figure 3, where in order to make the air barrier continuous, it is turned back over a wood frame built into the wall opening as indicated (broken line). It may also be turned back directly over the upper face of the top course of concrete block, which for this purpose should be solid.

Wood may shrink as much as one per cent across the grain, and it may warp, causing the joint between it and the concrete block to open up. Accordingly, if mastic were used it is possible that a break in the air barrier would occur at the interface. To prevent an air leak from developing here, a flexible membrane such as butyl rubber may be adhered to the mastic coat on the outer face of the wall and turned over the top of the wood frame, with the continuity of the air barrier maintained by the application of a flexible sealant to the opening between the membrane and the window frame. The frame itself, the inner glazing seal and the inner pane of glass of the sealed glazing unit then form a continuation of the air barrier.

Figure 4 provides details of a window jamb, which are essentially the same as to those of the sill. The air stop is taken to the inside of the window frame so that it can be repaired more easily than if it were on the outer surface, especially where sealed glazing units are used. In addition, the edges of concrete blocks are often roughly cast or damaged during handling, making it difficult to achieve a good seal at the outer corner.

The proper functioning of a window of this type in cold weather depends upon the inner part of the window frame (the aluminum box section) being maintained at a temperature above the dew point, otherwise condensation will occur. In addition, because the tensile stresses at the edges of the inner pane of glass of a sealed glazing unit increase as the edge temperature decreases, the possibility of fracture is heightened. It is important therefore that cold air be prevented from circulating freely in the spaces between the wedges. This is accomplished by installing an outer caulking of compressible foam plastic rope which is secured between the concrete block, the window frame and a metal finish plate at the jambs and head, and at the metal sill as shown in Figure 3.

An approach to the design of the window head and floor/wall junction is given in Figure 5. The arrangement shown allows the insulation blanket to continue past the edge of the slab, broken only by the shelf angle supports, spaced at intervals of 5 or 6 ft (1.5 - 1.8 m), thus avoiding the massive thermal bridge that occurs when the edge of the floor slab interrupts the insulation blanket.

The joint beneath the edge of the floor slab at the top of the wall will experience a reversal of movements. With drying shrinkage of the panel-wall, the joint will first of all open fairly uniformly, followed by a closing which will be greatest at mid-span as the panel wall above is being constructed. A further closing, again greatest at mid-span, will occur as creep-shortening of the columns and creep deflections of the edges of the slab continue. Because the combined elastic and creep deflections of the edge of the slab will normally be greater than that due to drying shrinkage of the wall, the total effect of these movements will be to close the joint. Consequently, unless sufficient space is provided, the slab will eventually rest on the top of the wall and begin to transfer loads to it, which could lead to buckling and collapse.

In a high-rise building with identical floor layouts above the first floor or two, the floors and beams are usually of the same structural design because they carry similar loads. Under these conditions the edges of the slabs deflect about the same amount with the result that the vertical distance between floors is likely to be fairly uniform across the span. Only the creep shortening of the columns will be significantly different from storey to storey because the actual amount varies with the level of stress and with the ratio of the area of steel reinforcing to that of the concrete.

Nevertheless there will be some variations in the movements of the slabs and infill walls, therefore the materials used to block these potential air-leakage paths must be sufficiently flexible to accommodate the opening and closing of the joints. In addition, the differential movements between the edge of the slab and top of the panel wall have implications for the details of the brick veneer. Sufficient space, filled with a suitably flexible sealant to exclude the rain, must be provided beneath the structurally supported shelf-angle to avoid transferring compression stresses from the structure to the brick cladding.

Design details in the horizontal section of a column and window jamb are shown in Figure 6. The wall insulation is brought as close to the window frame as the construction will allow, but finishing the window surround with brick means that the wall insulation stops some 5 or 6 in. (128 - 153 mm) away from the jamb. The resultant thermal bridging means that the window jambs will be colder than the head and sill. At the columns, the outer surface of the wall is in the same plane as the column face, simplifying the application of the mastic and insulation blanket. The two joints between the panel walls and the column may be left without mortar, but at the outer face the space should be bridged by a sealant bead of the proper geometry to permit extension of the joints as the wall shrinks, without excessive strain in the sealant material.

At each floor, and at the roof line as detailed in Figure 7, the joint between the top of the panel wall and the underside of the concrete slab will present the same problem. The air stops must be flexible, durable and sufficiently tight that they cannot be dislodged by the highest pressure difference to which they will be subjected.

The provision of a continuous air boundary in a steel frame building with concrete block panel walls can be very difficult if the designer attempts to place them in the same plane in the building envelope. However, a relatively simple alternative is suggested in Figure 8; that of extending the floor slabs beyond the outer surfaces of the structural steel by an amount sufficiently wide to allow the laying of uninterrupted concrete block walls. The outside surface can be treated to form the air barrier and the insulation installed in the same manner as was used for the concrete structure.

If the floor slab is not extended as shown in Figure 8, support of the shelf angles for brick veneer may require complicated appendages to the structure protruding through the panel walls and promoting air leakage. When necessary, shelf angles can be supported as they are at the edge of the slab of a reinforced concrete structure, but an easier solution for a building of only two or three storeys is to support brick cladding at foundation level and carry it up to the roof line.

Details of a horizontal section through a steel column and window jamb, essentially the same as that for the concrete structure except that the column is now completely inside the panel wall, are given in Figure 9. Here the vertical joint becomes a shrinkage control joint in the block wall.

It is sometimes desirable that steel columns be recessed into the walls, for example, in a school gymnasium. A solution for such a situation, which follows the approach of applying both air-barrier and insulation to continuous plane surfaces, is presented in Figure 10. The outer surface of the block wall is bridged by a strip of sheet steel attached to the flanges of the column before the masonry work is started. Shrinkage of the wall will cause cracks to open between the wall and the flange faces, but these potential leakage paths are stopped with back-up caulking and sealant as indicated. At the base of the column care is needed to ensure that infiltration and circulation of cold air does not occur, because this would nullify the purpose of the insulation and lead to condensation on the interior surfaces of the column.

Resistance to lateral movement is provided by clips attached to the bottom flange of the spandrel beam, shown in Figure 11. They make it impossible to use caulking and a sealant bead as a continuous air stop at this joint. Continuity of the plane exterior surface is maintained by placing gypsum board or plywood sheets to cover the spandrel beam but flush with the outer face of the concrete block wall. Differential movements will take place between the wall and the roof structure, therefore a flexible seal, such as a butyl-rubber membrane, should be used to span the joint at the top of the wall.

In summary, because of the differential movements of the various materials and components of a panel wall structure the joints between them must be sealed to prevent air and moisture leakage through the wall. It is critical to the continued satisfactory and economical performance of a building that such seals and air stops be properly designed, properly installed, and of suitable materials.

METAL STUD WALLS

by R.L. Quirouette

Exterior walls of metal studs and gypsum board are gaining popularity for use as infill walls in frame construction of industrial, commercial and high-rise residential buildings. While many of the practices followed in this type of construction are based on the traditional wood-frame construction, the metal wall as an infill panel for frame structures must be designed and built to resist the lateral loads imposed by wind, must resist rain penetration, and must serve as a member to which thermal insulation is applied.

One of several constructions of this type, introduced in western Canada several years ago, consists of nominal 4 in. (100 mm) metal studs faced on both sides with gypsum board, with an additional covering of light metal on the outside to provide protection from the weather. A polyethylene vapour barrier incorporated in the wall serves as an air barrier, and special attention is given to the sealing of joints at the floor, ceiling and interior partition wall intersections to produce a relatively airtight assembly. This construction, however, suffers from poor thermal performance because of the high conductivity of the metal studs and the horizontal channel sections supporting them. The result, in addition to heat loss, is dust marking and the possibility of condensation on the interior surface of the wall.

Measurements[1] of the surface temperature of metal stud walls have confirmed that the temperature over the framing members is substantially lower than elsewhere on the interior surface under cold outside conditions. Low surface temperature was also noted in the vicinity of electrical outlet boxes. Open joints between the concrete panels that clad this particular stud wall appeared to affect its thermal performance by allowing the air to circulate in the cavity between the panels and the stud wall.

The problem of high heat loss through the concrete floor slabs that are projected through walls to serve as balconies is not solved by metal stud construction, but in the absence of balconies the construction can permit the thermal protection of the edge of floor slabs. This may be done by cantilevering outward the metal framework beyond the edge of the slab to allow the insertion of rigid insulation between the frame and the slab's edge.

Thermal bridging at the slab edge is a major problem when precast concrete cladding is used with a metal-stud wall infill panel because the heavy weight of the cladding requires substantial support, which is usually obtained by using the floor slab as a direct shoulder. Accordingly there is no means to reduce the heat transfer through this portion of the wall, although detailing for air tightness is relatively easy.

Any openings in the interior cladding of a metal stud wall, such as those involving services carried in the stud space, should be sealed because moist air will leak into the insulated space, condense on the sheathing, and lead to the eventual deterioration and loss of strength of the sheathing material.

The application of an exterior coating to the outer sheet of gypsum board, to act as its weather protection, has not been successful, as revealed in a number of buildings in which the gypsum board has deteriorated. It appears that the separation of the outer gypsum board sheathing from the exterior cladding, with the cavity between them vented, is good practice for this type of construction.

Observations of installations of metal-stud infill walls have shown that cracks frequently occur in the interior gypsum board. The cracking has been attributed mainly to deflections of the floor slab.

One approach to the design of a metal stud wall supported on a concrete foundation is given in Figure 12. In this case the stud wall is protected by brick veneer, supported on a steel angle attached to a cast-in-place anchor. The insulation is applied to the exterior of the metal framed wall as well as to the foundation wall. The air leakage barrier of the wall is applied to the exterior side of the metal stud wall and is extended down the concrete frame with flexible connections at appropriate locations. In this way services may be installed within the metal stud wall without violating the integrity of the air barrier.

Details of the metal stud walls above and below a floor slab are shown in Figure 13, where the outer gypsum board has been carried down over the edge of the floor slab. The vertical metal studs, shortened by an amount equal to the anticipated maximum deflection of the floor slab, move within the ceiling channel, or they may be covered with a nesting channel that moves within the one fastened to the underside of the floor slab. This allowance for movement is necessary to prevent the interior cladding from cracking under the deflection of the frame. A flexible joint or a sliding cover strip should be provided at the top and bottom edges of the gypsum board, which should not be fastened directly to the lower channel.

In the design shown in Figure 14 the exterior sheathing need not be extended over the edge of the floor slab because a mastic is being used to provide a flexible seal between the interior gypsum board and the floor. While this arrangement should provide satisfactory service if the installation is carefully done, it would probably be better to employ a membrane at the joint to provide air tightness and flexibility.

In steel frame structures it must be ensured that the exterior sheet of gypsum board covers the outside of the structural members to provide the basic air flow barrier. Allowance must be made for deflection of the spandrel beams and floor slabs by using appropriately shortened studs and sliding connections. Mastic caulking and adhesive can be used to apply the insulation to the exterior sheathing and a suitable flexible membrane such as butyl rubber should be employed at critical locations to allow for differential movement.

In the detail shown in Figure 15 a hollow structural section is used to frame the window opening, while the remainder of the infill wall is built with metal studs and channel sections. A flexible flashing installed over the lintel supporting the masonry serves as a soffit closure to screen the insulation.

A plan section at a column and window is shown in Figure 16, in which the line of air resistance is brought inward to the inner face of the window where a suitable gasket and sealant is applied.

A means of applying exterior sheathing at the roof/wall junction of a steel frame building is shown in Figure 17. Short studs with sliding joints are used to handle deflection of the spandrel beam, while a flexible membrane secured at the exterior sheathing accommodates any differential movements, thus maintaining the joint airtight at the location.

In conclusion, the detailing of exterior steel-stud wall design must be closely coordinated with the structural design. Where possible and practicable steel-stud exterior walls should be insulated on the outside surface. The air barrier should be applied on the outside of the steel stud but on the warm side of the insulation to provide a service space for electrical and other mechanical services that will not break the air barrier. As with any other assembly, air barriers require control joints of good quality to ensure that they will work properly and have a long service life.

Reference

1 Sasaki, J.R. Thermal performance of steel-stud exterior walls. National Research Council of Canada, Division of Building Research, BR Note No. 77, Ottawa, August 1971.

WALL/ROOF JUNCTIONS AND SOFFITS

by R.G. Turenne

Efflorescence on masonry walls at roof level and damage to brick parapets from freeze-thaw action, due to excessive dampness, may result from moisture-laden air escaping from buildings because of chimney effect and wind action. Such air leakage results from a failure to make the walls and wall/roof junction airtight. Although these problems generally appear when the air is highly humid, any air leakage contributes to the total energy cost of operating a building.

While stack effect is a dominating force behind air leakage in high-rise buildings, wind action, which creates relatively high suction forces along the windward eaves, can be a major source of air leakage in low buildings. In both cases large quantities of air are drawn from inside the building unless the wall/roof junction is made airtight. Suction forces created by the wind vary with its speed, and they affect different areas of the building depending on the wind's direction.

A wind speed of 20 mph (32 km/h) exerts a velocity pressure of 0.20 in. (5 mm) of water, but the stagnant pressure acting on the walls of a building is usually less than the velocity pressure. Along the eave on the windward side, however, local suctions are created that are two to three times greater than the velocity pressure of the wind. This means that a crack 1/16 in. (1.6 mm) in width at the wall/roof junction can allow air to exfiltrate at a rate from 5.5 to 8.0 cfm (0.15 to 0.23 m^3/min) per foot (0.3 m) of crack from a 20 mph (32 km/h) wind, depending on its direction, the height of parapet, etc.

It is often said that up to 85 per cent of all roofing problems originate along the roof edges and other discontinuities of the membrane where water infiltration can saturate the insulation and find its way into the building. The lack of success in making buildings both air and watertight in these locations suggests that the quality of building enclosures should be improved by modifying the design of the wall/roof junction and other problem areas.

In the design of a building enclosure, a water vapour retardant is usually called for in the wall, but as shown in Figure 18, it may or may not extend to the roof deck, and it or some other component may perform the role of air barrier. A roofing membrane, whether conventional or inverted, is mandatory but seldom extends to the edge of the roof. Instead it is turned up a cant strip and bituminous flashings are installed on the inside face of the parapet wall. The result is that a hole is left in the building envelope which allows moist air to escape, and water vapour to condense within the wall and parapet.

A solution to this problem might consist of extending the roofing membrane to the edge of the roof where it is turned downward to overlap the air and vapour stop of the wall (as shown in Figure 19). This might involve its relocation in the wall, but the result would be a completely sealed envelope separating the building interior from the exterior. A parapet could then be added to satisfy the aesthetic and functional requirements of the wall/roof junction, with base and cap flashings installed in the usual manner, although their performance would no longer be as critical. The continuous membrane would prevent any water seeping into the parapet from gaining access to the roofing and the building.

It is important to establish in the early stages of the design which element of the roofing system is to constitute the air barrier. A deck made of cast-in-place concrete makes a good air barrier. When using a steel deck, a vapour retardant should be specified, otherwise the membrane becomes the air barrier by default. When a protected membrane system is specified, either the deck, if of cast-in-place concrete, or the membrane, can constitute the air barrier. Whatever element is chosen, however, it must be impervious to air, must be sealed at all penetrations and made airtight whenever it joins with another material, otherwise air leakage will occur.

Designers are sometimes influenced by architectural details shown in catalogues distributed by manufacturers of building components. Though details relating to the use of these products are generally correct, this does not necessarily mean that the over-all performance requirements of the enclosure will be met. Since designers have the final responsibility for the selection of materials, their arrangements and the performance of the system, they should examine these suggested details carefully and modify them when necessary.

With respect to the wall/roof junction, steel construction is frequently difficult to make airtight, especially when incorporating a steel deck. Yet steel frames are used extensively in conjunction with masonry walls in the construction of schools, low-rise office buildings, warehouses, plants and retail stores, sometimes with little thought given to achieving air tightness.

Air tightness is not readily achieved with the arrangement shown in Figure 20, a steel frame set in the same plane as the interior wythe of a cavity wall because it is not possible to install the insulation as shown with any hope that it will remain in place, much less will such a detail result in an airtight construction. In addition, masonry walls cannot be built tightly to the underside of a steel spandrel beam because of the difficulty of filling the mortar joint. Subsequent shrinkage of the wall will open a crack between the bottom flange of the beam and the top of the wall, providing a channel for air leakage. The general situation at the wall/roof junction is such that construction tolerances, the instability of construction materials and building movements all conspire to open up cracks in this area.

The details shown in Figure 20 have been modified in Figure 11 to improve air tightness and structural performance. The changes involve

(1) leaving a gap between the top of the concrete ~~block~~ wall and the spandrel so that the beam can deflect freely under its superimposed load and not transfer the load to the wall. The top of the wall is supported laterally if required by clip angles welded or bolted to the bottom flange of the beam.

(2) the steel beam is faced with drywall;

(3) a continuous strip of flexible membrane is installed along the edge of the steel deck, overlapping the drywall on one side and the roofing vapor retardant on the other;

(4) a continuous strip of flexible membrane is installed so as to seal the gap between the drywall and the block wall;

(5) the vapor retardant of the conventional roof is turned up the inside face of the insulation stop to act as a water stop and the membrane can be nailed along its edge to the insulation stop prior to the installation of the cant strips;

(6) the roofing is completed with the installation of bituminous flashings and metal counterflashings.

Placing the steel frame inside the masonry wall line, as shown in Figure 21, does not necessarily guarantee a successful design since the detail as shown does not attempt to incorporate an effective air seal at the wall/roof junction nor does it concern itself with the differential movement that is likely to occur between the steel structure and the masonry wall. Some of the deficiencies of the design shown in Figure 21 can be overcome by the arrangement shown in Figure 22 where

(1) steel joists are kept clear of the masonry wall so that the beam can deflect freely;

(2) the insulation and air barrier are moved outside the concrete blocks;

(3) the roof's vapor retardant is joined to the wall air stop by means of a strip of flexible membrane material which is supported by a sheet metal closure supplied and installed by the steel deck contractor.

The masonry bearing wall shown in Figure 23 provides an easy solution to the problem of achieving air tightness at the wall/roof junction, obtained by installing a strip of flexible material at that location. In this design, too, differential movements between structure and wall are not a matter of concern.

Perimeter venting of the insulation, a practice adopted by some designers, must be carried out in such a way that the opening created in the membrane prevents water from getting into the roofing. Warm moist air from inside the building must be prevented from entering the roof insulation, where it can condense, by the installation of a continuous air barrier under the insulation.

A major obstacle in achieving air tightness at the wall/roof junction stems from the fact that a number of trades are usually responsible for its construction, which involves the supply and installation of various materials, such as masonry, wood, roofing, steel. Unless their individual responsibilities are clearly defined, and a proper sequence of work established, air tightness is unlikely to be achieved. To obtain a satisfactory result the general contractor must coordinate the work of his subcontractors.

Where a wall rises above a roof, such as shown in Figures 24, 25 and 26, the continuity of the wall/roof air barrier is just as important as it is at the perimeter of the building. It has been generally considered that a base flashing extending 8 to 10 in. (200 to 250 mm) above a roof and counterflashed into a wall with sheet metal is all that is required to keep water out and warm air in. In certain areas of the country, however, snow can accumulate on multi-level roofs to depths of 3 ft (900 mm) or more and a sudden rainfall during the winter can cause water to back up against a wall to depths greater than is waterproofed by the base flashings, resulting in water infiltration. In addition, air leakage at the base of a wall can melt snow and ice in contact with the wall. Accordingly, it is a good policy to join the wall air/vapour barrier to the roof membrane with a strip of flexible flashing to ensure both the water and air tightness of the junction, and where a vapour retardant is used on the deck it should also be joined to the wall air/vapour barrier.

Expansion joints in roofs and penetrations through roofs are other areas where air tightness is difficult to achieve and problems often arise.

Canopies and soffits do not always receive the attention they deserve. Where a steel deck is cantilevered over an exterior wall to form a canopy, for example, it is difficult to seal the corrugations. Neoprene closures are sometimes used for this purpose but if the steel frame is located inside the wall line, the air can usually circumvent the closures. If the steel structure is set in the wall then the structure itself can create a problem. Where the exterior wall is erected after the steel deck is in place, the blocking of all the corrugations becomes a laborious job. It must also be remembered that wherever a steel deck is cantilevered over an outside wall, the corrugations on the top side of the deck must also be made airtight, otherwise they provide a direct path for air leakage between the inside and outside of the building. Stuffing some loose insulation into these corrugations is generally not sufficient to prevent air movement.

It may be preferable to build the canopy as a separate structure, but this may create problems of its own, such as drainage and the need to provide an independent supporting structure, but the benefits may well offset the disadvantages. If, however, the canopy is attached to the main structure, although the deck itself is not continuous, a large number of holes may have to be cut through the wall for the support of the canopy, in which case every hole must be sealed to restore the air barrier, as installing a soffit may conceal the holes but will do little more.

Insulated soffits can be a source of air infiltration in buildings unless a proper air stop is installed. An insulated metal soffit extending over an entrance is shown in Figure 27. The wall at ground level, built of steel studs faced both sides with drywall, has its inside sheet of drywall extended to the suspended ceiling, while the exterior sheet stops at the soffit. The wall is insulated with batts, which are extended over the inside face of the horizontal metal siding, and are covered by a sheet of polyethylene. It is obviously difficult to assemble an airtight barrier under such conditions since the polyethylene sheet has to be perforated by the metal braces supporting the soffit framing. Thus outside air is capable of flowing freely through the insulation and polyethylene film under stack or wind effect, reducing the thermal efficiency of the insulation.

A better solution to the soffit problem from the point of view of air tightness might consist in extending the exterior sheet of drywall along the outside face of the canopy framing (metal studs in this case); the friction fit insulation and polyethylene vapour retardant could be installed as before. Air movement between the exterior and interior of the building is prevented by the drywall, improving the efficiency of the insulation. This solution, however, raises the possibility of warm moist air, transported by convection through openings in the polyethylene vapour retardant, coming in contact with cold drywall; condensation may then form on the inside face of the drywall and be absorbed by the gypsum, causing it to deteriorate.

A superior solution to the above canopy problem is shown in Figure 28 where the vapour retardant and the insulation are placed on the outside of the drywall, thus properly controlling air, vapour and heat flows through the assembly.

In conclusion, air tightness is difficult to achieve at a wall/roof junction unless it is carefully considered in the design of the wall, the structure and the roof deck or slab. It is at the wall/roof junction that cracks and openings frequently form as a result of the differential movements of materials and components, thus requiring the use of adequately flexible air and vapour barriers. An additional problem in achieving air tightness arises because the wall/roof construction usually proceeds in stages and involves various trades, each of which contributes to its success or failure. The potential for air movement through stack effect and wind action is always present in buildings; only good design can hold in check the driving force for air leakage.

LEGEND

1 Asbestos-Cement Board
2 Brick
3 Concrete Block
4 Concrete Block Lintel
5 Concrete Column
6 Concrete Curb
7 Concrete Foundation Wall
8 Concrete Slab
9 Aluminum Sill
10 Dovetail Anchor
11 Flashing
12 Furring Channel
13 Hollow Metal Frame
14 Metal Anchor
15 Steel Deck
16 Metal Counter Flashing
17 Metal Siding
18 Metal Sheet
19 Sheet Steel Closure
20 Metal Stud
21 Metal Tie
22 Metal Up-Stand
23 Metal Z Bar
24 Nesting Channels
25 Shelf Angle
26 Sill
27 Soffit Closure
28 Spacer
29 Spandrel Beam
30 Steel Column
31 Open-Web Steel Joist
32 Wedge Insert
33 Batt Insulation
34 Rigid Insulation
35 Semi-Rigid Insulation
36 Bituminous Flashing
37 Flexible Membrane Flashing
38 Window Frame
39 Caulking
40 Compressible Mastic
41 Foam Plastic Rope
42 Built-Up Roofing Membrane
43 Air-Vapour Barrier
44 Gypsum Board
45 Plywood
46 Gravel
47 Wood Frame or Brick
48 Wall Cladding
49 Sealed Double-Glazed Window
50 Clip Angle

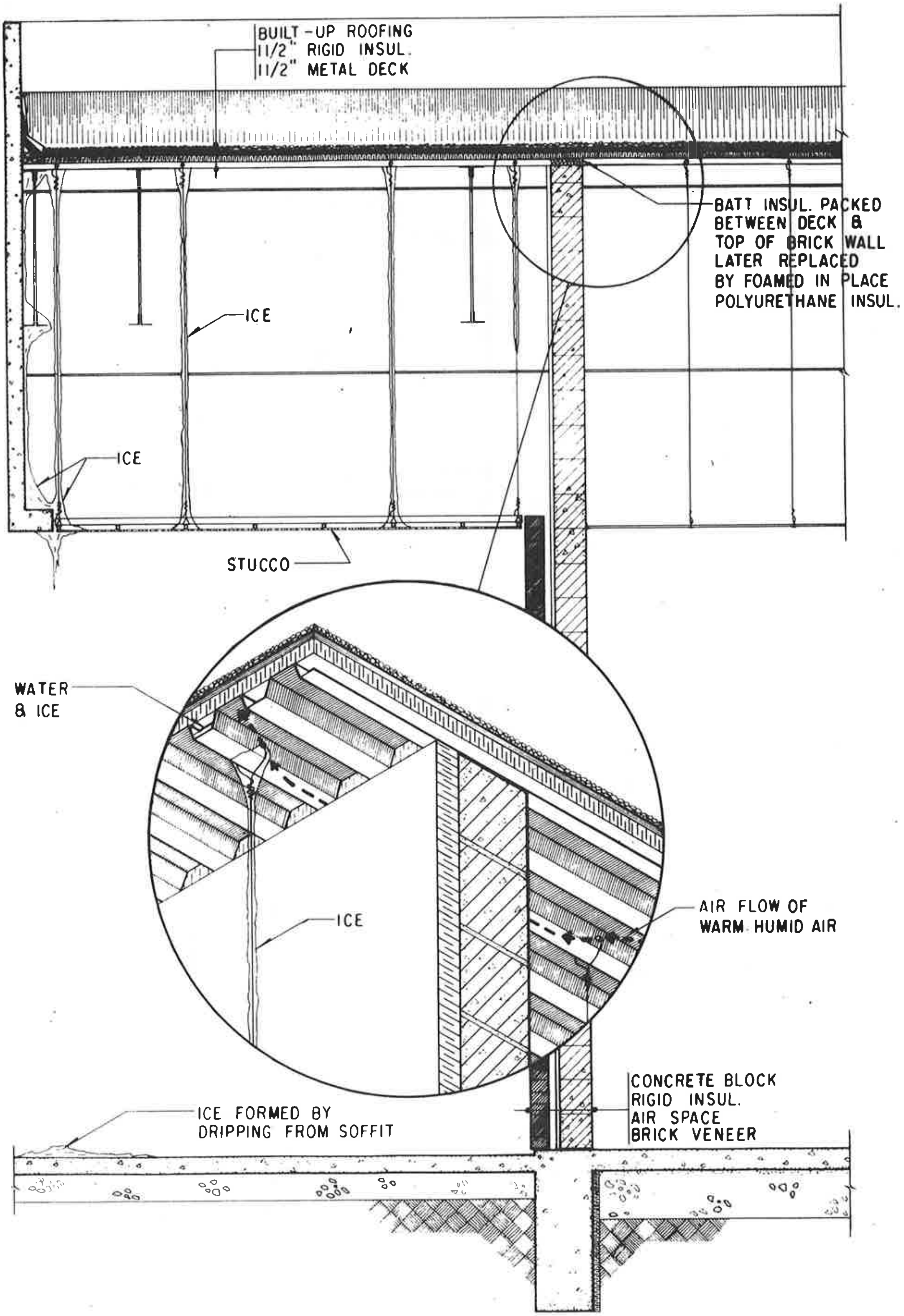
BUILT-UP ROOFING
1 1/2" RIGID INSUL.
1 1/2" METAL DECK
BATT INSUL. PACKED BETWEEN DECK & TOP OF BRICK WALL LATER REPLACED BY FOAMED IN PLACE POLYURETHANE INSUL.
ICE
ICE
STUCCO
WATER & ICE
ICE
AIR FLOW OF WARM HUMID AIR
CONCRETE BLOCK
RIGID INSUL.
AIR SPACE
BRICK VENEER
ICE FORMED BY DRIPPING FROM SOFFIT

FIGURE 1

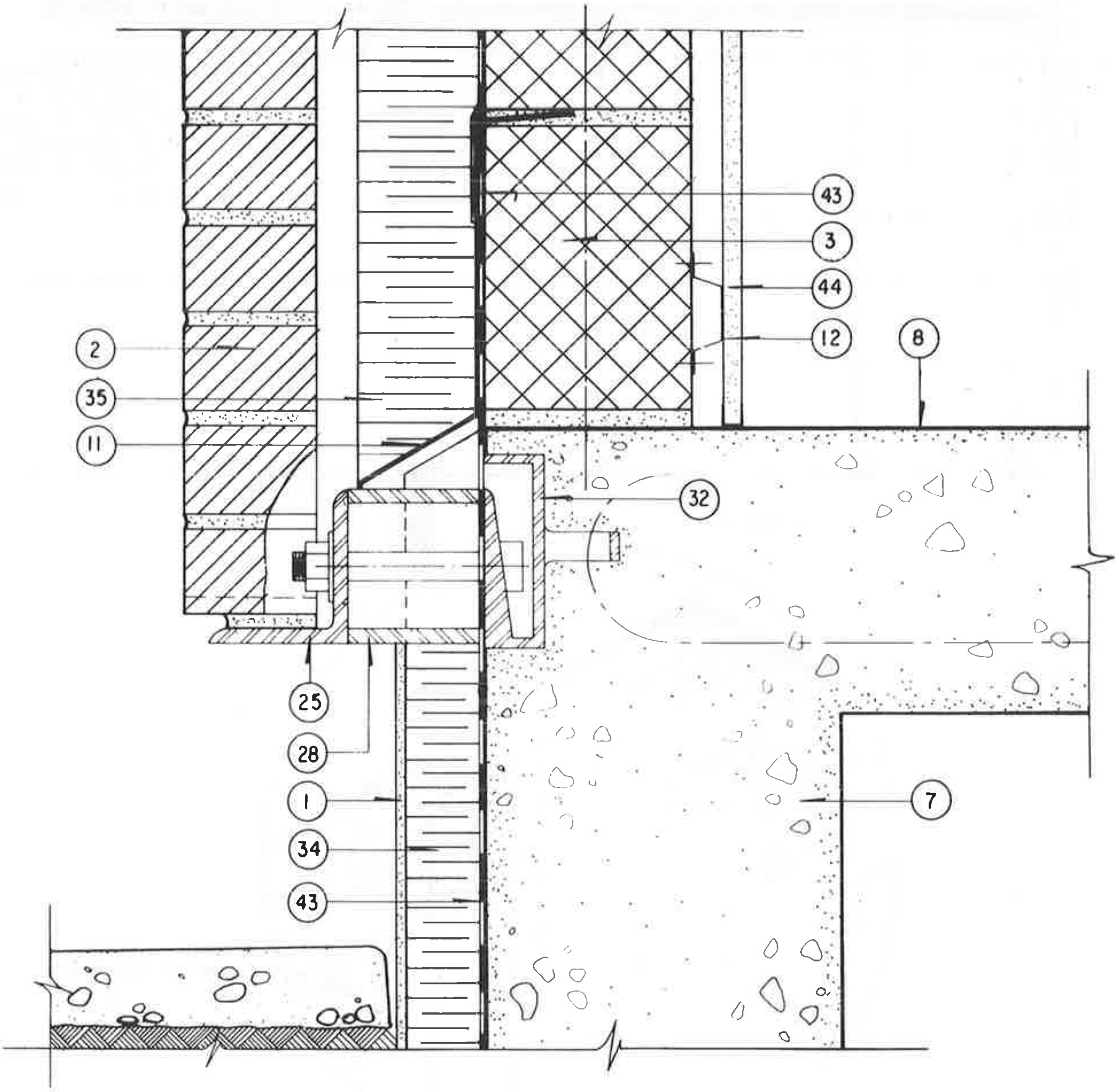

FIGURE 2

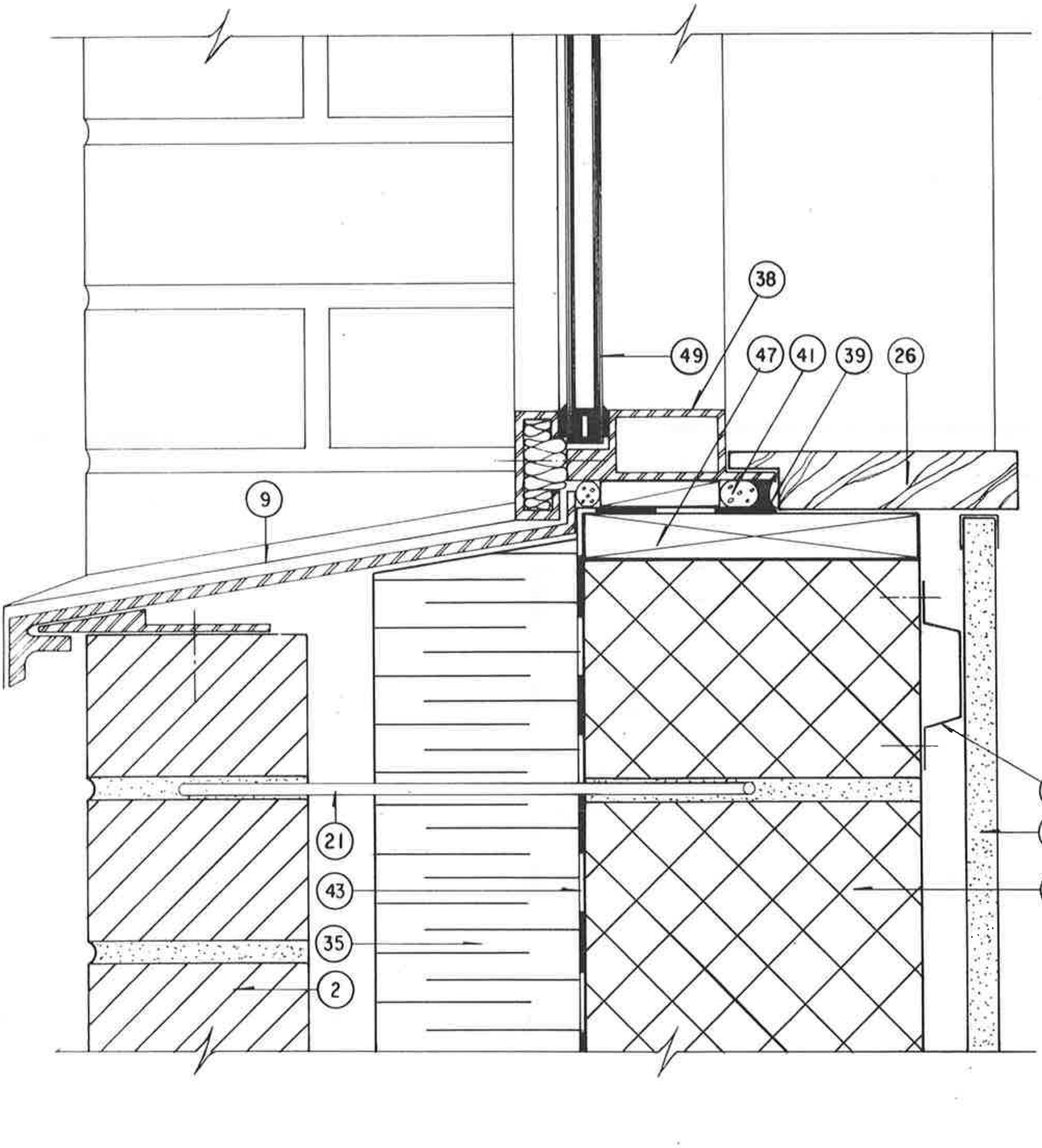

FIGURE 3

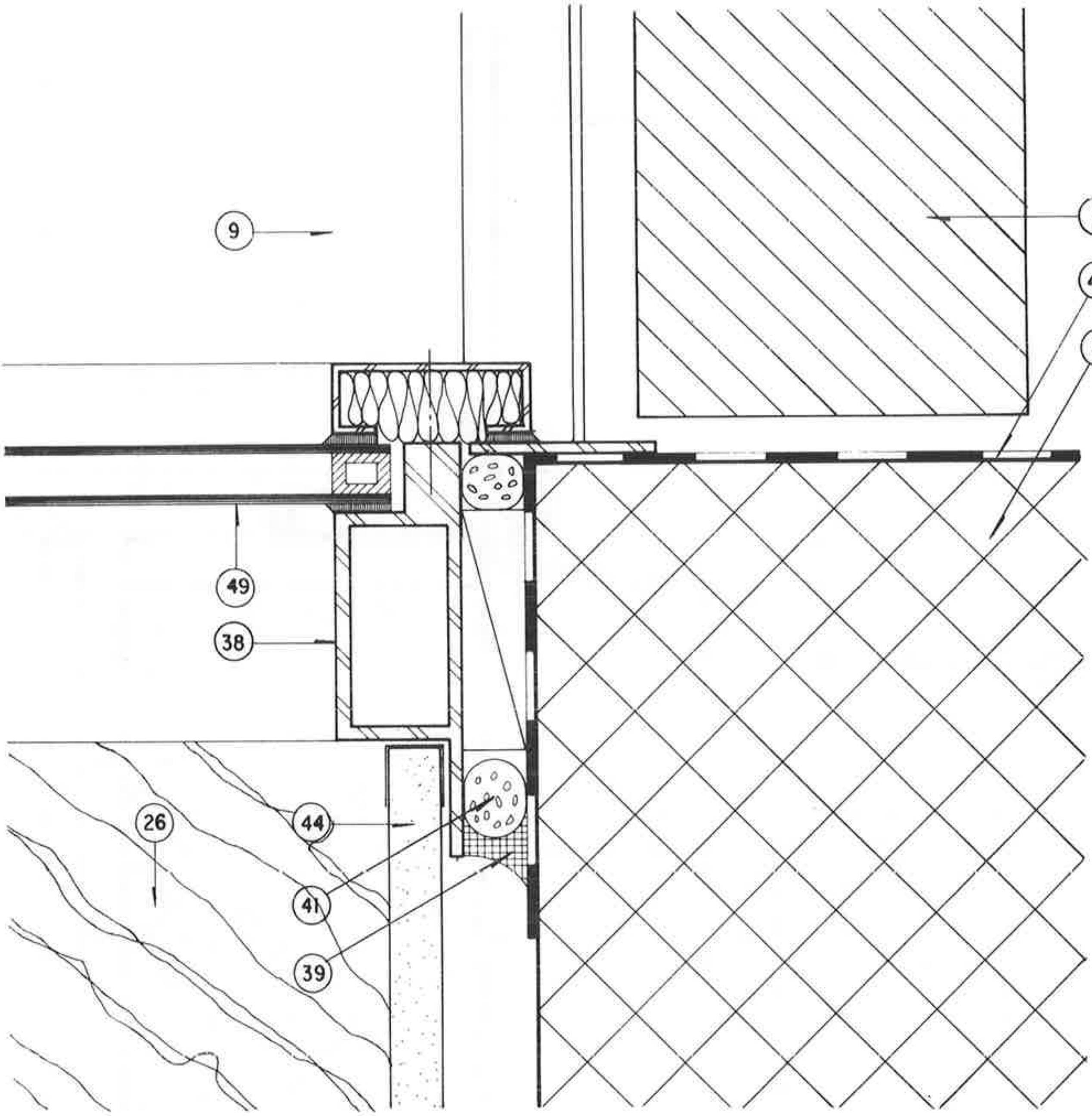

FIGURE 4

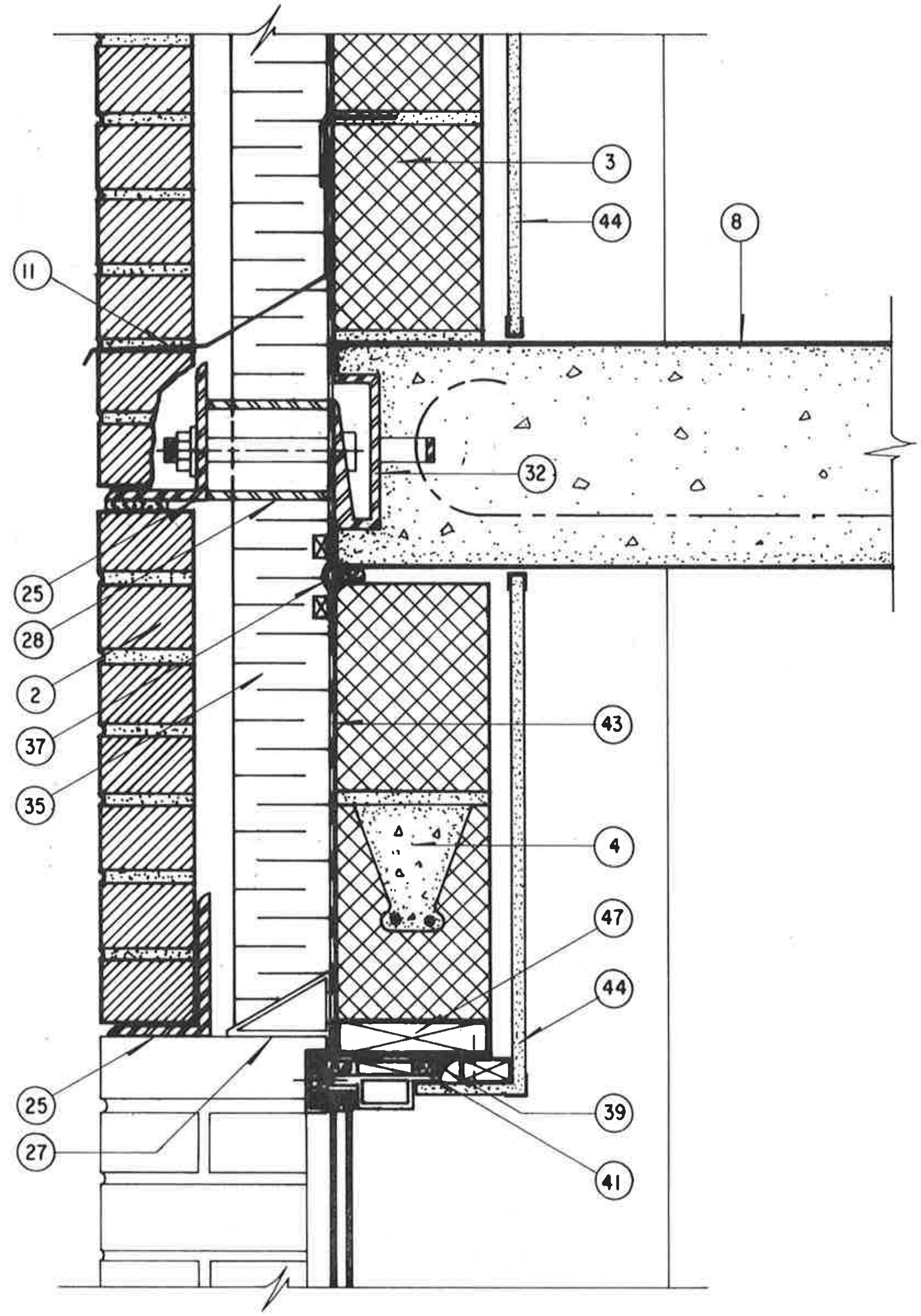

FIGURE 5

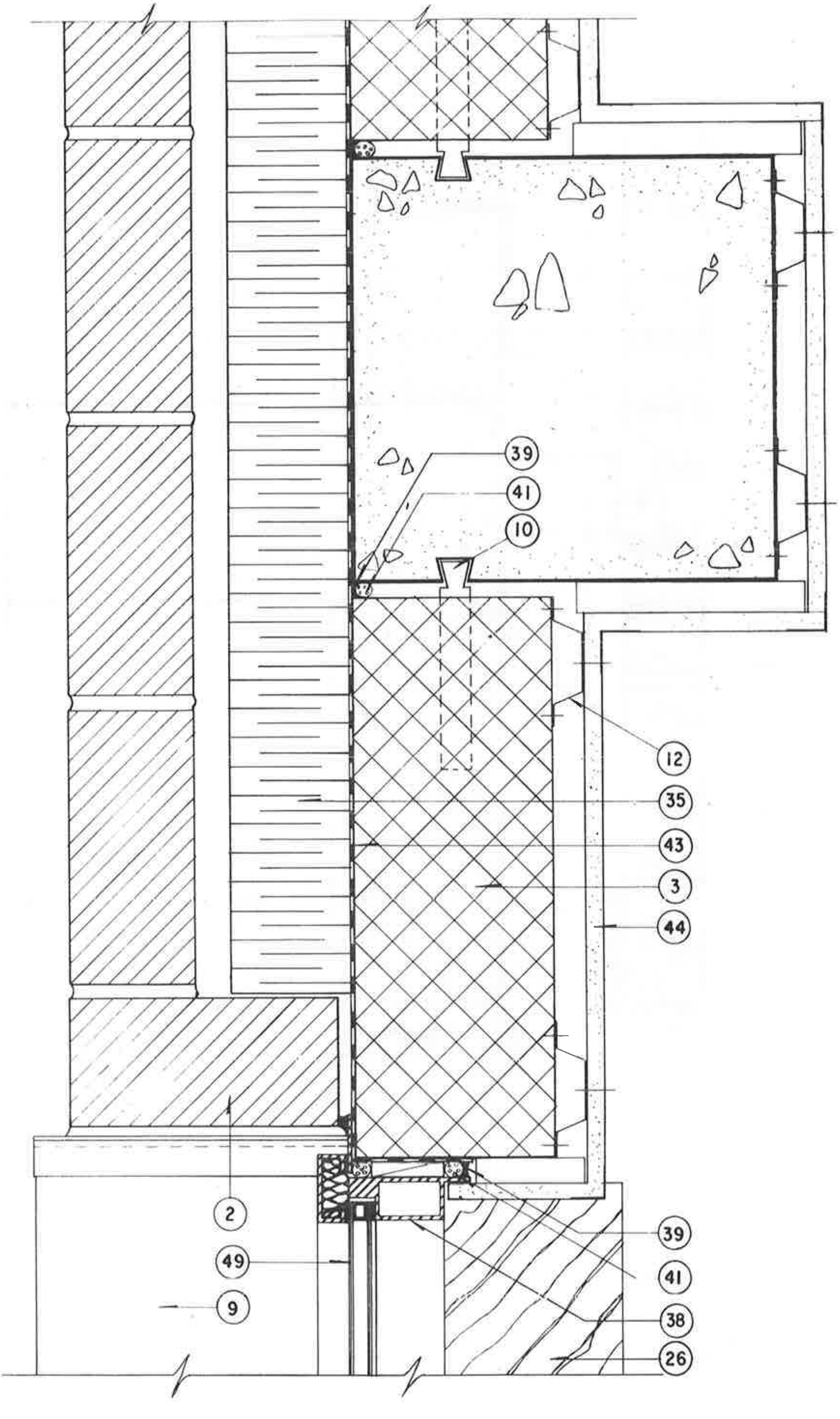

FIGURE 6

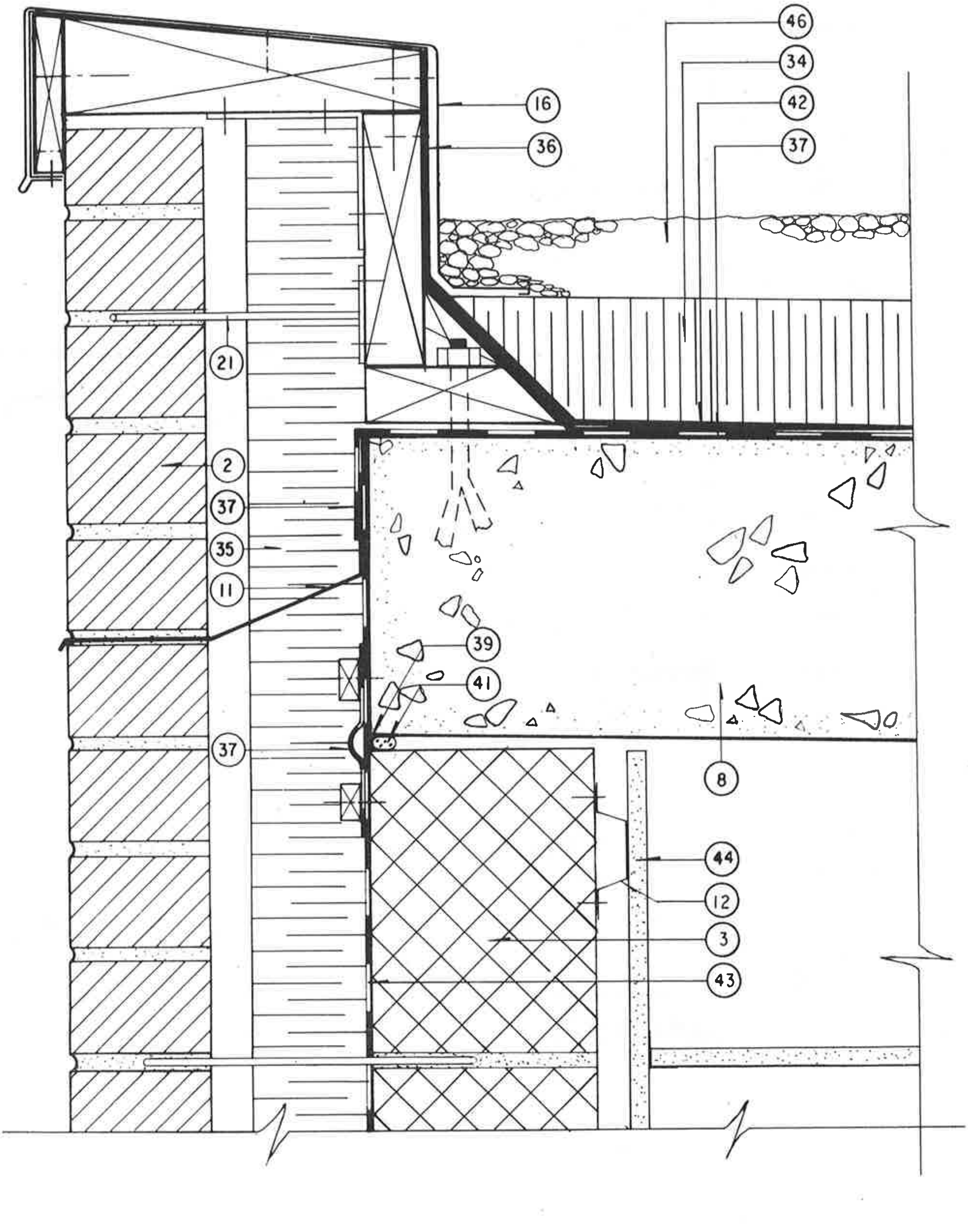

FIGURE 7

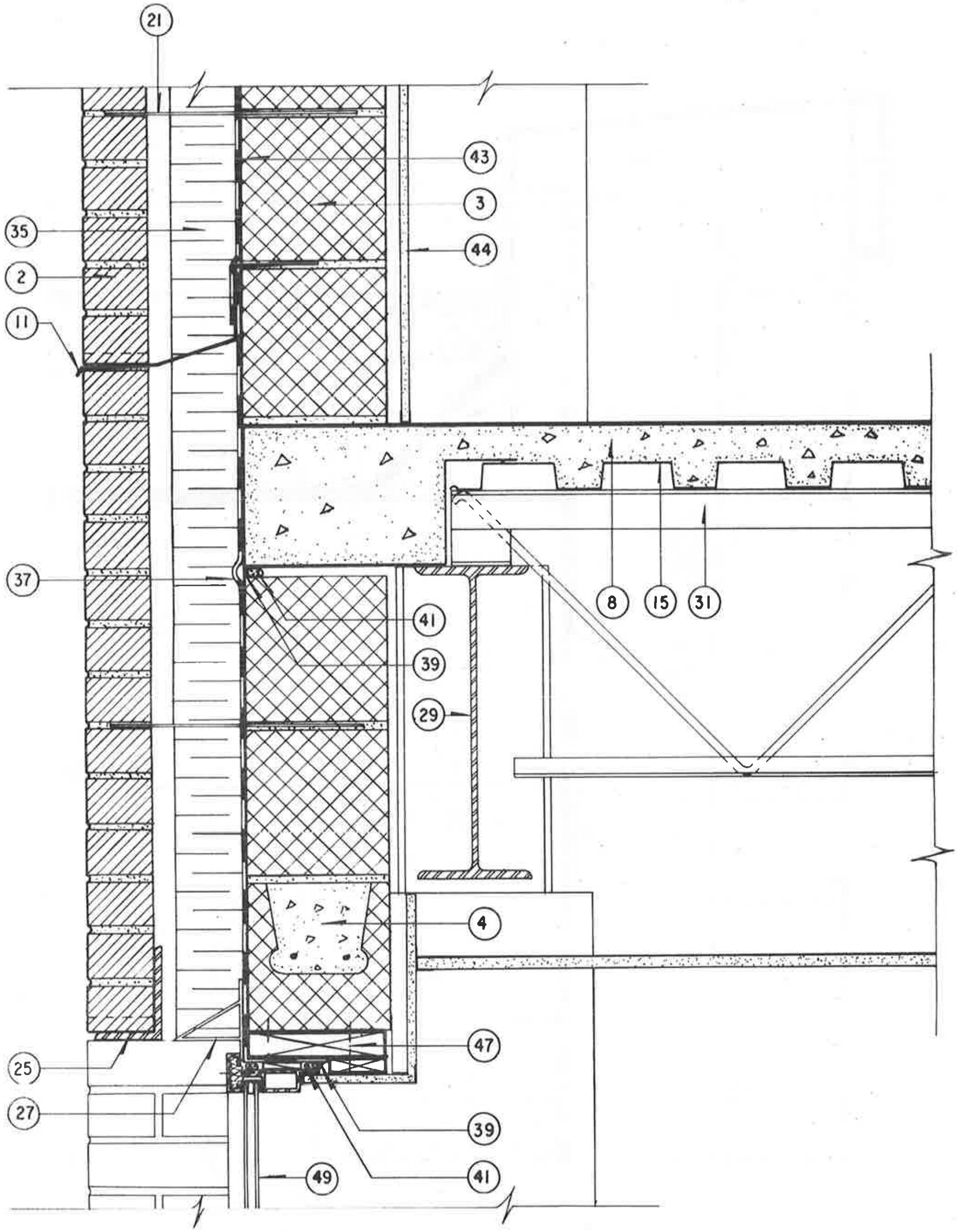

FIGURE 8

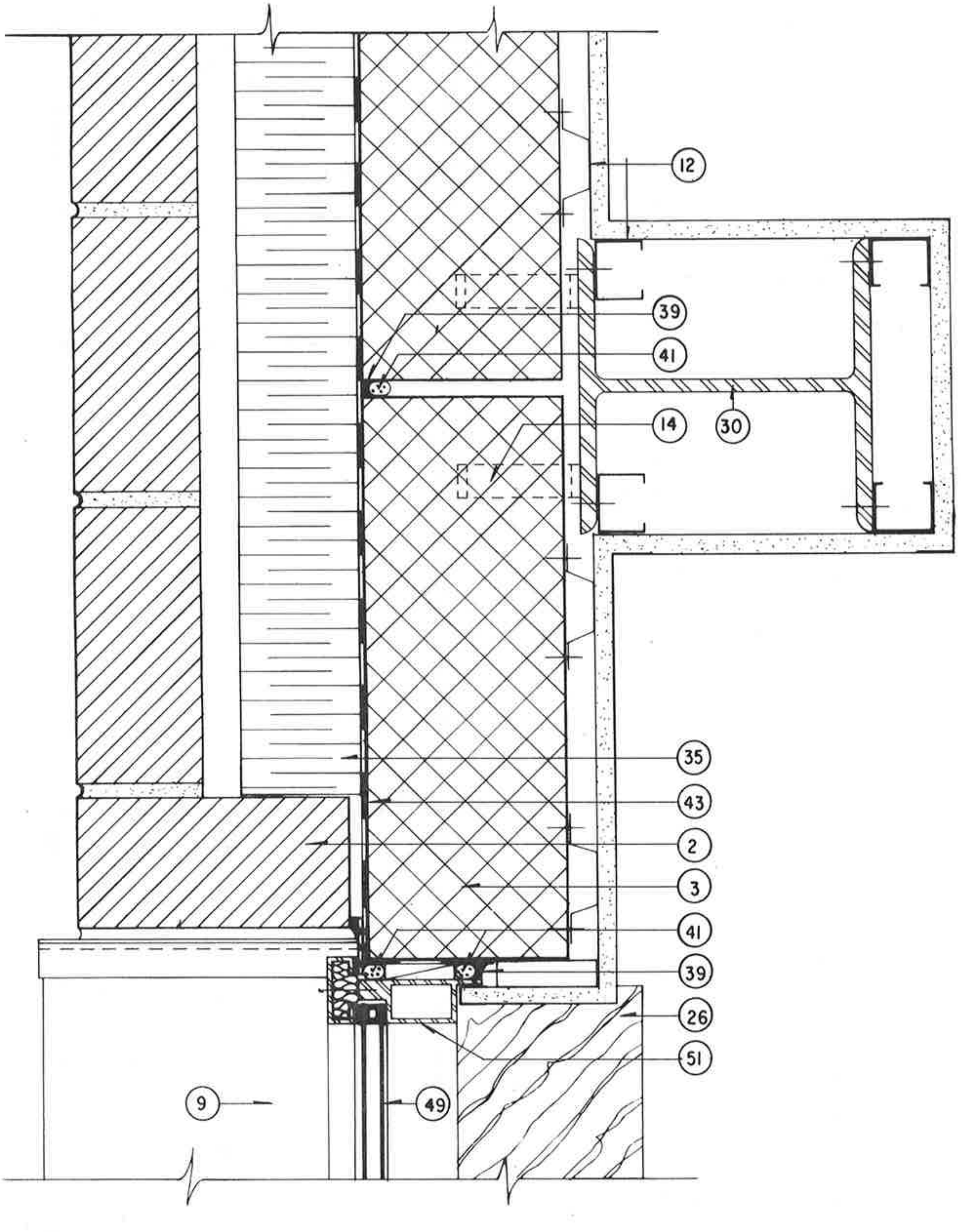

FIGURE 9

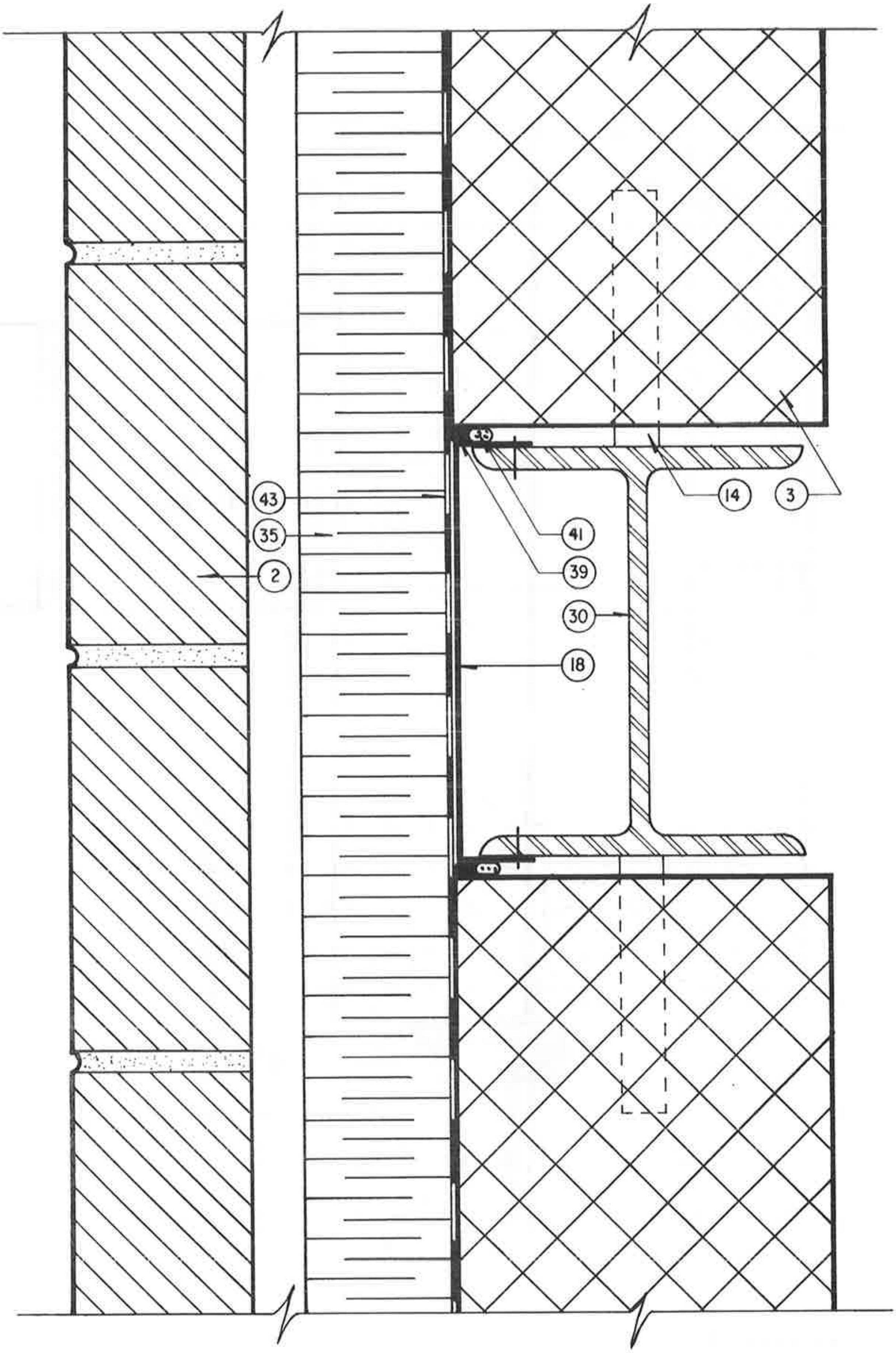

FIGURE 10

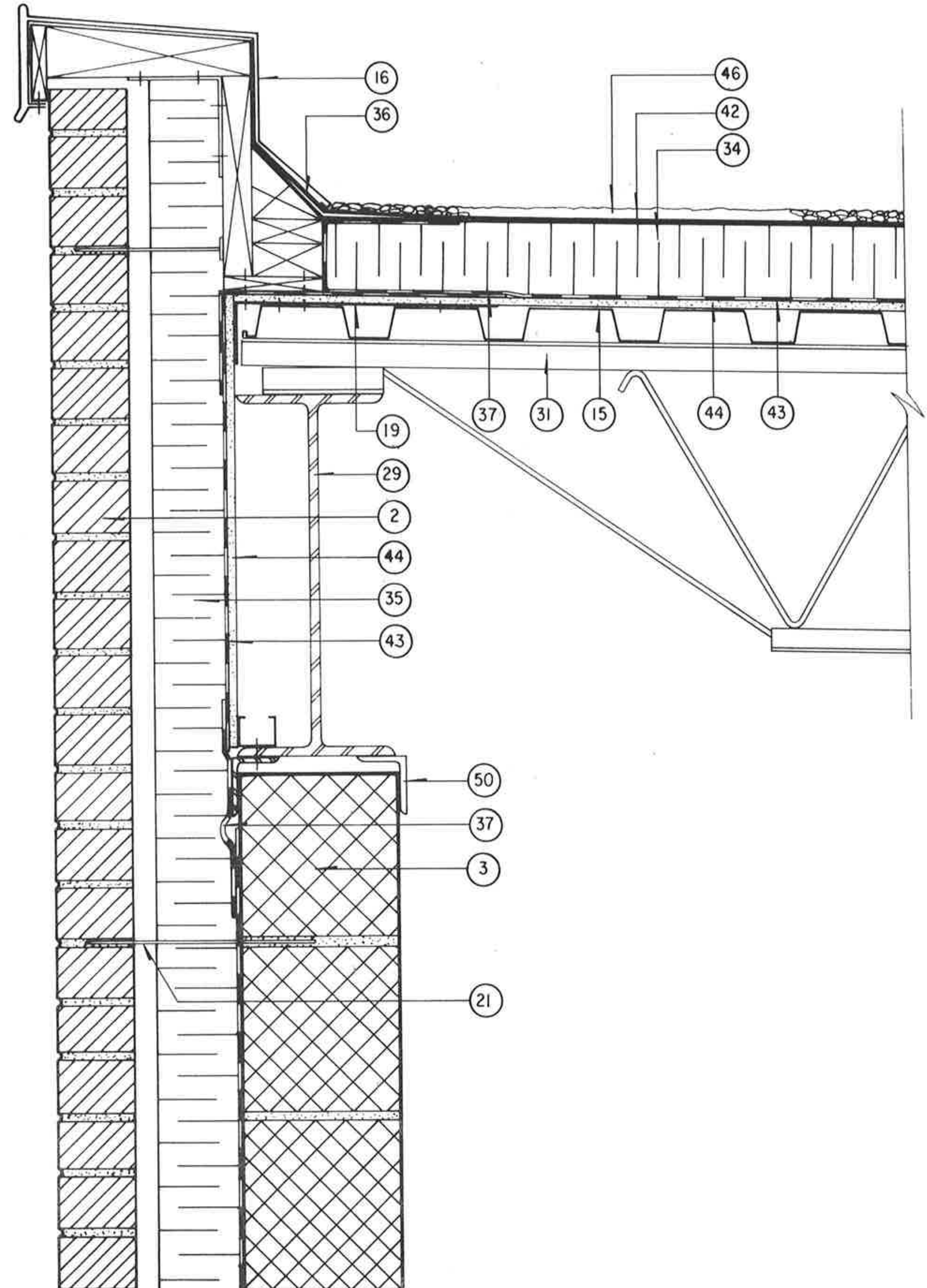

FIGURE 11

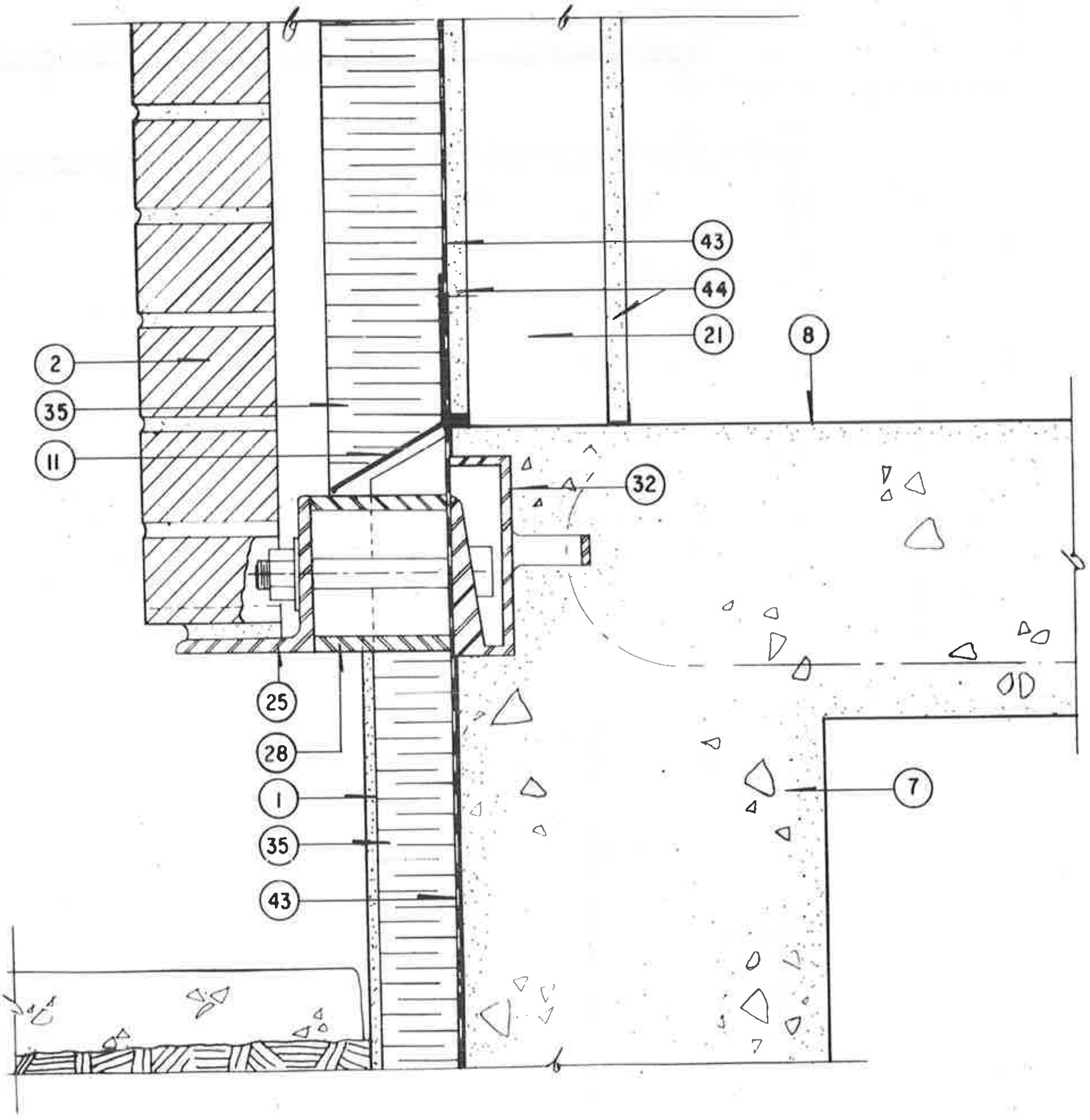

FIGURE 12

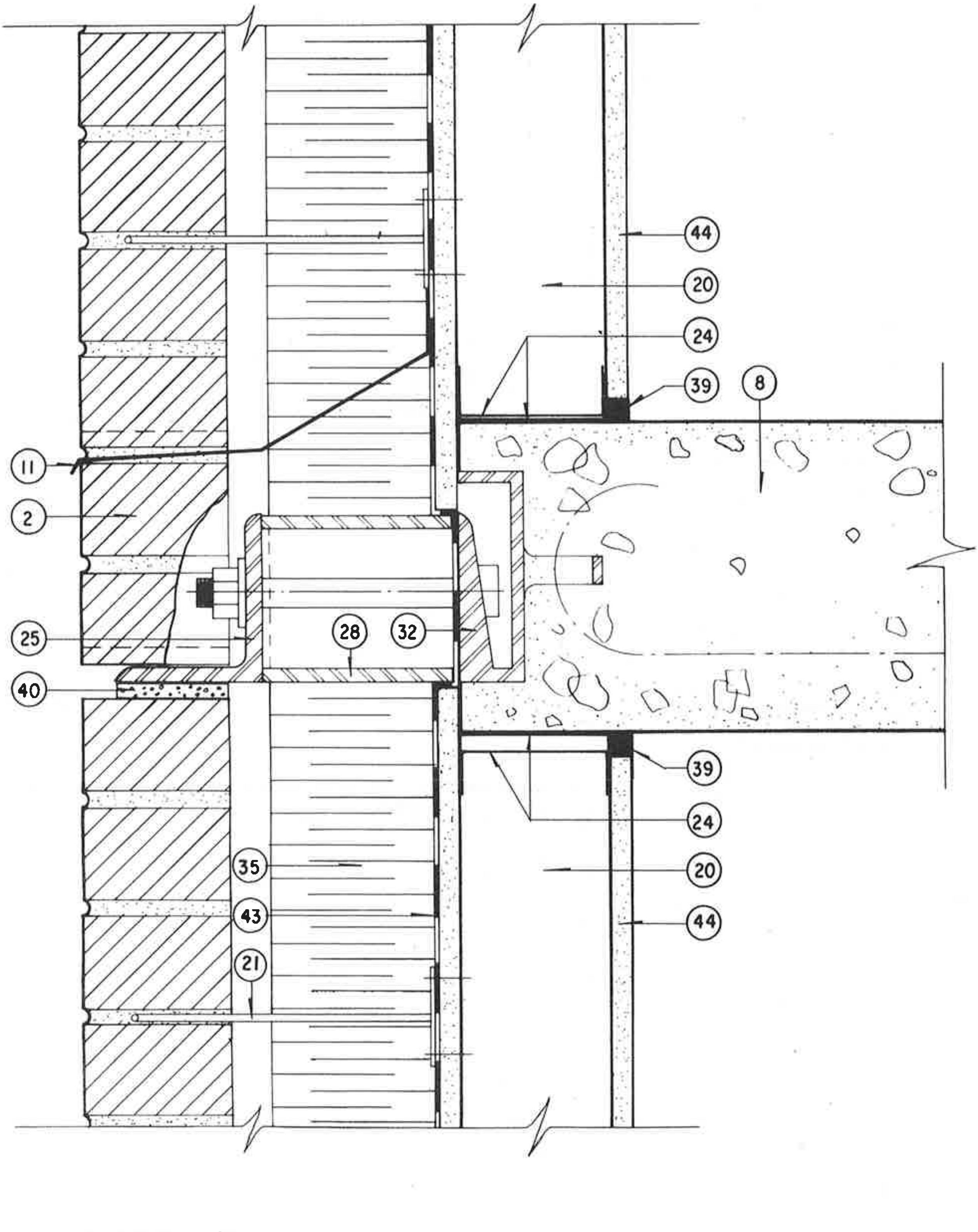

FIGURE 13

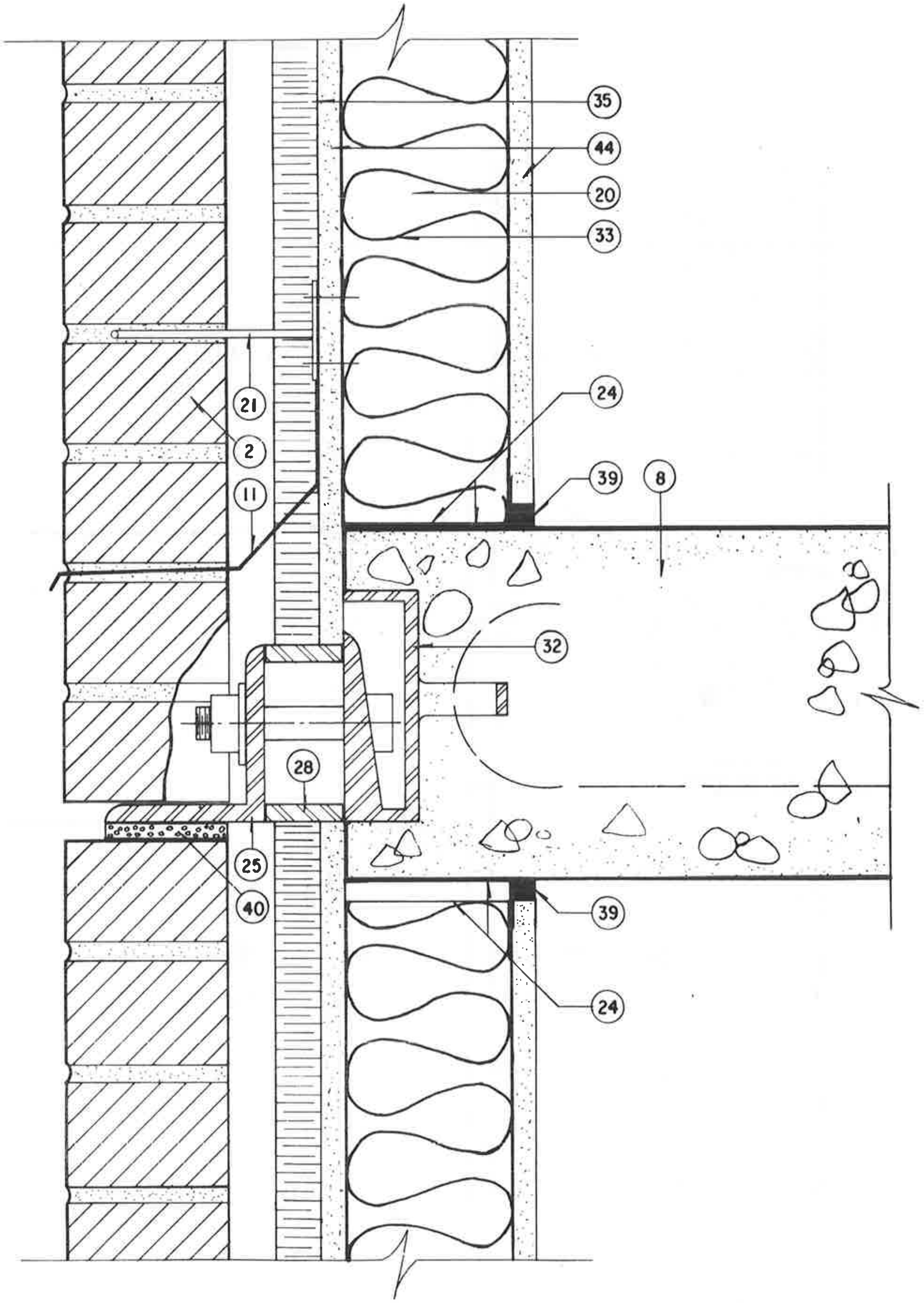

FIGURE 14

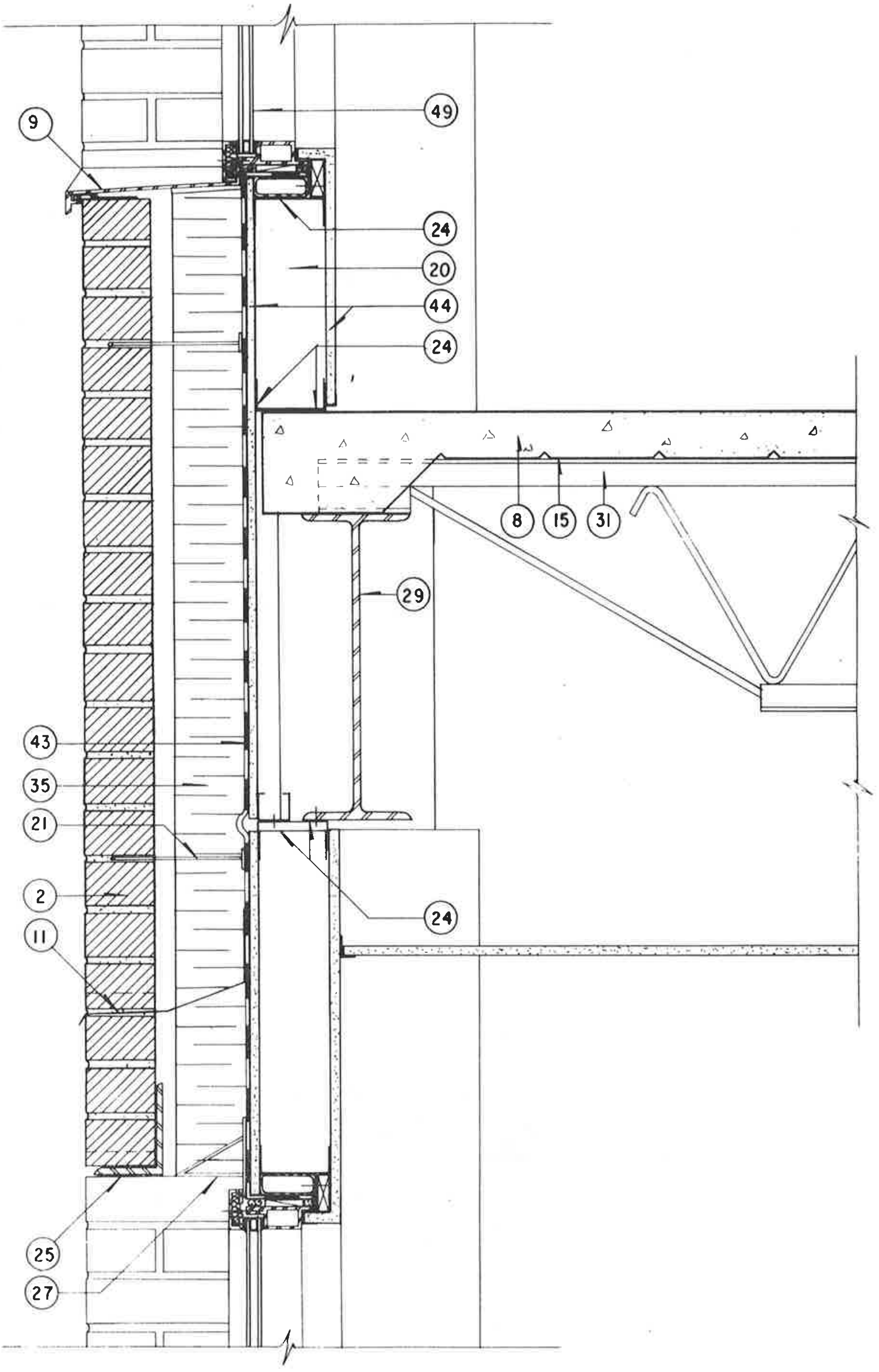

FIGURE 15

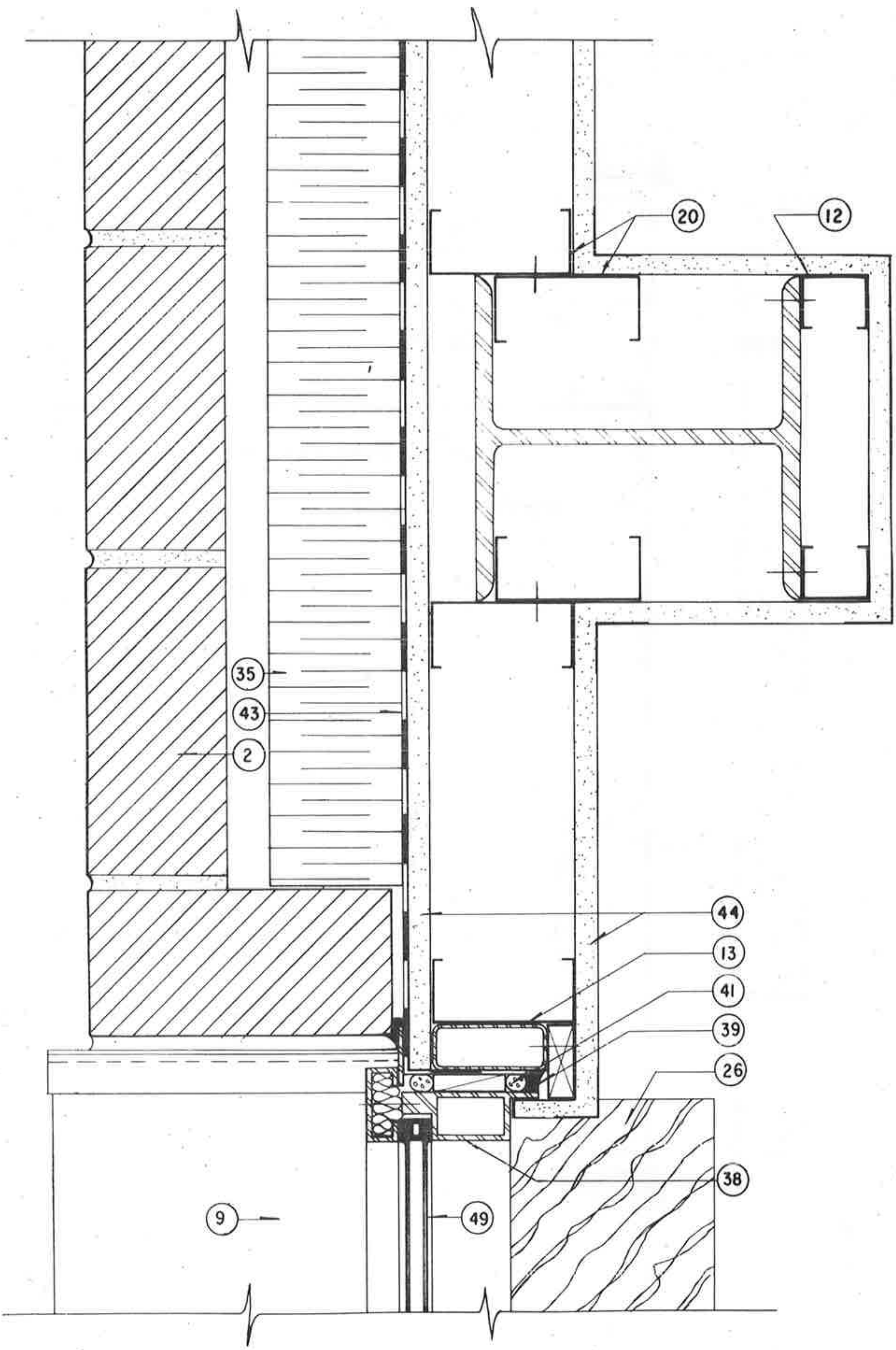

FIGURE 16

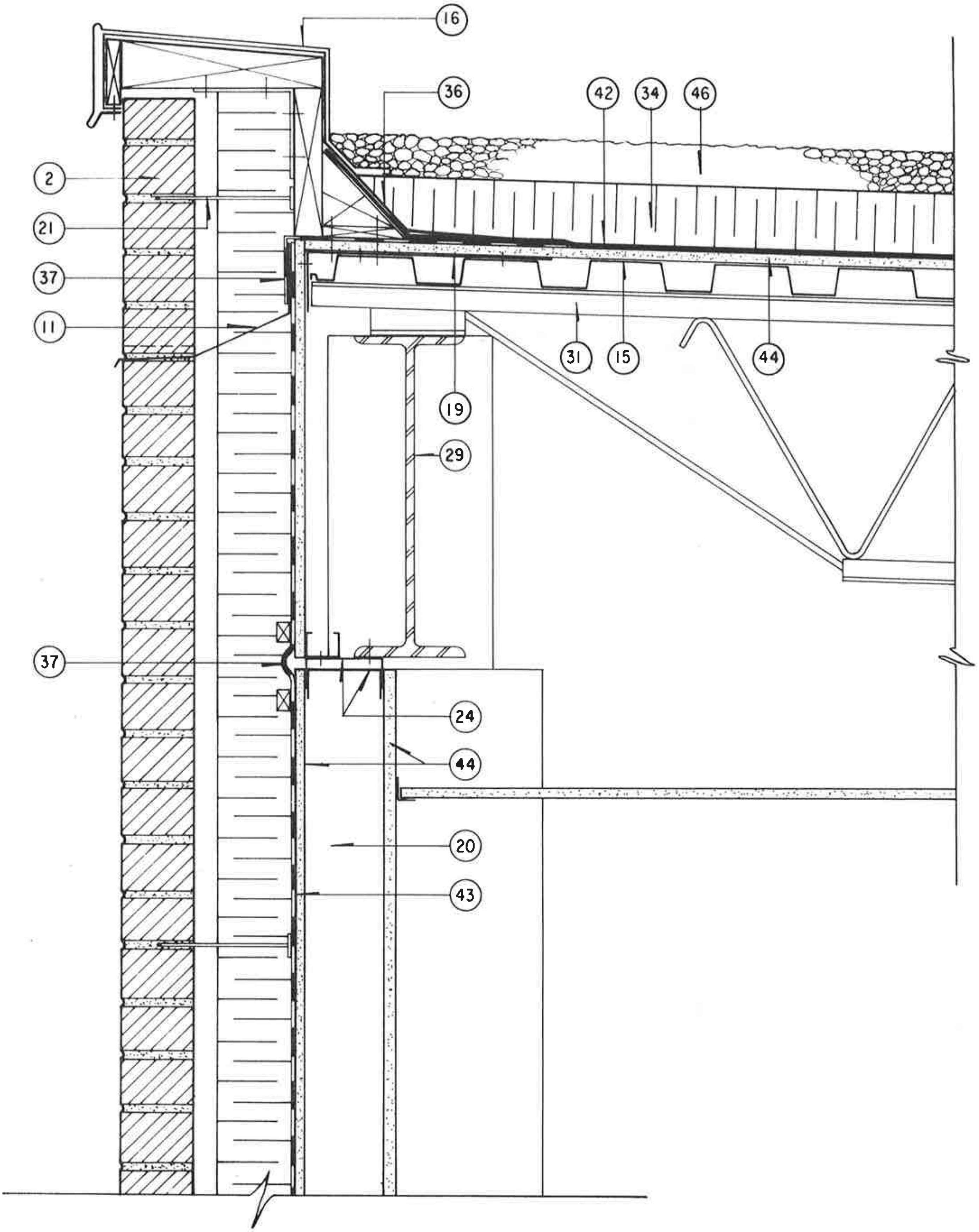

FIGURE 17

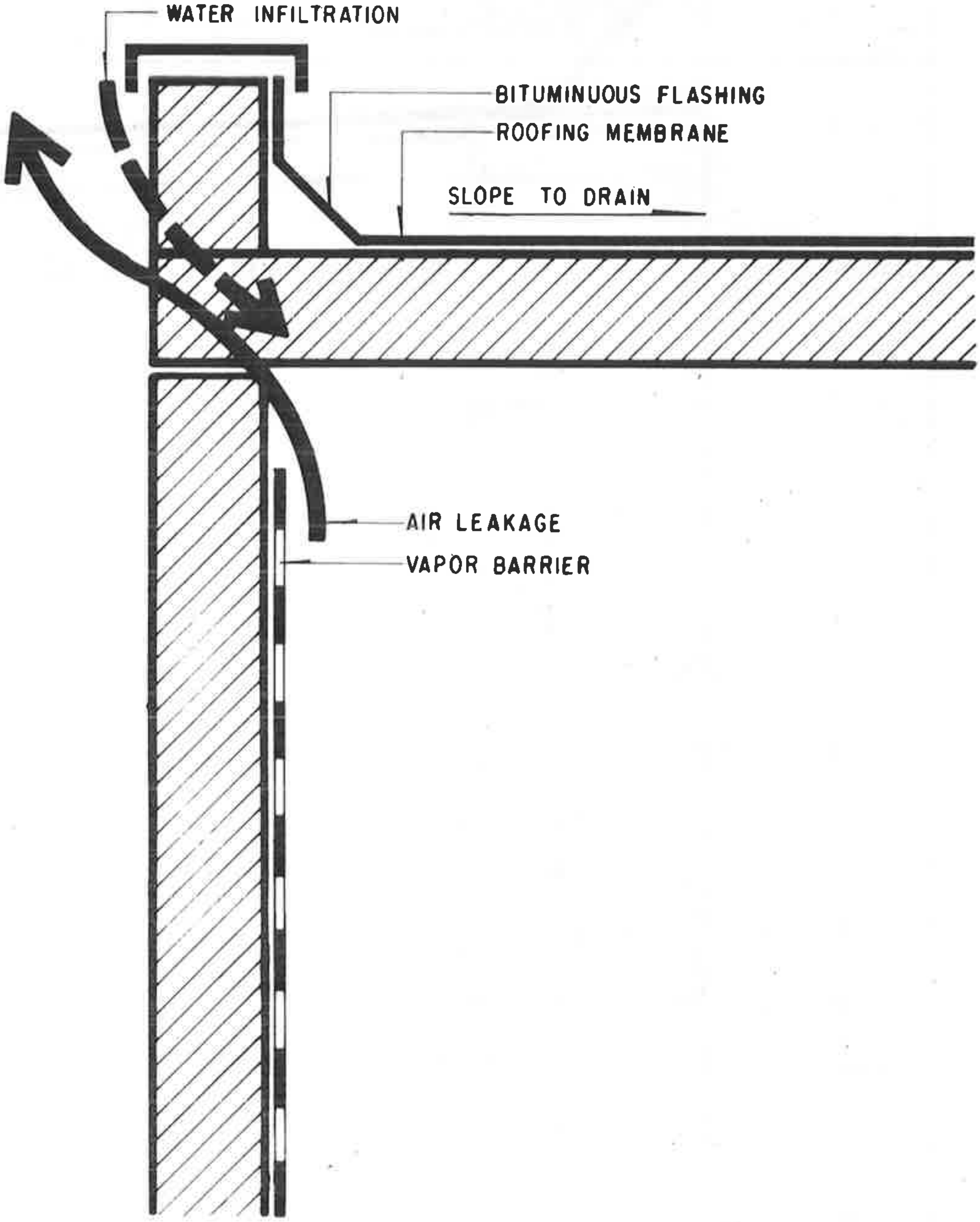
WATER INFILTRATION
BITUMINUOUS FLASHING
ROOFING MEMBRANE
SLOPE TO DRAIN
AIR LEAKAGE
VAPOR BARRIER

FIGURE 18

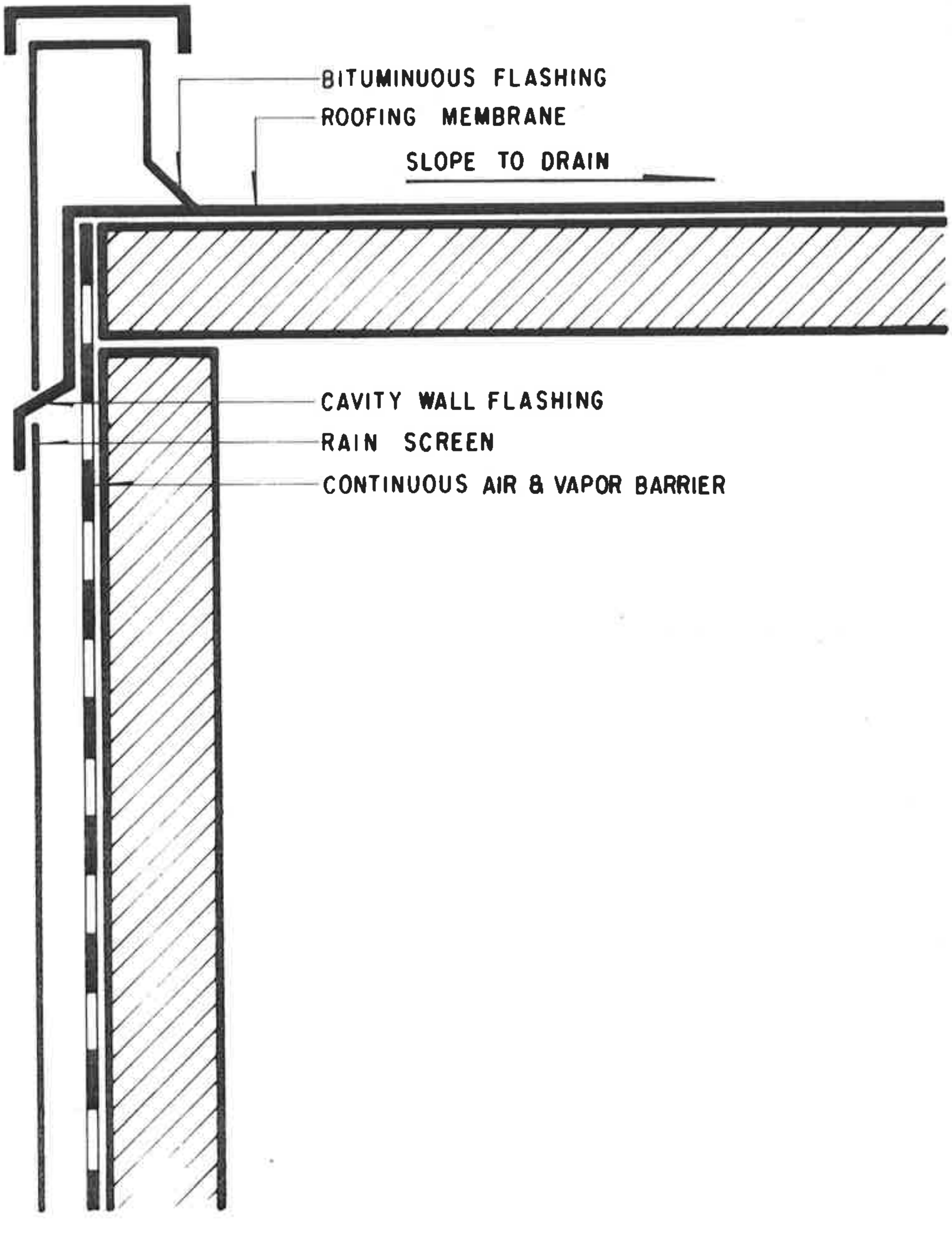
BITUMINUOUS FLASHING
ROOFING MEMBRANE
SLOPE TO DRAIN
CAVITY WALL FLASHING
RAIN SCREEN
CONTINUOUS AIR & VAPOR BARRIER

FIGURE 19

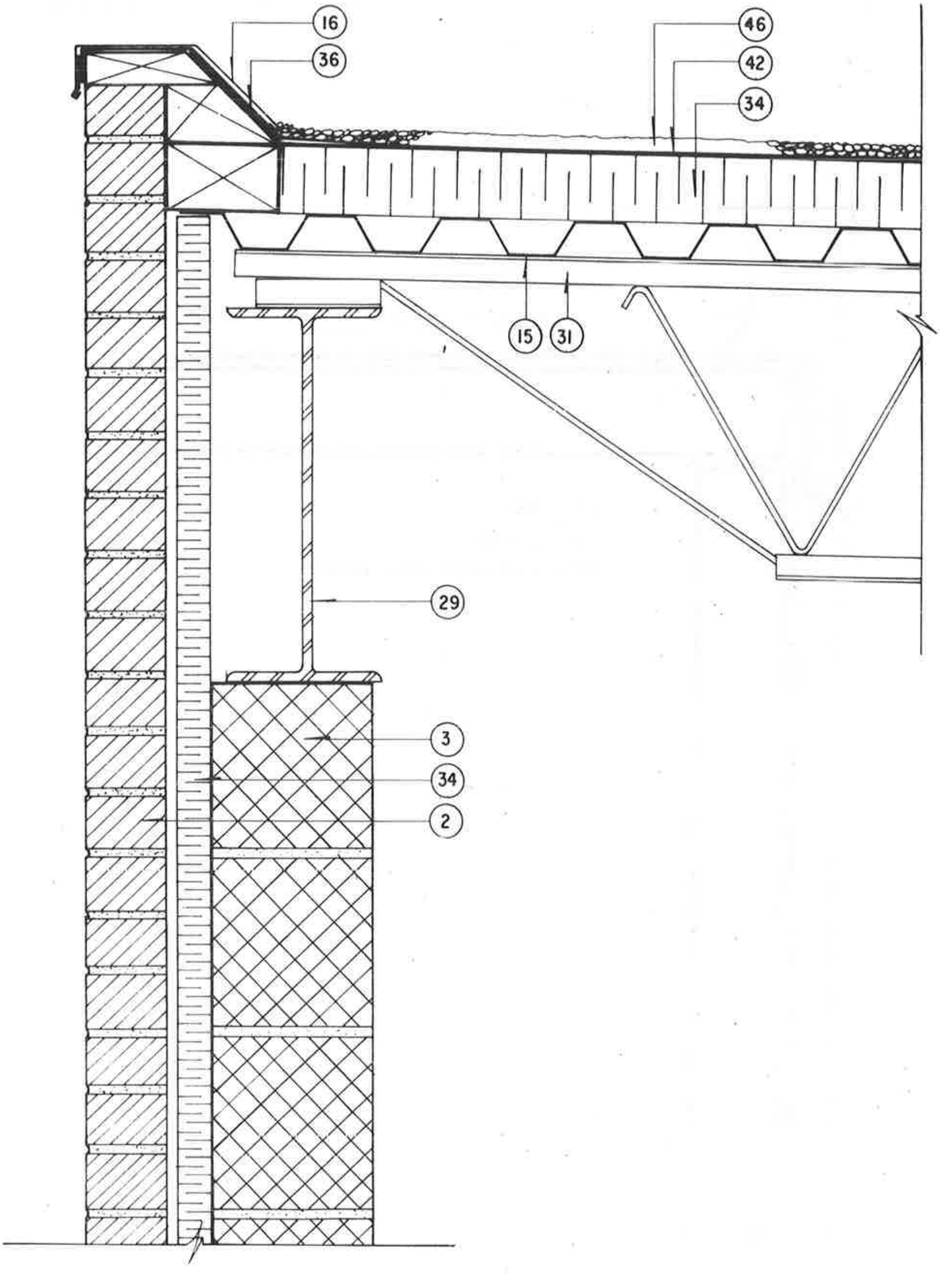

FIGURE 20

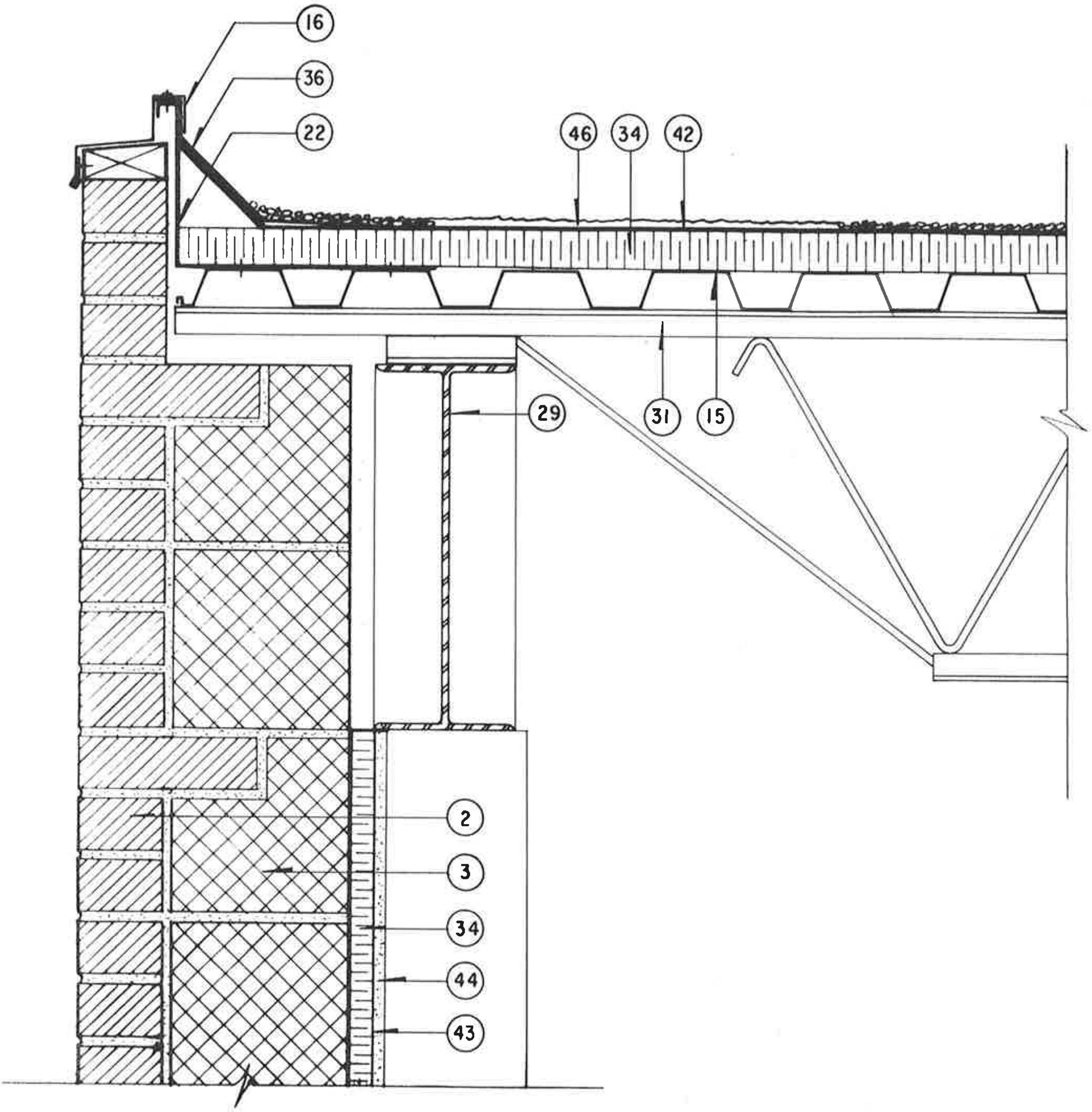

FIGURE 21

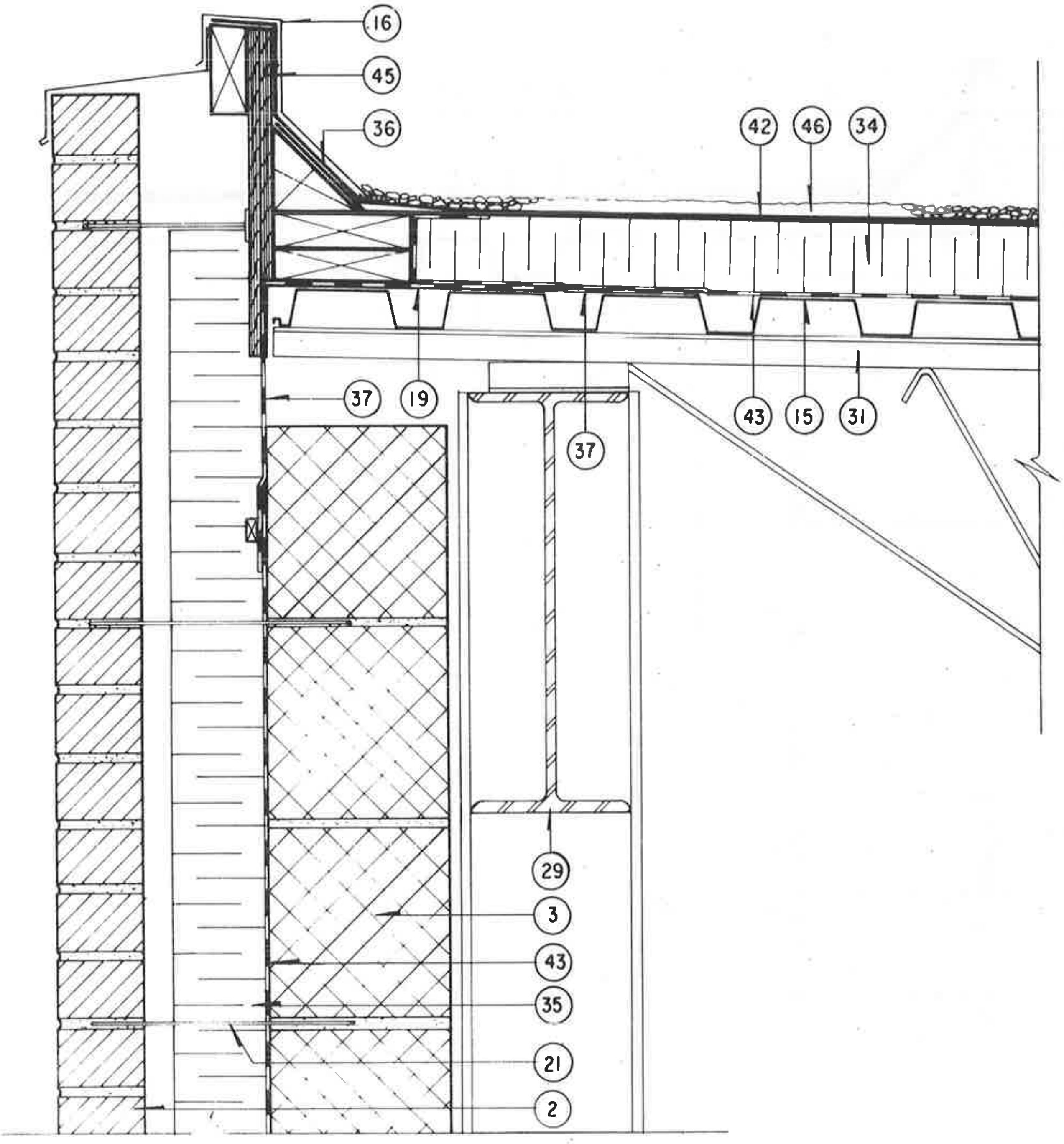

FIGURE 22

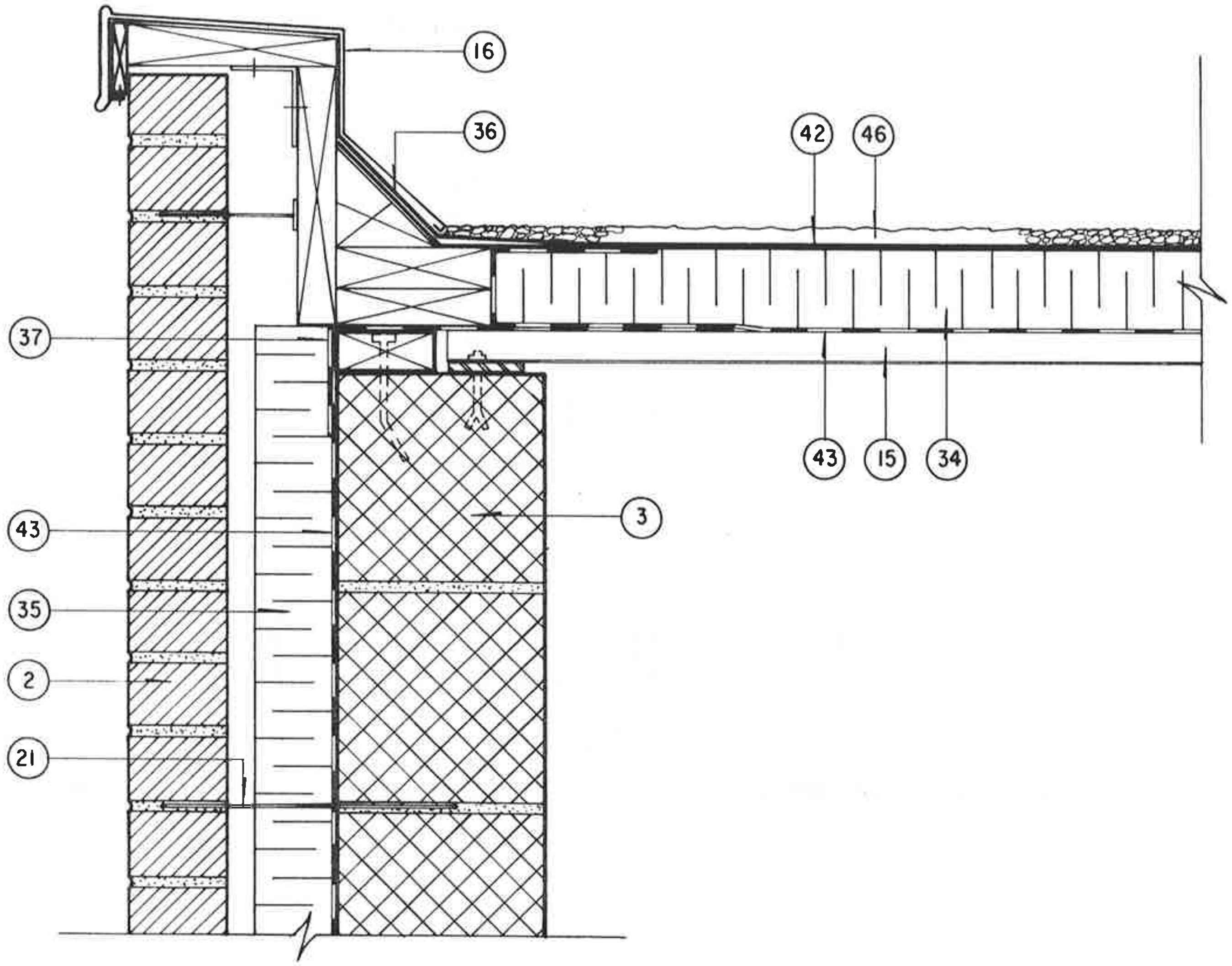

FIGURE 23

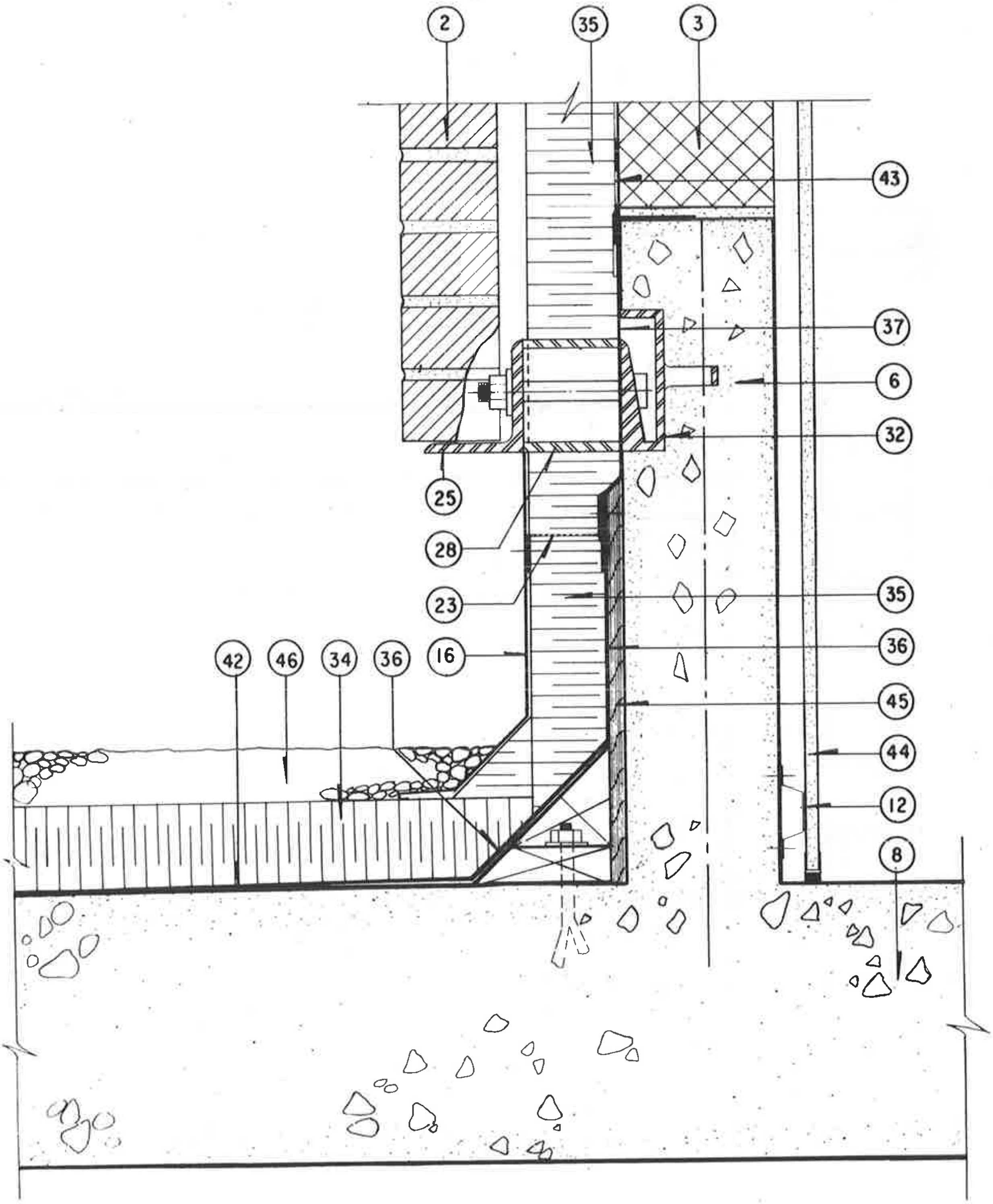

FIGURE 24

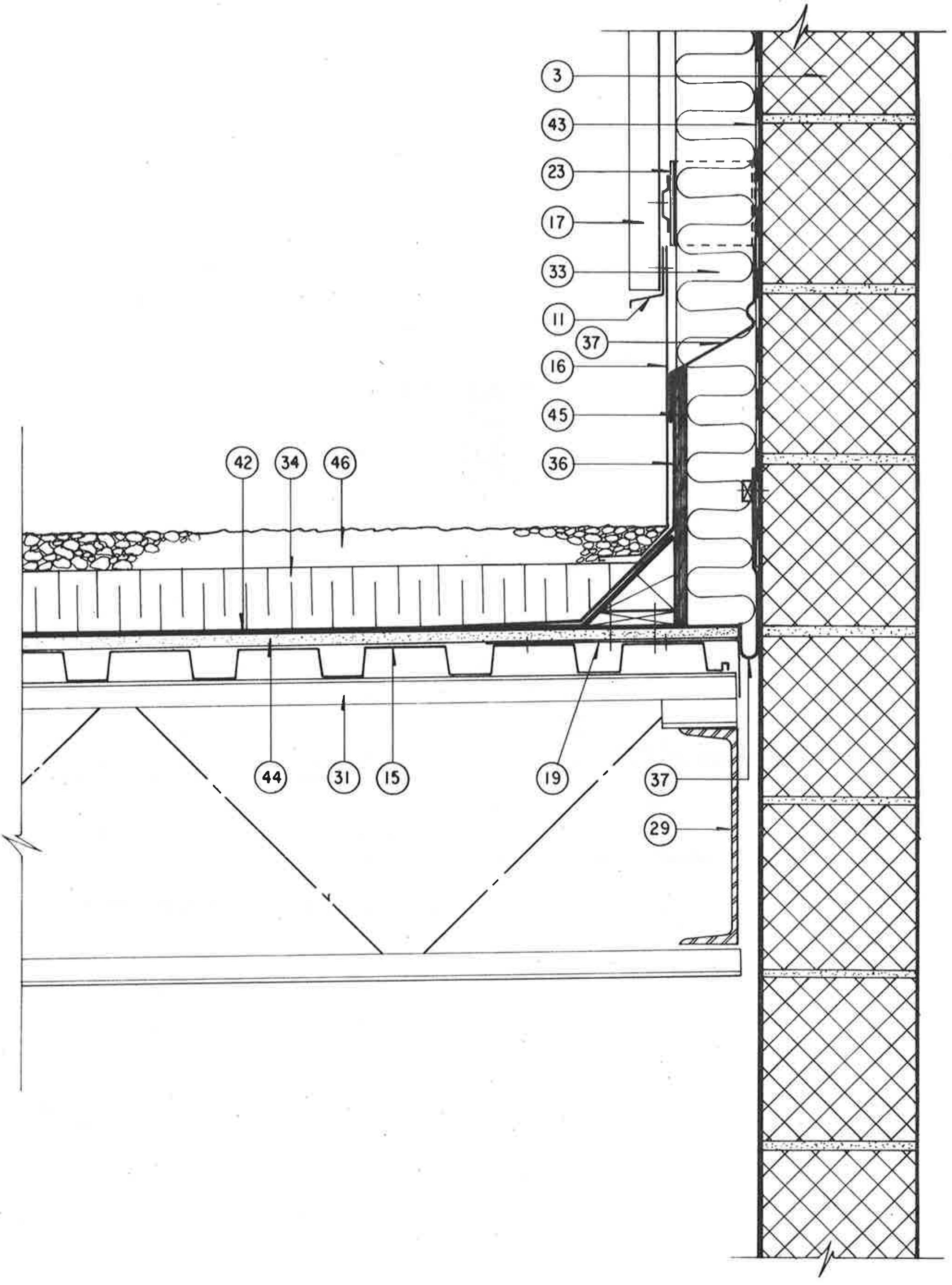

FIGURE 25

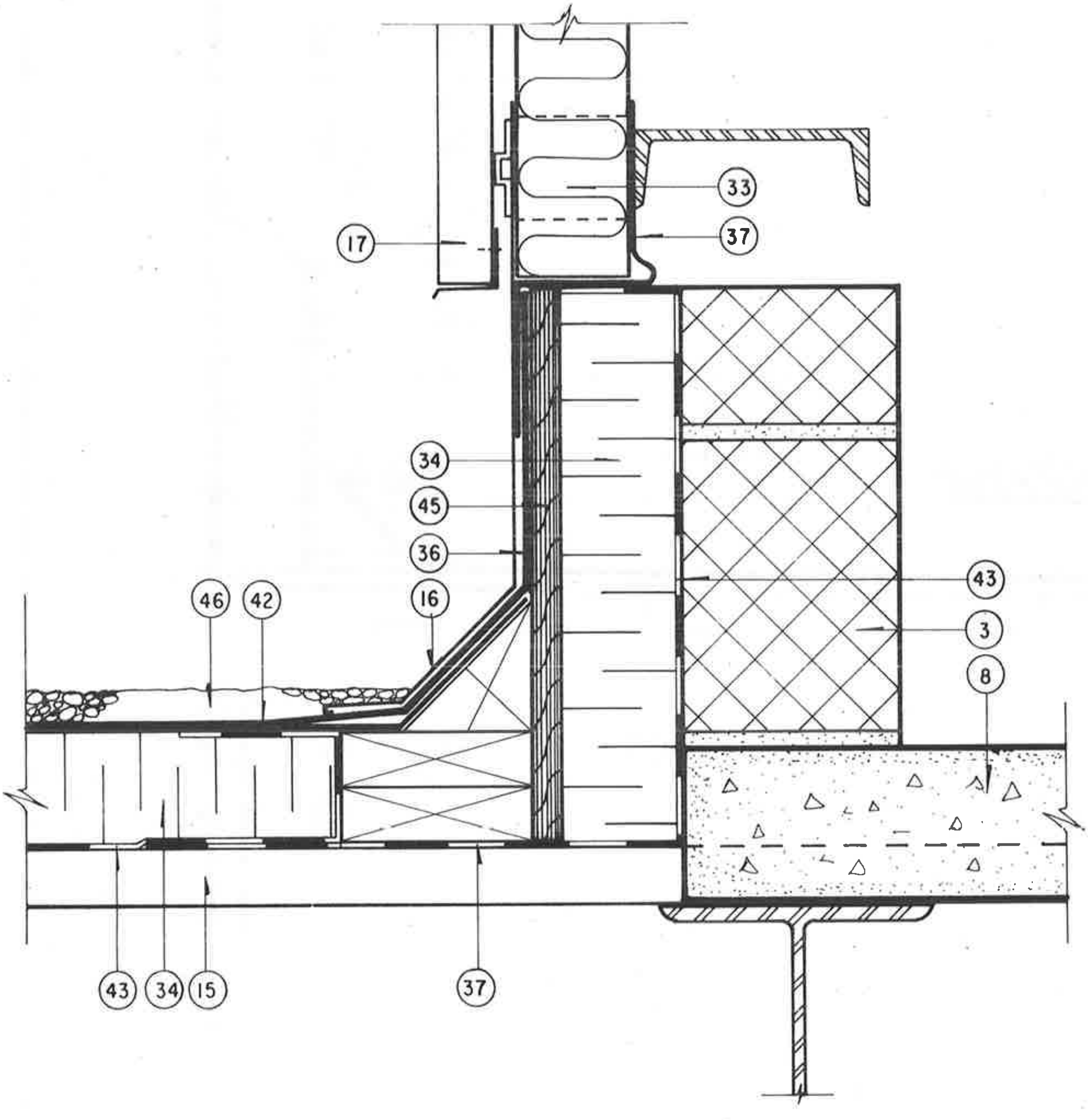

FIGURE 26

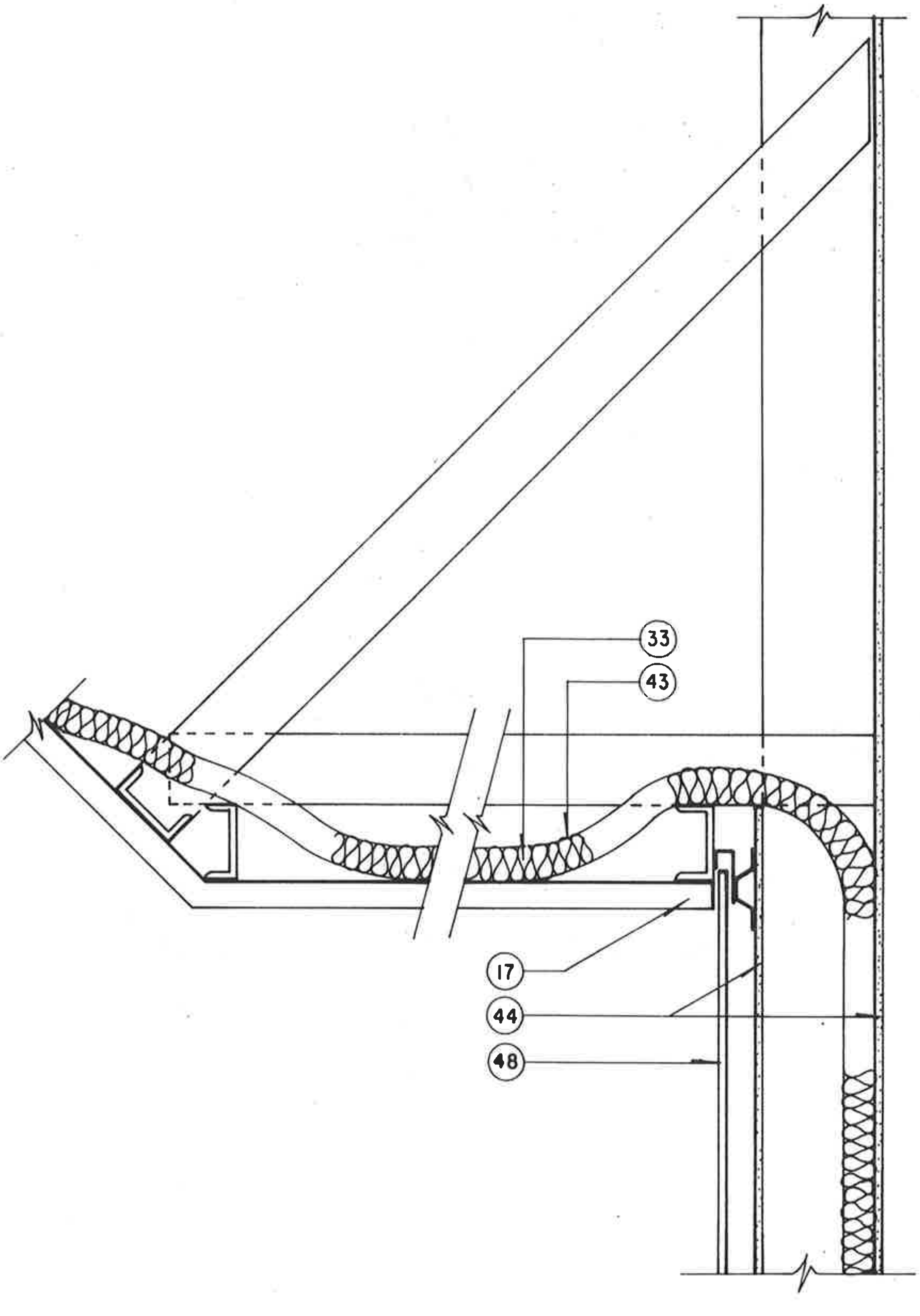

FIGURE 27

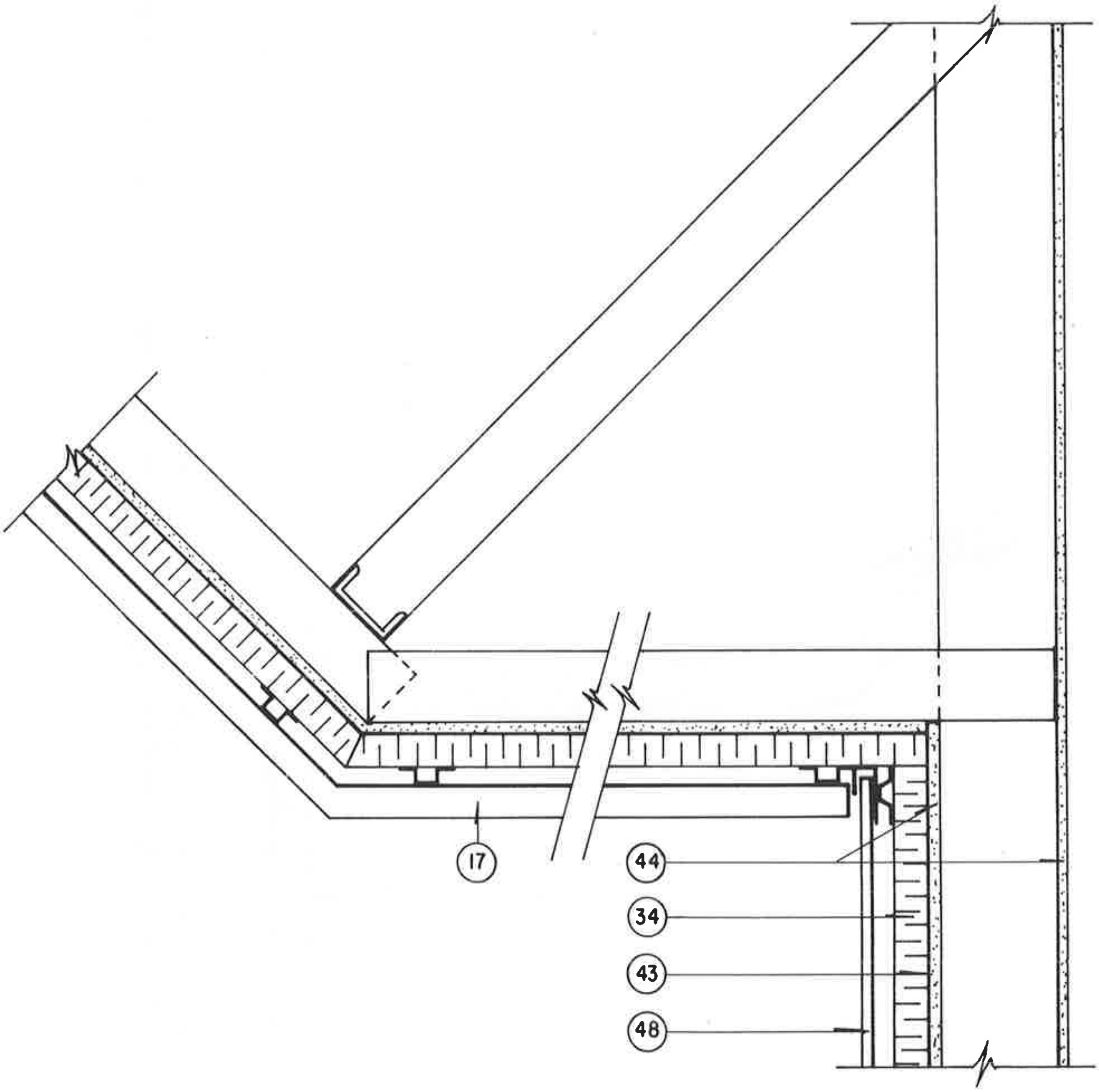

FIGURE 28