MASONRY FAÇADE ANCHORAGE FAILURES

The need for greater investigation prior to repair.
The following article allows one to understand why façade veneers are failing and what constraints and criteria should be analyzed during the Forensic Engineer’s investigation, in order to properly determine a repair solution.

- What are the physical forces acting on a veneer?
- What previous repairs may have accelerated the veneers deterioration?
- What should one investigate prior to designing a repair?
- What are some of the repair options?
- What are the expected repair life spans?
Hundreds of thousands of dollars are annually being spent on maintaining building envelopes. Unfortunately, many of the building façade repairs are being performed without a complete understanding of the building's current overall condition. That is “the veneer's current capacity has been reduced due to deterioration and the system can no longer continue to perform in its intended role”.

**Veneer Anchorage Theory:**

Today's common dictionary defines Masonry veneer walls as a construction system consisting of a single non-structural external layer of masonry work, typically brick, backed by an air space. The innermost element is usually structural, and may consist of wood, metal framing, concrete or masonry. Walls constructed in this manner have several advantages over solid masonry, some of which are shared with the Cavity wall (where inner and outer layers are both structural) while others are distinct to masonry veneer walls. Anchors are defined as “any device that holds something else secure”.

**Newton's Law:**

Newton's law states “a body at rest needs to stay at rest unless acted upon by an outside force”. So it is easy to understand that when a veneer fails there must have been forces acting upon it. Actually there are multiple forces at work which originate from several primary sources such as:

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Photograph 1 - Approximately 5 years prior to this photograph, this upper parapet wall was repaired using a stronger mortar than the original and a stainless steel helical pin anchorage system. The original construction was a much lower strength mortar, pigmented black with very little compressive or tensile strength. This failure occurred on the first day of school for the elementary children. The collapse landed in the walkway between the school and play yard, during school. Flashing and counter flashing systems is a concept that was not adopted until mid-century. Today's flashing systems are normally installed by masons, not water provers. Therefore, flashing systems and sealants that are sensitive to moisture are ignored since brick masonry can be installed in damp conditions. Once truly needs to understand the condition and waterproof integrity of a flashing system during the investigation.
What forces are aiding in failure?

Gravity:

This force is always vertical in direction and always proportional to the mass of the veneer. Gravity applies the same pulling force regardless of the location of the veneer on a building façade.

Wind:

Wind exerts pressure on the veneer walls of a building via both pushing from the direction of the wind and suction on the backside or sides of the building as the wind wraps around it. Typically, negative or suction forces are greater than the direct prevailing wind forces on a building. Wind loads tend to be greater near corners or other locations of discontinuity of the veneer.

Seismic:

Seismic loads are induced due to the accelerations of the earth during an earthquake or aftershock. Unlike wind loads, seismic loads can be both perpendicular and parallel to the face of the veneer.

Vibration loading:

Whether it is rail traffic, truck traffic, construction nearby or construction within, the continued vibration of the building façade from the constant pounding of external forces can aid in the disruption of the veneer connections.

Understanding design deterioration.

Load paths:

Load paths start with the individual sections of veneer. They accumulate and reach a supporting element such as a lintel or anchor; which transfers the load into the structural element, such as a column, lintel, bearing plate etc. These elements then transfer the load into the building frame. If deteriorated or deteriorating, they have reduced function.

Façade Anchorage devices:

Brick ties are the most common type of anchor for holding sections of brick from being pulled away from the façade. Steel lintels are employed to transfer the weight of the brick (gravity load) to the building frame.

Veneer assembly deterioration:

The veneer itself, when considering brick masonry, starts with the individual brick unit itself, and includes the mortar that either separates the brick or glues them together. These sections of brick are prevented from rocking or blowing away from the base structure via utilization of brick anchors. The mass of brick is occasionally interrupted, utilizing a lintel to transfer the load to the structure. It should be noted that all common anchorage devices in the past have been made of steel. Occasionally they have been painted and most recently have begun to be galvanized.

Veneer bonding:

When veneer construction began to be utilized, the backup frame was quite often vitrified clay tile. This material possessed the same thermal coefficient of expansion and creep characteristics as brick masonry. Evolution in building design switched from vitrified clay tile (VCT) to utilization of backup masonry consisting of concrete masonry units (CMU). These units have different thermal coefficients and opposite creep characteristics. Bricks tend to expand over time and concrete blocks tend to shrink over time. Most recently, veneer construction is connected to steel studs.

Weep tubes:

Air gaps between the veneer and masonry are installed as thermal break and to allow any leaks to
be removed by installing weeps. Weep tubes are installed in the veneer or cavity Masonry to allow water a path to escape if it enters into the cavity wall. However, in many cases water running down the face of the building can enter through these weep tubes. This is especially prevalent when there’s a negative vacuum within the veneer cavity.

**Flashing systems:**

If you think that there actually may be a flashing system installed, you had better verify its integrity; especially at the seams.

**Mortar systems:**

The mortar that has been used in building veneers has progressed from low compressive strength/high ductility lime and sand mortars to high-strength/low ductility mortars that contain Portland cement and other proprietary additives. In some cases that new mortar has higher strength than the surrounding brick units.

**Brick systems:**

Exterior bricks have now become highly vitrified high-strength bricks with a high degree of initial creep due to their high firing temperatures. Due to the vitrification these bricks are have a low absorption rate.

**What are the age related causes for these failures?**

If the building has been erected properly and maintained throughout the years why are we now seeing these failures?

**Long term positive creep:**

Bricks and clay tile etc. are fired components that shrink or get smaller in the firing process. They naturally grow or creep with time after they are introduced into the environment. Therefore we need to look at the effects of creep on the masonry structure. This is especially important if the veneer is composed of long-term positive creep material while the backup structure is composed of a long-term negative creep material.

**Long term negative creep:**

Portland cement based materials such as concrete and concrete block have a creep in the opposite direction of brick. Concrete tends to slightly shrink a bit after casting.

**Thermal coefficient of expansion:**

All materials expand and contract with various temperature fluctuations. Veneers that are located on the exterior of a facility go through a higher range of temperatures and rates of change than the interior back up material as it is subjected to the more controlled environment of the interior of the facility.

**Moisture intrusion positive:**

Positive moisture intrusion is defined as moisture that originates from the exterior of the building. This would be in the forms of rain or driving rains.

Photograph 2 - 200 feet of jumbo brick wall sits above this vertical sheer. This wall has moved both vertically and horizontally and is in need of immediate shoring and investigation for permanent repairs. However, the owner has elected to repoint and replace the existing failed brick. All parties involved need to clear themselves from responsibility of the possible failure and collapse of this failure of wall.
Many buildings have been found to have a negative vacuum on the interior of the building. This is quite commonly due to an imbalance in mechanical systems. The building shown in photograph 2 above has a severe negative vacuum in the interior. Thus, moisture is being pulled through building weeps and other void spaces within the veneer which has resulted in deterioration. The deterioration is a result of the freeze/thaw cycle where water has been trapped within the veneer.

**Mortar additives:**

Additives such as latex polymers, bond enhancers, set accelerators, retarders and freeze preventers have all been used as additives to common mortars. Many of these have shown to produce adverse long-term effects to the durability of the veneer unit. Historically, calcium chloride has been added during the winter or cooler weather to speed up the set of mortar. The calcium chloride increases the corrosion potential of the steel within the construction that has contact with the mortar. If you haven’t tested for the existence of detrimental additives, can you really define the cause of the effect that you are trying to repair?

**Steel corrosion:**

The expansive forces of corroding structural steel are very large and easily override the adhesive bond of the mortar to veneer. As the steel corrodes, the exfoliated flake pushes the mortar and veneer away from the steel. Additionally, the steel loses physical strength due to the reduced steel cross section.

**Previous mortar repairs:**

If previous repairs, such as brick replacement, tuck pointing and patching do not match the original mortar and stone or brick characteristics, this discontinuity in materials affect the behavioral characteristics of the veneer system. Harder and denser tuck pointing mortar reduces the veneer’s ability to flex with thermal movement and allow trapped moisture to evaporate out. Thus, quite often, accelerating the deterioration of the parent mortar.

**Penetrating sealer applications:**

Penetrating sealers have commonly been applied to the exterior to reduce moisture infiltration and theoretically reduce the veneer deterioration. These have often been the cause of further accelerated deterioration of the mortar behind the sealer due to the inability for moisture to escape. Any moisture that has found a way into the system accumulates behind the penetrating sealer and in freezing conditions ruptures the mortar, stone or brick face. This moisture accumulation can be from either humidity transfer condensing into liquid water after reaching its dew point or water entering from open cracks or voids.

**Joint sealant maintenance:**

While masonry clad buildings give the impression of permanence (brick and mortar). The Achilles tendon is the sealants at expansion joints or around openings. These have until recently been installed utilizing urethane. Urethane sealants have shown a typical life expectancy of 5 to 7 years. A predictable maintenance schedule is rarely followed after initial construction is complete. Therefore once the joint sealant deteriorates water can leak behind the veneer for years prior to corrective action being taken.

What type of investigations should be performed to evaluate façades?

**Nondestructive testing:**

There are many observations that one can make while just looking at the outside of a building while not disturbing it. But what you see is what you get. If you can’t see all the elements and understand
how they interact, it makes it extremely difficult to prescribe the proper treatment. Many owners due to budget restrictions would prefer that you just look at the building façade and give it a clean bill of health. It’s like going to the doctors and telling them you are sick, but due to your budget you only want them to look at you and prescribe medical treatment.

**Up close visual:**

Real close up investigation of just a few feet away can provide valuable insight as to what is happening at the time of inspection. However caution must be used, as areas that have been repaired in the past may be providing a false cover of security.

![Photograph 3 – A 1 ½’ inner bow not visible from the sidewalk.](image)

**Metal detection:**

A metal detector can aid in the locations and spacing of the original existing ties and load transfer devices. However, knowing where an existing brick tie or anchor is located, does not tell you its condition or load bearing capacity.

**Thermal imaging:**

Thermal imaging is extremely helpful in finding abnormalities behind the veneer. The photograph, below indicates moisture build up behind the brick veneer.

![Photograph 4 – The dark blue images show water on the surface, while the green shows moisture behind the brick.](image)

**Negative pressure testing:**

A simple test for negative pressure within the building envelope or cavity of the veneer system is, to insert a manometer tube into the weep of the building cavity. Using the manometer tubes can provide you with measurable results that can verify that there is a cause behind water infiltration. This can be a cause for the corrosion of the anchorages or heavy freeze thaw deterioration of the mortar and masonry system. If no weeps are provided, a simple drilled hole is effective. Recommended good practice is to obtain the pressure differential from the exterior to the veneer cavity, and from the exterior face of the backup material on the interior of the building.
Photograph 5 – 1920 construction consisted of a variety of load bearing materials, including: cast stone, hard fired brick, low fired brick, terra cotta tile, steel, hard dense pointing mortar, and lime sand mortar.

**Plane:**

Checking the vertical and horizontal plane for straightness can give a good indication of stress action on the façade. If the wall has begun to bow, then the veneer is moving and the anchors are giving way in either the veneer or the substrate.

**Original design drawing review:**

Original drawings if they are available are a good resource. However do not rely on the idea that it was actually built according to plans.

**Disturbance (destructive) testing:**

Destructive testing really sounds like a bad thing. But, since the goal is to properly fix the problem and ultimately save the building façade, a small disturbance is a small price to pay, compared to an “uncontrolled disturbance” aka: a section falling on its own. Not to worry, we’ll put it back. If you don’t know what is there, it is hard to design a fix.

**Boroscope:**

By drilling a small hole into the façade one can have a limited view into what is just behind the veneer. While the view is quite small and isolated to only a single location the information gained may add to the overall understanding and help determine whether further investigation is required.

**Chloride testing:**

Simple extraction and testing of the mortar can verify if chlorides were used in the mortar mix. If taken at various depths, this test can also determine if acid salts are present from inappropriate initial cleaning. Utilize caution against drilling too fine of a dust extraction. Too fine of a dust will alter the results.

**Mortar removal:**

Selective mortar removal allows one to visually assess the mortar condition and constancy. Visually the mortar on the exterior may look good, but if the sample is repointing mortar, the remaining original mortar may not be up to par. Photograph 7 shows the importance of understanding the mortar placement on an existing building.

Photograph 6 – This gauged brick was laid in the early 1900’s. To allow for new anchorages, the engineer required pinning through the mortar with a SS Helical pinning device. Inappropriate pull out teething showed an adequate value. This was only at the backing material.

**Mortar tension capacity:**

If the mortar is to be relied on for a tension holding device (helical anchors) it should be tested for its capacity. Most mortars that are a pure lime mortar have low to zero tensile capacity.
Veneer capacity:

Current building code requires brick veneer tie spacing at 2.67 square feet or no more than 24” on centers. This is based on the veneer’s strength assumption of utilizing code compliant brick (fbx) and mortar (commonly type N or S). These have a minimum compressive strength of 4500 psi for brick and 2500 to 3000 psi for the mortar. The existing facades strength capacity needs to be determined in order to properly design the repair, especially if the repair has to bring the façade up to meet current code compliance.

Back up material condition:

During the installation of the backup material many contractors did not see the importance of quality workmanship since the backup material is hidden by the veneer. As can be seen in photograph 8 there seems to be randomness to the infill material installation. We need to verify just what we are anchoring into. Otherwise we are throwing darts at the wall in regards to the expectant capacity of the proposed fix.

Photograph 7 – Destructive removals of this veneer system surprising found that the backup structural block system was parged coated during construction for waterproof integrity. The tie brick was actually inserted into the block wall system. The differential movement concern of the block vs. brick was the resulting distress prompting the investigation.

Back up material load bearing capacity:

If a new anchor system is designed as a restoration program, then the strength of the anchor holding device will be limited by what is holding it to the frame. Photograph 7 is a prime example of finding a very limited backing material.

Existing load transfer devices condition:

Assuming you are examining the façade due to its age, condition, or code inspection requirements; there is the possibility of deterioration of the existing transfer devices. The transfer devices condition needs to be evaluated to properly determine the existing systems capacity.

Mock up testing:

Once a method has been determined for a repair, this method should be tested in place to determine if the prescribed solution is capable of meeting the requirements of the engineer. This testing should be done individually on both the backup material and the new anchorage device to verify that each element is capable of obtaining the desired strength. Photograph 9 shows a pull test being performed on
a 1/4 inch stainless steel anchor rod inserted in modified cement, mortar grouted.

Veneer diaphragm testing:

The spacing of the original anchors is normally based on the determination of the original strength of the veneer. However, one needs to now look at the current condition of the strength of the veneer. For example, a simple understanding of this concept would be to nail a 1/8 inch sheet of plywood over a window opening. You might need more nails around the parameter as compared to utilizing its ½ inch piece of plywood. The strength of the veneer, as a plate structure, needs to be analyzed prior to determining the recommended spacing on any new anchor spacing.

Repair Considerations

Surprisingly, many owners are not aware of all of the options available to them for repairing their buildings. An evaluation team should keep the owner informed of all options and their expected longevity, along with the required maintenance plan after the repairs have performed. Common sense would tell you that to maintain an automobile, there needs to be a schedule of maintenance activities. The older the automobile becomes, the greater the need for increased preventative maintenance activities. This is also true for older buildings. Considerations for repair should include the following criteria:

- **Short Term Immediate Needs for Life Safety:** Obviously there are times when buildings are looked at that there are immediate concerns that should be addressed while onsite, for life safety. These concerns should be reviewed with the owners’ representative immediately upon finding them, and followed up in writing immediately thereafter.

- **Medium Term Repairs:** A definition of the life expectancy of repairs should be given to the owner with all options available to the owner regarding concerns on the longevity of repairs. An owner should be given the understanding of life expectations for medium and long term repairs; why the old original system failed, what the new repair will provide, along with its life expectancy prior to continuing maintenance.

- **Long Term Repairs:** One should always keep in mind the cause and effect of deterioration mechanisms. The question would be if the same mortar is used to repair the building that is 100 years old, that it was originally built with, would one anticipate this repair to last an additional 100 years. Theoretically, if the cause has been taken care of the 100 year repair would be correct.

**Maintainability:**

Once the repair has been made, is it possible to continue the maintenance plan, or has the repair covered up the possibility of observation to the building in the future. This would be the case with exterior insulating finish systems better known as EIFS or siding systems. Once the repairs are complete, it is strongly suggested that you provide
the owner with a maintenance schedule. This can also be in the form of a re-inspection schedule. Many owners consider the repairs that have taken place as final. The engineer needs to protect their liability by ensuring that the facility owner is aware that no repair is permanent and the building needs to be maintained.

**Repair Checkup Review:**

After repairs are complete or even prior to repairs beginning, a review of the structure should be anticipated to allow all to understand that things are working as designed and installed.

**Teamwork**

If the contractor, engineer, and building owner work as a team, versus protecting their territory, the building repairs can be performed with greater success and longevity. All who come to the table come with an area of expertise parallel but not similar to one another’s. If all are combined, the greater good is then achieved. Consider this the next time a building is in need of repair.