ARCHITECTURAL DETAILING OF DIRECT ADHERED CERAMIC TILE FACADES

Richard P. Goldberg B. Arch., B. Bldg. Sci., AIA, CSI

Architect & Director of Technical Service
LATICRETE International, Inc. USA

INTRODUCTION

As we approach the new millennium, the construction industry is being subject to extreme economic and social pressure to develop new and alternate technologies for cladding building facades. This is due to the rapid depletion of natural resources and the escalation of material and labor costs for traditional construction. New developments in ceramic tile and adhesive technologies have opened up an entire new world of aesthetic and technical possibilities for external cladding of facades with ceramic tile. Combined with sound design and construction principles, direct adhered external ceramic tile cladding is likely to become one of the most important building construction technologies of the future.

However, all too often, direct adhered ceramic tile cladding is designed and constructed without consideration of the complex interactions that occur with the other components of an exterior wall assembly. As a result, inconsistent performance of direct adhered ceramic tile facades has hindered the ceramic tile industry from realizing the vast untapped potential of this segment of the market. It is beyond the scope of this paper to examine the design criteria for selection of ceramic tile or installation adhesives. The primary focus of this paper is to provide a summary of architectural and structural design considerations that are necessary to insure successful performance of ceramic tile cladding as an integral component of a building facade.

EXTERIOR WALL CONCEPTS

Function of exterior walls - The primary purpose of an exterior wall assembly of a building is to separate the external environment from the internal environment. To perform this function, the exterior wall must act simultaneously as a restraint, a barrier, and a selective filter to control a complex, often conflicting series of forces and occurrences listed below.

FUNCTIONS OF EXTERIOR WALLS

- Wind pressure and seismic force resistance
- Thermal and moisture movement resistance
- Energy conservation / control of heat flow between interior-exterior
- Rain penetration resistance and control
- Water vapor migration condensation control
- Sound transmission resistance
- Fire resistance and containment
- Allow daylight to the interior environment; vision to exterior
- Allow movement of air between & within the interior - exterior
- Allow passage of occupants

Types of exterior wall structures - exterior wall assemblies are generally classified in three broad categories of wall types structures shown below according to the method used to support the loads or forces imposed on the building, and the method of structural attachment to the building's internal components.

TYPES OF EXTERIOR WALL STRUCTURES

- Bearing walls
- Non-bearing walls
- Curtain walls

Bearing wall - A bearing wall is defined as a wall which supports both its own weight, and the weight all the other loads and forces acting on the building, including the weight of the floors, roof, occupants, and equipment. The bearing wall is supported by the building's foundation in the ground; it is the primary structural support of a building and an integral component of the other structural components such as the floors and roof. With the advent of modern structural (skeletal) framing systems, this wall type is typically used on buildings less than three stories high.

Non-bearing wall - This type of wall only supports its own weight, and is supported directly on the foundation in the ground. Non-bearing walls are also limited to low rise construction.

Curtain wall - This is broad category for a type of exterior wall assembly which is supports only its own weight and no roof or floor loads (similar to non-bearing), but is secured and supported by the structural frame of a building. The curtain wall transmits all loads imposed on it (lateral wind / seismic and gravity loads) directly to the building's structural frame. This is the most common wall type, especially in multi-story construction.

Types of exterior wall construction - Within each category of wall structure (bearing, non-bearing, and curtain wall), there are also three types of wall construction configurations as shown below. Each type of wall construction differs primarily by the method employed to prevent air, vapor, and water infiltration. To a lesser degree, the types of wall construction also differ by the methods and materials used to control other forces, such as heat flow or fire resistance.

TYPES OF EXTERIOR WALL CONSTRUCTION ASSEMBLIES

- Barrier wall
- Cavity wall
- Pressure-equalized rainscreen wall

Bearing, non-bearing, and curtain wall structures can employ any of the above types of wall construction, although certain types of wall structures are more adaptable to certain types of wall construction.

Barrier wall - Historically, we have relied on this type of wall since mankind first began building. A traditional barrier wall design was intended to provide a relatively impenetrable barrier against water and air infiltration, relying primarily on massive walls to absorb, dissipate, and evaporate moisture slowly. The mass of the wall also controlled other forces such as sound, fire, and heat flow quite efficiently. Openings or vulnerable joints were protected from water infiltration by roof overhangs, window setbacks, drip edges, and other types of physical shields.

Today, constructing a traditional barrier wall, with its massive walls and complex configuration, is cost prohibitive. Instead, economics of modern construction require that barrier wall construction be thin and lightweight. Modern barrier wall construction relies on impermeable cladding materials and completely sealed joints between exterior wall assembly components to resist all water penetration. While a barrier wall design typically has the lowest initial cost than other exterior wall configurations, the lower initial cost is offset somewhat by higher lifecycle costs, due to higher maintenance costs and lower expected life span due to more accelerated rates of deterioration. However, the pace of aesthetic and technological change has lead our culture to demand reduced life cycles for certain types of buildings, therefore the barrier wall's lower initial costs with risks of high maintenance or replacement after a short life cycle have become acceptable.

A direct adhered ceramic barrier wall facade constructed using barrier wall principles does have limitations that may increase maintenance or reduce expected life cycle of the wall assembly. An external direct adhered ceramic tile wall system is not impermeable. Varying degrees of moisture penetration will occur directly through the surface, or through hairline cracks in grout joints and sealants, that while not affecting safety, can occur from normal structural, thermal, and moisture movement in the building. Similarly,. While most ceramic tile suitable for exterior walls can be virtually impermeable, the cementitious joints between tiles will be permeable, unless they are filled with epoxy grout or silicone /

polyurethane sealants. Impermeable joint fillers, while they may solve one problem, create others:

- It is impossible to achieve a 100 % seal against water with a field applied sealant or epoxy grout over thousands of lineal feet / meters of joints.
- A totally impermeable exterior wall may perform well in warm, humid climates; but in colder climates, water vapor from the interior of the building may get trapped within the wall and condense, causing internal deterioration of the wall.
- Sealant joints require frequent maintenance and replacement.

However, new developments in direct bond latex waterproof membranes located beneath the adhesive layer now allow waterproofing protection for barrier walls without affecting the adhesive performance. The development of these membranes are the most significant advance in improving the performance of direct adhered ceramic tile cladding using the barrier wall method of construction. When installed with proper interfaces discussed later in this paper, direct bond membranes provide a continuous barrier to water while remaining vapor permeable to prevent condensation and deterioration within the wall. Direct bond waterproof membranes have the added benefit of isolation of differential movement caused by thermal expansion, and protection against shrinkage cracking.

Cavity wall - This type of wall construction consists of an inner and outer layer of wall components separated by an air cavity. Recognizing the difficulty of achieving a 100 % effective barrier wall, a cavity wall is designed to allow a certain amount of water to penetrate the outer layer into the cavity. The water can not bridge the air cavity easily, so it drops by gravity and is then controlled and directed by properly designed drainage outlets back to the exterior surface of the wall.

Pressure equalization - This type of wall construction is basically a more sophisticated type of cavity wall where specially placed and sized openings in the exterior cladding allow outside air to penetrate and ventilate the cavity, bringing the cavity to the same pressure as the outside air, thus the term "pressure equalize". This type of wall construction reduces the internal wall cavity pressure differential. A pressure differential could cause water and vapor to be forced and suctioned in either direction across the cavity, or directly through the face of a barrier wall resulting in leakage and deterioration. The internal wall cavity or interior space is normally at different pressures due to wind flow over the exterior facade, the "stack" rising effect of air flow in a building, and HVAC (heating / ventilating) system pressurization and imbalance.

To affect proper air pressure transfer, the inner layer of wall construction must be airtight. This is achieved by installation of an air retarder (in combination with a vapor barrier in cold climates) on the interior surface of the inner layer of wall assembly.

Future Exterior Wall Technology - The Dynamic Buffer Zone - Studies have shown that moisture accumulation in wall cavities occurs more often from the water vapor migration and build-up of condensation than from rain or snow penetration. One study has demonstrated that in one month, approximately 31 pounds / 15 kg of water could leak by air leakage and condensation through an electrical outlet with a net open area of 1 $inch^2$ / 6.5 cm^2 and an interior-exterior air pressure difference equivalent to a 9.3 mph / 15 km / hour wind[1].

The mechanism of moisture condensation is the exfiltration of humid indoor air in cold climates, and to a lesser degree, the infiltration of humid air in warm climates to the cool internal wall cavity. Though vapor barriers and the more sophisticated air barriers provided by ventilated or pressurized rain screen wall designs have greatly improved air and water vapor resistance of exterior walls, a perfect seal is not feasible. Water vapor condensation will continue to occur in buildings with moderate humidity levels in cold climates, and in air conditioned buildings in warm, humid climates. In direct adhered ceramic tile wall systems, many of the problems that we associate with apparent rain penetration are actually caused by accumulation of condensation. This internal moisture will not only cause water leakage and staining, but is often responsible for problems such as efflorescence, mildew odors, diminished insulation value, corrosion of metal components, and reduced strength, or even failure of adhesives and membranes.

Research and full scale testing was recently resurrected for an exterior wall concept known as the *Dynamic Buffer Zone (DBZ)*[2], which was first proposed in the 1960's. The DBZ concept, while fairly sophisticated, has been demonstrated to significantly reduce or even eliminate moisture in the internal cavities of exterior walls by mechanically pumping dry outdoor air into the wall cavities in buildings located in cold climates. Thus far, this concept has not been tested in warm humid climates, but the technology has promise to also solve similar problems unique to warm humid climates, such as condensation from air-conditioning, and mildew growth / odors.

The DBZ technology works through pressurization of the exterior wall cavity using partially heated outdoor air. A DBZ wall system is designed so that the wall cavity pressure is above the indoor room pressure, thus limiting passage of indoor humidity by air leakage. The most significant challenge in the practical application of the Dynamic Buffer Zone concept is not necessarily the cost (much of the infrastructure and equipment already exists in modern commercial buildings); the challenge lies in the extensive level of detail and coordination of mechanical engineering and architectural disciplines, and the correlating trades on the construction site.

WALL CONSTRUCTION - ARCHITECTURAL & STRUCTURAL DETAILING

There are numerous types of back-up wall construction that are employed for direct adhered ceramic tile cladding. This paper will focus on the most common back-up materials, concrete or brick masonry units (blocks), and examine the architectural and structural considerations necessary for proper performance.

Concrete masonry unit back-up walls - Concrete block masonry units (CMU) are the preferred back-up wall system for installation of direct adhered cladding in

[1]. QUIROETTE, R.L., *"The Difference Between a Vapor Barrier and an Air Barrier"*, BPN 54, NRC Canada, 1985.
[2]. QUIROUTTE, R.L.,*"The Dynamic Buffer Zone"*, The Construction Specifier, August 1997.

buildings where a long service life and maximum durability is desired. CMU wall thickness must be calculated based on engineering analysis as required by building codes. However, the empirical rule of a height to thickness ratio of 18 remains a good guide for preliminary selection of wall thickness. Walls should be a minimum thickness of 8 inches (200 mm). CMU walls usually require vertical and horizontal reinforcing in order to satisfy seismic requirements. Joint reinforcing should be used at every second horizontal bed joint.

Barrier CMU Walls - Single wythe CMU back-up walls are barrier walls and therefore must be waterproofed, even if they are clad with a relatively impermeable cladding such as ceramic tile. Every joint between the ceramic tile is a potential source of water penetration. Cement or latex cement leveling plasters (renders) or parge (skim) coats may provide some degree of dampproofing, but water may still penetrate and either cause leakage, deterioration of underlying materials by corrosion, or sub-surface efflorescence which can cause adhesive bond failure. Through-wall flashing and weep holes can be provided in the CMU at the bottom of the wall and above the bond beam courses (at windows). The wall can be split into two thin wythes at the flashing.

Cavity CMU Walls - The outside face of the CMU back-up walls should be dampproofed in cavity walls, as cavity walls are designed with the anticipation of water penetration. Cavity walls should have an unobstructed air space between the inner and outer wythes. The air space prevents infiltrated water from bridging to the inner wall, and can be designed to equalize outside and cavity air pressure to prevent water from being driven across the air space and be directed back to the exterior surface of the cladding. (see Section 2 Pressure Equalization). The recommended width of a cavity is 2 inches (50 mm), and should not be less than 1 1/2 inches (32 mm) or greater than 4 inches (100 mm). If rigid insulation is used in the cavity in cold climates, a 2 inch (50 mm) air space should be provided from the face of the insulation.

Weep holes should be placed at the bottom of each floor level, bottom of walls, at window sills, and any other locations where flashing is provided. Weep holes are normally spaced at 24 inches (600 mm), but no greater than 32 inches (800 mm) on center, and located where the vertical joints of both the CMU and external cladding align. The cavity base should be provided with drainage material, such as gravel or plastic drain fabric to prevent mortar droppings from blocking drainage.

Flashings are used to collect water which has infiltrated the cavity and direct it back to the exterior through weep holes. Flashings must be terminated in a horizontal CMU joint, and must be turned up a the ends of window sills or other horizontal terminations to form a dam, other wise water will travel laterally and leak at the ends of the flashing. At the face of the external cladding, flashing should be terminated in a rigid sheet metal drip edge to direct any water away from the face of the cladding. If flexible sheet or fluid applied flashings are used, they need to be bonded to a rigid metal drip edge.

The external CMU wythe and external cladding are anchored to the back-up CMU wall with galvanized steel wall ties typically spaced 16 inches (400 mm) on center vertically and horizontally. Anchors require flexible connections in order to allow for misalignment of the CMU coursing, and to permit differential movement both within the CMU wall, and between the external cladding-CMU wall and the inner back-up wall and structural frame.

Clay (brick) masonry back-up walls - Clay brick masonry back-up walls, whether designed as barrier or cavity walls, are generally constructed using the same principles and design techniques as concrete masonry back-up walls. However, there is one important difference between the two materials. Clay brick will expand permanently with age as a result of moisture absorption while concrete masonry and mortar joints will shrink. When a clay brick is fired during the manufacturing process, all the moisture has been removed, and clay brick will gradually increase in volume from the original manufactured dimensions. Consequently, clay brick masonry back-up walls must make provision for expansion. This is particularly important where clay brick is used in a barrier wall configuration to infill between structural concrete frames; restrainment of expansion can cause the back-up wall to bow outwards.

ARCHITECTURAL & STRUCTURAL CONSIDERATIONS

While the direct adhered ceramic tile cladding and back-up wall construction are a major component of a facade wall assembly, performance will ultimately be determined by the suitability and quality of interfaces with the other components of the wall assembly. The first five considerations listed below deal primarily with the cladding (ceramic tile) material's suitability and compatibility for installation with the direct adhesive method . These considerations are beyond the scope of this paper, but are detailed in the companion manual to this paper entitled *"Direct Adhered Ceramic Tile, Stone, and Thin Brick Facades - Technical Design Manual"* by the author of this paper. Assuming compliance with those criteria , the remaining task is a methodical investigation , design and integration of the architectural and structural components of the entire wall assembly as a singular functional and aesthetic system.

KEY DESIGN CONSIDERATIONS FOR DIRECT ADHERED CERAMIC TILE CLADDING

- Suitability of the ceramic tile cladding for exterior use
- Compatibility of the bonding adhesive with both the cladding material and the substrate
- Dimensional stability of the cladding material and substrate
- Coefficient of expansion compatibility of the cladding material and the substrate
- Differential movement capability of bonding adhesive to accommodate different rates of movement between the cladding material and substrate, and the performance characteristics of the adhesive under in-service conditions
- ***Architectural detailing of system components (substrates, back-up structure, windows, flashing and waterproof membranes, vapor & air barriers, insulation, movement joints, sealants, etc.)***

STRUCTURAL CONSIDERATIONS

Building movement - The structural frames of modern buildings are considerably more vulnerable to movement than traditional massive masonry or concrete structures. This trend is not only dictated by economics, but also the development of new materials and methods that are stronger, lightweight, and capable of spanning great distances and heights.

While modern structural frames are safe, they are designed to be more flexible and typically provide less resistance to movement. It is essential that a direct adhered facade be designed and constructed to accommodate the types of structural movement listed below. Direct adhered facades differ from mechanically anchored systems primarily because structural movement can be transmitted through the direct adhesive connection, accumulate, and then exert stress on the adhered veneer, resulting in cracking, buckling, or crushing of both the veneer and the other wall components. Most of the structural movement in a direct adhered facade is controlled by the architectural and structural detailing of the underlying wall components and their connection to the building's structural frame; the adhered ceramic tile is simply a veneer and the key to cladding performance is the isolation and dissipation of movement through the use of low modulus or flexible adhesives and proper architectural detailing and use of materials.

TYPES OF STRUCTURAL MOVEMENT

- Live loads (wind, seismic) and dead loads (gravity)
- Thermal movement
- Dying shrinkage *
- Moisture expansion *
- Elastic deformation under initial loads
- Creep of concrete under sustained load
- Differential settlement

** denotes types of movement in concrete or wood structural frames only*

Live loads - Lateral forces due to anticipated gravity, wind or seismic loads must be analyzed to determine the required tensile and shear bond strength of adhesive mortars to resist these forces. For non-load bearing curtain walls, wind loading is typically the dominant structural load which a wall must be engineered to resist. The wall must be engineered to have not only sufficient strength to resist the positive and negative (suction) wind pressures, but also sufficient stiffness so that the direct adhered cladding material does not crack under high wind loads. *Deflection or stiffness of back-up wall construction should be limited to 1/600 of the unsupported span of the wall under wind loads.*

In regions with seismic activity, the shearing force exerted by seismic activity is by far the most extreme force that an adhesive must be able to withstand. *The shear stress exerted by an earthquake of a magnitude of 7 on the Richter Scale is approximately 215 psi or 1.5 Mpa /15 kg / cm^2, so this value is considered the minimum safe shear bond strength of an adhesive to both the surface of the ceramic tile and the substrate.*

Wind and seismic forces can also cause lateral building movement called *drift*. This type of movement is characterized by the swaying of a building from wind or seismic activity, and is the type of movement that can be controlled and isolated with movement joints. While seismic and wind movement joints are typically a structural engineering function of the underlying structure and wall, it is critical that this movement capability extend through to the leveling and adhesive mortars, as well as external cladding surface. In severe seismic or wind zones, the effects of structural drift on a direct adhered facade can be further minimized by isolating the underlying substrate (commonly a cement leveling mortar / render) with a cleavage membrane and applying the mortar over galvanized steel reinforcing wire or lath attached with flexible connections to the underlying support wall or structure. The substrate "floats" over underlying wall supports and is isolated from transmission of structural movement by flexible structural connections to the wire reinforcing.

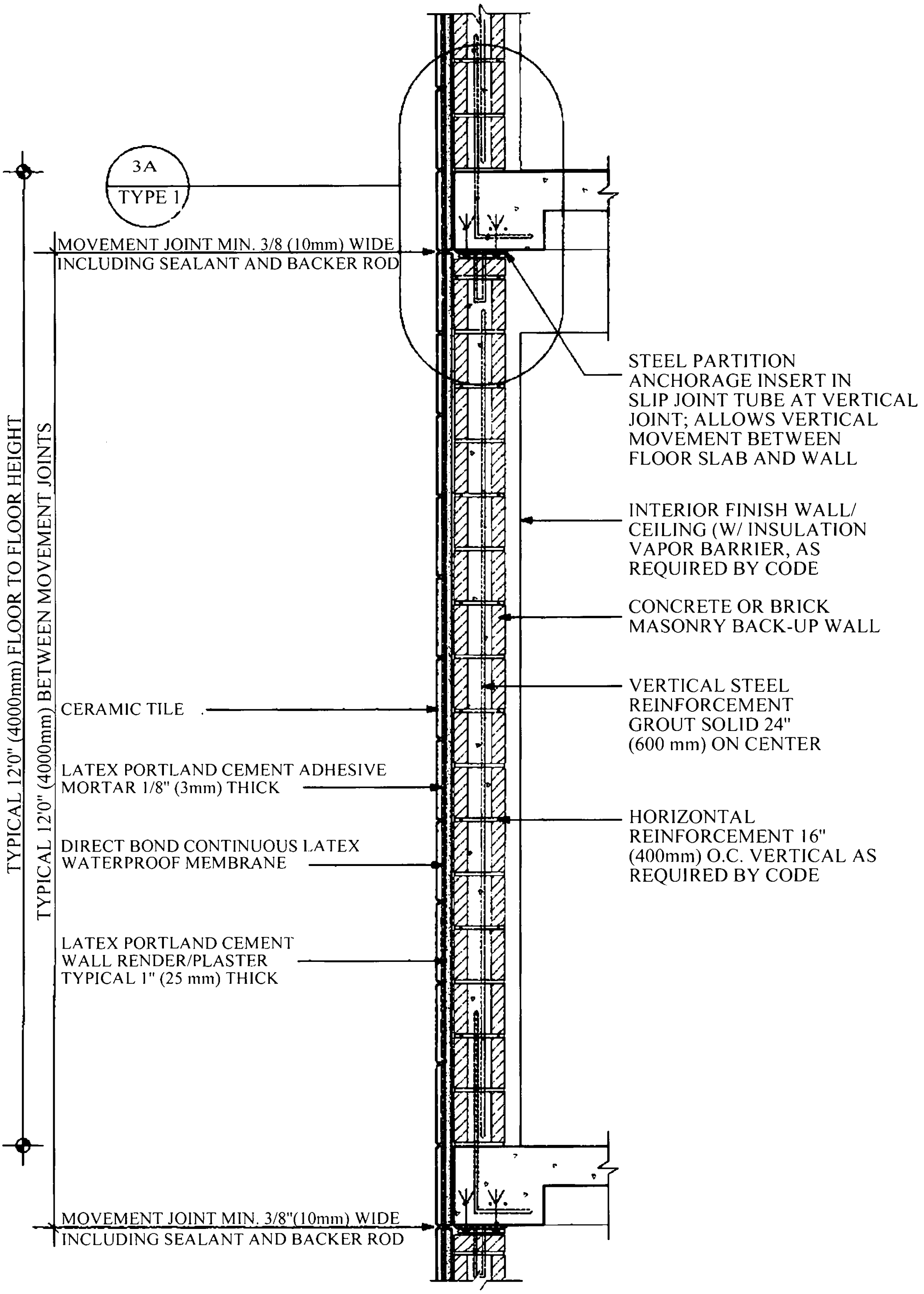
Thermal movement - All building materials expand and contract when exposed to changes in temperature. There are two factors to consider in analyzing thermal movement: 1) the rates of expansion of different materials (also known as the linear coefficient of thermal expansion), and 2) the anticipated temperature range exposure for the components of the wall assembly. The primary goal in analyzing thermal movement is to determine the amount of total, as well as differential movement, that occurs within and between components of the facade wall assembly.

Thermal induced structural deflection - Bending of the building's structural frame is another often overlooked cause of stress on a direct adhered ceramic tile cladding. This phenomena can occur when there is a significant temperature differential between the exterior and interior of the structural frame, causing the frame to bend and exert force on the exterior wall assembly.

Moisture Shrinkage / Expansion - Underlying structures or infill walls constructed of concrete or concrete masonry will undergo permanent shrinkage from cement hydration and loss of water after initial installation. The amount of shrinkage is dependent on several variables; water/cement ratio of concrete, relative humidity/rainfall, thickness of concrete, and percentage of steel reinforcement. While an average of 50 % of ultimate shrinkage occurs within the first 3-6 months (depending on weather conditions), the remainder can occur over a period of 2 or more years. In a wet, humid environment, the period of high initial shrinkage is difficult to predict. If possible, it is recommended to sequence or delay the direct application of ceramic tile and leveling mortars until after the majority of shrinkage of a concrete structure has occurred, which under ideal conditions may be about 6 months.

Structural deformation - As a building is constructed, the weight of materials increase, and permanent movement, known as elastic deformation, occurs in heavily stressed components of the structure. Long term deformation movement in concrete structures, also known as *creep*, occurs more slowly and can increase initial deflections by 2-3 times. Allowance for this type of long term movement must be considered in the design of movement joints. Creep is typically of greater concern in taller, reinforced concrete frame buildings, especially those that do not incorporate compressive reinforcing steel in the structural design.

Differential settlement - Buildings structures are typically designed to allow for a certain tolerance of movement in the foundation known as differential settlement. In most buildings, the effect of normal differential settlement movement on the exterior wall assembly is considered insignificant, because significant dead loading and allowable settlement has occurred long before application of ceramic tile. Differential

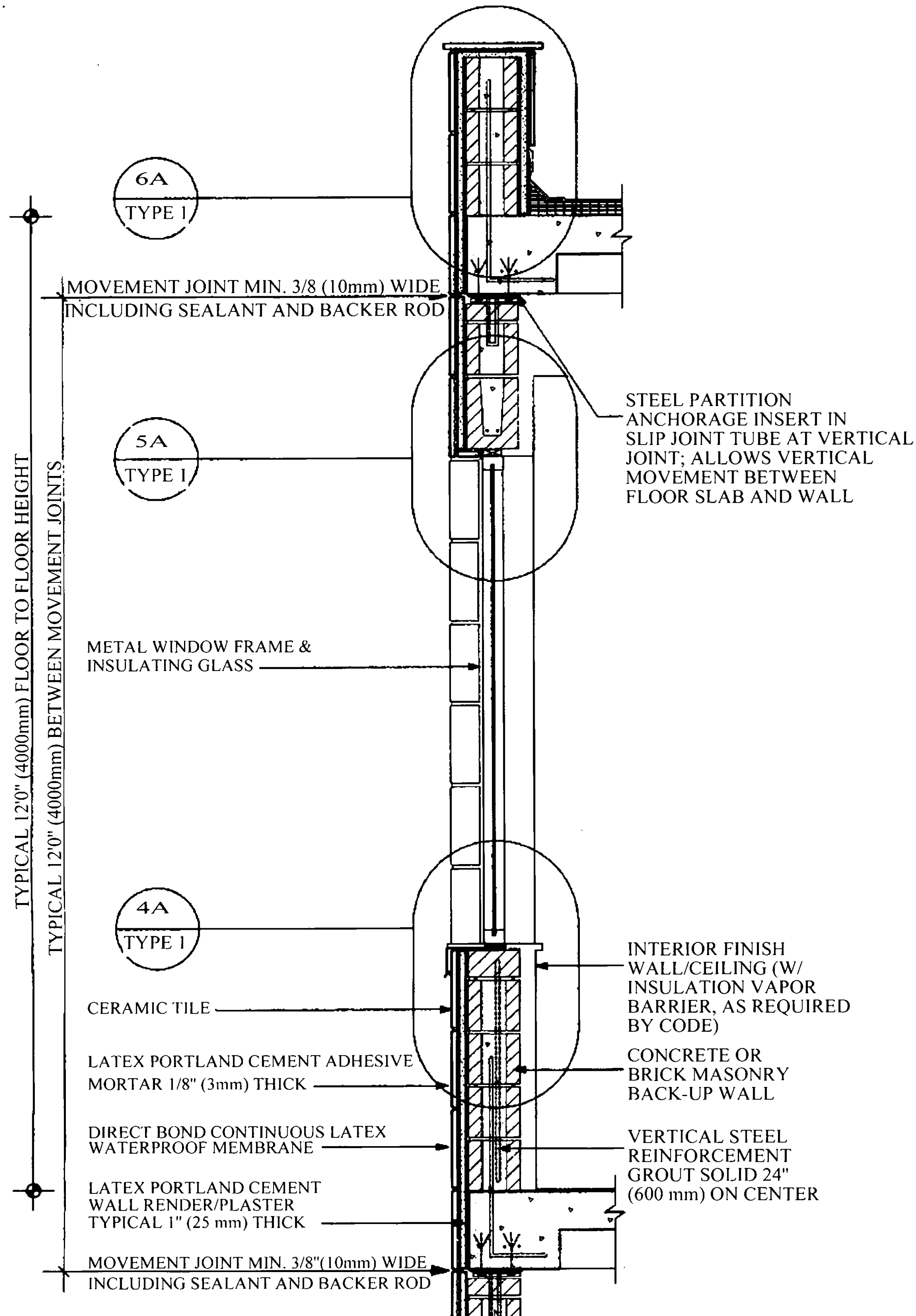


1A
TYPE 1

WALL SECTION @ WALL

BARRIER WALL - CONCRETE MASONRY BACK-UP WITH MEMBRANE
SCALE: 3/4" = 1'0" (~1:20)

DIRECT ADHERED CLADDING of FACADES



2A
TYPE 1

WALL SECTION @ WINDOW

BARRIER WALL - CONCRETE MASONRY BACK-UP WITH MEMBRANE
SCALE: 3/4" = 1'0" (~1:20)

DIRECT ADHERED CLADDING of FACADES

settlement of a building's foundation that occurs beyond acceptable tolerances is considered a structural defect, with significant consequences to a direct adhered ceramic tile facade.

WINDOWS & WINDOW MAINTENANCE SYSTEMS

In addition to satisfying obvious needs to provide interior daylight and exterior views, windows function in many of the same ways as the other components of an exterior wall assembly. Windows control heat flow and air infiltration, provide resistance to water and air pressures, sound attenuation, as well as an aesthetically pleasing facade.

Examination of the criteria for selection and design of windows is beyond the scope of this paper. However, the effect a window's interface with the wall assembly system is critically important to the proper performance of a direct adhered cladding system.

WINDOW INTERFACE REQUIREMENTS

- Configuration & location of windows
- Mechanical connection of the window frame (wall assembly or structure)
- Compatibility of materials
- Water & air infiltration resistance
- Flashing and drainage of infiltrated water (internal & external to window)
- Maintenance (window washing systems)

Configuration & location .- The configuration and arrangement of windows can control two very important aspects of direct adhered external cladding; water infiltration, and structural performance. Configuration refers to whether windows are designed as punched openings, horizontal ribbons, or large glass assemblies. Location refers to the position in the wall; the window can range from located flush with the external cladding to recessed or protected by overhangs and projections.

Configuration primarily affects structural performance. Horizontal ribbons or large areas of windows create a discontinuity of the structural back-up wall or frame for the direct adhered cladding. As a result, it is not only more difficult provide proper structural proper bracing and stiffness required to , but there may also be greater wind, seismic and gravity loads that may be transferred from the winnows to the back-up wall or frame.

Location of the window can have a significant effect on the control of water infiltration, and subsequent material corrosion from incompatibility. A window flush to the external cladding allows water that is shed by the external cladding to penetrate openings in sealant joints or improperly flashed cavities. Water penetration behind external cladding that is encouraged by the combination of flush window placement and poor sealant/flashing is the leading cause of efflorescence and freeze-thaw problems in direct adhered external cladding systems

Flush windows also are exposed to rain runoff from the external cladding which may contain alkalis from cementitious materials used in the installation of the cladding. The alkalis can etch window glass and corrode metal window frames and glazing materials.

Recessed windows can present the same problems if the horizontal sill is not properly sloped away from the window frame to shed water, and not properly flashed or waterproofed to recognize the potential for water penetration on a horizontal surface.

Mechanical connections - Aside from the need to anchor a window frame to transfer external wind loads, air pressure differentials and thermal loads, the mechanical connections of windows must be detailed and installed in a manner so as not to impart stress on the adhesive bond or the integrity of the ceramic tile. Connection must also avoid penetration of flashings and waterproof membranes to prevent water infiltration; any penetrations must be protected with sealant. Window frame attachments must not pass through or be anchored directly to the cladding, and window frames should be isolated from the veneer by flexible sealants and direct attachment to underlying structural components.

Compatibility of material - It is important to consider the compatibility of window frames and other window components such as plastics and rubber with the materials employed in a direct adhered wall system. Consider first that cement mortars, adhesives and grouts can have a corrosive effect on aluminum and glass. Aluminum must be separated from contact with cementitious materials by materials chemically inert to aluminum. Similarly, galvanic corrosion from moisture penetrating protective finishes, or from reaction of two different connecting metals in contact with moisture, can corrode both window frames or critical components of the direct adhered cladding, such as metal stud frames and screw / bolt connections.

Alkali & Acid Attack - Materials commonly used in direct adhered cladding can cause surface damage to glass in windows, and to a lesser degree to metal frames. Cementitious adhesives , grouts, and underlying substrates such as cement board, concrete masonry, or pre-cast concrete contain free alkaline minerals. Alkalis can be leached from these materials and stain or etch glass if allowed to remain on the surface for a few days. The alkaline solution attacks the glass surface by dissolving away surface ingredients (sodium) which results in haziness and roughness. When this occurs, there is no practical way of restoring the glass surface.

The location of the windows in the wall assembly, and the detailing and configuration of the cladding surface become critically important if alkali attack is to be avoided.

Window glass should always be set back and not flush with the cladding surface. The head of the window recess should also be configured to contain a recessed drip edge.

This design allows rain water sheeting down over the cladding surface to drip down and away from window glass. Even more critical is for internal wall flashings to have a drip edge of rigid metal to allow any alkaline water drained from internal cavities or joints to drip beyond both the surface of the cladding as well as the window glass. It is also good practice that window glass be washed periodically during construction and immediately after completion until high alkaline content from initial exposure to rain of building materials is reduced or eliminated by encapsulation in the wall assembly.

Glass, metal frames, and other components of a wall system can be also damaged by even dilute phosphoric or hydrofluoric acids that may be used in cleaning cementitious residue from cladding surfaces.

Water and air infiltration - Windows must be designed to anticipate some water infiltration both through the frame, and between the glass and the frame. Water will infiltrate either from rain driven by air pressure differentials, or from internal or external condensation. However, water should never penetrate beyond the inner window plane. The window should have an internal drainage and weep channel that prevents normal water penetration from escaping into and behind the wall assembly by directing the water to the exterior surface.

While air infiltration through windows has obvious effects on control of heat flow and pollutants, the primary concern in direct adhered cladding systems is the flow of moisture laden interior or exterior air which can condense within internal cavities between the window and the wall system.

THERMAL & WATER VAPOR CONTROL (INSULATION)

Thermal and vapor control is critically important to the proper performance of a direct adhered ceramic tile, stone or thin brick facade. The control of heat flow is of primary consideration in selecting an insulation for exterior wall systems in general. However, when designing a direct adhered cladding system, there is actually more concern over the effect of type and placement of insulation. The increased moisture sensitivity of this type of exterior wall, especially the lighter weight metal framed barrier walls, make prevention of condensation within wall cavities a critical consideration. The reason is that the type and placement of insulation effects the location of the dew point within the wall. Insulation changes the temperature gradients through wall assemblies, which actually increases the probability of condensation within the wall assembly.

Similarly, vapor and air retarders must be carefully selected and designed for proper placement in a wall system, depending on the climate, in order to diminish the flow of vapor.

Selection of thermal insulation and vapor barriers / retarders is dependent primarily on the climate and the type / method of wall construction.

Listed below are types and typical locations of wall insulation.

TYPES OF INSULATION

- batt
- rigid board (cavity or interior)
- loose fill
- integral

Batt insulation - Batt insulation is a glass or mineral fiber typically used between metal or wood stud framing, and is installed on the warm side of the stud cavity. Batt insulation is very susceptible to loss of thermal value and water retention when wet from rain penetration or condensation, therefore careful attention to moisture control is required with this type of insulation.

Rigid insulation - Rigid insulation is a general category for board type insulations that are manufactured from a variety of materials that have different physical characteristics.

Rigid wall insulation is commonly a glass or plastic material that is foamed by mixing with air, carbon dioxide, fluorocarbons and other gases. The gases are trapped and form insulating air cells that comprise of up to 90 % of the material. Polystyrene, polyurethane, poyisocyanurate, and glass foam are common types of rigid foam board insulation. Compared to fiberglass batt insulation, foam insulations do not lose insulation value when wet and have good resistance to moisture absorption and vapor permeability. Polyurethanes an polyisocyanurate boards are available with aluminum foil facings to reduce vapor transmission and the effects of aging. Rigid foam insulation is also available in pre-molded inserts to fit the cores of concrete masonry units. Most rigid foamed insulations, except for glass foam, are combustible.

Rigid insulation may also be made from glass fibers, organic fibers such as wood and perlite, a glassy volcanic rock which is expanded by heating. These types of rigid insulation are fair to poor in resisting moisture, and can deteriorate or lose insulating value. They often have a moisture resistant coating for protection.

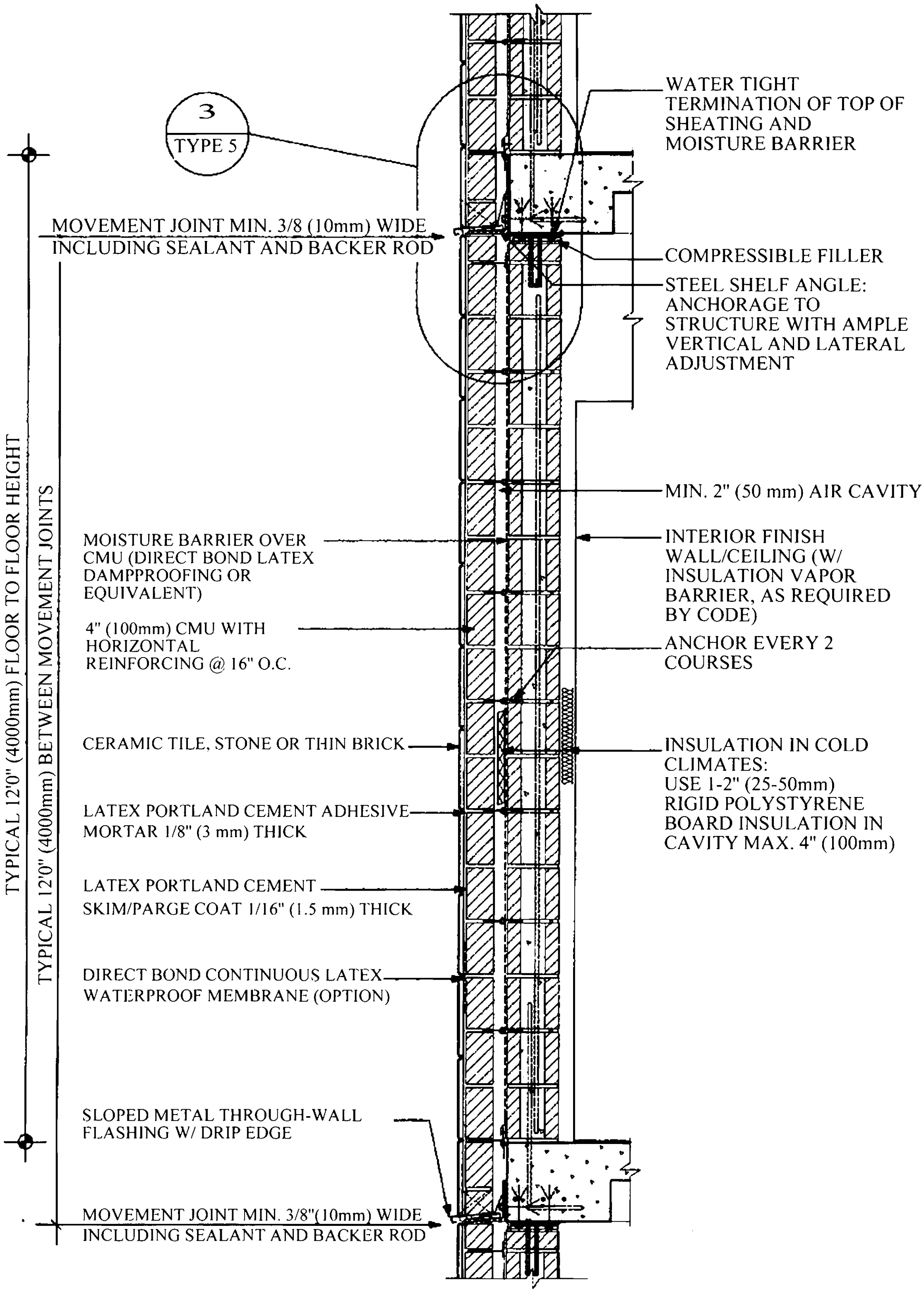
Depending on the climate and type of wall construction, rigid insulation may be placed close to the exterior or interior surface of the wall assembly, within the wall cavity, or cast integrally in pre-cast concrete wall assemblies.

Loose granular fill insulation - This type of insulation is typically made of perlite, vermiculite or pellets of foamed plastic, and is only recommended for filling the cores of concrete masonry units, or other controlled cavities in an exterior wall assembly. These materials commonly require treatment to improve resistance to deterioration from moisture.

MOISTURE CONTROL

Proper design and installation of moisture control components is one of the most critical factors to successful performance of a direct adhered facade. Moisture control is a broad category that not only includes the use of integral waterproof membranes prevent water infiltration directly through the face of the ceramic tile or stone facade, but also wall cavities, roofing, flashings, sealants, and vapor barrier systems that interface with the ceramic tile ,stone or thin brick surface.

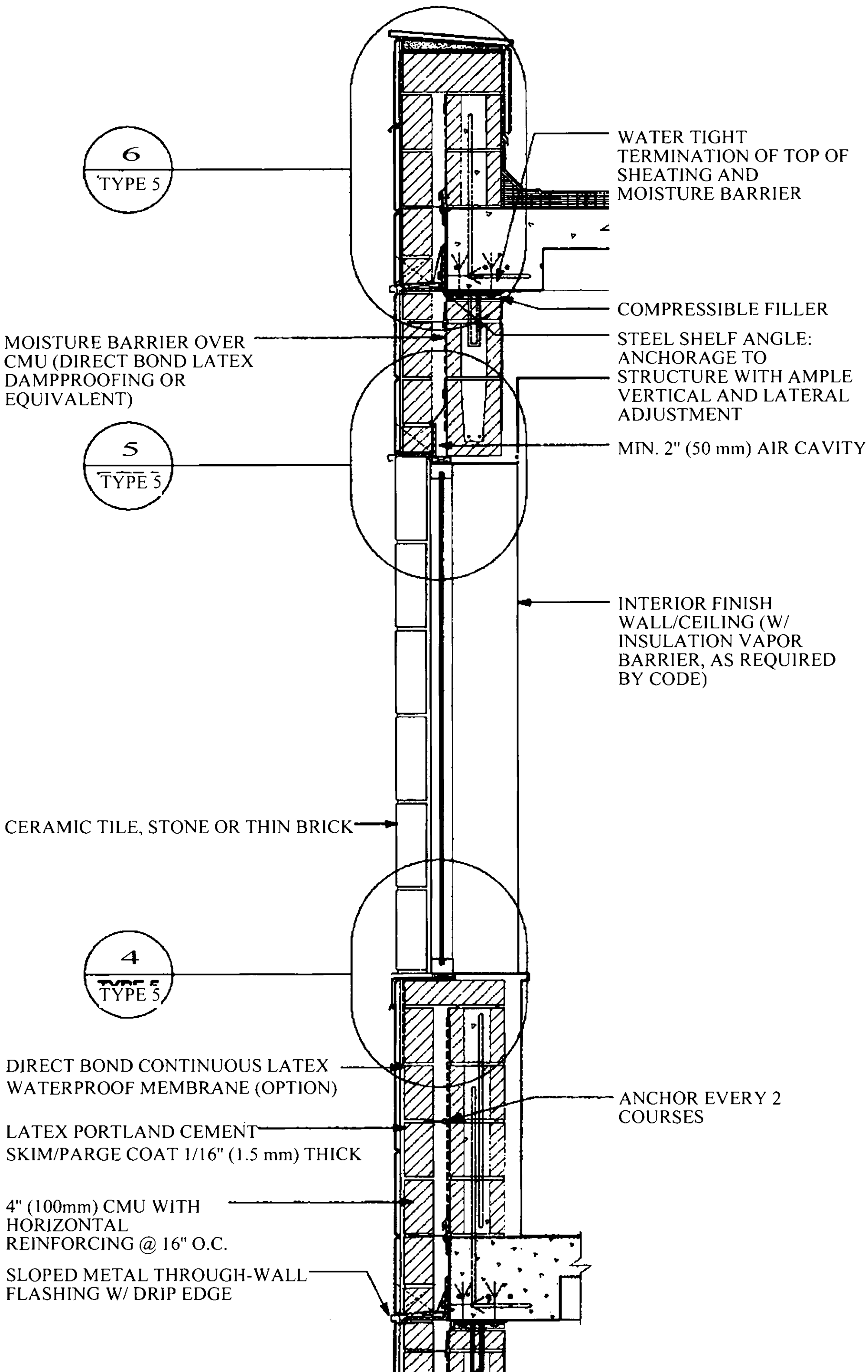
Control & prevention of water penetration - Most ceramic tile, stone and thin brick facades are naturally water resistant; that is water can penetrate through the adhered veneer through capillary action, but not in significant amounts. If protection against direct flow of water is provided at openings or adjacent wall components such as windows (see flashing below), then this may be the most cost effective method of control in warm, dry climates with occasional rain.



1 TYPE 5 **WALL SECTION @ WALL**

CAVITY WALL - CONCRETE MASONRY BACK-UP
SCALE: 3/4" = 1'0" (~1:20)

DIRECT ADHERED CLADDING of FACADES



2
TYPE 5

WALL SECTION @ WALL

CAVITY WALL - CONCRETE MASONRY BACK-UP
SCALE: 3/4" = 1'0" (~1:20)

DIRECT ADHERED CLADDING of FACADES

TYPES OF WINDOW & WALL FLASHING

- copper
- stainless steel
- galvanized steel
- elastomeric (preformed sheet of fluid applied)

Wall and Window Flashing - The function of wall flashing or through-wall flashing is to divert moisture which may penetrate the exterior face of the facade, or divert moisture which may condense within the wall from water vapor migration to or from the interior spaces. Flashings are commonly used at changes in configuration of the facade, and/or between different components of the wall. Typical locations requiring flashing are at the intersection of roof and wall assemblies, under roof parapet and wall copings, over window and door openings, under window sills, at shelf or relieving angles, and at bases of hollow or cavity walls.

Flashings must always turn up against the area or material which is being protected in order to prevent water penetration. Provision must be made to divert any trapped water back to the outside and away from the face of the building facade. This is commonly done by placing weep holes, tubes or absorbent wicks from 24-36 inches (600-900 mm) at the base of the flashing. Flashings must form a drip edge and extend a minimum of 3/8 inch (10 mm) beyond the face of the facade to prevent water from dripping down the face of the facade.

Copings, which protect the top of a parapet wall from water penetration, must be flashed at a minimum at the joints between the coping material (metal, stone, ceramic tile, pre-cast concrete), but preferably along and beneath the entire length of the coping.

Flashings which can not be adhered or imbedded in the wall construction are either attached to reglets, which are prefabricated and pre-cast into the wall assembly, or attached to the wall assembly with mechanical attachments and sealed with bulk sealants.

Types of flashings are listed above. In selecting a flashing, it is very important to verify compatibility of metals used in the window frame and the flashing in order to avoid corrosion from galvanic reactions of dissimilar metals. It is beyond the scope of this brief paper to discuss flashing materials in detail. However, due to the difficulty in flashing direct adhered cladding with traditional metal and plastic sheet flashings, the basic information below on direct bond fluid applied flashing and waterproof membranes is considered important.

Elastomeric-fluid applied - Fluid applied latex membranes and flashing are particularly recommended for direct adhered cladding systems due to the ability to bond directly to a substrate and in turn, allow a direct adhesive bond to their surface, unlike metal and other composite pre-formed flashings. In barrier wall types of direct adhered wall assemblies , this is the only material suitable to provide flashing protection against water penetration.

Direct bond latex membrane flashing is well suited to areas having a fully supported surface and requiring imbedment into the wall assembly. However, like PVC flashing, exposed and unsupported areas are subject to puncture or tearing, and rough or unusual configurations can be difficult to form in the field, especially with reinforcing fabrics required to provide tensile strength. Unlike PVC flashing, latex membranes do not lose plasticity or become brittle over time.

Other fluid applied and waterproofing materials, such as polyurethanes and bituminous materials, are only suitable for dampproofing the outer surface of concrete masonry wall cavities because they do not allow sufficient bond strength for direct adhesive bond of external cladding materials. Caution should be exercised in using these type of materials for cavity waterproofing, because unlike latex membrane which are vapor permeable, these materials are vapor barriers and could cause condensation within the wall cavity.

MOVEMENT JOINTS

One of the primary means of controlling stresses induced by building movement in a direct adhered facade is with movement joints (also known as expansion, dilatation, or control joints). All buildings and materials move to varying degrees, and therefore the importance of movement joints can not be understated. At some point in the life cycle of a direct adhered facade, there will be a confluence of events or conditions that will rely on movement joints to maintain the integrity of the wall system. Maintaining integrity of the wall system can be as simple as preventing cracks in grout joints, to preventing complete adhesive bond failure of the adhered veneer (which is the primary safety concern in direct adhered systems). Proper design and construction of movement joints requires consideration of the following criteria:

CRITERIA FOR DESIGN OF MOVEMENT JOINTS

- Location
- Frequency
- Size (width/depth ratio)
- Type and detailing of sealant & accessory materials

Location of Movement Joints - The main function of movement joints are to isolate ceramic tile surfaces from other fixed components of the building, and to subdivide the tile and the underlying wall assembly into smaller areas to compensate for the cumulative effects of building movement. While each building is unique, there are some universal rules for location of movement joints that apply to any direct adhered facade.

Existing structural movement joints - Movement joints may already be incorporated in the underlying structure to accommodate thermal, seismic or wind loading. These joints must extend through to the surface of the ceramic tile, and , equally important, the width of the underlying joint must be maintained to the surface of the tile.

Changes of plane - Locate movement joints at all locations where there is a change of plane, such as outside or inside corners. It is very important to note that movement joints ***do not*** need to coincide at the exact intersection of corners. The general rule is that joints may be located within a maximum of 10 feet (3 m) of the inside or outside corner, or the combined distance from joints on either side of the corner should not exceed the typical spacing of the joints (see *frequency* below).

Location - Dissimilar materials - Different materials have different rates and characteristics of movement. Movement joints must be located wherever the adhered veneer and underlying adhesive and leveling mortars meet a dissimilar material, such as metal window frames, penetrations, and any other type of exterior wall finish.

Location - Each floor level (horizontal) - Horizontal movement joints must be placed at each floor level (typically 10-12 feet / 3-4 m) coinciding with the intersection of the top of the back-up wall and structural floor or spandrel beam above, or at the lintel over the windows. This location not only isolates movement at each floor level, but also provides the architect the opportunity to incorporate movement joints into the design of the building facade in an aesthetically pleasing, rhythmic manner. Allowing for deflection movement between the spandrel beam or floor slab and the entire wall assembly (backup masonry, leveling /adhesive mortar, and veneer) is one location that often does not receive adequate attention.

Parapets, freestanding / projecting walls - Care should be taken to insure adequate movement joints at these types of locations. These areas of wall assemblies are typically exposed on both sides, resulting in greater movement stresses due to temperature extremes or wind. The architect should take the opportunity and coordinate location of movement joints in these areas with architectural features, such as alignment with window frames, openings, columns, or other building features which accentuate a vertical or horizontal alignment.

Frequency (spacing) of movement joints - A conservative general rule for facades is to locate movement joints at a frequency of no less than every 12-16 feet (4-5 m) in each direction (vertical and horizontal). With typical floor to floor heights less than 12-16 feet (4-5 m), a horizontal joint located at each floor level is sufficient to accommodate the vertical component of structural, thermal and moisture movement. Vertical joints to control horizontal component of movement should be located every 12-16 feet (4-5 m) maximum, with more frequent spacing often dictated by architectural elements such as windows. The only exception to the above general rules are where an engineer performs a mathematical calculation of movement which indicates either less or greater frequency is required, such as with a black ceramic tile in an extremely hot climate.

Size of movement joints (width/depth ratio) - The proper width of a movement joint is based on several criteria. First and foremost, regardless of the width as determined by mathematical calculations, the minimum functional width of a movement joint should be no less than 3/8 inch (10 mm); any joint narrower than this makes the proper placement of backer rods and sealant materials impractical, and does not provide adequate cover (*see width/depth ratio* below). The width of a movement joint filled with sealant material must be 3 to 4 times wider than the anticipated movement in order to allow proper elongation and compression of the sealant. Similarly, the depth of the sealant material must not be greater than 1/2 the width for proper function (width/depth ratio). For example, if 5 mm of cumulative movement is anticipated between floor levels, the movement joint should be 15-20 mm wide and 7.5-10 mm deep (a rounded backup rod is inserted in the joint to control depth; see *accessories* below).

Type and detailing of sealant & accessory materials - The first and most often ignored step in the design of a movement joint is *flashing or waterproofing the joint cavity*. Sealant materials, no matter how well installed, are not 100 percent effective as a barrier against water penetration. There are several techniques which rely on providing a second barrier to water , depending on the depth of the entire joint cavity. The most successful is the application of a thin, direct bond waterproof membrane, approximately 15 cm wide, which is applied at the leveling mortar surface, and looped down into the joint to provide for movement. Once this material is installed, ceramic tile is installed using adhesive mortar, and then the backer rod and sealant is applied. After secondary flashing or waterproofing is complete, the movement joint must be fitted with a rounded *backer rod*, with a slightly larger diameter than the joint width for a snug fit. The backer rod must be a closed cell polyethylene material or similar material that will not bond to the sealant used to fill the joint. The backer rod serves two important purposes: 1) control of sealant depth for proper width/depth ratio, and 2) to act as a bond-breaker with the sealant so that the sealant adheres only to the edges of the tile. This allows the sealant material to elongate and compress freely, thereby preventing peeling stress at the tile edges (the primary cause of sealant joint maintenance problems and failure). If a joint does not have the depth to receive a backer rod, polyethylene bond breaker tape is available (commonly used for joints in thin-set floor applications). The final step is selection and installation of the sealant joint material. Selection and performance criteria for sealants is presented in the accompanying technical manual. However, the frequently asked question of compatibility bears discussion.

Compatibility - Some sealants may stain porous ceramic tile, or curing by-products may be corrosive to concrete, stone, metals, or waterproof membranes. There are dozens of types and formulations of sealant products, so it is important to verify compatibility; compatibility varies by manufacturer's formulations, and not by sealant or polymer type. For example, acetoxy silicones cure by releasing acetic acid and can be corrosive; neutral cure silicones do not exhibit this characteristic.

Fluid migration and resultant staining is another compatibility issue to consider with sealants. There is no correlation with polymer type (i.e., silicone vs. polyurethane); fluid migration is dependent solely on a manufacturer's formulation. Dirt pick-up is another common problem and is a function of type of exposure, surface hardness, type of and length of cure, and the formulation, but not the sealant polymer type. Fluid streaking though, depends on both formulation and sealant polymer type. There are several new generation silicones on the market, (such as Dow Corning® #756 Silicone Sealant HP) which have specifically addressed and overcome the above aesthetic problems associated with sealants.

ROOFING & PARAPET WALLS

One of the most vulnerable parts of any exterior wall system is the interface between the roofing and the vertical parapet walls or roof fascia. Water often penetrates this critical intersection, so the design of direct adhered cladding must carefully consider detailing of waterproofing, flashing, and sealants. There are several important considerations that should guide detailing of at roofing and parapet wall locations:

1. Movement between the roof and parapet wall must be analyzed and allowances made in the flexibility of both the back-up wall and the waterproofing, flashing, and sealant connections. Parapet walls are the only part of the exterior wall assembly which is typically exposed to wind loading and wide temperature variations on both sides of the wall.

2. Parapet walls must be flashed or waterproofed beneath the top horizontal cladding surface (also known as the coping) in all types of wall construction to prevent water penetration through joints the coping. Water entry at this point is the number one cause of water related problems in direct adhered cladding. Water which is trapped within the exterior wall is the primary cause of efflorescence, freeze-thaw deterioration, and strength reduction of cement adhesive mortars.

3. The direct adhered latex or Portland cement latex membranes required for flashing or waterproofing of direct adhered barrier walls typically will not adhere to metal flashings. Latex membranes also are not compatible with many of the petroleum based built-up roofing materials, or the solvent based adhesives used for sealing / welding of seams in single-ply elastomeric (EPDM, PVC) sheet roof membranes.

ARCHITECTURAL DETAILS

The following architectural details depict the recommended prototypical design requirements for direct adhered ceramic tile cladding over concrete masonry unit (CMU) back-up wall construction. Details designated as Type 1A depict the most common type of barrier wall construction; Type 1A employs the use of a continuous waterproof membrane for cold, wet climates. Details designated as Type 5 depict a cavity wall construction type, which, with minor modifications, could depict a pressure-equalized wall in more severe climates. The details are prototypical, and are only examples of dozens of types of wall construction and detailing that are possible for direct adhered ceramic tile facades.