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# REPAIR OF FAULTS IN MASONRY BUILDING ENVELOPES

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## ABSTRACT

The assessment of the needs for repair of masonry requires that the operational and financial needs of the owners of the building be addressed in addition to the technical requirements to address the distress. This paper presents a system for organizing the thought process for investigation of the causes of deterioration. The fault tree system presented illustrates a root-cause assessment plan for investigators so that they may develop logical plans for repair.

Repairs must not only consider the technical issues but also the owner's financial and operational concerns. Cash flow and property value, future maintenance and aesthetics all must play a part in the decisions for repair. Three cases are presented to illustrate examples of the proper determination of root cause and the selection of repair alternatives.

## INTRODUCTION

Much of the existing building stock has, or will, experience some form of building envelope related distress. The resulting engineering and building repair work contributes in a very big way to the economic survival of those industries, particularly when new building construction is slowed. Typically, building envelope repair and replacement, including walls, roof and windows, makes up 20 to 30 percent of building repair and maintenance costs over the life of the building (unpublished work by the author). It is, therefore very important that those repair dollars be spent in the most cost effective way for each building and that each building be considered to be a separate entity with individual financial and operating constraints and opportunities as well as different examples of distress and repair requirements.

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## DISTRESS OR FAULTS

Before repairs are developed for performance failures, a distinction must be made between the fault that caused the performance problem and the evidence of distress that resulted. Too commonly, our industry sees water leaks, efflorescence, spalled brick or other form of distress as the fault rather than what it really is - a symptom of a fault. And so, considerable effort may be spent in examining, categorizing and documenting symptoms rather than faults. The result of those efforts may generate a good historical record of condition, but that is little more than data. You can't base decisions about repair on condition data alone and be sure of correcting the underlying fault in the way best suited to that particular building.. You can, though, use data, to form hypotheses concerning the cause of the distress that can then be evaluated, proved or disproved and then, design alternative repairs to deal with the fault rather than the symptom.

## FAULT TREE ANALYSIS

The fault tree is a useful tool than can be used by investigating engineers to help establish the cause of the fault resulting in the observed distress. Knowing why faults occur can prevent them from happening again. Such is one of the basic tenets of quality management - iterate to exclude learned weakness to preclude problems thus avoiding downstream costs for quality control and rework. Thus, while the fault tree shown in Fig. 1 is a useful organizational framework for the thought process leading to repair of buildings, it can also be used to decide which aspects of the production and use of buildings need process modification to reduce the occurrence of faults in the future.

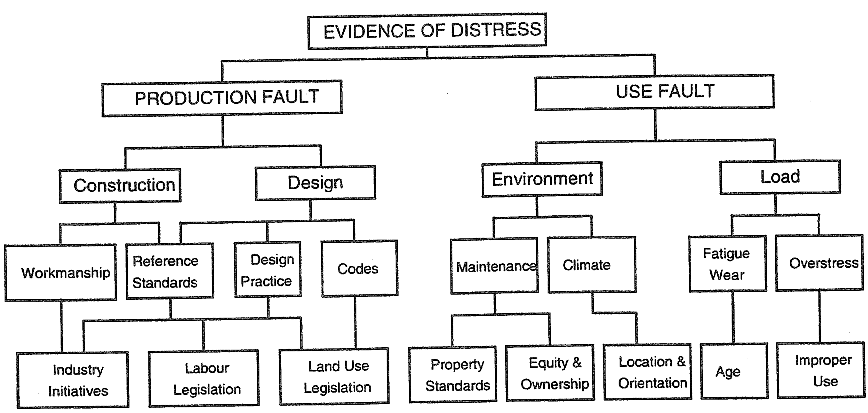


**Fig. 1: Factors Affecting Building Condition.**

The fault tree illustrates two main branches, the left side is related to creation of the building and the right side is related to its use. An imbalance between the two sides at any time during the buildings life results in some evidence of distress. It is probable that the fault causing the distress does not fit neatly into one box in the chart, but is some combination of faults in design, construction, use and applied loads. Discerning which of these prevails is of particular interest to courts of law when compensation for damages to repair distress is being sought.

## REPAIR STRATEGIES

Once the evidence of distress has been reduced to one or more faults in the production or use of the building envelope, alternative repair strategies can be developed to deal with the fault and reduce, or perhaps, eliminate the distress. It would be unrealistic to expect that one solution would respond to the requirements of each form of distress; so, engineers should offer alternatives, typically having various levels of expected performance and cost.

While engineers may have typical details for certain repair types and have experience performing various types of repair, the design of repairs for any particular building must take into account a variable for which the engineer has no 'typical' detail and for which they likely have little past experience - that of the owner's financial situation and the effect of the repairs on the operation of the building. These non-technical concerns of the building owner must be just as persuasive in the selection of the repair strategy as the technical concerns of the engineer. Figure 2 lists these concerns by category as Operational, Financial and Technical.

| OPERATIONAL | FINANCIAL | TECHNICAL |
|---|---|---|
| Public Liability | Cost and Cash Flow | Life Safety |
| Aesthetics | Distribution of Expenses | Structural Integrity |
| Municipal Property Standards | Equity Capital Available | Durability |
| Effect of Temporary Closure | Future Ownership | Availability of Materials |
| Urgency | Taxation Options | Availability of Trades |
| Ongoing Maintenance | Market Conditions | Effect of Deferral |

**Fig. 2: Engineering and Ownership Issues Affecting Design of Repairs.**

The owner may have limited funding, or the building may be in a location with market conditions that tolerate a less expensive repair approach. The owner may also prefer to accept a partial solution to handle the symptoms rather than a complete solution to eliminate the fault. It is not up to the engineer to decide which repair strategy is best for the building owner. That decision must be made by the owner with technical input from the engineer. Issues such as cash flow, capitalization tax options, market conditions and future ownership are vital inputs to that decision and generally not available to the engineer assessing the problem. It is only good sense that the building owner be involved in the development of the distress assessment protocol and the design of the repairs as it is only they that truly understand their needs.

## REPAIR TECHNIQUES - CASE STUDIES

Building envelope repairs require insight into a variety of technical areas and a technical maturity that is rooted in theoretical knowledge and developed through practical application. The design of a repair that fails to consider the true nature of the fault through assessment of all relative building science and engineering principals associated with the distress or fails to accommodate the owner's particular situation is not a solution to the performance problem. Equally intolerable is a repair that generates a second problem while correcting the first. To illustrate these points, two cases are examined. Case 1 considers the problems caused by inappropriately diagnosing a construction and maintenance fault as a design fault and hence creation of a new problem by modifying the design. Case 2 considers a situation in the design and climate created the distress and the repair incorrectly addressed building maintenance in an attempt to resolve the distress. These cases are hypothetical but are based on experiences of the author.

### *Case 1 - Correction of a Construction Fault*

This case involves the replacement of damaged brick and the addition of a bituminous air barrier on the wall to prevent air and water leakage. In this case the building is a residential condominium that is 15 years old and has minimal cash reserves. The exterior wall cross-section is shown in Fig. 3. The figure shows a plan view of a chimney that is part of the exterior wall. The main wall is a cavity system with insulation in the cavity, block masonry back-up and face brick. The chimney differs somewhat in that the wall is solid masonry with insulation inboard of the flue. Thus the chimney is outside the insulated section of the wall. Apart from spalling of the brick face, exploratory work found the sealants around adjacent windows are cracked, flashings are poorly terminated and brick joints require repointing. The collar joint at the chimney is only partially filled and the joints in the back-up block are typically poorly filled.

The building was constructed prior to the widespread use or the design code requirement for the installation of air barrier products as a means of reducing the ingress of moisture or the egress of vapour. However, the repair design considered that this apparent design omission was the cause of the leaking and spalled brick and, thus, the repair work applied a new air barrier, adhered to and thus structurally supported by the concrete block. The adhered bituminous barrier was formed into flashings at the floor slabs and made continuous across the full wall face. Such are the design requirements of air barriers as given in the 1990 National Building Code of Canada.

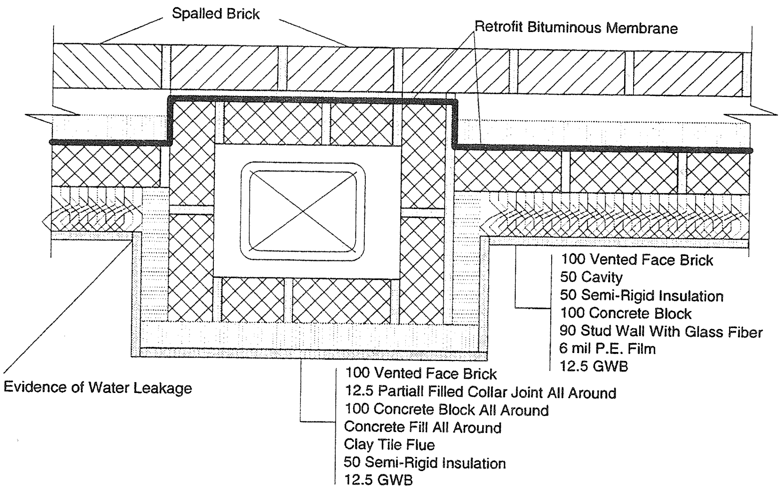


**Fig. 3: Case 1 Wall Plan Section.**

The bituminous air barrier will, no doubt, act as waterproofing and prevent any exterior water from entering the living space but, a new problem has been introduced. The wall now has a vapour retarder (bituminous membrane) on the cold side of the insulation in both the main wall section and the chimney section. Thermal gradient calculations through the main wall section would indicate that average interior relative humidity levels would result in condensation in the block at exterior temperatures of 0°C or less. The moisture from this condensation can affect the bond of the air barrier membrane allowing exterior water to enter once again and making the removal and replacement of the exterior brick, at \$600 to \$700/m², rather futile. More significantly though, the chimney wall section has a vapour retarder outside the portion of the wall that is subject to frequent freezing and thawing conditions. Condensation on the tile from flue gases would contribute considerable moisture to the chimney behind the air barrier. This places the chimney construction at considerable risk . The damage may even not be visible until it has reached an advanced state or the chimney has collapsed.

A more appropriate solution to the water penetration problem that would be more in line with the financial situation of the owner, would have involved reduction of water ingress through repointing of the brick, replacement of the cracked sealants and redirection of the water that did penetrate the cavity by reconstructing the poorly built flashings. Air leakage, if a problem at all, could be controlled through the use of interior sealants and modifications to the gypsum wall board to provide continuity. At the chimney, the leaks could have been controlled through the use of flashings, by repointing and by completely filling the collar joint with a low pressure grout application. These efforts would have cost roughly 20 percent of the cost of installing the air barrier membrane and would have effectively mitigated the moisture problems.

In this case the fault lay in the workmanship of the original flashing and chimney grouting construction and in a lack of maintenance of the exterior brick joints. The original wall design was, in fact, adequate even though it did not call for an air barrier membrane. The addition of the air barrier in this case was a change to the design of the wall and an attempt to address the only fault option that did not contribute to the distress.

*Case 2 - Correction of a Design Fault*

Moisture stains at windows are often associated with poor exterior seals; however, exterior sealant failure is not always the cause of the stains and dripping around windows. The windows in the 10 year old high rise building in this case were not leaking at all. The Owner was quite convinced that they were though, and the engineer that was hired, obligingly, developed remedial work specifications to recaulk the windows. Replacing sealants on the exterior was done at a cost to owners of approximately $375 per apartment.

This substantial cost to the Owners resulted in little change to the moisture problem. The reason that the problem was not resolved was that the initial fault in the design was mis-diagnosed. The water that the unit owners saw was actually condensation that collected on the inside face of the metal slab cover that formed part of the curtain wall system (see Fig. 4). The condensation soaked the slab edge insulation, dripped into the head and jambs of the window frame and drained down the inside of the wall, wetting the interiors.

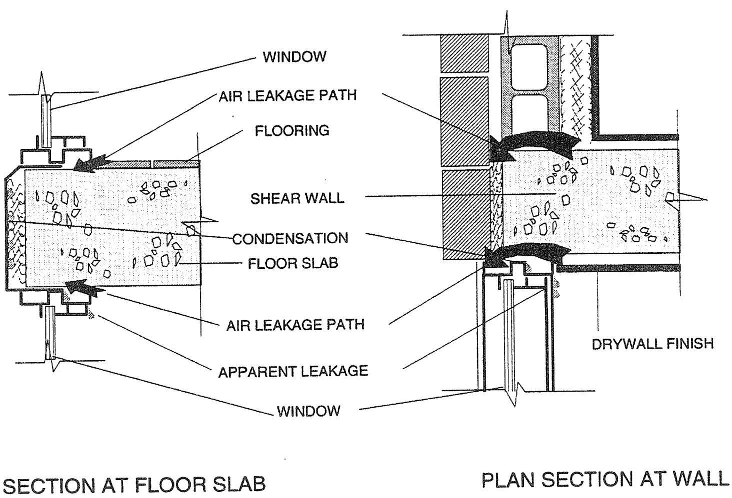


**Fig. 4 Condensation at Floor Slab Covers.**

The damage caused by the condensation water leaking back into the units was not unlike that caused by leaking of rain; however, water tests performed on the windows could not cause the same type of leaks that the owners observed. The true problem was identified only after considering the thermal bridge caused by the concrete floors and shear walls and the absence of a good air seal at the areas where walls and windows abutted concrete. Moisture carried by the exfiltrating interior air condensed during cooler evenings on the metal covers or collected as frost in the winter that occasionally melted when the dark metal was warmed by the sun. The result was periodic wetting of the interior floors and wall finishes.

The air leakage problem was corrected by providing air seals at the floor-to-window joints and by injection of urethane foam at the ends of the metal covers where these abutted shear walls (see Fig. 5).

The cost of the air sealing work was roughly one-third of the cost to reseal the exterior walls. Had the engineer assessed the true nature of the problem, the owner would have been spared the expense of redoing caulking that was in good condition.

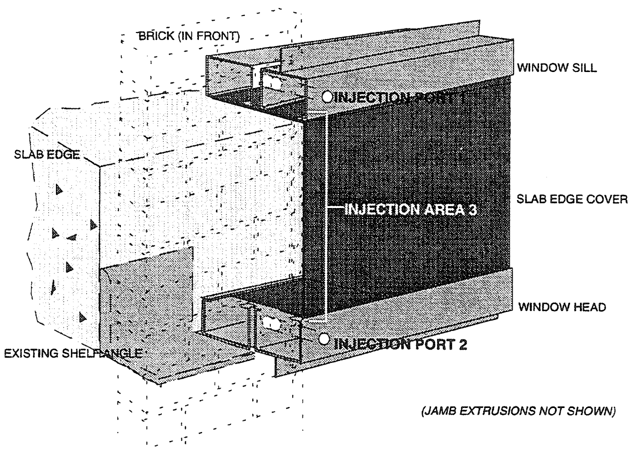


**Fig. 5 Air Sealing at Floor Slab Covers.**

*Case 3: Dealing with Owner's Expectations*

Masonry is, without doubt, one of the more attractive exterior wall building materials available today. Because of it's unit-construction "hand-made" qualities, it can be formed to suit the designer's needs. However, this versatility must also consider the properties of the bricks used and of the brick and mortar assembly - and the long-term effects of the environment on the assembly. This case examines one example of two owners with different objectives for repair of their masonry walls. The owners had the same problems involving improper design of the masonry walls and attack of the masonry by roots and deicing salts.

Two blocks of townhouses, each 12 years old were designed and constructed in the early 1980s. One of the more interesting features of these two blocks of townhouses is the heavy use of masonry at the entrances to the units. The townhouses are arranged with one-storey units one-half level below grade at the front of the building. The rear of these units is a walk-out at grade. Above these units is a three storey unit. Street access is provided by stairs down from a walkway to the lower units and stairs up to a common upper landing for two upper units. Figure 6 illustrates the arrangement.

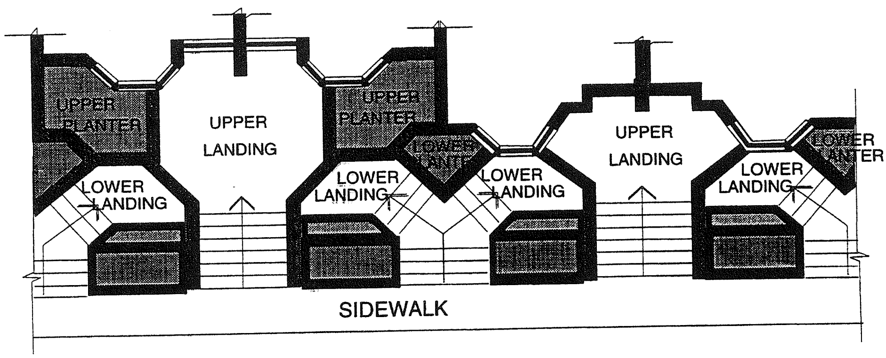


**Fig. 6: Masonry Landing Layout**

The upper units are of two types; one type has large brick planters, the other no planters. The lower units also have brick planters. The stairs to the upper landings had masonry walls supporting a short combination guard and handrail. The design of the walls employed a rowlock course on the top of the wall. After five to seven years, the occupants of the lower units complained of water leaks. The exterior faces of the stair and planter walls was spalling and the owners were concerned that the deterioration was affecting their property value and they were looking for a cost effecting repair. In the Spring, the upper units also complained of leaks.

Investigation of the existing conditions and the design revealed that the rowlock course resulted in leaks into the double wythe wall which, in turn, resulted in water leaks into the lower units and spalled the brick. In addition, the waterproofing of the planter was brittle and had been invaded by roots from shrubs in the planters and the drainage of the planters was in adequate. In the Spring, the melting of the snow and ice in the planters overflowed the waterproofing in the planters and leaked into the units.

Each of the two townhouse blocks chose a different approach to dealing with the problem. One townhouse block was decided that the spalling brick walls were unsound and should be removed. This included the planters, the landing walls and the stair walls. In addition, the owners decided that the concrete landings required new waterproofing. These decisions were supported by their consultant. The solution presented and implemented resulted in the complete removal of the walls and planters, application of a urethane membrane on the upper landings and installation of aluminum handrails. The leaks stopped and, obviously, the masonry spalling has been eliminated with the walls.

The other townhouse block wished to retain the aesthetics offered by the masonry entrances and preferred to retain the planters. After some assessment of the extent of the deterioration and the nature of the leaks GRG Building Consultants determined that the landings did not leak; however, their was a risk of leaking through the landing-to-slab joint where the landings were poorly drained. The leaks in the upper units resulted from the inadequate drainage of the upper planters and the poor condition of the planter waterproofing. The masonry walls were generally sound but required extensive isolated brick replacement. Brick was in particularly poor condition on the inside faces of the stair walls adjacent to the stair treads, likely due to the use of deicing salts. The brick originally used is no longer available so replacement would have to be made using reclaimed brick.

The repairs the second block adopted included the rewaterproofing of the upper and lower planters using a modified bitumen, torch-applied membrane, addition of a "chimney drain" to the planters. The rowlock course was removed from the walls and planters and a precast concrete cap was placed on top of the existing walls. The rowlock course was reclaimed for use as repair brick for spalled areas. The stair walls were removed to the stair level, a new concrete curb was poured to act as a stair stringer and new precast concrete caps were installed. In order to regain the appearance of masonry at the stairs, new 300 x 300 brick columns were added to the top and bottom of the stairs. Precast concrete caps were added to the columns. The masonry columns served not only as architectural features but also provide support for the new handrails and guards.

The townhouse block that removed the walls completely, lost the look of masonry at their entrances; however, they also avoided the costs associated with future repair of spalling brick. The second townhouse preferred to retain the appearance of masonry and agreed to accept the possible future spalling of the brick. After one winter we noted that approximately 80 brick had delaminated but not yet spalled. That represents approximately 6 percent of the total number replaced during the repair program. Since the source of the leaks and the cause of the spalling has been dealt with, the number of spalled brick should decrease annually.

In this case the two owners each had different expectations for the completed repair. One wanted no future maintenance and was willing to accept the aesthetic change to the front of the property; the other owner was willing to accept some future repairs but wanted to retain the character and value of their entrances. The two remedial schemes were roughly the same cost.

## SUMMARY AND CONCLUSIONS

1. The fault tree is a fairly simple tool that can be useful in organizing the thought process of investigations of building envelope performance problems.

2. Each branch of the tree is influenced by factors that can affect the way that buildings are designed, constructed and maintained. Effective change to the long-term performance of new buildings must begin at the lower levels of the tree where policy and legislative actions and industry initiatives arise.

3. Effective repairs to existing buildings must correctly address the true fault(s) causing the distress rather than the symptoms of the distress.

4. No repair should be undertaken without consideration of the operational and financial issues known only to the owner. In this regard, the owner and the engineer must jointly assess alternative repair strategies and select the procedure that best suits the needs of the particular situation.



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# Brick Veneer/Steel Stud Walls
## - A Repair Solution -

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## ABSTRACT

The paper describes the investigation and subsequent repair work carried out on the brick veneer/steel stud masonry walls of a highrise apartment building in Calgary, Alberta. The paper deals with the original design details, with workmanship deficiencies and with the selected repairs.

## INTRODUCTION

For the past 20 years, brick veneer/steel stud (BV/SS) walls have been used extensively in North America as an economical exterior wall system both for commercial and residential construction. Since the construction of these walls preceded the development of adequate design, construction and inspection standards, serious concerns have been expressed by building officials, consultants and contractors over the longterm safety, serviceability and durability of this form of construction. A survey conducted on behalf of CMHC (Keller, 1986) established that by 1986, approximately 1000 buildings had been constructed in Canada; of these 42% were residential and 58% commercial or industrial. More than 34% of this apparent inventory was more than 4 storeys in height. The survey showed that no standardized procedures existed for design and inspection during construction. In addition, a number of practices that we now know are deficient were reported as relatively commonplace. For example, exterior insulation was not used on two thirds of the projects reported, 72% of the brick ties did not connect directly to the stud and on 22% of the projects, corrugated brick ties were used.

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