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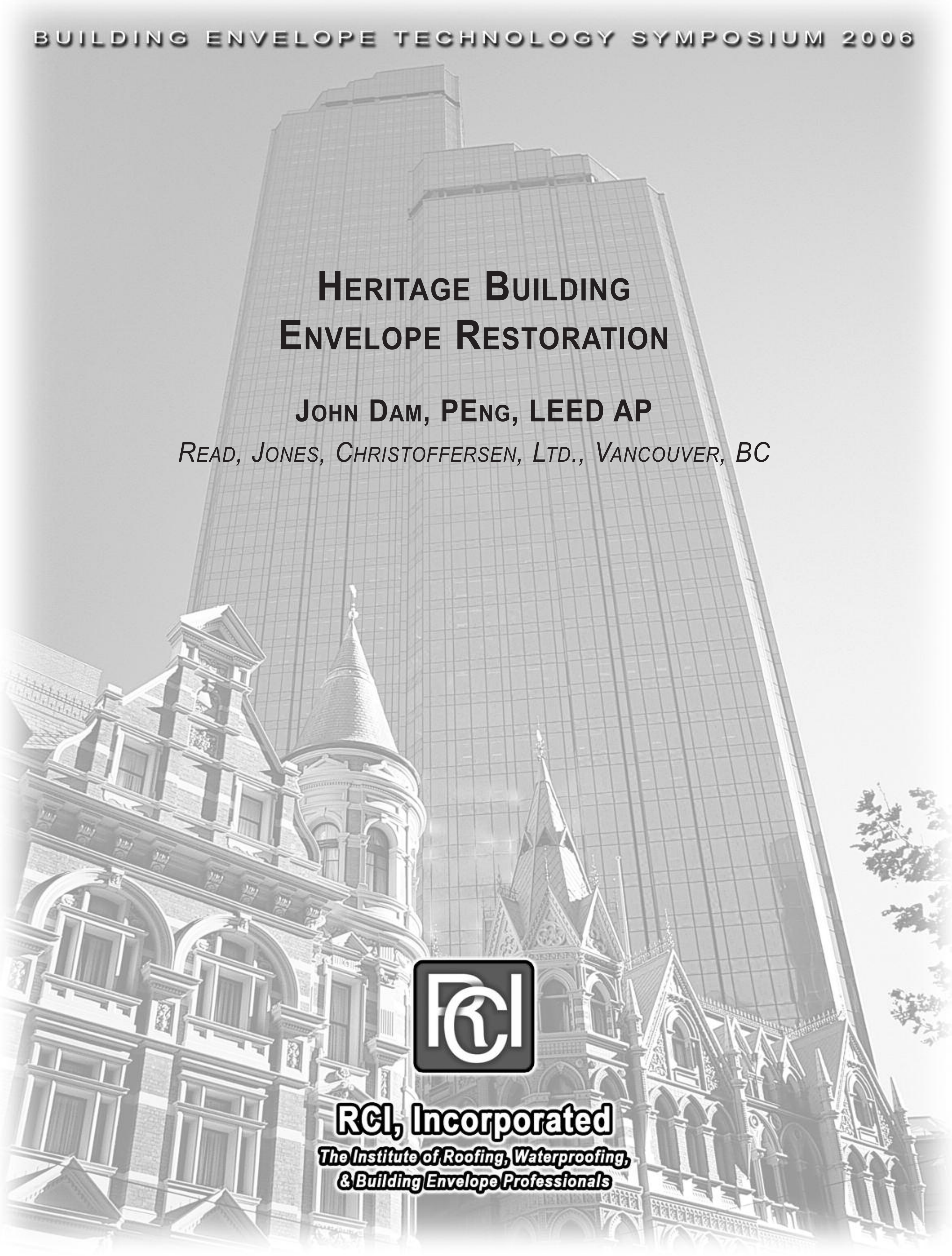

# HERITAGE BUILDING ENVELOPE RESTORATION

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The Institute of Roofing, Waterproofing,
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## ABSTRACT

Many buildings constructed around the turn of the 20th century are being challenged to meet the demands of today's occupants, while progressively deteriorating. This deterioration, often addressed as a safety concern, typically evolves beyond the anticipated scope of work, which, when further evaluated, often poses an economic barrier. This presentation will discuss a variety of restoration methods and materials used to economically address the durability of the building envelope of heritage buildings, reviewing both the cladding materials and the materials comprising the primary and secondary structural elements.

## SPEAKER

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John Dam, PEng, is a design engineer in the restoration group of Read Jones Christoffersen Ltd. in Vancouver, BC. He studied structural engineering at the University of British Columbia, is a graduate of the AIBC Building Envelope Education Program, and a LEED® Accredited Professional. He has been consulting for seven years in the fields of structural and building envelope restoration, while also providing the wood frame design for restoration projects and engaging in building envelope and materials consulting for the restoration of heritage buildings. Dam is currently involved in a variety of construction and renovation projects, including building envelope and structural consulting for new structures and evaluating and administering the restoration of low-rise residential structures.

# HERITAGE BUILDING ENVELOPE RESTORATION

## 1.0 INTRODUCTION

The early stages of deterioration in the older masonry buildings of Vancouver, B.C., often go unnoticed until falling debris manifests a crack or displaced wall cladding. The concern for public safety is raised and containment nets or canopies are often installed. Measures may even be taken to remove loose debris from the building, but addressing the wall cladding, the support system, and the source of deterioration does not typically follow. Unfortunately, the damage within the walls at this point is likely massive and the restoration scope and requirements are poorly understood.

Determining the extent of deterioration and restoration requirements with a level of tolerance for structural safety that will provide a scope of work can sometime prove difficult. Options are to direct financing toward a thorough investigation with reduced resources to address the problem or conduct a reduced investigation focusing the finances on the repair work. Choosing an option is dependent on the level of confidence in the scope of work that is comfortable to those engaging it.

The high-rise buildings addressed in this report are two such typical cases with significant scopes of deterioration, ambitious restoration attempts, and abrupt conclusions associated with a shortfall of funds.

## 2.0 TRANSITIONAL BUILDINGS

To successfully restore a heritage building, one must understand the behavior and aging of the wall systems and determine how the materials react to each other in the presence of a changing environment.

*Figure 1 – Vancouver Block.*

The Vancouver Block and Dominion buildings (*Figures 1* and *2*) in downtown Vancouver, BC, are two of the city's finest examples of terra cotta-clad, high-rise structures. Built in 1911 and 1910 respectively, they can be properly classified as "transition" buildings where the structural support is carried by a steel frame, while the building envelope is built of massive masonry. The term "transition" is used to define a period of building during the time when traditional load-bearing masonry construction evolved into a hybrid of a structural frame combined with massive masonry. Construction technology over time evolved further to shed the massive masonry and developed into a structural frame with a lightweight veneer or other cladding. "Transition" period buildings are the era that presents the most significant level of deterioration in our cities today.

Traditional masonry construction has proven to be resilient to deterioration over time. With the use of unreinforced multi-whythe masonry to provide both the structural support and building enclosure, there is little to deteriorate (other than the mortar) in most cases.

It was the desire to build higher and the constraint of supporting significant mass at upper elevations that lead to the development of a primary structure to support the secondary elements, a concept in almost exclusive use today. We now know that a significant drawback of the "transition" period building was embedding the structure – typically steel – in the familiar mass masonry element without realizing the long-term consequences of corrosion. These consequences are a result of the mass masonry absorbing and retaining moisture, similar to the original wall of mass masonry construction, but depositing it against steel members vulnerable to moisture. Not only does the massive masonry draw moisture toward the primary structure, but also the increasing volume of corrosion product displaces the tightly fit masonry, causing cracking and eventual dislodgement. This damage allows yet more moisture into the wall system and constitutes a destructive cycle that can cause significant damage to the cladding, and ultimately, the primary structural elements.

*Figure 2 – Dominion building.*

## 3.0 REPAIR STRATEGIES

When restoring masonry buildings, increasing the water-shedding capability of the envelope through a combination of improved materials and methods is a primary goal. An improvement in the thermal dynamics of the wall system can often be addressed simultaneously to suit the current trend of increasing environmental responsibility. However, in restoring the façade of a heritage building it is often difficult to achieve either of these objectives. It is the very construction of the wall system and the materials utilized that provide this difficulty.

Improving the performance of the wall system or the materials it comprises often means introducing additional exterior elements, including flashing, membranes, coatings, or over-cladding to improve the water-shedding capabilities. Unless this can be done discretely, those with an interest in preserving the heritage element of the building and its façade will oppose it.

Insulating the walls from inside would have no effect on the character of the façade but would clearly alter the dynamics of the wall. Instead of being the main thermal insulator, thermal transition would occur inboard of the wall, placing the main mass on the exterior side.

Reducing the temperature of the masonry can cause several problems, including an increased retention of water and detrimental freeze/thaw activity, both of which accelerate deterioration of the cladding. It is important that the heritage wall systems that included frost-vulnerable materials continue to be warmed by the interior air to evaporate absorbed moisture and prevent destructive expansion of moisture under freezing conditions.

In restoring the building envelope and structure of a heritage building while considering the appearance and functional dynamics of the wall system, one is typically constrained to addressing the already damaged elements as best as possible. It should be expected that deterioration of other original units would continue to occur over time.

Addressing the material deficiencies in a comprehensive way would involve removing all original elements, damaged or not. The wall elements determined to be suitable to remain should be repaired and protected as best as suitably possible, while understanding that these repair efforts may require periodic maintenance.

In reassembling the wall system, consideration must be made for the continued ingress of moisture and the management of this ingress within the wall system. Methods of moisture deflection and dissipation must be considered, while alterations that would increase moisture retention must be avoided.

## 4.0 RESTORATION OF A TERRA COTTA HIGH-RISE

Believing we have an understanding of the deterioration process of “transition’”buildings and the performance mechanism of heritage wall systems is the first step to successfully restoring masonry high-rise buildings built during the “transition” era. Applying this understanding and utilizing the skills of the contractor and sub-trades in innovative and economical ways is an equal challenge.

### 4.1 Structural Steel Frame

The main structural support in the “transition” building is typically provided by the element with the most significant deterioration, particularly in mild and moist climates like the Pacific Northwest. In these climates, with water saturation prevalent throughout much of the year, the masonry constructed tightly around steel elements retains moisture against these elements for a prolonged length of time. This is significant in terms of wetness leading to corrosion. The result is significant corrosion of the structural steel, a process dependent on the level of moisture at the surface of the steel, temperature, and the length of time the moisture is retained.

Corrosion of steel members and the resultant effect is dependent on the purpose of the member. Columns and beams provid-

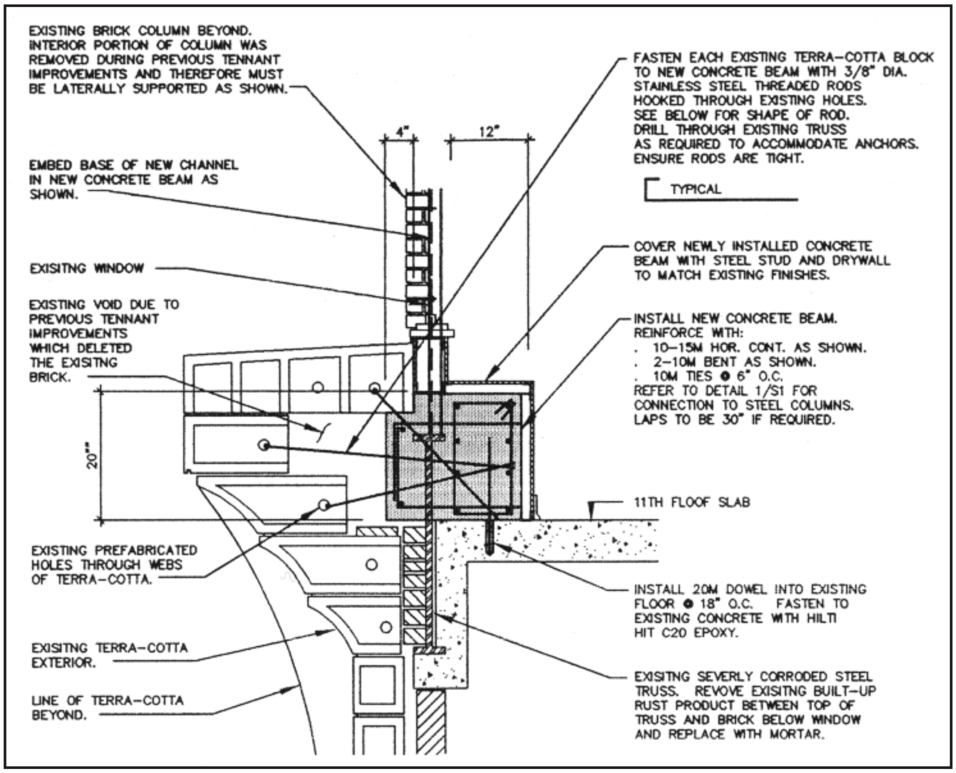

*Figure 3 – Concrete replacement beam.*

ing the primary structural support are typically large members that can often absorb a proportionately higher level of deterioration (sometimes up to 10% loss in thickness) than more slender secondary members, without a significant loss in resistance capacity. As corrosion doesn't differentiate between members, it is often observed that the smaller members have a similar level of material loss to corrosion as the larger members, resulting in more significant effect, up to 30% loss in thickness. This, in turn, would directly affect the terra cotta cladding as the smaller members are often embedded closer to the exterior surface and provide the primary role of the cladding support.

In addition to the corrosion mechanism affecting the structural integrity of the "transition"-era terra cotta high-rise, steel members other than those detailed in the drawings are commonly observed. This is likely due to the necessity to utilize what steel members were left to finish the structure; the specified members possibly removed from transit prior to reaching the west coast or used in other local projects or areas of the specified project. The result was typically spliced smaller members providing resistance to loads intended to be addressed by larger single members; smaller members with connections being much more vulnerable to corrosion.

If the steel is severely corroded, the only restoration option is replacement of the member. Getting at the member may be achieved by dissembling the exterior masonry and the cladding around it, or if possible, disassembling the material from the interior space retaining the exterior terra cotta cladding. An economical alternative involves cutting the member out from the interior. If the location of the member is known, the masonry can be saw cut with minimal material removed to extract the member. In selecting substitute materials, structural capacity is important but consideration should also be made for member durability in an adversely moist environment; a thicker, smaller section is more durable than a larger, thinner alternative and HSS members shed water more easily than rolled sections. The substitute material should also be at least galvanized or preferably fabricated of stainless steel, depending upon placement location and orientation.

*Figure 4 – Deteriorating terra cotta.*

Another durable replacement option is to utilize concrete where possible (*Figure 3*). Steel beams can be effectively replaced with reinforced concrete if space permits, the increased load can be supported, and effective connections made. This option often provides a more economical reassembly of the wall system utilizing the concrete material for a variety of structural support conditions.

Where the steel is insignificantly corroded, it is always more economical to retain the member and treat the deterioration. This can be achieved by removing the corrosion product with a wire brush or wheel or a needle gun. With the corrosion removed, the member should be protectively coated with a high zinc-content coating and could be additionally coated with a paint layer to protect the zinc coating from consumption during the life of the wall system. Installing a protective membrane, particularly over horizontal members, is also effective in protecting the steel members from retained moisture.

### 4.2 MASS BRICK MASONRY

As in structures built prior to the "transition period," mass brick masonry comprising the wall system rarely experiences deterioration itself due to the surrounding environment. The masonry is damaged by the corrosion of adjacent structural steel. The compressive forces of the expanding corrosion product have been observed to crush or shear the brick masonry and displace it out of plane.

Typically, being infill of no particular quality, this material is easy to replace. Giving attention to the mortar used will ensure that its strength will not detrimentally affect the brick units. A soft mortar is often recommended with increased lime and decreased cement contents. The placement of infill bricks is also important. Clearance should be provided around steel members to allow for air circulation that will assist in the dissipation of retained moisture. The reassembly of mass brick masonry, typically built right into the terra cotta shells as well as behind, should also be completed with sufficient care to provide a stable back wall to support the terra cotta cladding. This may involve reassembly of rubble infill that was hastily and poorly placed.

## 4.3 TERRA COTTA CLADDING

The terra cotta cladding is often the element that manifests the deterioration of the "transition" building with the displacement of the wall system and the release of material to the ground below. Made of fired, pressed clay units and typically glazed, the terra cotta units are often thin in section with delicate detailing that can crack, delaminate, and split. This fragile nature makes it the major contributor of deterioration in the wall system by allowing increased moisture infiltration as it deteriorates.

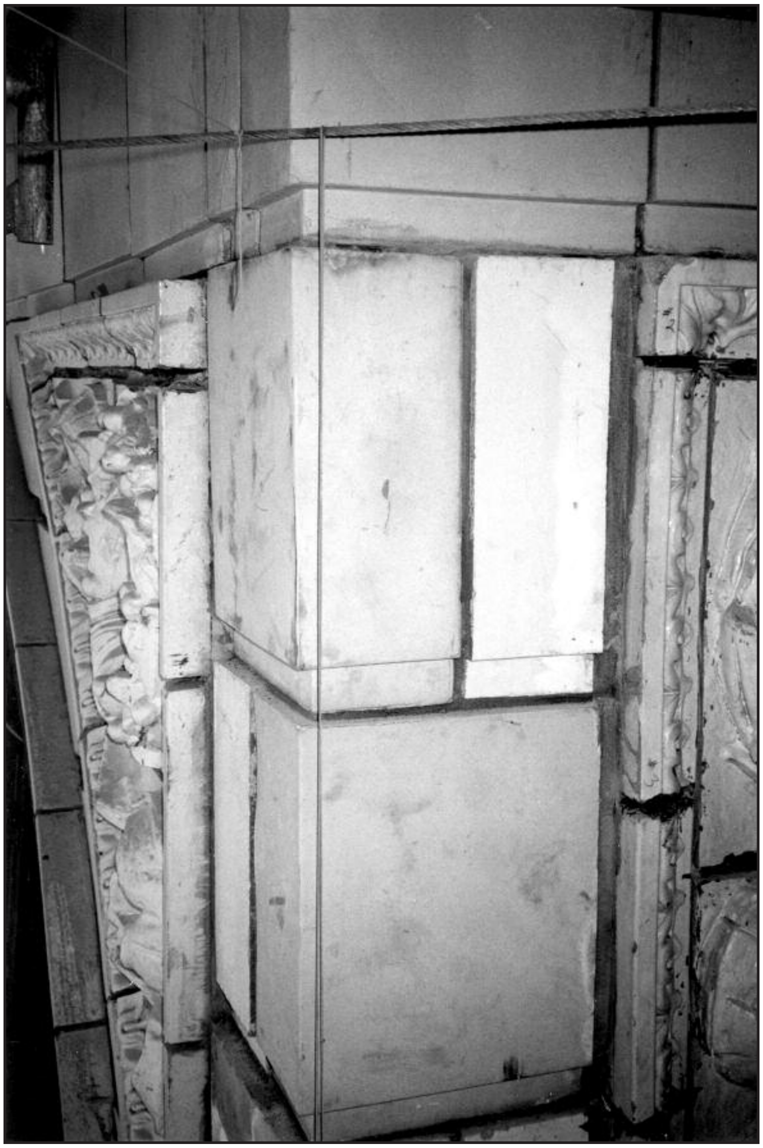

***Figure 5 – Concrete replacement units around original terra cotta unit.***

The cracking and breaking apart of terra cotta cladding is often attributed to material displacement within the wall system, be it the infill masonry or the structural steel. Terra cotta also expands with age, often stressing itself and delaminating the face shell. Other forms of deterioration are impact force and freeze/thaw cycling, which can spall the surface of the unit; and poor repair methods such as the cutting of the glazed protective layer while repointing the mortar is common. These forms of deterioration all expose the porous clay material, which easily draws in water.

Prior to restoring terra cotta cladding or the structure behind it, if the deterioration is severe over a large wall area, it is recommended that the unit geometry and locations be mapped to facilitate reassembly. The severely damaged members can then be removed for replacement, while those members that can be saved can be repaired.

For replacing terra cotta members, there are several options that can be considered. Installing fiberglass replacement units is considered an economical option. These units are light, easy to fabricate and install, and they reduce the overall load on the primary structure. They can also be made to appear similar to the original terra cotta and from a distance are often difficult to distinguish from it. The drawback is that they do not age or deteriorate in the same manner, which will become visible over time, and they take away from the heritage integrity of the cladding. Considered a better option – the casting of concrete units, utilizing a variety of concrete mixes, including the option of white cement – can provide quite favorable results (*Figure 4*). The units can be "glazed" with a concrete sealer to better match an original glazed terra cotta unit. The end result is a heavier but more durable replacement unit that can be affixed in the original manner to the wall system. A concrete unit would "age" better than a fiberglass unit, but the drawback once again is the loss of heritage integrity of the cladding.

The best option in terms of cladding integrity would be to specify replacement terra cotta units. If handled and installed with care, these units would blend in best with the original terra cotta, age in a similar manner, and be historically true to the integrity of the cladding. The obvious drawback with this option is the high cost, often making this a prohibitive choice.

As with replacing terra cotta units, there are also a variety of methods to repair the retained terra cotta unit. Polyester resins with fillers are often used to fix chips and spalls, while another option would be to use a cementitious patch material modified with a latex adhesive to improve bond and control thermal movement. Patches can be painted and sealed to blend in with the surrounding existing material with care taken not to coat over existing glazing. If the damage is more severe, such as broken pieces or face shells, mechanical pinning is recommended to stitch the unit together (*Figure 5*). With the piece "glued" in place, slots are cut in the surface of the unit and stainless steels pins and epoxy are placed in the slots to enhance the mechanical bond. The pins can then be patched over in similar fashion with spall repairs. If possible, the pins should be inserted in discrete locations or from behind to reduce the impact on the protective glazed layer.

Cracking in the glazing can be difficult to address with little that can be done that would not adversely affect the overall performance of the glazing or the final appearance with a reduced durability. Cracks might be best left alone; however, they are thought to contribute to absorption as units age and cracks expand.

## 4.4 JOINT MORTAR

The original joint mortar, often lime-based, is typically soft and exhibits little durability in wet climates. The benefit of soft mortar is that movement could be absorbed in the joint and not the terra cotta cladding. The detriment is that the mortar requires regular maintenance, which is often neglected. As with the terra cotta units, previous repair efforts often add to the deterioration of the mortar and adjoining units, since harder material with increased cement content or epoxy was typically used during the 1960s and 1970s. The intent was to provide a more durable joint, but the detrimental impact was to transfer differential movement into the terra cotta unit, which being the weaker material, often cracks or spalls.

When repointing terra cotta cladding, consensus amongst preservationists is a soft mortar must be used, preferably matching the original material. A profile that can effectively shed water should be tooled into the joint if a raked joint or similar water-retaining profile was originally used. This may, however, affect the final appearance of the cladding, which will have to be considered. A siloxane sealer can be applied to the mortar joints to minimize moisture ingress or the joints replaced with a sealant where applicable.

## 4.5 WALL SYSTEM CONNECTIVITY

The final elements of the wall system to be addressed during restoration are those connecting the wall system together. Mass masonry construction simply interwove the elements to provide this connectivity. Brick wythes were row-locked together, while the terra cotta cladding units were infilled with rubble masonry. This idea carried over into "transition" buildings with some success. As the walls became thinner, however, it became necessary to have a secondary structural system connecting the cladding elements to the primary structure. Masonry ties and infill framing members provided this connection in some early buildings, but being smaller elements, they experienced relatively higher rates of deterioration, particularly masonry ties which are often found to be entirely corroded with no structural capacity.

Especially in seismic zones, deteriorated ties should be replaced. This is an easy task if the wall is being reconstructed. Galvanized or stainless material should be utilized for its durability. If these elements are to be installed *in situ* without disturbing the wall material, they can often be inserted by drilling through the exterior mortar joints or the body of masonry elements. A 1/4-inch, stainless-steel rod with a t-end can be installed from the exterior side of the wall cladding or epoxy adhesive can be used along the length of a straight, threaded, stainless-steel rod (*Figure 6*). Where ends of a rod must be slotted into a terra cotta unit, care should be taken regarding where the

***Figure 6 – Pinned terra cotta unit.***

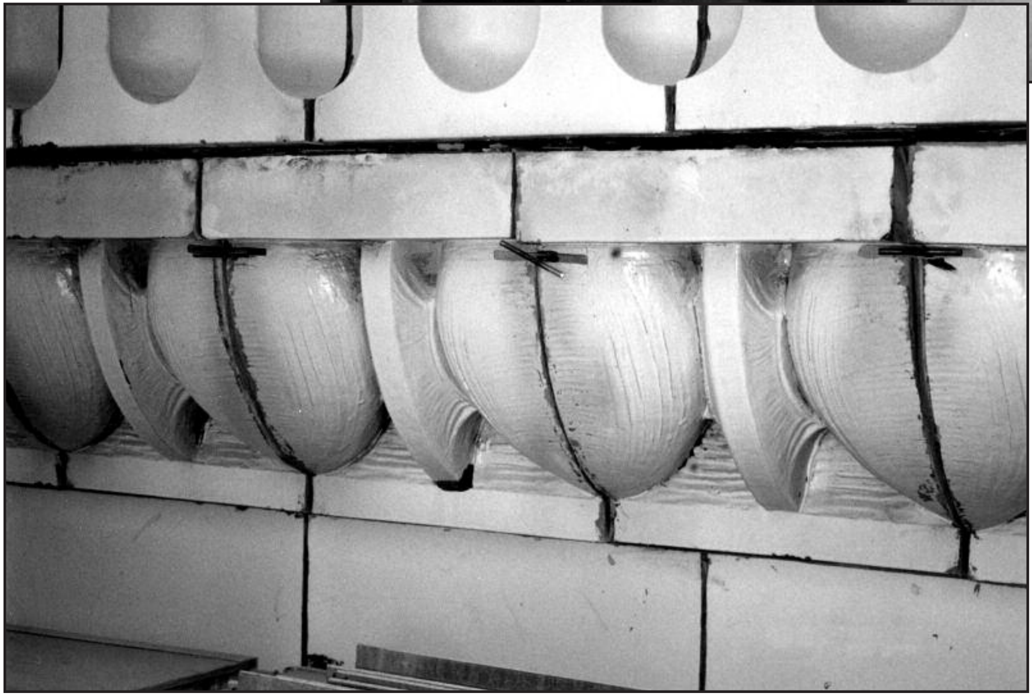

***Figure 7 – Anchor rods slotted into terra cotta units.***

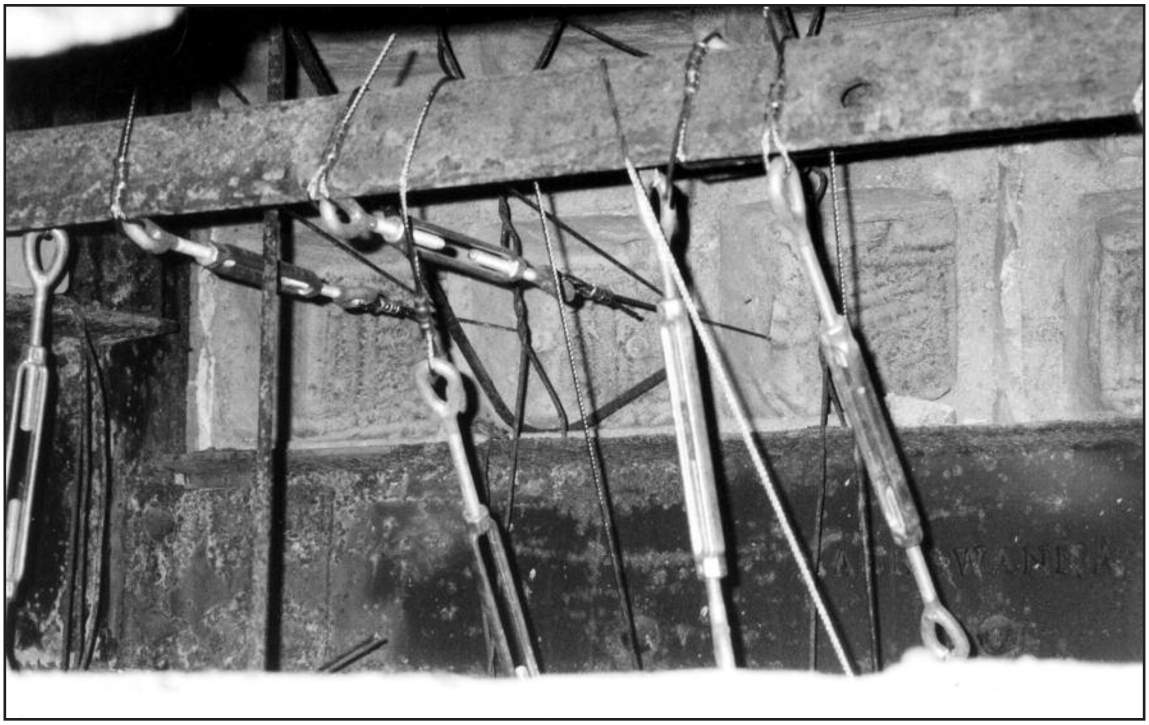

*Figure 8 – Cornice ties with turn buckles.*

slot is cut and how the terra cotta unit is patched over the rod to blend in with the remaining glazed surface.

If the back-up brick masonry is reasonably sound and capable of providing the required structural restraint, pinning the terra cotta units to it is often sufficient. If the wall appears to be unstable or too thin, structural elements should be installed on the inside face to connect to the ties and transfer the loads into the primary structure. A variety of steel elements, including small angles or HSS members, can be used in this instance with little impact on the interior finishes. Alternatively, a concrete wall or beam can be cast in place to secure the ends of the ties, provided the extra mass can be carried by the existing structure.

When wall cladding is already adjacent to a primary structural element, as the case may be with corner terra cotta units, the ends of a stainless steel wire can be welded to the steel element laid in the mortar joint. Care should be taken to ensure that the load can be sufficiently picked up by the soft mortar joint. This can be achieved by forming an epoxy-setting block in the corner or along a portion of the joint prior to repointing the remainder of the joint.

Some units can be found to be adjacent to the original steel frame but are too large to be supported by a wire in the mortar joint, while other units may require vertical support. This is often the case with cornice elements that clad over steel columns or beams or are supported by an overhanging floor slab. In the case of the overhanging elements, replacing the existing support elements, often wire ties, is sufficient. The existing steel ties, being small in section, are often found to be severely corroded and a more durable tie material should be used to address the rapid deterioration of small section elements. Stainless steel is a preferred option, especially if solid ties are being used as the zinc coating of galvanized material will flake off when the ties are twisted in place. Another proven option is to thread stainless steel cable ties through the original holes cast in the terra cotta units and crimp the ends in place. Turn buckles (*Figure 7*) can be used to tension the wire with care taken to avoid over tightening the wire as the terra cotta shell fin is easily sliced or broken off. The replacement tie can be secured back to the structure by drilling holes in the structure to pass the wire through, welding the tie to the structure, or threading the ties through clamps that are welded in place.

With the larger terra cotta units facing a column or beam, more than a mortar connection may be required – especially if there is insufficient back-up masonry to facilitate a strong enough connection or the area of steel displaces significant local back-up masonry. An additional complication may be that the unit is too large to remove and all work must be done *in situ*. An example would be with terra cotta units forming caryatids or other large ornaments. Holes can be drilled through the joints as in the mass masonry connection and the tie inserted, but instead of an adhesive connection, the tie can be welded to the structural steel. If using stainless steel ties, the supporting steel element should be preheated to address the difference in thermal conductivity between the stainless and plain steel, particularly if the tie rod is being utilized as the welding rod. If the welded connection cannot be directly observed, the rod should be tested to determine the load capacity of the connection and ensure that it meets the required resistance. Another option is to drill and thread the original steel and thread a stainless steel rod into the steel. This option is more labor-intensive, due to the nature of the older steel and the difficulty with drilling and tapping it.

## 5.0 CONCLUSION

Restoration methods addressing a deteriorated "transition" building incorporating a steel frame structure with mass masonry walls and terra cotta cladding are particularly challenging, given the typical extent of damage to the primary structure. Replacement material for the steel and mass masonry is easily sourced, while replacement units for the terra cotta cladding units can often be easily fabricated utilizing acceptable materials.

Consideration must always be made for the durability of the restoration materials and methods incorporating those options with the highest durability whenever economically possible. Attention should also be given to how the wall is reassembled, understanding the paths of moisture ingress and providing ways for the moisture to dissipate.

The environment is constant and materials will deteriorate. It is only in giving consideration to these constraints that restoration work should be designed and applied when addressing a deteriorated, terra cotta-clad, high-rise structure.