9) **CHOOSE** where the file will be stored, most likely in a temporary directory, and name it.

The file is now downloaded onto the user's hard drive.

V. **How to Add a Case Study Package:**

Use the menu on the left hand side of the screen.

10) **CLICK** on Add Your Own Failure Example (shown in Figure 2) on the menu frame, at the left hand side of screen. A screen like Figure 8 will appear.

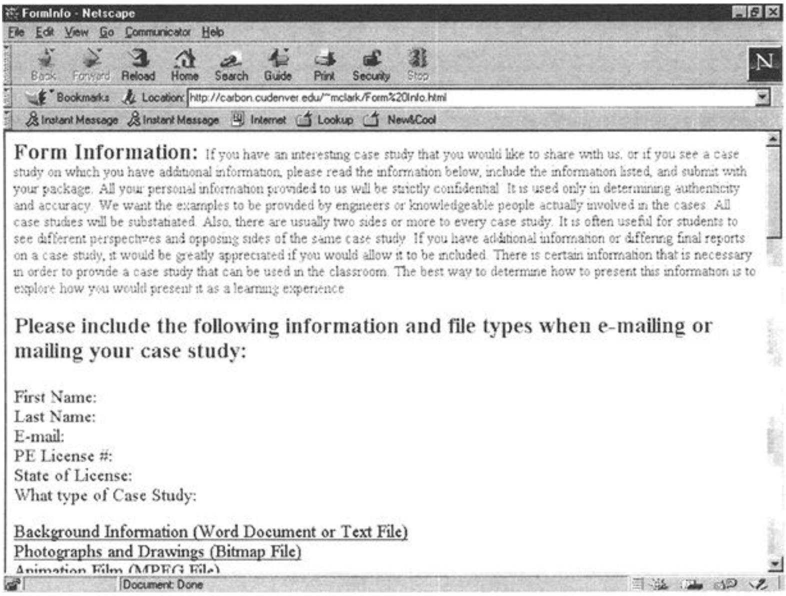

Figure 8 Add Your Own Failure Example

11) **SCROLL** through the information provided on the page.

12) **CLICK** on Ready to Send Package. Every browser may be a little bit different, but an e-mail composition, like in Fig. 9, will appear.

13) **CLICK** on Attach Files from pull down menu. Go through an individually select files from the hard drive or if the files have been zipped, attach only that file as shown in Fig. 10.

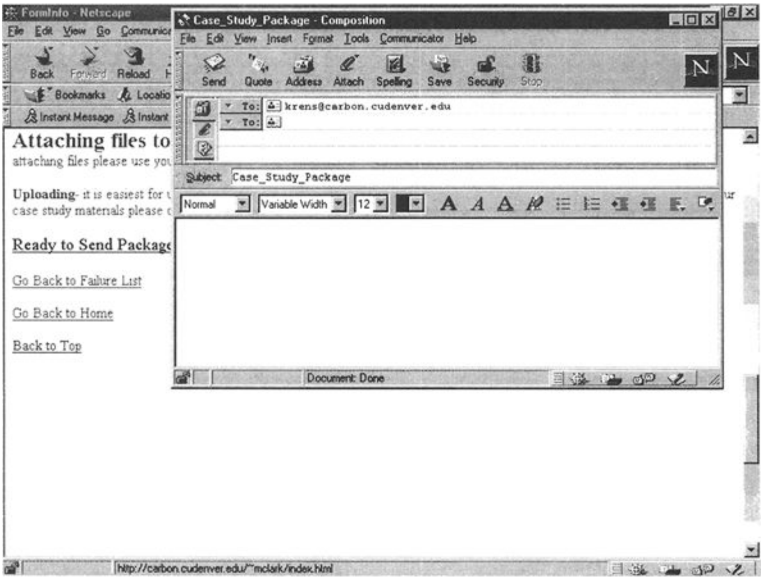

Fig. 9 Attach Package to an E-mail Composition

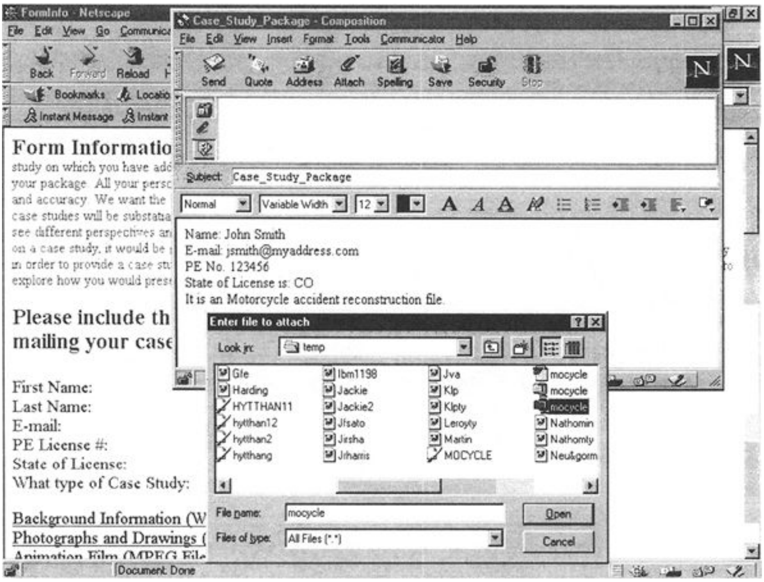

Fig. 10 Attach File to an E-mail Composition

14) **TYPE** in

Common Failures With Contemporary And Traditional Wall Systems

By Kimball J. Beasley[1]

Abstract

Early traditional building walls were usually constructed of stone or brick, sometimes several feet thick. Such massive walls served not only to support the floors and roof but also to keep out the weather. In the early 1900's economic pressures and the need for taller buildings led to the development of thinner, lighter, and less costly wall systems. While these thinner walls did not usually carry structural loads, they often involved a combination of materials and multiple wythes requiring more complex leak control and connection/support mechanisms. A wide variety of unanticipated problems, such as accumulated differential thermal expansion, increased water leakage due to a lack of drainage redundancy, and cracking or displacement related to material incompatibility, sometimes accompanied these new wall systems.

Typical Wall Systems

Traditional masonry ***barrier walls*** usually accommodated external loads (e.g., wind, gravity, etc.) by the wall's great mass and strength. Support conditions were generally simple with largely concentric loading. Water leakage was avoided because the limited rainwater that penetrated the wall surface was absorbed and dispersed in the masonry and then slowly expelled as water vapor. As these walls age, failures sometimes result from gradual corrosion of embedded metal wall elements or deterioration of masonry components.

Cavity walls came into existence in the 1950's. With this construction, the wall cladding was usually removed from the structure's load path. Failures occasionally occurred when wall or facade support systems were not designed to adequately accommodate differential movement between the facade and the structure, or when eccentric loads were not accommodated. Leakage problems often developed when the wall cavity and flashing/weep drainage system became blocked or breached during construction. The "rain screen" wall system, which relies upon open exterior panel joints and equalize air pressure within the wall cavity to control water leakage, has recently emerged as a modern cavity wall system.

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[1] Principal, Wiss, Janney, Elstner Associates, Inc., 1 Penn Plaza, Suite 2010, New York, New York 10119

The ***skin barrier wall*** system has gained popularity over the past 20 or 30 years. This new wall is lighter and requires a less substantial support system. However, connections must be designed to resist loading without unduly restricting planar cladding movements from thermal or moisture effects. Also, since the skin barrier wall must deflect all water at the surface to avoid leakage, any open crack or joint can allow uncontrolled water entry into the building interior. The quest for ever lighter, stronger, and less expensive skin barrier wall systems has led to numerous failures from the use of new materials, or a combination of incompatible materials, without adequate performance history.

Wall Failure Categories

Two broad categories of wall failures include ***stability failures*** (e.g., complete wall collapse, dislodged fragments or partial collapse, or loose pieces) and ***serviceability failures*** (e.g., water leakage, cracks, or aesthetic degradation). When a wall collapses there is seldom any question that a failure has occurred. However, a wall that appears to be intact but cannot sustain anticipated wind loads because of missing or damaged anchors behind the wall surface is also a failure. Such "latent failures" are more insidious because they are difficult to detect and may collapse without warning. Wall serviceability failures are seldom as dramatic as stability failures, however, the resulting loss of function of building walls is far more common than failures resulting in a catastrophic collapse that claims life and property. Collectively, the economic consequences of such serviceability failures may be far greater than of collapses.

Failures Common to Traditional Wall Systems Collapse

Collapse of a wall can result from loss of support, from external loading that exceeds the wall's capacity, or from deterioration that diminishes the wall's structural integrity. External forces leading to collapse of massive, self-supporting traditional walls usually include earthquake or gravity loads, and less frequently, wind loads. Collapse of traditional walls is often precipitated by distortion or dislodging of foundations or strength loss from long-term deterioration of masonry elements. Figs. 1 and 2 show typical examples of traditional masonry walls that collapsed from loss of support.

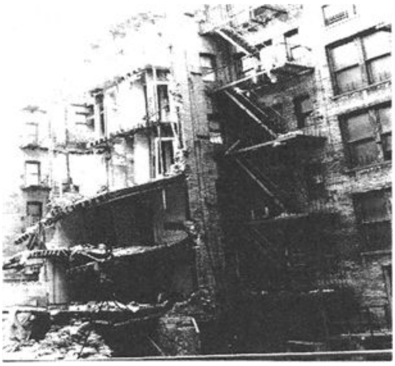

Fig. 1 - A five-story wall and supported floors collapsed from a severely deteriorated foundation wall.

Fig. 2 - Loss of support for a load bearing wall caused collapse of a major part of this building.

Water Related Distress

Aside from erosion of mortar joints or of soft stone, water may damage traditional wall systems in a variety of ways.

Freeze-thaw Deterioration: When saturated with water and subjected to cyclic freezing and thawing, stone, concrete, mortar, or clay masonry materials can deteriorate from freeze-thaw action. This phenomenon occurs when water fills microscopic voids in the material and e)ands upon freezing, progressively rupturing the adjacent masonry (Figs. 3 and 4).)urability of concrete against freeze-thaw deterioration can be improved by air er 'aining. Freeze-thaw sensitivity of clay masonry products can be determined by meas ring the ratio of water absorption in cold water and in boiling water. This ratio called the saturation coefficient, is detailed in ASTM C216.

Fig. 3 - Freeze-thaw deteriorated brick units

Fig. 4- Severe freeze-thaw deterioration of concrete façade element.

Corrosion Jacking: Traditional walls are often comprised of masonry units filled partially or completely with mortar. When mild steel reinforcement embedded in the wall corrodes, the oxidation product (rust scale) occupies up to 10 times the volume of the original steel. Several factors that are characteristic of traditional wall systems (i.e., solid walls; increased water penetration as the wall ages; corrosion sensitive, ungalvanized embedded steel) combine to increase the probability of corrosion jacking (Fig. 5). Steel corrosion may be further exacerbated by soluble chlorides introduced during construction or accidentally via salt water in the mortar mix, or from a marine environmental exposure.

Fig. 5- Spalled stone veneer at corroding embedded mild steel.

Leak Sensitivity: Water that penetrates the wall surface migrates downward within the wall. Cavity walls convey the water down to through-wall flashings that should be water tight, continuous, and properly enveloped with weep holes configured to promptly drain water collected on the flashing. Blocked or bridged wall cavities, breached flashings, and blocked or poorly positioned weep holes may each result in water leakage to the interior. Exterior walls built directly over interior spaces, such as at set-back terraces, or over continuous horizontal penetrations, such as at horizontal ribbon windows, are especially prone to water leakage. Failure of the wall drainage system results in direct water entry to the interior.

Restrained Expansion and Contraction

Restrained accumulated expansion and contraction of the wall or facade material relative to the building's structural frame is a frequent cause of failure in a traditional wall system [Beasley, November 1988]. This type of distress is often related to cyclic thermal expansion of the facade or wall, coupled with resistance from the structural frame. The frame does not expand to the same degree as the cladding because it is usually sheltered from the weather and relatively free from wide thermal fluctuations. Also, with fired clay masonry products, slow moisture expansion of the masonry contributes to differential movement [BIA, January 1991]. Load-induced elastic deformation and shrinkage and creep of reinforced concrete frame construction further increases vertical planar wall forces by shortening the structural frame. Differential movements accumulate in long or tall walls, compressing walls or facades to stress levels many times greater than from normal gravity or wind loading.

Failures Common to Contemporary Wall Systems Collapse

Since contemporary walls tend to be lighter and supported by the building's structure as compared with self-supported traditional walls, collapse or displacement from external forces such as wind is more common. Also, internal forces, such as restrained thermal or moisture expansion/contraction of wall panel skins or frames can overload connections or wall elements (Fig. 6).

Fig. 6 - Accumulated thermal expansion of thin marble panels coupled with bowing (see thin marble hysteresis, below) led to collapse from support failure.

Water Leakage

Compared with traditional walls, contemporary walls tend to rely on barriers to control water leakage. Cavity walls rely on two masonry layers and flashings and skin barrier or rain screen walls rely on impermeable membranes. The skin barrier wall system is designed to deflect all water at the wall's surface to avoid leakage. The watertight integrity of the skin material and elastomeric joint sealants is the only protection against leakage. When the sealant joints fail or cracks develop there is usually no redundancy to protect against leaks. Numerous skin barrier wall systems, such as prefabricated walls with a wide variety of single-material or composite panels, are now available to the designer. Exterior insulation and finish systems (EIFS) have become ubiquitous new skin-barrier wall systems. This type of system involves a thin (about 0.3 mm thick) polymer based surface layer that is trowel-applied to a rigid insulation board. New improvements in EIFS design incorporate a moisture resistant board and an internal drainage mat.

Material Incompatibility:

Composite Panels: Several composite skin barrier wall systems recently introduced into the marketplace involve two or more materials intimately bonded together. Some of these wall systems are composed of exposed veneers of thin stone or ceramic tiles rigidly adhered to a portland cement based backer board, screw-fastened to a light-gauge steel stud framework. While each of these materials may be stable and durable independently, in combination they are often incompatible. A relatively volume-stable veneer, such as stone tiles, rigidly affixed to a wood fiber reinforced backer board, for example, has a high probability of failure due to expansion and contraction of the backer board with normal fluctuations in relative humidity. This restrained movement can induce high planar stresses and bowing forces, along with high shear forces at the tile-to-board bond line. A thermal gradient across the panel skin and/or a high difference in coefficient of thermal expansion of the various composite materials can also induce high planar and shear stresses.

Laboratory testing and evaluation of composite wall panels in their final configuration us essential to avoid trial and error performance testing en masse after installation on buildings (Fig. 7).

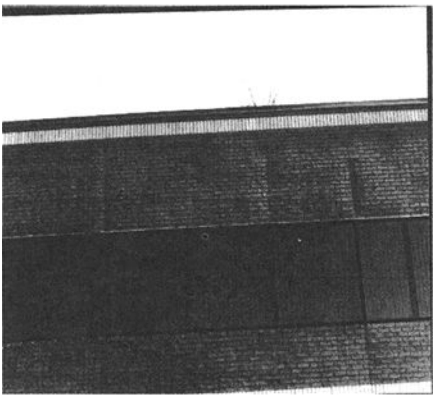

Fig. 7 - Bulging and cracking failure of prefabricated composite wall panel.

Thin Marble Hysteresis: Marble is one of the oldest traditional building materials. However, contemporary wall construction employs marble veneers cut into extremely thin (2 to 5 cm) panels. Certain types of marble commonly experience failure in the form of bowing, disaggregation (sugaring), and strength loss when cut into thin panels and exposed to the weather. Marble is vulnerable to this failure because of its complex grain morphology (interlocked crystalline calcite hexagonal shaped crystals adhered together with a calcite binder). Thermal cycling lead to intergranular fracturing along the grain boundaries; the grains tend to dislocate and not return to their original position [Wildhelm, February 1997]. This process is sometimes called hysteresis. Disassociation of grains near the exposed surface of thinly cut marble panels causes uneven expansion of the panel, resulting in bowing. Further, the microscopic fractures cause increased water absorption, leading to dissolution of the calcite grain binder and strength loss. This phenomenon has resulted in several recent spectacular and costly failures (Fig. 8).

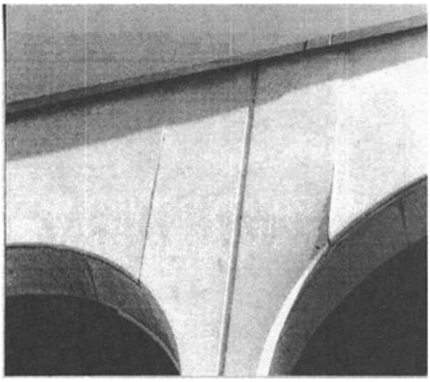

Fig. 8 - Severely bowed 3 cm thick marble panels.

Repair Concepts

Various repair options are available with both traditional and contemporary wall systems. The nature and extent of repairs required will depend on the type of failure. Temporary emergency repairs may need to be undertaken before long-term repairs can be implemented.

Temporary Repairs

Depending on the potential for life-safety hazards, such as loose wall elements in danger of falling onto pedestrian accessible areas, temporary stabilization of masonry units or complete wall panels may be required on an emergency basis. Such repairs may involve netting (Fig. 9), strapping, shoring, or anchoring unstable wall elements. Complete removal of loose masonry or dislodged wall components is often needed as emergency protection measures, with only limited consideration for the immediate aesthetic impact. If the temporary repairs are to remain for a protracted period, damaged wall areas need to be protected from the weather.

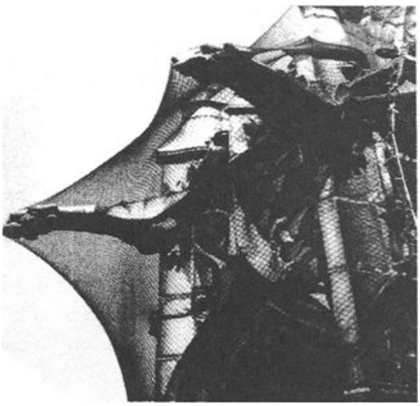

Fig. 9 - Unstable masonry is temporarily secured by netting.

Long-Term Repairs

Long-term repairs may include anchoring wall areas using supplemental pins, or patching with patch materials that match the failed material both aesthetically and in physical properties (Fig. 10). In some cases, reducing locked-in masonry cladding stress by retrofitting horizontal expansion joints may be warranted (Fig. 11). Replacement of deteriorated or loose wall components may involve restoring with similar materials or with substitute materials (Fig. 12). The decision to use replacement materials rather than to reproduce the original materials may be driven by economy, schedule, preservation restrictions, structural limitations, fire codes, or other reasons.

Fig. 10 - Limestone is patched using cementitious material.

Fig. 11 - Horizontal expansion Joints are cut into this cavity wall brick facade after securing shelf angles.

Fig. 12 - Architectural precast ornament replaces deteriorated terra cotta .

Conclusions

Most problems and remedies common to traditional masonry walls have become well understood over the past several decades. Contemporary wall systems, however, often experience more complex failures due to less predictable behavior with combinations of materials in unproven configurations.

Most often the successful wall system employs components that are not overly complex, with materials, connections, and details that are time-proven. A successful wall system design incorporates features that do not invite construction errors, and includes redundancy both in the wall support and the internal wall drainage system.

Biography

Kimball J. Beasley is a structural engineer and manager of the New York City office of Wiss, Janney, Elstner Associates, Inc. Mr. Beasley has investigated over 1,000 failures and problems with buildings and structures for the past 27 years.

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