
Lessons to be Learned from Performance Failures of Framed Walls in High-Rise Buildings

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ABSTRACT

The building science and construction communities are now well aware of the high incidence and magnitude of premature envelope failure, due to rainwater intrusion, of wood-framed buildings in the temperate coastal climates of North America's west coast. What has been less publicized is the prevalence and magnitude of problems with the wall assemblies used on high-rise and other noncombustible buildings. The types of assemblies proving to be most at risk are metal stud-framed wall assemblies with gypsum sheathing. Major repairs, including recladding, have been required on numerous buildings in the region with steel stud-framed walls under a variety of claddings, including cementitious stucco, exterior insulation and finish systems (EIFS), metal claddings, and masonry veneer.

The ability to review, compare, and contrast damage to several buildings that have had their exterior cladding removed is an opportunity afforded to few construction professionals. This paper will use project photos and analysis to share the findings and insights gained from a number of such projects. The case studies will be used to discuss important lessons for the design professional, including

- *modes of failure of materials and systems,*
- *sources of water into the wall assemblies,*
- *location of systemic and isolated damage,*
- *problematic details,*
- *apparent contributory and mitigating factors,*
- *recommended modification to design practice, and*
- *areas requiring further investigation.*

INTRODUCTION

Light gauge metal-framed and gypsum wall systems have many advantages. They are low-cost, lightweight (which pays a special premium in seismic regions), and they have remarkable fire resistance and separating properties for their weight. These advantages have allowed steel stud construction to be the most common method of constructing both interior and exterior wall systems in buildings of noncombustible construction.

Unfortunately, when subject to moisture ingress or accumulation, durability has not proved to be a characteristic of these systems. There have been numerous buildings in the coastal climate of North America's west coast that have required major repairs to exterior steel stud-framed walls due to degradation and corrosion caused by water ingress (Morrison-Hershfield 1996; RDH 2001).

The intent of this paper is to characterize the nature and pattern of damage found in three projects with steel stud infill walls that the author has been involved with and to identify modifications to design practices that could reduce the risk of

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such failures in other buildings. The three cases can be summarized as follows:

- Case 1: an 11-year-old, 6-story, brick and stucco clad building
- Case 2: a 15-year-old, 15-story, EIFS clad building
- Case 3: a 27-year-old, 19-story, metal siding clad building

FRAMED WALL SYSTEMS FOR HIGH-RISE BUILDINGS

The types of wall systems addressed in this paper are light gauge metal stud infill wall systems that are designed to resist lateral loads (wind and seismic forces), but not floor loads. In general, these consist of a frame of vertically oriented metal studs (typically 18 to 20 gauge). Nesting the stud into U-shaped top and bottom tracks that are anchored to the floor slabs provides the end support to transfer lateral loads from the stud to the primary structure (the slabs). Some provision to accommodate slab deflection is provided at the top track so that floor loads are not transferred to the studs. The studs are typically galvanized to a G60/Z180 level (0.014 mm).

The inside of the frame is generally finished with paper-faced gypsum wallboard and the outside with some form of exterior grade gypsum sheathing and a cladding system. In all of the buildings used as examples for this paper, the exterior sheathing was paper faced. (In the latter part of the 1990s, more moisture and mold resistant gypsum products without paper facing have become more available and used.) Insulation is often, but not always, placed in the stud cavity.

Many kinds of cladding systems are used on steel stud walls. These include:

1. Cladding systems that have a single line of defense against water penetration, including:
 - a. Stucco on lath on a weather resistive barrier but without drainage provisions
 - b. Exterior insulation and finish systems (EIFS)
 - c. Most tile or thin veneer stone claddings
2. Cladding systems that have an internal drainage plane that provide a second line of defense against moisture entry. These include:
 - a. Some stucco systems
 - b. Drained EIFS systems
 - c. Panel or plank sidings
3. Cladding systems that have a space or cavity outside an internal drainage plane that provides a capillary break, free drain space, and, in some arrangements, ventilation to remove moisture from behind the cladding. These include:
 - a. Masonry veneer claddings
 - b. Drained cavity stucco system
 - c. Panel or plank sidings that are furred out to provide a drained cavity
 - d. Many metal panel systems or siding systems

Wall systems also require elements to provide adequate control of air leakage (the air barrier system) and vapor diffusion (the vapor retarder). The materials used and connected together to perform these functions and where they are in relation to insulation depends on the indoor and outdoor environment in which the building operates. All of the cases used to illustrate principles in this paper were located in the coastal region of British Columbia. In all cases, there was a polyethylene vapor barrier on the inside of the insulated cavities. The plane of airtightness was not generally clearly identified.

The same basic systems are used on many types of buildings, including low-rise and high-rise buildings of residential, commercial, and institutional occupancies.

DEGRADATION AND MODES OF FAILURE

The patterns and modes of failure that we have seen in our field investigation of steel stud-framed walls in British Columbia's coastal climate are remarkably consistent. The modes of failure can be listed in categories and subcategories in an order that reflects, in our opinion, the frequency of occurrence of failure requiring significant remediation.

1. Corrosion of metal elements.
 - a. Corrosion of the outer flange of the studs starting at the point where the fasteners that attach claddings and sheathing penetrate the flange to the point where the structural attachment of the cladding and sheathing is compromised.
 - b. Corrosion of the fasteners that attach claddings and sheathing to the point where the structural attachment of the cladding and sheathing is compromised.
 - c. Corrosion of the top and bottom track and/or the fasteners that attach the tracks to the slabs such that load transfer from the studs to the primary structure is compromised.
 - d. Corrosion of the studs to the point that the loss of section compromises resistance to the moments created by lateral forces (wind and seismic).
2. Mold growth on sheathing surfaces. This could be subcategorized by growth surface:
 - a. Outside face of exterior sheathing
 - b. Inside face of exterior sheathing
 - c. Outside face of interior sheathing
 - d. Interior face of interior sheathing
3. Physical degradation of the exterior gypsum sheathing.
 - a. Softening or crumbling of the sheathing to the point that fasteners that attach sheathing and claddings have insufficient support to resist rotation under gravity loads. This can result in detachment of some types of claddings.
 - b. In systems with adhered claddings (e.g., EIFS), failure of the bond between the facing and core of the exterior sheathing.

MOISTURE TRANSPORT AND COLLECTION ISSUES

To summarize the above observations, the consequences of water collection in framed walls operating in the coastal climate of British Columbia are generally focused at the plane of exterior sheathing and where it attaches to the steel framing. This is not surprising when one considers the nature of the materials used and moisture transport mechanisms active in an insulated framed wall.

Steel stud walls have little useful moisture absorption capacity. The steel framing provides no absorption capacity, and gypsum sheathing provides very little. Figure 1 shows the moisture storage characteristics of gypsum board from the Hydrothermal Properties Database of the National Research Council of Canada Institute for Research in Construction (NRC/IRC). One can see that a small increase in moisture content is associated with a high equilibrium relative humidity. High relative humidity accelerates corrosion of metals in contact with the sheathing and supports biological growth on paper facings. Moisture also softens the gypsum core, reducing structural characteristics, including pull through resistant of fasteners.

The attachment point where screws penetrate the flange of the framing is particularly vulnerable to corrosion if the sheathing gets wet because of the limited engagement of the screw with the thin metal of the stud and because there is some compromise of the sacrificial corrosion protection provided by the galvanizing where the screw pierces the flange.

In a temperate coastal climate, there are several mechanisms that lead to moisture collection in the exterior sheathing.

1. Rain penetration past the cladding system can wet the sheathing directly.
2. The combination of moisture absorbed or held in a cladding and solar radiation on the cladding can lead to high inward vapor pressure differences that can drive moisture across the weather resistive barrier into the sheathing.
3. In winter, humidity from the indoor environment can enter the cavity by diffusion or air movement (the dominant mechanism). This moisture will tend to collect on the materials on the cold side of the cavity—that is, the exterior sheathing.
4. Any water that enters the inside of the cavity by bypassing the cladding system, weather resistive barrier, and exterior sheathing (such as leaks at window penetrations) also tends to be driven to the materials on the cold side of the cavity.

British Columbia's coastal climate can be characterized as having a very high wetting duration and a predominantly outward temperature differential and vapor pressure drive across the walls. This puts the exterior sheathing in an extremely vulnerable position with respect to moisture collection.

The combination of moisture susceptible materials in a location prone to moisture accumulation can have serious consequences. The Case Study 1 photos (Figures 2 to 6)

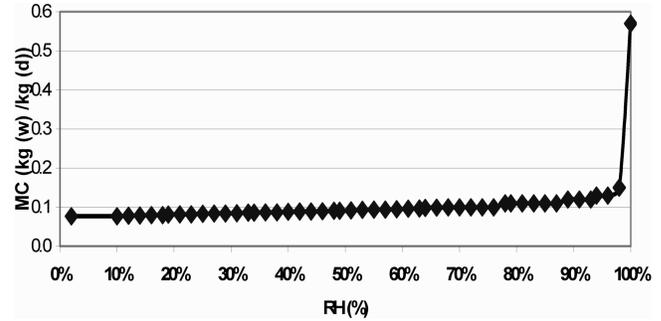


Figure 1 Moisture storage function of gypsum board.

include pictures of moisture-troubled steel stud walls that have had the exterior sheathing removed. In these walls, the exterior flanges of the studs have suffered corrosion to the point that the attachment of the exterior elements has been compromised. The extent of corrosion can be limited to localized corrosion at the screw attachment points to virtual disintegration of exterior flanges to the point that the ability of the flange to carry lateral load (wind and seismic) would be compromised even if the attachment were not an issue. Note that the webs and inner flanges of the studs show little corrosion.

With the bottom track, there is typically the same pattern of corrosion on the outer flange, but often one can also discern a pattern of corrosion indicative of water pooling in the track.

It is our observation that buildings clad with cement stucco over a weather resistive barrier, but without an intentional drainage space or cavity, suffer the most from corrosion of the outer parts of the steel studs. We would postulate that the combination of absorptive cladding, lack of a capillary break, and lack of thermal resistance outside the sheathing creates a very challenging environment for moisture-sensitive materials at the sheathing plane. However, the typical pattern of damage is not limited to stucco clad buildings. The Case 2 photos (Figures 7 to 13) are from a building that was clad with 38 mm (1 ½ in.) of face-sealed EIFS outside the insulated framed wall. The presence of the thermal insulation outside the sheathing significantly changes the hygrothermal properties of the wall. The EIFS keeps the sheathing warmer and reduces the potential of wetting and drying to the outdoors compared to a stucco-clad wall. In our investigation of the EIFS clad walls, we see similar patterns of framing and fastener corrosion, but the severity or rate of corrosion appears to be less than with stucco. However, with adhered EIFS systems, another mode of failure occurs: the loss of the adhesive bond of the foam to the paper facing of the gypsum sheathing or, more usually, the bond between the paper facing and the gypsum core of the sheathing.

Figure 14 shows one elevation of a building (Case 2) where the original face-sealed EIFS cladding was removed and replaced with an alternate cladding system. The pattern of damage found has been identified on the drawing. The type of



Figure 2 General view of building in Case Study 1.



Figure 3 Wall with exterior sheathing removed showing relatively light corrosion on exterior flange of studs.



Figure 4 Wall with exterior sheathing removed. Note heavy corrosion of studs and the interior gypsum, inside of polyethylene vapor barrier, is in good condition.



Figure 5 Showing corrosion on top and bottom tracks as well as studs.



Figure 6 Opening from inside showing degradation of inside face of exterior sheathing.



Figure 7 Southeast corner of building (Case 2) where damage was most intense.



Figure 8 After EIFS removal. Note mold and paper delamination.

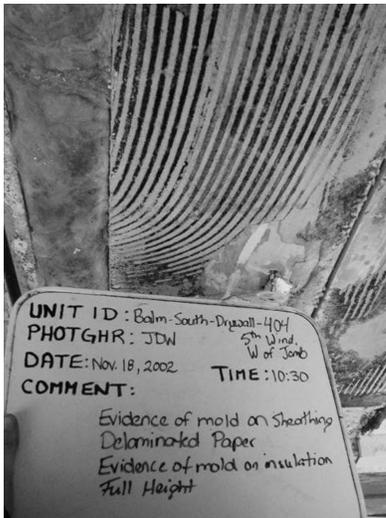


Figure 9 Mold growth on exterior face of sheathing.

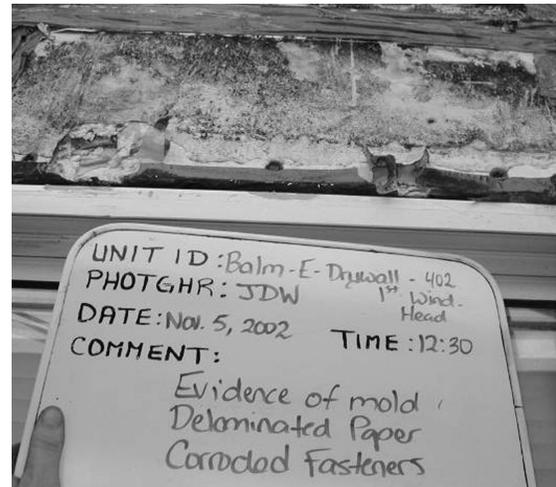


Figure 10 Water damage on exterior face of sheathing.

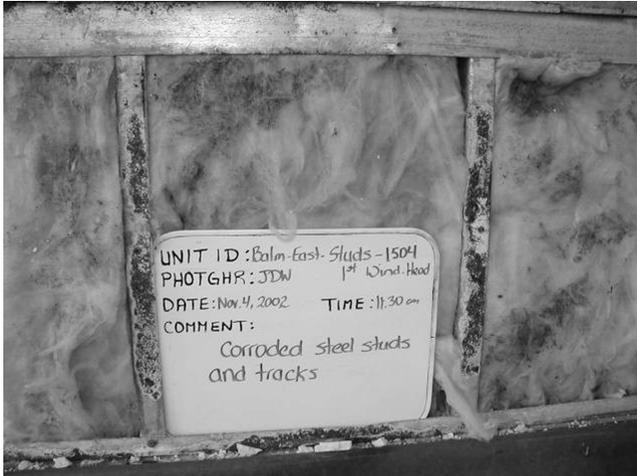


Figure 11 Stud corrosion below window (Case 2).

damage includes areas of mold growth on the exterior face of the sheathing, delamination of the paper face from the gypsum core of the sheathing, and corrosion of the framing detected once the exterior sheathing was removed. From an engineering perspective, it is important to note the following:

- The pattern of damage was strongly associated with areas of known risk of rain penetration, notably windows, parapets, balconies, vent hood penetrations, and sealant joints.
- The damage was the worst on the south and east façades of the building. This is the direction of wind coincident with rain in the Vancouver area.
- There were areas of framing corrosion outside of the areas where there was significant observable degradation of the exterior sheathing.
- In this building, there were very limited areas where there was mold growth on the outside face of the interior sheathing. This can be explained, in part, because the sheathing is kept warm, and because it was protected from exposure to exterior source moisture by a polyethylene vapor barrier.

The Case 3 photos (Figures 15 to 22) are drawn from a 27-year-old building with an unusual cladding system for a high-rise building. The basic construction uses framed infill walls with strip windows spanning between parallel concrete shear walls. The wall construction consisted of a typical metal stud-framed wall (interior gypsum board, polyethylene vapor barrier, 90 mm metal studs with fiberglass insulation, exterior gypsum sheathing), but the cladding was simply metal siding that had been installed directly over the exterior gypsum sheathing without any type of weather-resistive barrier to act as a secondary moisture barrier. The walls had a history of water penetration at the window frames extending back for many years prior to our involvement, which started when the



Figure 12 Stud corrosion at SW corner.



Figure 13 Showing one of limited locations with mold on interior gypsum board.

owners decided that it was necessary to change the windows. As part of planning for the window replacement, we undertook an investigation of the wall systems below the windows.

Our investigation of Case 3 found widespread evidence of water penetration into this wall, but the significance of the damage was less than we expected considering the age of the building. The exterior sheathing was heavily and widely water stained, but it was intact and the framing had localized corrosion. Mold growth on the sheathing was widespread but limited in intensity. However, we found that the gypsum

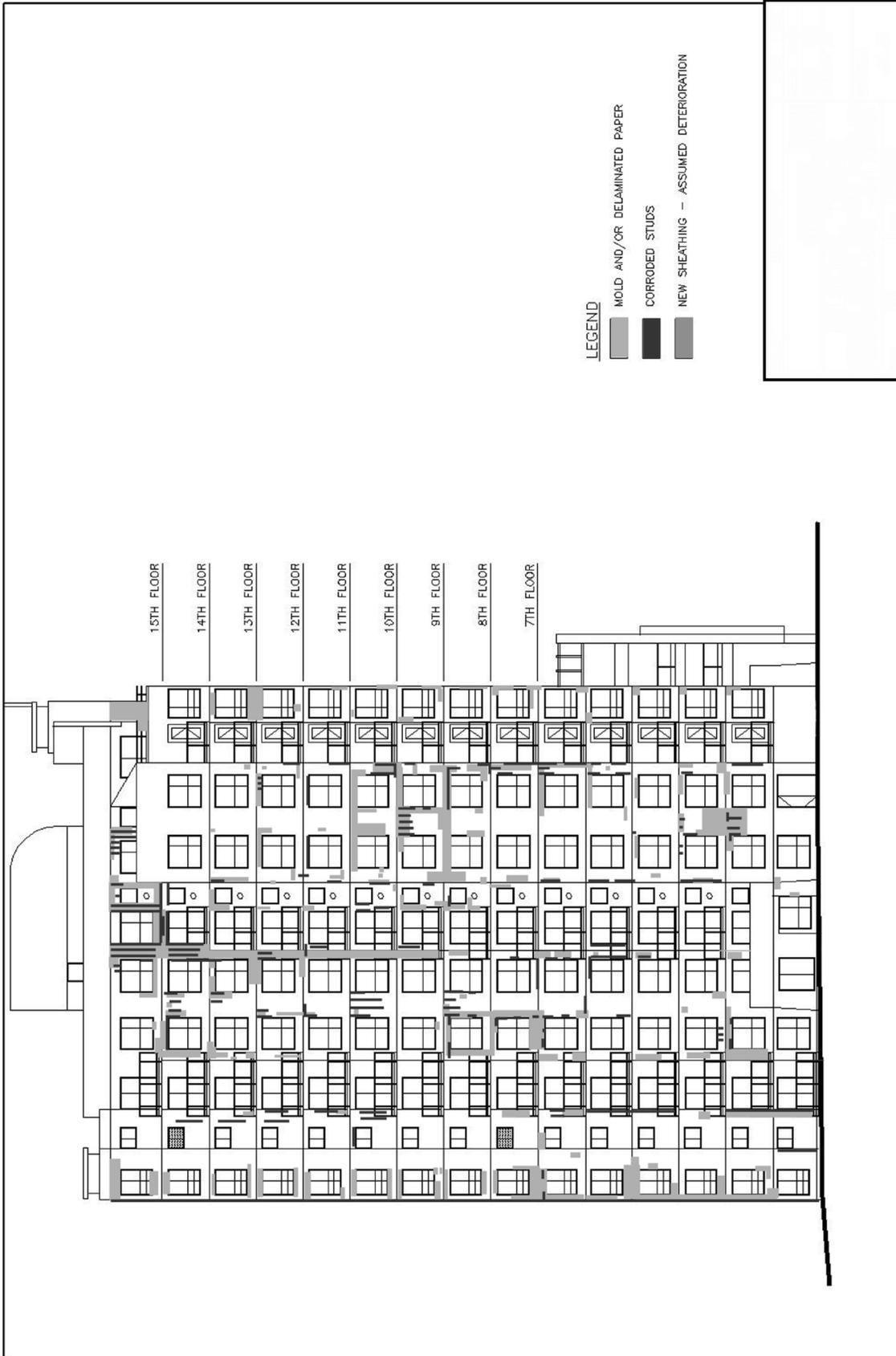


Figure 14 East elevation of Case 2, showing found water damage.



Figure 15 Elevation showing infill section between shear walls (Case 3).

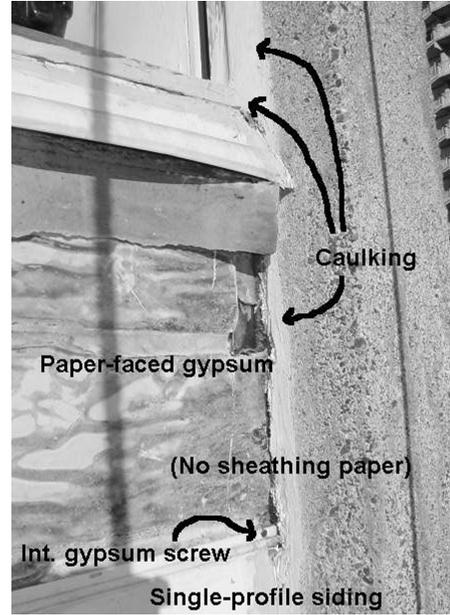


Figure 16 Test opening showing cladding. Note lack of weather-resistant barrier under metal siding.



Figure 17 Showing water in frame wall after ASTM E1105 water leakage test.

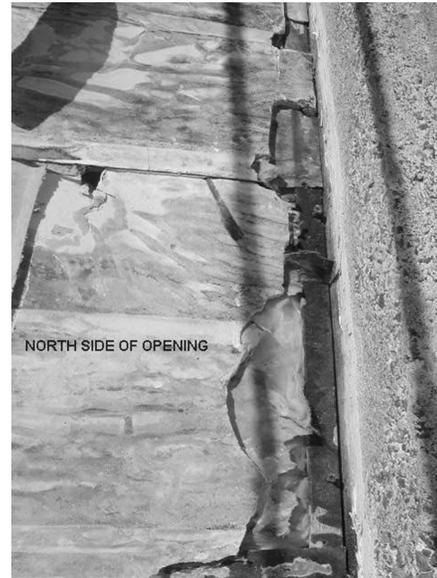


Figure 18 Showing corrosion of framing at test opening.

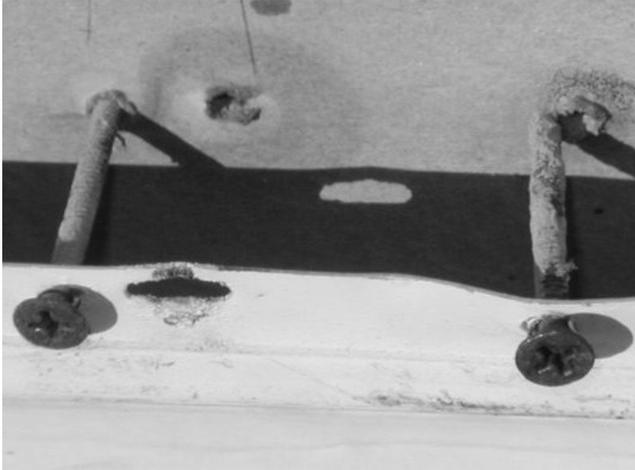


Figure 19 Rusted fasteners that had little pullout resistance (Case 3).

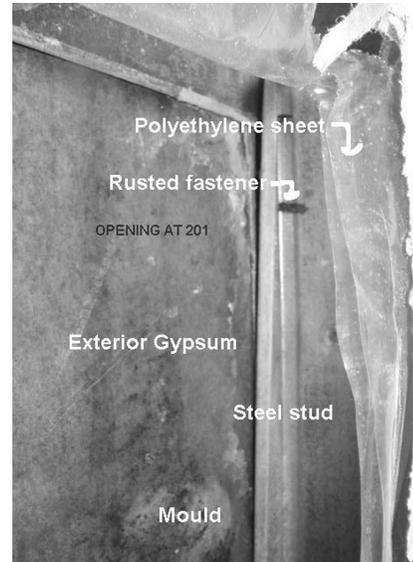


Figure 20 Interior test opening showing arrangement of materials (insulation removed).



Figure 21 Stud at shear wall. Note corrosion on outer flange.



Figure 22 Water damage on interior face of exterior sheathing.

sheathing and metal cladding had been installed with drywall screws. These had limited corrosion resistance and they were corroded to the point that resistance to lateral loads was compromised. These findings prompted the decision to re-clad the walls in conjunction with window replacement.

The limited nature of corrosion to the steel studs or degradation of the gypsum sheathing in spite of the widespread evidence of water penetration was a bit surprising. We speculate that two major factors resulting in this performance were the lack of absorptive materials outside the sheathing and the degree of ventilation through the cladding. The metal cladding was not intentionally vented, but neither were the horizontal joints well sealed. It appears that these factors promoted drying to the point where corrosion of the galvanized elements and mold growth was limited. If appropriate fasteners had been used to affix the cladding and sheathing, it may have been more difficult to convince the owners of the need for major wall repair.

SUMMARY, COMMENTS, AND CONCLUSIONS

Our main observation is that in the temperate coastal climate of British Columbia, metal stud-framed walls degrade from the outside in. This pattern of damage is similar to wood-framed walls in the same climate, and it can be explained by the moisture transport and collection mechanisms that one expects in an insulated wall system.

From an engineering perspective, this is important for design and for assessing the condition of walls in existing buildings.

When assessing existing buildings, it is critical to assess the conditions of the exterior sheathing, the outside flanges of the steel studs, and the fasteners that attach the cladding and sheathing to the studs. In our experience, this is most easily done by direct visual observations through test openings through the interior finishes. Interior test openings initially should be carried out at locations with a high risk of water entry (under windows, exterior corners, balcony interfaces, etc.).

If there is an adhered cladding system (EIFS), it is also necessary to evaluate the condition of the series of adhesive bonds between the sheathing and insulation. This could require some test openings from the exterior. This is best done where there is some indication that water may have penetrated into the wall system.

From a design perspective, it would appear that in coastal climates, much more emphasis should be placed on the durability of the materials and systems we use on the outer portion of wall systems. We suggest that paper-faced gypsum sheathing is too vulnerable to moisture-induced degradation to be used as exterior sheathing in temperate maritime climates because physics tends to concentrate moisture collection in the exterior sheathing.

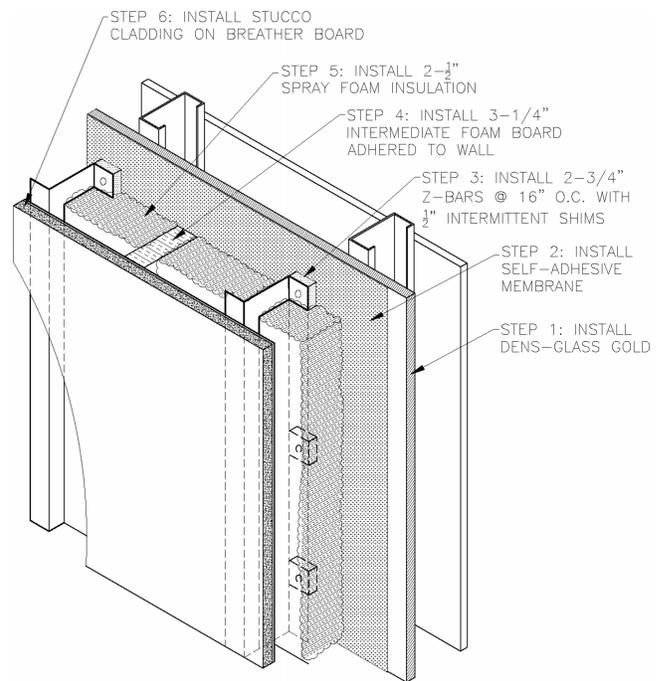


Figure 23 Exterior insulated wall system.

Clearly, all practical measures to eliminate moisture penetration to the sheathing and into the cavity need to be employed. We have become strong proponents of cladding systems that provide a capillary break between any moisture absorptive material, such as stucco and the exterior sheathing and the detailing of penetrations with impervious flashings that can collect incidental water penetration and direct it back to the outside of any moisture-sensitive materials.

In very high-risk circumstances, one can consider wall systems that keep the steel stud construction and sheathing inside all insulation and an impervious air, moisture, and vapor barrier. Figure 23 shows such a system that is now used as a remedial solution for failed metal stud wall systems in British Columbia's lower mainland.

REFERENCES

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