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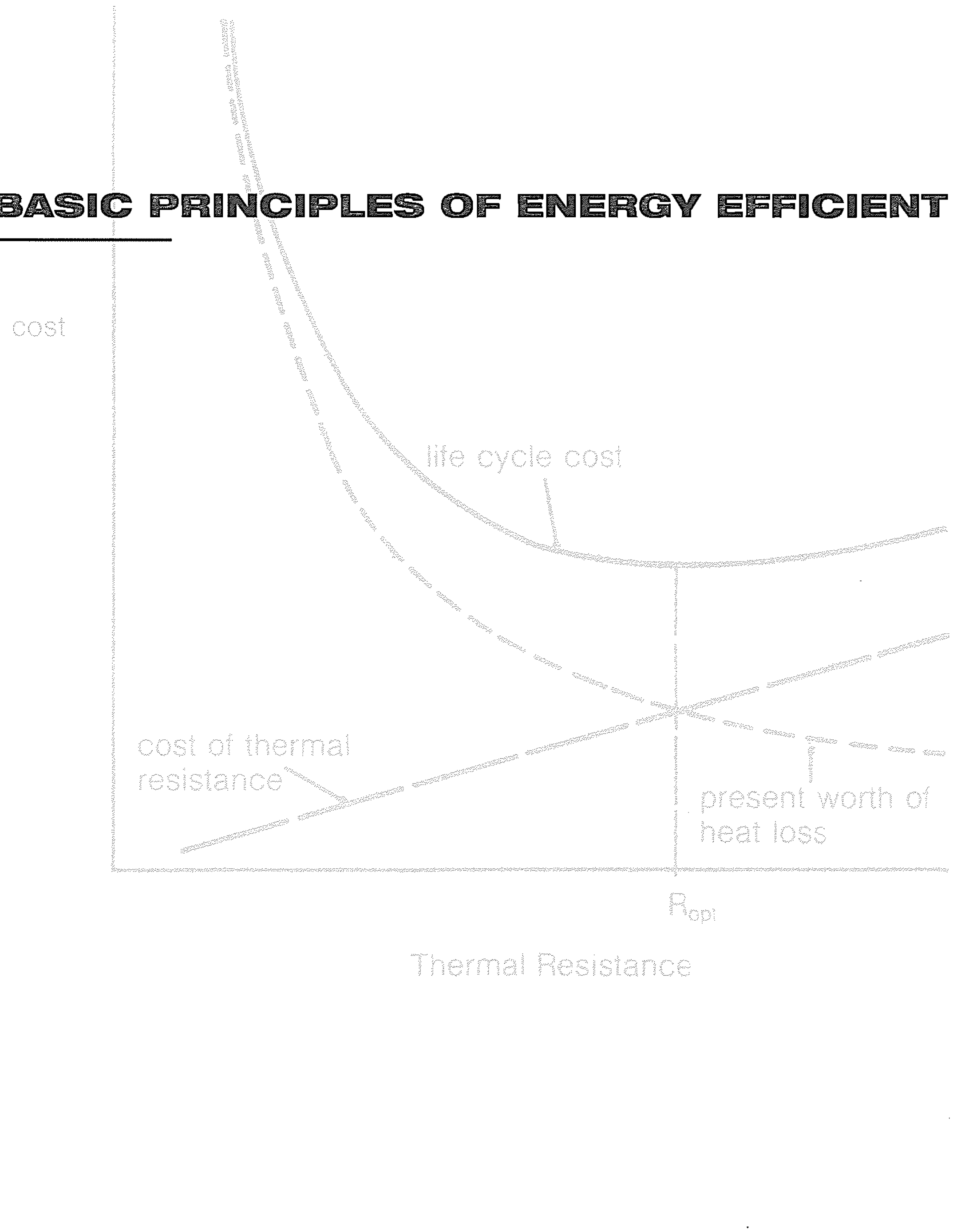

BASIC PRINCIPLES OF ENERGY EFFICIENT WALLS

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1. INTRODUCTION

The purpose of a building is to house some form of human activity and to provide protection from the weather. The building should be designed to meet the basic requirements of form, function, aesthetics, safety, durability and economy. These requirements are, of course, interrelated and frequently governed by the need to meet budget.

Form, function and aesthetics establish what the building will look like and how effectively and comfortably the users can function in their activities. Safety and durability ensure the security of users and how long they can expect that security to last. Satisfying those constraints can be expensive, which is why economics are important and where design skills come into play.

Key aspects of economy are the initial construction cost, the cost of operating the building, and the cost of maintenance. Much of these costs relate to the nature of the outer portion of the building (roof, exterior walls, windows and doors), referred to as the building envelope, which provides the main protection from the weather. For example, if an inappropriate exterior wall system is selected for a building, or if the wall is poorly detailed and constructed, there could be considerable cost associated with heat loss on an ongoing basis. Furthermore, moisture can accumulate in the wall, causing damage and requiring expensive repair. Frequently, a wall system that has been poorly selected or poorly built has to be replaced; usually at much greater cost than choosing the correct wall in the first place.

Rising energy cost requires that buildings be better insulated than in the past, but this in turn leads to other problems associated with moisture. This moisture can originate from inside the building, migrating out through the wall assembly, or it can travel from the outside inwards. To save energy loss requires insulation, and preventing moisture movement in the wall requires a vapour barrier and an air barrier.

In the last decade many very serious building envelope failures have taken place in Canada. These failures were largely the result of a building boom of condominiums in the previous decade when the implications of increased insulation levels were largely unknown, and designs and detailing were carried out with an insufficient appreciation of building science; and the construction was poorly done and inadequately inspected.

Designing for an effective exterior wall system that prevents excessive energy loss and damaging moisture accumulation requires a knowledge of building science.

This document introduces the principles of building science; applies those principles to wall system design, and describes a number of details that function efficiently in buildings. Some of the discussion goes beyond that directly required for wall design, but is included for a better understanding of the process.

2. BUILDING SCIENCE

2.1 Introduction

Building science is a relatively new term applied to the physics of heat flow, air flow and moisture vapour flow in the building and through the building envelope. The science is also applied in determining the energy requirements of a building. Proper application of this science can minimize operation costs, building damage and maintenance costs.

The purpose of this section is to provide an introduction to Building Science, and the application of its principles to the design, assessment and prediction of the performance of building envelopes.

To understand the movement of heat, air and moisture through the building envelope it is necessary to consider the following factors:

1. Moisture content of air
2. The outdoor and indoor environments
3. Temperature gradient in the exterior walls
4. Vapour pressure gradient in the exterior walls
5. Thermal bridging and placement of insulation
6. Air leakage
7. The effect of wind
8. Stack effect in buildings
9. Condensation in the building envelope
10. Expansion and contraction
11. Rain and moisture penetration
12. Operation of mechanical equipment

2.2 Moisture Content of Air

The amount of water that can be held in the air as water vapour depends on air temperature, the warmer the air the more moisture it can hold. When the air cannot hold any more moisture it is said to be saturated, and its relative humidity is defined as 100%, or 100% rh. If the same air is heated, its relative humidity drops, although it still contains the same weight of moisture. If, on the other hand, the saturated air is cooled, then the moisture in the air starts to condense out, and it forms as a water deposit on a cooler surface – such as a window or inside the insulation. The temperature at which moist air reaches saturation (100% rh) is referred to as the dew point.

The temperature at which moist air reaches 100% rh depends on its actual moisture content, and some of the relationships governing the properties of moist air are rather complex. However, the properties of moist air may be determined by graphical means using the Psychrometric Chart. Figure 2.1 is a psychrometric chart for the properties of moist air at sea level, and Figure 2.2 is merely an enlargement of the lower temperature portion of Figure 2.1. Figure 2.3 is a simplified version of Figure 2.1.

2.2.1 The Psychrometric Chart

Total atmospheric pressure consists mostly of air pressure, but also of vapour pressure. Differences in air pressure move the air around, while differences in vapour pressure move moisture. Movement is, of course, from higher to lower pressure.

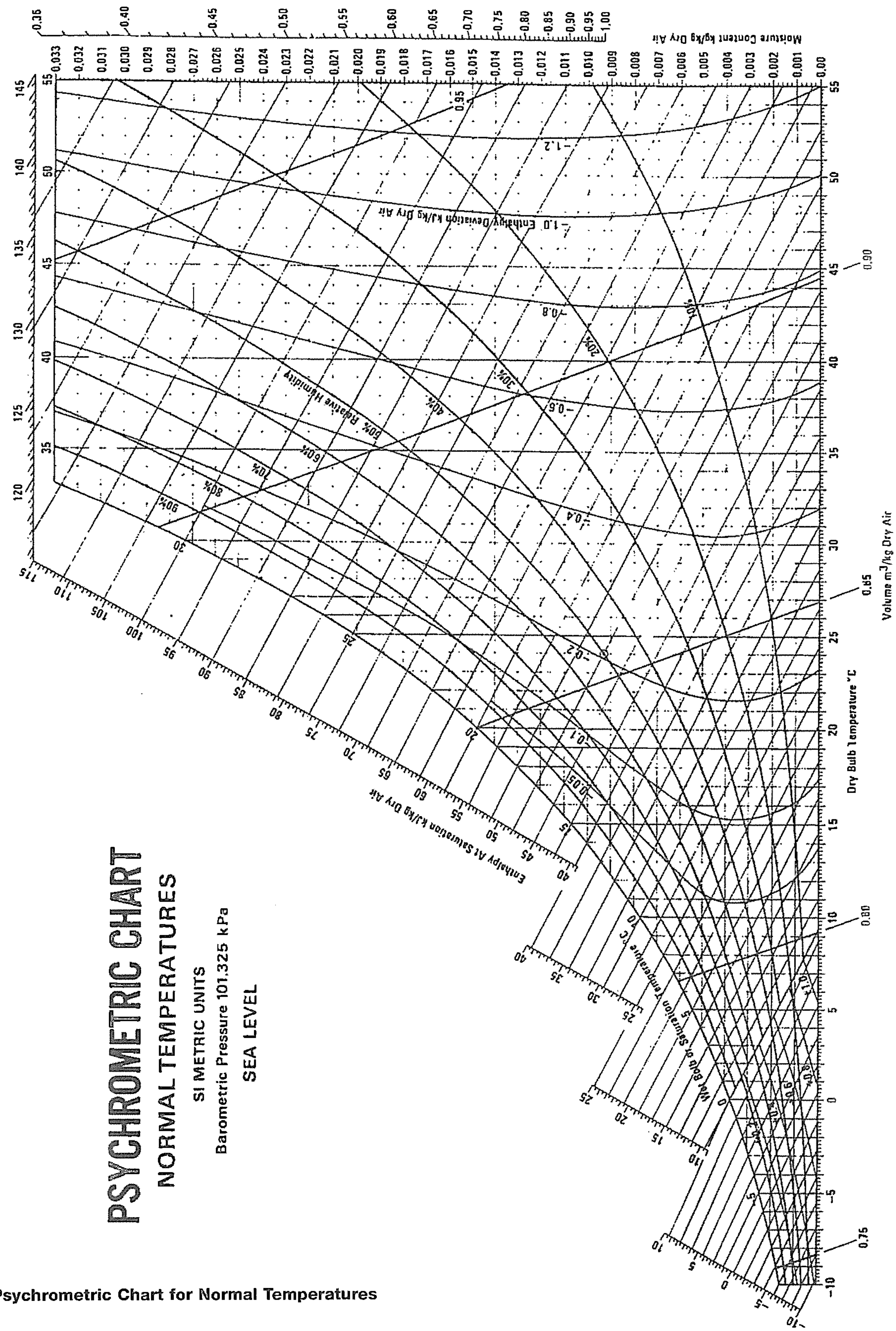


Figure 2.1 Psychrometric Chart for Normal Temperatures

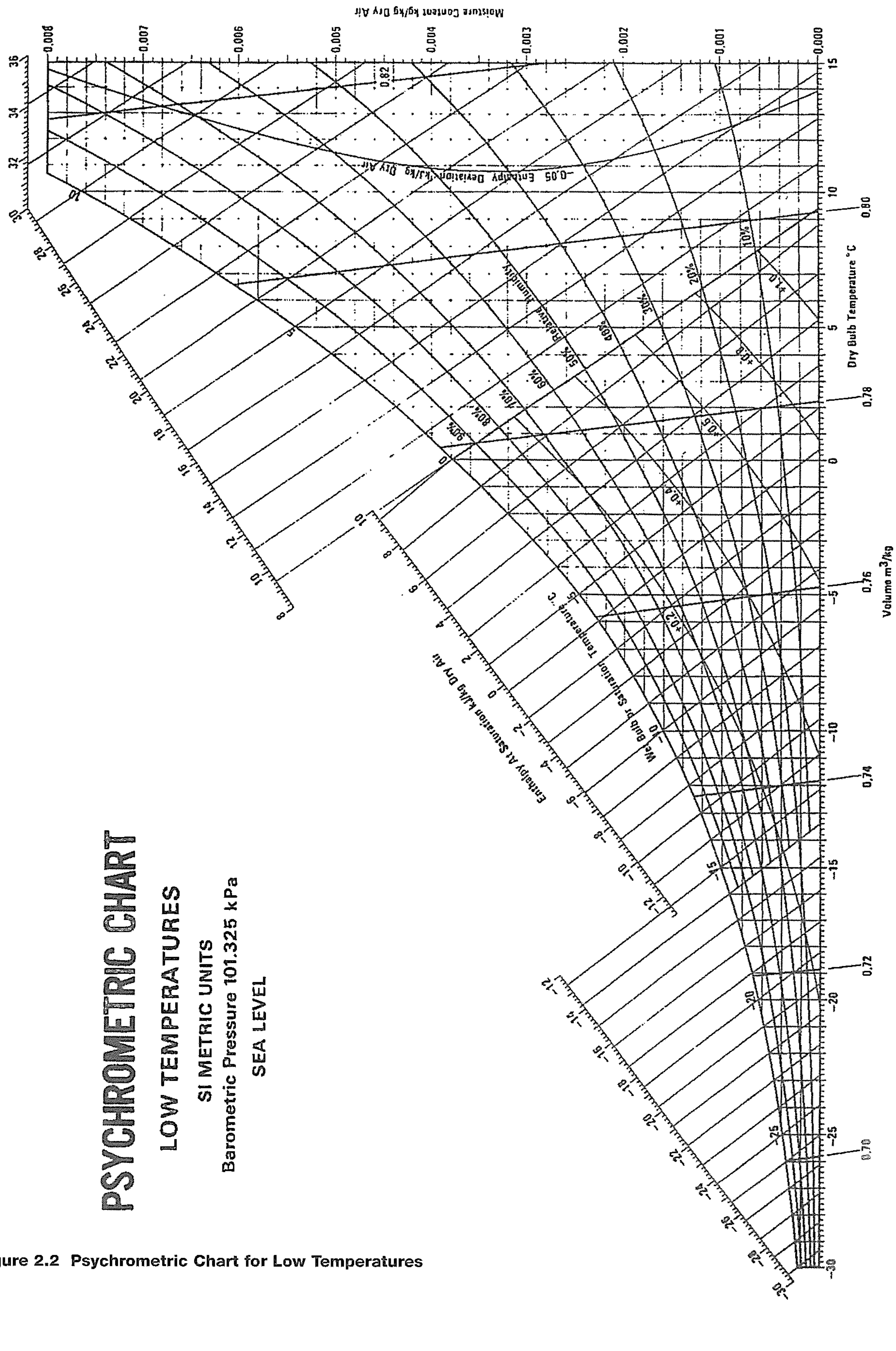


Figure 2.2 Psychrometric Chart for Low Temperatures

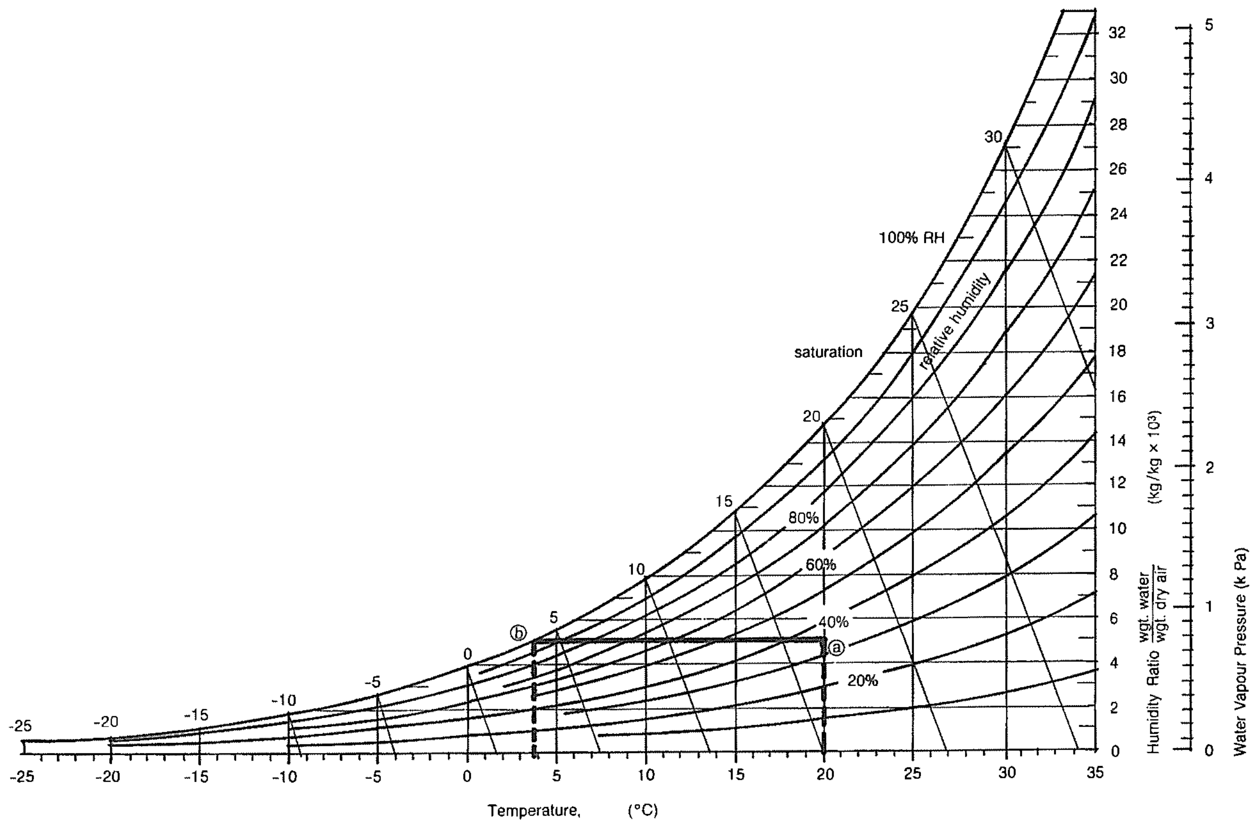


Figure 2.3 Simplified Psychrometric Chart

The water vapour pressure is related to the moisture content of the air by the expression:

$P_W = (W.\ P_T)/(0.622 + W)$

Where P_W = water vapour pressure, kPa

W = moisture content, kg of moisture per kg of dry air

P_T = total atmospheric pressure, kPa (101.3 kPa at sea level)

The psychrometric chart has a horizontal scale of air temperature in degrees Celsius (°C) and a vertical scale of the moisture content of the air in kg/kg of dry air. There are intermediate curved lines showing relative humidity, with 10% rh being the lowest curved line shown (0% rh being the horizontal axis), and the top curved line being saturation at 100% rh. Other lines shown relate to enthalpy and heat requirements, which is not discussed in this document.

Referring to Figure 2.3, if the air temperature (shown as dry bulb temperature) is 20°C and the moisture content of the air is 0.005 kg/kg, then projecting vertically from 20 and horizontally from 0.005 (5.0 = 0.005 x 103), these projections intersect at a relative humidity of 35%, and projecting horizontally to the left to the top curve (100% rh) the saturation temperature is seen to be about 4°C. This means that air with a relative humidity of 35% at 20°C will reach its dew point (saturation or 100% rh) when the temperature drops to 4°C. This clearly is of importance if moist air is leaking out of the warm interior of a building to a colder exterior: when the temperature of the air reaches its dew point, moisture in the air condenses out and is deposited in the wall, and moisture accumulation can lead to serious deterioration. Another point illustrated here is that if the 35% rh air at 20°C is cooled below 4°C at a window surface, for example, the window will start to fog up with condensation, and if the window surface were below freezing temperature the condensate would form as frost.

While differences of air pressure cause air movement (unless a barrier is present) so also do differences in vapour pressure tend to cause moisture movement. For example, the vapour pressure of air with a moisture content of 0.0040 kg/kg at a barometric pressure of 101.3 kPa can be calculated from the equation given earlier as:

$$P_W = (W.\ P_T)/(0.622 + W)$$
$$= (0.0040 \times 101.3)/(0.622 + 0.0040) = 0.4052/0.626 = 0.6473 \text{ kPa}$$

This is the vapour pressure of air with 20% rh at 25°C and also of the same air saturated at 1°C. It also illustrates that vapour pressures are a very small percentage of the total barometric pressure.

Referring to the psychrometric chart, the term "dry bulb temperature" refers to the air temperature determined in the normal manner. The term "wet bulb temperature" refers to a wetted thermometer which is swung around in the air and cooled by the surrounding air, the drier the air the greater the evaporation and therefore the cooling also. The temperature levels off at the saturation temperature for that particular moisture content.

The psychrometric chart has many applications in building science. For example, mechanical engineers refer to it for resolving heating, ventilation and cooling issues, humidification, dehumidification and air mixing, and condensation control. However, its main use in understanding the design of exterior walls is in determining the dew point of air at various levels of relative humidity.

2.3 The Outdoor and Indoor Environments

A building should be designed to provide a comfortable indoor environment for the users, comfort normally being associated with temperature, but relative humidity is also an important factor. Since the interior will be kept at a reasonably constant temperature, the outdoor climate will be variable with changes in wind, rain and temperature, and the building enclosure is required to be weather proof. That is, it is required to provide protection against differences between the indoor and outdoor environments.

2.3.1 Outdoor Air Conditions

The outdoor environment is normally described according to the prevailing weather, but primarily by air temperature, then by precipitation (rain or snow), and then wind. Relative humidity is an important factor that is rarely mentioned.

Outdoor air temperature is highly variable, changing hourly, from night to day, and seasonally. Factors that affect the performance of building envelopes include the variation in the daily high, daily low and daily average. If these temperatures were recorded over a number of years and the mean calculated and shown graphically, Figure 2.4 represents how those temperatures might vary in one location over a year.

Heating systems are designed to provide at least the heat loss from a building over the coldest month (January in the Northern hemisphere), and heat loss depends on the insulation provided and on air exchange by leakage through the building envelope. The interior temperature is normally somewhere between 19°C and 25°C and the design temperature normally relates to the coldest temperature recorded for the coldest month.

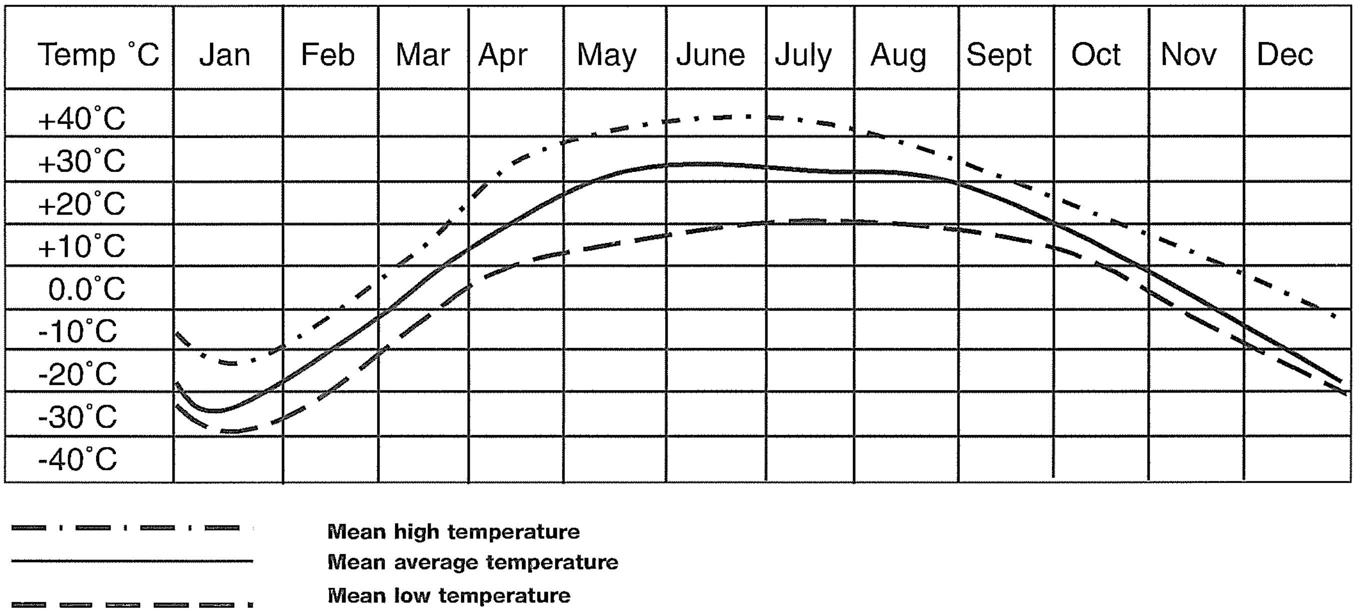


Figure 2.4 Typical Average Temperature Variation

Once the design temperature has been established, then heating requirements for the building can be based on a percentage of the design temperature, that is, the percentage of time during the coldest month that the outdoor temperature falls below the design temperature. For example, a 10% winter design temperature means that for 10% of the month (10% of 31 x 24 = 74.4 hours) outdoor temperatures will fall below the design temperature.

Another useful concept in evaluating heating requirements is the degree day. A degree day refers to the average outdoor temperature being one degree below the required indoor temperature for one day (24 hours). A summation of the degree days when the temperature falls below the indoor temperature, over the year, is useful in calculating annual fuel costs. There are other factors affecting heat loss and fuel costs, such as sunshine and solar radiation and their affect on wall temperature and at windows, but they are beyond the scope of the present discussion.

2.3.2 Indoor Air Conditions

What constitutes suitably comfortable indoor conditions depends on usage. For example, a refrigerated storage warehouse has, of course, temperature requirements that differ from those of a residential building. Also, because of different clothing worn in summer and winter, there may be seasonal comfort conditions that differ from each other, and one person may have a different definition of comfort from another.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) have studied the concept of comfort conditions and have recommended that comfortable indoor conditions for people lie within a "comfort envelope" defined on the psychrometric chart as lying between the points:

Winter: 19.5°C and 23.0°C at 16.7°C dew point, and
20.2°C and 24.6°C at 1.7°C dew point
Summer 22.6°C and 26.0°C at 16.7°C dew point, and
23.3°C and 27.2°C at 1.7°C dew point

These points, then, form the boundary of comfort for most people.

When cold air from the outside is brought into a building and heated, its relative humidity changes even though it still contains the same amount of moisture. The psychrometric chart illustrates clearly for a given quantity of moisture in the air, the relative humidity changes with temperature.

However, this does not mean that the interior of a building is drier than outside. The occupants of a building add to the relative humidity through perspiration, respiration, and general activities such as showering, cooking, and washing and drying clothes.

Recent studies show that the respiration of a family of four adds about 0.2 kg/h of moisture to the indoor air, a figure that can double once cooking and washing is considered. Without some degree of air exchange the indoor air can become very humid. This, of course can lead to problems in a wall system that leaks air.

2.4 Temperature Gradient in Exterior Walls

The purpose of an exterior wall is to protect the occupants from the weather. This means that the wall should shed driving rain, and it should prevent excessive heat loss, either by conduction through the insulation, or by air and moisture leakage. The main components then are a rainproof exterior skin, sufficient insulation and a vapour barrier, and the amount of insulation required will depend on the temperature difference between the interior and the exterior, more insulation being required in colder climates.

The temperature distribution within the building envelope/exterior wall will be somewhere between the outdoor and indoor temperatures, and the distribution of temperature, referred to as the temperature gradient will depend on the arrangement and thermal characteristics of the individual components and materials.

The basic equation governing the rate of heat flow through one square metre of the wall under steady-state conditions is

$q = 1/R_t \times (t_i - t_o)$

where q = rate of heat flow W

R_t = total thermal resistance of the wall $m^2 \times °C/W$

t_i = indoor air temperature °C

t_o = outdoor air temperature °C

Because the heat flows in series through the components of the wall, each component will be subject to the same rate of heat flow. That is, for each component the equation is:

$q = 1/R \times (t_1 - t_2)$

where R = total thermal resistance of the component $m^2 \times °C/W$

t_1 = temperature °C on the warm side of the component

t_2 = temperature °C on the cold side of the component

Since the heat flow is the same in both cases

$1/R \times (t_1 - t_2) = 1/R_t \times (t_i - t_o)$

and $(t_1 - t_2) = R/R_t \times (t_i - t_o)$

This means that for a given indoor/outdoor temperature difference, the temperature difference across each component is directly proportional to its thermal resistance compared to that of the whole wall.

Thus for a series of components, 1 to n, the total thermal resistance can be expressed as:

$R_t = R_1 + R_2 + \text{--------} + R_n$

The thermal resistance, R , of a component is related to its thermal conductivity and thermal conductance by the expression:

$R = l/k$ or l/C ($m^2 \times {}^\circ C/W$)

Where l = layer thickness m

k = thermal conductivity $W/(m \times {}^\circ C)$

C = thermal conductance of the component $W/(m \times {}^\circ C)$

Thermal conductivities k are reported per metre thickness of materials and thermal conductance C are reported for components of a specific thickness. These values are available from handbooks for generic products and from manufacturers' manuals for proprietary products.

From a knowledge of the thermal properties of a wall assembly and the difference between indoor and outdoor temperatures, the temperature distribution within a wall can be calculated and the thermal gradient plotted. This is illustrated in Example 2.1.

Example 2.1

The wall assembly shown in Figure 2.5 consists of an outer 100 mm face brick, 25 mm air space, 75 mm polystyrene insulation, 100 mm concrete block and 13 mm gypsum board. Given the following material properties, and if the outdoor and indoor temperatures are -25°C and +20°C respectively, calculate and plot the temperature gradient through the wall.

Data: *Resistance R (m^2. °C/W)*

outside air layer = 0.030

90 mm brick = 0.074

25 mm air space =0.171

75 mm insulation = 2.603

13 mm gypsum board = 0.081

inside air layer = 0.030

Solution

It is interesting to note that there is a thin layer (about 12 mm) of air close to the inside and outside surfaces of the wall that is almost stationary and that also contributes to insulating the wall. The outside layer is thinner. The effect is small, but can be included in the analysis, with some approximation. Note that a air/vapour barrier is normally placed on the warm side of the insulation (on the outside of the block). This will normally be a torch-on membrane, liquid applied membrane or a peel-and-stick membrane that can be assumed to have no insulating value.

The solution is summarized in the following table, where the third column R is the resistance (reciprocal of the conductance), and the fourth column is obtained as $R/\sum R(t_i - t_o)$, the temperature difference in one component.

Component	Resistance R ($m^2 \cdot °C/W$)	$R/\sum R$	Temperature Difference °C	Temperature °C
				- 25
Outside air layer	0.030	0.009	0.4	- 24.6
Face brick	0.074	0.023	1.0	- 23.6
Air space	0.171	0.053	2.4	- 21.2
Insulation	2.603	0.812	36.5	+15.3
Concrete block	0.125	0.039	1.8	+17.1
Plasterboard	0.081	0.025	1.2	+18.3
Inside air layer	0.120	0.037	1.7	+20
	$\sum R = 3.204$			

Figure 2.5 shows a cross section of the wall, and Figure 2.6 a plot of the temperature gradient.

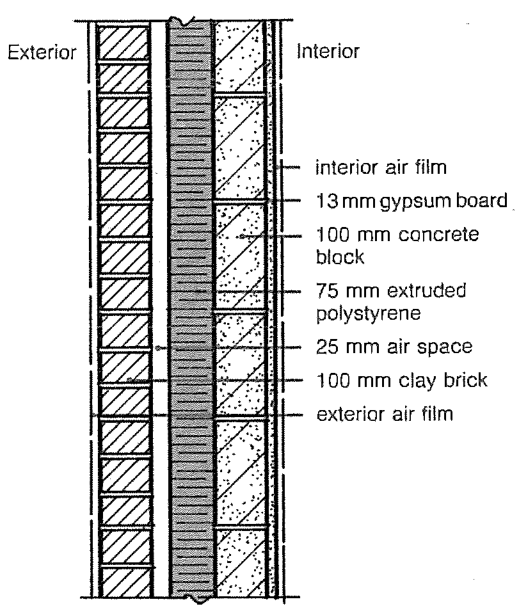


Figure 2.5 Wall Assembly

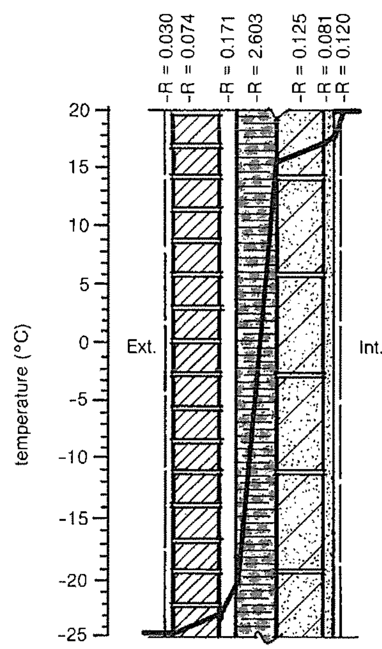


Figure 2.6 Thermal Gradient

Figure 2.7 shows the temperature profiles across masonry cavity walls with various levels of insulation – from A uninsulated through to E with 100 mm of extruded polystyrene. This figure and Figure 2.8 illustrate the very little difference in heat loss between 75 mm and 100 mm of insulation, and the question of how much insulation is right arises. The question of optimising cost will be covered in a later section.

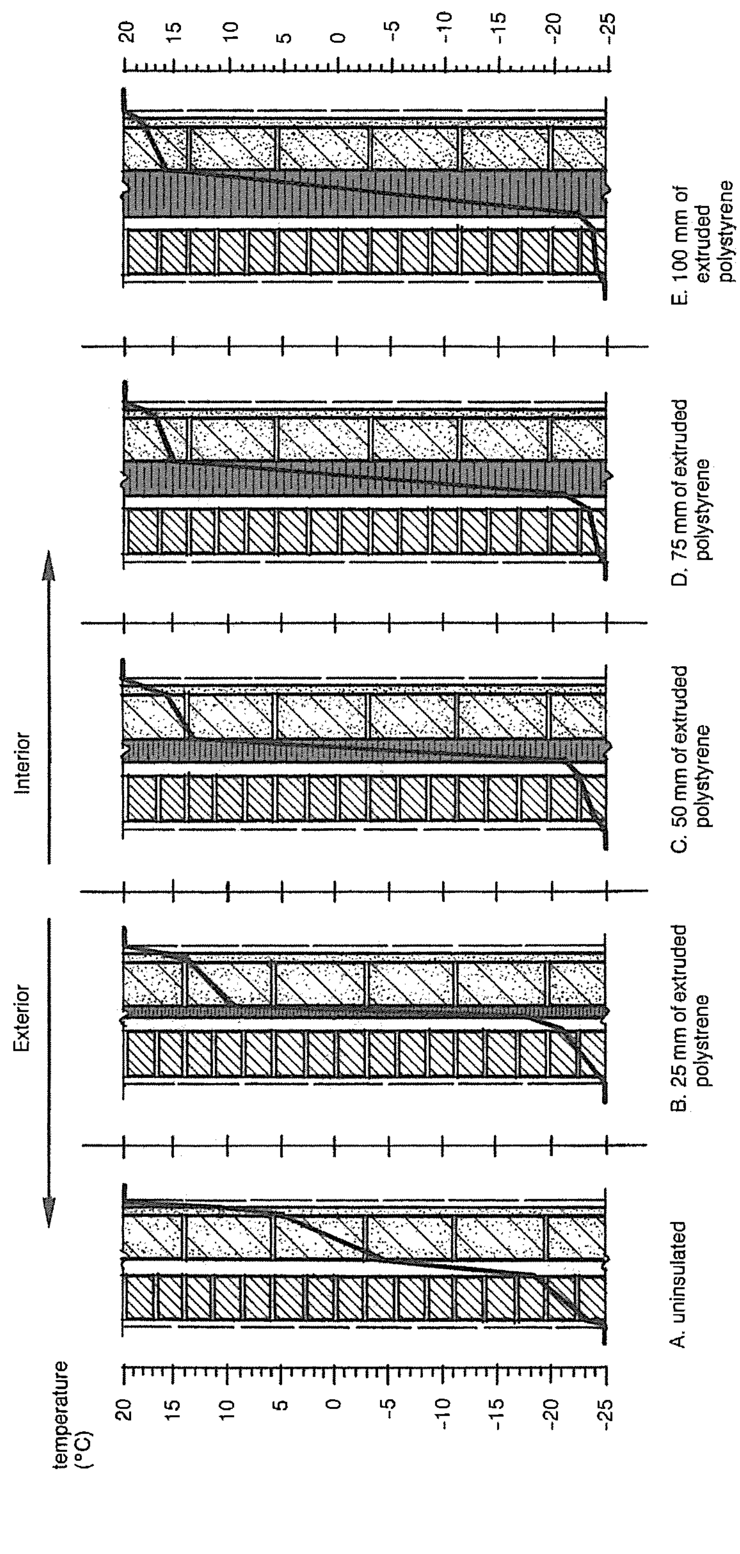


Figure 2.7 Temperature Profiles on a Cold Day for Various Levels of Insulation

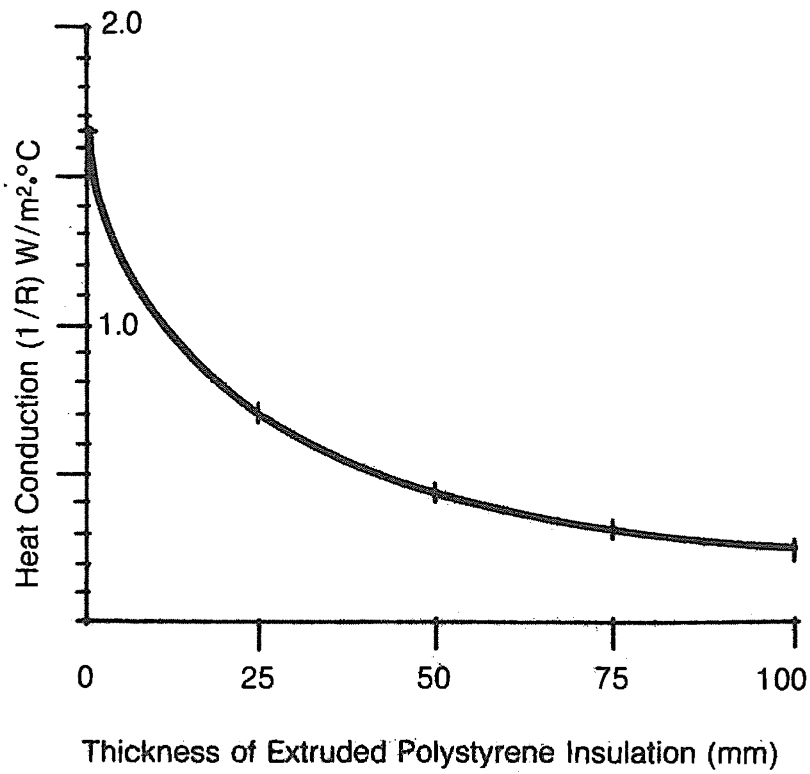


Figure 2.8 Schematic Depiction of Heat Loss for Varying Insulation

2.5 Vapour Pressure Gradient in Exterior Walls

While the most important factor in an exterior wall assembly is providing enough insulation to prevent significant energy loss, the diffusion of moisture through the wall should be minimized. If water vapour is allowed to diffuse through the wall, then on the colder side of the dew point, where the air reaches saturation, condensation takes place and moisture is deposited in the wall. Frequently this point is within the insulation and, since the interior of the wall is not normally well ventilated, serious deterioration of the wall can occur.

The movement of moisture through a wall depends on the difference of vapour pressure from inside to outside, the higher vapour pressure normally being inside the building. Moisture movement can also result from air leakage through the wall. This movement is normally controlled through the use of a vapour barrier - usually polyethylene film.

The majority of components in a wall have some degree of permeance; that is, they allow some moisture vapour to diffuse through. The most impermeable of the components is usually the vapour barrier – a component that allows very little moisture to pass. Permeance is normally expressed as a permeance coefficient W ng/(m^2 x s x Pa) - ng being nanograms - and resistance to the diffusion of moisture is given as its reciprocal, $1/W$. Representative values of the permeance coefficients and resistances to vapour for some building materials are as follows.

Material	Permeance coeff.icient ng/(m² x s x Pa)	Resistance to vapour (m² x s x Pa)/ng
Brick veneer	46	0.0220
Sheathing paper	475	0.0021
Sheathing	3000	0.0003
Insulation	2000	0.0005
Vapour barrier	15	0.0667
Gypsum board	3000	0.0003
		Total Resistance 0.0919

In this example the vapour barrier represents 73% of the resistance to vapour transmission.

Note that since the materials are in series, moisture loss, like heat loss, takes place through all components and the total resistance is the sum of the individual resistances.

If outside air is drawn into the enclosure, the relative humidity drops to a lower value and, if that were the only source of air, the exterior vapour pressure would be greater than the interior vapour pressure. However, use and occupancy adds considerably to the interior moisture and the interior vapour pressure is normally higher, with the tendency for the interior vapour to diffuse out. Without a vapour barrier, the diffusion will be considerable, with moisture condensing on the cooler side of the dew point. Even with a vapour barrier, some diffusion will take place and moisture will still condense on the cooler side of the dew point. However, in this instance the amount of moisture condensing out will be very small, with a better chance of evaporating away. In such instances, wall deterioration from accumulated condensation is unlikely.

An air/vapour barrier performs two functions – namely that of reducing air leakage, and also that of reducing moisture diffusion through the barrier. If, for example, a high quality vapour barrier is used, thereby preventing moisture diffusion, but it has not been properly sealed, air leakage can cause moisture accumulation in the wall assembly. Generally speaking, air leakage is more critical than vapour diffusion, and since vapour diffusion is proportional to surface area, coverage is not as critical with a vapour barrier. An air barrier on the other hand must be continuous and well sealed to be effective. Polyethylene unless fully structurally supported on both sides (sandwiched) should not be encouraged as an air/vapour barrier. Much better options are torch-on membranes, liquid applied membranes or peel and stick membranes applied to the structural substrate or, if insulated on the inside, the use of drywall as a rigid air barrier.

Whenever an air/vapour barrier is interrupted, such as at an electrical fixture set into the wall, at such locations the opening in the vapour barrier should be sealed around the interruption, otherwise there will be a serious leakage of moisture vapour into the insulation, with subsequent condensation and deterioration.

The vapour barrier is available in standard widths, and should be lapped at the joint with the next width. Building codes specify the width and method of lap required to prevent excessive diffusion of moisture.

2.6 Thermal Bridging and Placement of Insulation

Where possible a wall should be properly insulated to prevent significant heat loss. Ideally, the structural components will lie inside the insulation - in other words, the insulation should be placed outside the supporting structure. This is the wall arrangement shown in Figure 2.5.

On the other hand, where the insulation is placed inside the wall, and therefore inside the structure, as shown in Figure 2.9, the overall resistance to heat loss across the wall is unchanged, but thermal bridges will occur where the inside structure has to project through the insulation for support on the structure outside the insulation.

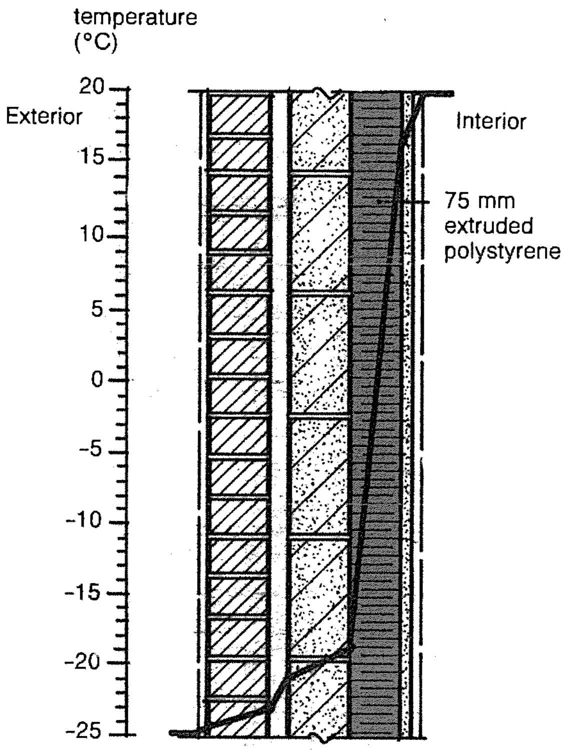


Figure 2.9 Insulation on Interior

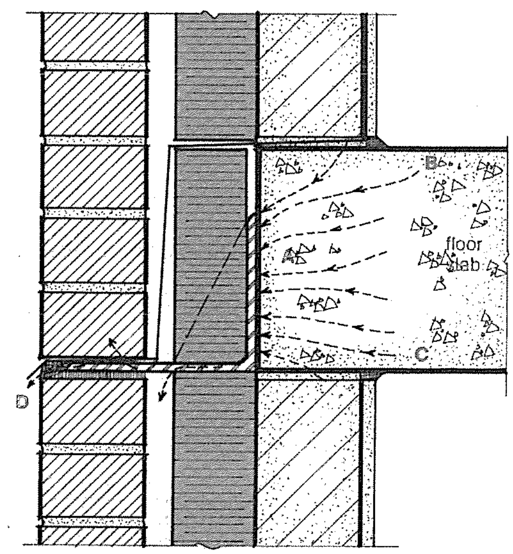


Figure 2.10 Unavoidable Thermal Bridge

There may be instances where some thermal bridging is unavoidable, such as that shown in Figure 2.10 where a steel angle to support a brick veneer is itself supported on the interior structure.

Where the thermal bridging is considerable, such as in the situation shown in Figure 2.11 where an extension of the interior floor extends through the insulation to form a balcony. In such cases, there is considerably energy loss and condensation can lead to the problems shown.

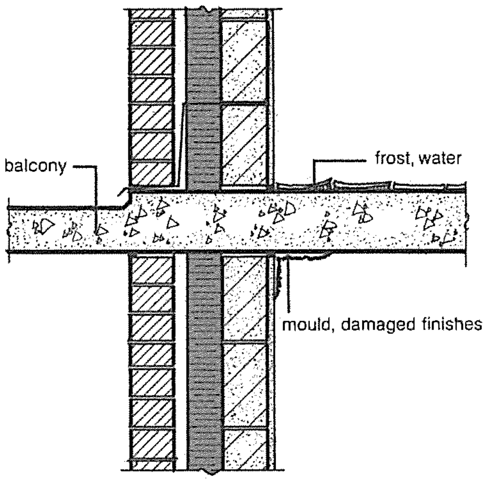


Figure 2.11 Effect of Thermal Bridge with High Indoor Relative Humidity

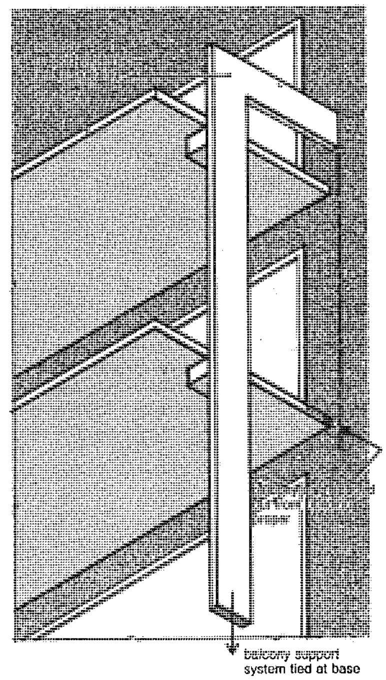


Figure 2.12 Balconies Supported Externally to Avoid Thermal Bridging

A better solution would be to have the balcony independently supported, as shown in Figure 2.12.

2.7 Air Leakage

There are two types of air movement through the building envelope:

Air Leakage – an uncontrolled exchange of air between indoor and outdoor through unplanned openings in the building envelope.

Ventilation – controlled exchange of air between indoor and outdoor through planned openings in the building envelope.

Some exchange of air is required in a building to control air quality, and the amount of air to be exchanged depends on the use of the building. Planned and controlled ventilation is preferable to air leakage, since air leakage can lead to condensation within the components of the building envelope. Figure 2.13 shows the result of air leakage and condensation. Figures 2.14 and 2.15 illustrate moisture and frost build-up that can occur as the result of moist air leakage outward.

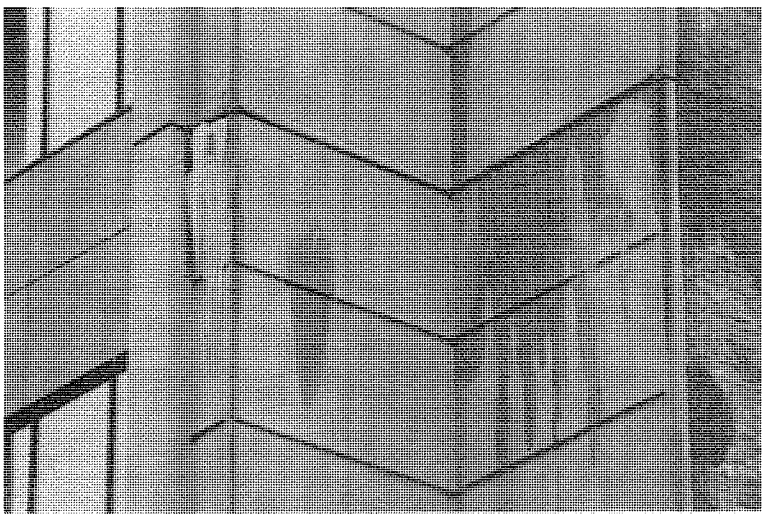


Figure 2.13 Exfiltration and Condensation

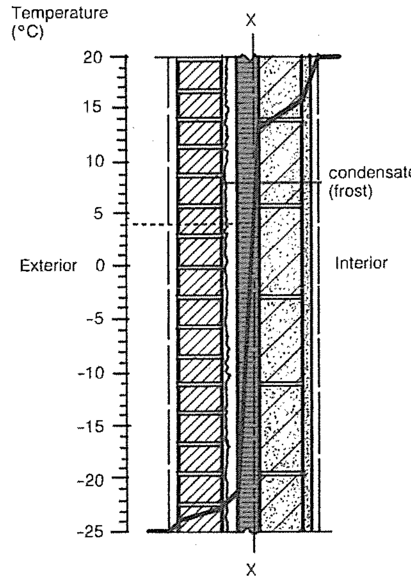


Figure 2.14 Condensation (frost) on Cold Side of Insulation

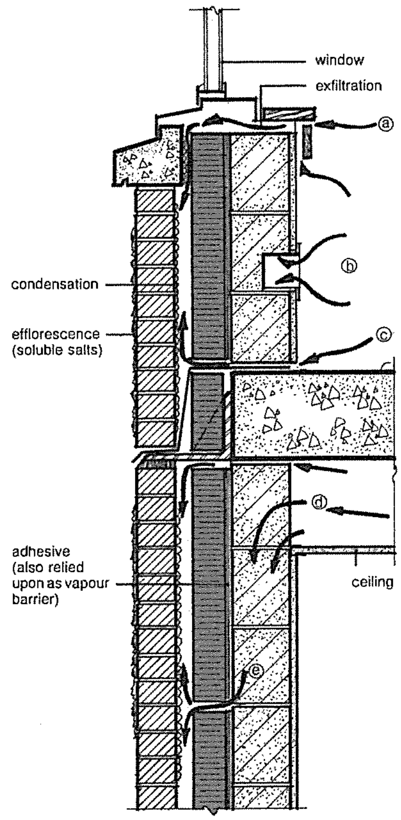


Figure 2.15 Exfiltration (air leakage) Paths

2.8 Effect of Wind

Wind creates positive pressure on the windward side of a building and negative pressure on the leeward side. There will also be negative pressures on the roof surfaces and on exterior walls parallel to the direction of the wind.

As a result, there will likely be a pressure difference between the interior and exterior of the building, and the pressure differences will likely cause any breaches in the vapour barrier to leak air.

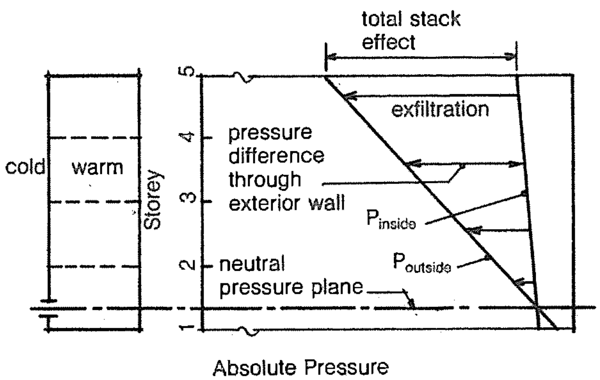
2.9 Stack Action

The forces that push (or tend to push) air through a building envelope are due to differences in pressure between the interior and the exterior. These are caused by "stack effect" (or stack action), operation or mechanical equipment and wind. While, generally, differential pressures from stack action are less than those due to wind, they act 24 hours a day, while the wind is intermittent.

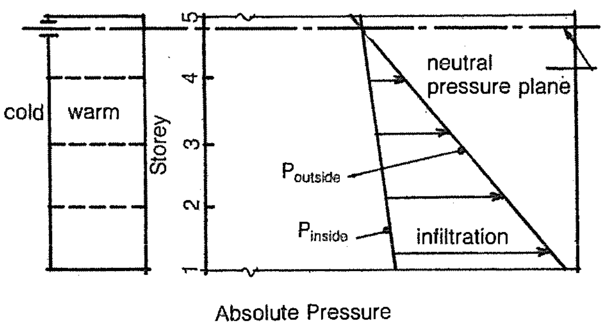
Stack action is due to the fact that in the winter cold outside air is heavier than warm outside air, and the heavier outside tends to enter the building at lower levels, pushing the warm air out at higher levels, and the effect is greater in taller buildings. A form of reverse stack effect can occur in air conditioned buildings in the summer where cooled indoor air leaks out of the base of the building and in turn is replaced by warm air leaking into the upper parts of the building. In a hot humid climate this can lead to moisture deposition inside the structure. Wind, on the other hand, tends to force air in on the windward side and draw air out on the leeward side.

The effect of stack action is explained diagrammatically in Figure 2.16.

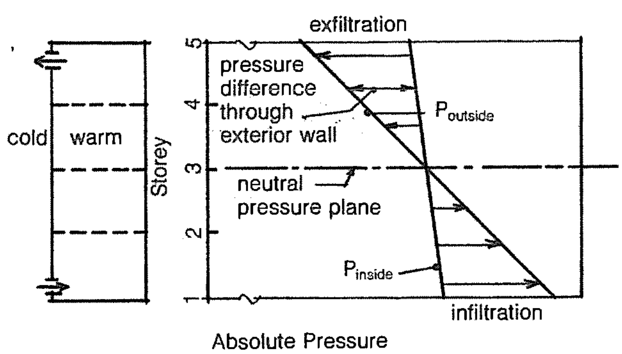
Figure 2.16 "Stack Effect" and Differential Air Pressures across a Building



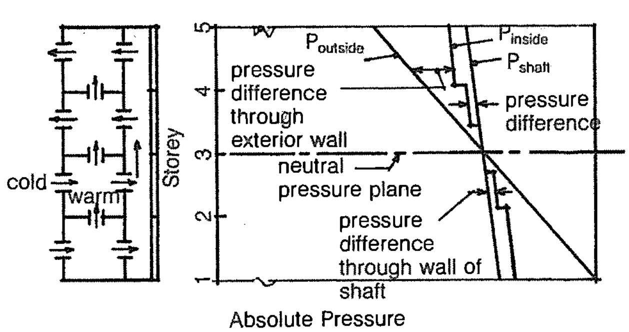
A. Air pressure inside and outside a heated building with openings at the bottom and no internal partitions



B. Air pressures inside and outside a heated building with openings at top and no internal partitions



C. Air pressures inside and outside a heated building with evenly distributed openings and no internal partitions



D. Air pressures inside and outside a building with evenly distributed openings and some internal restrictions to flow

Figure 2.16 A and B illustrate the simplified situation where openings exist only at the bottom or top of a building, respectively. The interior of the building will then be subject either to positive pressure (A) or negative pressure (B) throughout the entire height. Situation A leads to exfiltration, and B to infiltration.

When the openings in exterior walls are distributed fairly evenly throughout the height, pressure distribution will be approximately as shown in C, and there is a tendency toward exfiltration higher in the building, and infiltration at lower levels.

A, B, and C relate to a simplified situation where there are no interior partitions.

Where there are interior partitions, the more complicated situation illustrated in D can be expected.

Figure 2.17 shows the theoretical pressure differential across a building envelope due to stack action based on a 20°C interior temperature.

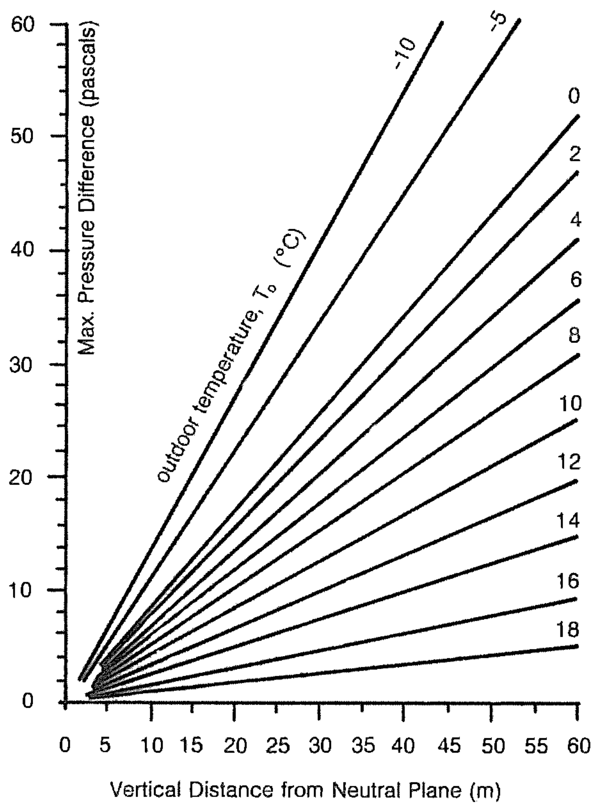


Figure 2.17 Pressure Differential due to Stack Action

2.10 Condensation in the Building Envelope

In the preceding sections it has been shown that moisture can accumulate in the building envelope from a variety of causes. Normally in winter it is due to moist air from the interior exfiltrating to the exterior due to a difference in air pressure across the exterior wall system. The difference in pressure is most likely due to wind, operation of mechanical equipment or stack effect, and in almost all instances the air leakage is unplanned or unavoidable. Moisture movement resulting from differences in vapour pressure is fairly minimal if the vapour barrier is of good quality and has been properly placed, and normally is not a concern.

Whether air infiltrates or exfiltrates depends on the pressure differential between the interior and exterior, and whether there are openings that allow for air movement; and whether there is condensation in the wall depends on whether the air is being cooled and reaches the dew point as it passes through the wall. Normally, in a cold climate, it is the warm moist air leakage from the interior to a cold exterior that causes condensation. In hot humid climates, the condensation is likely due to infiltrating air reaching its dew point somewhere in the wall assembly as well as vapour diffusion.

The main problems associated with condensation within the building envelope are:

a) Loss of effectiveness of the insulation when it becomes wet
b) Deterioration of materials in the wall assembly. For example, wood studs can begin to rot, or steel studs can start to rust.

To reduce uncontrolled air leakage that can lead to envelope deterioration a continuous air barrier must be incorporated in the building envelope. The air barrier is typically made of a series of building components and materials that are systematically sealed at all joints and penetrations throughout the exterior walls, floors and roof. The most airtight element in the building envelope – the air barrier must be able to resist the full wind load exerted on the building. In multi-storey buildings, this requires a rigid structurally supported air barrier. Air barriers often consist of a membrane that is well adhered to the concrete frame and masonry block infill and sealed to all window and door openings and mechanical and electrical penetrations. A rigid air barrier will also permit a rain screen cavity if correctly constructed to pressure equalize further resisting wind driven rain penetration.

To reduce or prevent deterioration of spaces susceptible to condensation and moisture accumulation, such as the air space between brick veneer and back-up wall, and in the stud space, drainage can be provided. Weep holes in the brick veneer should be provided for this purpose, and holes drilled at the base of stud walls will provide similar drainage.

In Canada, the Canada Mortgage and Housing Corporation (CMHC) has developed a computer program EMPTIED (Envelope Moisture Performance Through Infiltration Exfiltration and Diffusion) that analyses stack effect, condensation planes, moisture accumulation and other related effects, given statistical weather data for a particular climate.

2.11 Air / Vapour Barrier

To minimize the possibility of condensation in the exterior assembly, a component is introduced and placed in a strategic location within the wall assembly to prevent moist air from reaching its dew point. This component is the air barrier or vapour barrier. The topics of moisture diffusion, air leakage and condensation have been introduced in Sections 2.4, 2.6 and 2.9 and are further discussed in this section, which reflects guidelines from the National Building Code of Canada (NBCC) 1995.

Air barriers and vapour barriers are somewhat synonymous in that the material used serves the dual purposes of inhibiting air flow and moisture transmission through the assembly. However, the guideline requirements for each differ.

The most common types of air barrier used in the construction of masonry cavity walls are thermally-fused or 'peel and stick' bitumen-based membranes, polyethylene sheet and sprayed-on material. For a wall with a masonry veneer the bitumen-based types of air barrier are used when insulation is placed in the cavity between the veneer and the back-up system, and the polyethylene is used when insulation is incorporated into the back-up system. Since sprayed-on air barriers are relatively new, there is no reliable history of performance and they are used less frequently.

The performance of the air barrier system is a function of many parameters, the most important ones being related to continuity of the barrier to prevent air leakage:

- continuity at control or expansion joints and the ability of the air barrier to accommodate anticipated movement at thislocation;
- continuity at locations where the structural components are designed to accommodate deflection;
- continuity at penetrations of the entire assembly; and proper design; and
- continuity at the wall-roof junction.

Again, to minimize air leakage there should be proper termination of the barrier at locations where continuity is not practical, such as the underside of concrete slab balconies. Proper connections to window and door openings, and proper seal at any penetration that may be required to construct the assembly, such as at masonry ties, stone anchors, pre-cast concrete supports, etc.

The performance of the system as a whole is a function of many factors, the most important being:

- structural integrity of the assembly;
- durability of the materials of the entire assembly;
- impact of use and occupancy

The structural integrity of the assembly relates to its ability to perform under service loads, this being primarily air pressure due to wind. To evaluate its performance, load testing of the assembly may be required. When evaluating the performance of the complete system, the National Research Council has suggested the use of a load equal to 1.5 times the design wind load for the building. The Canadian Construction Materials Centre has suggested the use of this level of loading when testing complete wall assemblies containing some critical features such as windows, penetrations, etc. selected for this purpose. The performance of the assembly can be affected by the performance of any of the elements. For example, consider a cavity wall consisting of an exterior veneer, air space, insulation, air barrier, and a back-up concrete block wythe enclosing a swimming pool: the performance of the system relies on all components functioning at all times. If the insulation is not structurally supported and under the action of a force or for other reasons moves away from the assembly and air is allowed to circulate between the insulation and the air barrier, the system has failed. The air barrier is now in the wrong location within the overall assembly, condensation will occur in the concrete block because of the high humidity in the building; most likely more than 35%. If the same failure occurred in the same wall in a school gymnasium the effects will not be noticed.

The performance of the air barrier is dependent upon a number of parameters the most important being:

- proper location within the wall assembly to limit the possibility of condensation from occurring within the assembly;
- if condensation occurs, the moisture should dry at least once a year; and
- no damage should occur in the assembly as a result of the condensation.

For air barrier components placed between the insulation and the back-up system in masonry cavity and masonry veneer walls the bonding of the air barrier to the back-up system is not a factor in the expected performance of the assembly. There are no requirements in the codes and standards on the means of securing the air barrier to the support system because the performance of the system is not affected by bonding or adhesion.

The Canadian requirements are covered in Part 5 of the National Building Code of Canada, namely in Section 5.4 Air Leakage and Section 5.5 Vapour Diffusion, and can be summarized as follows.
Essentially, air/vapour barriers are required in all instances unless it can be shown that air leakage or uncontrolled vapour diffusion will not adversely affect:

- the health or safety of building users;
- the intended use of the building; or
- the operation of building services.

Generally, the air barrier system provides resistance to air leakage and should have an air leakage characteristic not greater than 0.02L/(s.m2), L being litres, and s seconds. Greater air leakage rates are permitted when the conditions bulleted above apply.

Air barrier systems subject to wind load are required to resist 100% of the wind load, and deflections of the air barrier system at 1.5 times the specified wind load should not adversely affect structural elements.

When the barrier is acting to resist vapour diffusion it should have sufficiently low permeance and shall be so placed to minimize moisture transfer by diffusion.

Excerpts from Part 5 of the NBCC are included in Appendix A at the end of this document.

2.12 Expansion and Contraction

All building materials are subject to some dimensional changes resulting from changes in temperature and, in some instances, from changes in moisture content. For example, newly hardened concrete is still quite wet from the curing process and will subsequently shrink about 0.1% as it dries out over a long period of time – about one year, depending on ambient temperature and relative humidity. Burnt clay products such as brick, on the other hand, are completely dry following the kiln process and will expand about the same amount as moisture is absorbed from the air, again over an extended period of time that depends on temperature and relative humidity. There are also the dimensional changes that take place with temperature, materials lengthening when heated and shortening when cooled. For example, steel and concrete each have a coefficient of thermal expansion of about $a = 10.0\ (10)^{-6}$ mm/mm/°C such that a length L mm of the material subject to a temperature change Δt will be subject to a change in length $\Delta L = a.L.\Delta t$ mm.

For example, a 3.0 m steel rod subject to a temperature increase of 100°C will elongate $\Delta L = a.L.\Delta t = 10.0\ (10)^{-6}\ (3{,}000)\ (100) =$ 3.0 mm.

These dimensional changes if permitted to take place freely may cause differential movement between components in a building. For example, the interior of a building is at a relatively constant temperature and will normally be relatively stable dimensionally. On the other hand, the exterior brick veneer may undergo a temperature of 100°C through the year. This differential movement has to be accommodated in the detailing.

On the other hand, when building elements are attached such that environmental movements are restrained or prevented, internal forces develop in the restrained element that may cause damage. For example, foundations are generally held in place, and whatever is constructed above may be partially restrained. If this is a concrete block wall, horizontal shrinkage will be at least partly restrained, be placed in horizontal tension and be liable to vertical tension cracks. This cracking can be alleviated by placing vertical separations at regular intervals that will relieve the stresses. These separations are called movement joints or control joints. Occasionally they are referred to as expansion joints and are normally place no further apart than 8.0 m, close to corners, and at points of weakness, such as at window or door openings. Typical placement locations are given in Section 5.5, and are reproduced below in Figure 2.18. Figure 2.19 illustrates a typical movement joint in a masonry wall.

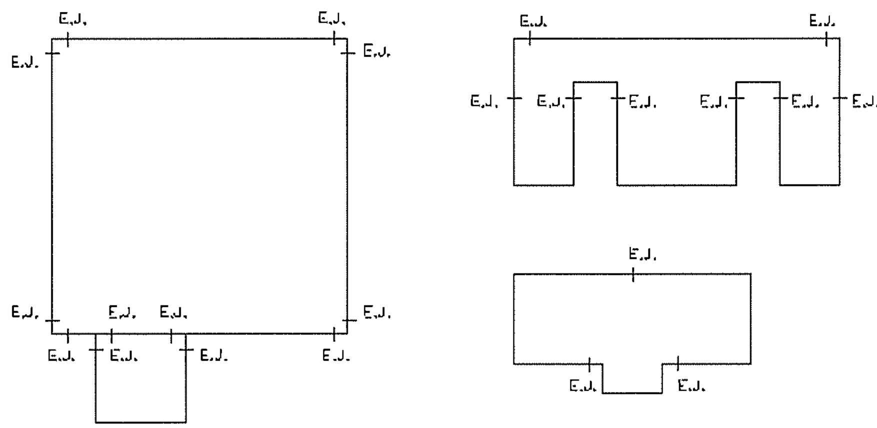


Figure 2.18 Placement of Movement Joints

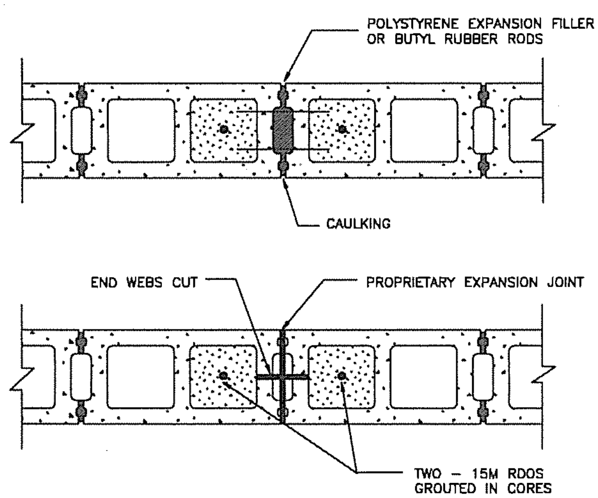


Figure 2.19 Detail of Typical Movement Joints in Concrete Masonry Wall

In both cases illustrated in Figure 2.19, horizontal movement in the plane of the wall can take place, while differential horizontal movement normal to the plane of the wall is prevented.

The width of the movement if the wall is of normal modular construction will be 10 mm (the width of a normal mortar joint – although it could be made wider if so required.

For example, the outside wythe of two-wythe construction is subjected to an annual temperatures variation of 80°C (from -30°to +50°C for a cold climate and exposure to hot summer sunlight) the total movement in the joint will be $a\Delta tL$ where L is the distance between movement joint. If the spacing between movement joints is 8.0 m then the maximum displacement in the movement joint is $a\Delta tL = 10\ (10)^{-6}\ (80)(8000) = 6.4$ mm and, since the joint width is normally 10 mm, this should be adequate.

If a flexible filler is used to fill and seal the joint, and if that filler is installed at around the mean temperature, that filler will be expected to undergo some tension and compression – about 6.4/2 = 3.2 mm through many annual cycles without failing. This means that the 10 mm of filler material should safely expand and contract about 30%. If, however, the filler material has an expansion and contraction capability of only 10%, then clearly the 3.2 mm represents 10% of the joint width, and the required joint width is 32 mm. Any lesser joint width is likely to result in eventual deterioration of the joint filler material.

The preceding discussion has focused on horizontal movements. However, movements also takes place in the vertical direction. For example, there are elastic strains due to load in load-bearing walls and columns, and there is the subsequent creep strain that may eventually exceed the elastic strain. Concrete elements undergo drying shrinkage over an extended period, and all of these strains lead to anaccumulating vertical movement. Normally, with two-wythe construction the interior concrete or concrete block structure is at a reasonably constant temperature, so thermal strains are not so serious.

The brick veneer, on the other hand, tends to expand over an extended period, and is also exposed to extremes of temperature change. There is, thus, a differential vertical movement between the interior and exterior. If this movement is not allowed to take place, there will be a transfer of vertical load from the supporting structure and the veneer is likely eventually to be severely damaged.

In a multi-storey building, the procedure is normally to provide a shelf angle (or ledge angle) attached to the structure at each floor to support the veneer. The veneer is built with a soft joint just below the angle, one that can accommodate some differential movement. The thickness is normally about 6 – 10 mm. This is shown in Figure 2-20, and also discussed briefly in Section 5.

2.13 Rain and Moisture Penetration

While much of the preceding discussion has dealt largely with moist air escaping outward through the exterior wall system as the result of air leakage and then condensing in the wall system causing damage, water can also enter from the outside, largely as the result of rain and driving wind. Moisture can also enter the wall system through diffusion from a moist outside environment to a dryer building interior. Water vapour diffusion can be significantly increased across the wall from exterior to interior by solar radiation falling on a rain soaked cladding. Of all causes, driving rain is likely to be the most severe.

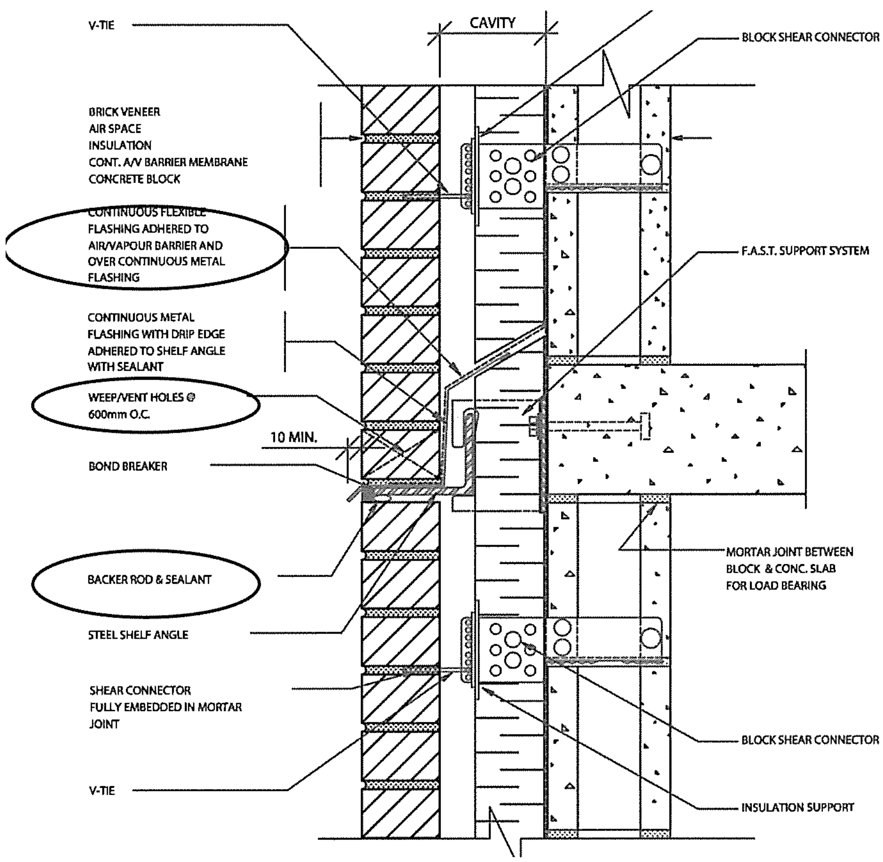


Figure 2-20 Shelf Angle / Flashing

One of the most effective methods of protecting a building from rain is to have a two-wythe system that uses the rain screen principle. The outer brick veneer sheds most of the rainwater, in effect acting as a screen against the rain. Then any moisture that leaks through to the air space behind the veneer travels down by gravity toward the base where it is diverted outward by the flashing and through weep holes to the outside. A typical detail is that shown in Figure 2-20. Another purpose served by the weep holes is to keep the air space vented and reasonably dry.

The performance of a rainscreen wall assembly can be enhanced by pressure equalization of the cavity behind the brick veneer when wind is acting on the building (Figure 2-21). Pressure equalized rain screens consist of the cladding, a rigid air barrier and compartmentalization of the cavity behind the cladding. For example, if wind is blowing against the wall in a pressure-equalized rain screen assembly, the wind enters the vented cavity and cannot pass around the building behind the cladding due to compartmentalization or through the wall due to the rigid air barrier, leading the pressurization of the cavity. With the cavity pressure equal to that of the wind on the wall the wind force is neutralized and cannot push water across any openings in the cladding.

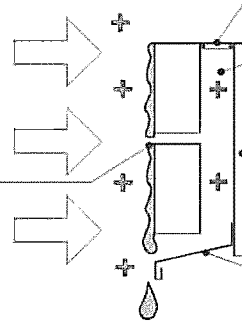


Figure 2-21 Rainscreen Principle

2.14 Operation of Mechanical Equipment

The type of use and occupancy for a building has a profound effect on its interior environment. For example, a cold-storage plant will have a very different interior environment from a power plant, an apartment building or an office building, and each will have its own unique needs for heating, air conditioning and ventilation. When the heating or cooling system is working, exterior air may be drawn into a building changing the relative humidity of the interior; or if the interior is at a higher internal air pressure than outside, air may be forced out through leakage. Operation of mechanical equipment generates heat, free heat that is beneficial in cold weather, but that might have to be removed during hot weather.

The requirements for heating and air-conditioning equipment will depend on climate, both temperature and relative humidity. For example, the requirements for a city in Canada depend on which part of the country and whether the average relative humidity is relatively high or low. Or, as another example, in a city like Lagos where the temperature and relatively humidity are normally high year round, there will be no heating requirement but a cooling system is of high importance. The equipment requirements, then, depend on climate and type of occupancy.

3. ENERGY REQUIREMENTS

3.1 Introduction

When heat is lost from a building during cold weather, that heat has to be replaced. Heat loss is by conduction through building components such as roof, walls, windows and doors, and by air leakage. Heat gain comes from the heating system for the building, and from free heat. This free heat comes from the sun shining through windows, from the sun warming exterior walls and roof, reducing the temperature difference across the wall, and free heat is generated by occupation – body heat, working appliances, lights, etc.

While a precise evaluation of heat loss, free heat and heat requirements is not possible, a reasonably good estimate can be made. This section covers the principles associated with estimating heat loss and predicting heating requirements. Also, since in the hot season there are cooling requirements, that aspect of interior environment control is discussed.

3.2 Heat Loss

The heat loss equation developed in Section 2.3 Temperature Gradient in Exterior Walls can, for a component in the building, be written as:

$$q = A\,\Delta T / R$$

where q is the rate of heat flow (W)
A is the surface area of thecomponent of the envelope
ΔT is the difference in temperature from inside to outside (°C), and
R is the total thermal restistance of the materials making up the
Component of the envelope (m^2. °C / W)

The total heat energy transferred over a period of time can the be expressed as

$$Q = A\,\Delta T_{AVG}\ t / R$$

Where Q is the total heat transferred (W . hr)
ΔT_{AVG} is the average temperature difference over a period of time t, and
t is the period of time (hr.) being considered

If the period of time being considered is the entire heating season then

$$\Delta T_{AVG}\ t = 24\ D$$

Where D is the degree day accumulation over the heating season – a degree day being defined as one day when the average outdoor temperature drops one degree below the required indoor temperature (see Section 2.2.1 Outdoor Air Conditions).

Therefore, the annual heat loss H_C due to conduction through the area A is

$$H_C = 24\,A\,D / R$$

This equation does not include heat loss due to air leakage, nor does it distinguish between purchased and free energy. H_C is merely the annual heat loss (W.hr) due to conduction.

Air leakage also contributes to heat loss and consists of two components, namely

a) Controlled air exchange, such as intentional ventilation, and many ventilation systems also incorporate a means of heat exchange where the entering cold air receives heat from the exiting warm air.
b) Uncontrolled air leakage, such as at windows and doors, and at unintentional breaches of the vapour barrier.

Since the cold air entering the building is normally dryer than the exiting air, there is more than "sensible" heat loss q_S – there is some q_E latent heat loss.

If the air exchange rate is known, air-leakage heat losses can be expressed as

$q_S = 0.335\ n\ v\ \Delta T$ and
$q_E = 823\ n\ v\ \Delta W$
where n is the number of air exchanges of the complete volume of air in the building per hour
v is the volume of the building (m^3) of the building
ΔT is the difference in temperature from inside to outside (°C), and
ΔW is the difference in humidity ratio between the indoor air and outdoor air (kg water / kg dry air)

Clearly, there are many variables and uncertainties involved in the calculation of heat loss due to air exchange, and the latent heat component is frequently an unnecessary complication.

3.2.1 Buildings with Low "Free" Heat

The total heat input to a building includes purchased heat energy and "free" heat. This free heat includes solar energy through windows and on the exterior of walls, and the heat produced by occupancy, such as lighting, equipment and human and animal activity.

The following expression for heat loss by conduction through the building envelope has already been developed:

$$H_C = 24\, A\, D\, /\, R$$

And, in a similar manner, the annual loss of sensible heat can be expressed as

$$H_A = 24 \times 0.335\ n\ v\ D$$

Now, combining these two expressions, the total annual heat loss from a building can be expressed as

$$H_T = 24\ D\ (\Sigma\, A/R + 0.335\ n\ v)$$

Where H_T is the total annual heat loss (W.hr)
$\Sigma\, A/R$ is the sum of A/R for all components of the building envelope
n is the average rate of air exchange (air exchanges per hour) over the heating season, and
v is the volume of the building (m^3)

The following substitution may be made:

$G = \sum A/R + 0.335\, n\, v$

Where G is the heat loss coefficient of the building (W / °C)

Therefore, $H_T = 24\, D\, G$

However, as pointed out earlier, not all of this total heat requirement has to be purchased since there normally is some free heat input. Also, depending on the efficiency of the furnace the purchased heat energy may have to be increased. Then, taking free heat and furnace efficiency into account, the heat energy to be purchased is

$H_P = (24 \text{ D G} - F) / E$

Where H_P is the amount of energy purchased annually, specifically for space heating (W.hr)

F is the annual accumulation of free heat (W.hr), and

E is the heating system efficiency (%)

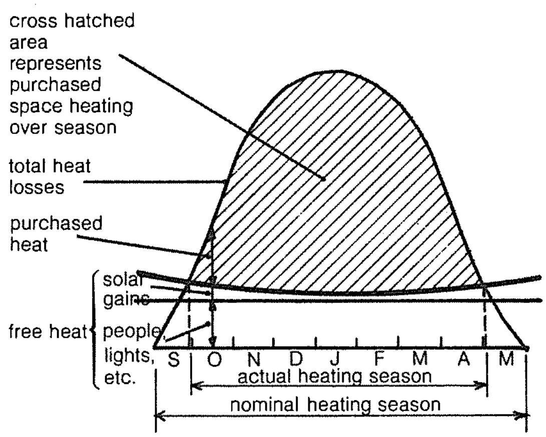


Figure 3.1 Relationship between Free and Purchased Heat

Figures 3.1, 3.2 and 3.3 are idealized graphical representations of the relationship between total heat requirement, free heat and purchased heat through the heating season Heat is plotted on the vertical and months of the year on the horizontal axis. The hatched area under the curve is the heat requirement.

The overall bell-shaped curve represents the total requirement during the nominal heating season (when the temperature outside drops below the required indoor temperature). There is no need for purchased heat until the free heat is lost – free solar heat and occupancy free heat are represented by the two almost horizontal lines crossing the main curve. The cross-hatched area shown in Figure 3.1 represents the heat required from purchased heat.

If now, the building is upgraded, for example, more insulation added, then there is a saving of energy requirement. This is shown as the double cross-hatched area at the top of Figure 3.2. In that case, the required heating season is shorter.

In the situation illustrated it is possible to do an economic study to determine how cost-effective the upgrade is likely to be.

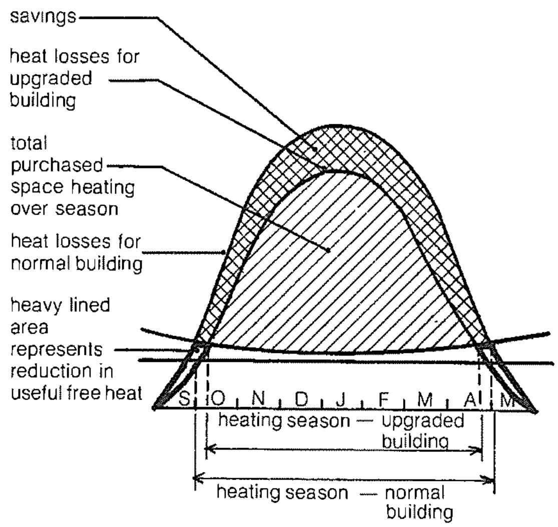


Figure 3.2 Relationship Between Free and Purchased Heat for an Upgraded Building

3.2.2 Buildings with High "Free" Heat

If the building is upgraded for high free heat (for example, by increasing the solar energy input through increase but well insulated glazing), the relationship might be as shown in Figure 3.3. The heating season is shortened and the required energy purchase is reduced.

It is clear from the discussion in Section 3 that there are many variables in estimating heat loss, heating requirements, and the relative value of upgrading a building.

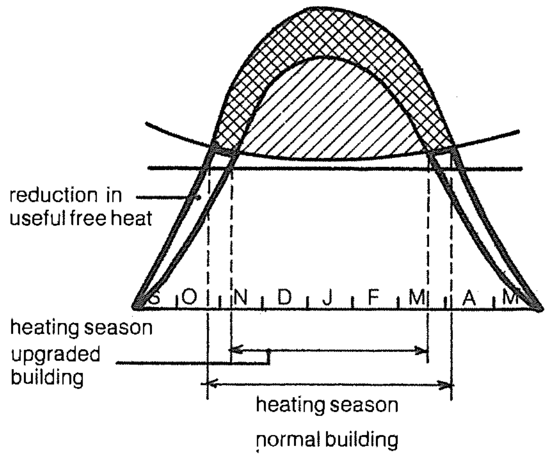


Figure 3.3 Upgraded Building with High Free Heat

The analysis given in Section 3 is relatively straightforward, but at best gives a rough approximation. Fortunately there are sophisticated computer programs available that greatly simplify the analysis.

3.3 Cooling Requirements

Control of the interior environment, unless it is accomplished through natural ventilation, requires energy. In cold weather heating is generally required, unless the "free" heat from use and occupancy is equal to the heat loss. In hot weather the building will likely require cooling, this being accomplished through the extraction of heat energy. And, since energy is expended in the air- conditioning equipment, the may be a considerable amount of heat to be exhausted from the building. In an ideal situation, that surplus heat could be used where heat is required.

The extent to which heating or cooling is required depends on the climate, type of building, type of use and occupancy, and budget.

A building whose interior is being air-conditioned (that is, cooled) in general requires insulation to prevent heat gain, and a wall assembly that is constructed for a cold climate will normally be sufficient to protect the building from heat gain in the hot weather. In such instances the thermal gradient is the reverse of that experienced in cold weather.

The main difference is that in hot weather a wall designed for cold weather will have the air/vapour barrier on the inside to prevent moisture condensing in the wall assembly. The same wall in hot weather, depending on moisture content of the exterior air may very well have a dew point inside the wall assembly, in which case condensation may take place in the wall, even within the insulation. However, in a hot, dry climate there may be insufficient moisture to condense out, or in a short hot season the amount of moisture deposited will likely evaporate out.

In a long, extended, humid, hot climate special wall designs with the air/vapour barrier outside the insulation may be required.
In summary, a wall assembly designed for cold weather protection will normally be sufficient for the hot weather. The heat loss in one instance becomes heat gain in the other, and energy requirement estimates are made in similar ways.

4. Exterior Insulation and Finish Systems - EIFS

4.1 Introduction

Exterior insulating and finish systems (EIFS) are non-load-bearing exterior wall cladding systems that can be used for new buildings or for retrofit to existing buildings. As the name implies, the system in its simplest form consists of insulation with a waterproof exterior barrier that can be applied to a wall. EIFS gained favour during the rebuilding that followed World War II because of their light weight and ease of installation on the exterior of a building. In North America EIFS accounts for 15% - 20% of the cladding on commercial buildings and about 4% of cladding on residential buildings.

Traditionally, EIFS cladding has consisted of panels which have the following components, starting with the exterior, working toward the interior:

- an acrylic co-polymer stucco-like finish on the exterior, with the colour blended into the coating, and the finish sprayed or troweled on for a specific look;
- a water-resistant base coat applied to the insulation board with a reinforced fibre-glass mesh embedded for strength;
- a moulded polystyrene insulation board, an extruded polystyrene board, or a polyisosanurate board from _" to 2" thickness; and,
- mechanical or adhesive fasteners to keep the insulation boards on the wall. EIFS panels are normally attached to the wall sheathing, or to a concrete or masonry back-up.

However, as noted below, more recent EIFS systems incorporate a vented, drained space that provides a very desirable rain screen.

The exterior coat is normally one of two broad types:

- The polymer-based coat that is relatively soft and flexible;
- A polymer-modified coat with a cementitious base that is relatively hard and stiff.

The benefits of EIFS include:

- Increased energy efficiency provided by the increased insulation;
- Design flexibility; and,
- A lightweight cladding finish, which is of structural significance in retrofit situations.

4.2 Types of EIFS

There are four main types of EIFS designs:

- the surface barrier, or face-sealed, design;
- the drainage plane design;
- the drainage plane design incorporating the rainscreen principle; and,
- the mass storage design.

The principle of the surface barrier design is that all exterior water must be kept outside the building – that is, no exterior moisture can make its way past the coating. The goal is for a water-tight building for the life of the building.

The drainage plane design features a moisture retarding film between the insulation board and the substrate (back-up) with grooves formed in the back of the insulation to channel away any moisture that makes its way through the coat and the insulation.

The drainage plane design incorporating the rainscreen principle, sometimes referred to as pressure-equalized design, and it incorporates a ventilated air space for pressure equalization.

Figure 4.1 shows the basic components of the traditional EIFS system. Figures 4.2 and 4.3 shows EIFS system incpororating a vented rainscreen component.

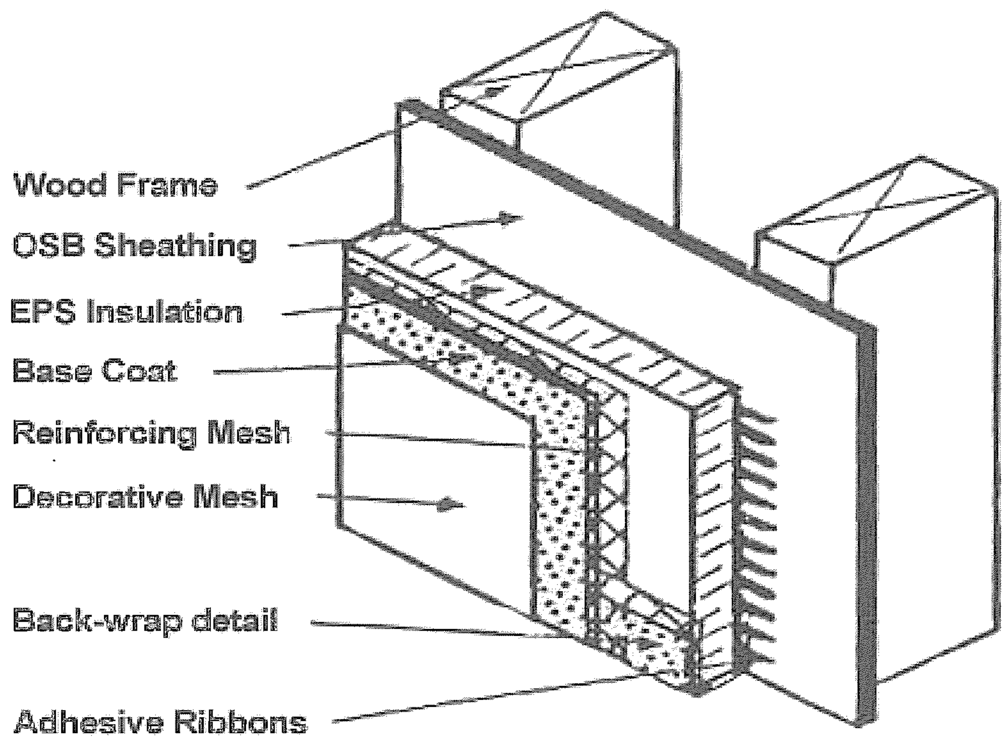


Figure 4.1

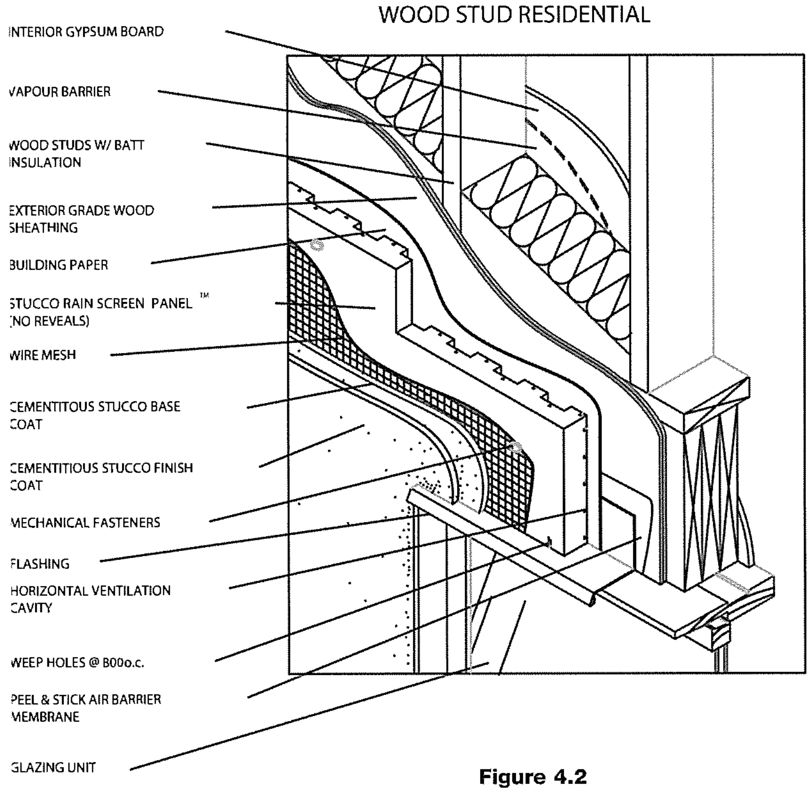


Figure 4.2

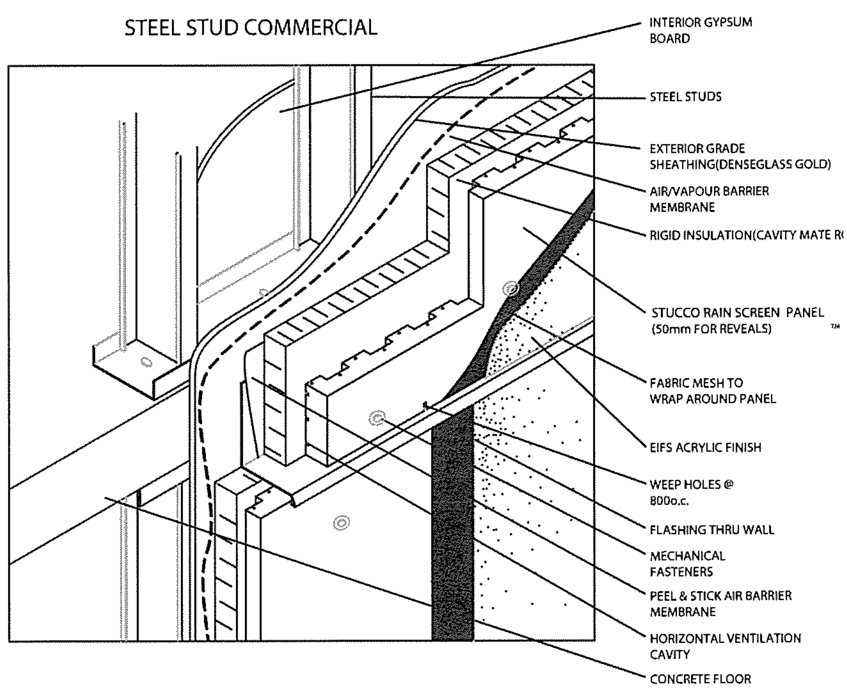


Figure 4.3

The mass storage design is used most frequently in Europe. The principal feature here is that the surface barrier design is applied directly to a concrete or masonry back-up wall. The principle here is that if any moisture makes its way past the barrier, it can be absorbed into and stored in the back-up. Because the concrete and/or masonry are non-deleterious in nature, the presence of moisture does not support rot-inducing fungi or insects.- problems that affect wood and gypsum board adversely.

One of the problems with the surface barrier, or face-sealed, system is that, in the event of even a minor defect in the barrier, moisture can enter the back-up wall and cause serious deterioration. Since all too frequently design details are inadequate, and construction practices flawed, this system has led to very serious building envelope problems. In fact, there is some question about the insurability of the system and of professionals who incorporate it into their design.

Since the purpose of the exterior shell of a building is to protect the occupants from the elements over an extended period of time, and without costly maintenance and repairs, the exterior wall system is the most vulnerable. Also, since minor flaws in the exterior surface of a wall can lead to major problems, it is advisable to select an EIFS system with back-up drainage and venting incorporated. This becomes especially true in severe climates, such as are experienced in Canada and the northern part of the United States of America. The selection of an EIFS system with proper drainage is essential. While the drainage plane design is an improvement on the surface barrier design, the preferred EIFS design is the drainage plane design incorporating the rainscreen principle.

Details of an EIFS system incorporating vented rainscreen principles are shown in Appendix B. This new system features a panel designed to guide any moisture that penetrates the stucco to a drained and vented air space.

5. COST ANALYSIS

5.1 Introduction

Section 3 discusses heat loss and methods of estimating energy saving. In an overall cost analysis, there are also building costs to be considered – a topic beyond the scope of this document. However, the general principles of cost analysis can be explained.

Once savings and costs have been developed, there are methods available for weighing one against the other. All of these methods involve comparing present costs with future savings, although, of course, there is no precise way of predicting future cost of fuel and future interest rates.

The following methods, arranged in order of increasing complexity, are summarized below:

- Simple payback period
- Annual cost
- Discounted payback period
- Rate of return
- Life cycle cost
- Optimum R value

5.2 Simple Payback

In this method, the initial cost premium of an option is divided by the first year saving from selecting that option. This gives the number of years required for the saving to return the initial investment.

That is, $n_{SP} = I/S$

Where n_{SP} is the number of years
I is the initial cost, and
S is the first year saving

This method assumes that energy costs will not change and that compounding interest rates do not apply.

5.3 Annual Cost

This method is fairly commonly used where the initial cost is covered by a loan, the owner wishing to estimate annual cash-flow requirements. The expression then is:

$$A = P.\ a \,/\, [1 - (1 + a)^{-n}]$$

Where A is the annual mortgage payment
P is the principal (the amount of the loan)
a is the interest rate, and
N is the amortized period (years)

5.4 Discounted Payback Period

The discounted payback period is that period of over which the present value of the energy savings just equals the initial cost increment required to achieve the savings. The following expression applies:

$$n_{DP} = \frac{\ln(1 - I.a/S)}{\ln(1 - I.a/S)}$$

where n_{DP} is the discounted payback period
ln indicates natural logarithm
I is the initial investment, and
S is the first year saving

5.5 Rate of Return

The rate of return on an investment in energy conservation is the effective interest rate which would prevail if the present worth of the savings over the life of the investment just equalled the initial investment. This calculation is normally accomplished using trial-and-error methods, with trial values of interest rate.

5.6 Life Cycle Cost

The life cycle cost of an energy conservation option is the sum of the initial investment and the present worth of the heating costs associated with that option over its economic life. The lower the life cycle cost, the more effective is the option.

5.7 Optimum Insulation Value

Clearly there is some relationship between life cycle cost and level of insulation R. In fact, work at the National Research Council of Canada suggests that the optimum R value can be approximated by the following expression:

$$R_{OPT} = \div[20\ D\ B\ F\ /\ (M\ E)]$$

Where D degree days over the heating season
B present cost of energy ($/W-hr)
F present worth factor ($/$)
M cost per unit of thermal resistance ($/R. m^2)
E heating system efficiency (%)

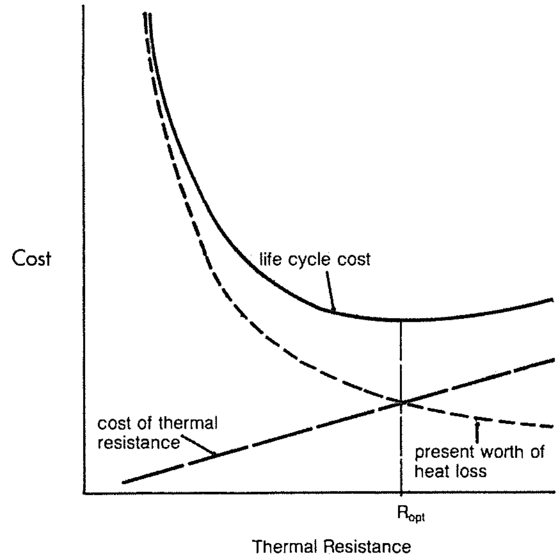


Figure 5-1 Concept of Optimum R

5.8 Summary

Cost-benefit analysis is clearly a complex issue and, while there are many aspects to consider and many variables, there are software programs that can better handle the details.

6. WALL DETAILS

6.1 Introduction

There are three components essential to the successful production of a building: design, detailing and construction, all of which must be of high quality. Without proper architectural design the building will not have the humanistic qualities of function and aesthetics important to the user and the public; proper structural design is essential to safety and durability; appropriate materials and details must be selected and effectively shown and described on construction drawings to avoid unnecessary energy loss and irritating and expensive repair and retrofit; and the designer must inspect construction regularly to ensure that the building meets the intent of the design - and all within the constraints imposed by the client's purse. If one or more of the three components falls below an acceptable standard, there will be problems, the severity of which will depend on the particular deficiencies.

The preceding sections have been concerned largely with ensuring an understanding of the science on which the energy efficiency and effective performance is based. However, more knowledge than an understanding of principles is required, but all too often designers are unfamiliar with details that ensure the integrity of the building envelope.

The purpose of this section is to provide the designer, whether structural or architectural, with some examples of the type of detailing required for good quality construction. Since buildings provide protection from the weather, good detailing of exterior walls in regions of climatic extremes becomes especially important. This section illustrates a number of masonry details for single-wythe walls and block walls with brick veneer - with accompanying explanations. They are a few that have been extracted from the much more thorough Masonry Details that Work prepared by the Canadian Masonry Research Institute. Note that although the details for walls with veneers show shear-connector ties between the veneer and back-up wall, other conventional ties may be used.

For the most part the details are for exterior walls of buildings, since it is there that the most serious problems normally become evident. In any case, if the designer is familiar with good details for exterior walls, those required for interior walls, being simpler, are relatively easy to devise. The details show how masonry supports other structural components such as floor and roof joists, and how masonry in turn is supported.

Since exterior walls are featured, the placement of insulation for energy efficiency is important, as is the prevention of moisture migration, either in or out, through the wall system. Rainwater entering the building is obviously undesirable. In a cold climate such as that in Canada, moisture-laden vapour tends to migrate outwards in the winter, and condensation of moisture in the wall must be prevented to minimize subsequent freeze/thaw deterioration or corrosion of metal components.

The reader is expected to have a sufficient knowledge of construction to read and understand the details, and to appreciate that certain information peripheral to weather protection may not be shown: for example, if masonry is shown supported by concrete without reinforcement, this does not mean that the concrete is unreinforced! Nevertheless, some terms may be unfamiliar to the novice. The term wythe refers to one vertical layer of masonry wall one unit thick – for example, a brick veneer is a wythe, as is the concrete block back-up. Air/vapour barrier (or air barrier) is a highly flexible, durable and impervious material, such as polyethylene, acting as an effective barrier to the passage of air and water vapour. Flashing is a continuous strip of durable and relatively flexible material located at the bottom of a wall (or section of wall) to collect and divert water out of the wall system. Weep holes are openings provided in the head (vertical) joints of the veneer, directly above the flashing, to allow any accumulated water behind the veneer to escape. Weep holes also act as vents to equalize air pressures inside and outside of the veneer. Although masonry veneer at the foundation level can be supported directly on the grade beam or foundation wall, it may also be supported on continuous horizontal steel shelf angles (sometimes referred to as ledge angles). In a multi-storey building the veneer is usually supported on shelf angles at each floor level above the third floor. This is to allow for the different expansion and contraction characteristics of the veneer and the masonry backing wall. For example, clay bricks in a veneer, having been fired in a kiln, tend to take on some atmospheric moisture and expand with time, whereas concrete blocks, having been moist-cured, tend to shrink as they dry. Also, since the two wythes may be at different temperatures, some differential thermal expansion and contraction is to be expected. To alleviate potential stress build-up, soft (that is, easily compressible) joints, rather than hard mortar joints are provided at the top of each section of veneer, just below the next shelf angle above. These principles are illustrated in the details.

Section 6-2 illustrates masonry-to-foundation support details; Section 6-3 shows some typical details for single-wythe exterior walls; Section 6-4 provides details for two-wythe (veneer plus back-up) walls; Section 6-5 illustrates movement joints; and Section 6-5 discusses the implications of construction dimensions and tolerances.

6.2 Masonry to Foundation Support Details

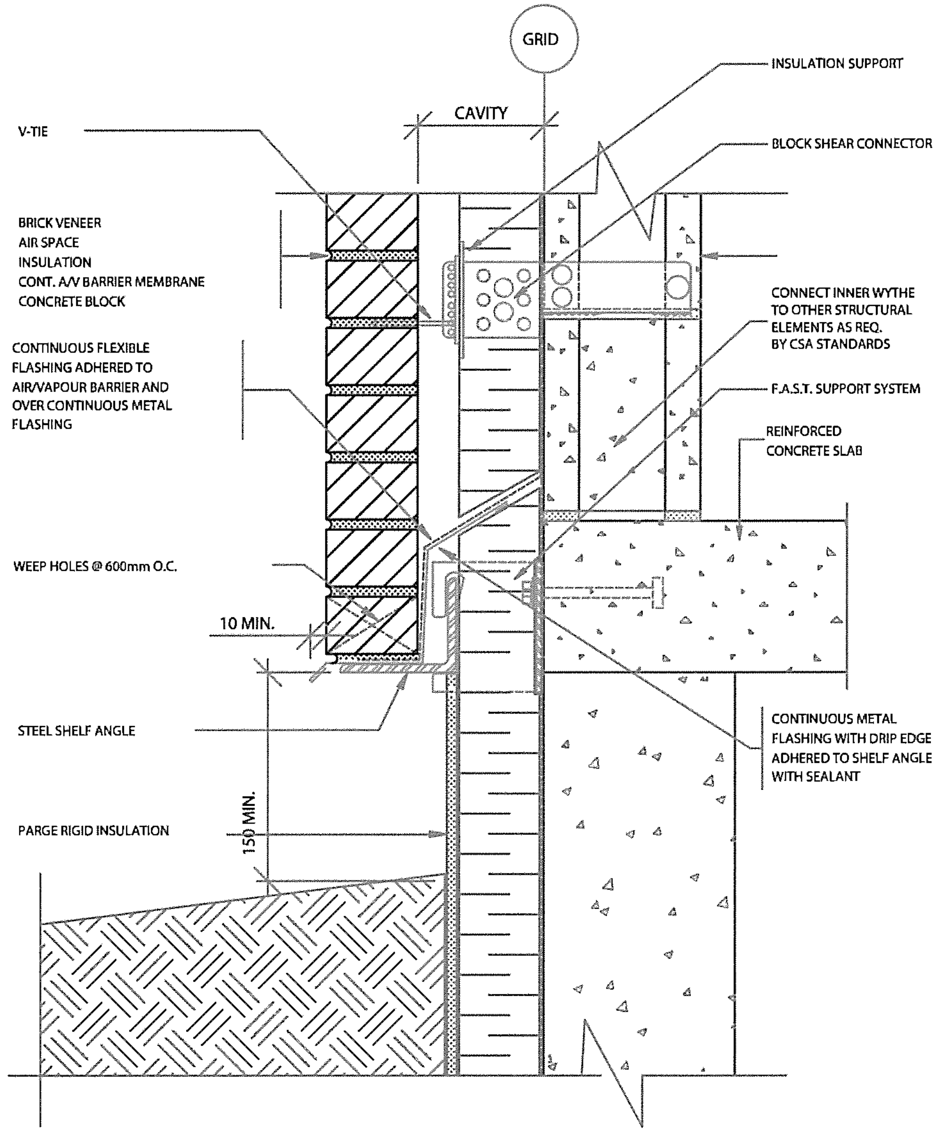


Figure 6.1 Brick Veneer / Concrete Block Detail at Foundation

Figs. 6.1 and 6.2 show a concrete block wall with a brick veneer supported on a reinforced concrete foundation, the former having a structural floor slab while the latter has a ground floor slab-on-grade. To be noted here are the placement of insulation between the block wythe and the veneer and the air/ vapour barrier inside the insulation, and the shelf angle, flashing and weep holes. Not shown are the reinforcement in the foundation or any dowels extending from the foundation to match vertical reinforcement in the wall. In this example, the structure is enveloped in insulation with little thermal bridging.

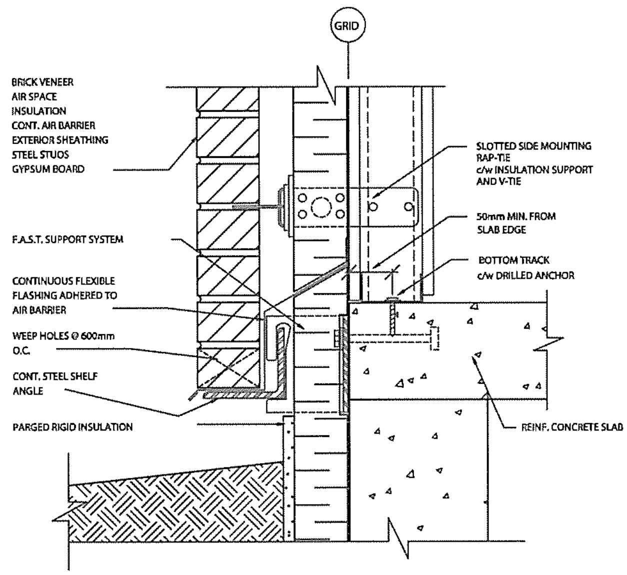


Fig. 6-2 Alternate Brick Veneer / Concrete Block Detail at Foundation

Fig. 6-3 shows an appropriate detail of the foundation support for a single-wythe load-bearing wall. Note the insulation on the inside of the wall, and the location of the air/vapour barrier on the inside of the insulation to prevent moisture condensation in the insulation. In this instance, because the insulation is on the inside of the wall, there is some thermal bridging where the structural concrete floor projects through to the exterior load-bearing wall. Flashing is incorporated into the bottom of the masonry wall to allow any condensate in the wall to drain out, and to minimize exterior moisture from seeping inside.

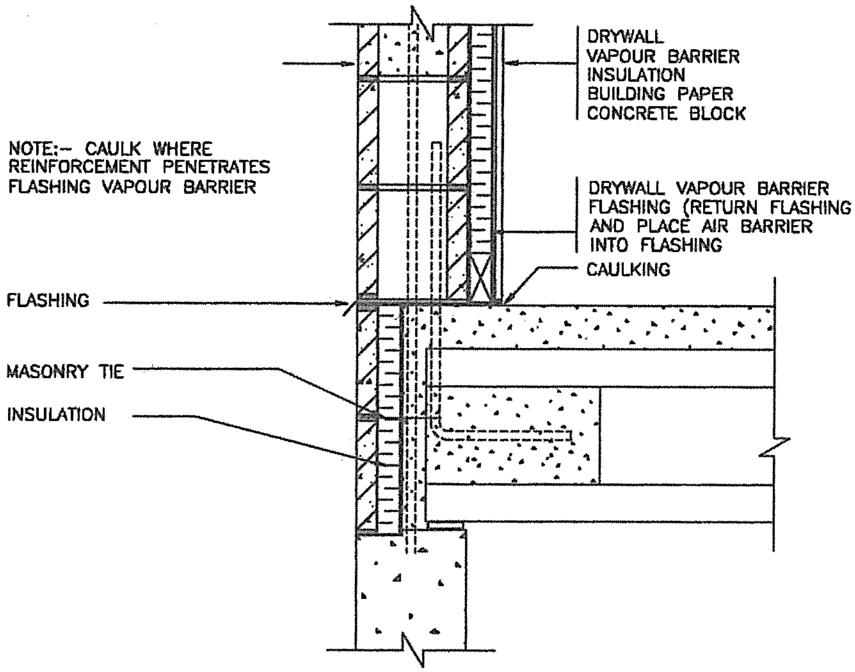
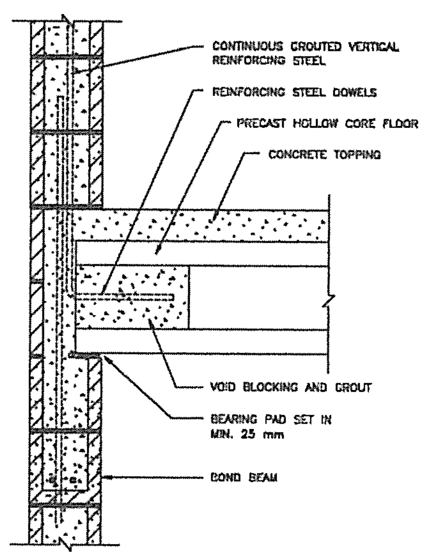


Fig. 6-3 Masonry Wall Flashing Above Floor Slab

6.3 Single Wythe Masonry Wall Details

Fig. 6.4 shows a precast concrete hollow core slab supported on a concrete masonry bearing wall. Note the presence of the bond beam providing a horizontal tension tie at the general floor level. The steel dowel is normally provided in the grout keys between adjacent hollow core slabs, and will be longer than the bar shown. The hollow core slabs may not have the concrete topping shown but instead may receive a levelling coat of grout. One additional comment: although the dowel from the floor extends vertically into the wall, the anchorage is not likely to be able to develop the full resistance of the bar; generally, though, it will not be required to do so.



Note that this figure does not show details of insulation and air/vapour barrier

Fig. 6-4 Load Bearing Exterior Wall

Figs. 6-5 and 6-6 show the bearing details for wood and open-web steel joist floors, respectively. Note again the bond beam. These two figures show structural details only, without indicating insulation or vapour barrier.

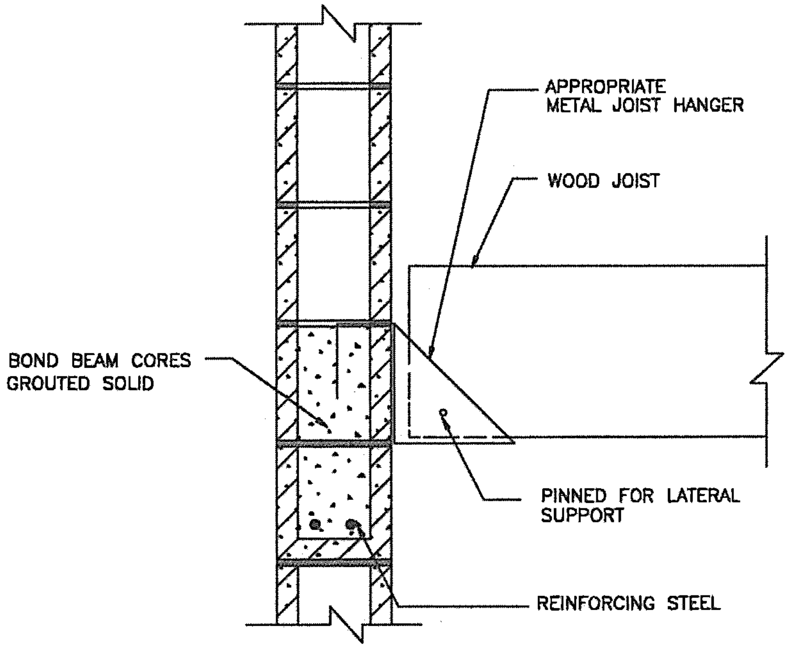


Fig. 6-5 Load Bearing Masonry Wall With Wood Joists

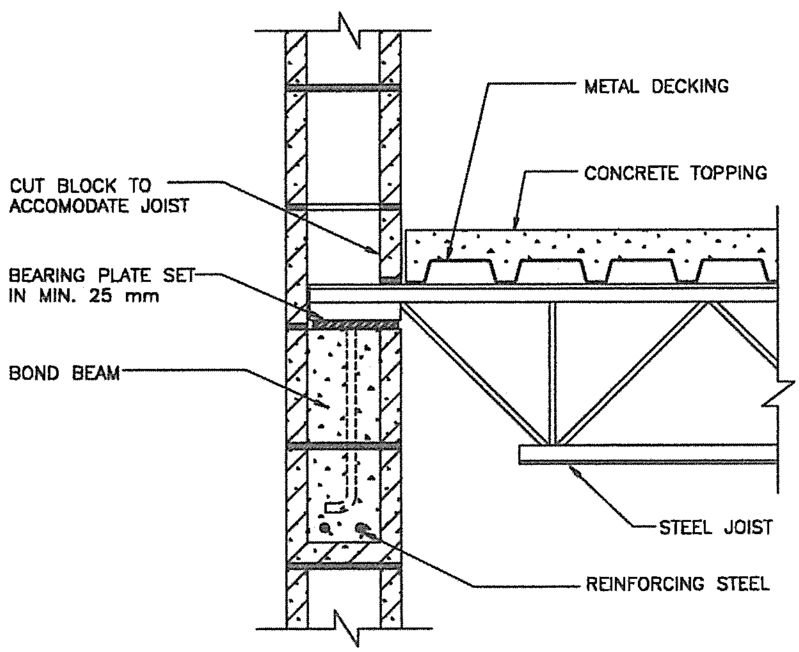


Fig. 6-6 Load Bearing Masonry Wall With Steel Joists

Figs. 6-7 and 6-8 show the details of a balcony wing wall extending out from a load-bearing interior wall. The vertical control joint permits differential vertical movement between the inside and outside walls, but because of the heat bridge, insulation is shown on both sides of the interior wall. Also to be noted are the steel plates placed above and below the balcony slabs to prevent horizontal movement of the slabs from splitting the block. The horizontal dowels in the balcony slabs will normally be longer than shown.

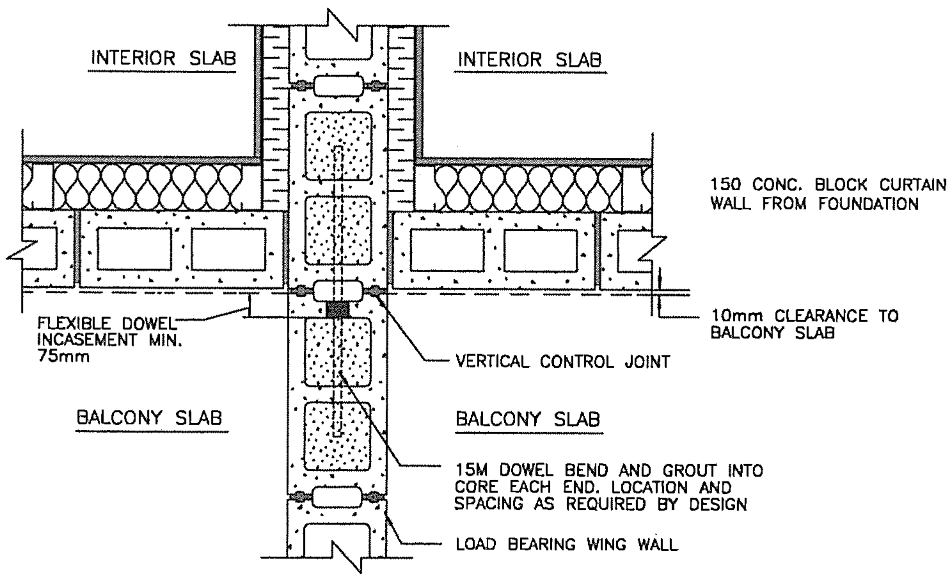


Fig. 6-7 Balcony Wing Wall Plan Detail

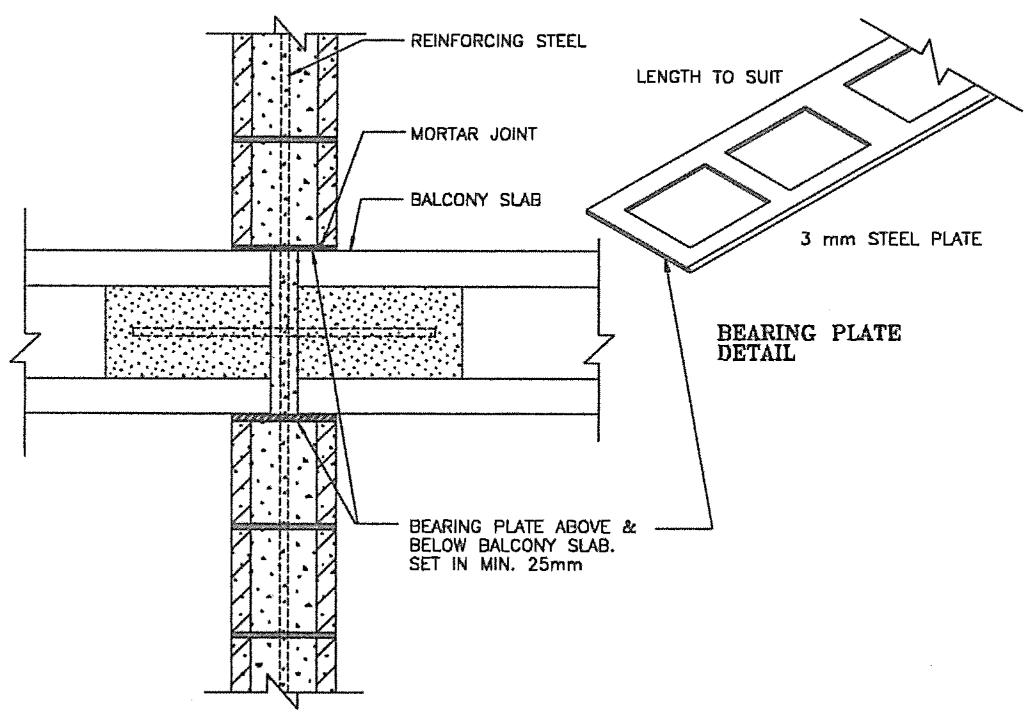


Fig. 6-8 Balcony Wing Wall Section

Fig. 6-9 shows the support for a precast concrete hollow core roof. To be noted are the dowel from the slab to wall (which will normally extend further into the slab) and the reinforcement and grouting of the masonry parapet.

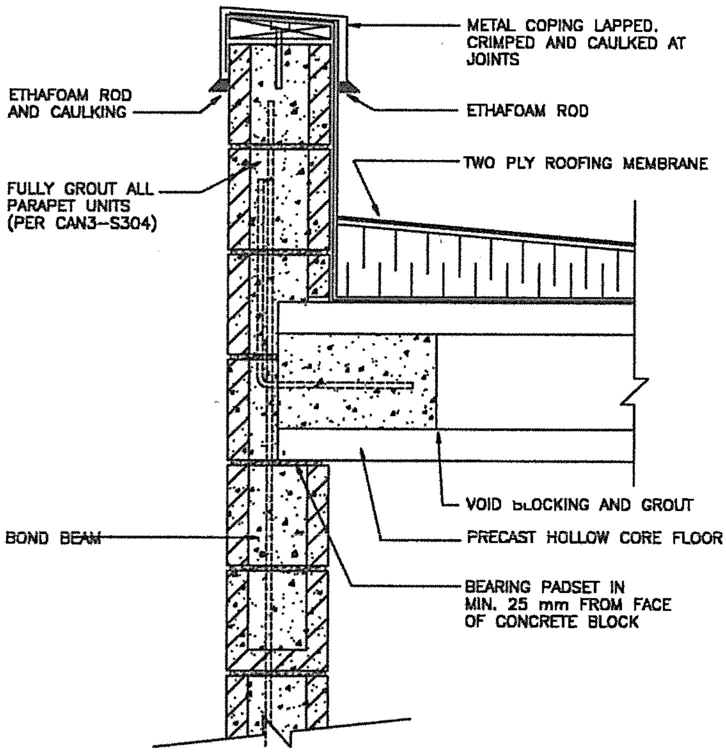


Fig. 6-9 Parapet With Metal Coping

Note that this figure does not show details of wall insulation, vapour barrier, parapet flashing or roofing membrane.

Fig. 6-10 shows the connection between a precast concrete hollow core slab to a non-load-bearing exterior wall. A Z-type bar is grouted into the slab and also into the wall to carry lateral wind or seismic loads. This being a single-wythe wall, the air/vapour barrier and insulation are on the inside of the block wythe.

Fig. 6-11 shows the bearing of precast concrete hollow core floor slabs on an interior masonry wall. The horizontal reinforcing dowels shown in the floor are normally placed in the grout key between the slabs and longer than shown. If concrete topping is present, as shown, reinforcement can be placed in the topping to provide a substantial tie across the bearing wall. To be noted here is that although it is simple to show the wall below grouted, it is not so simple in practice. The problem here is that the contractor finds it convenient to grout the wall after the floor slabs have been placed. A glance at the figure shows there is very little room between the slabs for thorough grouting, and careful inspection is clearly warranted. Since this is an interior wall, there is no need for insulation and vapour barrier. The detail is of structural significance.

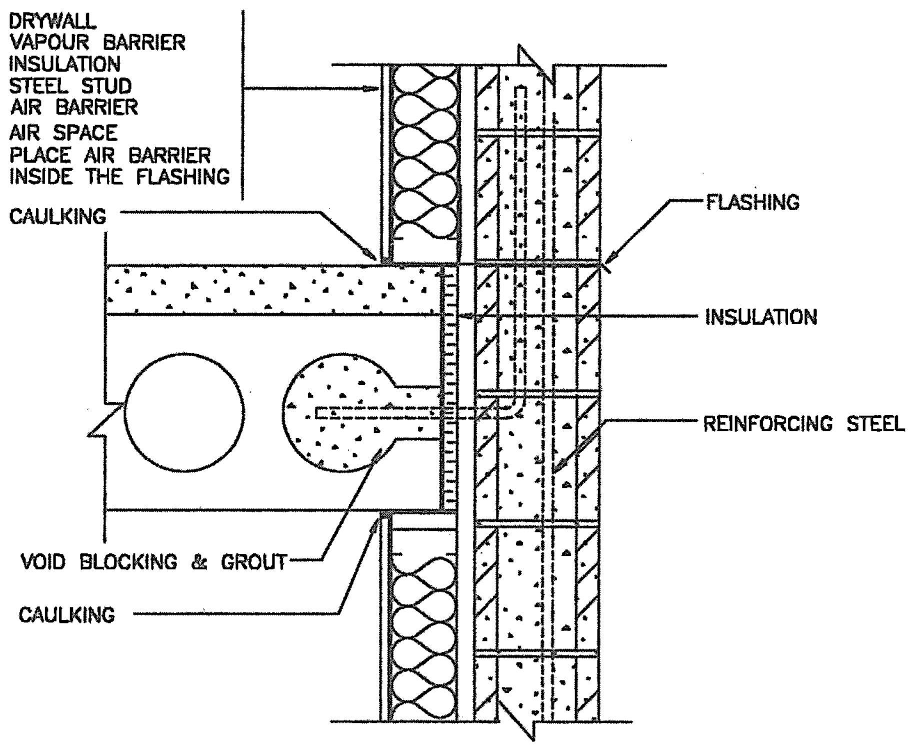


Fig. 6-10 Non-Load Bearing Exterior Wall

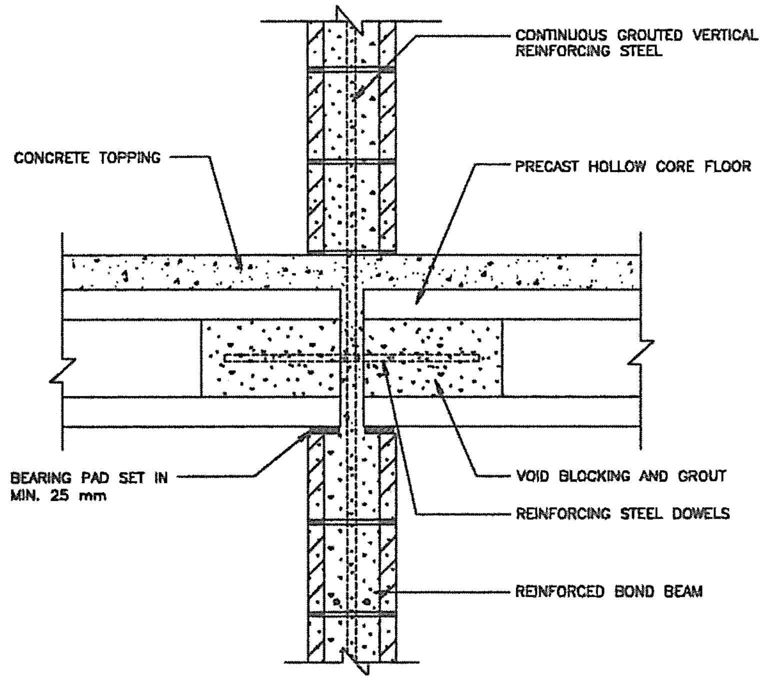


Fig. 6-11 Load Bearing Interior Wall

6-4 Two-Wythe Masonry Wall Details

Fig. 6-12 shows the details of connection between block wall, reinforced concrete floor and brick veneer. To be noted here are the location of insulation and air/vapour barrier, shelf angle support, flashing and weep holes, and the compressible joint immediately beneath the shelf angle.

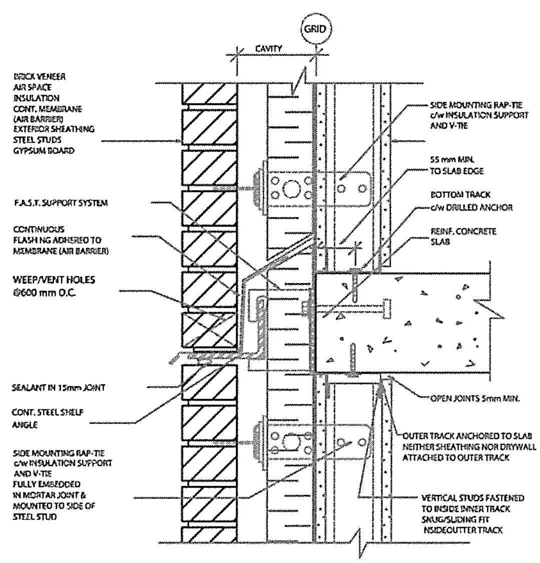


Fig. 6-12 Brick Veneer / Concrete Block Detail at Slab Edge

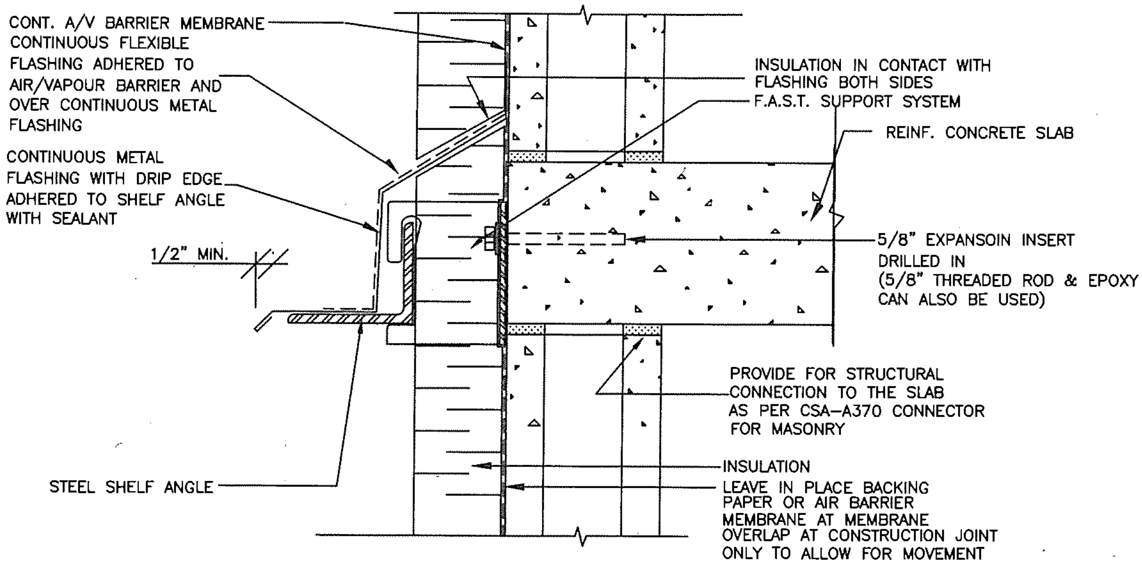


Fig. 6-13 Membrane (Air Barrier) Detail at Movement Joint

Figs. 6-13 and 6-14 show the recommended air/vapour barrier detail for the connection shown in Fig. 6-12. If the masonry wythe beneath the slab is an infill panel, there is likely to be a soft joint between the top of the masonry and the underside of the reinforced concrete. In that case, provision should be made in the air/vapour barrier for some differential movement.

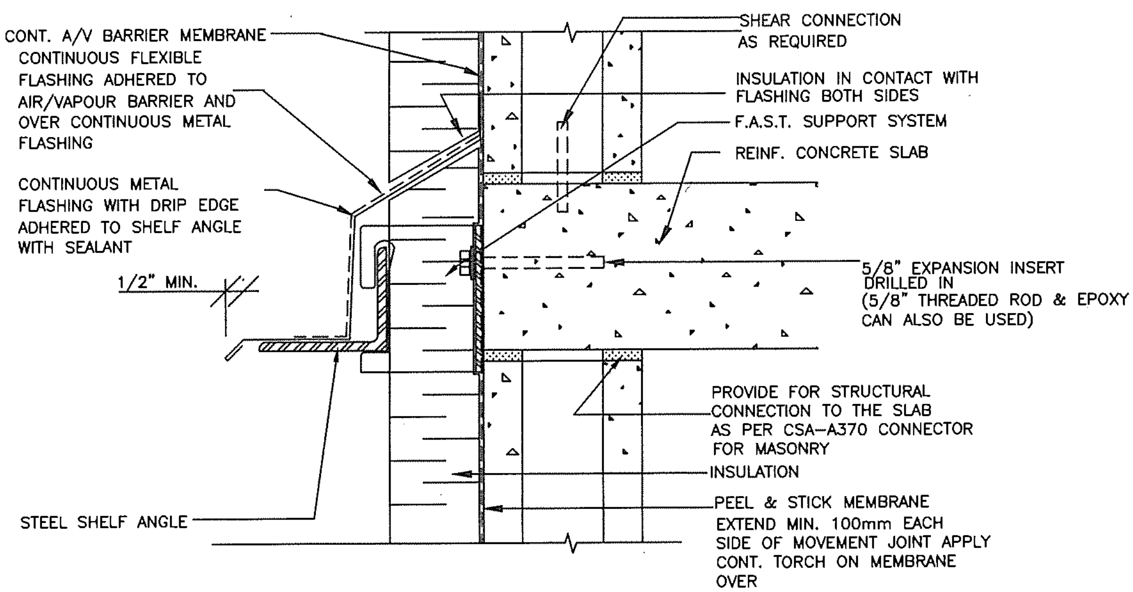


Fig. 6-14 Alternate Membrane Detail at Movement Joint

Fig. 6-15 shows the recommended detail for a low masonry parapet. Note that the roof membrane is continued over the parapet and lapped with and sealed to the wall air barrier. Also note the reinforcing dowel from the concrete slab into the parapet block, with accompanying grouting. A bond beam would normally be provided in the block wall below the slab, but in this instance the slab, being reinforced, may be used in place of a bond beam. If the structural roof system were of the joist type, the detail would be similar, except that a bond beam would be required, with a vertical bar extending from the bond beam into the parapet.

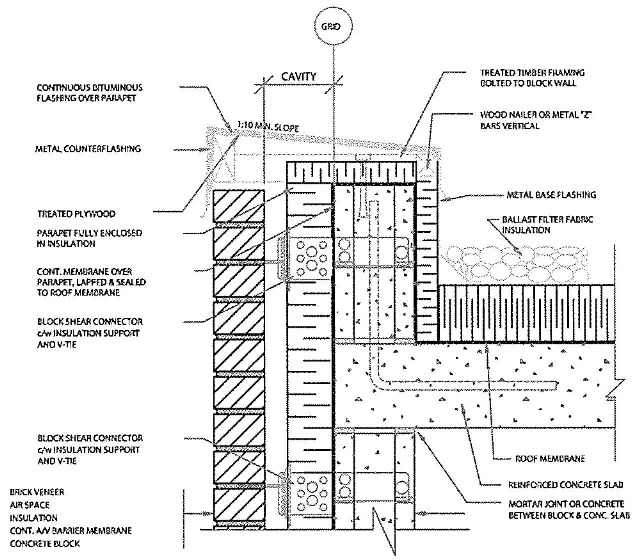


Fig. 6-15 Brick / Block Detail of Low Parapet W/ Protected Membrane Roof

Fig. 6-16 shows an appropriate detail at a high parapet. Note the roof membrane below the roof insulation and continued over the slab to lap with the wall membrane, where it should be sealed. If the roof structure were joists the vertical bars in the parapet wall would be anchored in the bond beam.

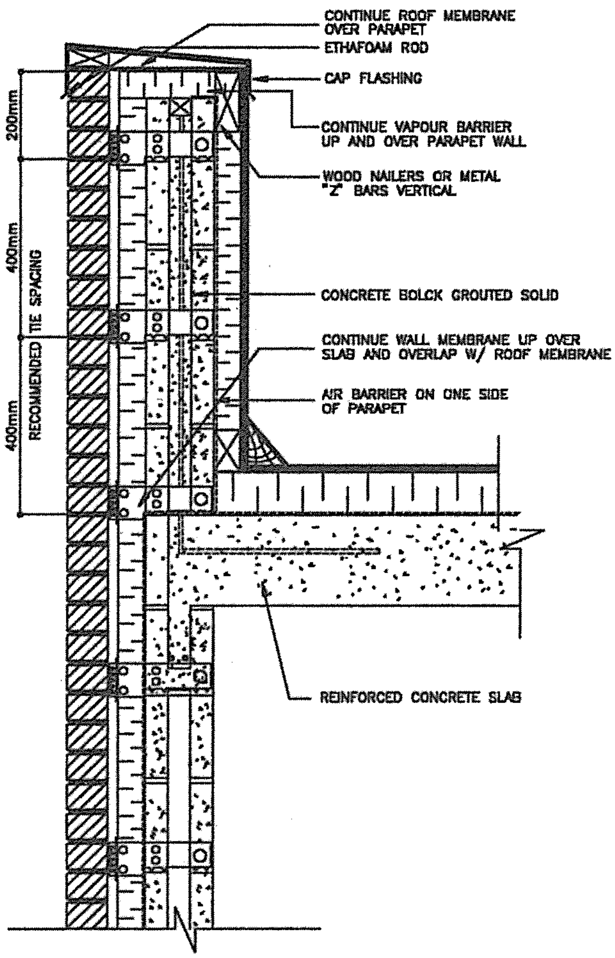


Fig. 6-16 Brick Veneer / Concrete Block Detail at High Parapet

6-5 Movement Joints

The joints featured in Figs. 6-17 and 6-18 are commonly referred to as expansion joints or control joints. They run vertically in the masonry wall, their purpose being to allow relatively unrestrained horizontal expansion and contraction. Clay brick expands with time and concrete block shrinks to some extent, so the terms control or movement are more representative of their function. These joints extend right through the wythe, or through both wythes if there is a veneer. As shown in Fig. 6-17, the joints are placed close to the corners of buildings to prevent movements of abutting walls from causing local cracking and spalling, and they should also be placed no further apart than about eight metres. There should also be control joints at points of natural weakness in the wall: for example, in the vicinity of door and window openings.

Fig. 6-18 shows two acceptable movement/control joints. Note that the joint allows in-plane movement but the joint material may be required to act as a shear key, inhibiting differential out-of-plane movement between the two sides of the joint. Note also that one vertical core on each side of the joints is reinforced and grouted.

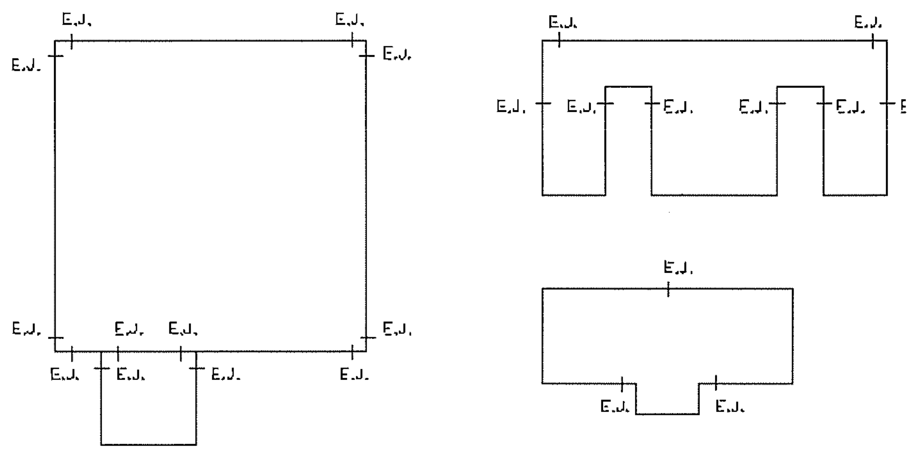
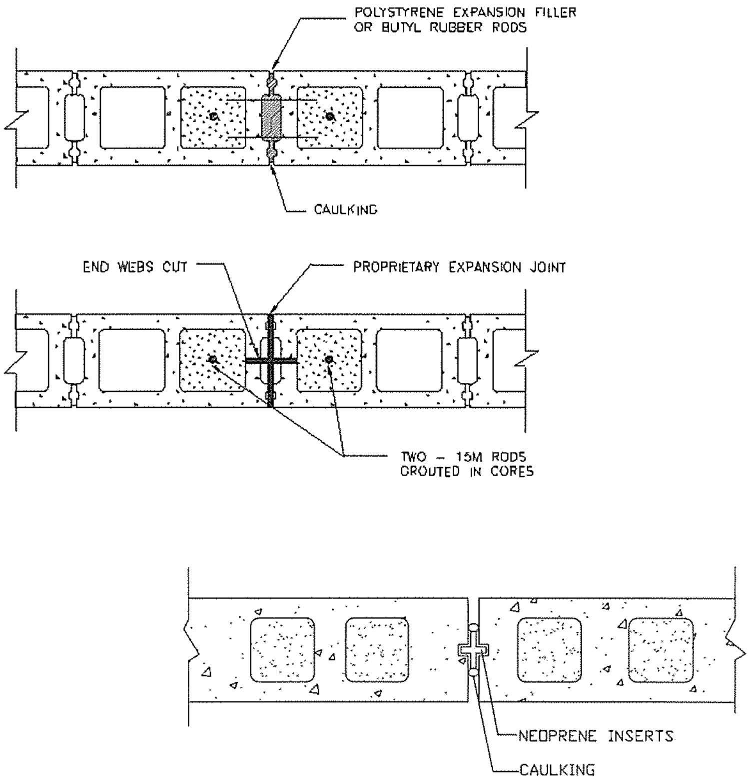


Fig. 6-17 Typical Expansion Joint Placement (will vary with size of building)



Use sash blocks with premanufactured neoprene inserts

Fig. 6-18 Single-wythe Hollow Block Horizontal Section

Other masonry wall details are included in Appendix C of this document.

6.6 Construction Tolerances

Although all relevant dimensions for a building are clearly shown (or should be) on the construction drawings – in plan and section views, the building cannot be constructed exactly to those dimensions. For example, a reinforced concrete beam shown dimensioned 6000 mm long may in fact be a few millimeters longer or shorter – which may be due to a small discrepancy in the formwork, to the initial layout, to shrinkage or to thermal expansion or contraction. With this in mind, most specifications permit some small field variations from the specified dimensions. For example, a 6000 mm long beam measuring 6002 mm delivered at the jobsite is likely to be acceptable. These small field variations from the precise dimensions are referred to as tolerances. These tolerances, of course should not be allowed to accumulate in a long building or a tall building to the point where the discrepancy becomes inconvenient. Consequently, most specifications outline tolerances for individual members and for overall dimensions.

In Canada, the maximum tolerances are specified in the Canadian Standards Association Specification covering the various construction materials – one specification for structural concrete, one for structural steel, and one for masonry. These tolerances are more liberal for steel and concrete structures than they are for masonry. For example, a steel or concrete multi-storey structure can be out-of-plumb (off vertical) by as much as 50 mm, while a masonry structure or its components can be out0of-plumb no more than 13 mm.

To some extent the strict tolerances imposed on masonry is understandable – especially for veneer that forms the finish coat for the building, one that should look good. Another likely reason for the discrepancies between maximum tolerances for various materials is the fact that these tolerances are set by different specification-writing committees.

However, the differences in permissible tolerances can lead to serious problems. For example, if a multi-storey concrete structure is 50 mm out-of –plumb and the tolerance of 13 mm is observed by the mason, there is a discrepancy of 50 – 13 = 37 mm. This discrepancy has to be allowed for in the construction. If the detail of the wall calls for an airspace of 20 mm behind the veneer, that airspace will either become 57 mm or will be lost and some of the brick will have to be split off. And the situation can be worse if the concrete contractor has violated those tolerances governing concrete. If the concrete is now too far in, the masonry contractor has to devise a means to extend the shelf angle out, which adds to cost and will likely be done rather poorly. On the other hand, if the concrete structure is too far out, the contractor may have to use a smaller angle and split the brick to a considerably smaller thickness than 90 mm. This, in turn, leads to higher compressive stresses in the brick – and possible failure.

The designer should be aware of the potential problems associated with tolerances, bear this in mind during design, and the inspection of the building should be carefully carried out. Once the "footprint" of the building has been laid out, subsequent sub-trades will be faced with having to accommodate their work within the as-built structure they now face.

BIBLIOGRAPHY

1. *Masonry Details – Ties and Connectors*, FERO Corporation, Edmonton 2002
2. Drysdale, R.G., Hamid, A.A., and Baker, L.R., *Masonry Structures – Behaviour and Design*, 2nd Edition, The Masonry Society,1999
3. Glanville, J.I., and Hatzinikolas, M.A., *Engineered Masonry Design, Limit States Design*, Winston House, Winnipeg 1996
4. *Guide to Energy Efficiency in Masonry and Concrete Buildings*, Masonry Council of Canada, 1982
5. Handegord, G., *Building Science and the Building Envelope* – a study course, Handegord and Company Inc., Ontario 1996
6. *National Building Code,* National Research Council of Canada, 2000
7. *National Energy Code for Buildings*, National Research Council of Canada, 1995
8. CAN/CSA-A23.1 *Concrete Materials and Methods of Concrete Construction*, Canadian Standards Association, 1994
9. CAN3-S304.1 *Masonry Design for Buildings*, Canadian Standards Association, 1994
10. CAN3-A371 *Masonry Construction for Buildings*, Canadian Standards Association, 1994
11. CAN/CSA-S16.1 *Limit States Design of Steel Structures*, Canadian Standards Association, 1994

APPENDIX A

Excerpts from Part 5 of NBCC 1995

Section 5.4 National Building Code of Canada 1995

(The following material has been taken directly from Part 5 of the National Building Code of Canada 1995)

Section 5.4. Air Leakage

5.4.1. Air Barrier Systems

5.4.1.1. Required Resistance to Air Leakage

1) Except where a building component or assembly separates interior conditioned space from the ground, or environ mentally dissimilar interior spaces, the component or assembly shall contain an air barrier system.

2) An air barrier system is not required where it is can be shown that uncontrolled air leakage will not adversely affect any of

a) the health or safety of building users,
b) the intended use of the building, or
c) the operation of building services.

5.4.1.2. Air Barrier System Properties

1) Except sheet and panel materials intended to provide the principal resistance to air leakage shall have an air leakage characteristic not greater than 0.02L/(s · m^2) measured at an air pressure difference of 75 Pa.

2) The air leakage limit is permitted to be increased where it can be shown that the higher rate of leakage will not adversely affect any of

a) the health or safety of building users,
b) the intended use of the building, or
d) the operation of building services.

3) The air barrier system shall be continuous

e) across construction, control and expansion joints,
f) across junctions between different buildings, and
g) around penetrations through the building assembly.

4) An air barrier system installed in an assembly subject to wind load, and other elements of the separator that will be subject to wind load, shall transfer that load to the structure.

5) An air barrier system installed in assembly subject to wind load, and other elements of the separator that will be subject to wind load, shall transfer that load to the structure.

6) Except an air barrier system installed in an assembly subject to wind load shall be designed and constructed to resist 100% of the specified wind load.

7) Except deflections of the air barrier system and other elements of the separator that will be subject to wind load shall not adversely affect non-structural elements at 1.5 times the specified wind load.

8) Where it can be shown by test or analysis that an air barrier system installed in an assembly will be subject to less than100% of the specified wind load,

   a) the air barrier system is permitted to be designed and constructed to resist the lesser load, and
   b) deflections of the air barrier system and other elements of the separator that will be subject to wind load shall not adversely affect non-structural elements at 1.5 times the lesser load.

Section 5.5 Vapour Diffusion

5.5.1. Vapour Barriers

5.5.1.1. Required Vapour Barrier

1) Except where a building component or assembly will be subjected to a temperature differential and a differential in water vapour pressure, the component or assembly shall include vapour barrier.

2) A vapour barrier is not required where it can be shown that uncontrolled vapour diffusion will not adversely affect any of

   a) the health or safety of building users,
   b) the intended use of the building, or
   c) the operation of building services.

5.5.1.2. Vapour Barrier Properties and Installation

1) The vapour barrier shall have sufficiently low permeance and shall be positioned in the building component or assembly so as to

   a) minimize moisture transfer by diffusion, to surfaces within the assembly that would be cold enough to cause condensation at the design temperature and humidity conditions, or
   b) reduce moisture transfer by diffusion, to surfaces within the assembly that would be cold enough to cause condensation at the design temperature and humidity conditions, to a rare that will not allow sufficient accumulation of moisture to cause deterioration or otherwise adversely affect any of
      i) the health or safety of building users,
      ii) the intended use of the building, or
      iii) the operation of building services.

2) Where materials installed to provide the required resistance to vapour diffusion are covered in the scope of the standards listed below, the materials shall conform to the requirements of the respective standards:

   a) CAN/CGSB-51.33-M, "Vapour Barrier Sheet, Excluding Polyethylene, for Use in Building Construction, "or
   b) CAN.CGSB-51.34-M, "Vapour Barrier, Polyethylene Sheet for Use in Building Construction."

3) Coatings applied to gypsum wallboard to provide required resistance to vapour diffusion shall be shown to conform with the requirements of Sentence (1) when tested in accordance with CAN/CBSB-1.501-M, "Method for Permeance of Coated Wallboard."

4) Coatings applied to materials other than gypsum wallboard to provide required resistance to vapour diffusion shall be shown to conform with the requirements of Sentence (1) when tested in accordance with ASTM E 96, "Test Methods for Water Vapour Transmission of Materials" by the desiccant method (dry cup).

A-5.2.1.2.(1) Interior Environmental Loads

The interior environmental conditions required depend on the intended use of the spaces in the building as defined in the building program. Spaces in different types of buildings and different spaces within a single building may impose different loads on the separators between interior and exterior spaces and between adjacent interior spaces. The separators must be designed to withstand the expected loads.

A-5.3.1.2. Minimize

The word "minimize" is used because not all moisture ingress or accumulation in an assembly need be of concern. Few designs of separators defined in Article 5.1.2.1. (Separation of Environment) can completely prevent condensation. For example, moisture condensing during very cold weather may not affect the long-term performance of the assembly, provided the moisture dries out or is drained away before it initials deterioration of the building materials.

A-5.3.1.2.(5) Heat Transfer through Fire Rated Glazed Assemblies

Thermal bridging through fire rated glazed assemblies should not be ignored; measures should be taken to minimize condensation.

A-5.4.1.1. Resistance to Air Leakage

The air barrier system in above grade building components and assemblies separating conditioned space from the exterior will reduce the likelihood of condensation due to air leakage, discomfort from drafts, infiltration of dust and other pollutants, and interference in the performance of building services such as HVAC and plumbing. These can lead to serious health or safety hazards.

Currently, the most obvious and significant problems are due to moisture-related mateial deterioration such as rot and corrosion, which can lead to failure of component connections. Infiltration of dust and other pollutants can lead to a wide range of health problems. Where the separator is subject to high moisture levels, the pollutants may include fungus spores. Interference with the performance of building services can lead to unhealthy conditions, and potentially hazardous conditions during the heating season in many regions of the country.

Where adjacent interior environments are sufficiently different, control of air flow between those spaces is necessary to maintain conditions.

And air barrier system may be required in components and assemblies in contact with the ground to control the transfer of soil gases such as radon and methane.

A-5.4.1.2.(1) and (2) Air Leakage through the Air Barrier

System Material Requirements

The current requirements specify only a maximum air leakage rate for the material in the air barrier system that provides the principal resistance to air leakage.

The report, "Air Permeance of Building Materials," prepared by AIR-INS Inc. for CMHC (1988) identifies, from 36 common building materials, 19 which would comply with the leakage limit of 0.02 L/(s · m^2) at 75 Pa. Air leakage characteristics greater than the maximum of 0.02 L/(s · m^2) at 75 Pa may be acceptable where

- exterior temperatures are mild,
- the moisture content of the indoor air is low,
- the assembly is resistant to moisture-related deterioration,
- higher vapour permeance materials are installed toward the cold side ofthe assembly, or
- the air barrier system separates two interior spaces that are not intended to provide significantly different environments.

System Requirements

Ideally, a maximum air leakage rate for the complete air barrier system would be specified. The maximum acceptable rate would ultimately depend on warm and cold side temperature and humidity conditions, and on the susceptibility of the environmental separator to moisture deterioration. Recommended maximum leakage rates for the air barrier system in an exterior envelope in most locations in Canada, depending on indoor relative humidity, are as shown in Table A-5.4.1.2.

Table A-5.4.1.2.
Recommended Maximum Air Leakage Rates

Warm side relative humidity at 210°C	Recommended maximum system air leakage rate, L/(s · m^2) at 75 Pa
<27%	0.15
27 to 55%	0.10
>55%	0.05

Determining the leakage rate of a particular assembly, however, is problematic. There is little information available on the airtightness of the many air barrier systems used in building construction, and testing requires specialized equipment and expertise. Depending on the type of test,

- testing may not represent the performance of the complete installed system
- location of deficiencies may be difficult to identify
- rectification of deficiencies may not be feasible.

Despite the difficulties, it is recommended, when using a system whose performance is not known, that tests be conducted.
Testing options include:

- laboratory tests of small sections of the air barrier system, including joints and intersections of different assemblies
- laboratory tests of large wall sections
- in-situ tests of characteristic envelope areas.

A-5.4.1.2.(3) Airtightness of Components

It is important to note that Sentence 5.4.1.2.(3), pertaining to components of the air barrier system, is stated in such a fashion that the selection of components is not limited to those for which a standard is identified. This approach permits more flexibility than is provided by similar requirements in Part 9. So long as the selected component meets the performance requirements provided elsewhere in the Section, the component may be used to provide the necessary resistance to air leakage.

Where the selected component falls within the scope of any of the standards listed, however, the component must also comply with the standard. For example, if curtain wall is selected to clad a residential building, the glazed areas of the wall constitute part of the air barrier system and must provide the required airtightness. As curtain wall is not within the scope of the CAN/CSA-A440-M standard, these glazed areas need not comply with that standard. If, on the other hand, one decides to install standard residential windows, these must conform to CAN/CSA-A440-M.

A-5.5.1.2.(1) Vapour Barrier Materials and Installation

In the summer, many buildings are subject to conditions where the interior temperature is lower than the exterior temperature. Vapour transfer during these periods is from the exterior to the interior. In general, in Canada, the duration of these periods is sufficiently short, the driving forces are sufficiently low, and assemblies are constructed such that any accumulated moisture will dissipate before deterioration will occur.

Buildings such as freezer plants, however, may operate for much of the year at temperatures that are below the ambient exterior temperature. In these cases, the "warm" side of the assembly would be the exterior and a detailed analysis on an annual basis is required.

Steady state heat transfer and vapour diffusion calculations may be used to determine acceptable permeance levels for the vapour barrier and to identify appropriate positions for the vapour barrier within the building assembly.

The word "minimize" is used because not all moisture ingress or accumulation in an assembly need be of concern. Few designs of separators defined in Article 5.1.2.1. can completely prevent condensation from occurring and many can accommodate some moisture by limiting accumulation. For example, moisture condensing during very cold weather may not affect the long-term performance of the assembly, provided the moisture dries out or is drained away before it initiates deterioration of the building materials.

A-5.5.1.2.(2) Vapour Barriers

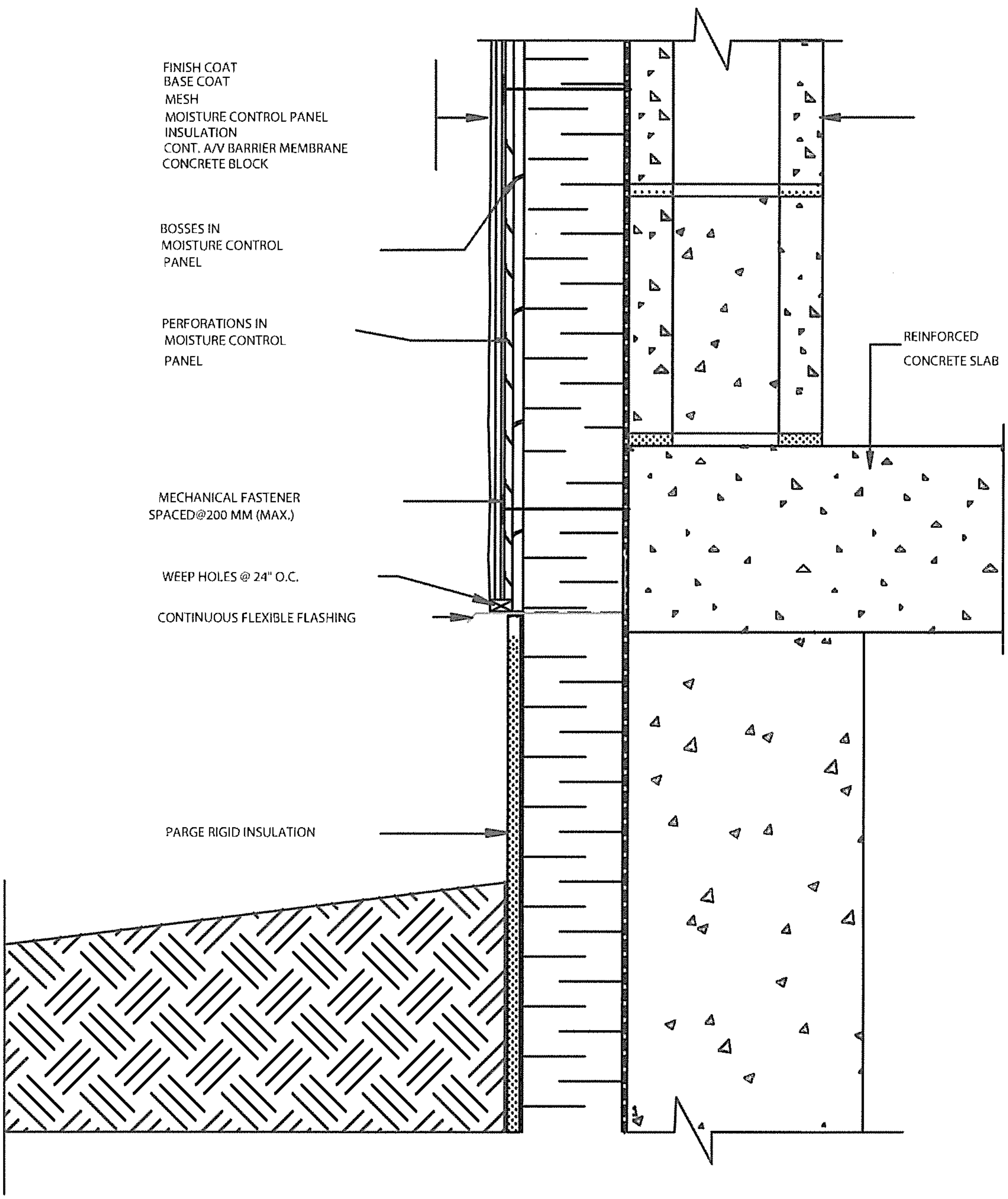
It is important to note that Sentence 5.5.1.2.(2) pertaining to materials intended to provide resistance to vapour diffusion, is stated in such a fashion that the selection of materials is not limited to those traditionally recognized as vapour barrier materials or those for which a standard is identified. This approach permits more flexibility than is provided by the equivalent requirements in Part 9. So long as the selected material meets the performance requirements provided elsewhere in the Section, the material may be used to provide the necessary resistance to vapour diffusion.

Where the selected material falls within the scope of either of the standards listed, however, the material must comply with that standard. For example, if a peel-and-stick modified bituminous membrane is selected and will provide the necessary vapour diffusion resistance, the installation of one of the 'vapour barrier' materials identified in the standard list is not required. If, on the other hand, one decides to install polyethylene as the vapour barrier, the material must conform to CAN/CGSB-51.34-M.

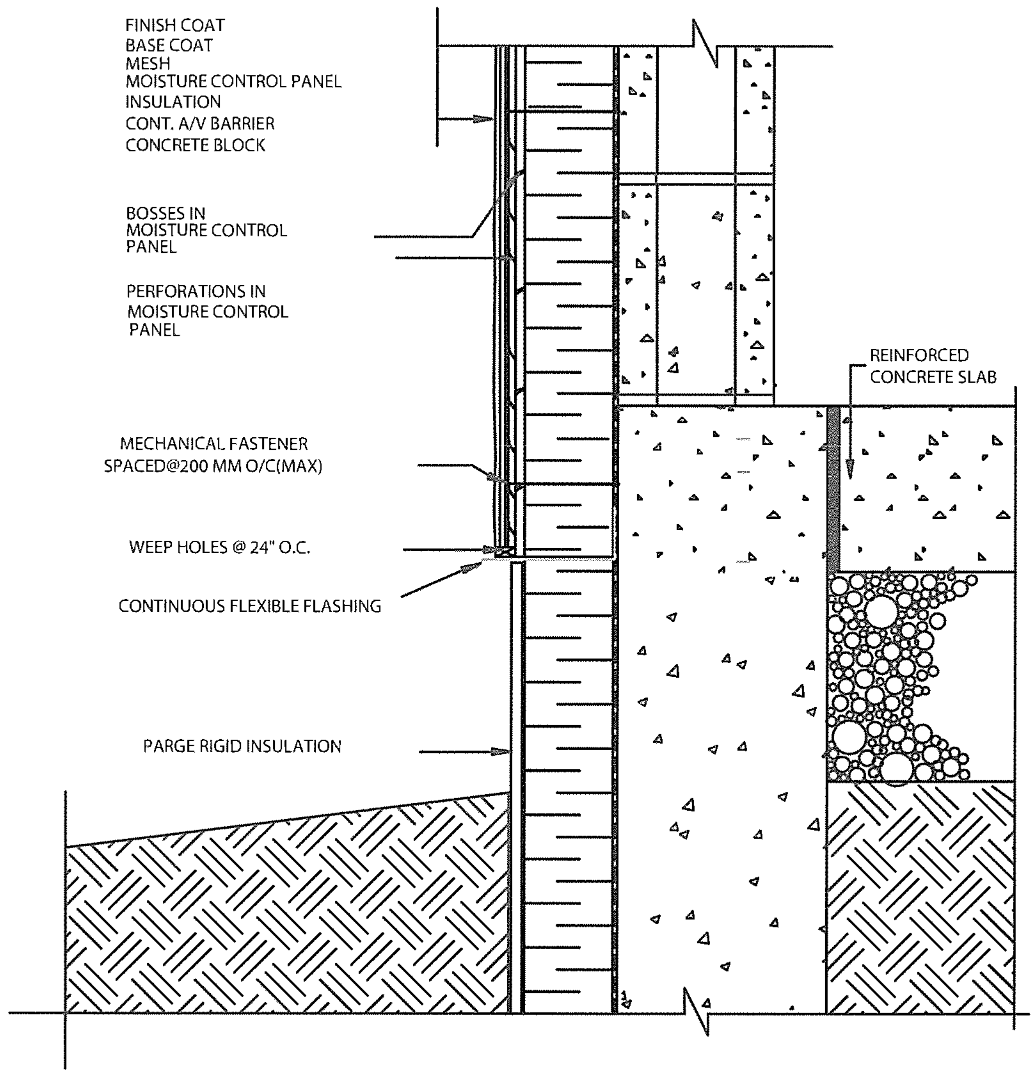
APPENDIX B

BASIC WALL DETAILS FOR EXTERNALLY INSULATING FINISHING SYSTEM (EIFS)

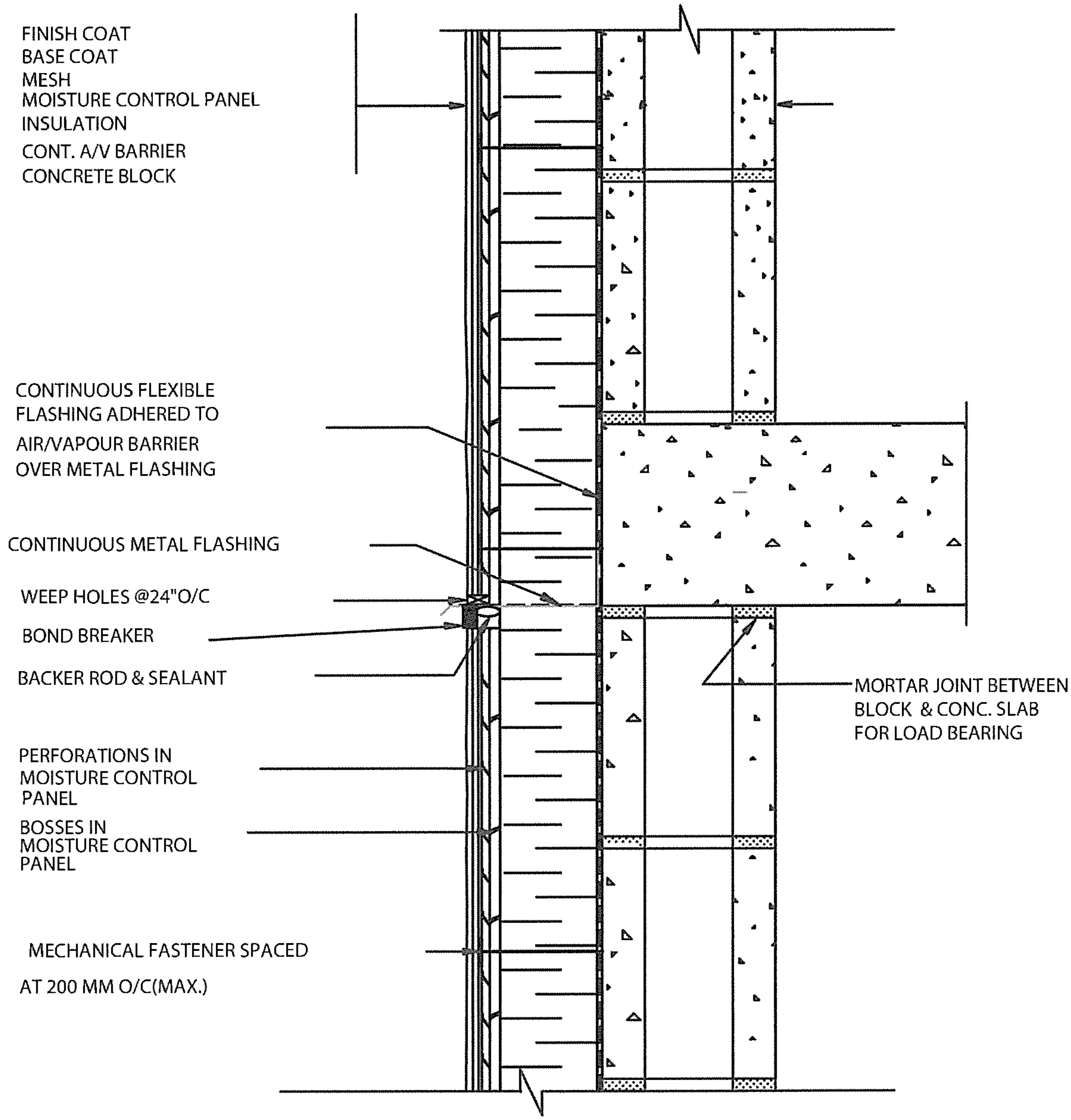
1. CONCRETE BLOCK BACKUP DETAILS



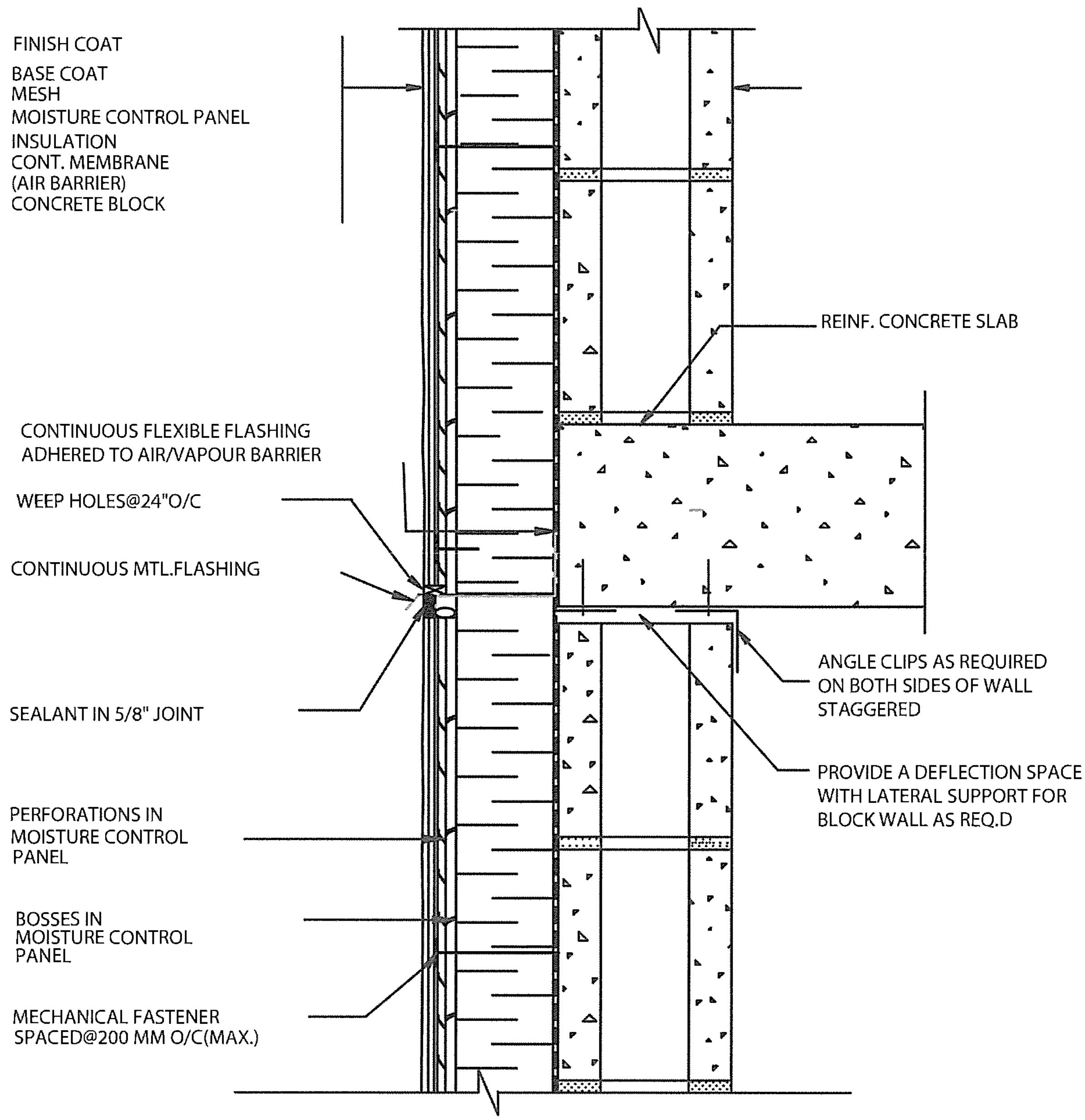
DETAIL 1.1 ACRYLIC STUCCO/CONCRETE BLOCK DETAIL AT FOUNDATION



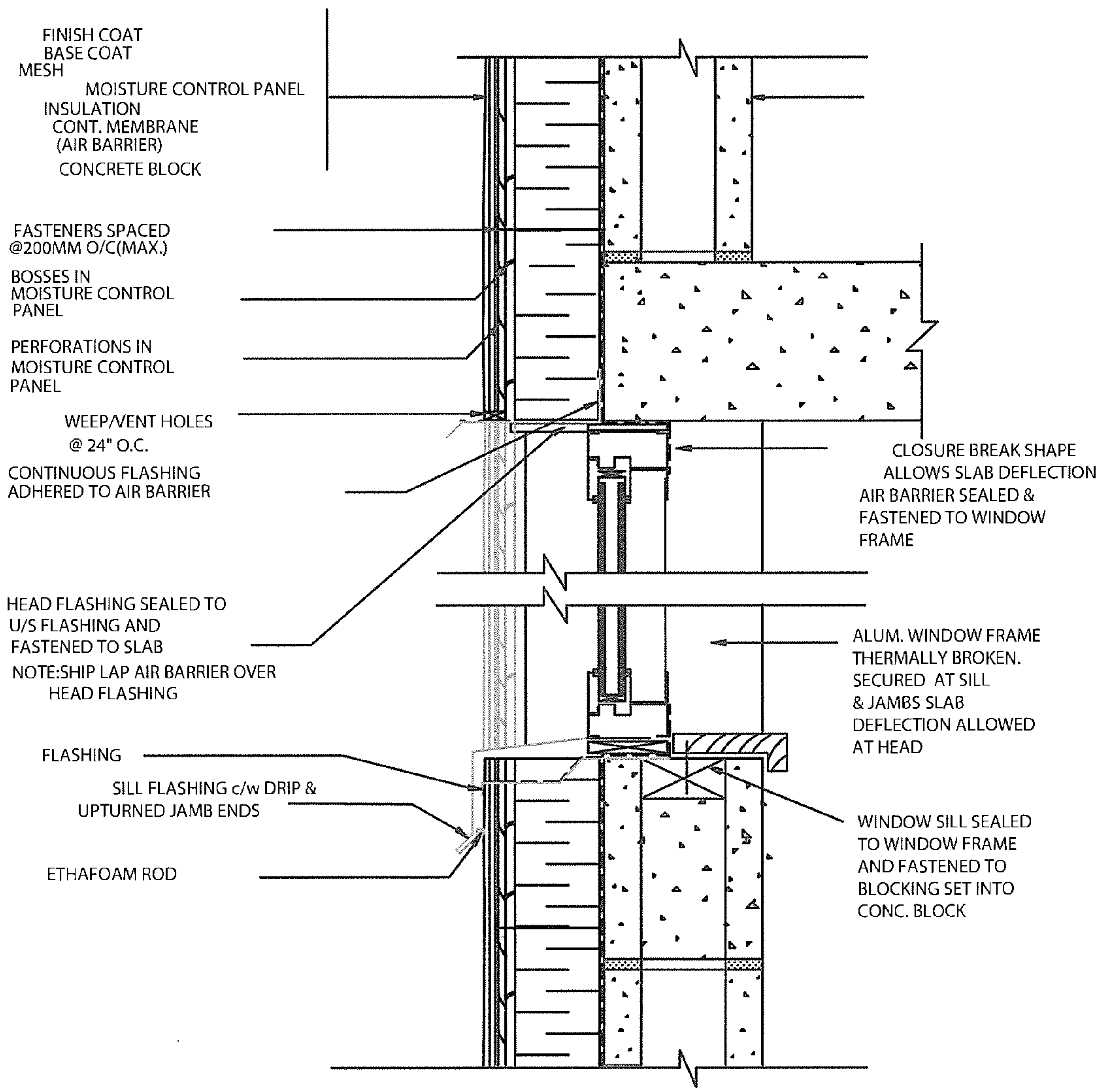
DETAIL 1.2 ACRYLIC STUCCO/CONCRETE BLOCK DETAIL AT FOUNDATION



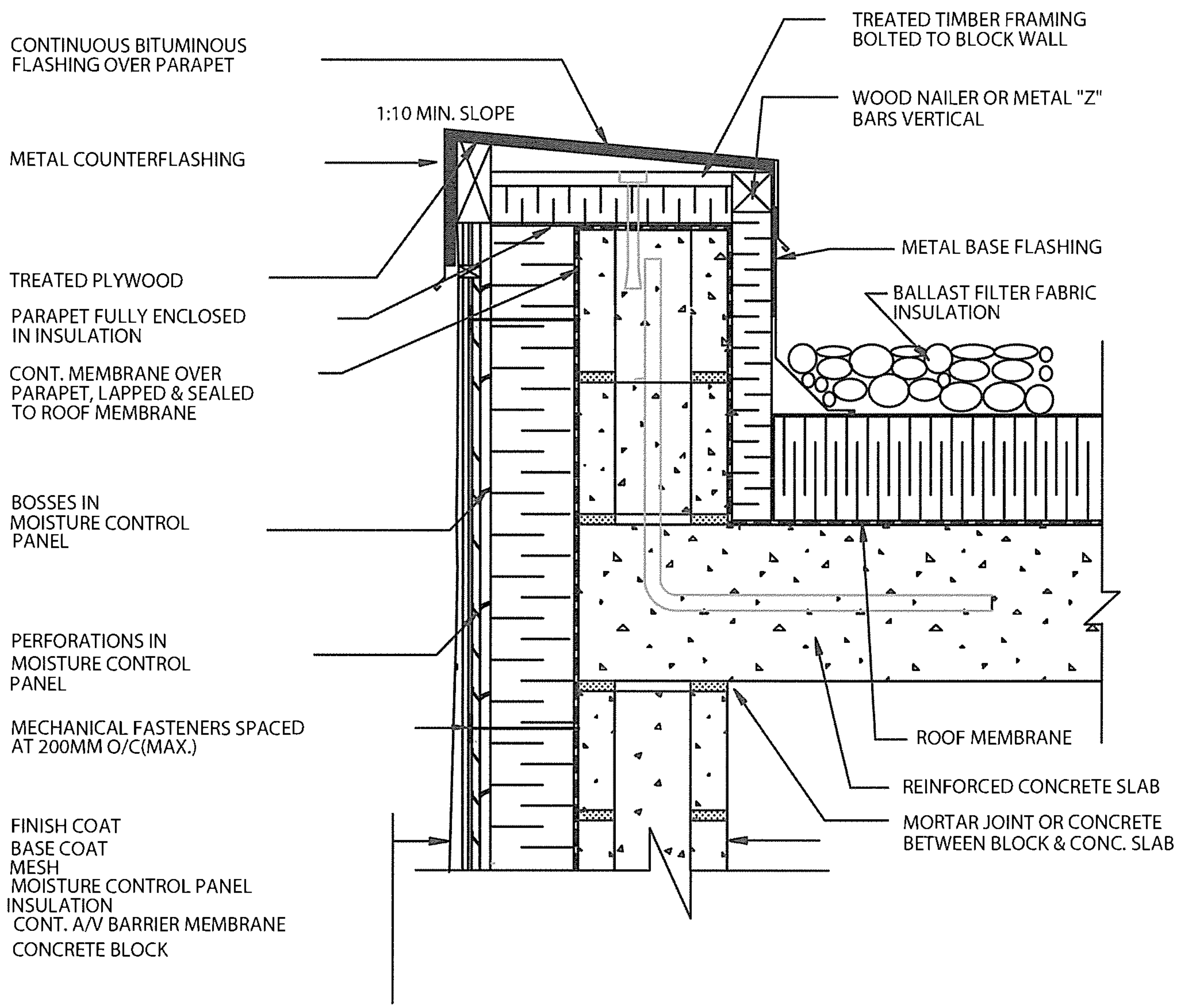
DETAIL 1.3 ACRYLIC STUCCOO/CONCRETE BLOCK DETAIL AT SLAB EDGE FOR LOAD BEARING WALL



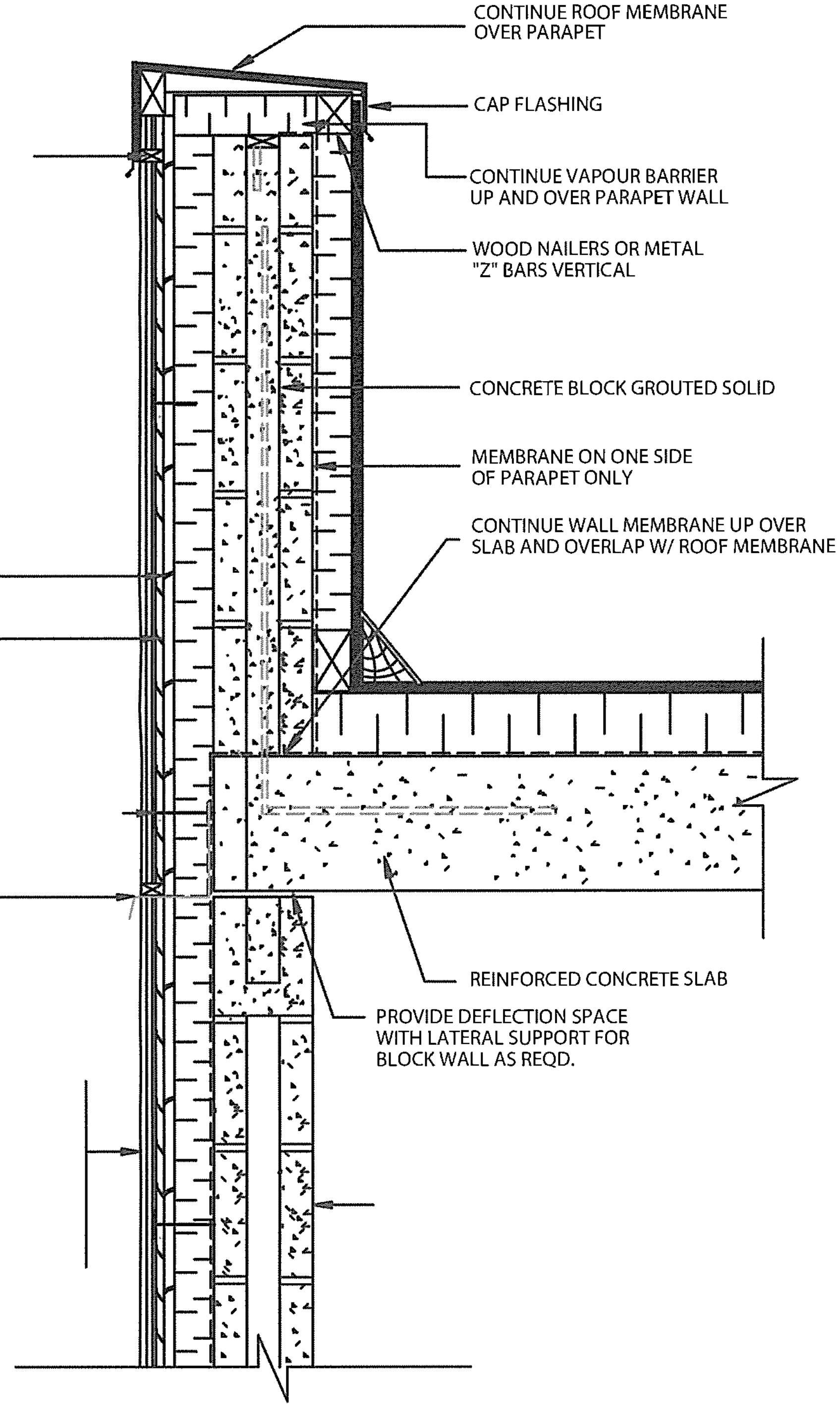
DETAIL 1.4 ACRYLIC STUCCO/CONCRETE BLOCK DETAIL AT SLAB EDGE
FOR NON LOAD BEARING WALL



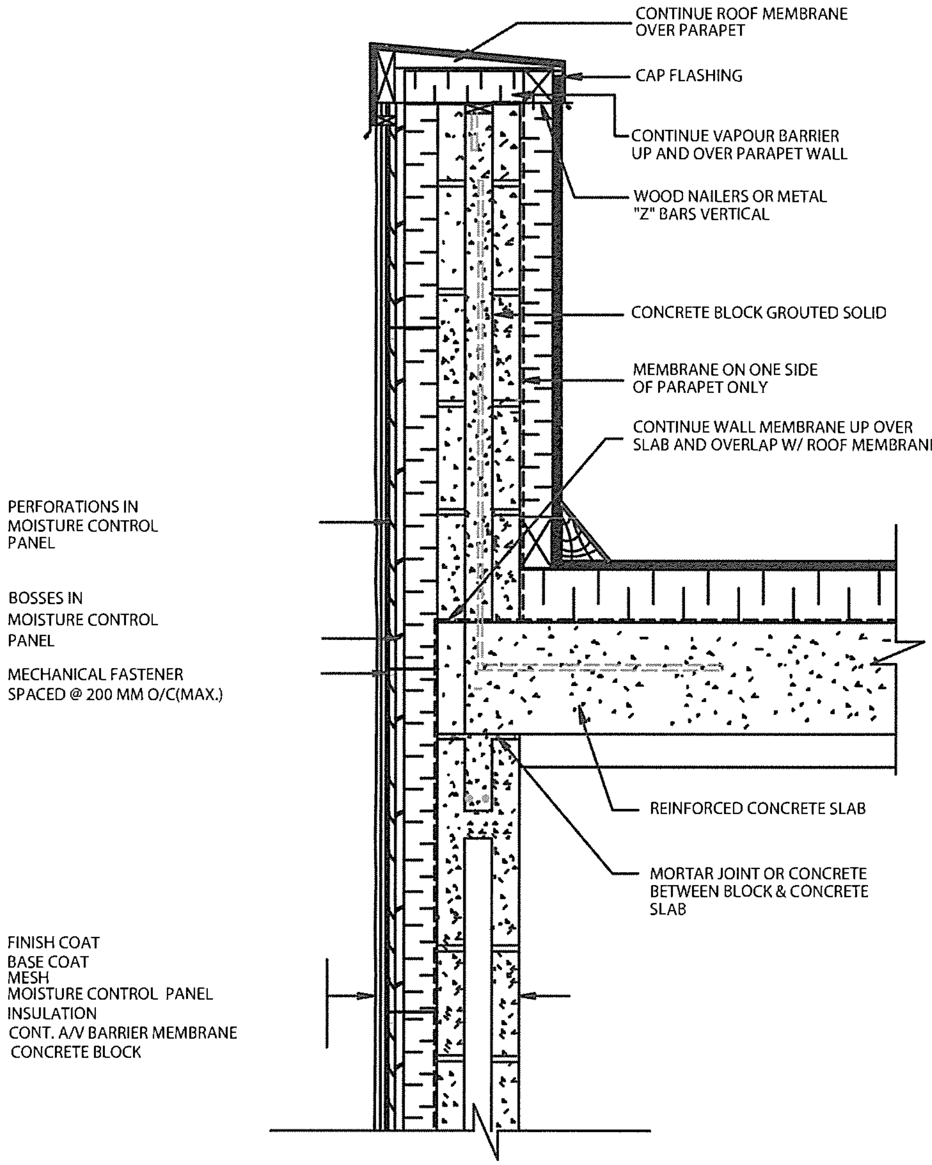
DETAIL 1.5 ACRYLIC STUCCO/ CONCRETE BLOCK - WINDOW HEAD & SILL DETAIL



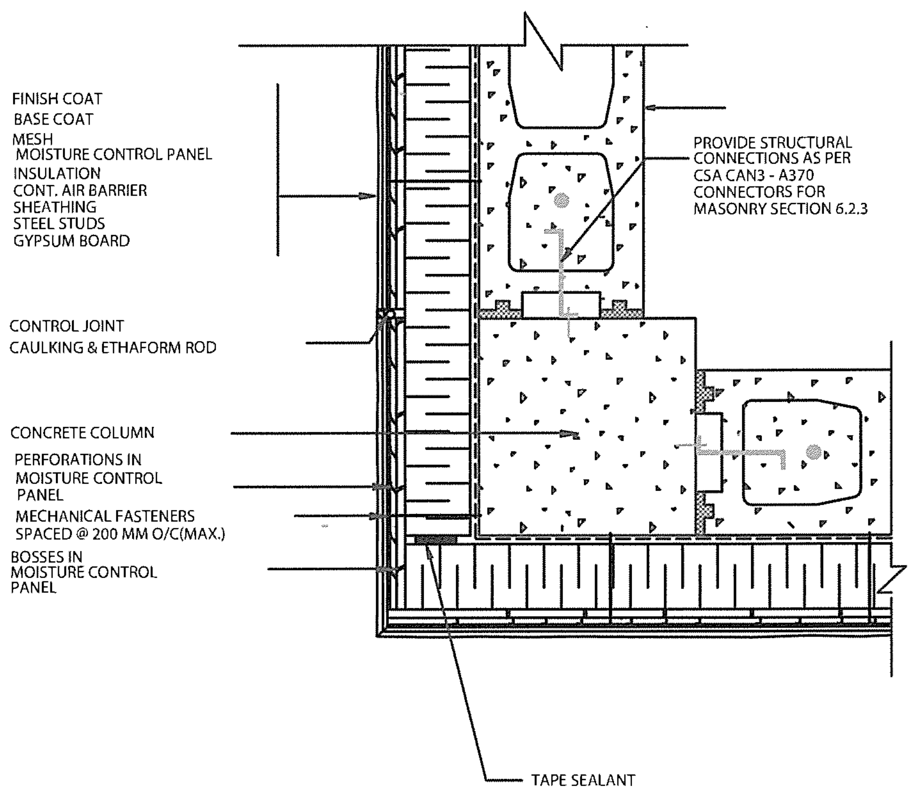
DETAIL 1.6 ACRYLIC STUCCO/CONCRETE BLOCK-DETAIL OF LOW PARAPET W/ PROTECTED ROOF MEMBRANE (LOAD BEARING WALL)



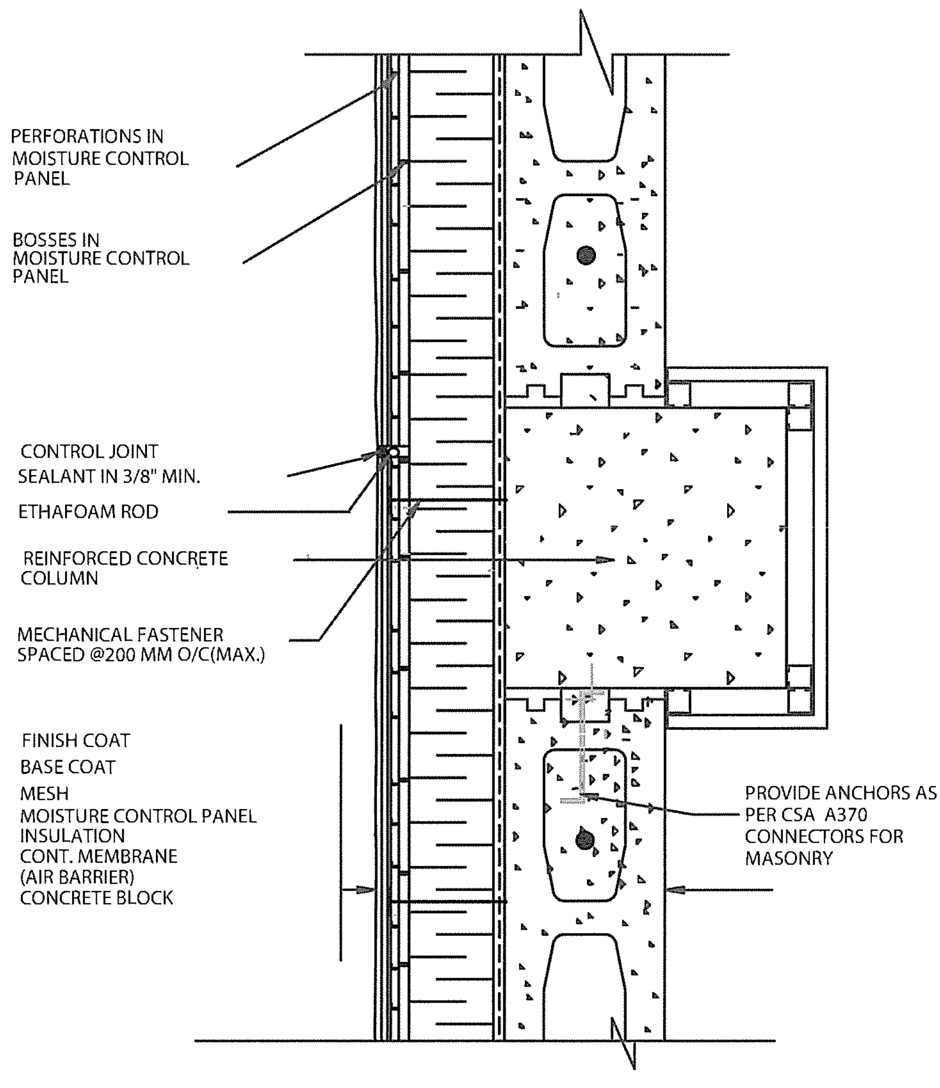
DETAIL 1.7 ACRYLIC STUCCO/CONCRETE BLOCK-DETAIL AT HIGH PARAPET FOR NON LOAD BEARING ASSEMBLY



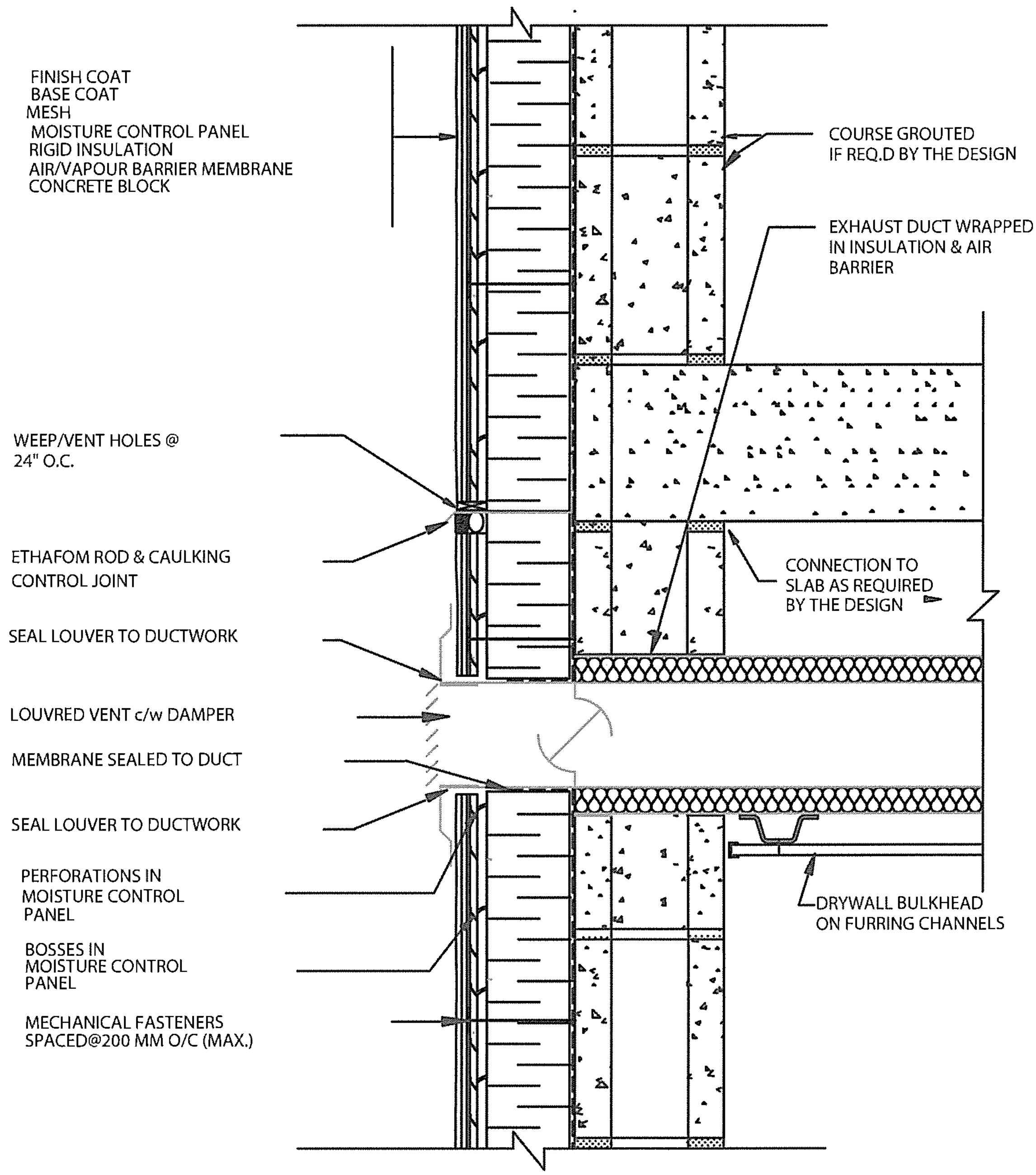
DETAIL 1.8 ACRYLIC STUCCO/CONCRETE BLOCK-DETAIL AT HIGH PARAPET FOR LOAD BEARING ASSEMBLY



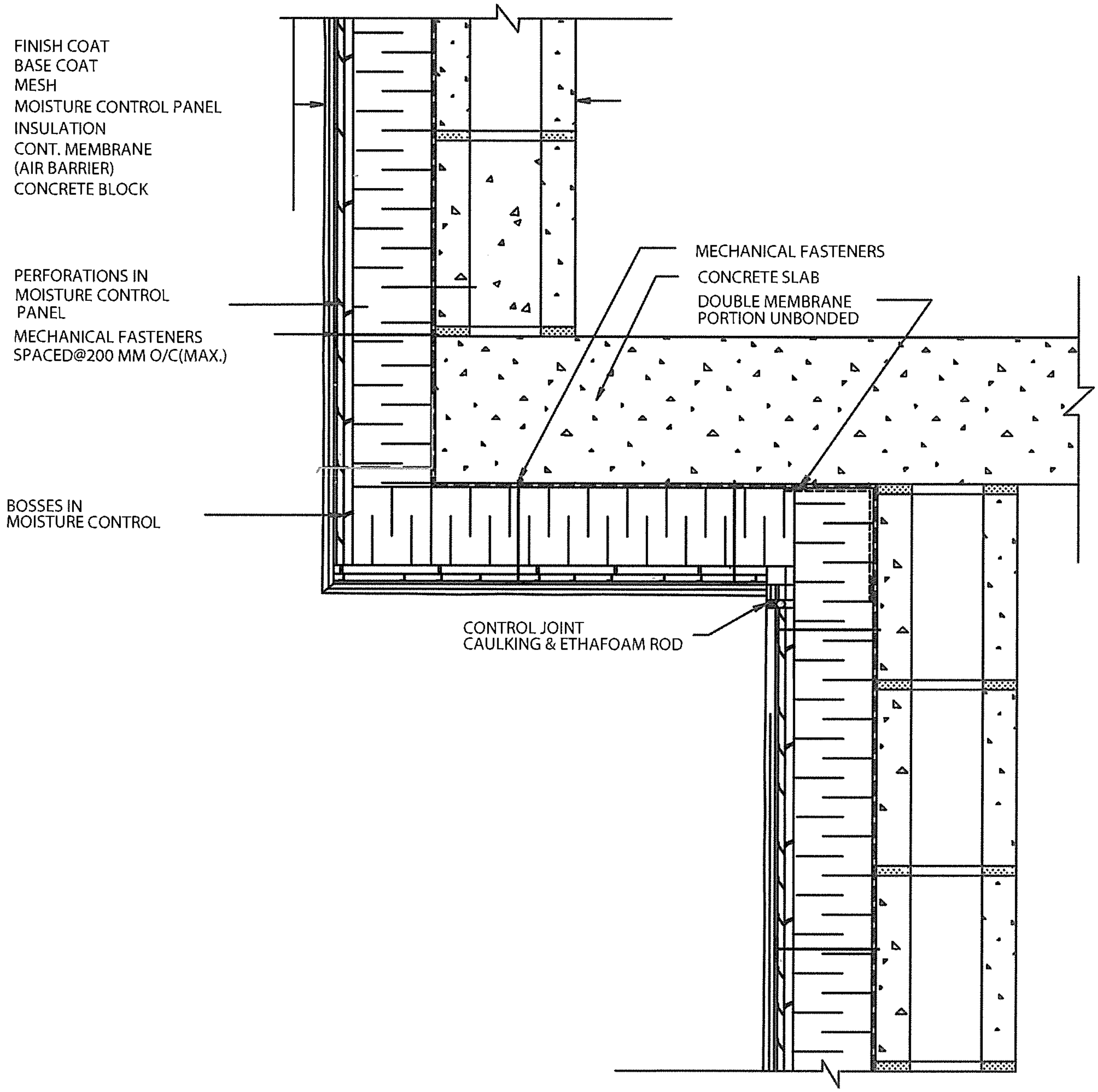
DETAIL 1.9 ACRYLIC STUCCO/CONCRETE BLOCK - CONTROL JOINT



DETAIL 1.10 ACRYLIC STUCCO/CONCRETE BLOCK - CONTROL JOINT

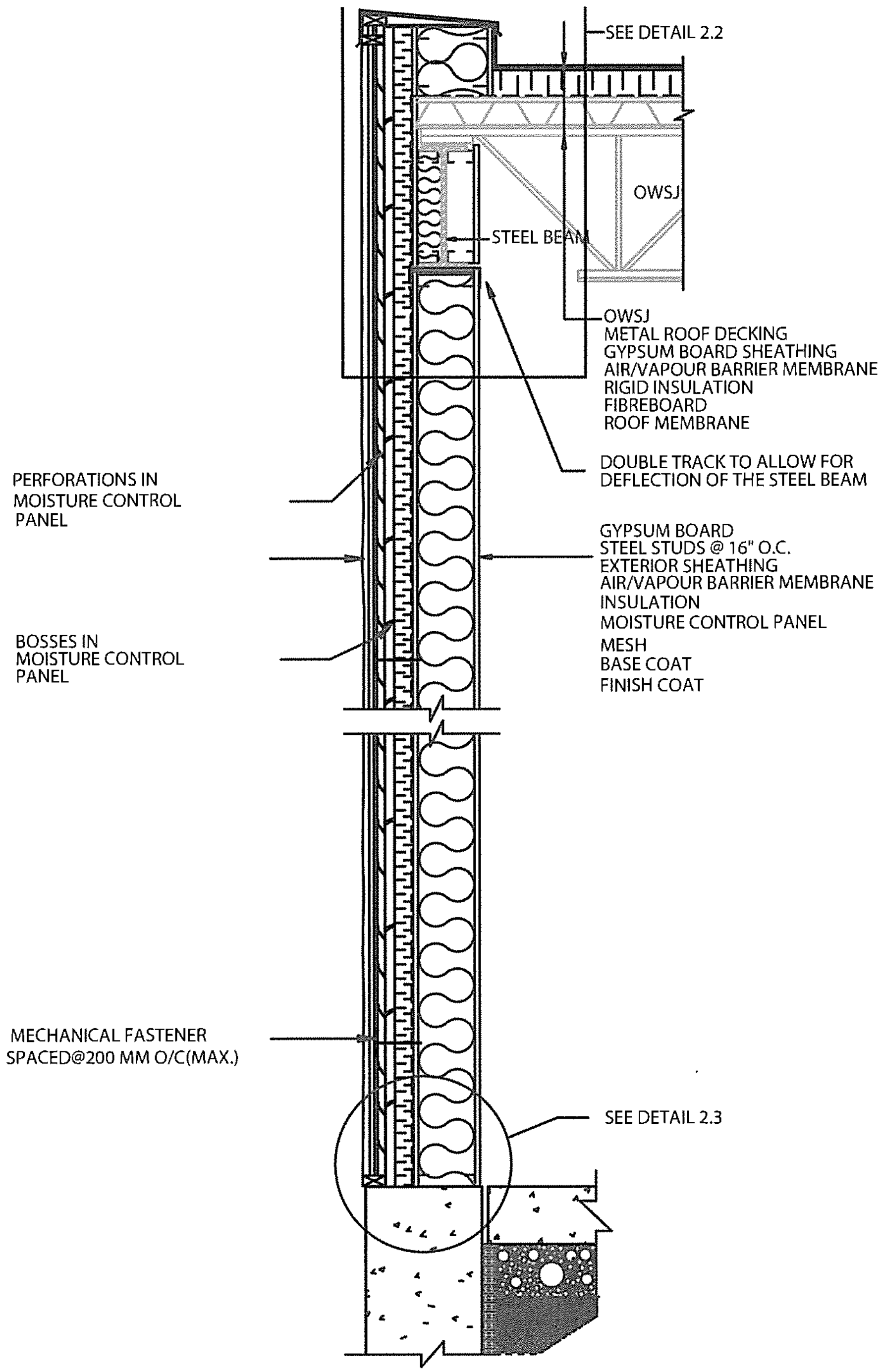


DETAIL 1.11 ACRYLIC STUCCO/CONCRETE BLOCK-EXHAUST VENT DETAIL

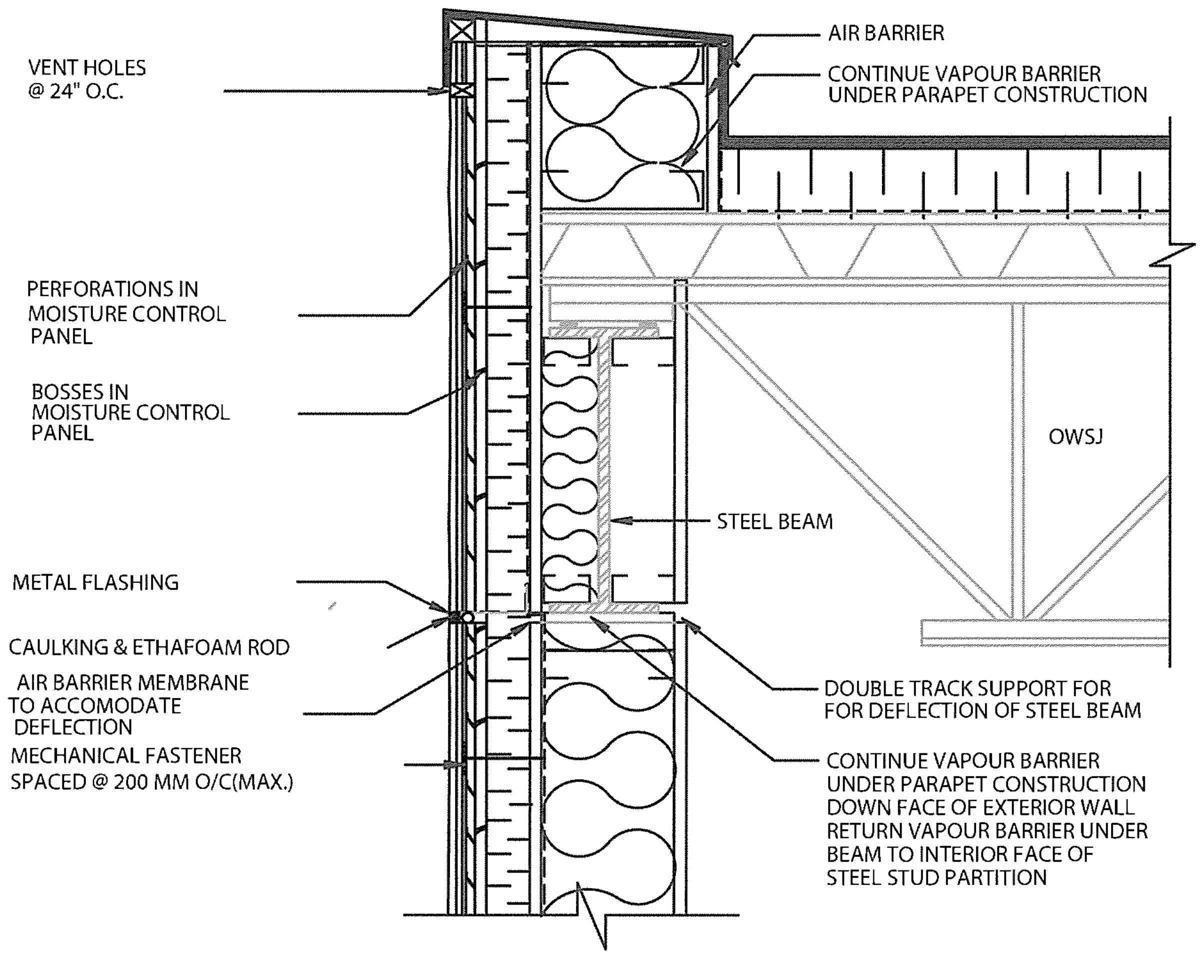


DETAIL 1.12 ACRYLIC STUCCO/CONCRETE BLOCK-COLD SOFFIT DETAIL

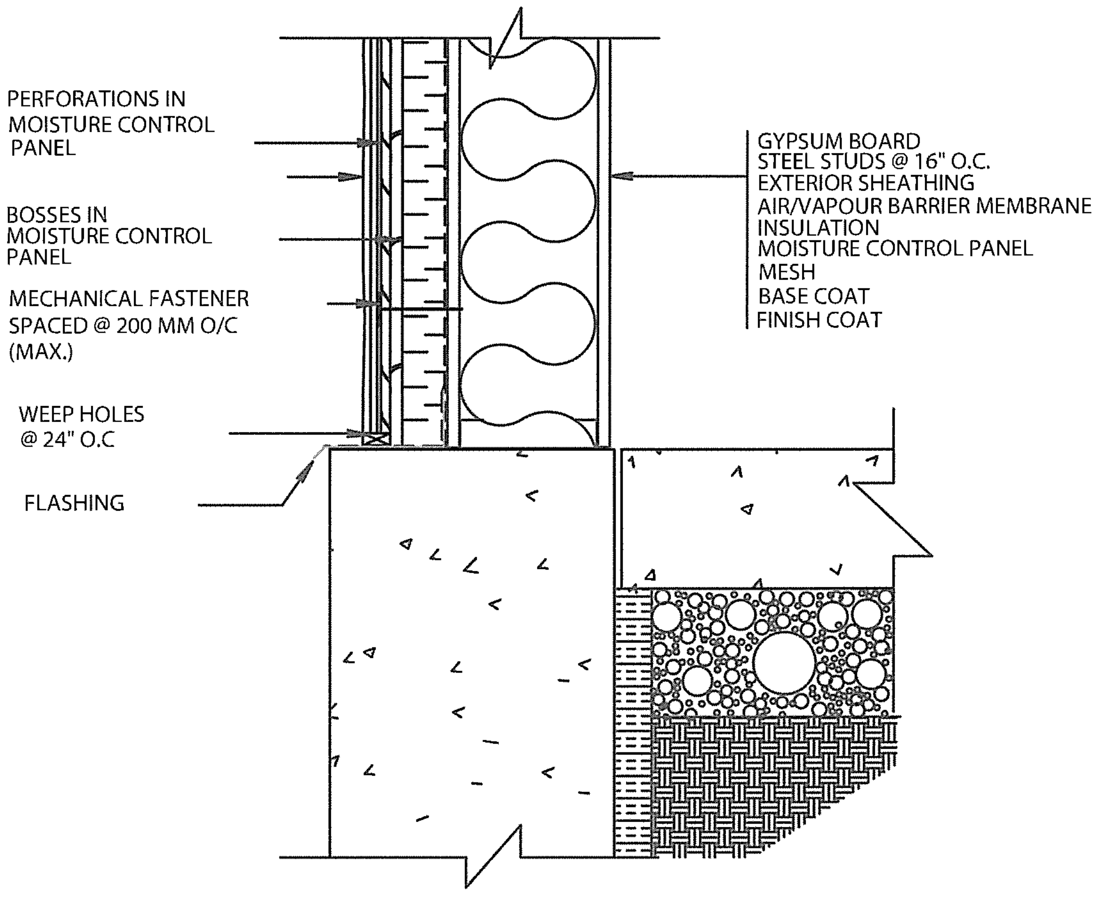
2. STEEL STUD BACKUP DETAILS



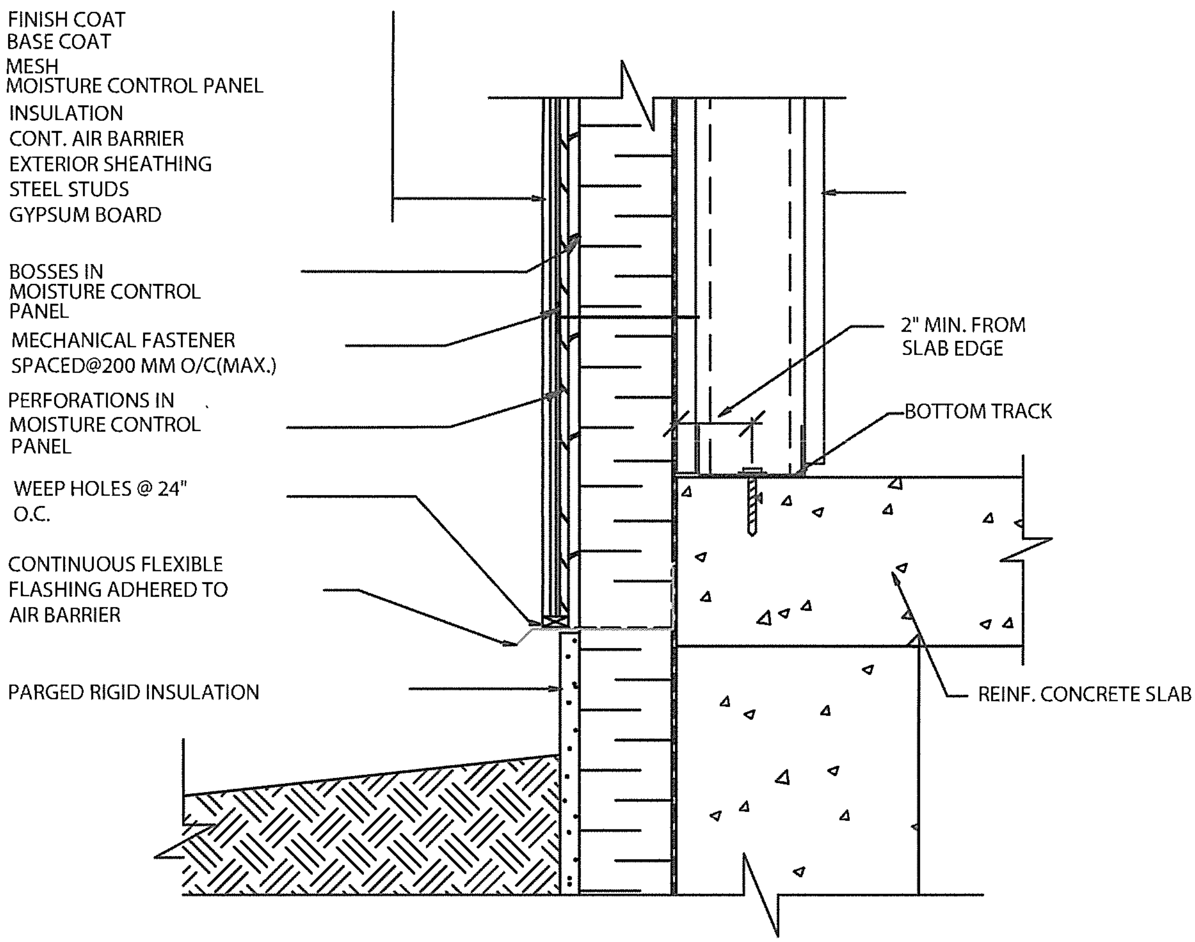
DETAIL 2.1 ACRYLIC STUCCO / STEEL STUD - O.W.S.J.



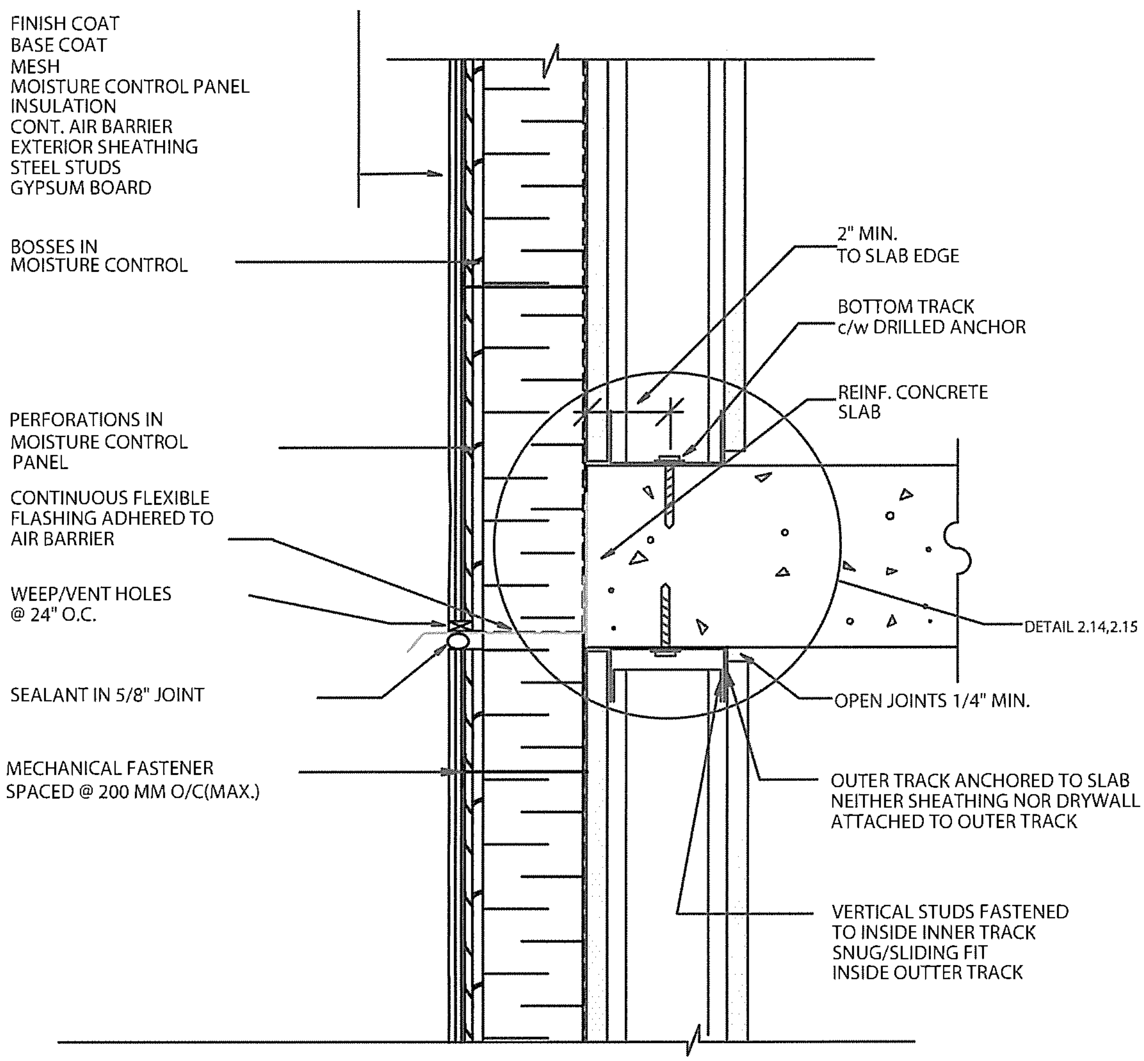
DETAIL 2.2 ACRYLIC STUCCO/ STEEL STUD
PARAPET DETAIL @ O.W.S.J.



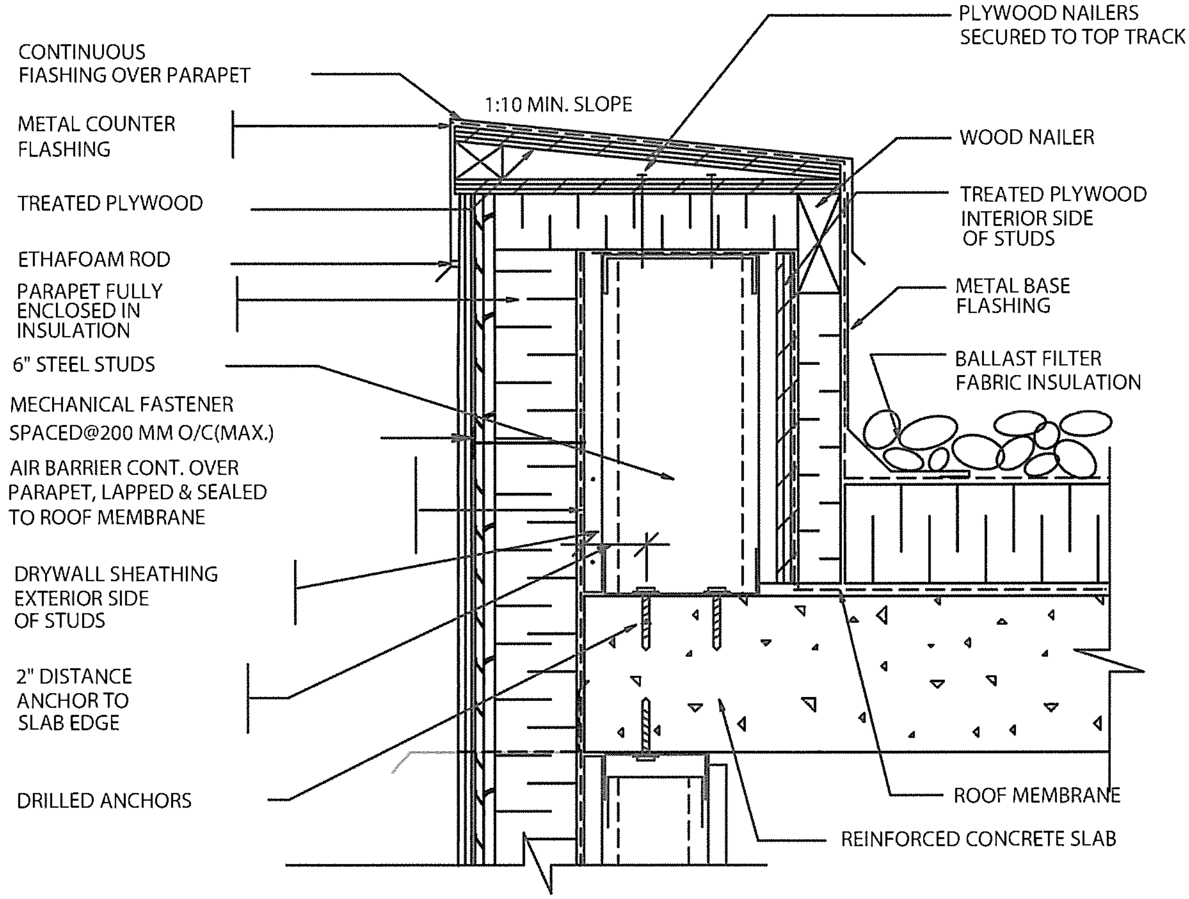
DETAIL 2.3 ACRYLIC STUCCO/ STEEL STUD - AT FOUNDATION



DETAIL 2.4 ACRYLIC STUCCO / STEEL STUD DETAIL AT FOUNDATION

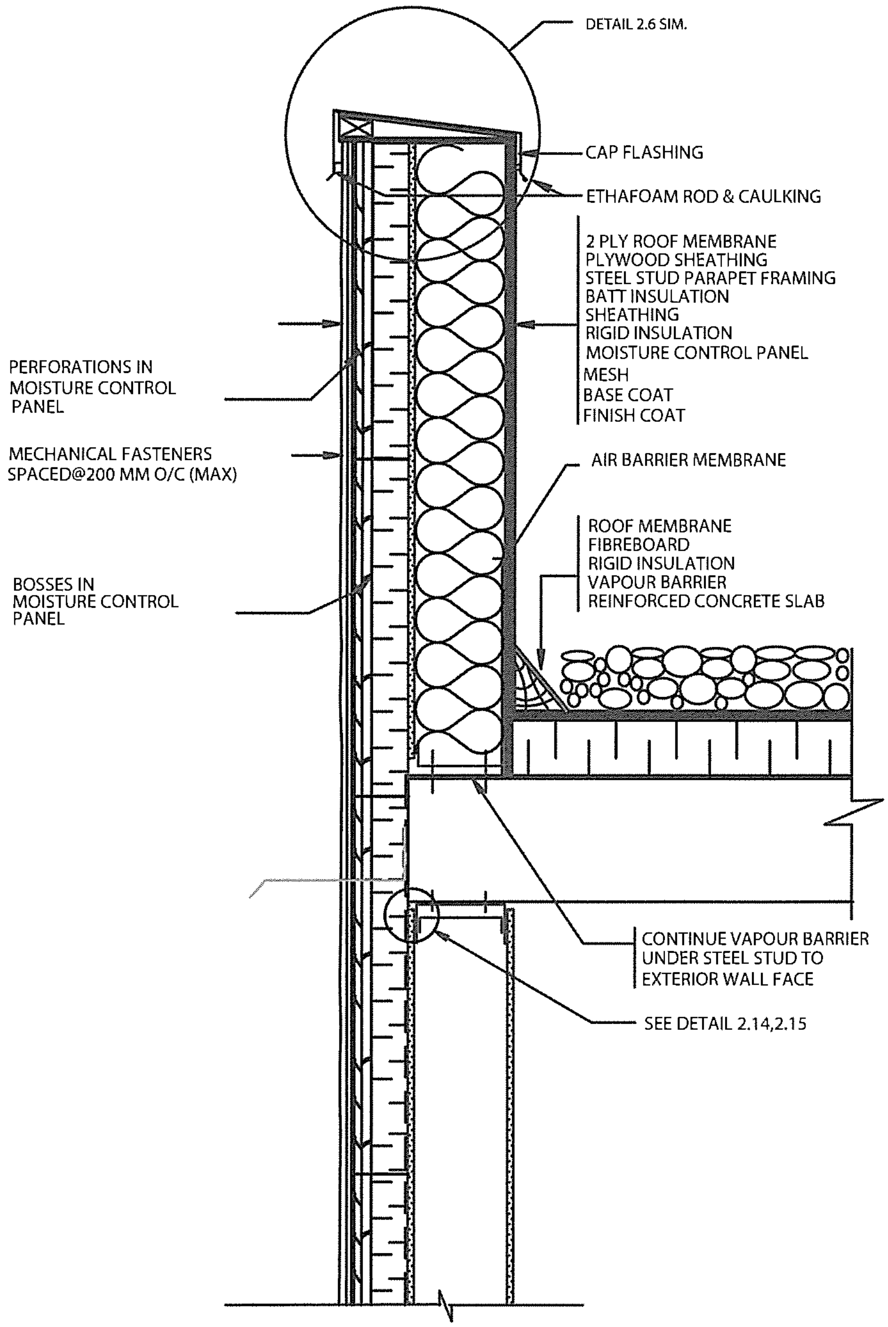


DETAIL 2.5 ACRYLIC STUCCO/ STEEL STUD DETAIL AT SLAB EDGE

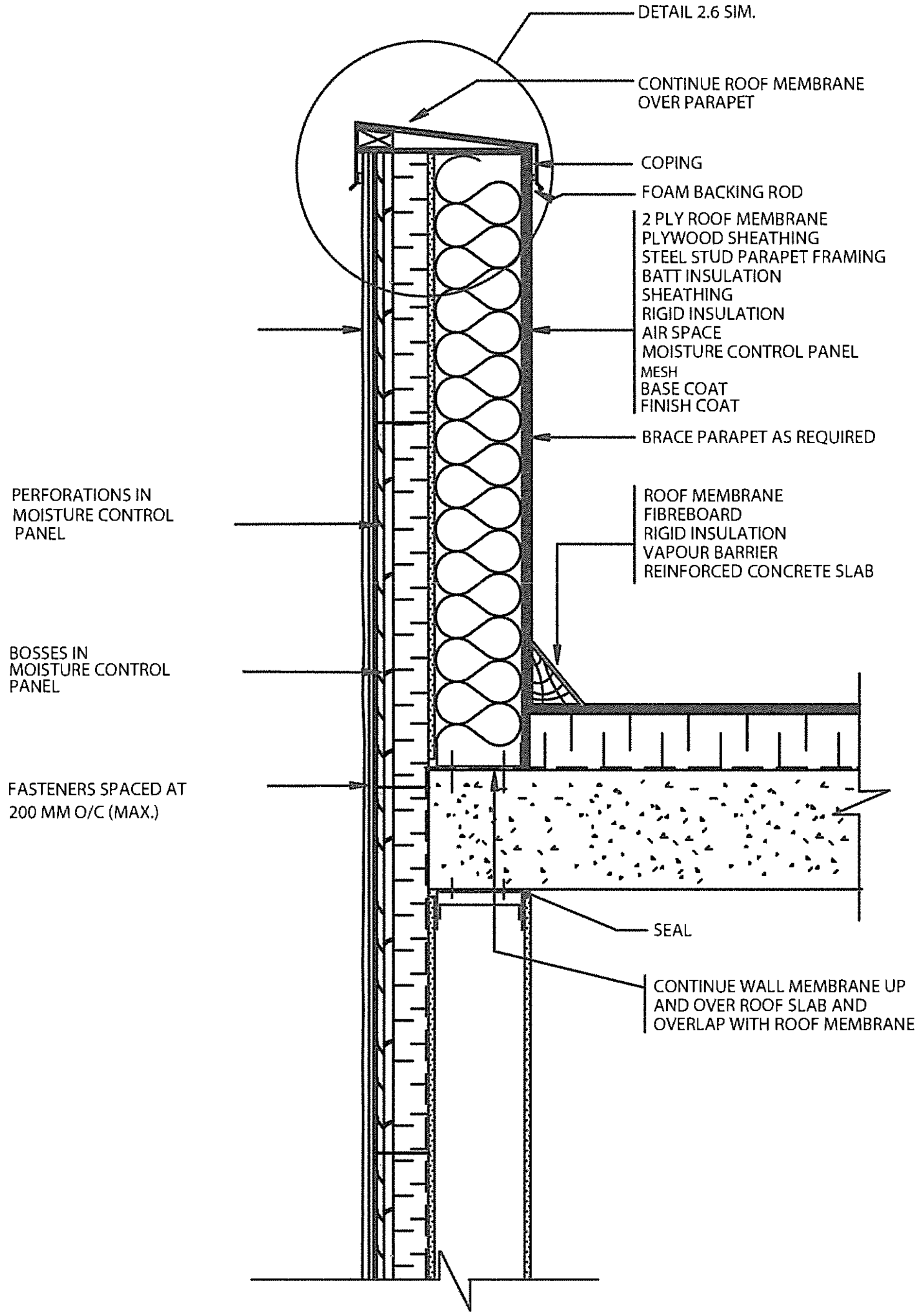


DETAIL 2.6 ACRYLIC STUCCO / STEEL STUD

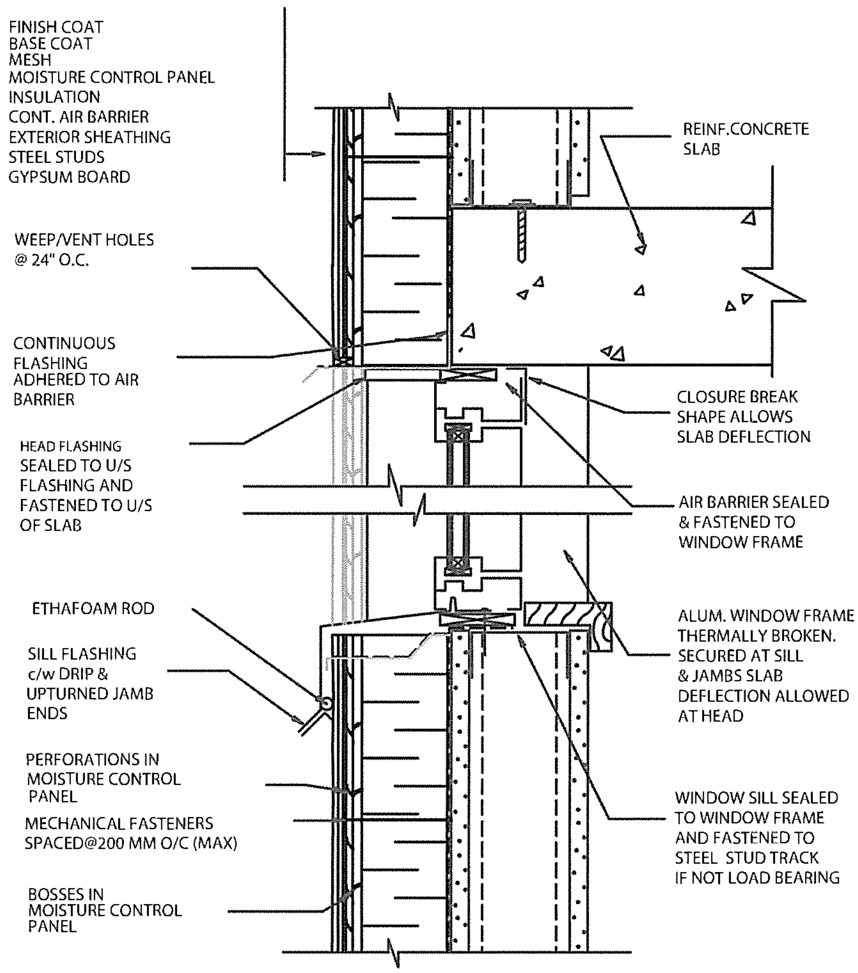
DETAIL AT LOW PARAPET



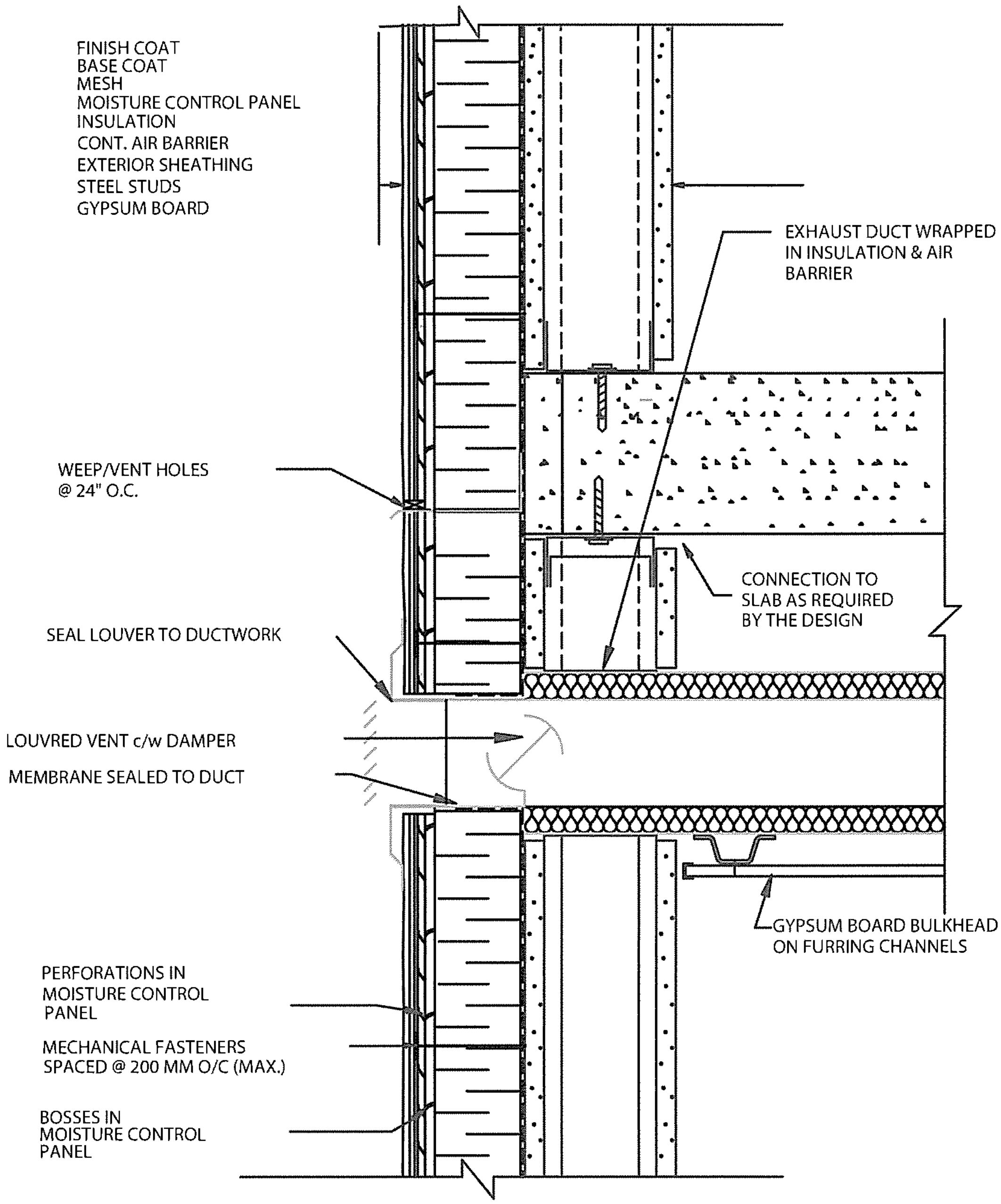
DETAIL 2.7 ACRYLIC STUCCO/ STEEL STUD
DETAIL AT HIGH PARAPET



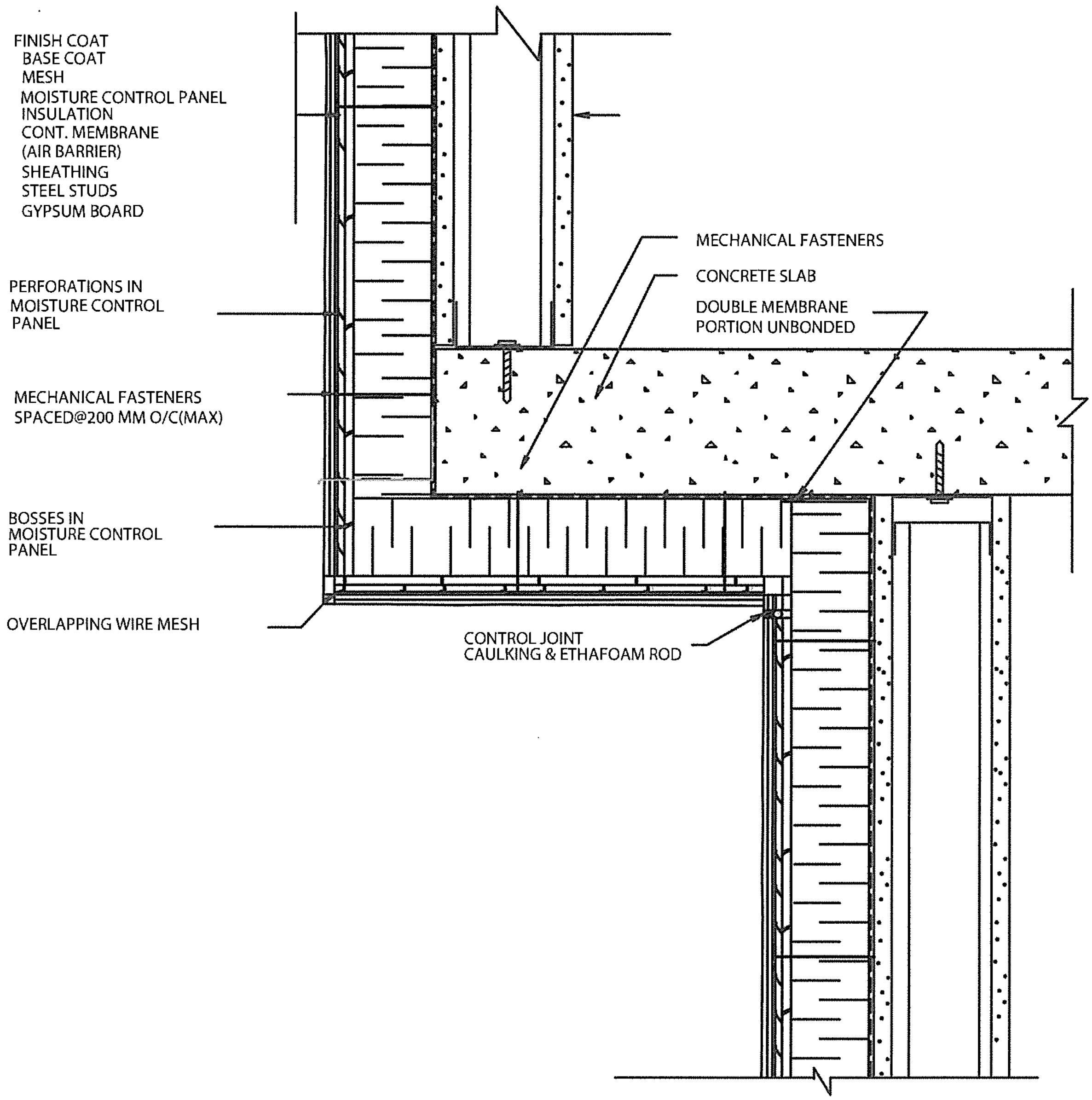
DETAIL 2.8 ACRYLIC STUCCO/ CONCRETE BLOCK
DETAIL AT HIGH PARAPET



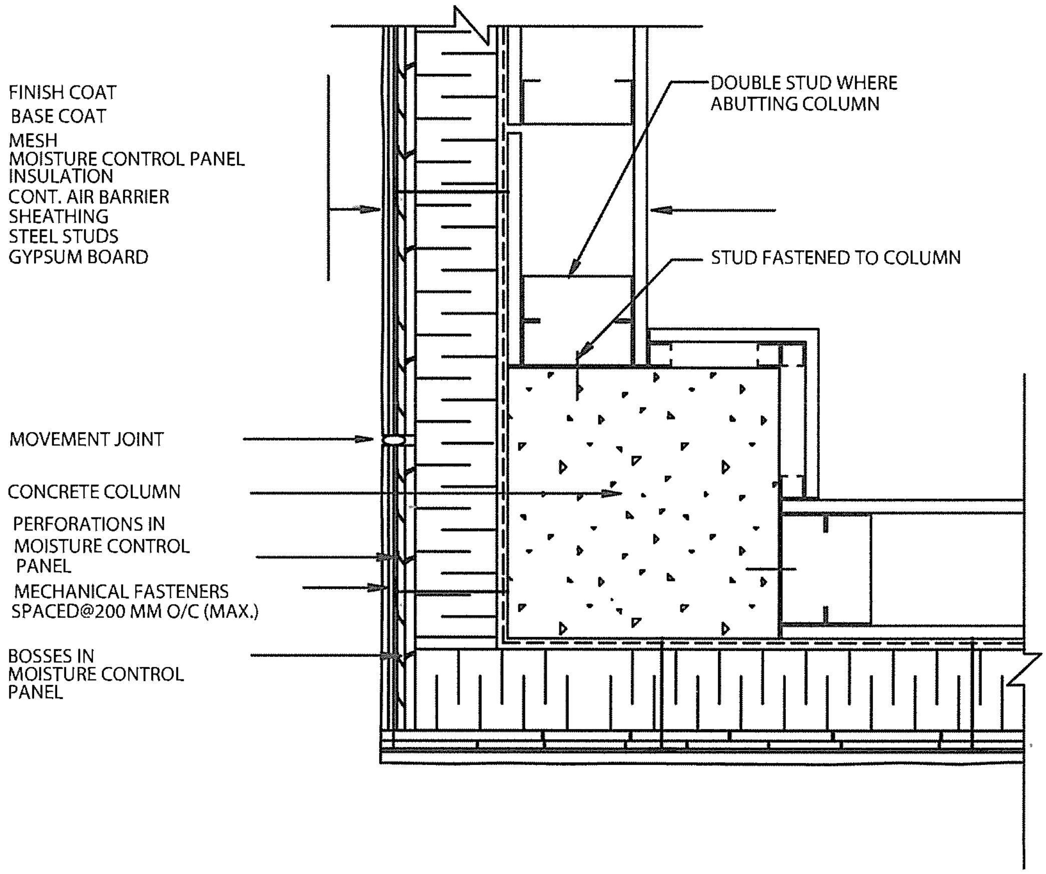
DETAIL 2.9 ACRYLIC STUCCO / STEEL STUD
WINDOW HEAD & SILL DETAIL



DETAIL 2.10 ACRYLIC STUCCO/STEEL STUD
EXHAUST VENT DETAIL

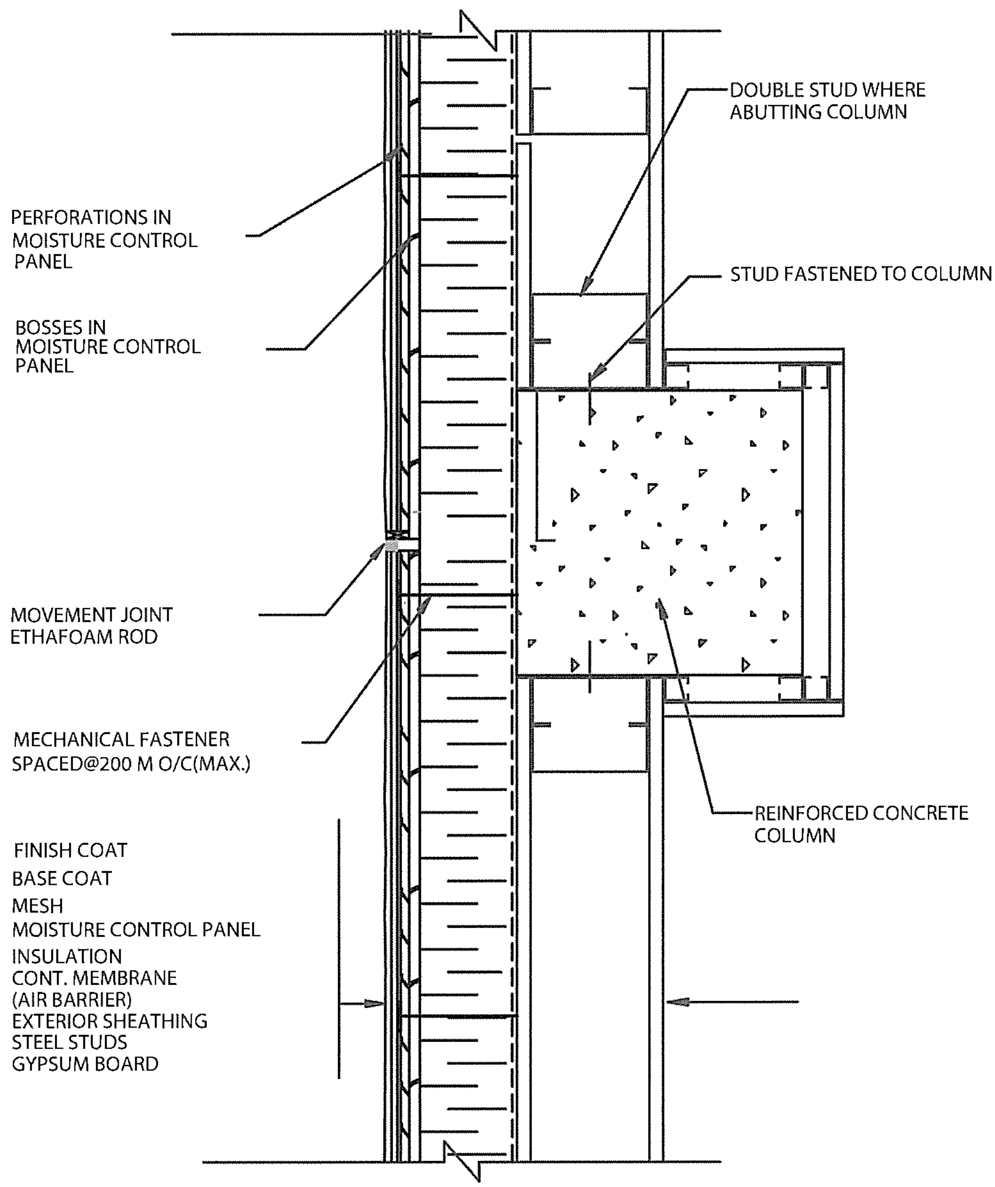


DETAIL 2.11 ACRYLIC STUCCO/STEEL STUD
COLD SOFFIT DETAIL



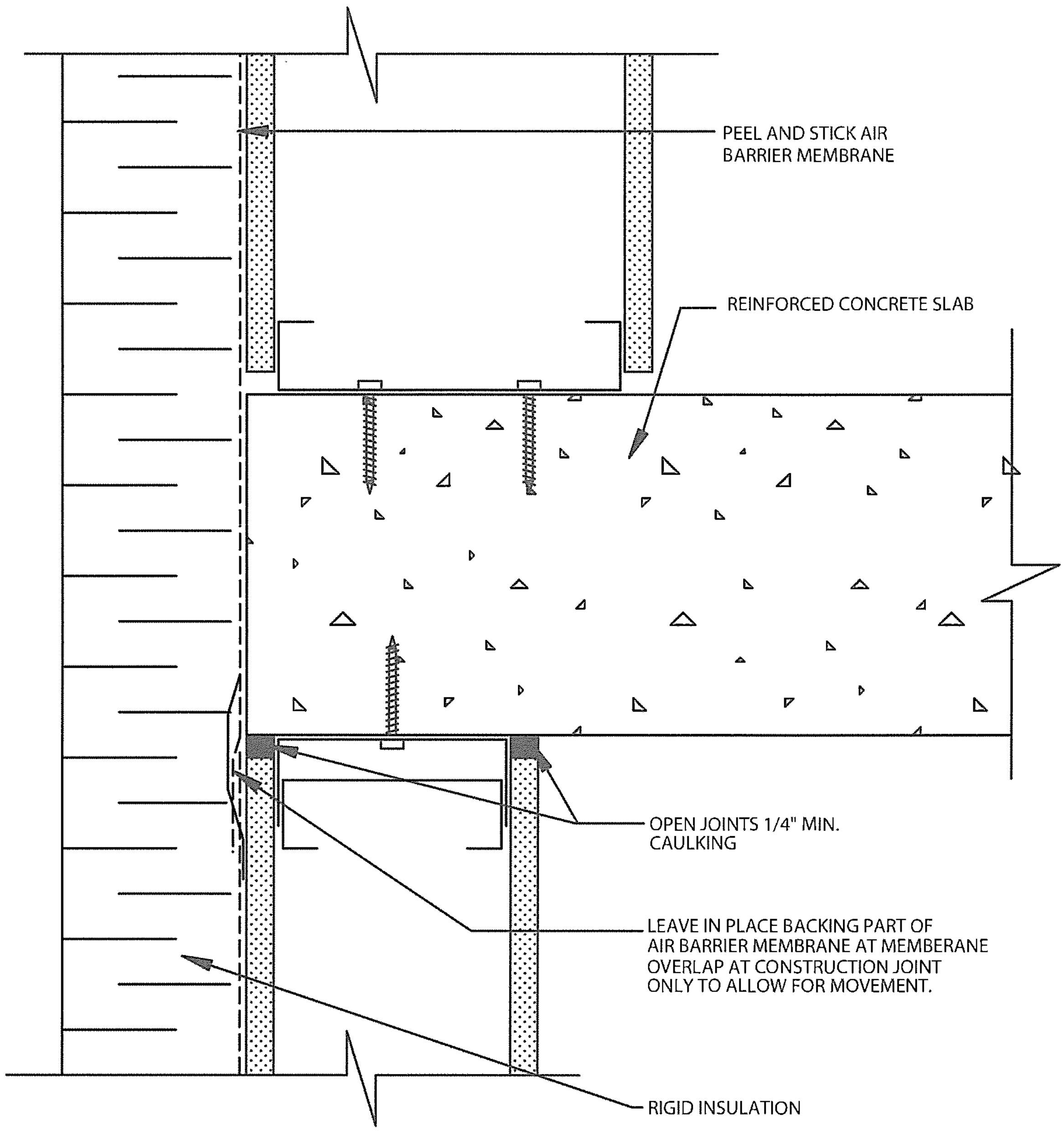
DETAIL 2.12 ACRYLIC STUCCO / STEEL STUD

CONTROL JOINT

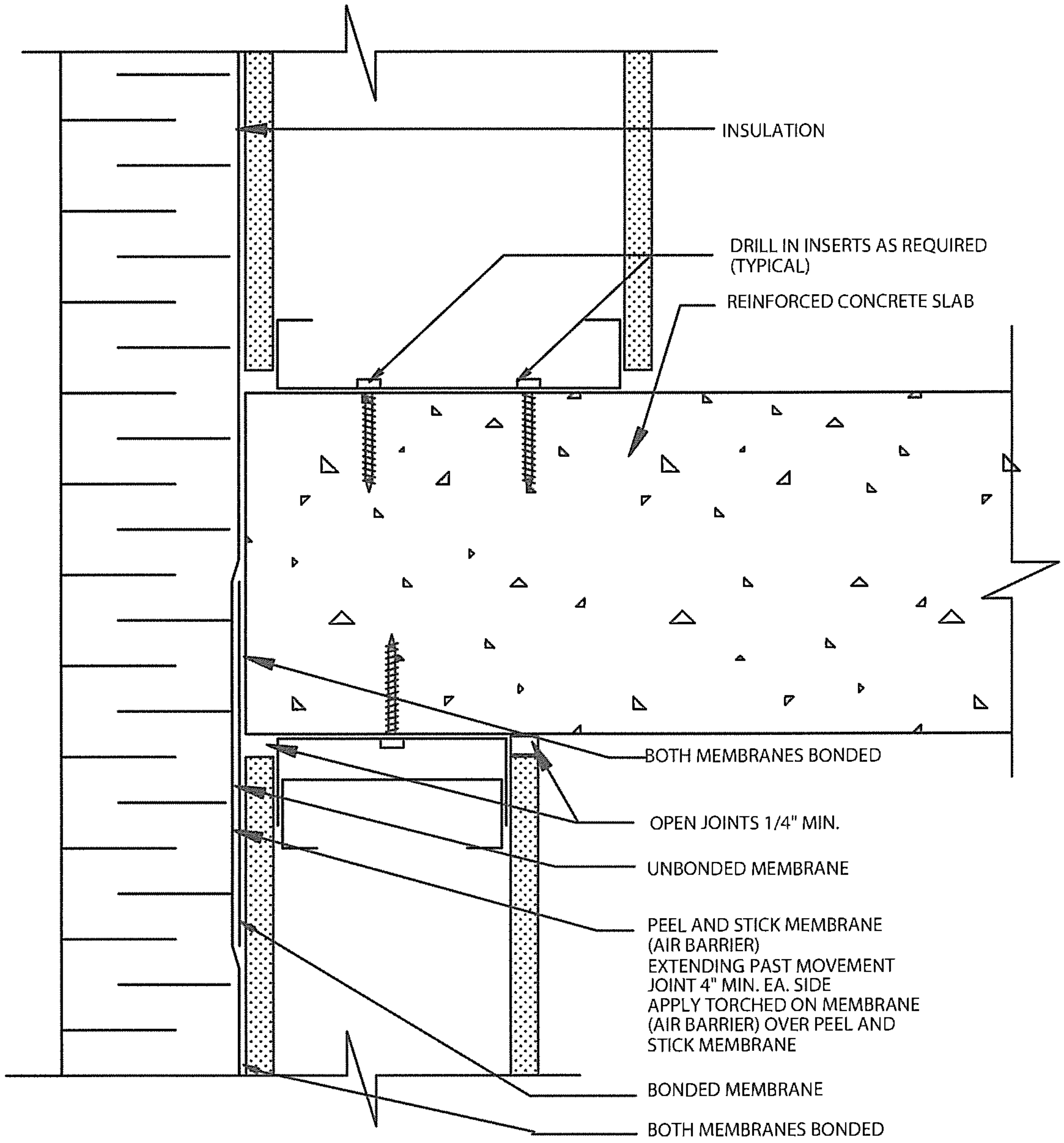


DETAIL 2.13 ACRYLIC STUCCO / STEEL STUD

CONTROL JOINT

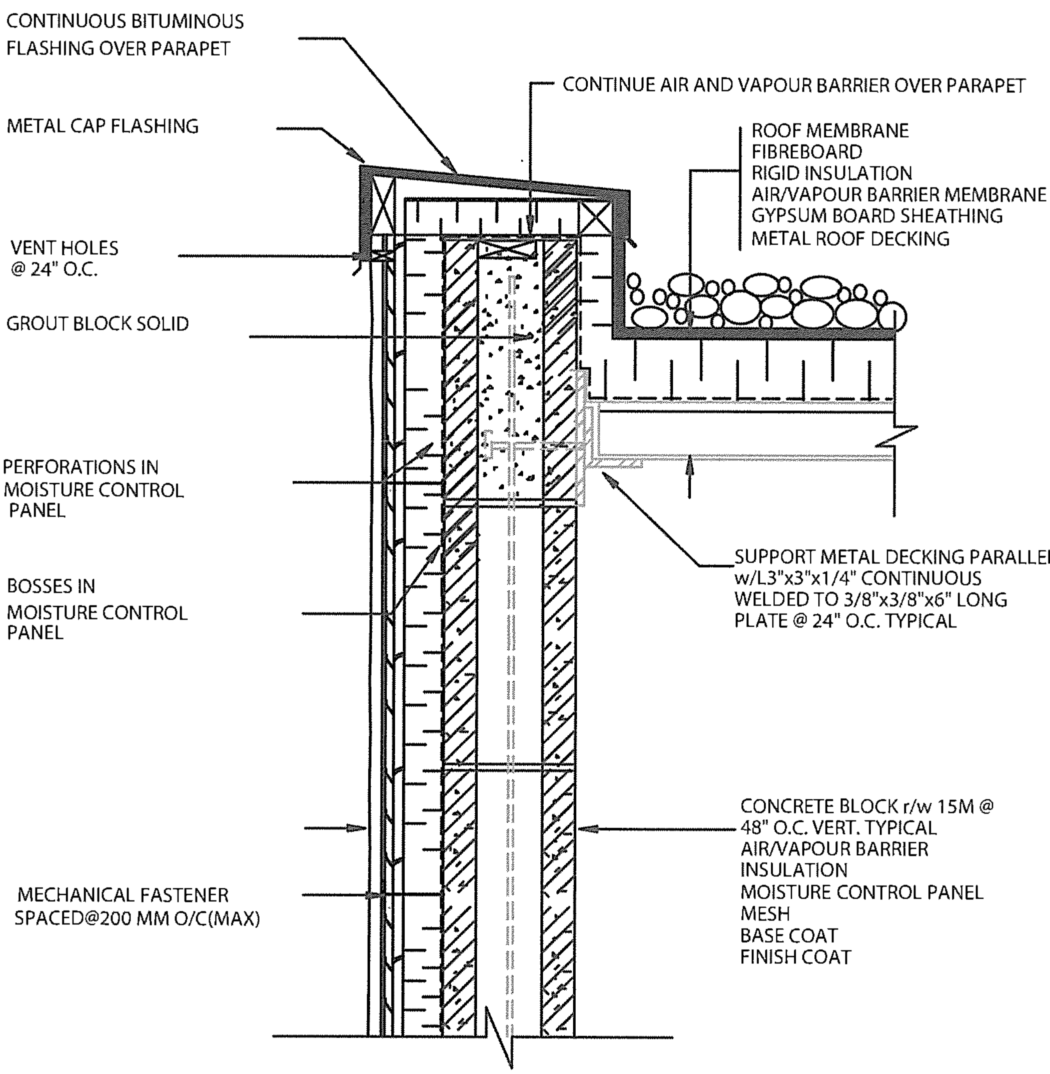


DETAIL 2.14 AIR VAPOUR BARRIER DETAIL AT MOVEMENT JOINT

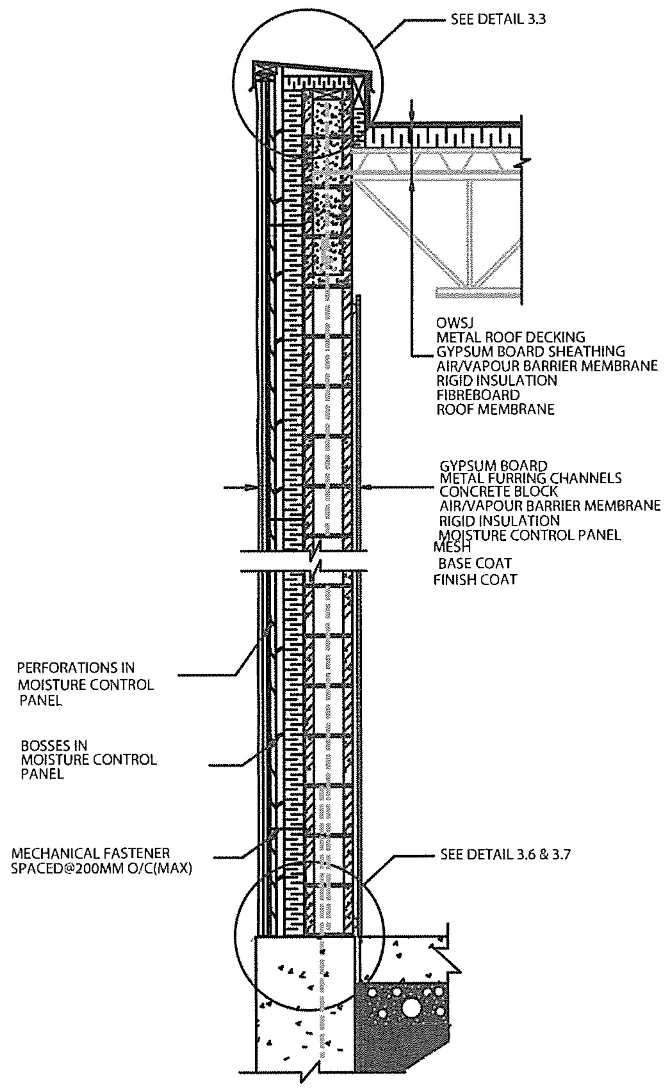


DETAIL 2.15 ALTERNATE MEMBRANE DETAIL AT MOVEMENT JOINT

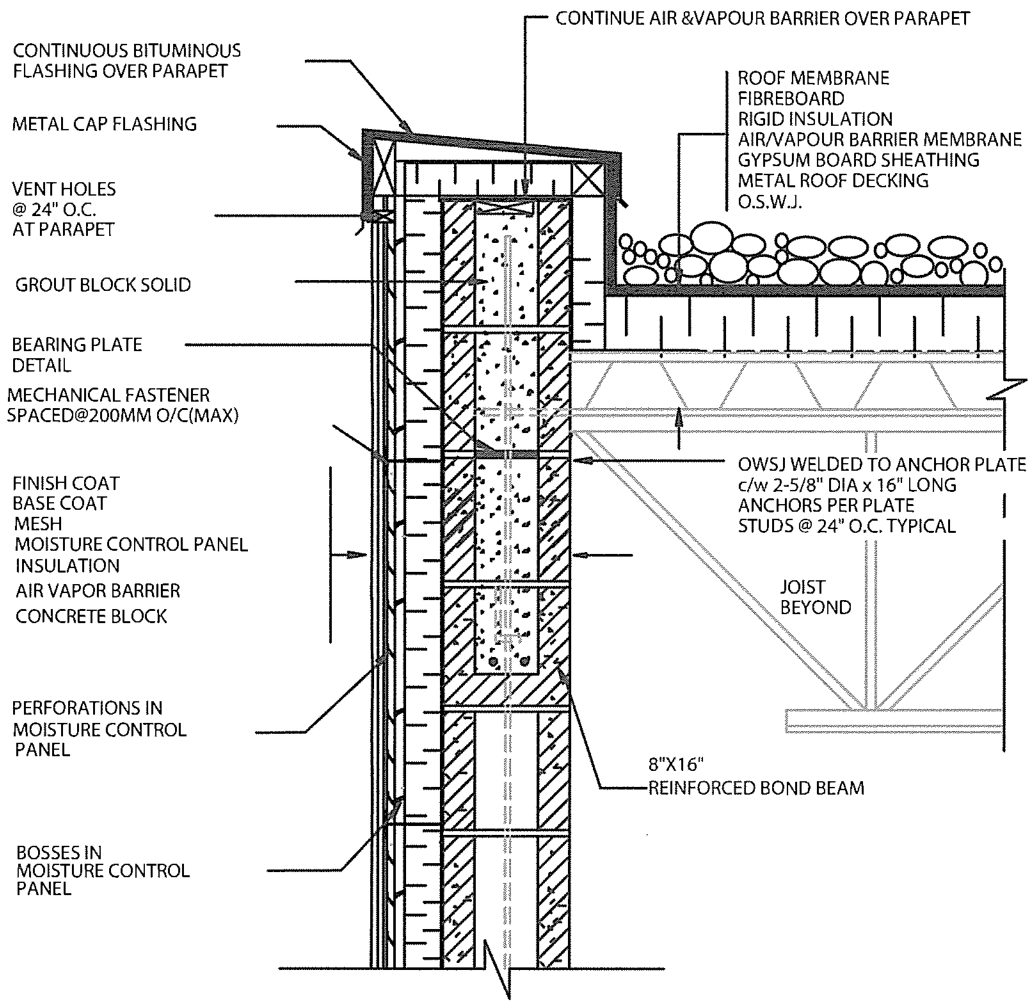
3. MISCELLANEOUS DETAILS



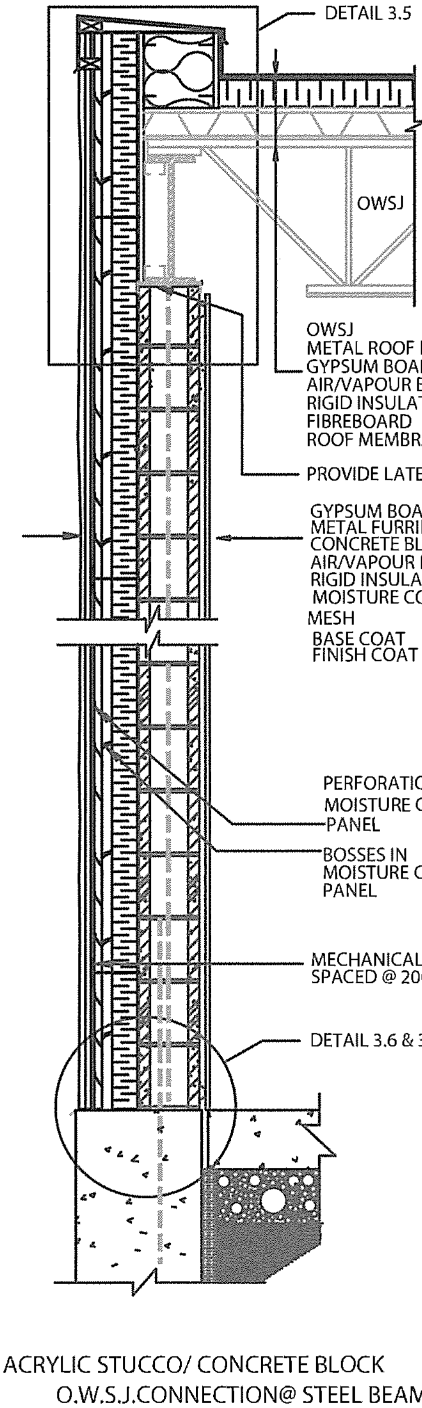
DETAIL 3.1 ACRYLIC STUCCO / CONCRETE BLOCK WALL PARALLEL TO O.W.S.J.



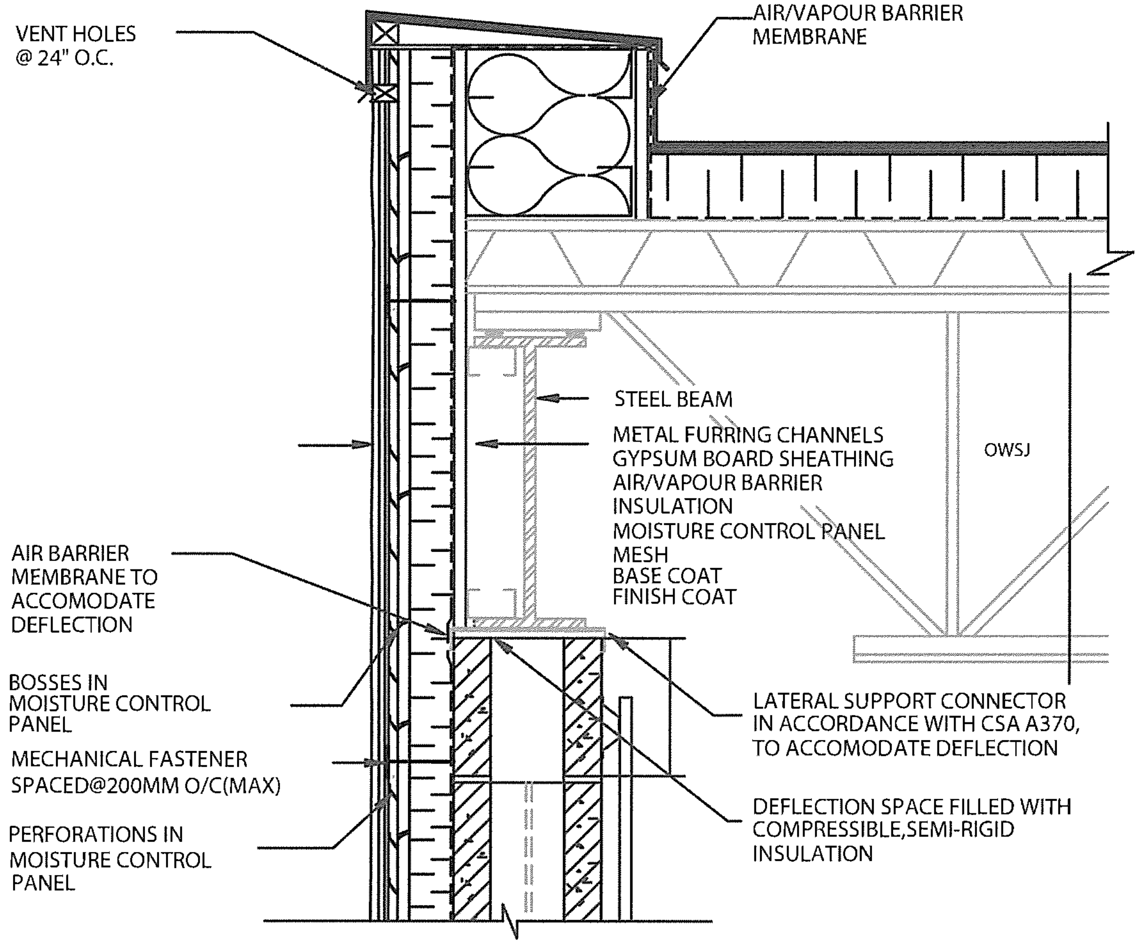
DETAIL 3.2 ACRYLIC STUCCO / CONCRETE BLOCK
NTS O.W.S.J. CONNECTION



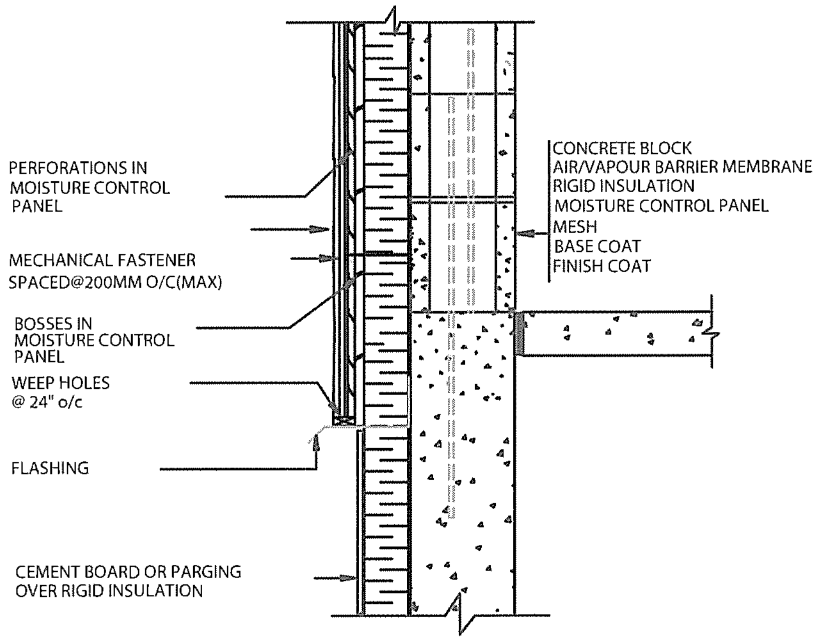
DETAIL 3.3 ACRYLIC STUCCO / CONCRETE BLOCK
PARAPET DETAIL @ O.W.S.J.



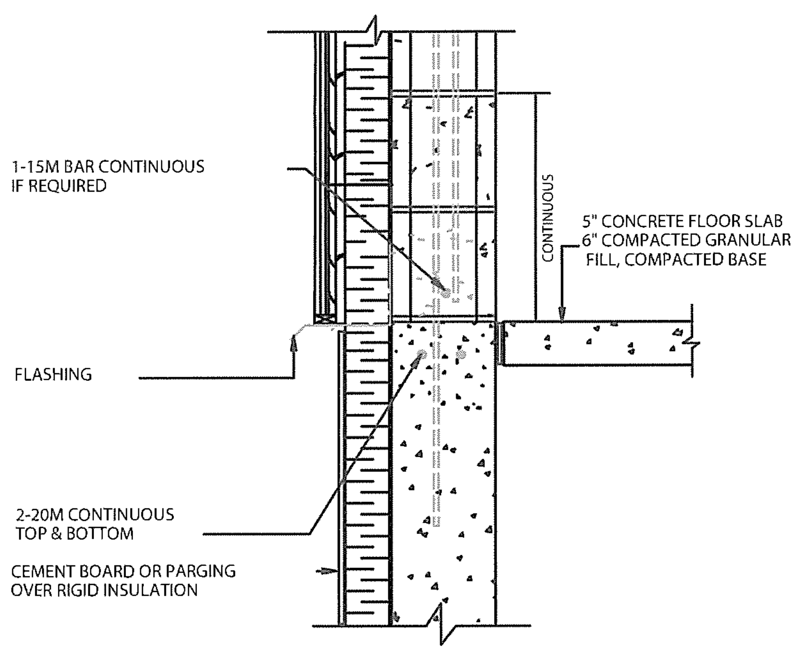
DETAIL 3.4 ACRYLIC STUCCO/ CONCRETE BLOCK
NTS O.W.S.J.CONNECTION@ STEEL BEAM



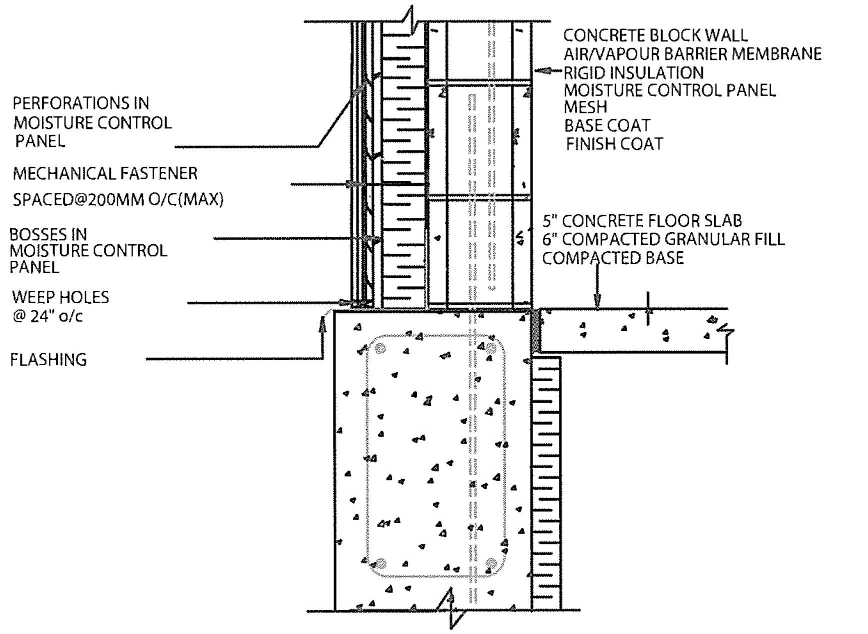
DETAIL 3.5 STUCCO / CONCRETE BLOCK
PARAPET DETAIL @ O.W.S.J.



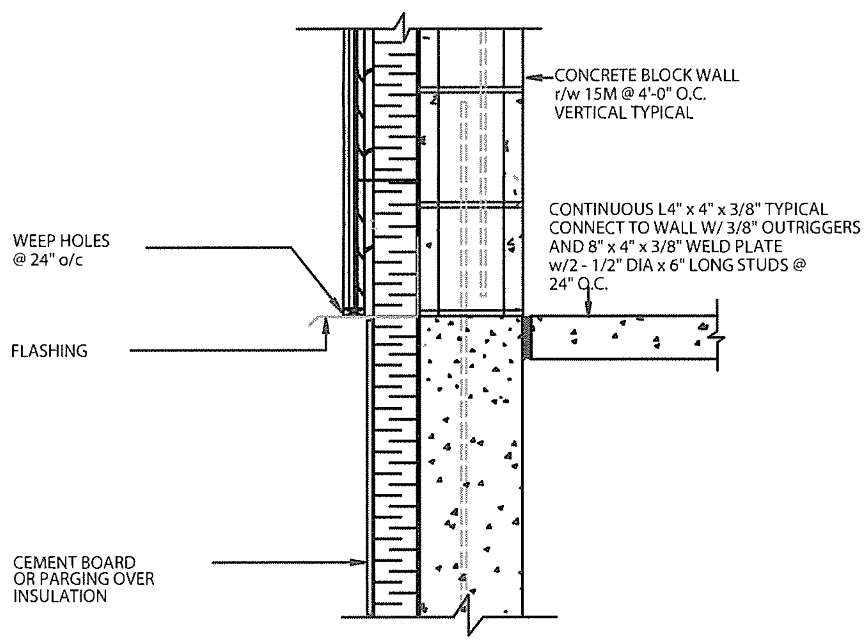
DETAIL 3.6a ACRYLIC STUCCO/CONCRETE BLOCK AT FOUNDATION



DETAIL 3.6b ACRYLIC STUCCO/ CONCRETE BLOCK AT FOUNDATION BOND BEAM

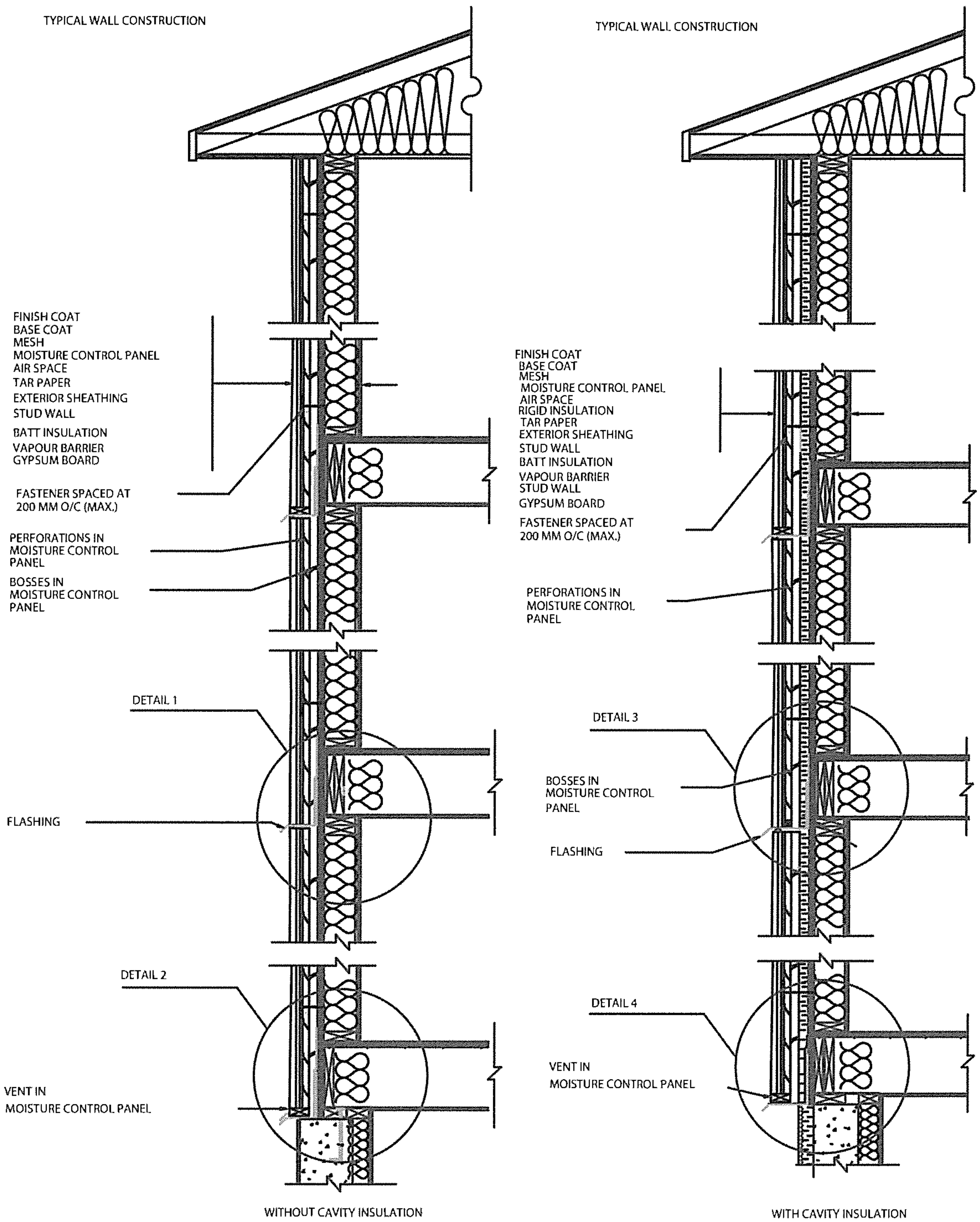


DETAIL 3.7a ACRYLIC STUCCO/CONCRETE BLOCK AT FOUNDATION

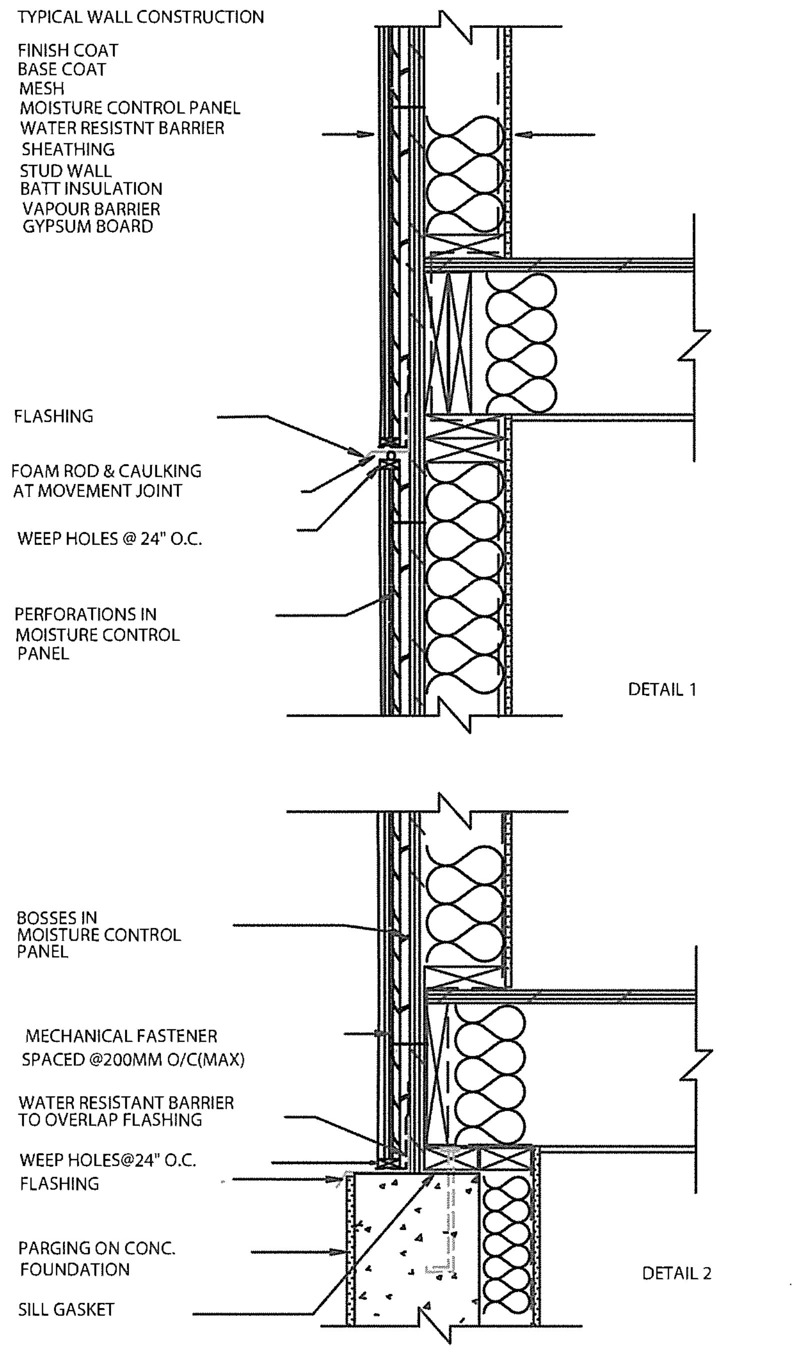


DETAIL 3.7b ACRYLIC STUCCO/ CONCRETE BLOCK AT FOUNDATION

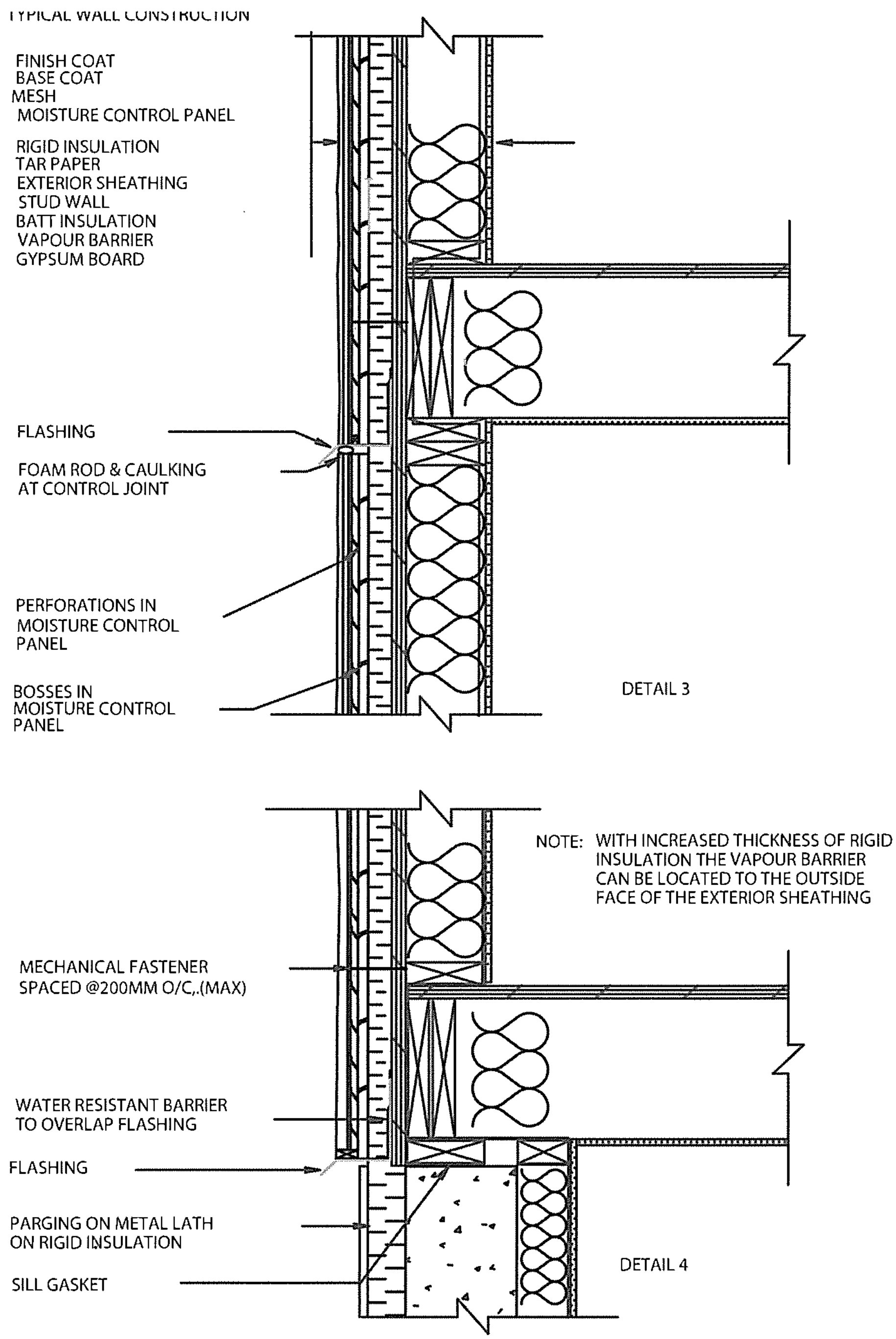
4. WOOD BACKUP DETAILS



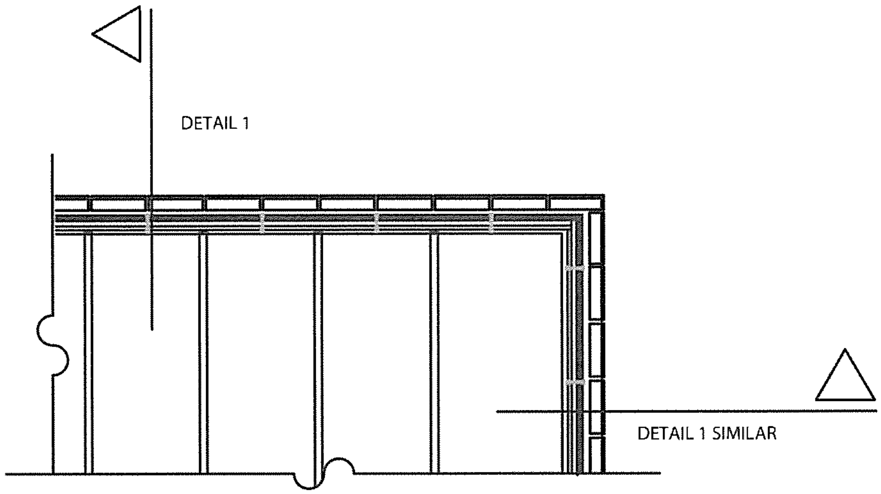
DETAIL 4.1 TYPICAL WOOD FRAME CONSTRUCTION APARTMENT BUILDING



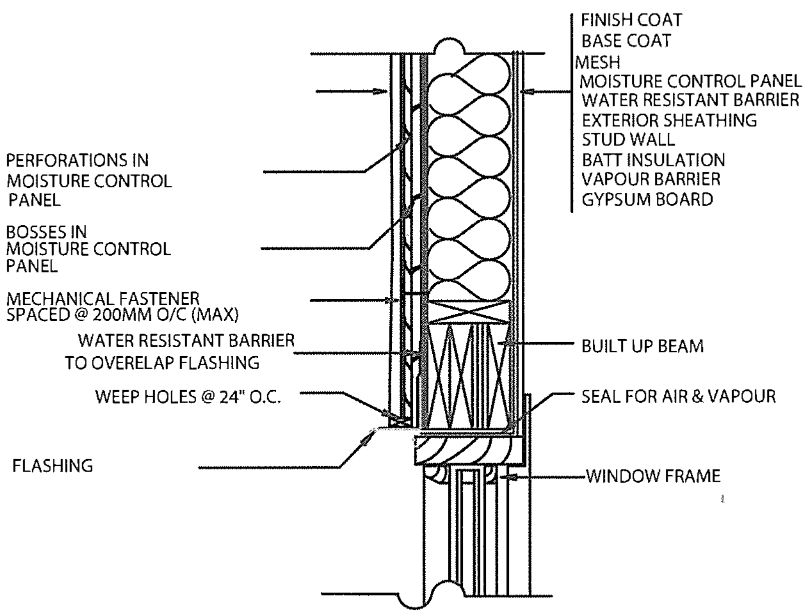
DETAIL 4.2 DETAILS OF CEMENTITIOUS STUCCO AT GROUND AND FLOOR LEVELS (UNINSULATED CAVITY)



DETAIL 4.3 DETAILS OF CEMENTITIOUS STUCCO AT GROUND AND FLOOR LEVELS (INSULATED CAVITY)



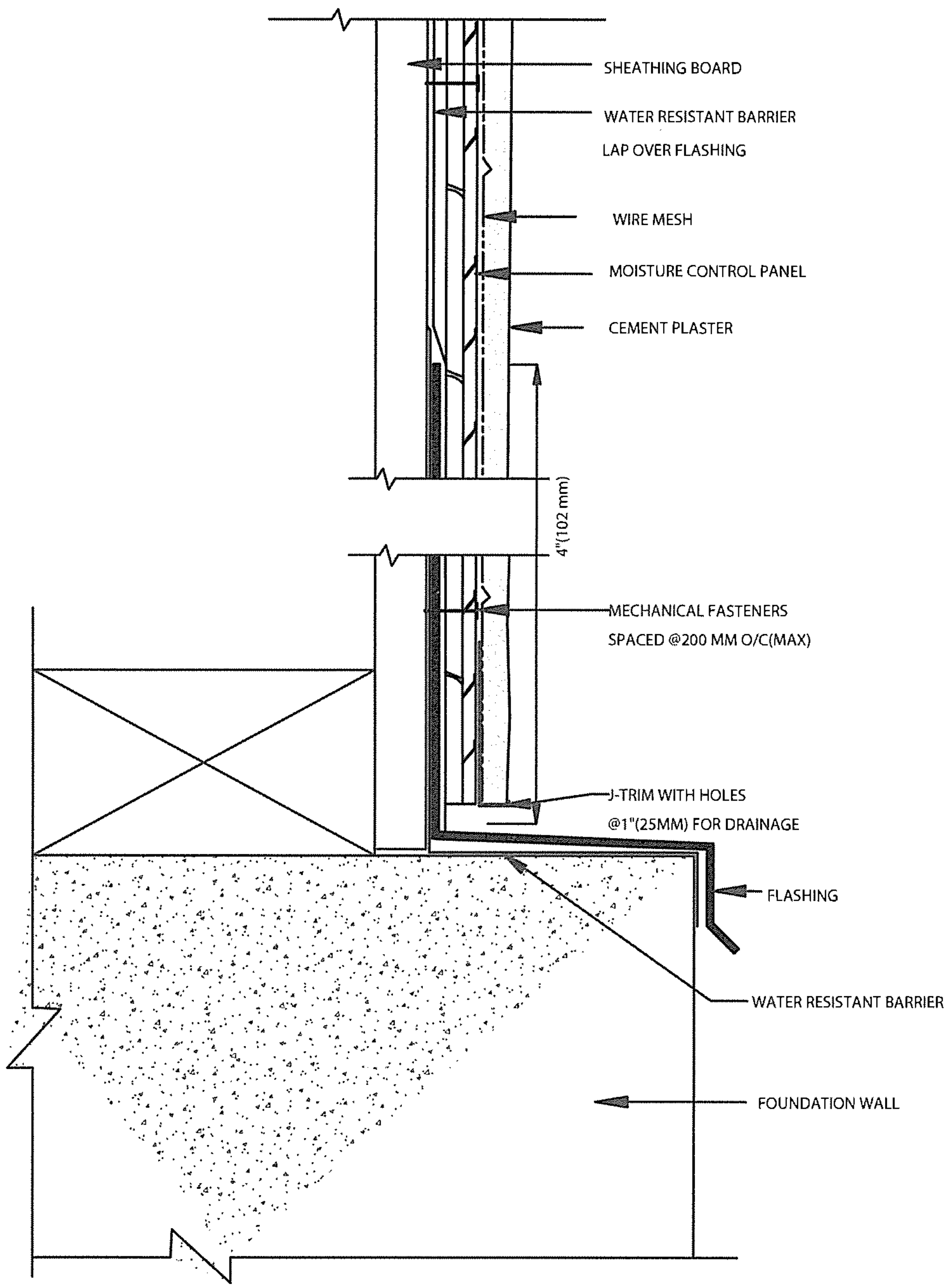
DETAIL 4.4a CORNER PLAN



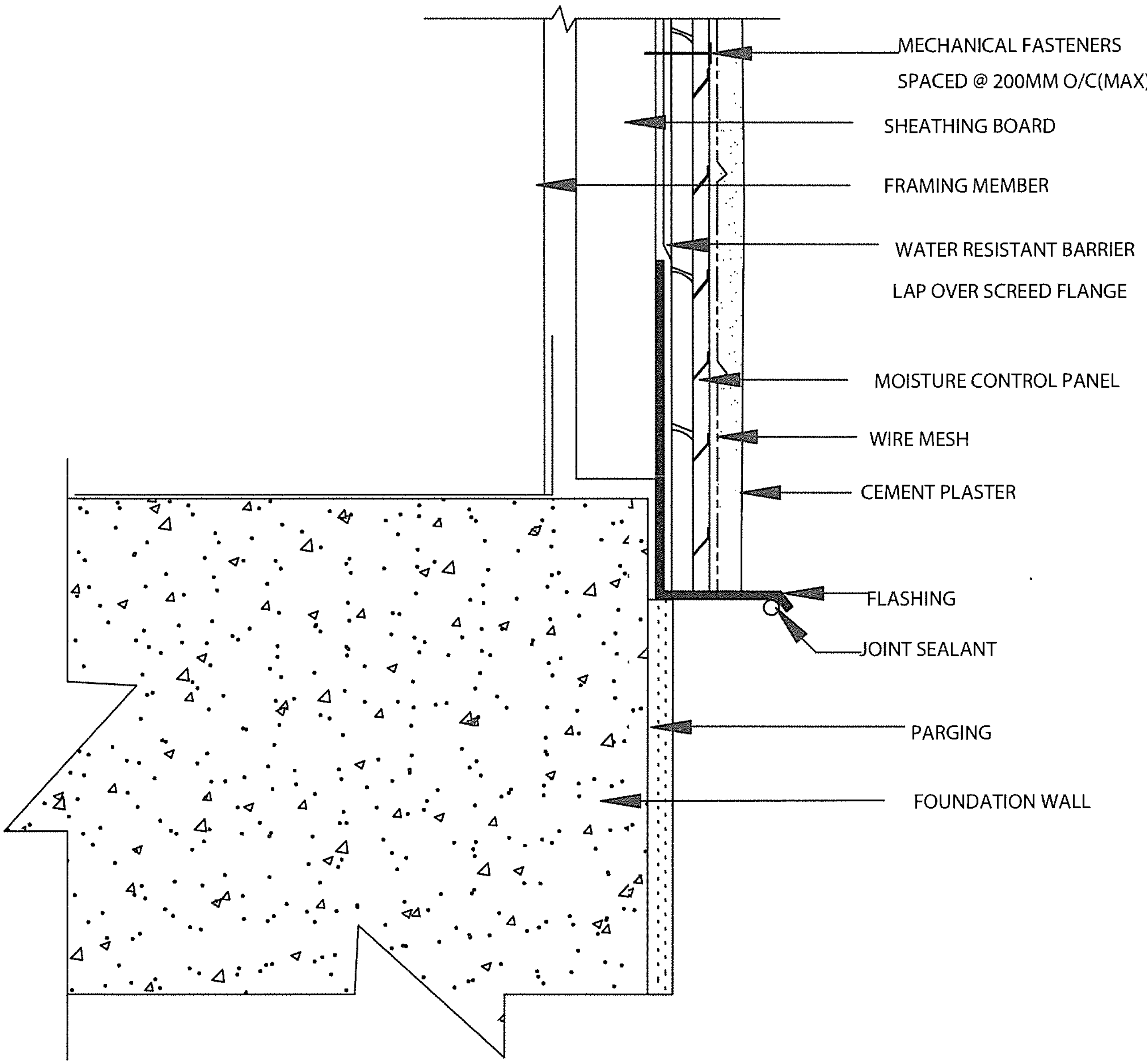
DETAIL 4.4 DETAILS OF WINDOW OPENING
WITH CEMENTITIOUS STUCCO

2. BASIC DETAILS FOR STUCCO SYSTEM

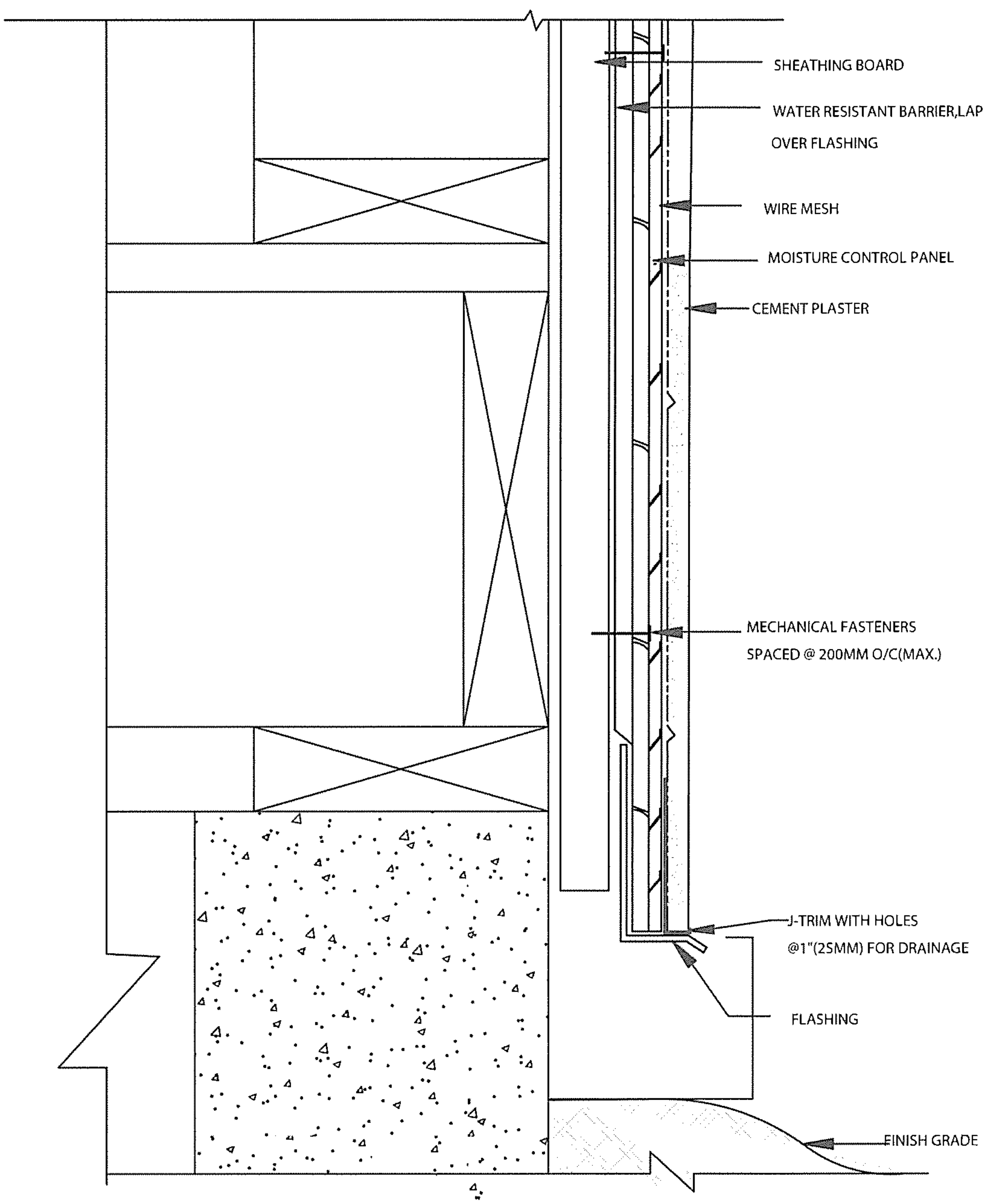
1. STUCCO DETAILS WITH MOISTURE CONTROL PANEL



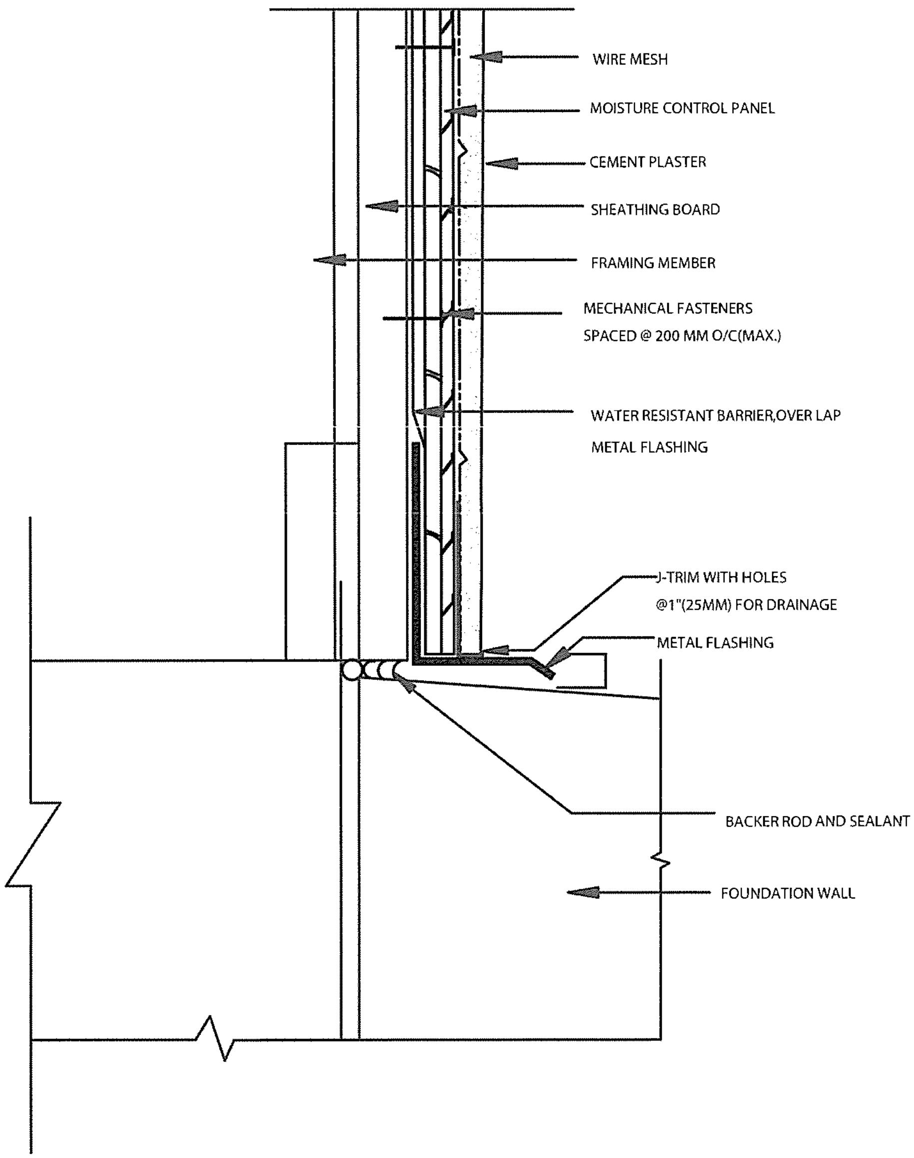
DETAIL 1.1 TERMINATION AT CONCRETE FOUNDATION



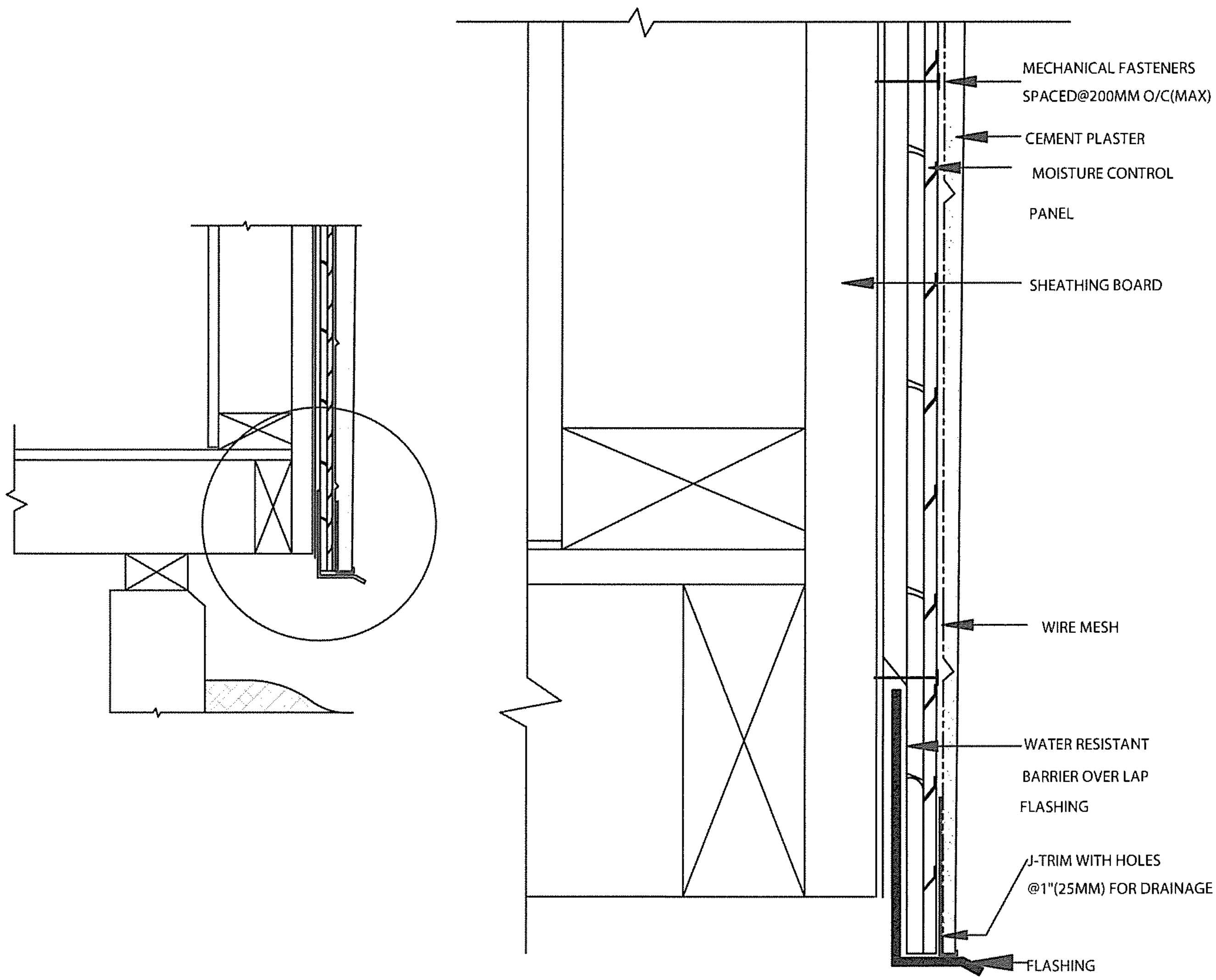
DETAIL 1.2 WEEP SCREED AT CONCRETE FOUNDATION



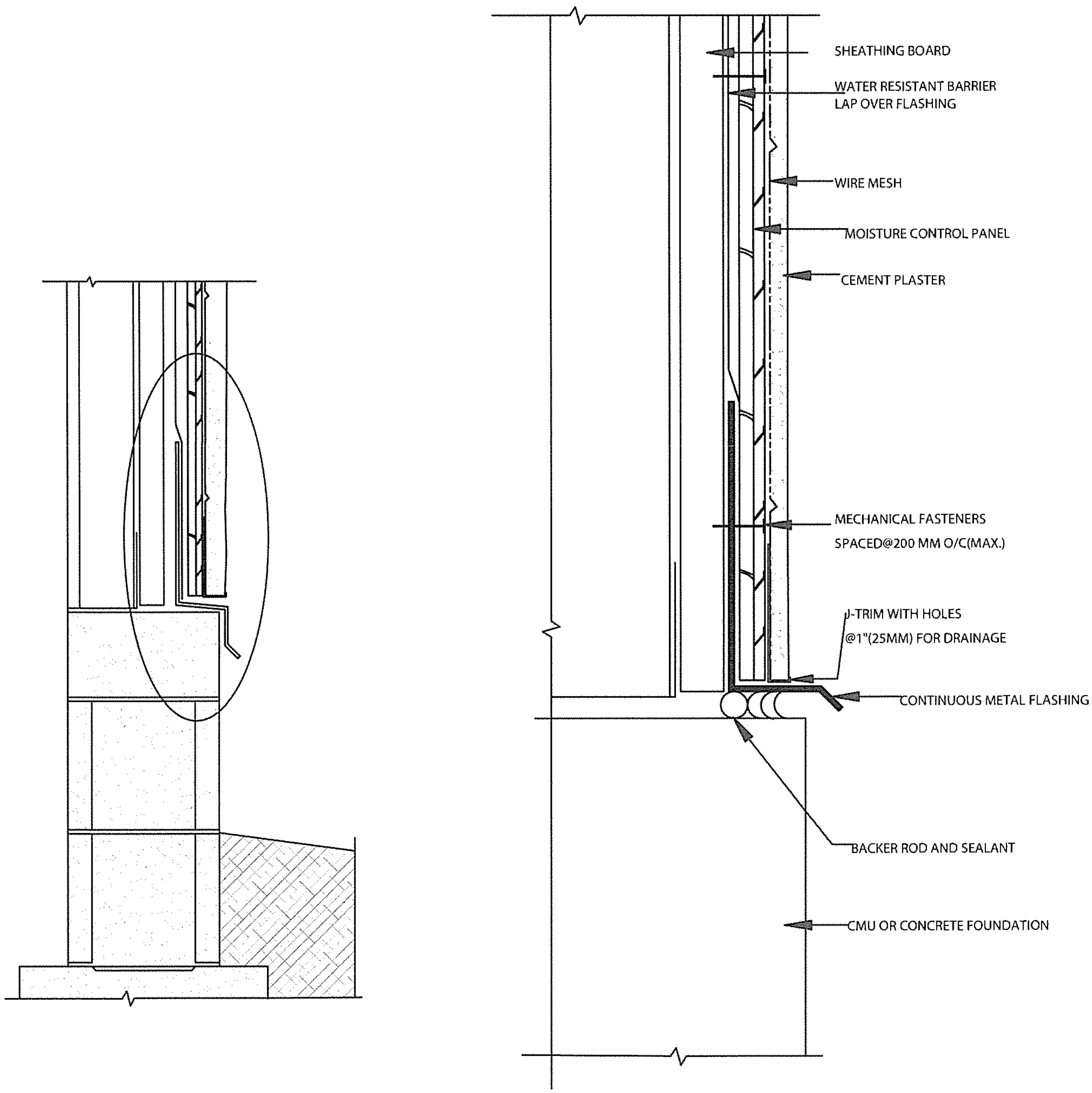
DETAIL 1.3 TERMINATION AT FOUNDATION /FINISHED GRADE



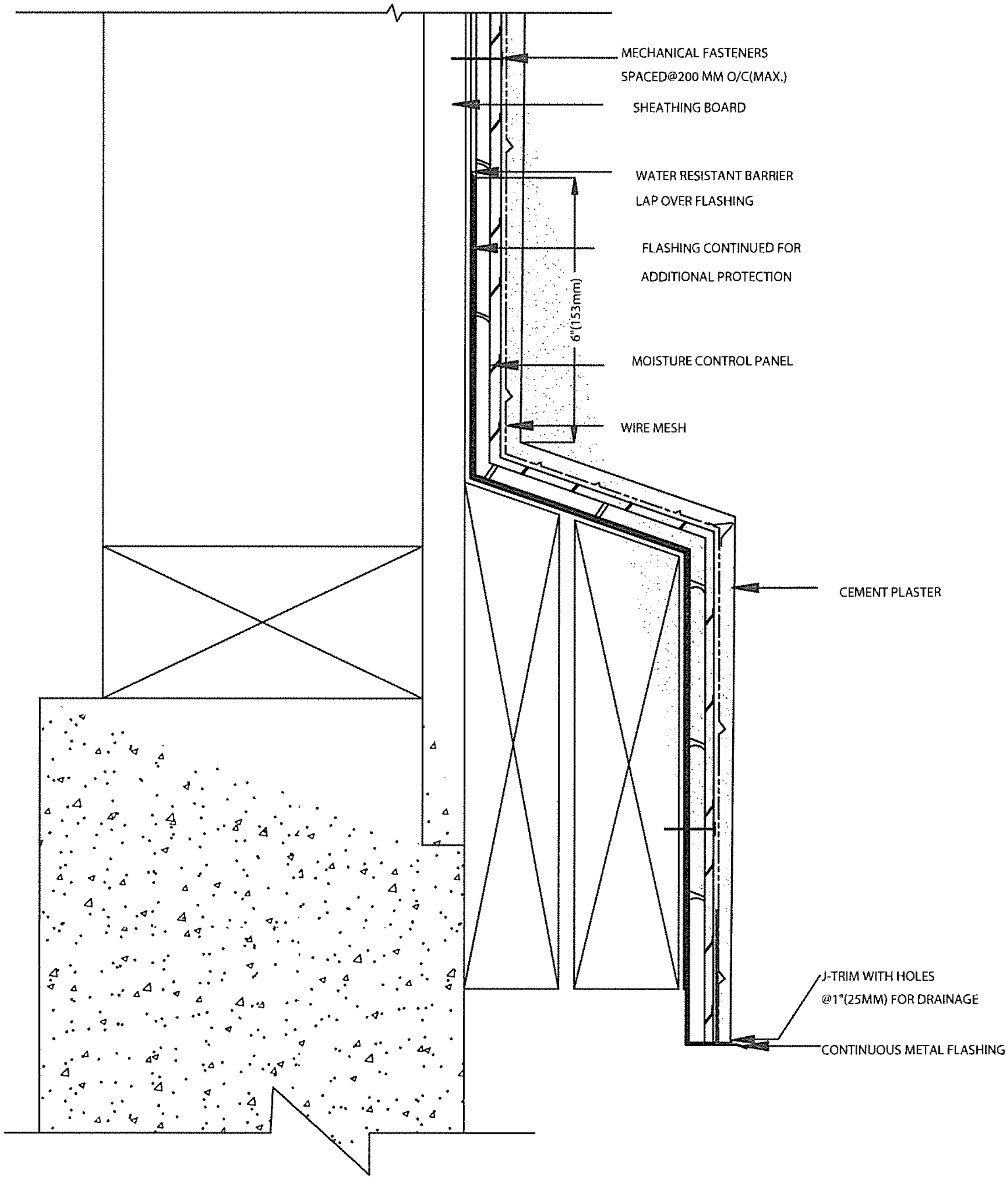
DETAIL 1.4 TERMINATION AT SLAB/SIDEWALK



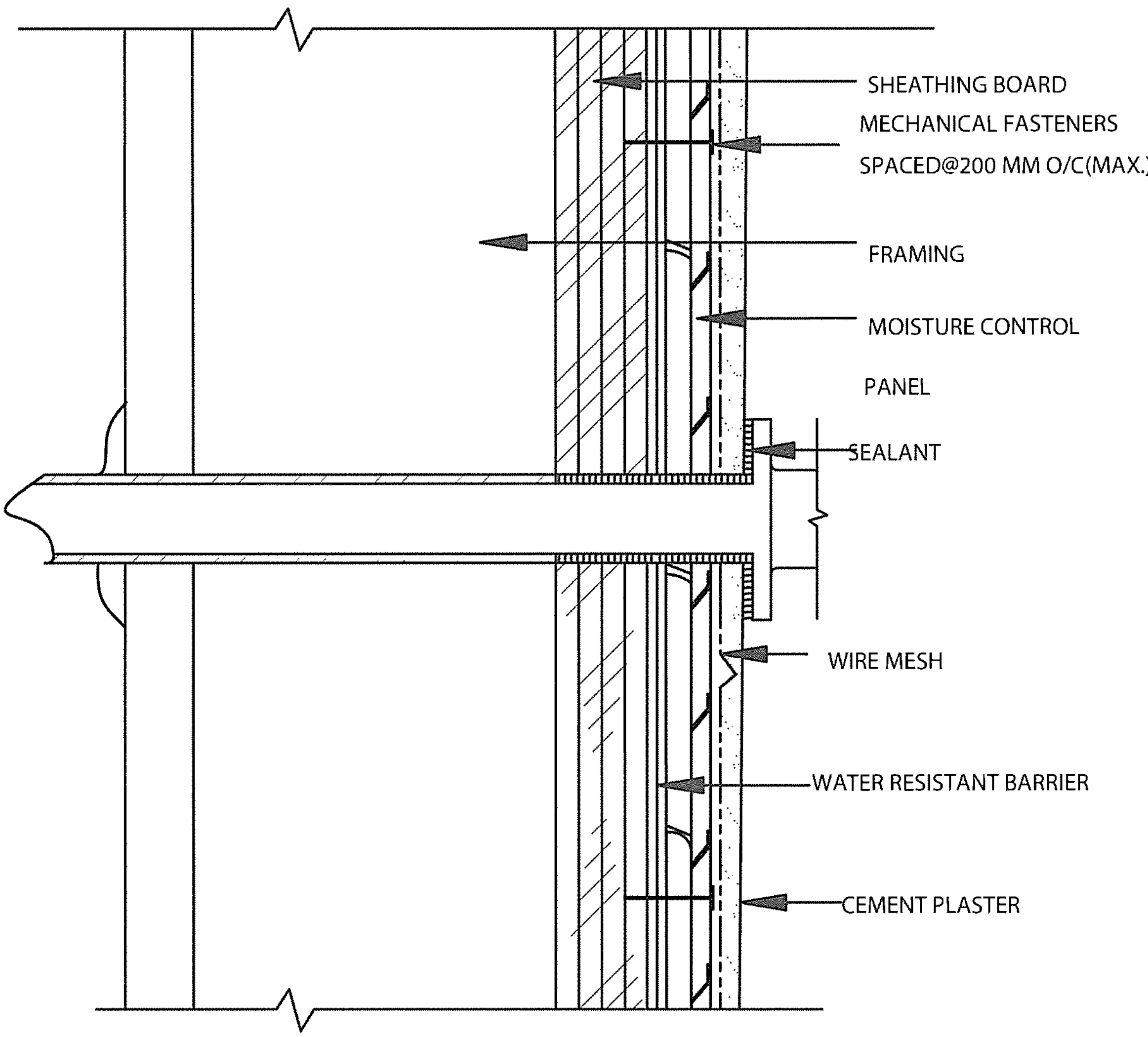
DETAIL 1.5 TERMINATION AT CANTILEVERED WALL



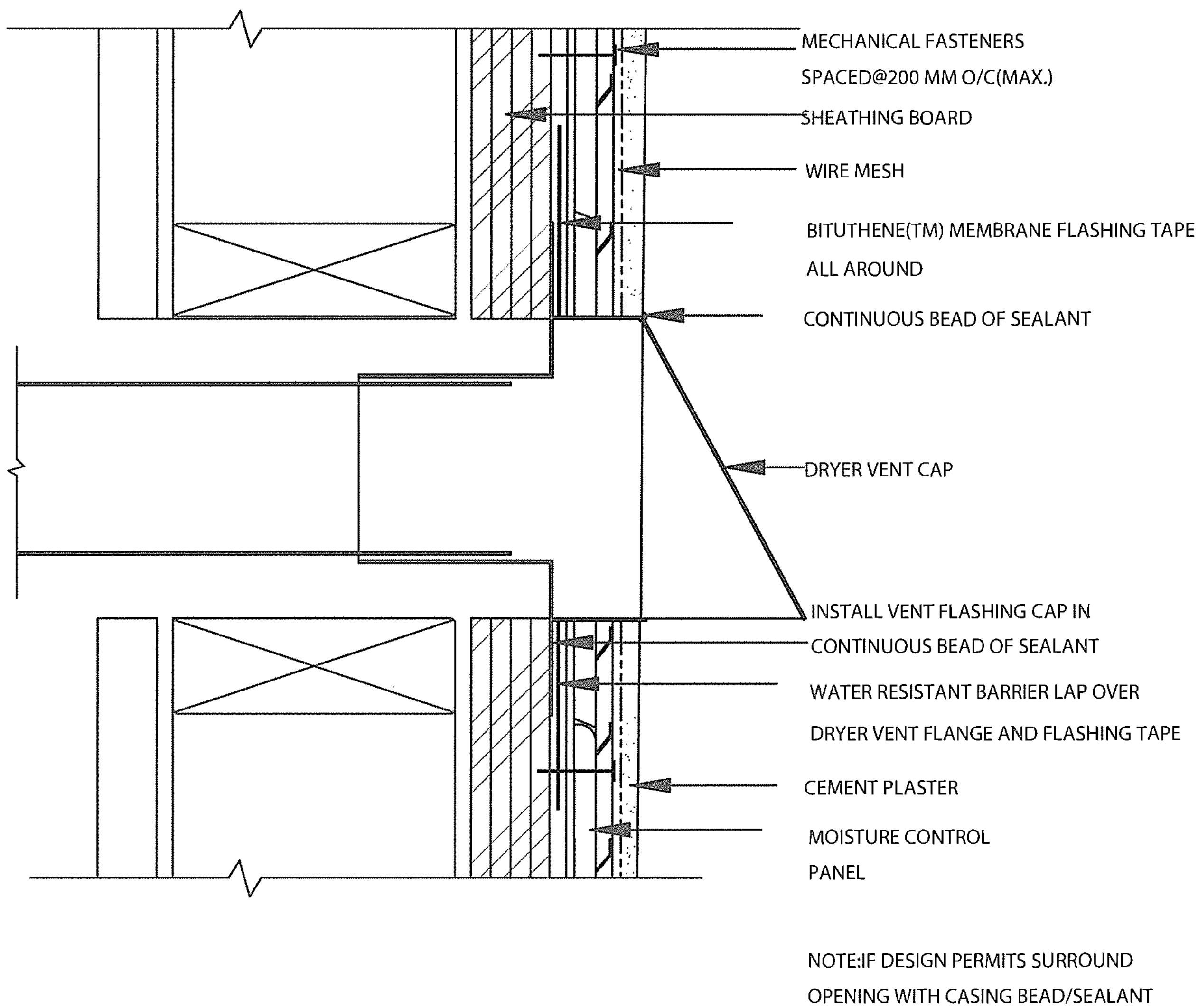
DETAIL 1.6 TERMINATION AT FOUNDATION



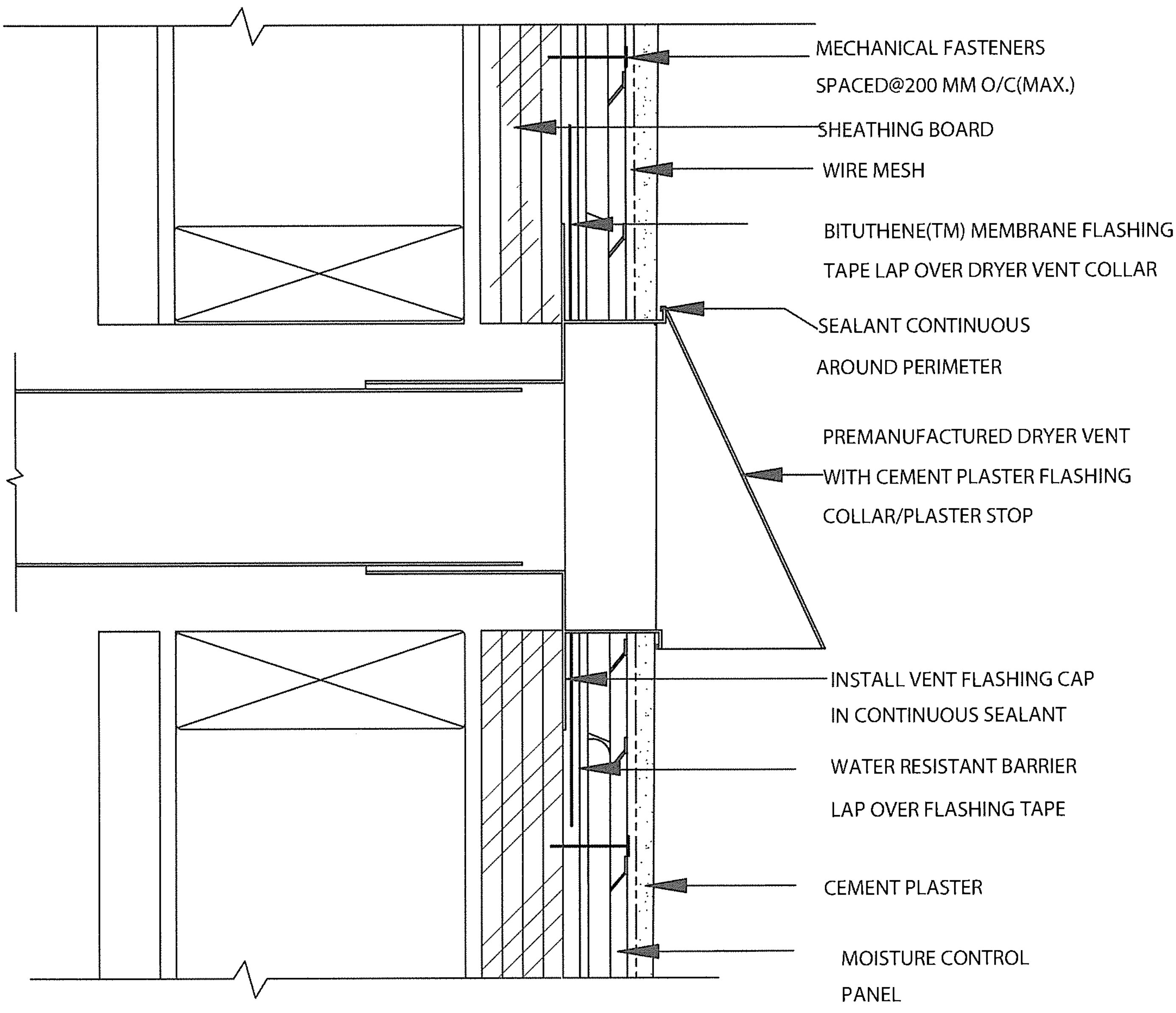
DETAIL 1.7 FOUNDATION /COLUMN TERMINATION



DETAIL 1.8 HOSE BIB PENETRATION



DETAIL 1.9 STUCCO WALL PENETRATION



DETAIL 1.10 STUCCO DESIGNED DRYER VENT

APPENDIX C

Masonry Wall Details

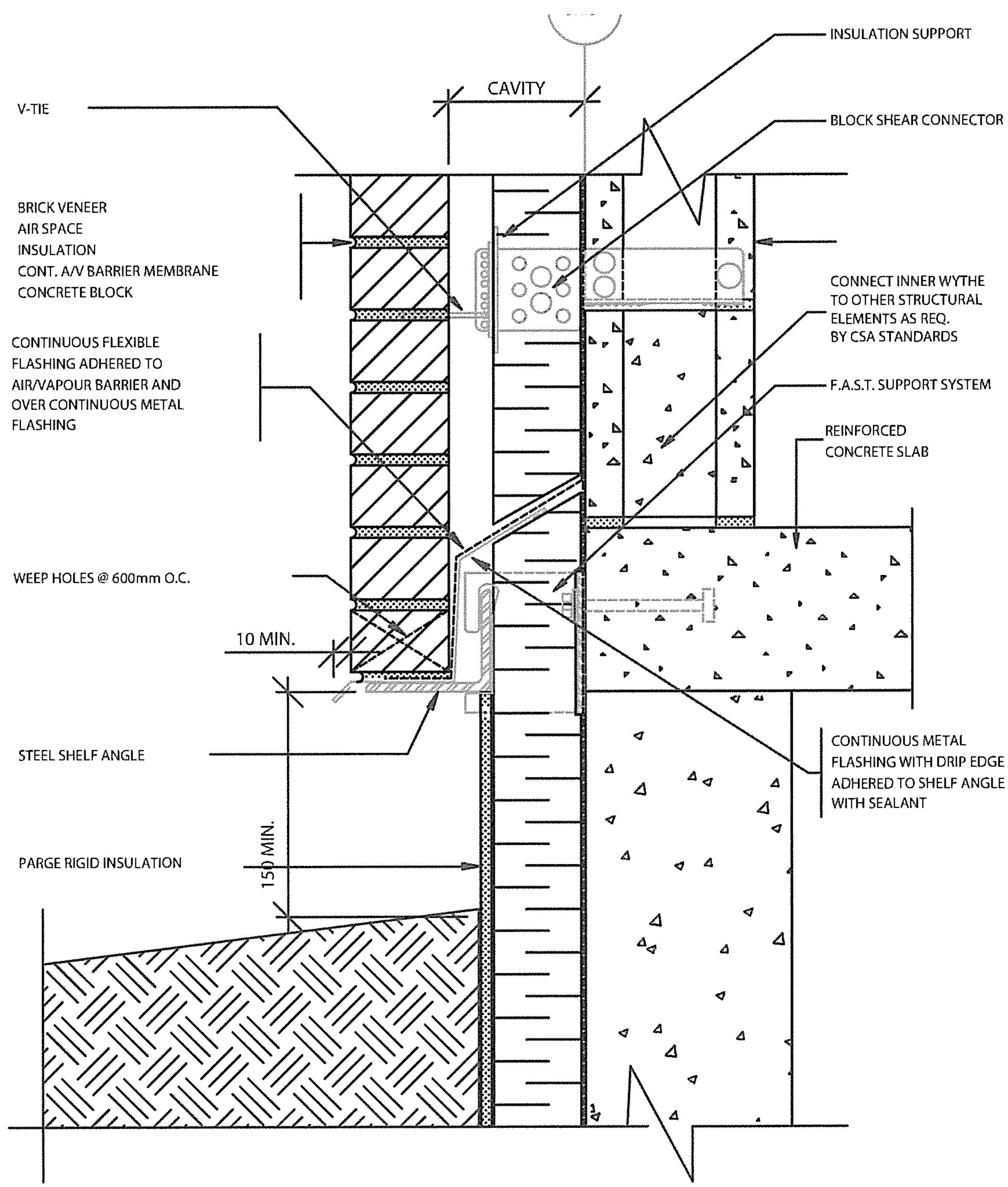


FIGURE 1 BRICK VENEER/CONCRETE BLOCK DETAIL AT FOUNDATION

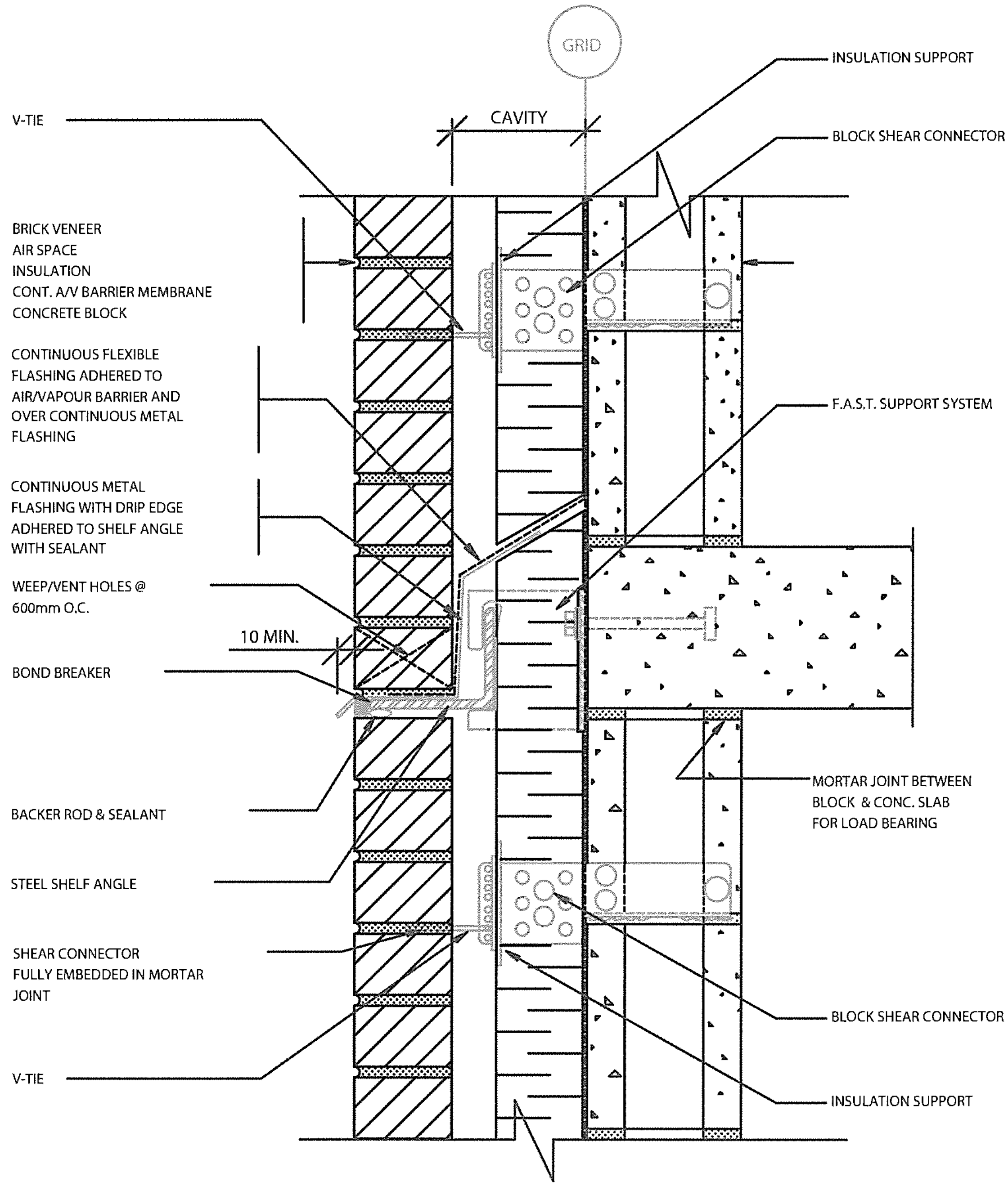


FIGURE 2 BRICK VENEER/CONCRETE BLOCK DETAIL AT SLAB EDGE
FOR LOAD BEARING WALL

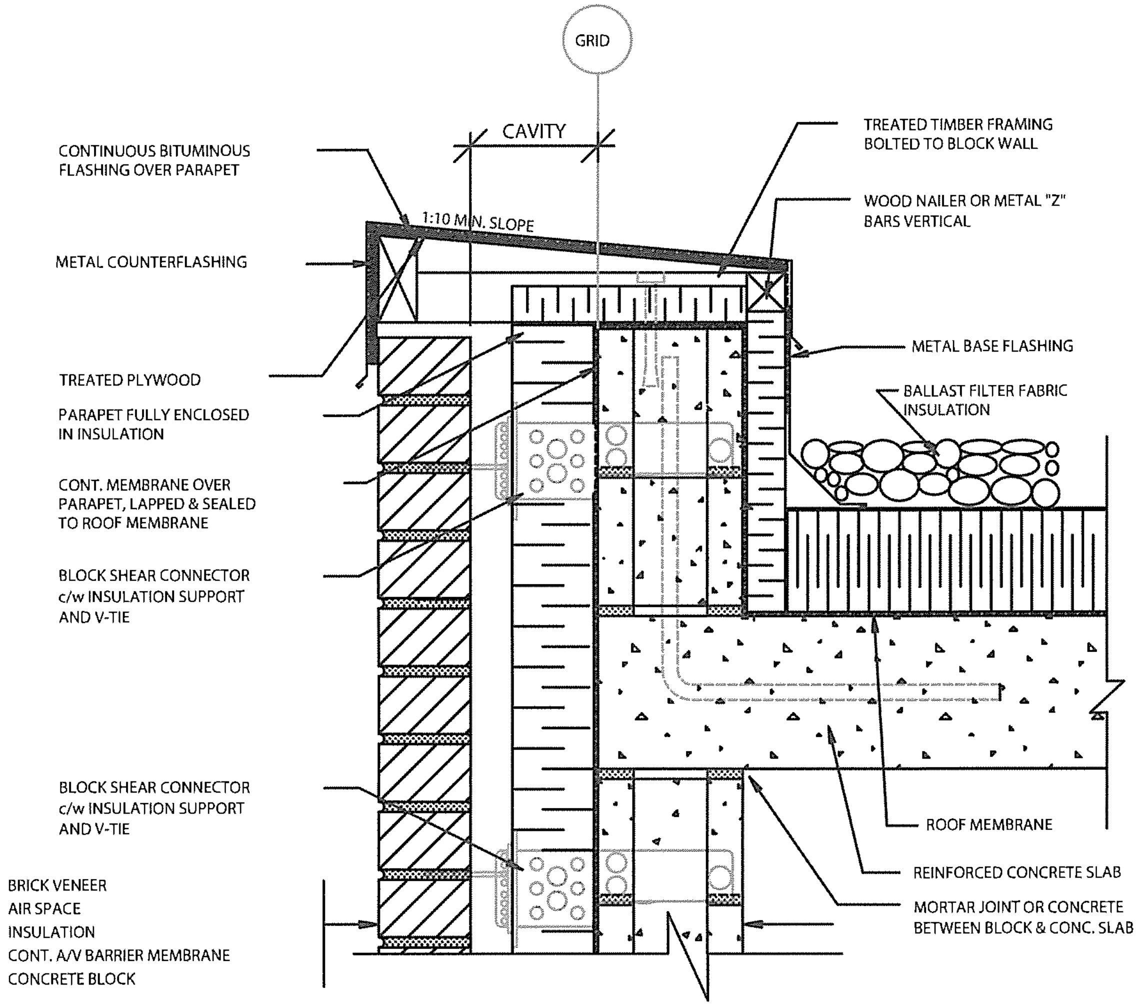


FIGURE 3 BRICK VENEER/CONCRETE BLOCK-DETAIL OF LOW PARAPET W/ PROTECTED MEMBRANE ROOF (LOAD BEARING WALL)

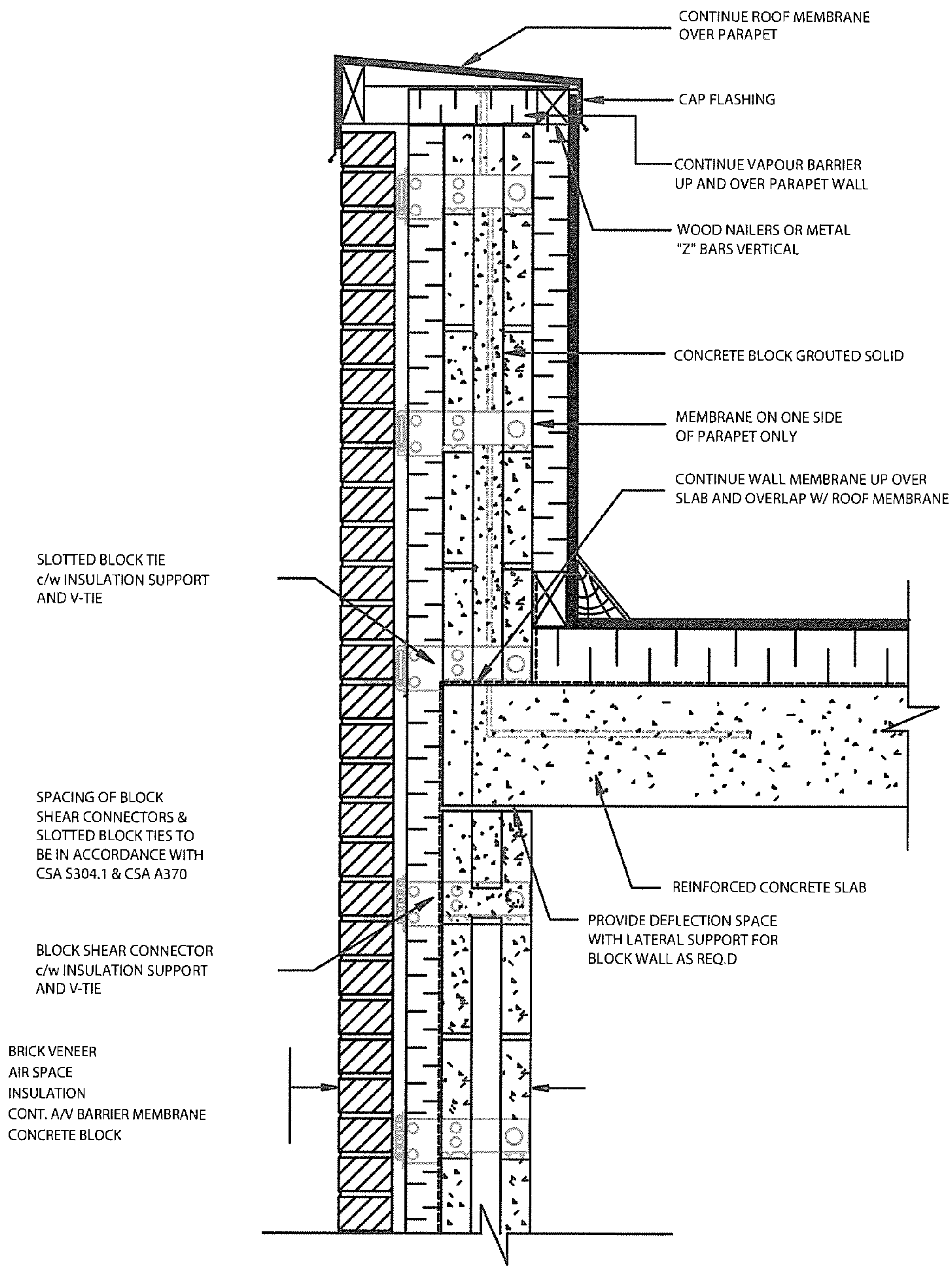


FIGURE 4 BRICK VENEER/CONCRETE BLOCK-DETAIL AT HIGH PARAPET

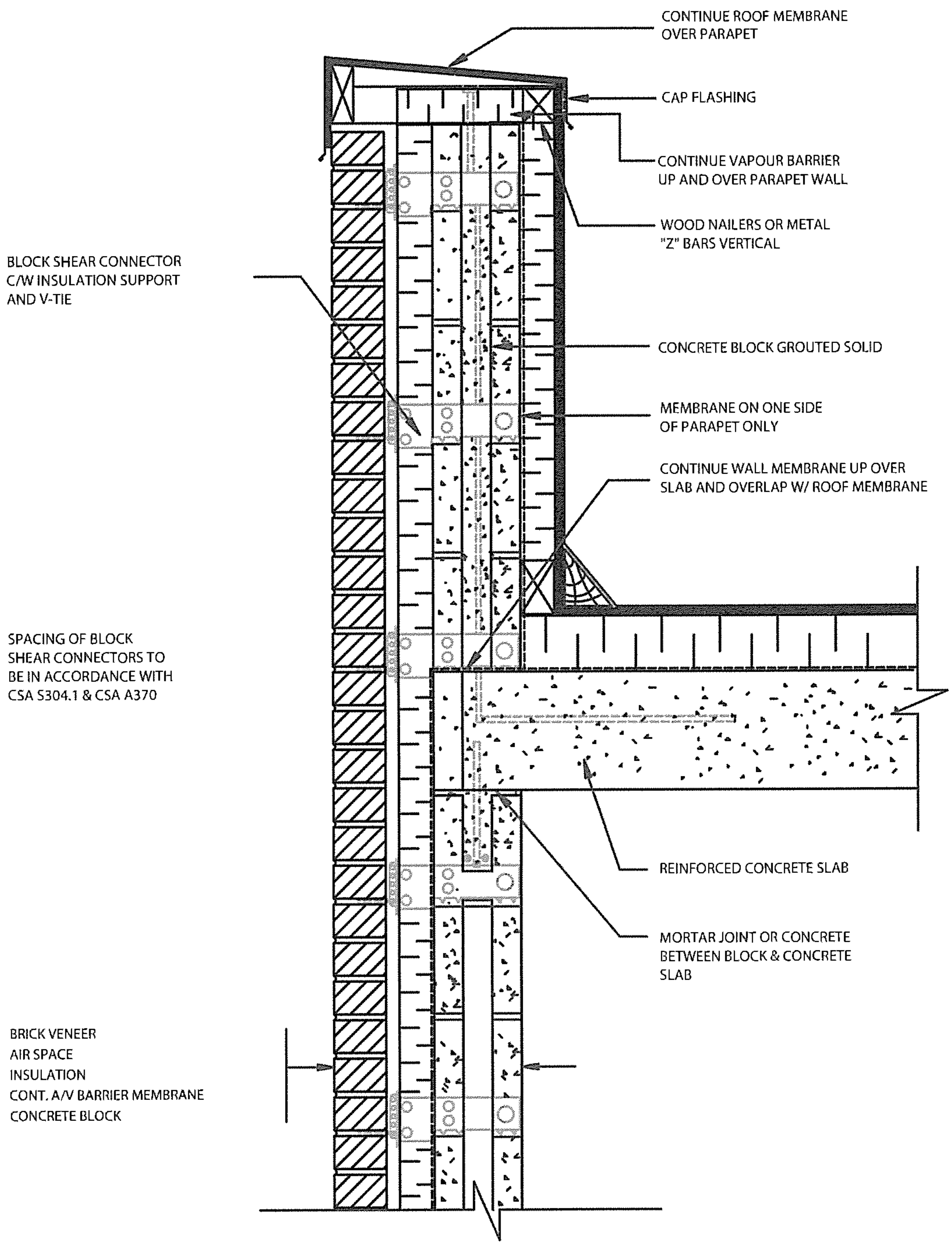


FIGURE 5 BRICK VENEER/CONCRETE BLOCK-DETAIL AT HIGH PARAPET FOR LOAD BEARING ASSEMBLY

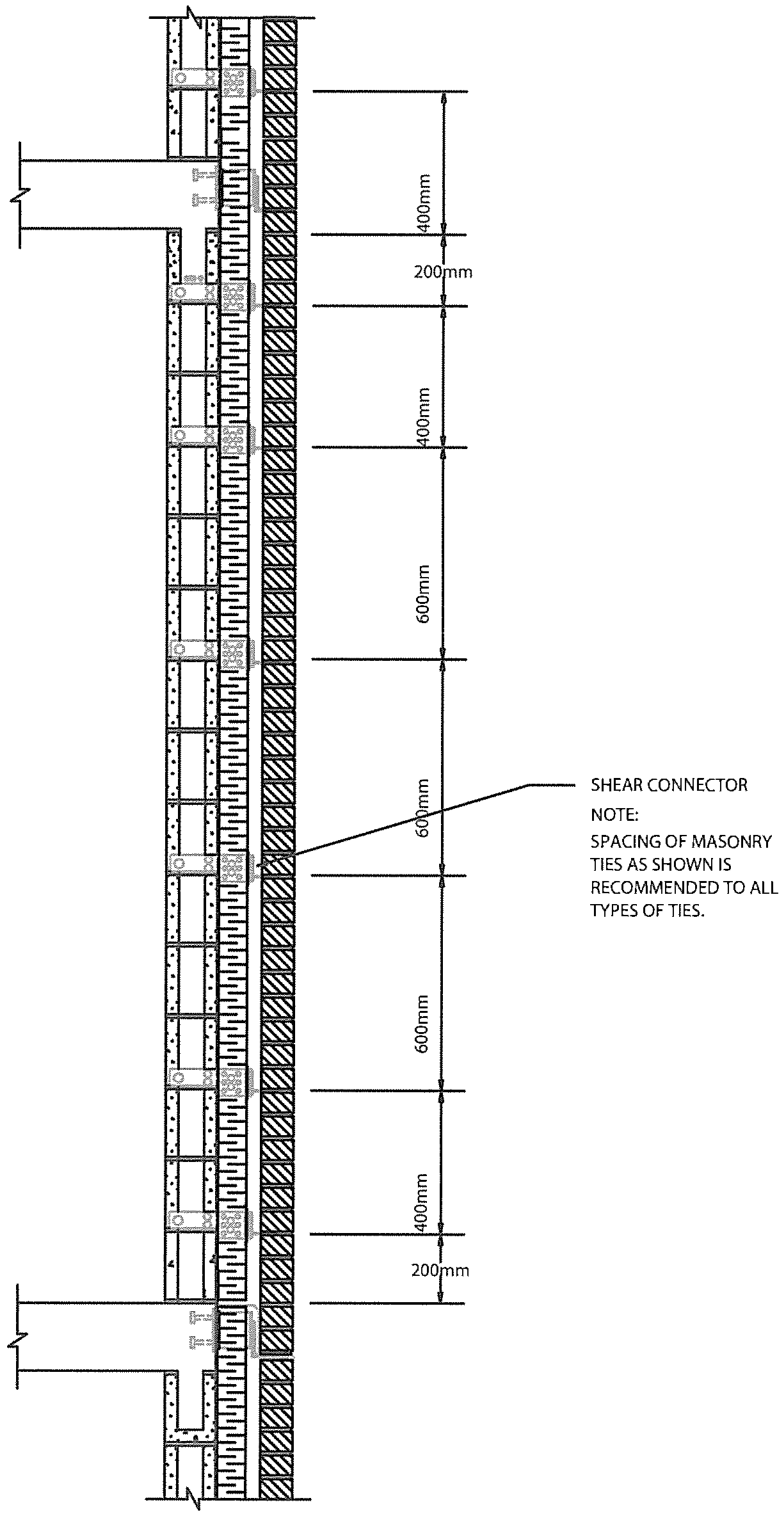


FIGURE 6 RECOMMENDED BLOCK SHEAR CONNECTORS SPACING
FOR CONC. BLOCK-BRICK VENEER WALL

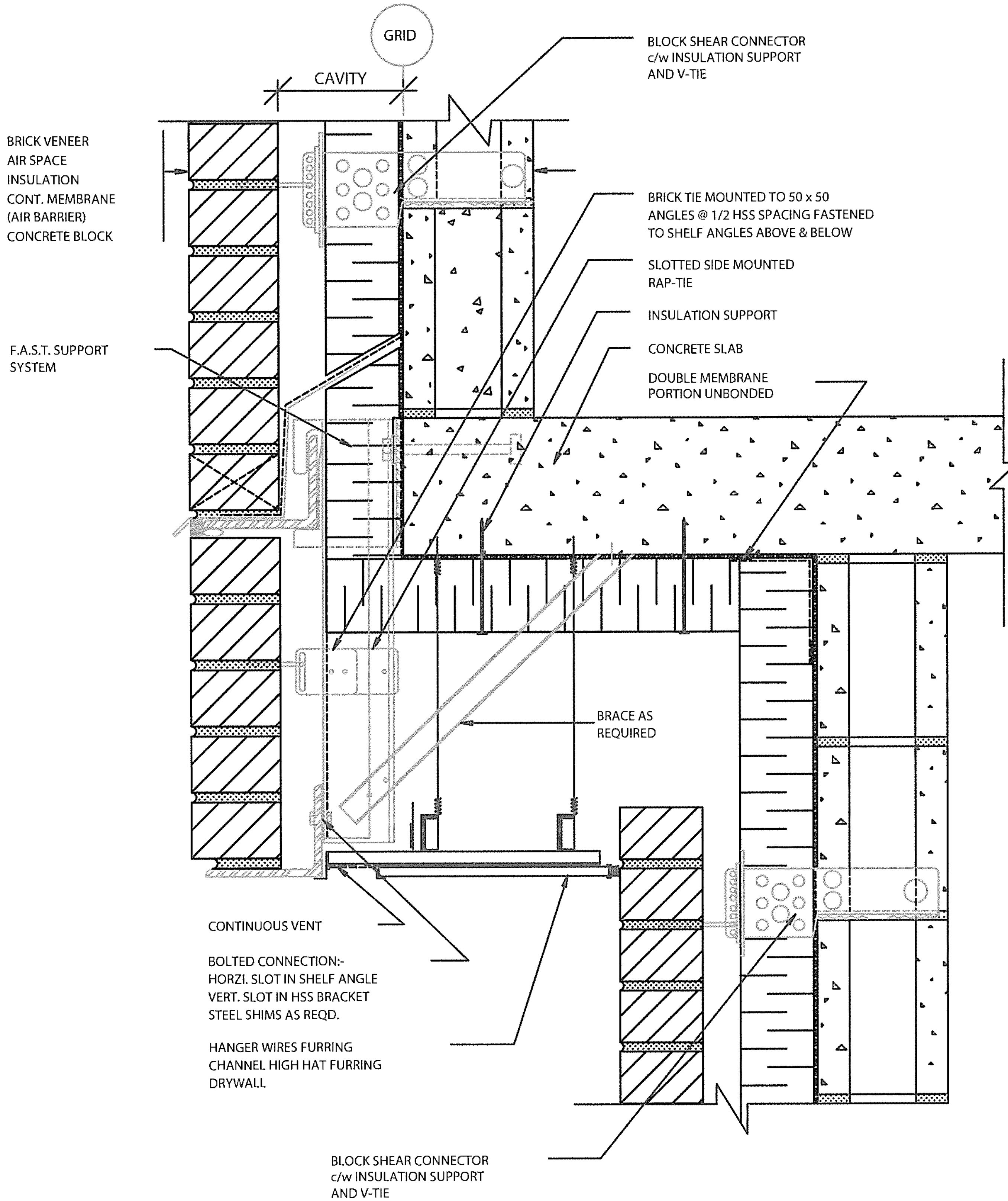


FIGURE 7 BRICK VENEER/CONCRETE BLOCK-COLD SOFFIT DETAIL

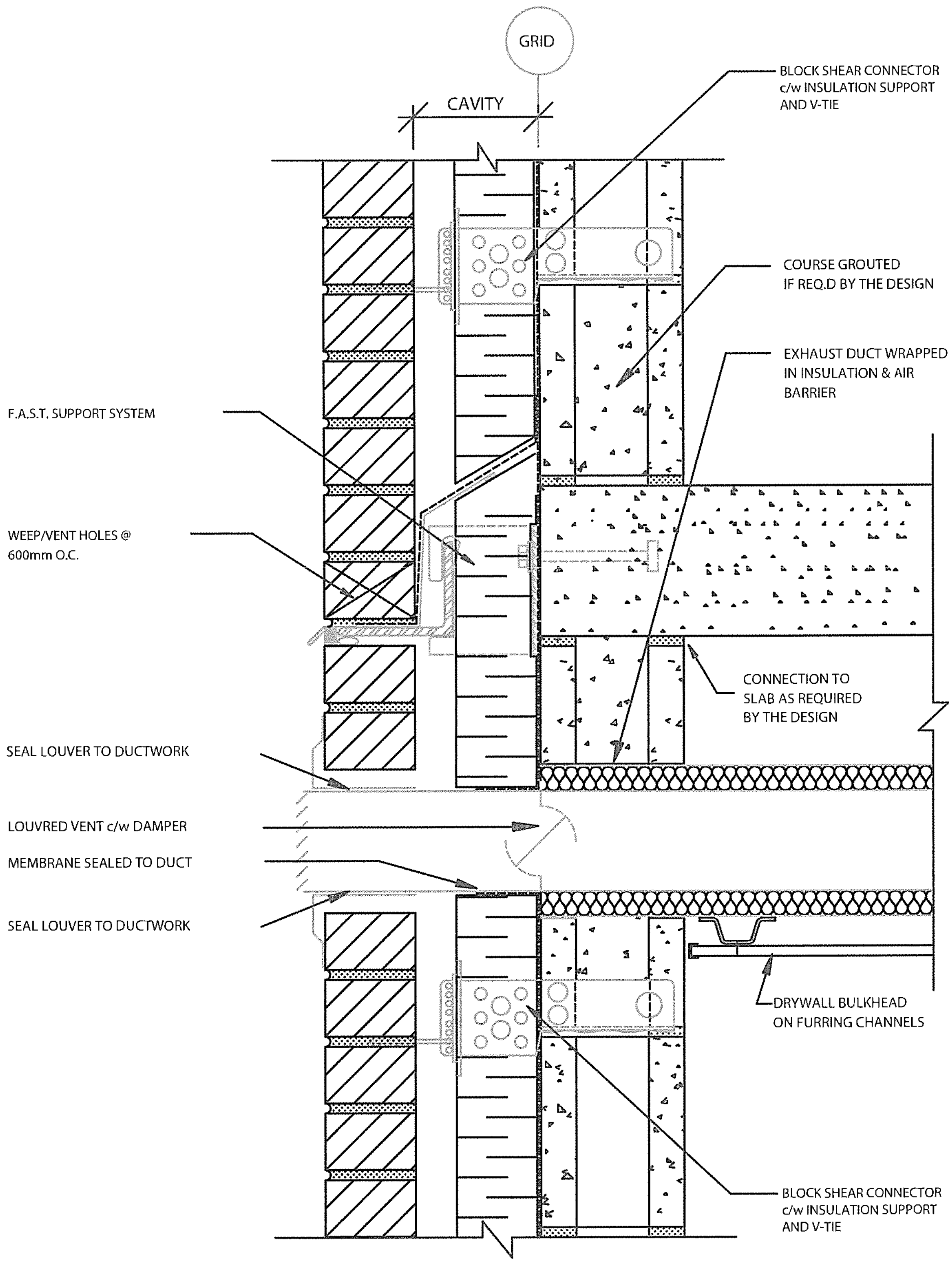


FIGURE 8 BRICK VENEER/CONCRETE BLOCK-EXHAUST VENT DETAIL

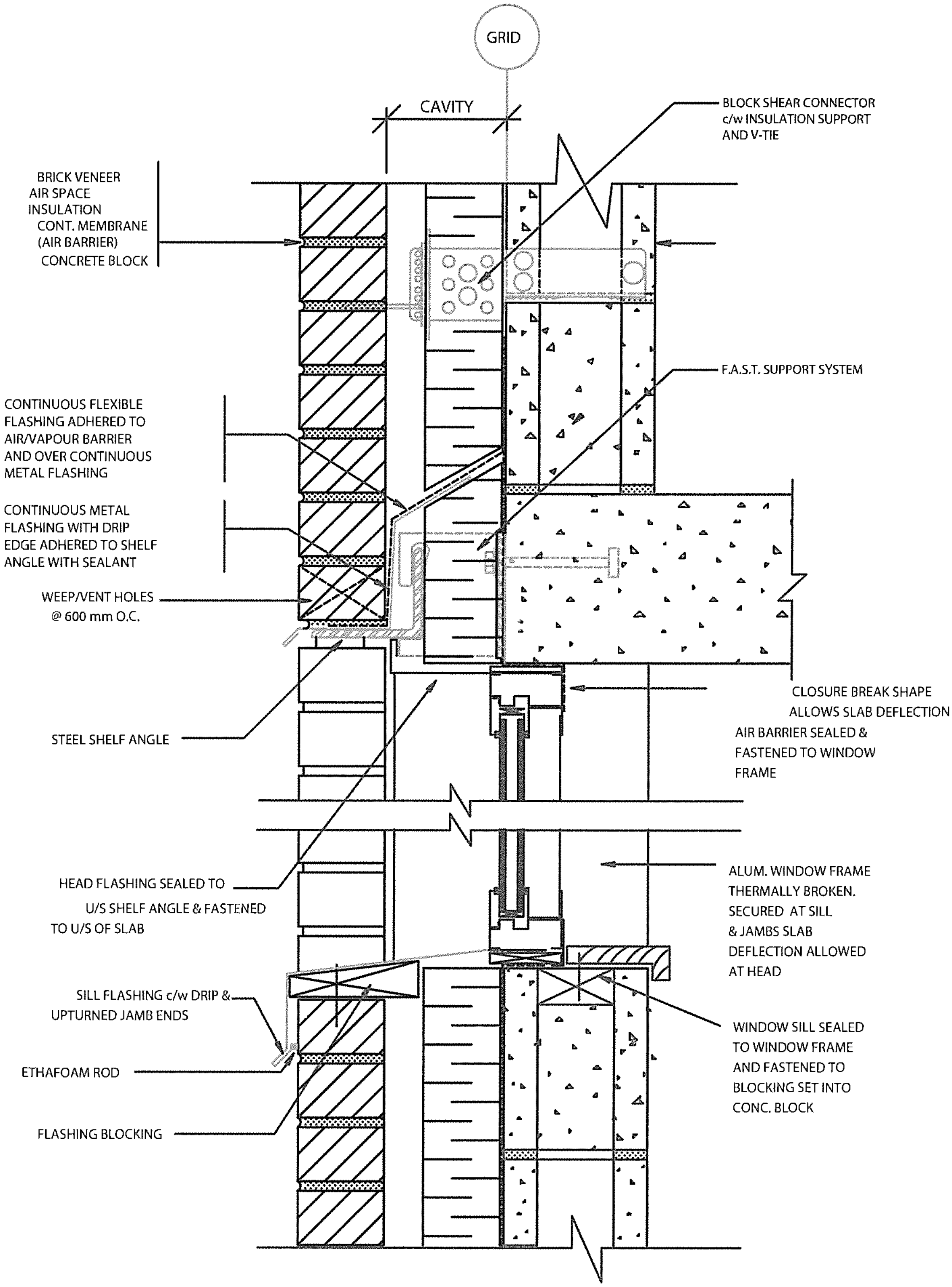


FIGURE 9 BRICK VENEER / CONCRETE BLOCK - WINDOW HEAD & SILL DETAIL

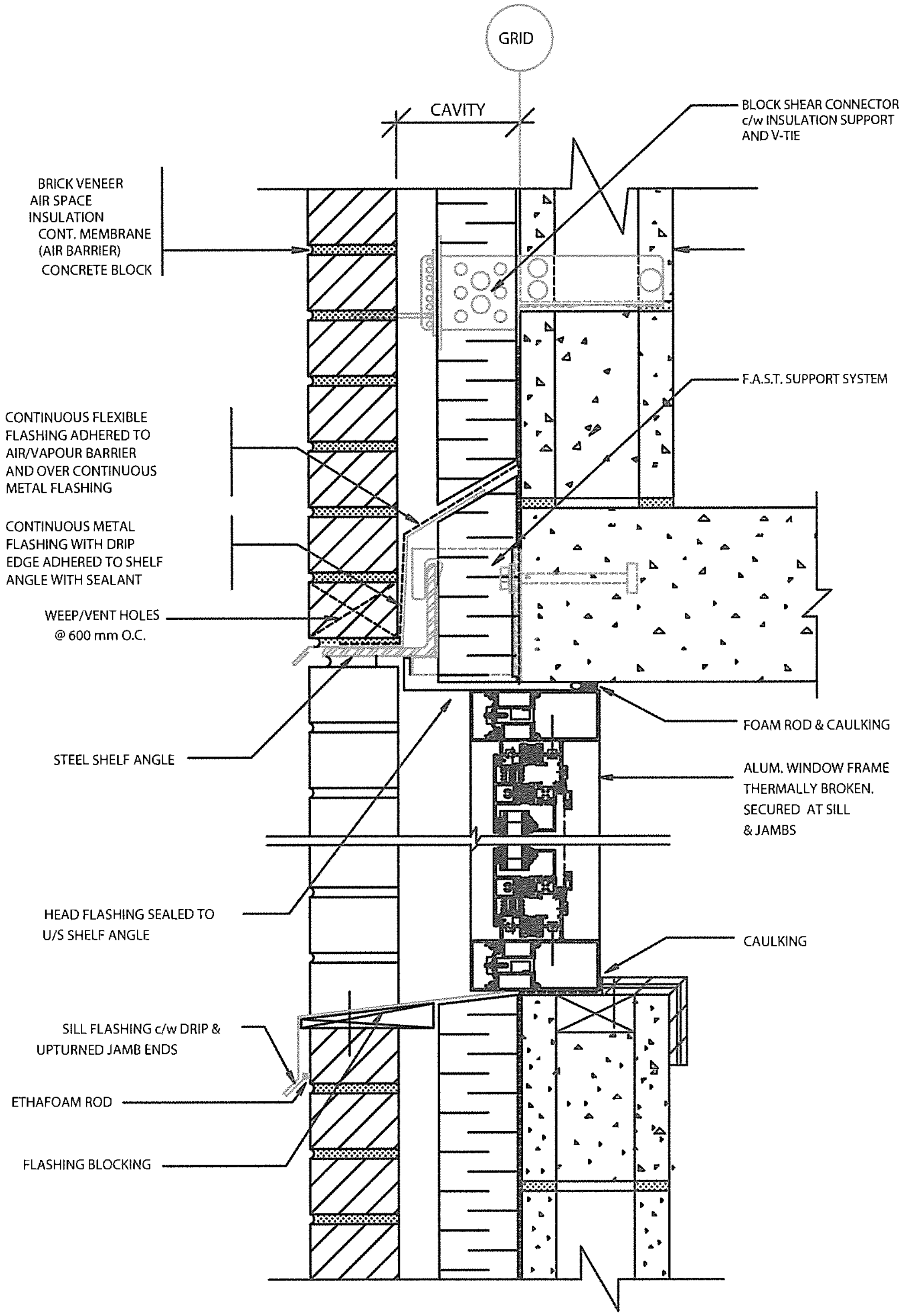


FIGURE 10 BRICK VENEER / CONCRETE BLOCK - WINDOW HEAD & SILL DETAIL

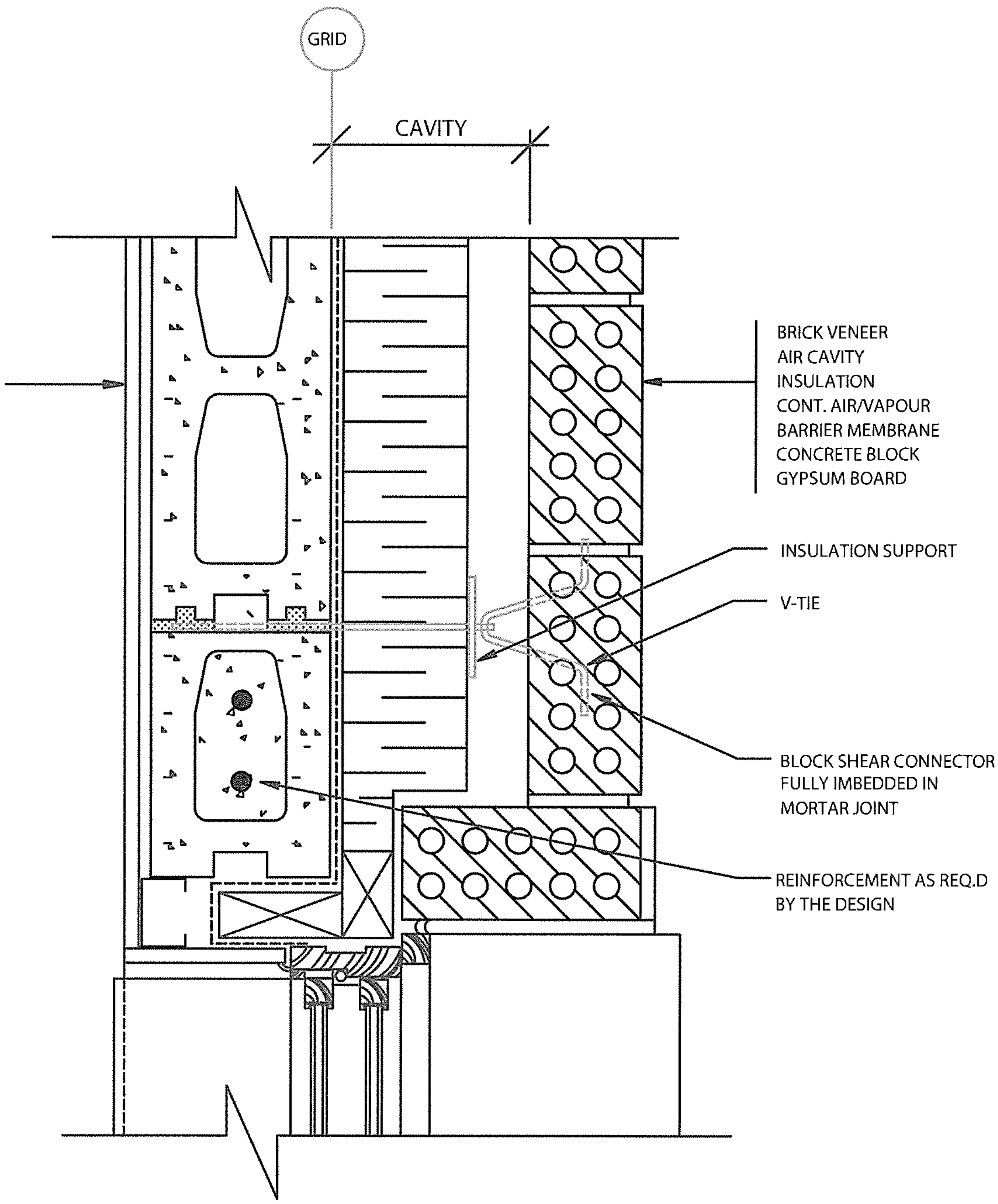


FIGURE 11 JAMB WOOD WINDOW

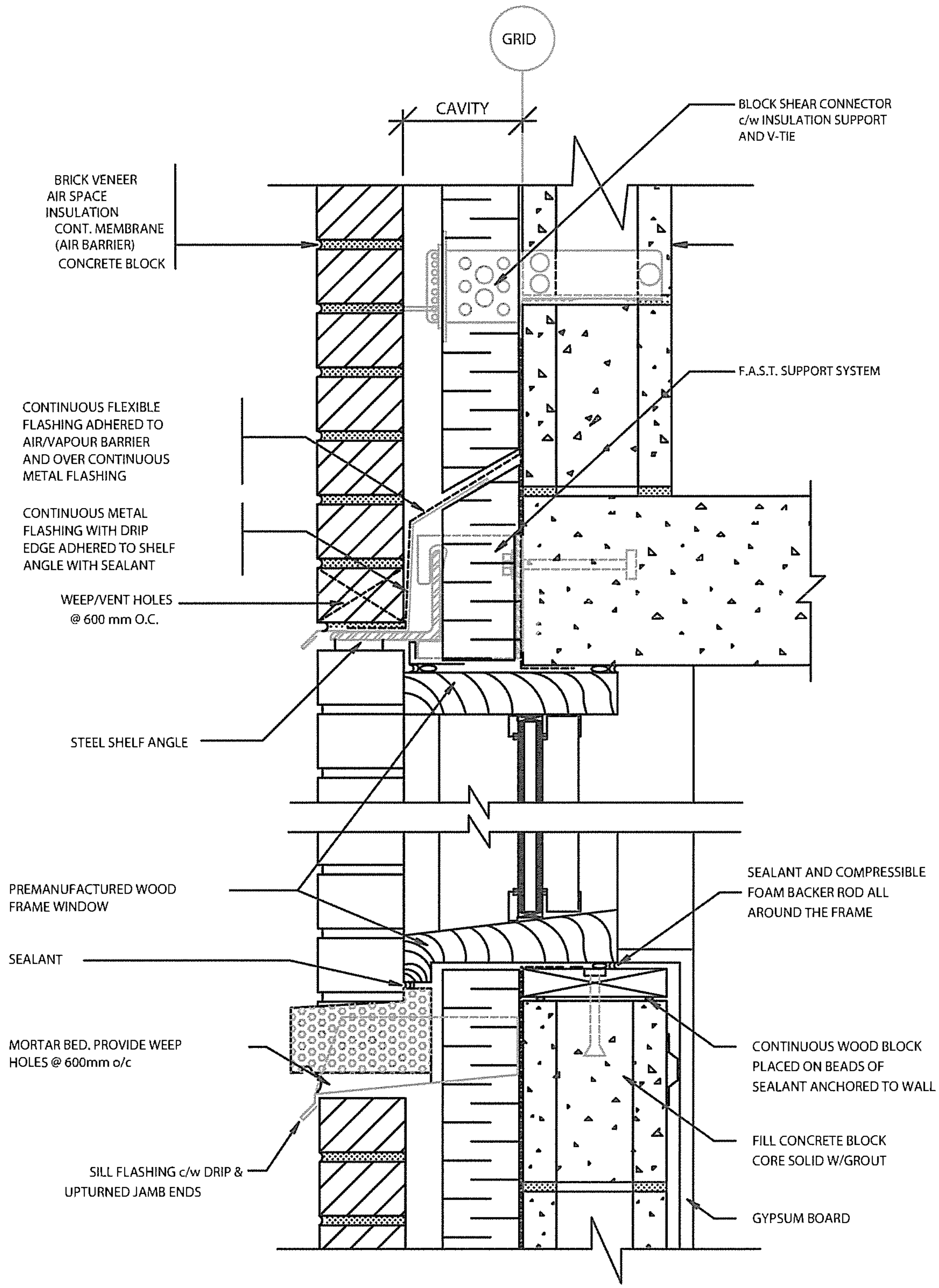


FIGURE 12 BRICK VENEER / CONCRETE BLOCK - WOOD WINDOW HEAD & SILL DETAIL

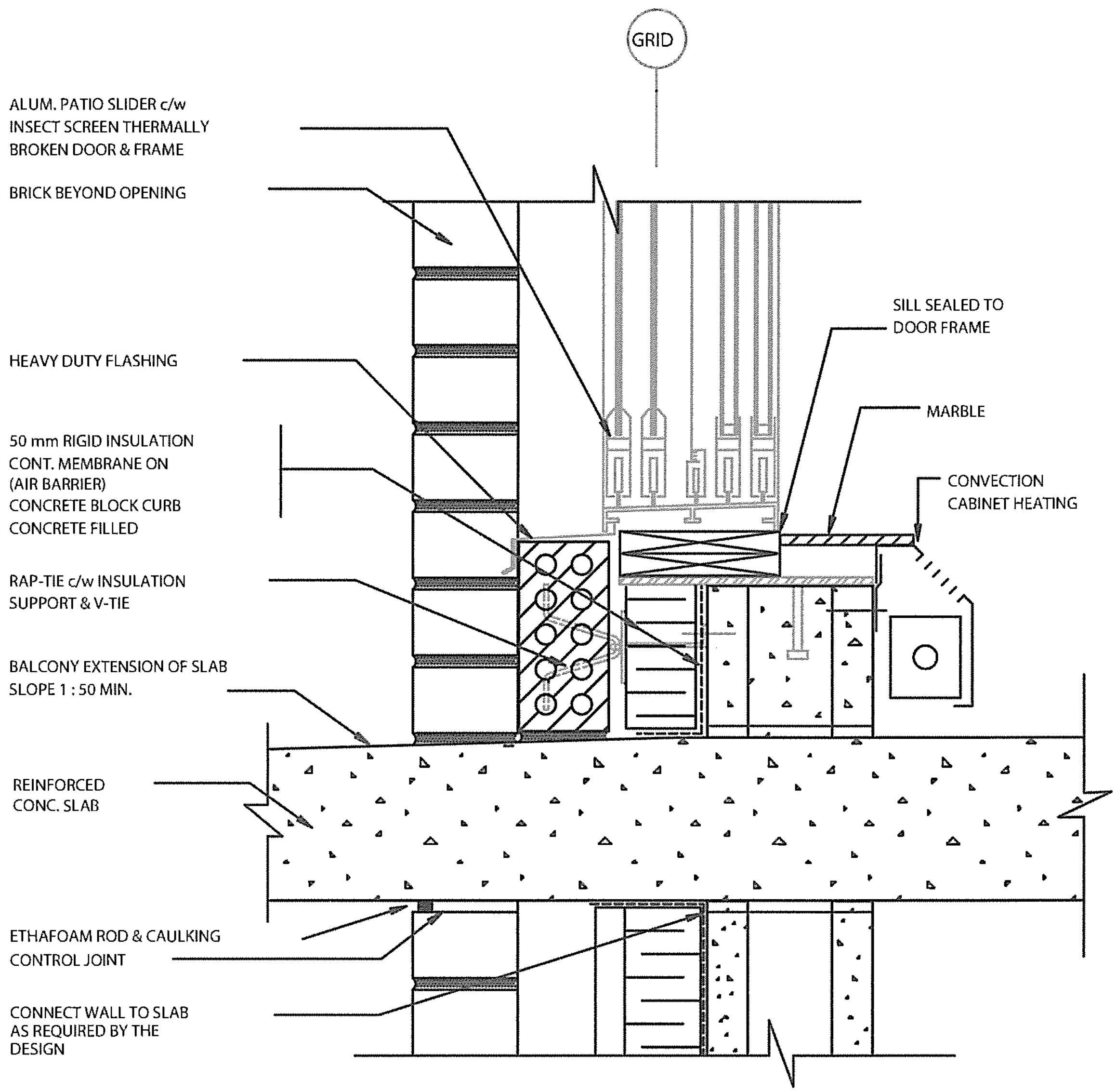


FIGURE 13 BRICK VENEER / CONCRETE BLOCK - BALCONY AT PATIO DOOR DETAIL

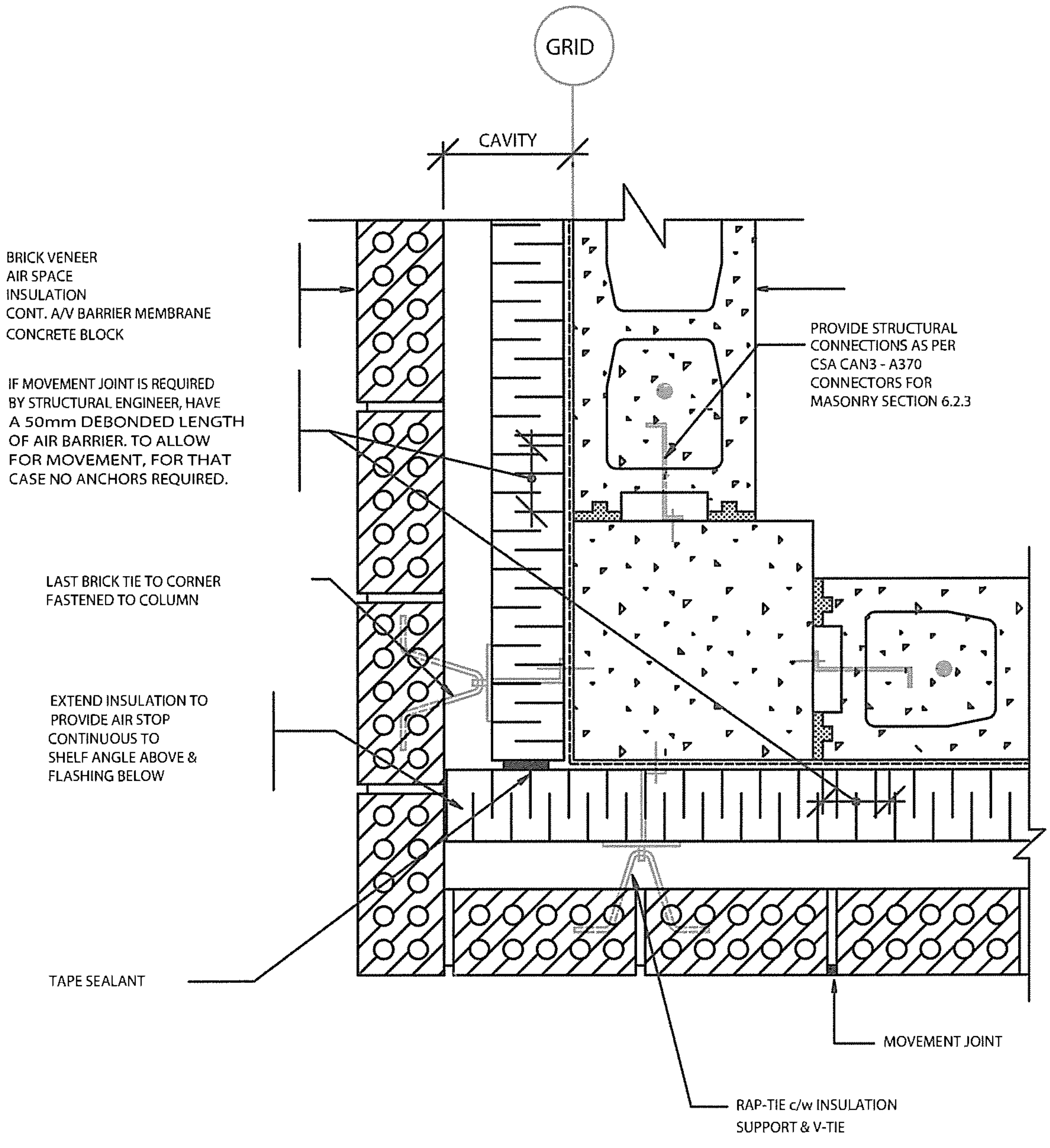


FIGURE 14 BRICK VENEER/CONCRETE BLOCK - CONTROL JOINT/AIR STOP

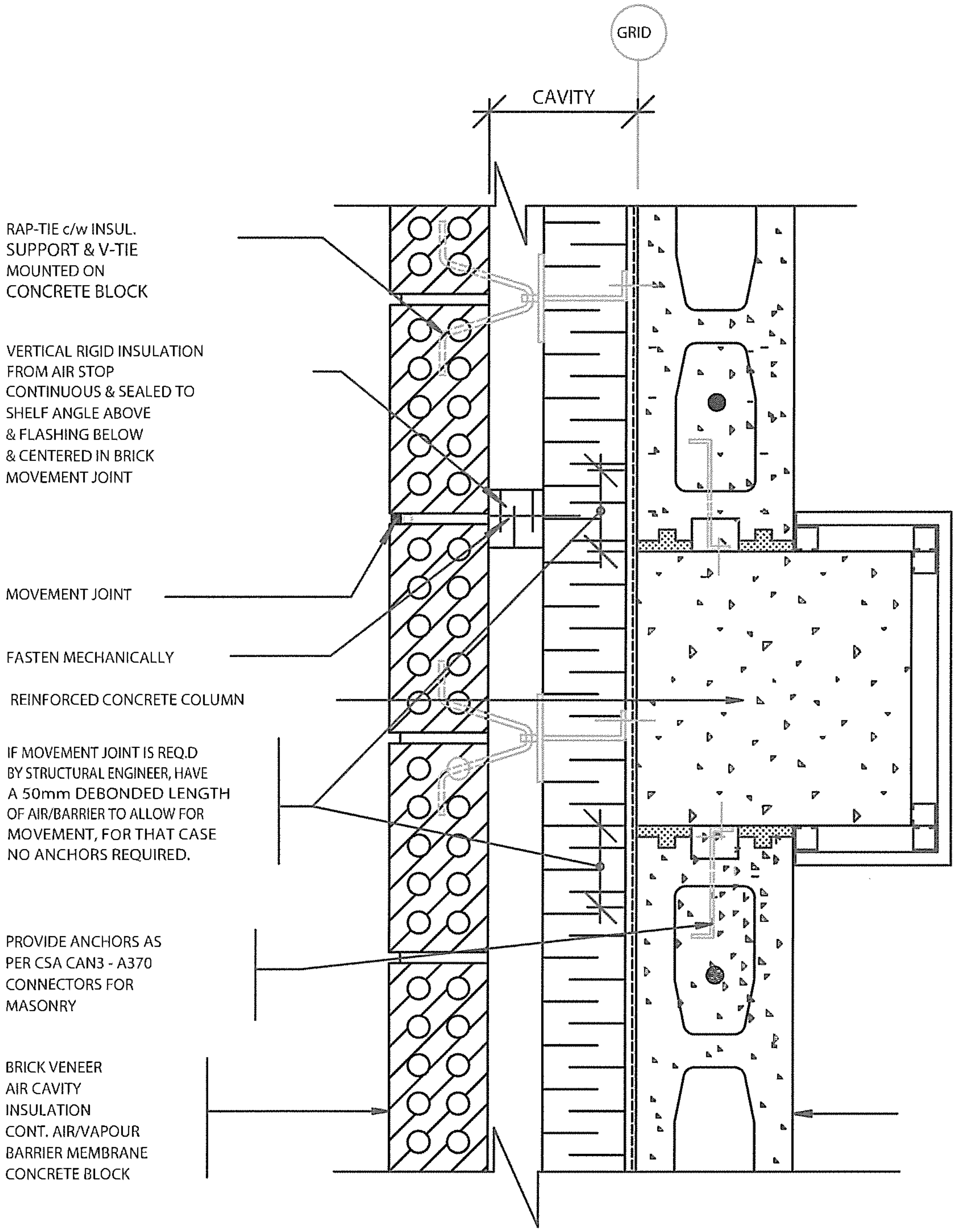


FIGURE 15 BRICK VENEER/CONCRETE BLOCK - CONTROL JOINT/AIR STOP

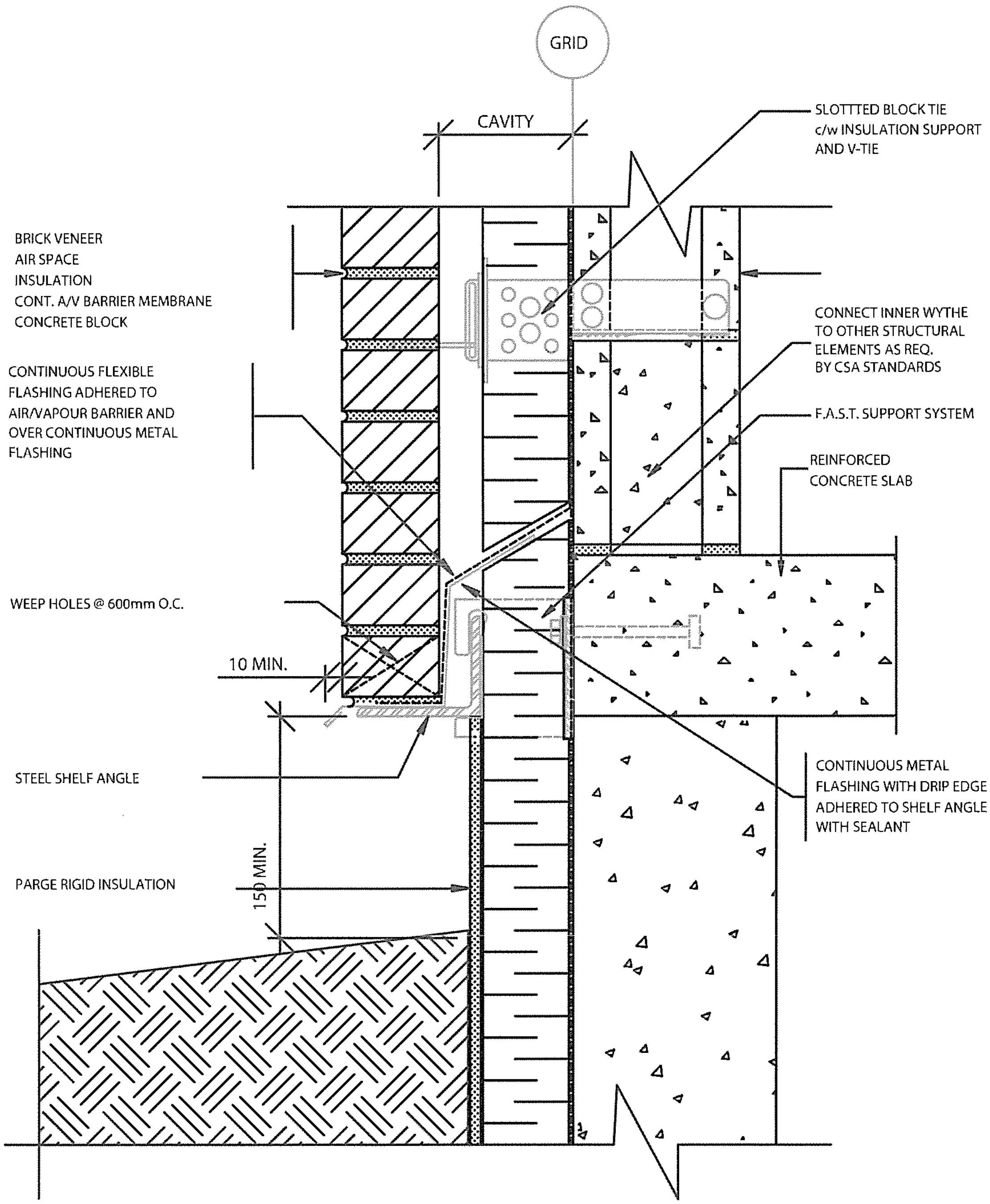


FIGURE 16 BRICK VENEER/CONCRETE BLOCK DETAIL AT FOUNDATION

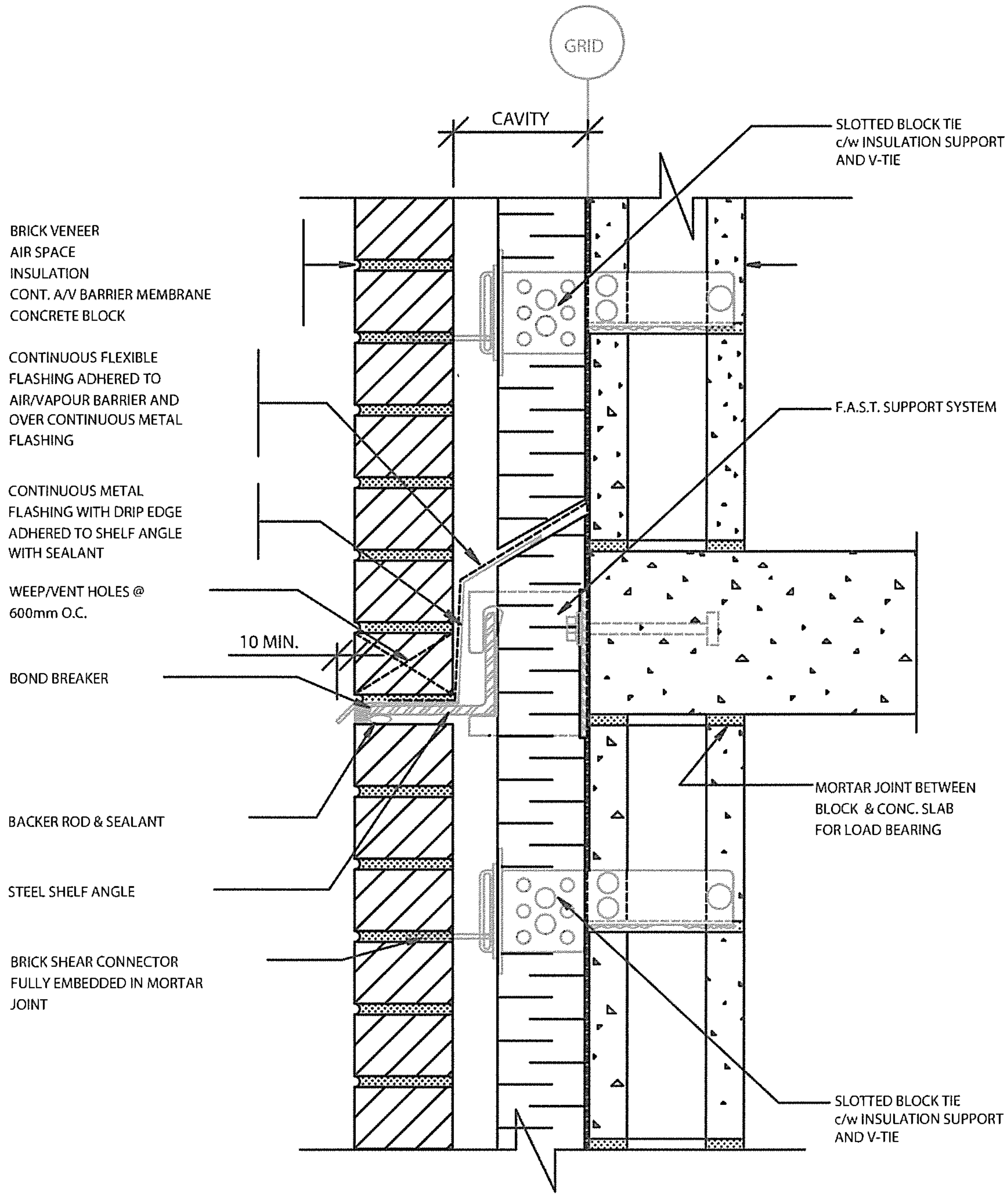


FIGURE 17 BRICK VENEER/CONCRETE BLOCK DETAIL AT SLAB EDGE FOR LOAD BEARING WALL

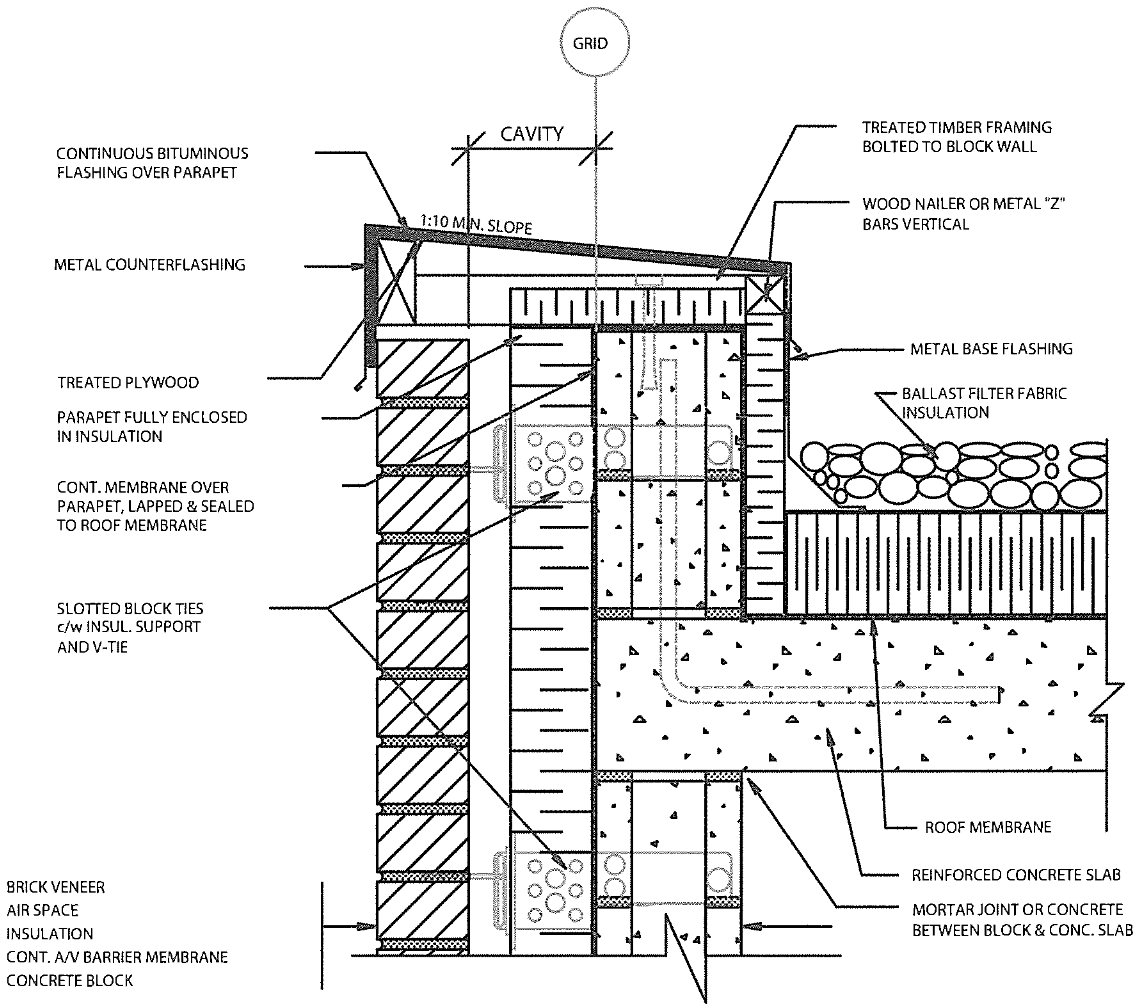


FIGURE 18 BRICK VENEER/CONCRETE BLOCK-DETAIL OF LOW PARAPET W/ PROTECTED ROOF MEMBRANE (LOAD BEARING WALL)

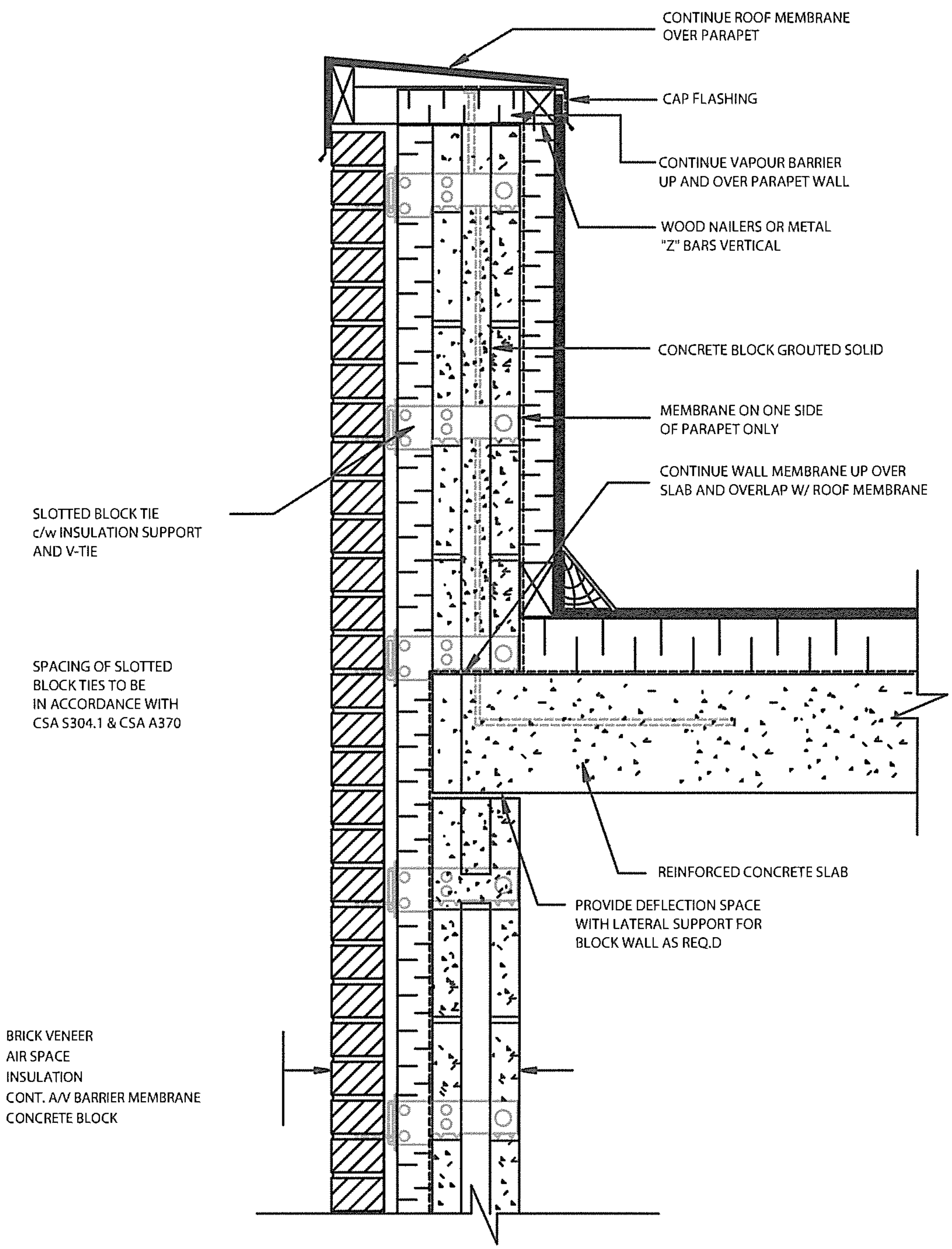


FIGURE 19 BRICK VENEER/CONCRETE BLOCK-DETAIL AT HIGH PARAPET
FOR NON LOAD BEARING ASSEMBLY

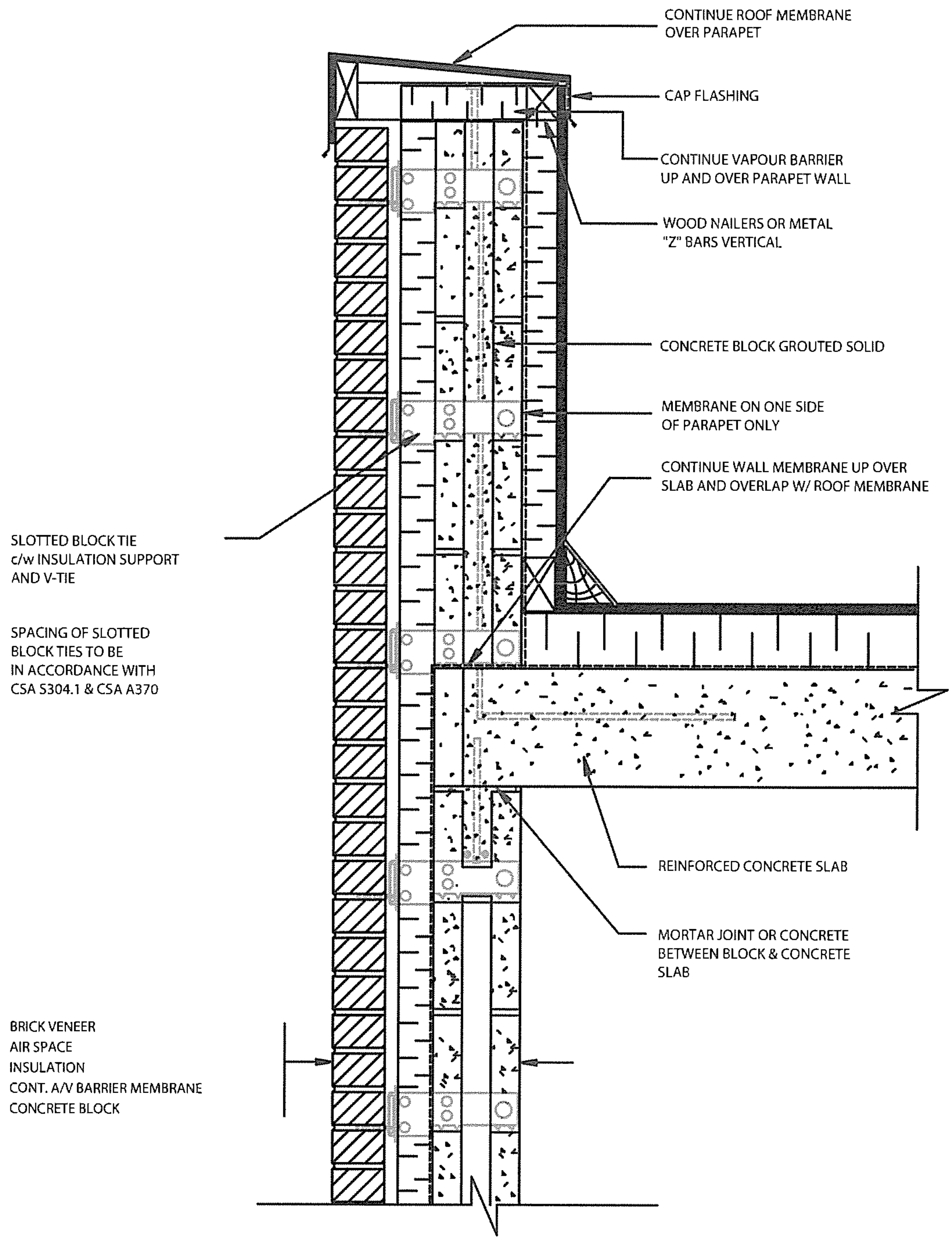


FIGURE 20 BRICK VENEER/CONCRETE BLOCK-DETAIL AT HIGH PARAPET
FOR LOAD BEARING ASSEMBLY

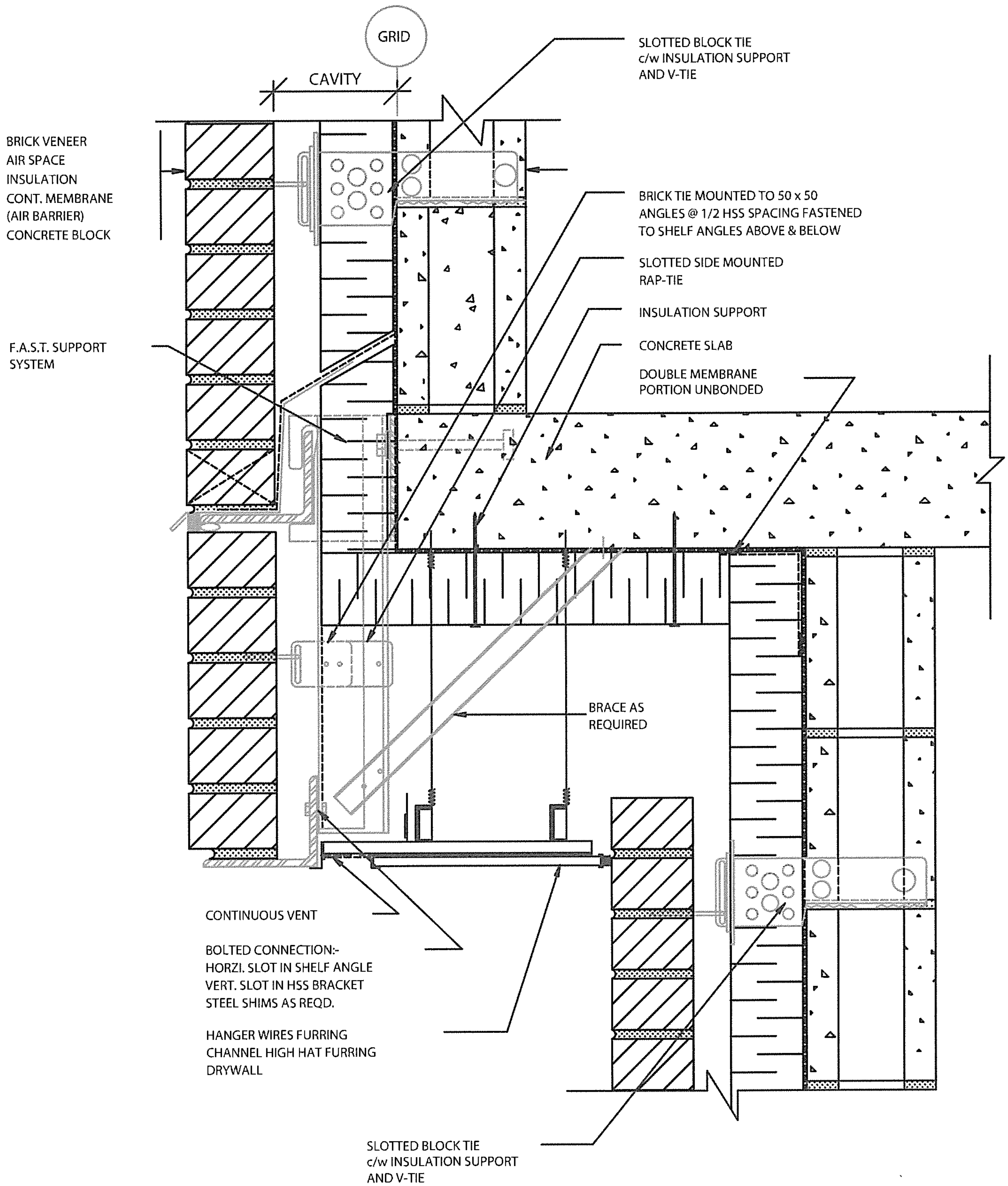


FIGURE 21 BRICK VENEER/CONCRETE BLOCK-COLD SOFFIT DETAIL

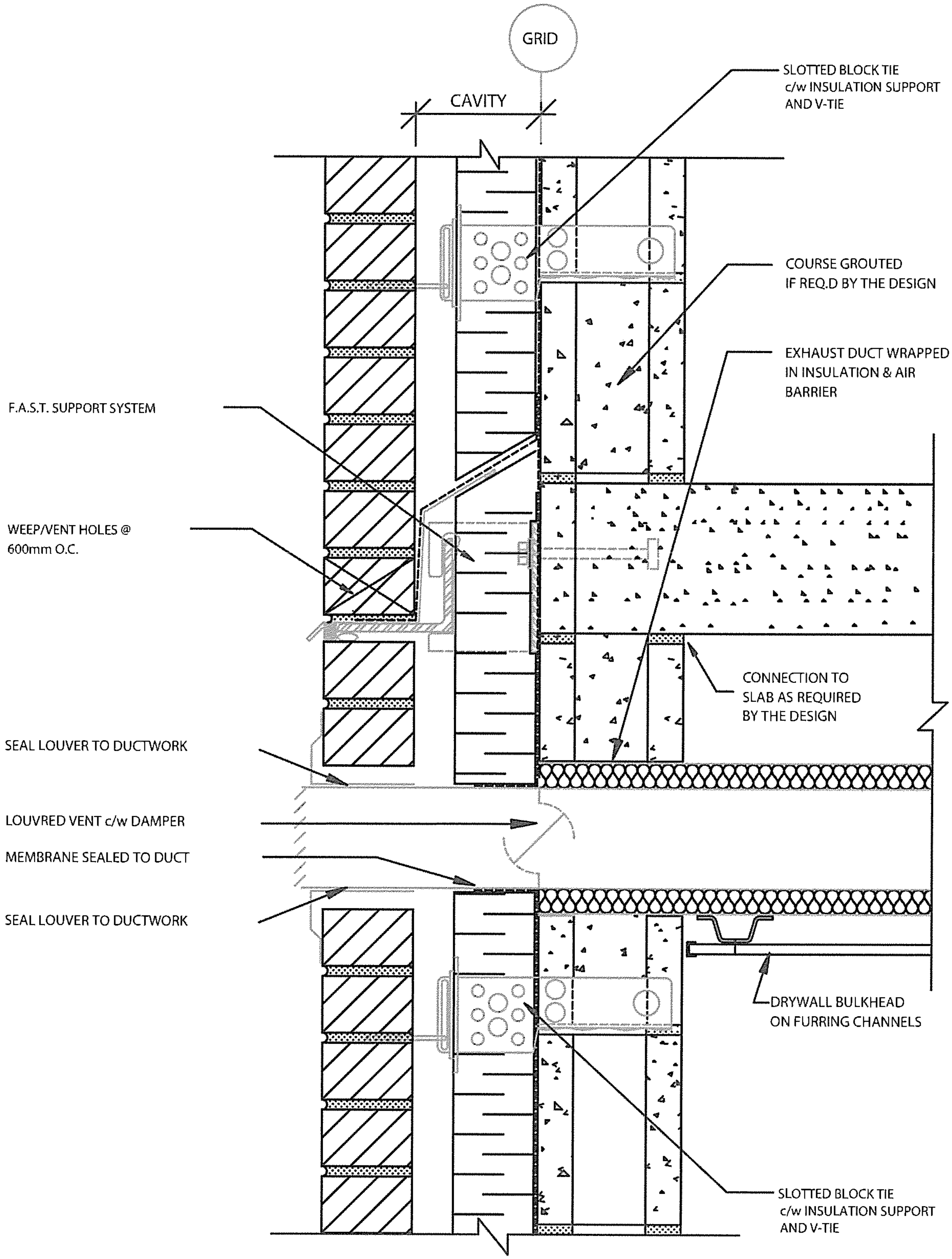


FIGURE 22 BRICK VENEER/CONCRETE BLOCK-EXHAUST VENT DETAIL

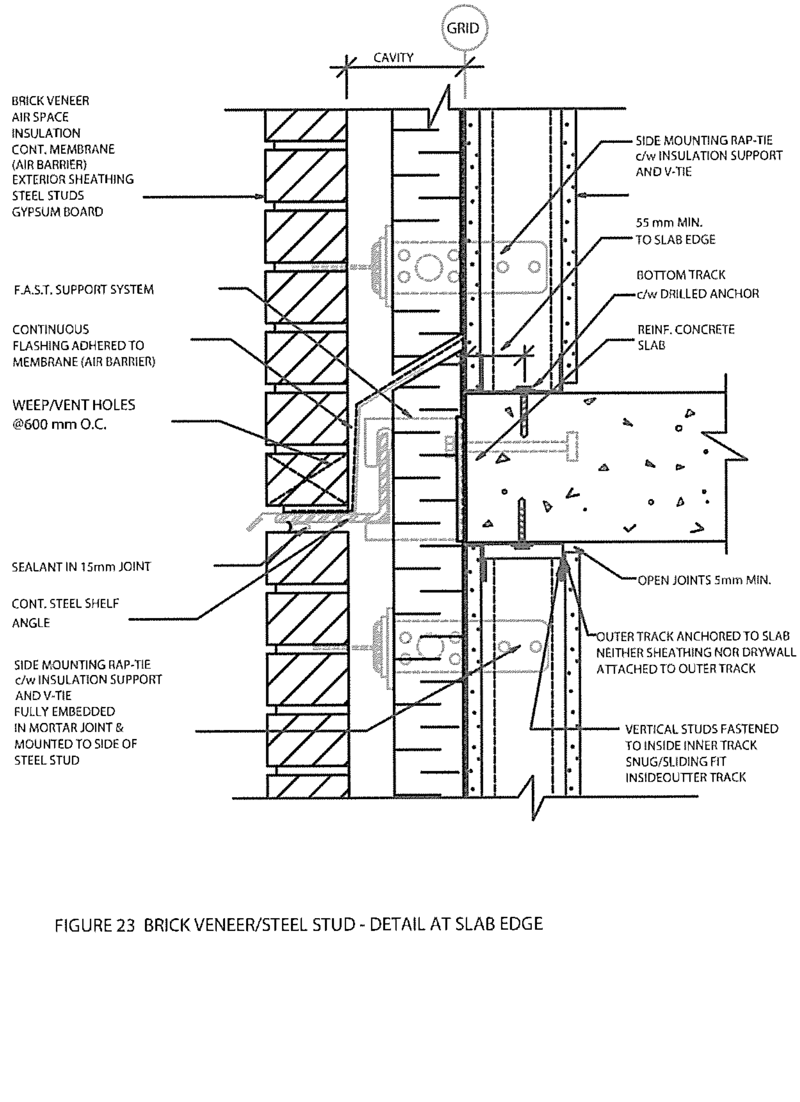


FIGURE 23 BRICK VENEER/STEEL STUD - DETAIL AT SLAB EDGE

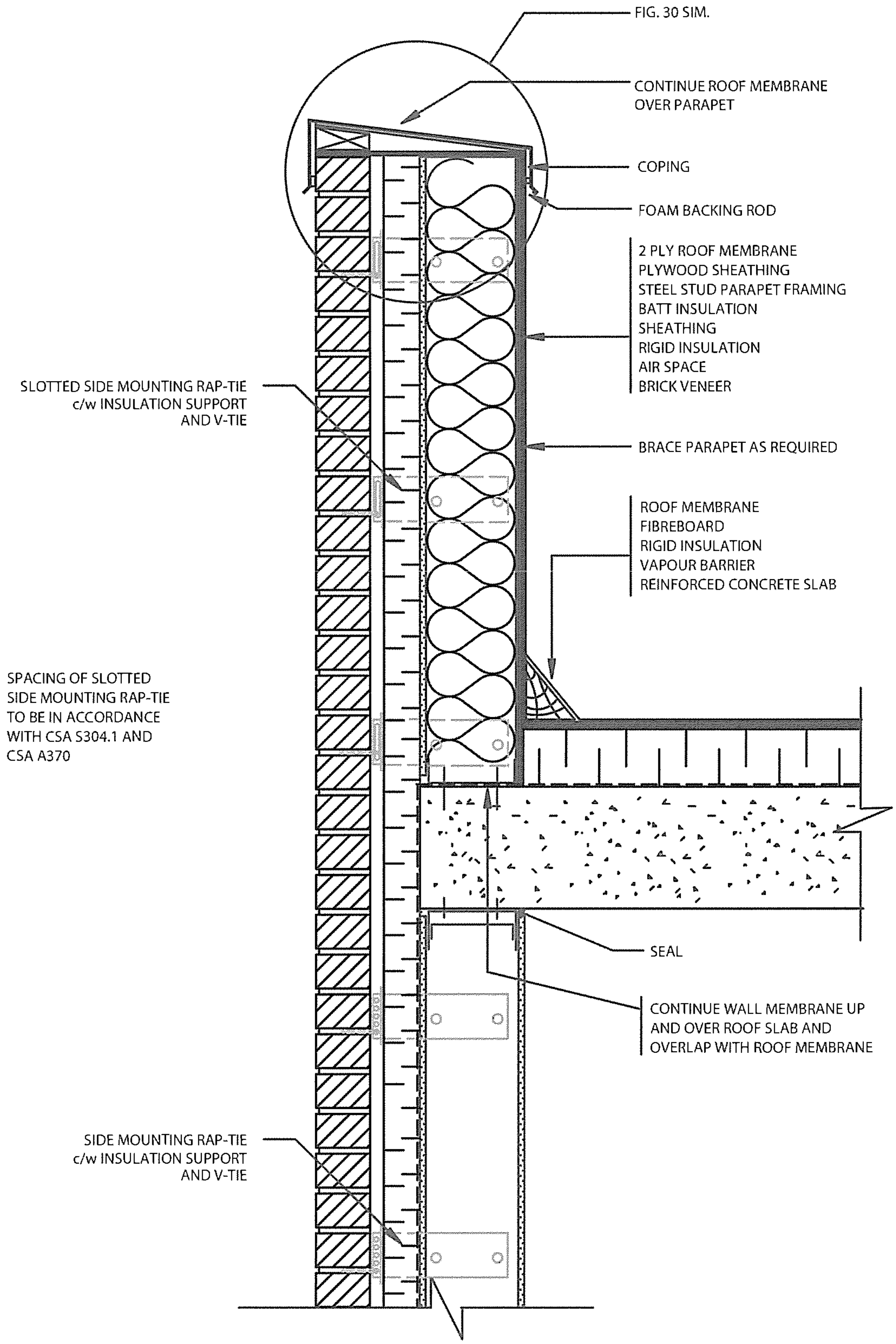


FIGURE 24 BRICK VENEER / CONCRETE BLOCK - DETAIL AT HIGH PARAPET

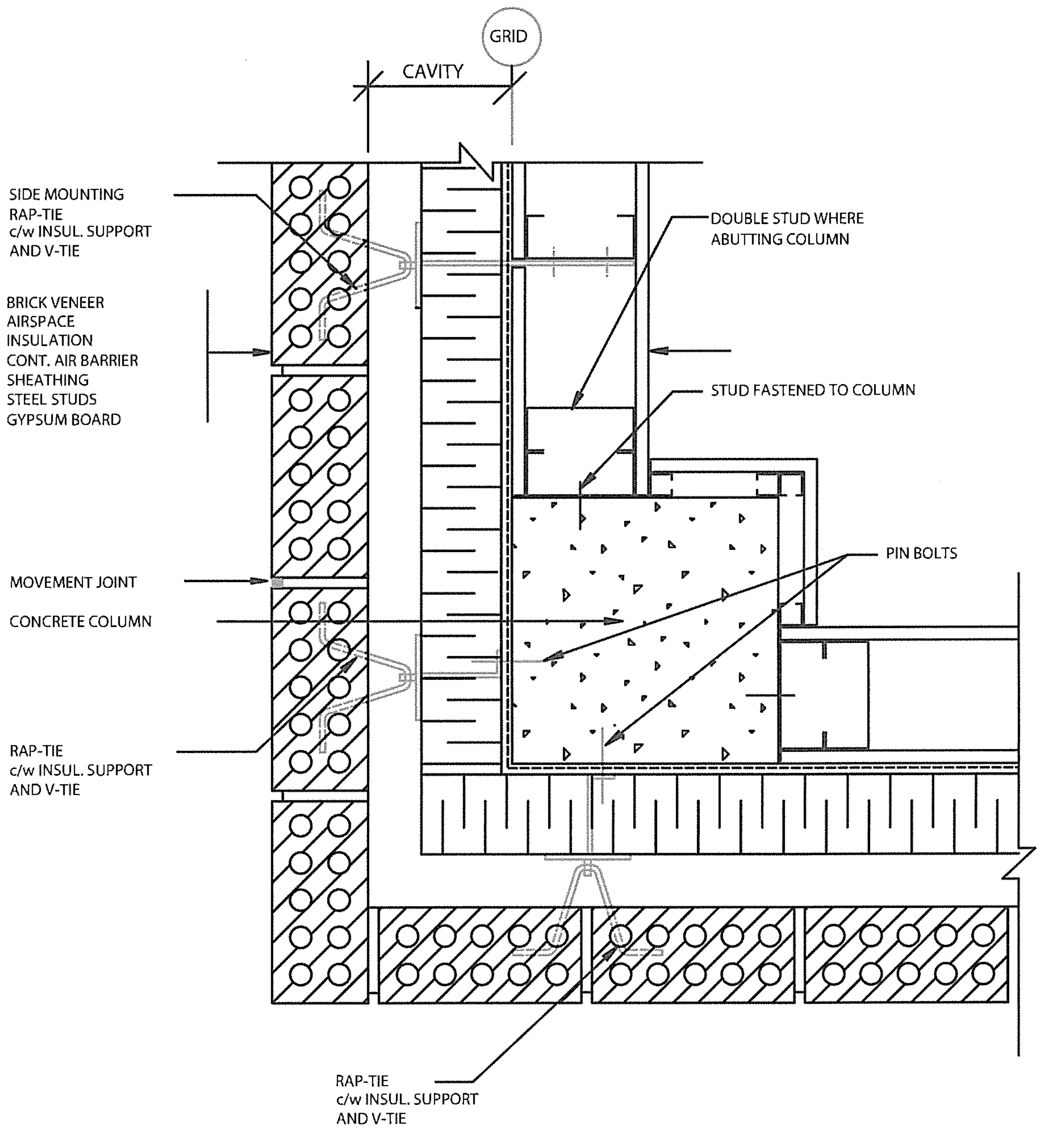


FIGURE 25 BRICK VENEER / STEEL STUD - CONTROL JOINT/AIR STOP

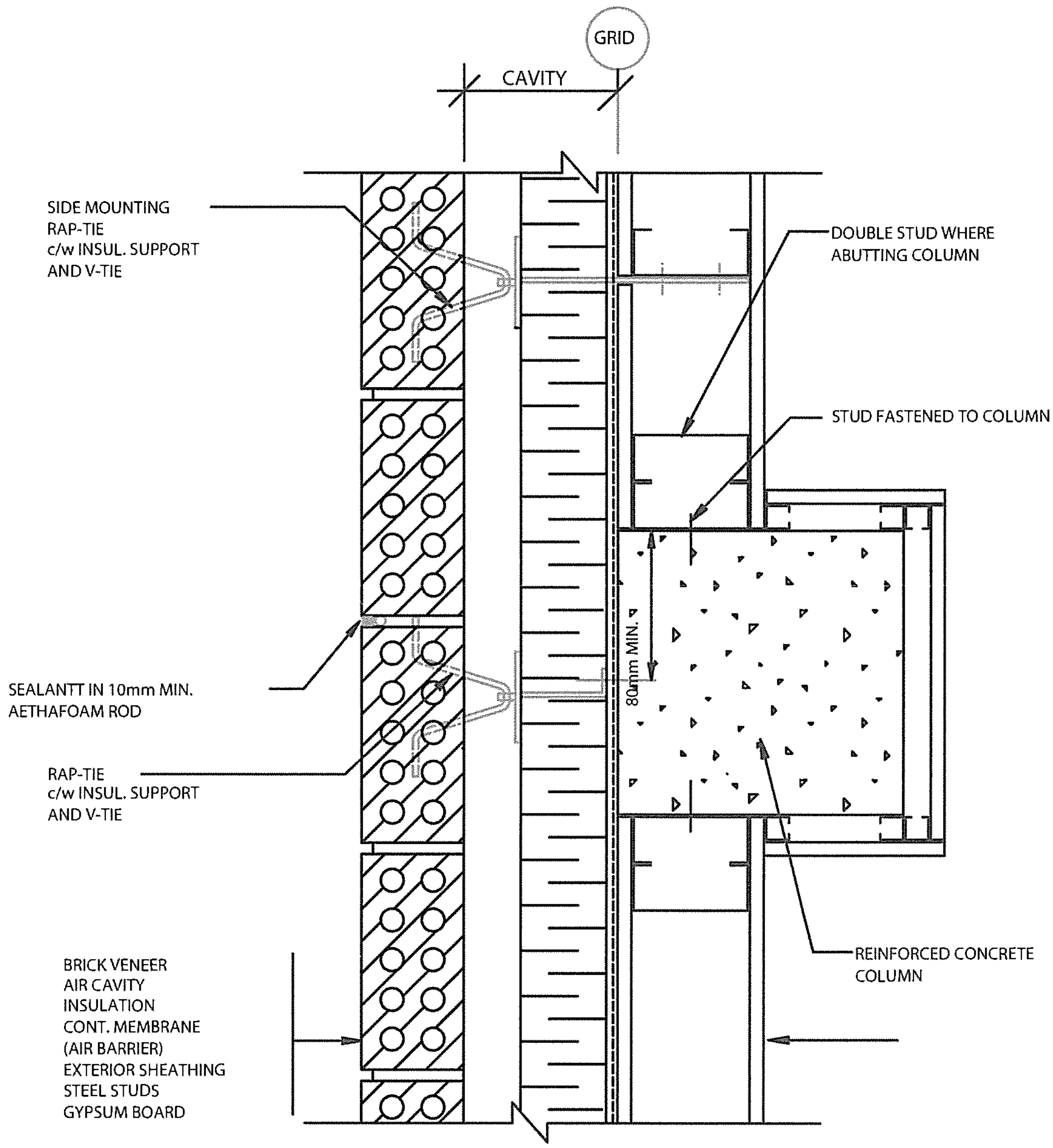


FIGURE 26 BRICK VENEER / STEEL STUD - CONTROL JOINT/AIR STOP

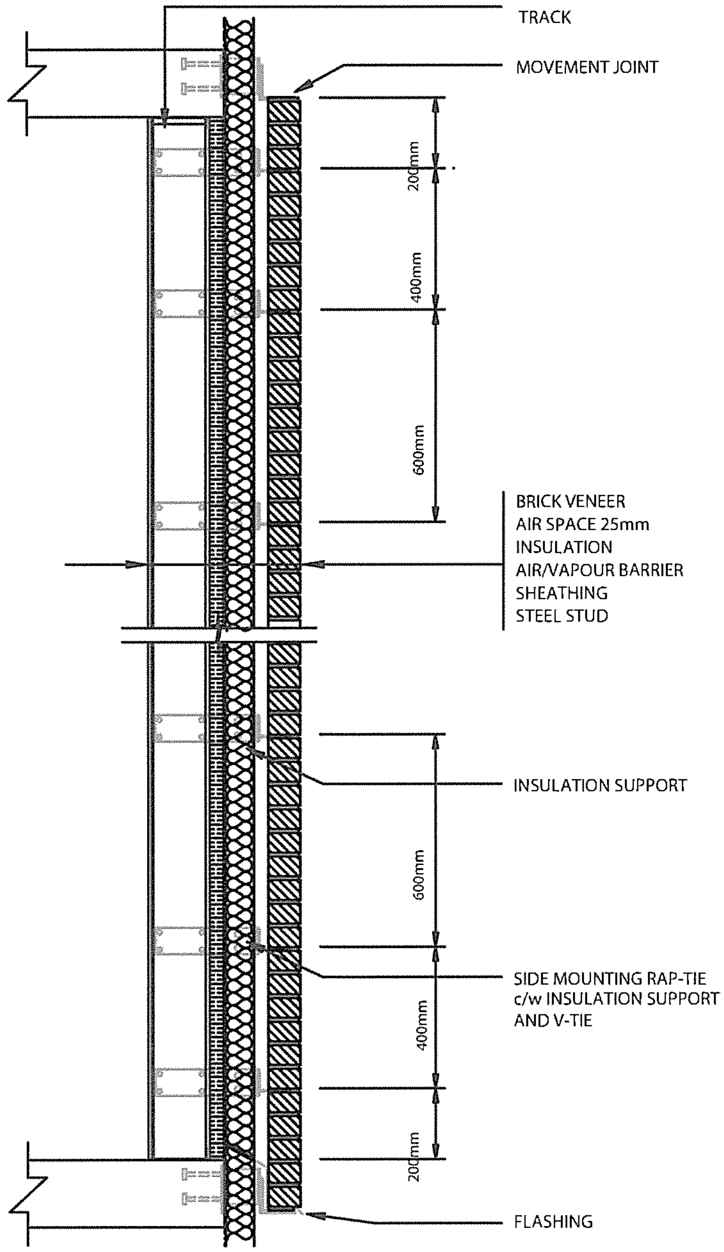


FIGURE 27 RECOMMENDED LOCATION OF SIDE MOUNTING RAP-TIES ALONG THE HEIGHT OF BRICK VENEER - METAL STUD WALL ASSEMBLY

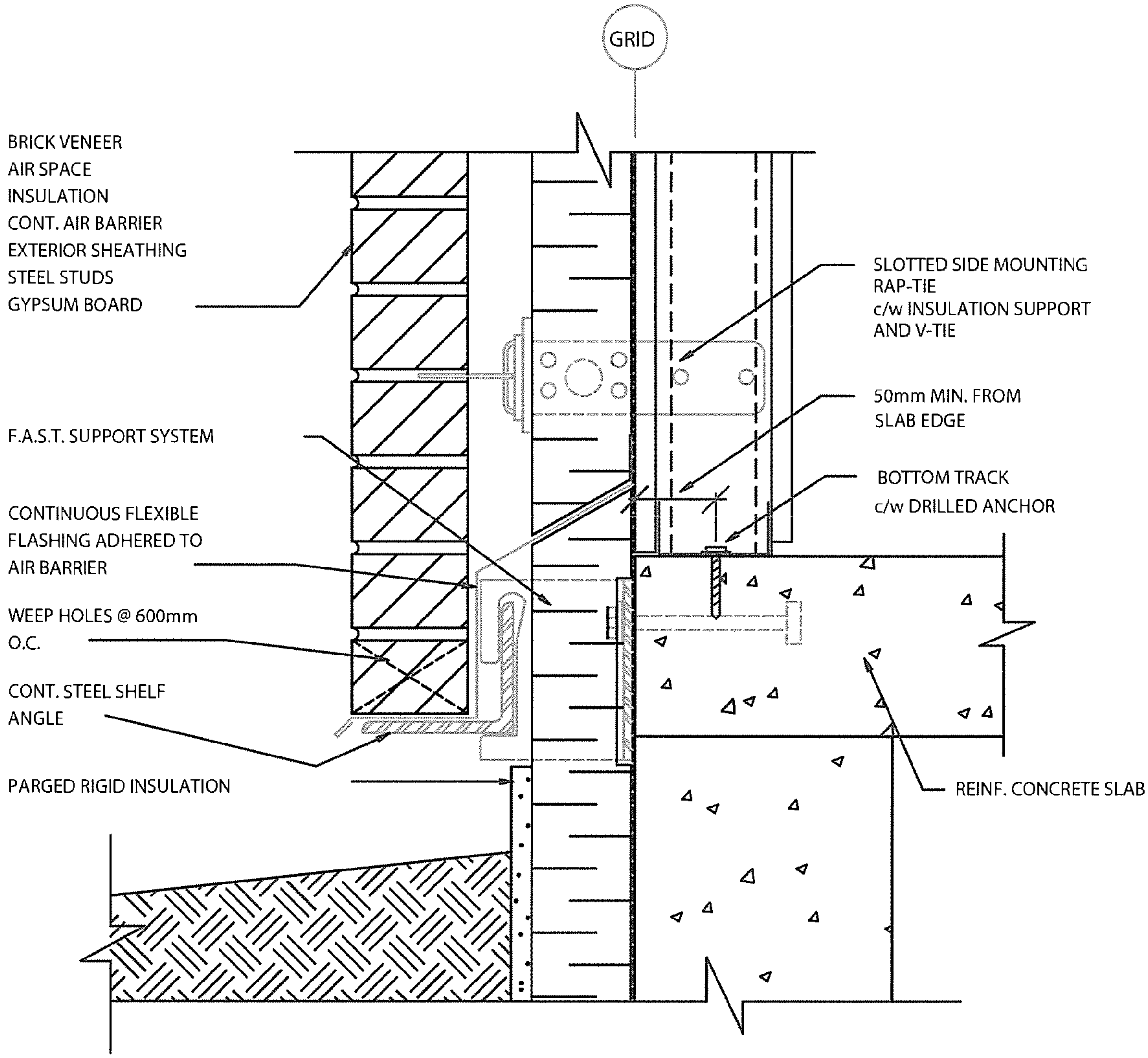


FIGURE 28 BRICK VENEER / STEEL STUD DETAIL AT FOUNDATION

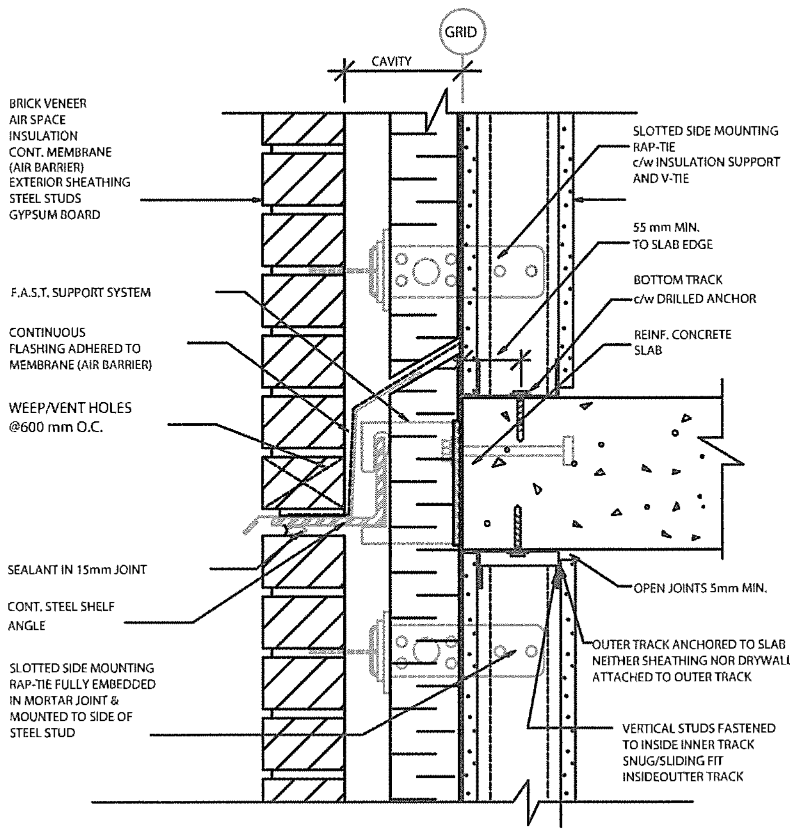


FIGURE 29 BRICK VENEER/STEEL STUD - DETAIL AT SLAB EDGE

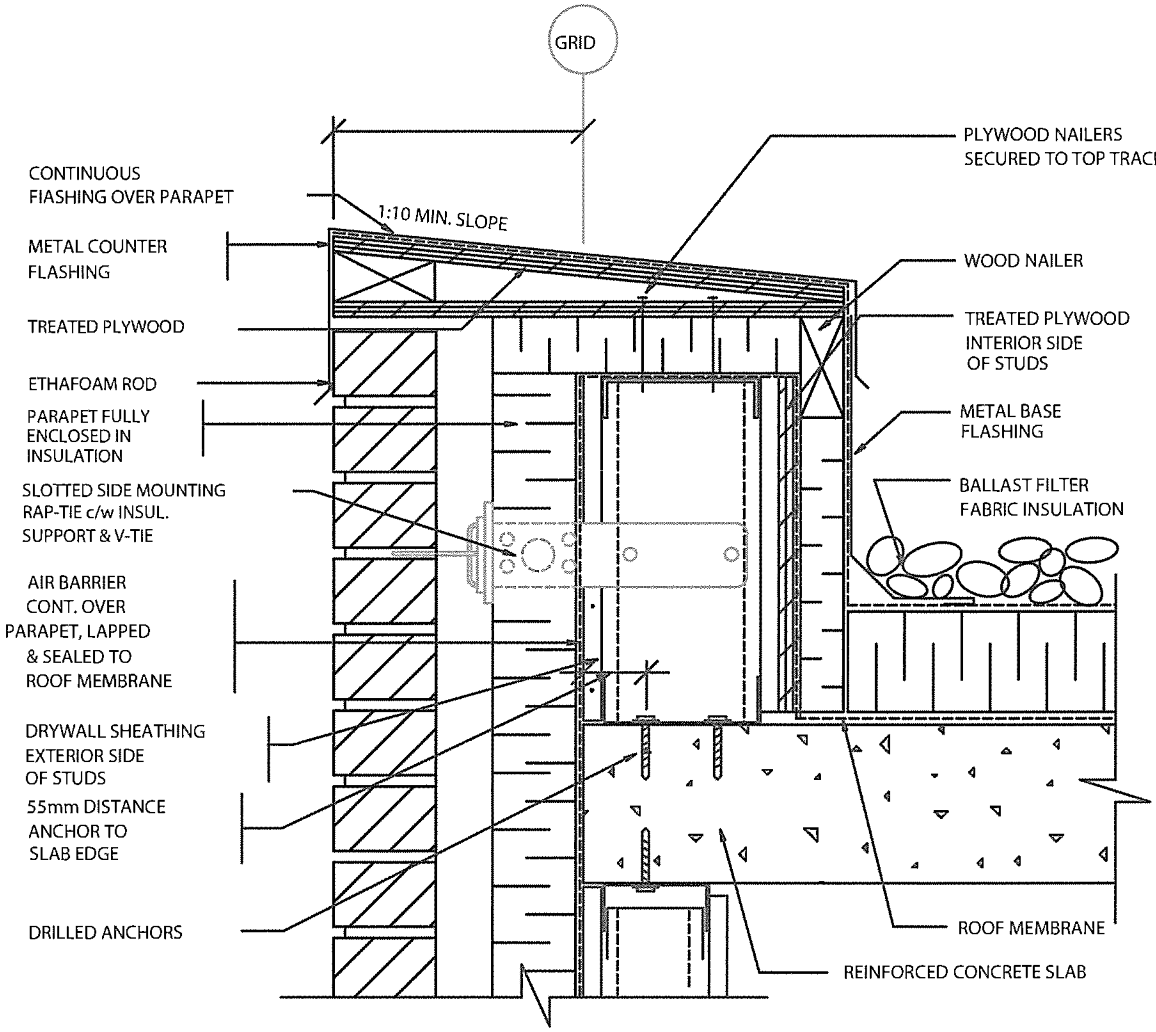


FIGURE 30 BRICK VENEER / STEEL STUD - DETAIL AT LOW PARAPET

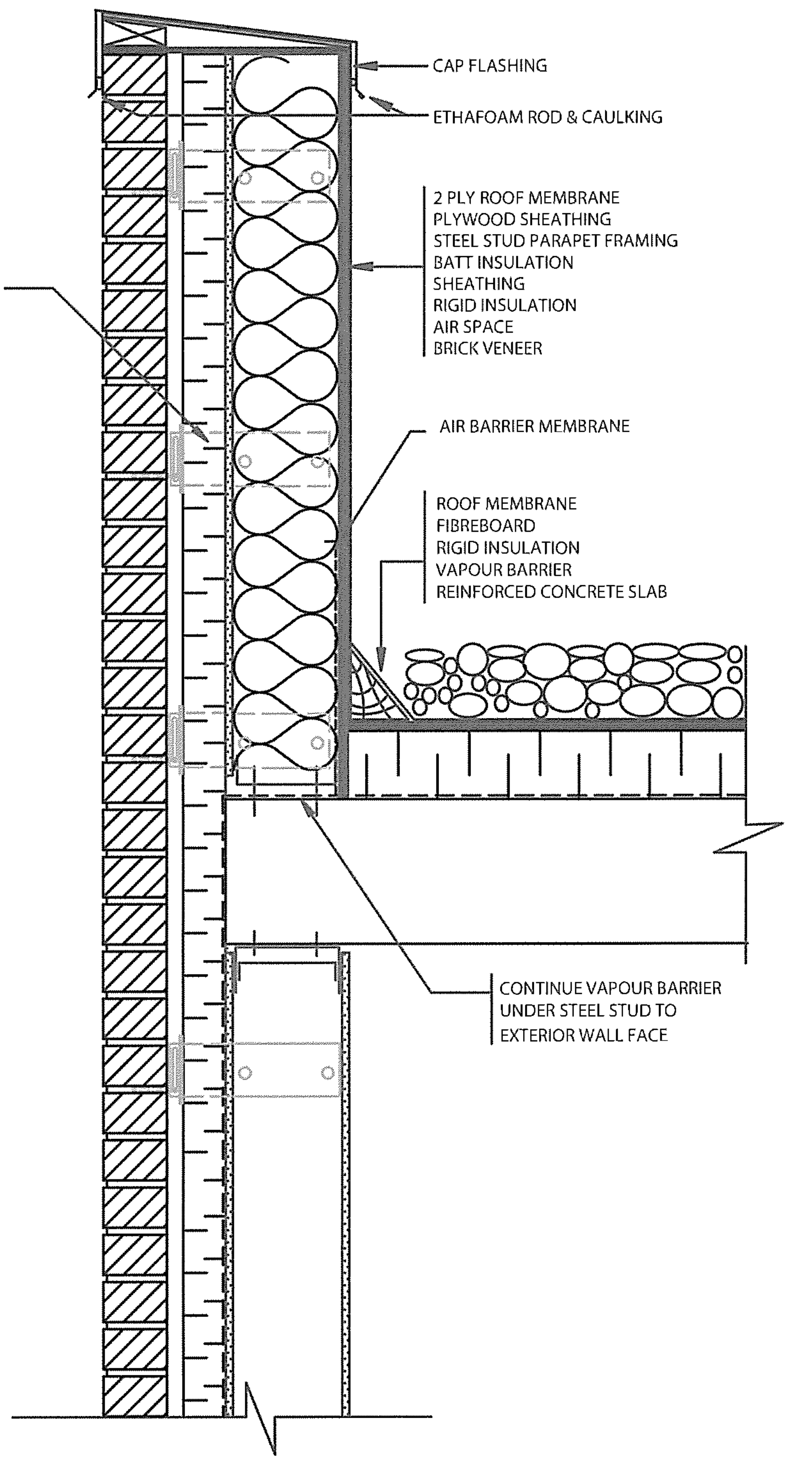


FIGURE 31 BRICK VENEER / STEEL STUD - DETAIL AT HIGH PARAPET

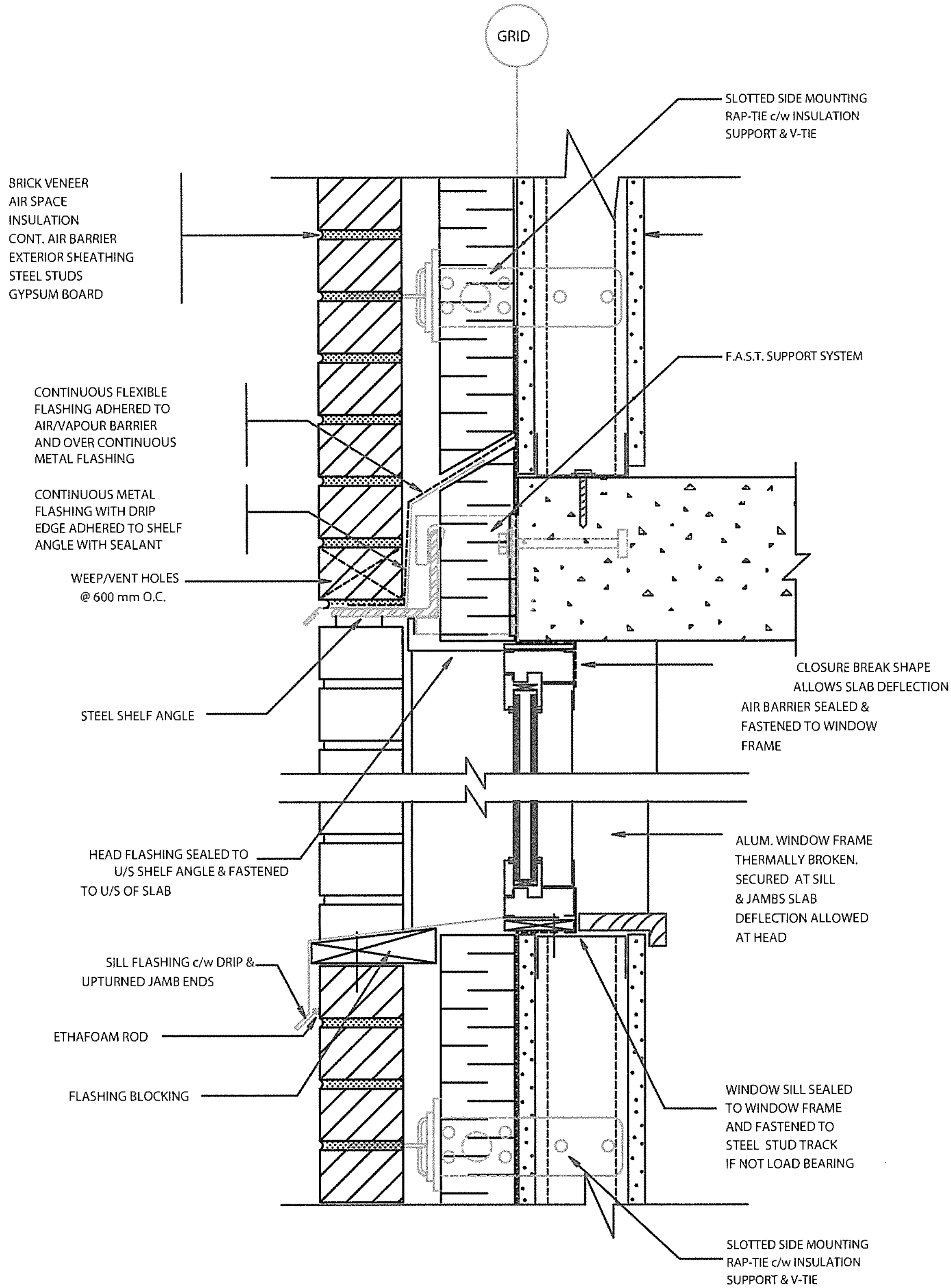


FIGURE 32 BRICK VENEER / STEEL STUD - WINDOW HEAD & SILL DETAIL

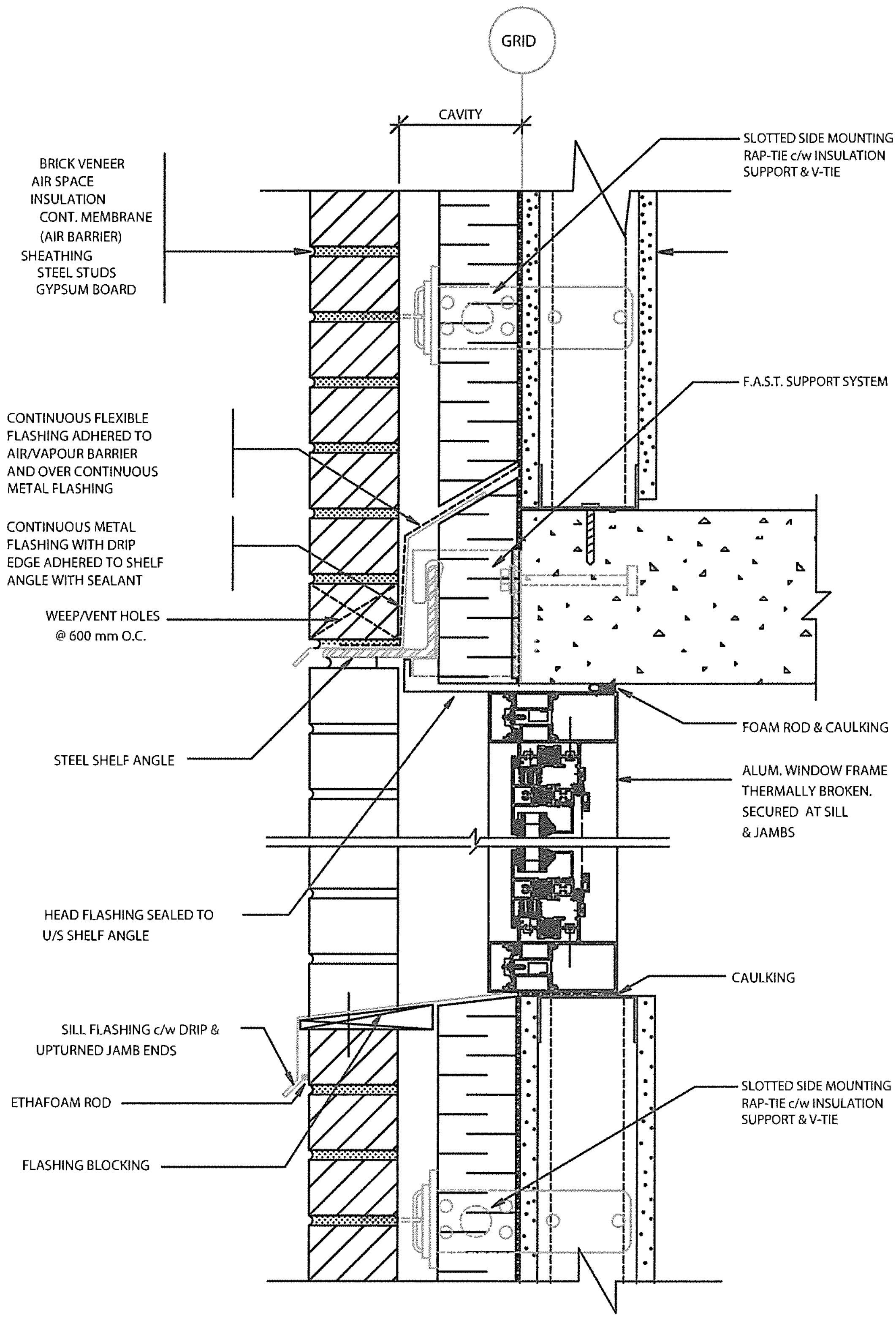


FIGURE 33 BRICK ALTERNATE BRICK VENEER / STEEL STUD WINDOW HEAD AND SILL DETAIL

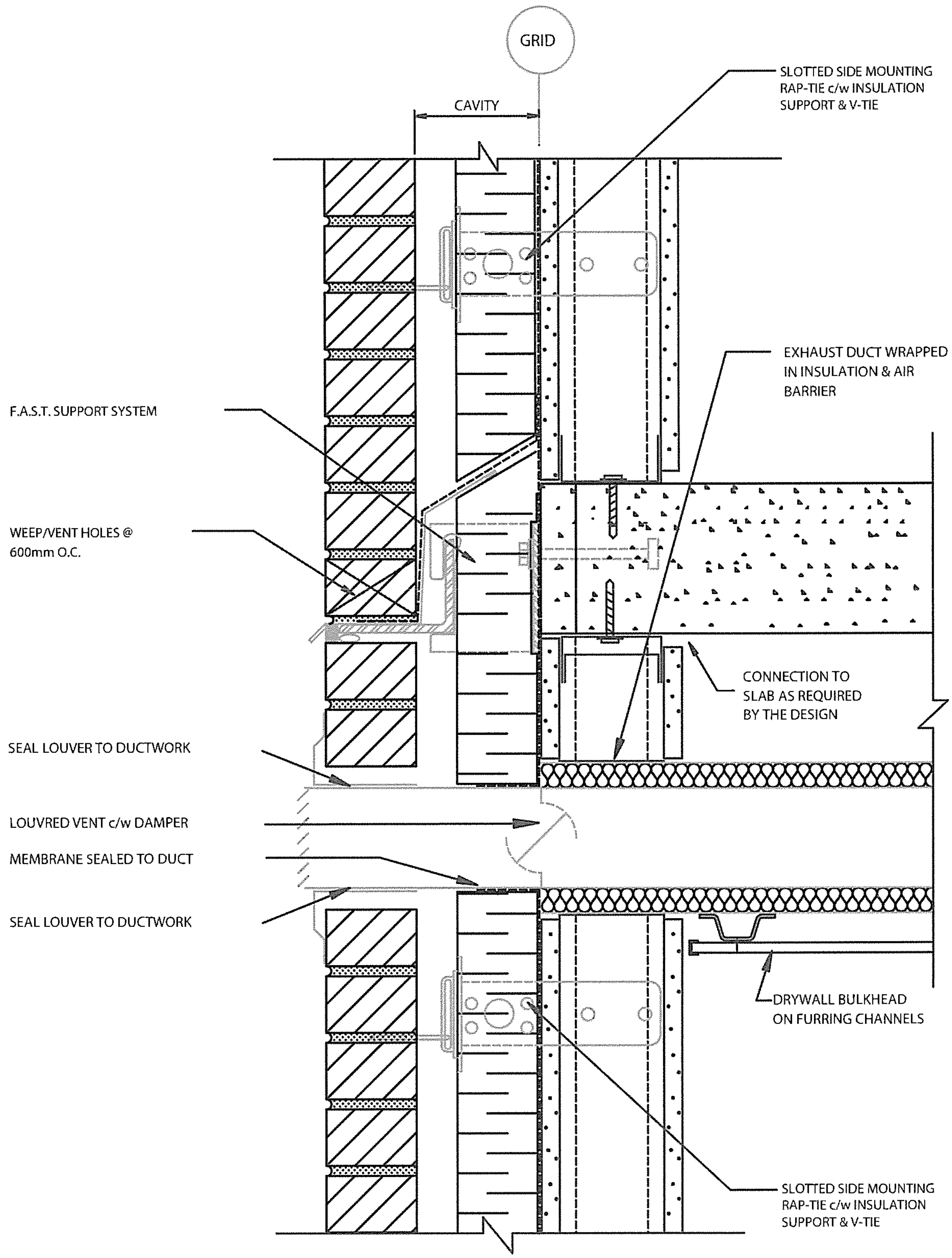


FIGURE 34 BRICK VENEER/STEEL STUD - EXHAUST VENT DETAIL

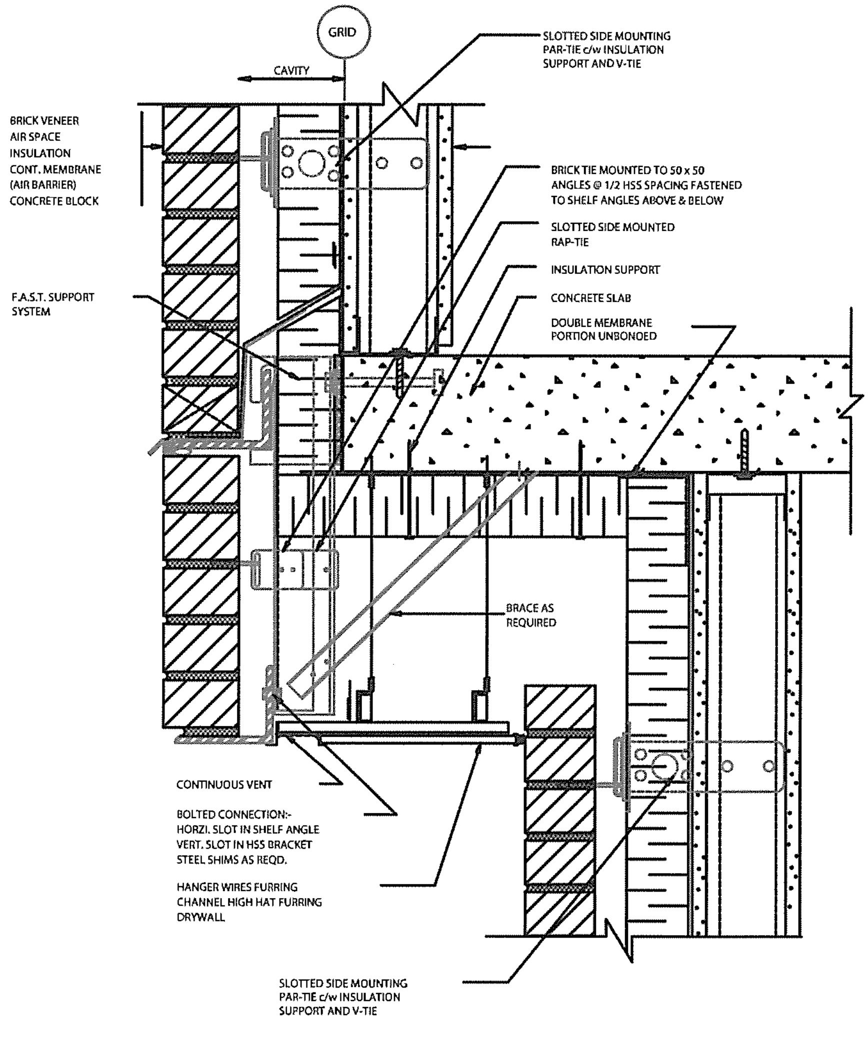


FIGURE 35 BRICK VENEER/STEEL STUD-COLD SOFFIT DETAIL

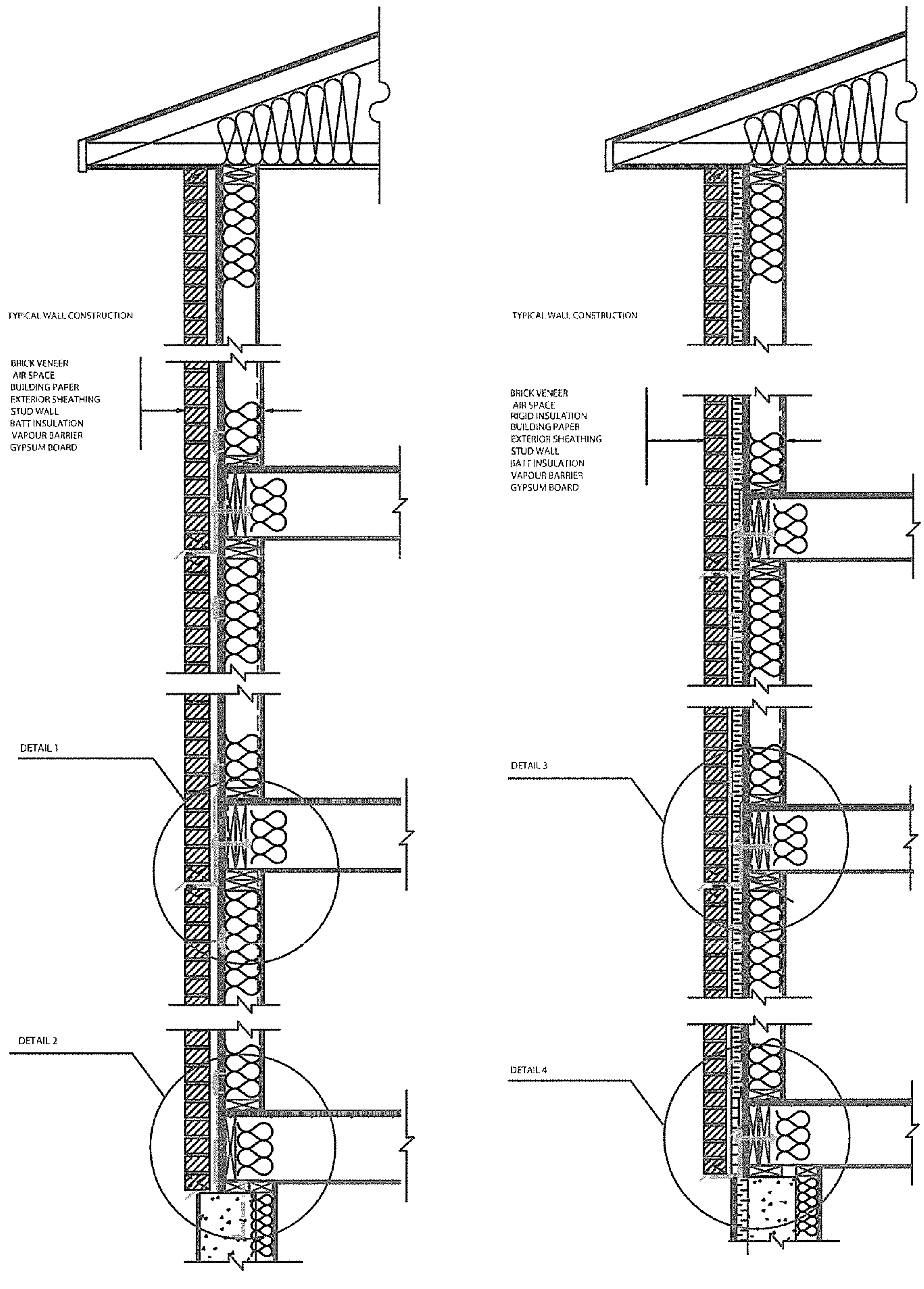
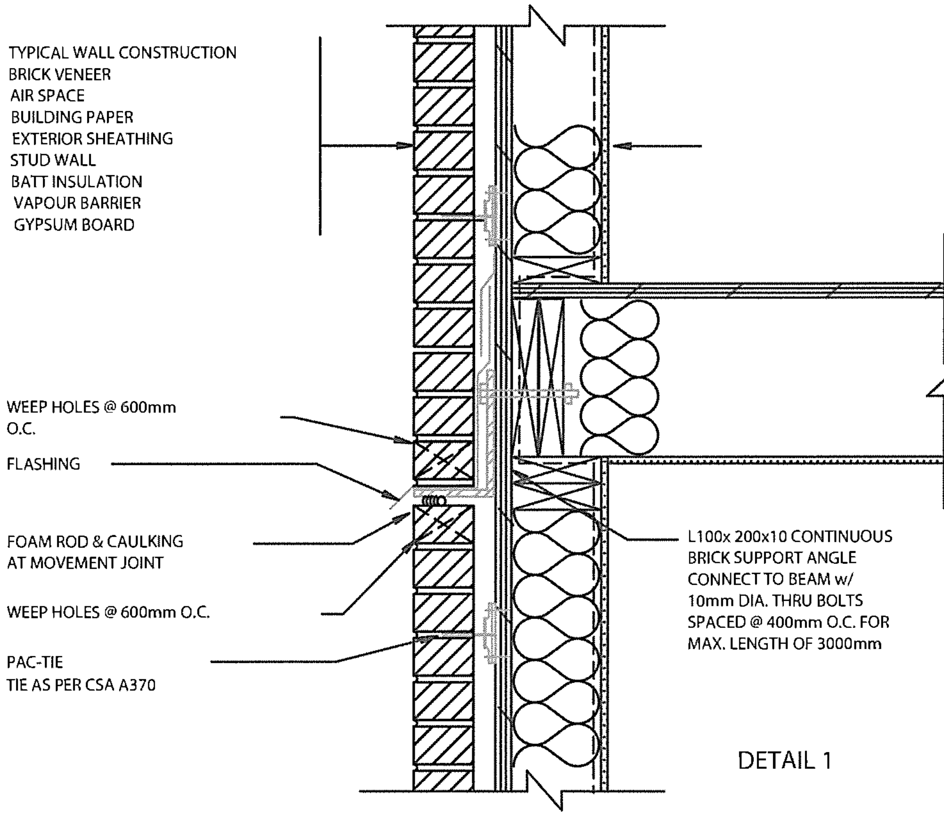


FIGURE 36 TYPICAL WOOD FRAME CONSTRUCTION APARTMENT BUILDING



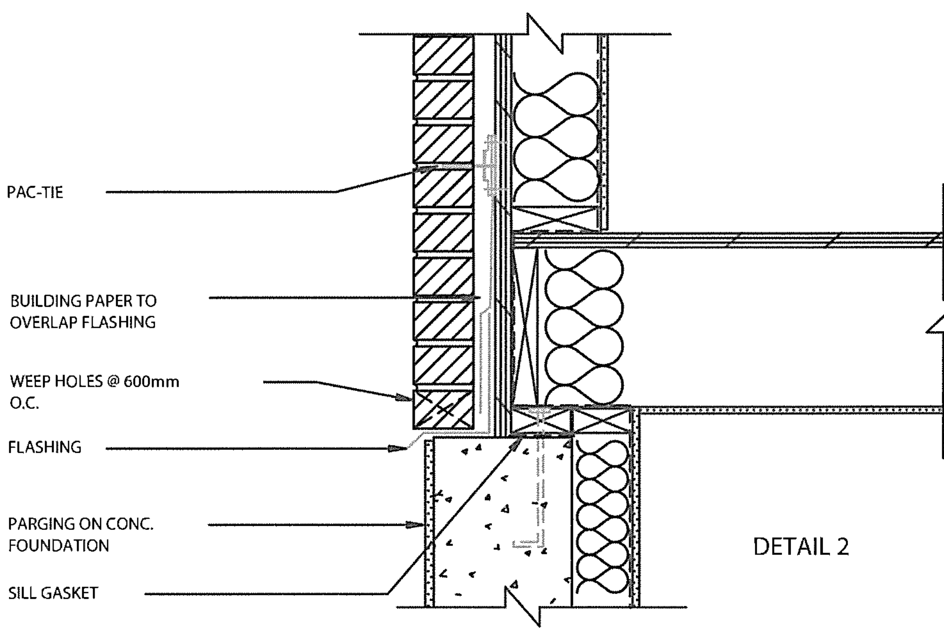


FIGURE 37 DETAILS OF BRICK VENEER AT GROUND AND FLOOR LEVELS (UNINSULATED CAVITY)

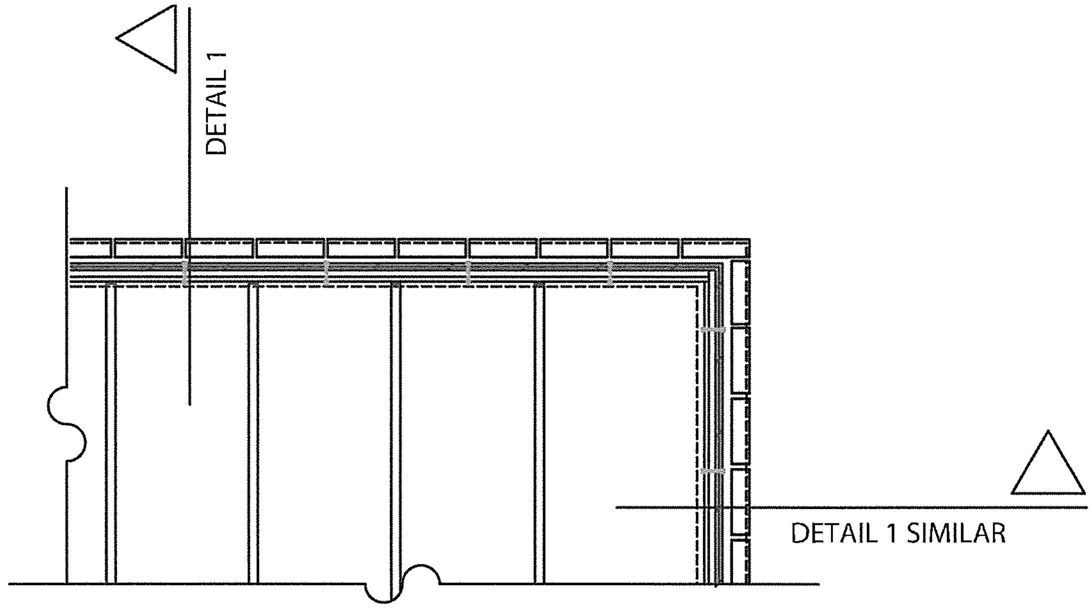


FIGURE 38 CORNER PLAN

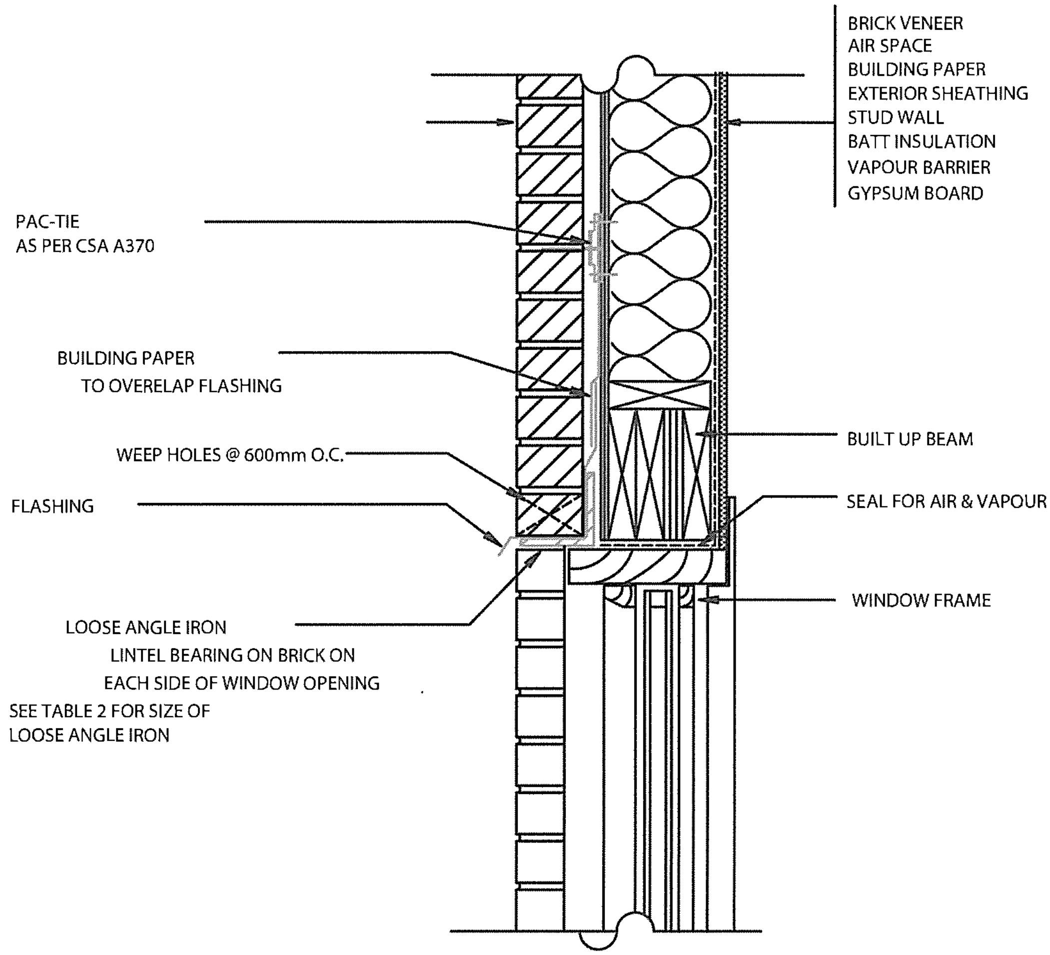


FIGURE 38A WINDOW OPENING WITH LOOSE ANGLE IRON LINTEL

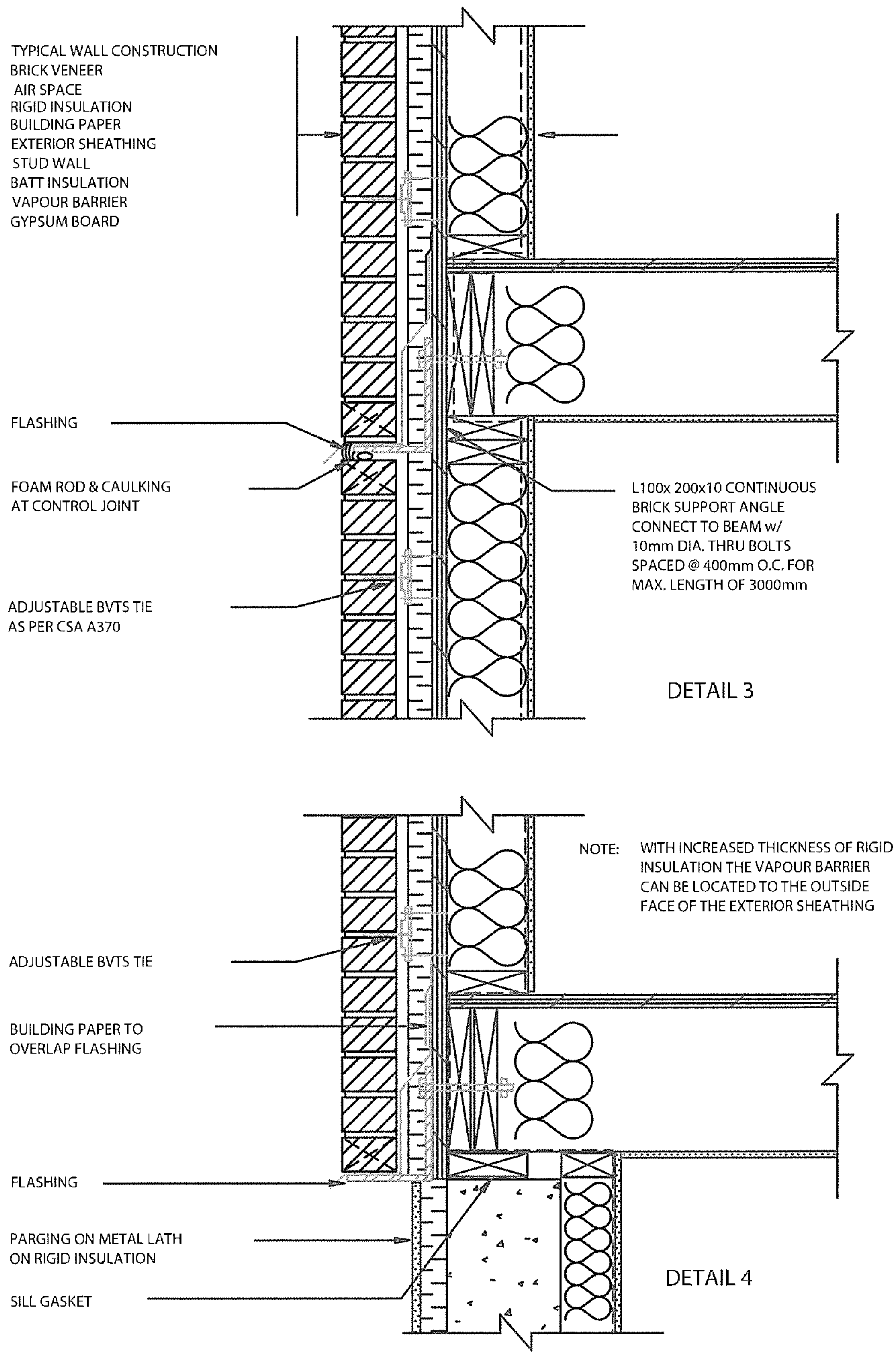


FIGURE 39 DETAILS OF BRICK VENEER AT GROUND AND FLOOR LEVELS (INSULATED CAVITY)

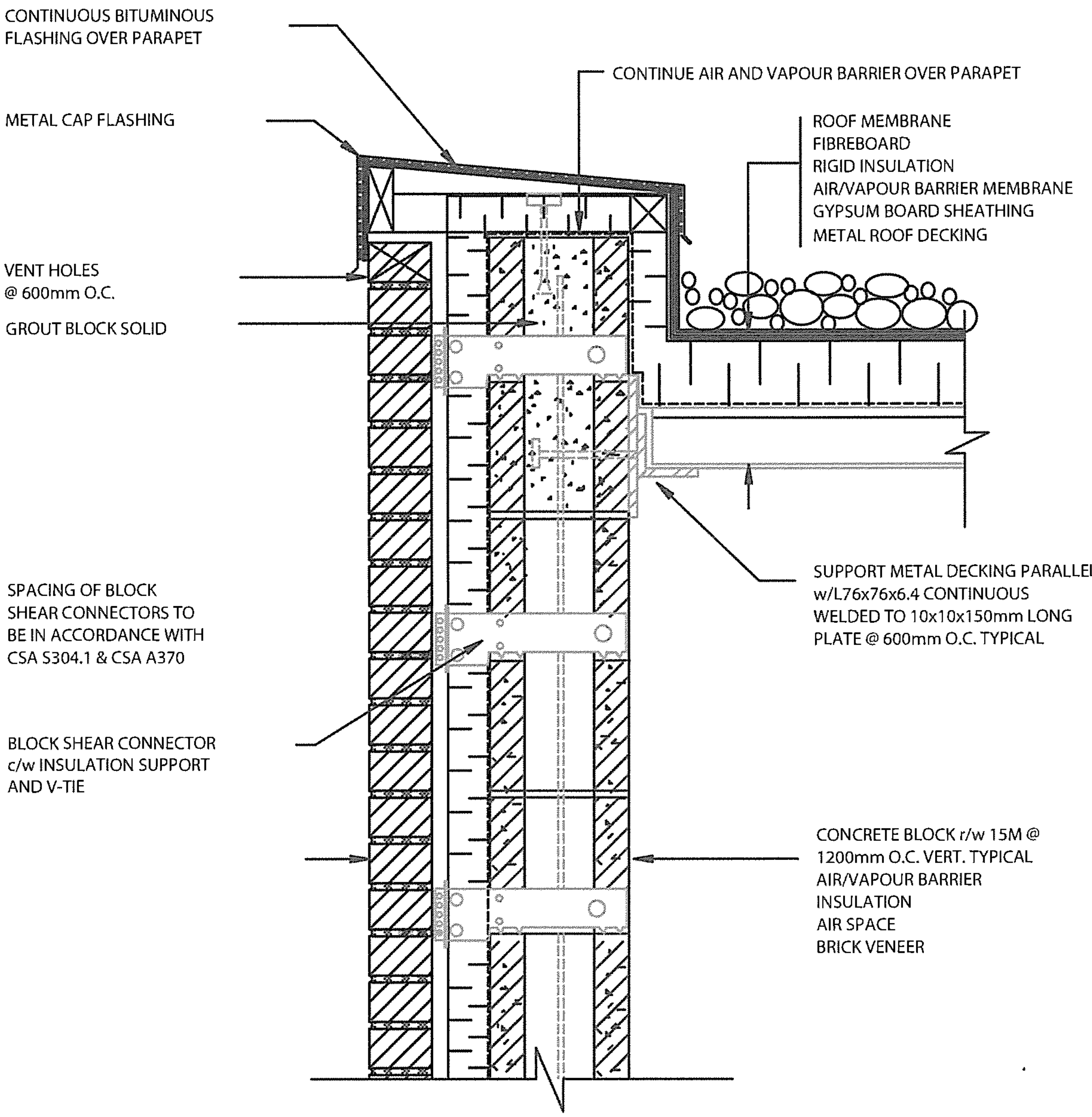


FIGURE 40 BRICK VENEER / CONCRETE BLOCK WALL - PARALLEL TO O.W.S.J.

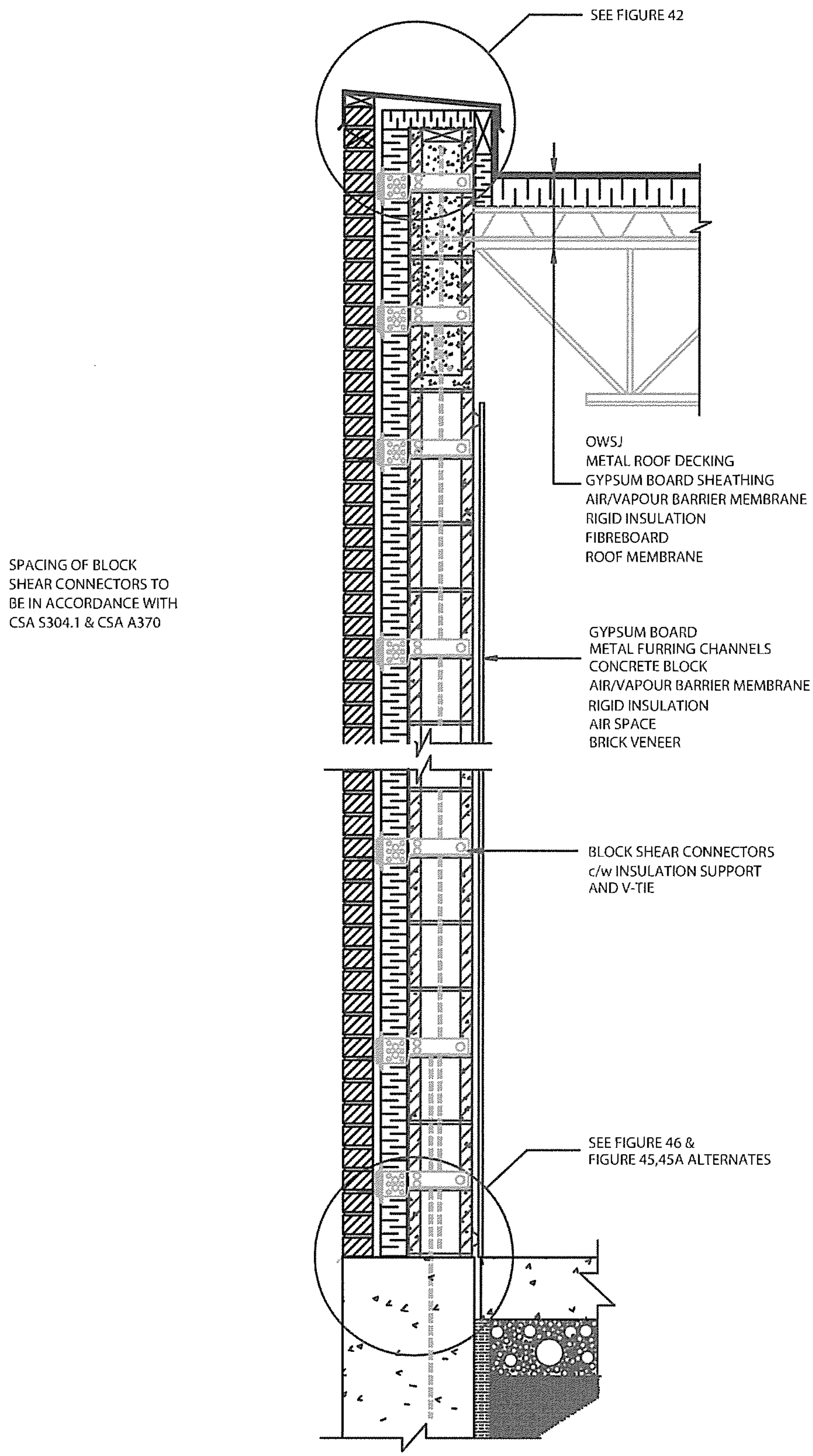


FIGURE 41 BRICK VENEER / CONCRETE BLOCK - O.W.S.J. CONNECTION
NTS

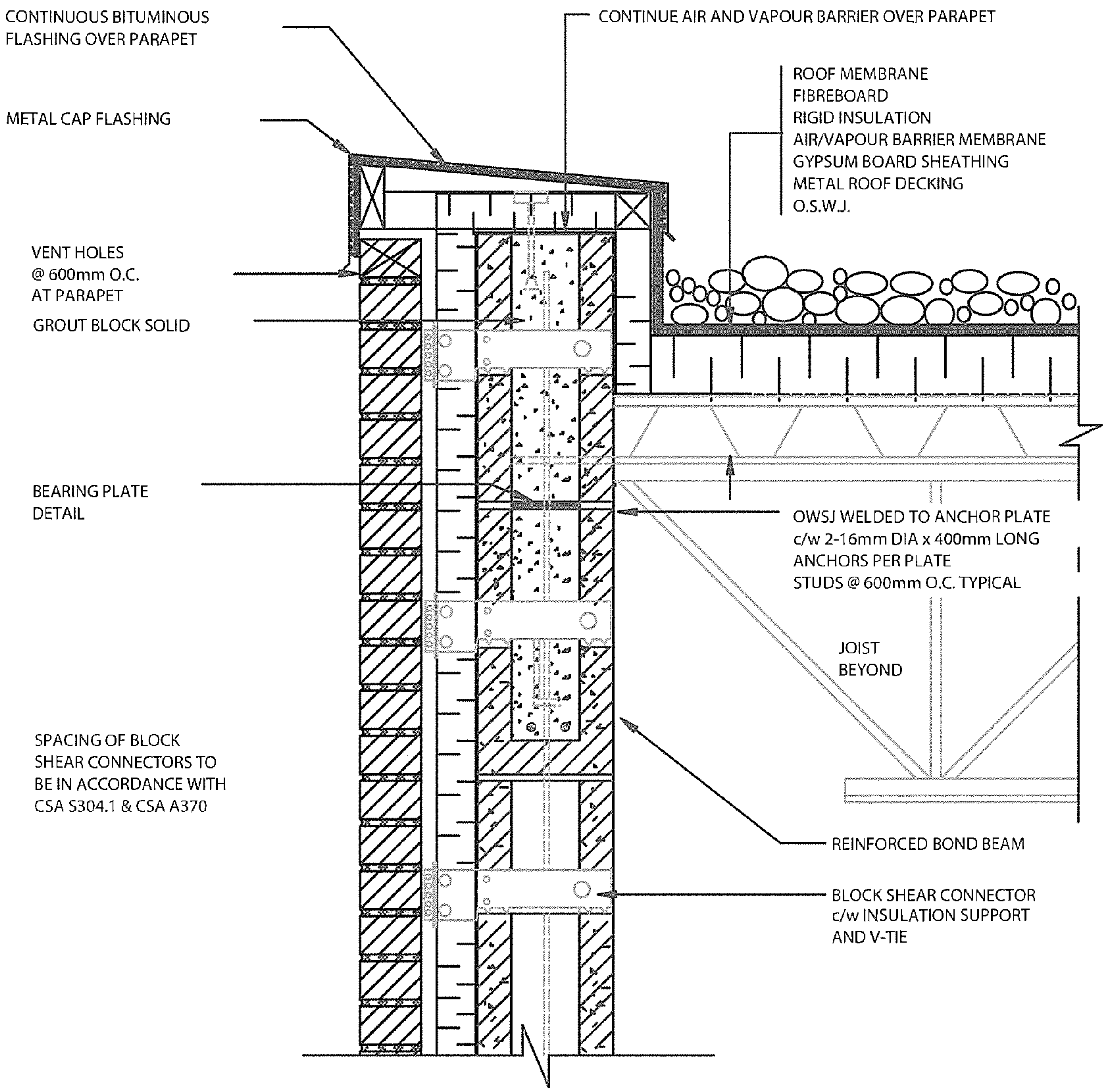


FIGURE 42 BRICK VENEER / CONCRETE BLOCK - PARAPET DETAIL @ O.W.S.J.

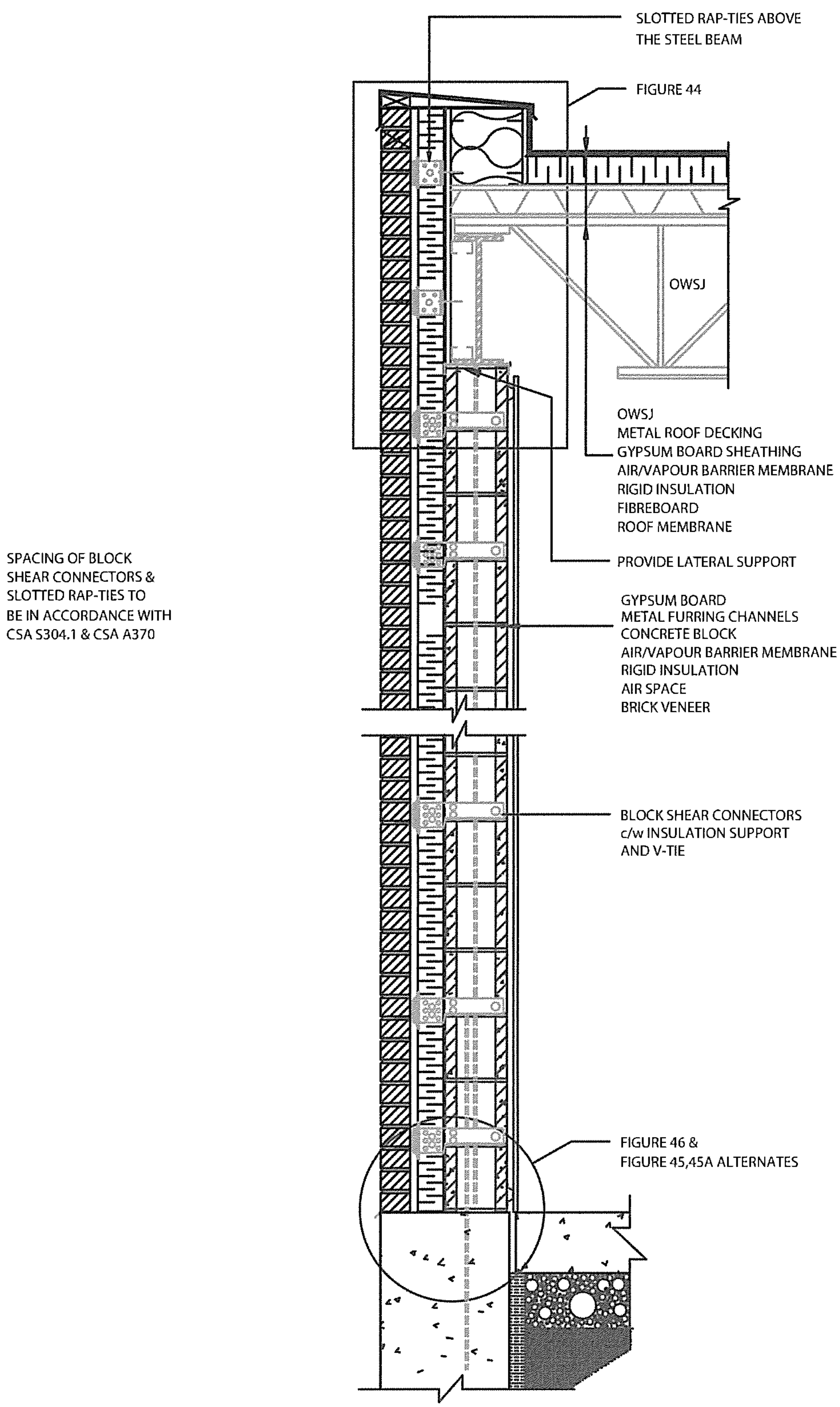


FIGURE 43 BRICK VENEER / CONCRETE BLOCK - O.W.S.J. CONNECTION
NTS @ STEEL BEAM

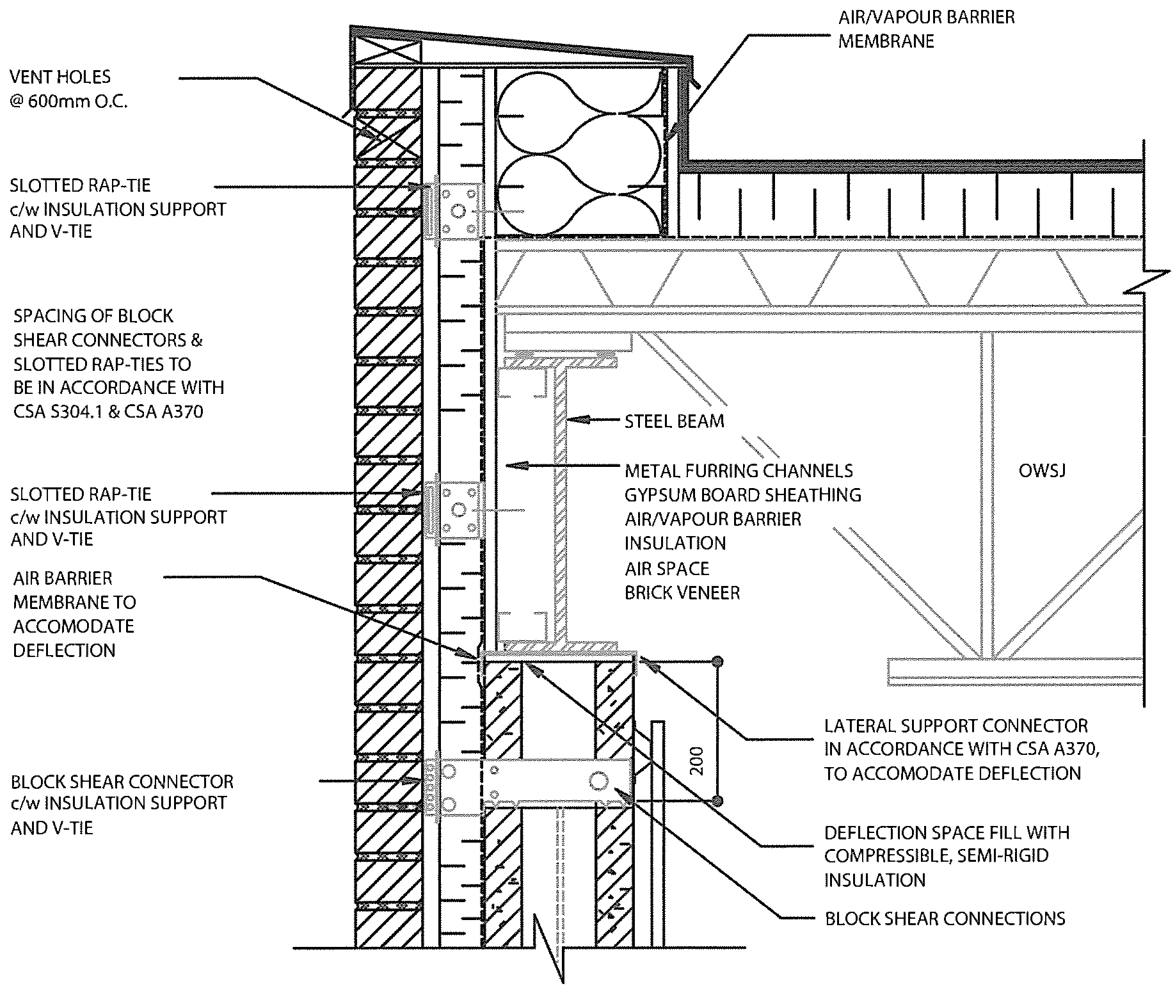


FIGURE 44 BRICK VENEER / CONCRETE BLOCK - PARAPET DETAIL @ O.W.S.J.

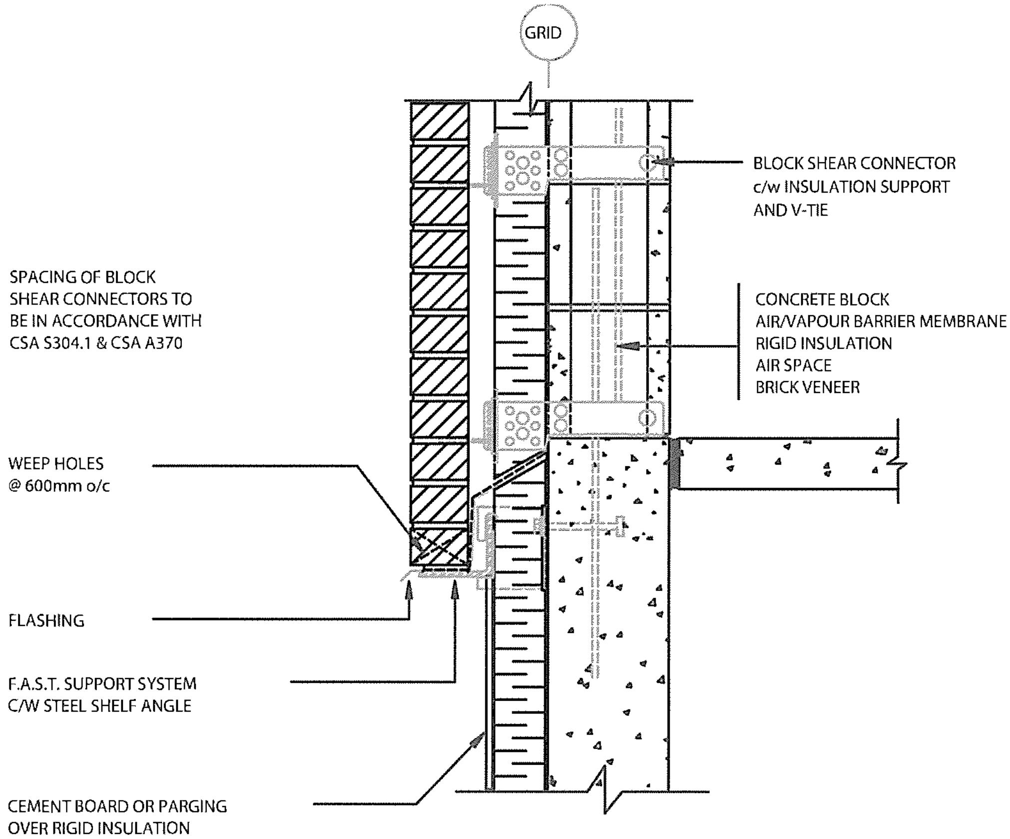


FIGURE 45 BRICK VENEER / CONCRETE BLOCK - AT FOUNDATION

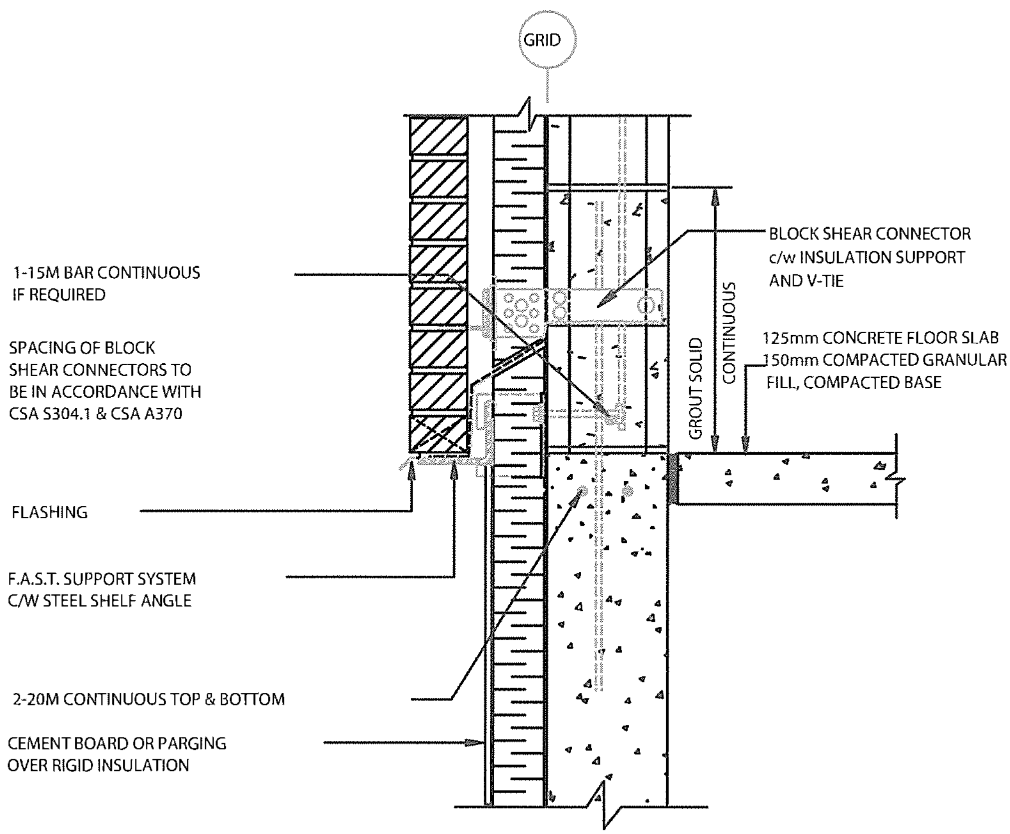


FIGURE 45A BRICK VENEER / CONCRETE BLOCK - AT FOUNDATION BOND BEAM

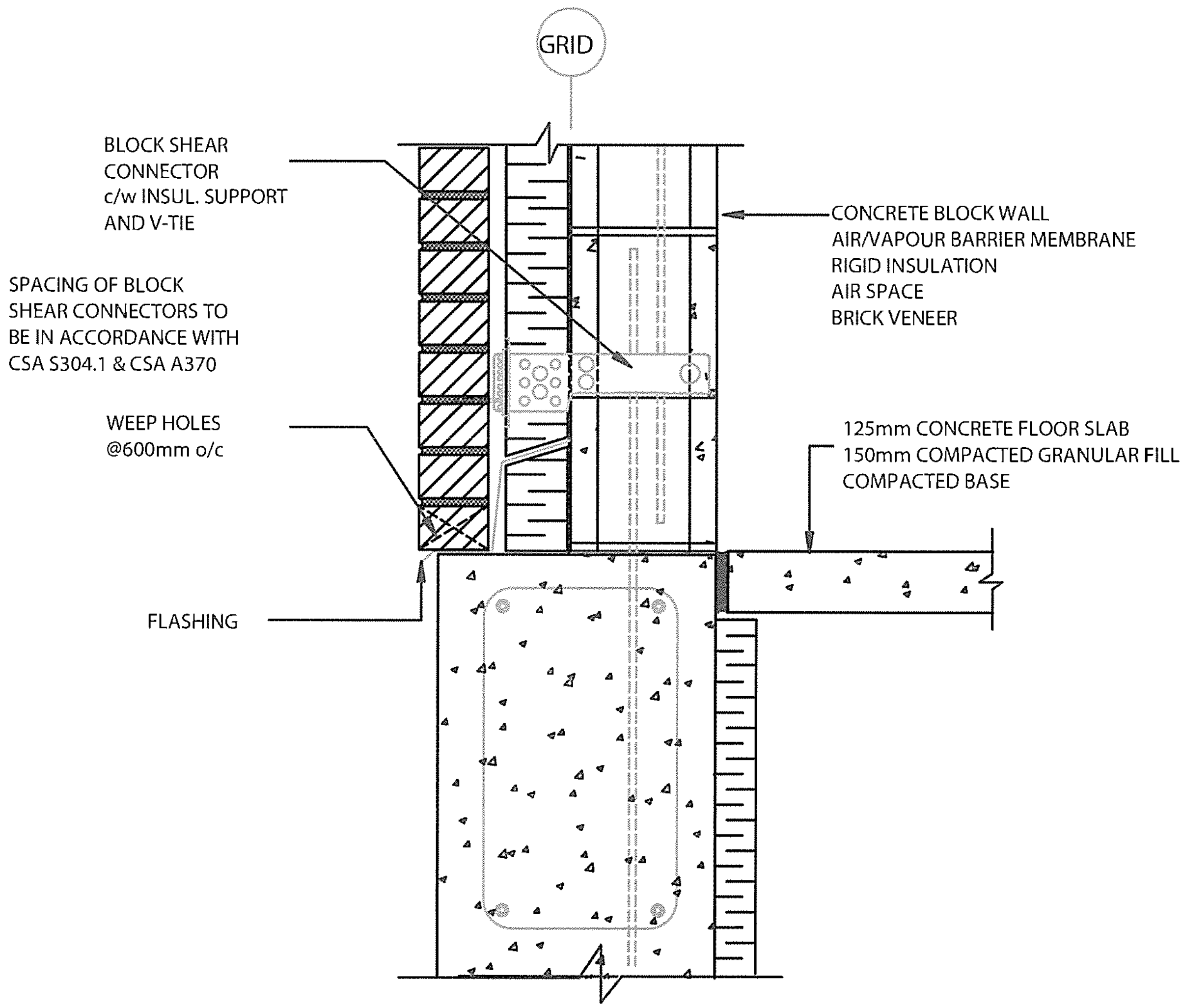


FIGURE 46 BRICK VENEER/CONCRETE BLOCK - AT FOUNDATION

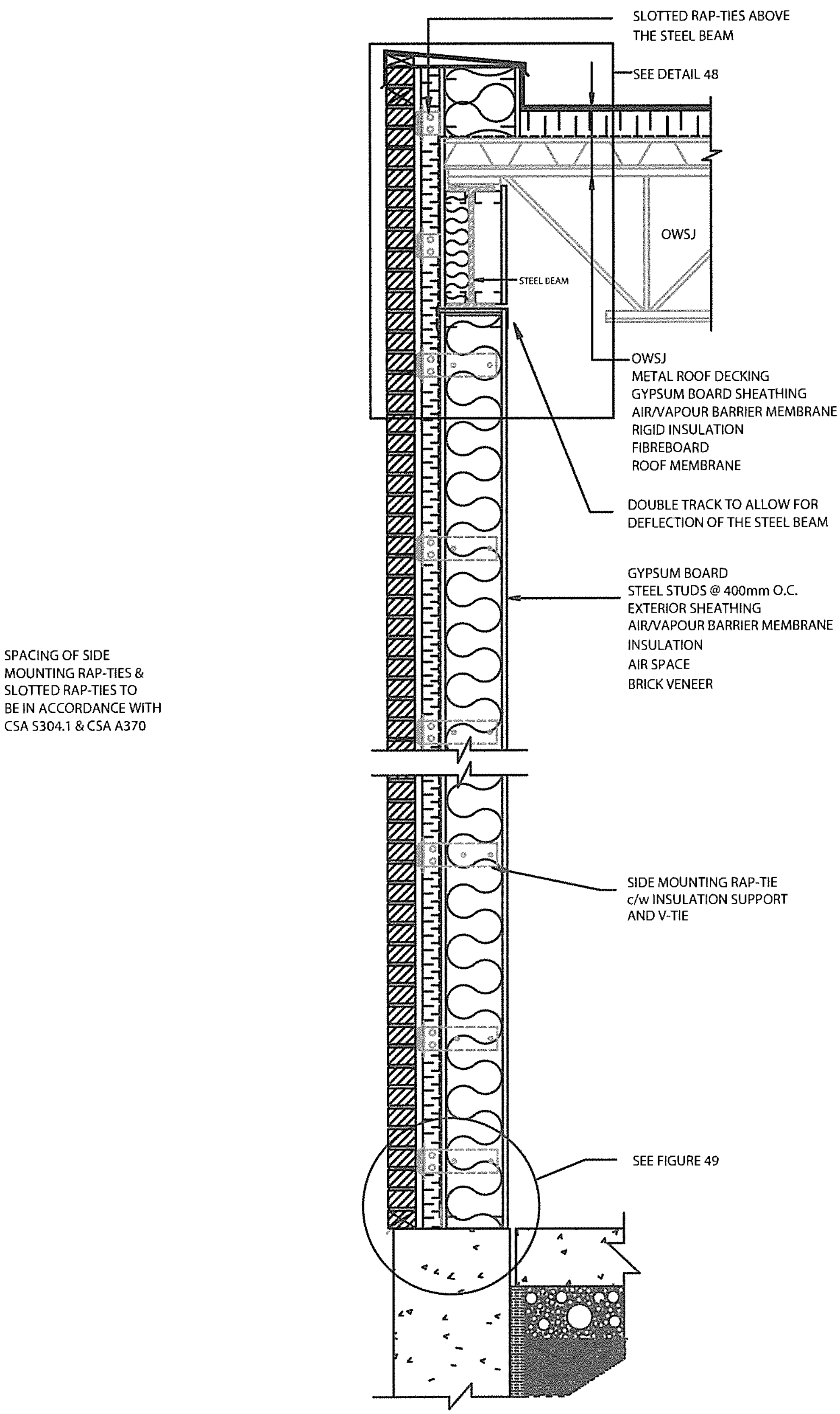


FIGURE 47 BRICK VENEER / STEEL STUD - O.W.S.J.

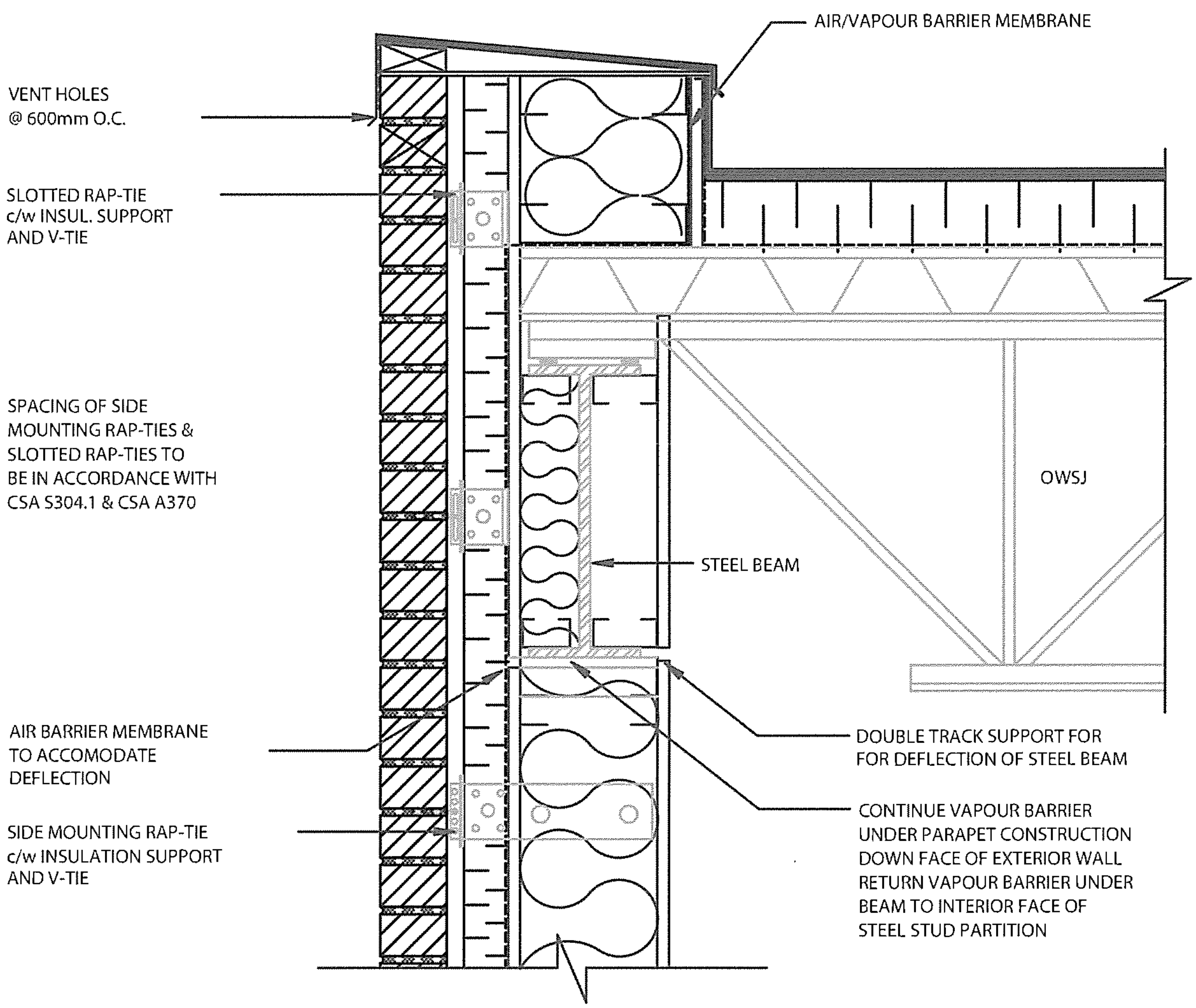


FIGURE 48 BRICK VENEER / STEEL STUD - PARAPET DETAIL @ O.W.S.J.

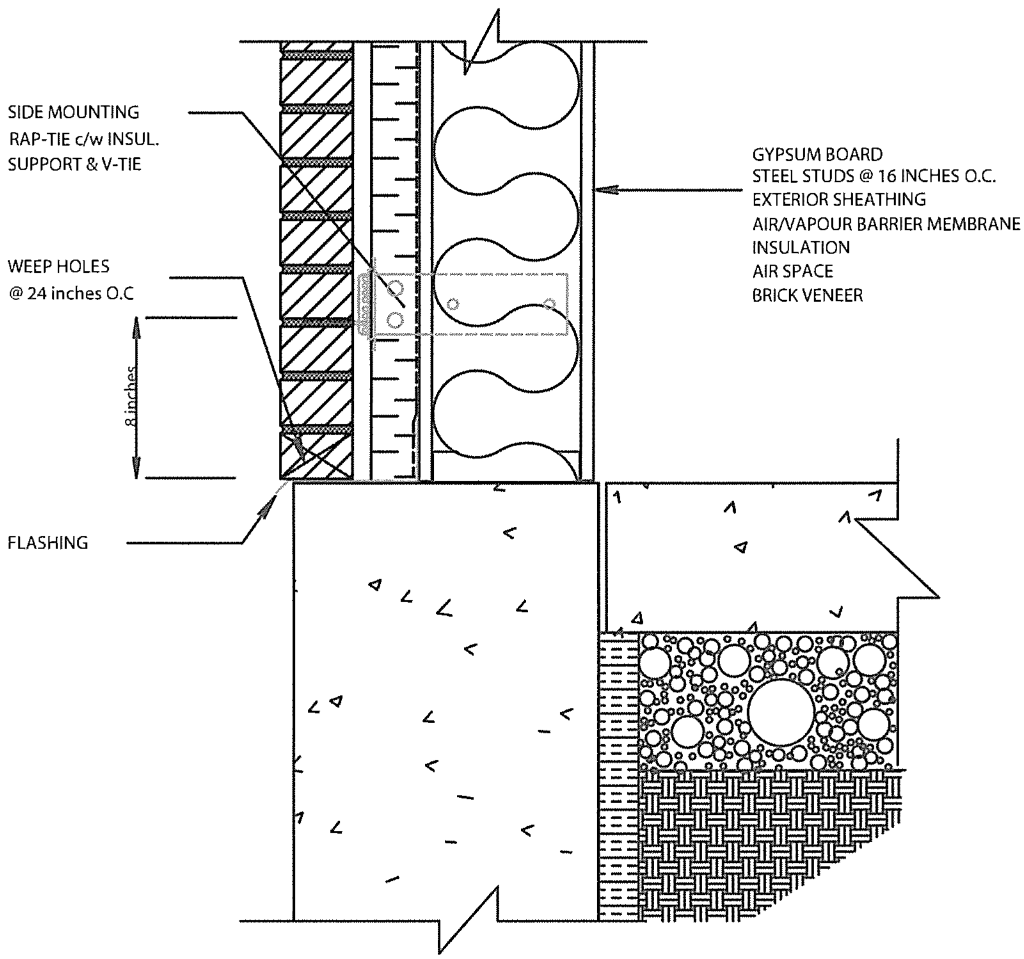


FIGURE 49 BRICK VENEER / STEEL STUD - AT FOUNDATION

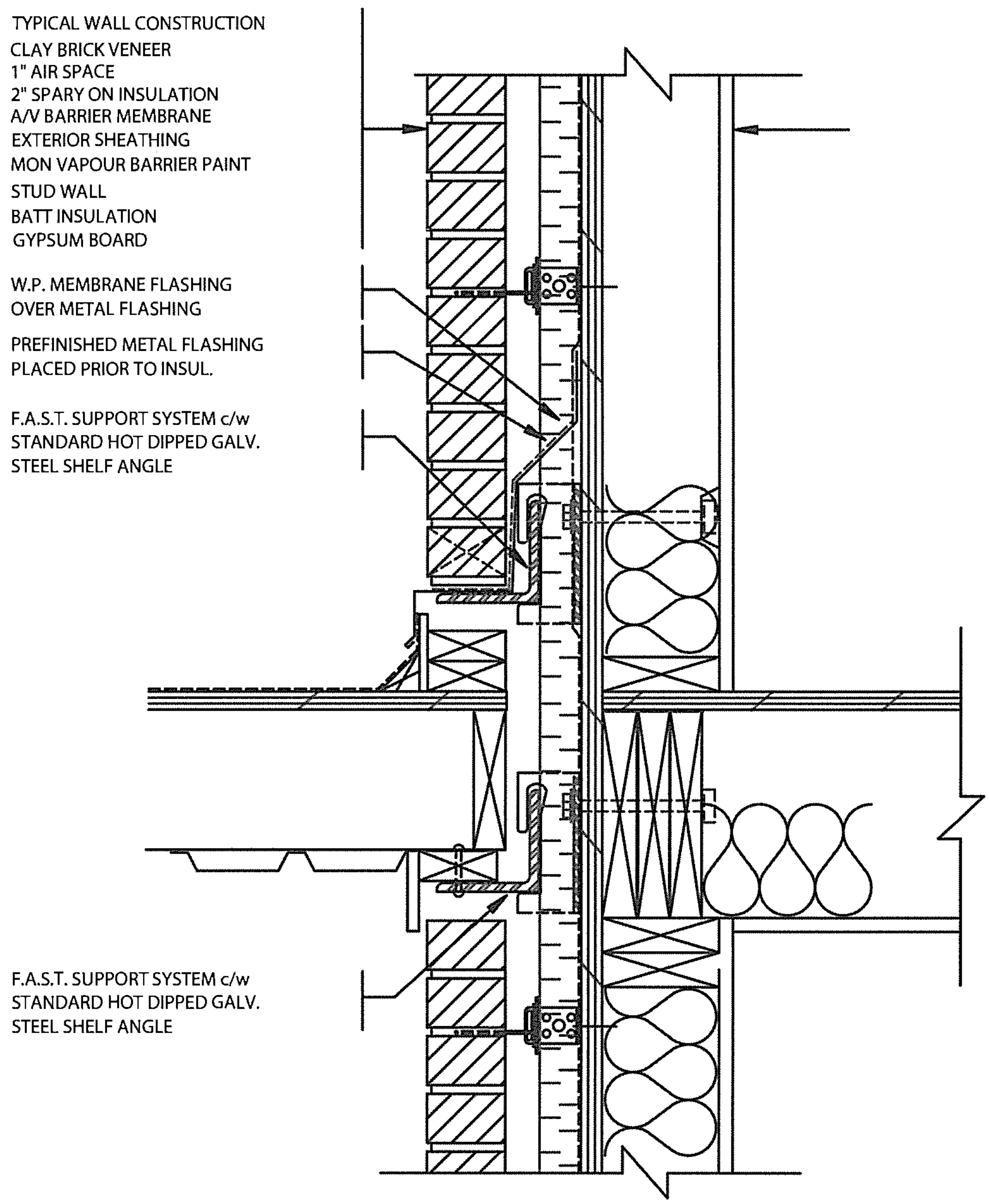


FIGURE 50 PATIO AND VENEER SUPPORT

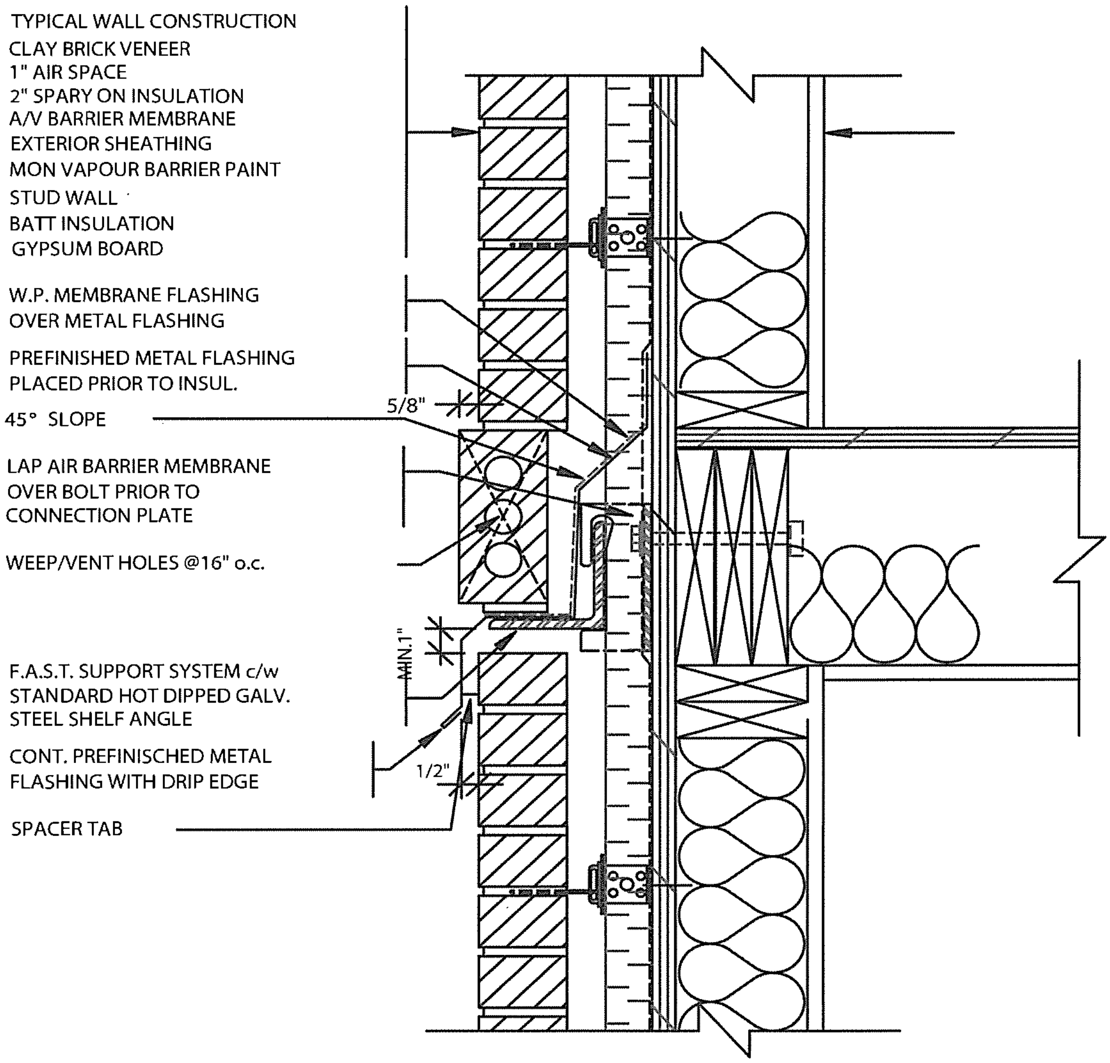


FIGURE 51 Use of FAST System to Provide support to Masonry Veneer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